1996

A simulation of roll wear in hot rolling processes

Bo Wang

University of Wollongong

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A SIMULATION OF ROLL WEAR IN HOT ROLLING PROCESSES

A thesis submitted in fulfilment of the requirements for the award of the degree

Master of Engineering (HONS)

UNIVERSITY OF WOLLONGONG

by

BO WANG

(BE, ME)

Supervisors: A Prof. AK Tieu
Dr. D Saini

Department of Mechanical Engineering
August, 1996
ACKNOWLEDGMENTS

I would like to thank my supervisors Associate Professor A K Tieu and Dr. D Saini for their imparted knowledge, guidance, enthusiasm, patience and financial support during the work. Without their valuable help, the work would never be finished.

I would like to acknowledge all the people in the workshop in the Department of Mechanical Engineering who have provided assistance in manufacturing of the test rig. Special thanks are due to S Watkins, T Kent, R Marshall, M Morillas, D Trifunovich, K Maywald and S Rodd for their mechanical and electrical work.

Thanks are also given to G. Hamilton in the Department of Material Engineering, for the assistance of design of the heating device, and R Young in Thermodynamic Laboratory, for the assistance during experiments in the Laboratory.

I would like to thank my parents and my brother, not only for their financial support in the first year, but also for their continuous encouragement throughout my whole education.

Lastly and importantly, special thanks to my wife Jin Liu, who bred my very young son by herself in the first year in my country, and checked the whole thesis in English composition and gave me some suggestions.
ABSTRACT

Hot rolling is an important steel production process. Rolls in a hot rolling mill cost significantly and influence quality of products. Wear is a major factor of roll fault. So, it is very important to study roll wear at high temperature, although roll wear study in a real rolling mill is very difficult, especially for a hot rolling mill.

To meet the need of practical production for the rolling process, simulating investigation for high temperature rolling process is a feasible method for roll wear study. A high temperature rolling wear test rig was designed and manufactured to simulate the real hot rolling mill as closely as possible. Newly-proposed wear test geometry, roller on disk, is implemented in this test rig, and a high temperature environment for the contact zone is established as well. Wear, friction force, sliding/rolling ratio, acoustic emission and vibration are measured in the experimental system. The computerised measurement and control system guarantees that the long-term wear experiment is conducted automatically and stably.

From the preliminary test for the experimental system, it was found that the system can be used to simulate roll wear in high temperature environment. This experimental system can be employed to develop and test some new roll grades or search optimum working parameters of the rolling process. It can be used to simulate both cold rolling and hot rolling processes. Versatile software in the system automate all the operation for the test rig, including hardware diagnosis, sensor and instrument calibration, pre-adjustment before experiment, and actual experiment.
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Introduction
Rolling is one of the most important steel production processes. Over 90% of all materials that are ever deformed are subjected to rolling\cite{58}. Rolls as the tool of rolling mill play an important role in the rolling mill production. Rolls generally contribute some 5-15 percent of overall production costs without including the cost of mill down time because of the roll changes\cite{1, 2}. The percentage will be more for the hot rolling mill because failure of the roll is more severe at elevated temperature. Tribological properties of rolls determine their life, and wear is the main cause of roll consumption. If roll wear can be reduced, roll cost is directly reduced. The indirect cost for roll turning, grinding and maintenance will be decreased as well. On the other hand, wear of the roll directly influences the dimensional and shape accuracy of products, which influences the strip production to a much higher degree. Therefore it is very important to study the roll performance, especially in the domain of wear.

Since increasing roll life can bring significant cost reductions for rolling processes, some endeavour has been conducted to develop special roll materials and some new materials are still in development. Wear resistance is certainly one of the most essential properties to estimate new materials.

Many experiments and studies have been done for sliding wear in the tribology community, but a relatively small amount of progress has been achieved on rolling friction and wear. Furthermore, study on rolling wear at high temperature has received very little attention. The rolling process is a kind of continuous production, in which the setting of process parameters and measurement of variables is very difficult and expensive, thus it is nearly impossible to study the tribological properties of rolls on a "real" rolling mill.
Therefore, this research aims to develop a method for the simulation of high temperature roll wear in a laboratory test rig. The method is expected to provide a fully-functional plateau system of rolling simulation test which can be used to, develop and test some new wear-resistant roll grades for both cold and hot rolling processes obtain some regularities for wear condition monitoring and to find suitable working parameters of rolling mills concerning tribological properties.

A new wear test geometry is proposed in this study and is implemented in the test rig. A tapered roller is pressed on a large rotating disk in this geometry. This is the closest geometry for simulation of roll wear in a rolling process. Some parameters such as wear, friction force, sliding/rolling ratio and vibration are measured in the experimental system. Electrical heating and ceramic fibre board insulation enable the test rig to operate at a high temperature, more than 700°C, and air cooling protects effectively the sensors and bearings from the high temperature. A computer is employed to monitor and control the system. Special software designed for the system makes it very simple to carry out the experimental operation automatically.

Preliminary commissioning tests have been carried out to ascertain the running of the test rig, the hardware and software. The main aim of the thesis is the design and commissioning of the high temperature wear test rig. The detailed friction and wear study at elevated temperature is beyond the range of this thesis.
Chapter 1

Literature Survey
Rolling is the process of plastically deforming metal by passing it through rolls and is used most widely among all metal working processes due to its high production speed and accurate control of final product[3]. Rolling is a manufacturing process producing slab, sheet, strip and foil with a dense attractive surface finish and increased mechanical strength.

Rolls are quite important for the rolling process because they influence the cost and stability of the production, as well as the quality and cost of products. Roll life is determined mainly by the tribological properties of rolls. Therefore, the wear and friction condition of rolls should be studied in detail.

1.1 Friction and wear

1.1.1 Contact and contact force distribution

Friction and wear are due to the forces between two contacting bodies in relative motion. Therefore the understanding of the contact situation and the friction force of the contacting bodies is essential for the study of friction and wear.

The most famous theory of contact is Hertz contact theory, which was published in Hertz's classic paper in 1882[4]. Though it is restricted to frictionless surfaces and perfectly elastic solids, it is still very important. Progress in contact mechanics later has been associated largely with the removal of these restriction based upon Hertzian contact theory[5, 6].
Two kinds of contacts are defined here, conforming and non-conforming contacts. A contact is said to be conforming if the surfaces of the two bodies 'fit' exactly or even closely together without deformation. Flat slider bearings and journal bearings are typical conforming contacts. Bodies which have dissimilar profiles are said to be non-conforming contact. The contact area between non-conforming bodies is generally much smaller than the dimensions of the bodies themselves. The stress is highly concentrated in the region close to the contact zone and is influenced little by the shape of the bodies at a distance from the contact area.

Solid bodies subjected to an increasing load deform elastically until the stress reaches a limiting value. In most contact situations, some asperities are deformed elastically, while others are deformed plastically. Actually, the tips of the asperities usually deform plastically.

The problems of elastic contact between two curved bodies were firstly solved by Hertz, and such situations are referred to Hertzian contact. Figure 1.1 shows the contact of the two curved bodies. The formulae for elastic contact stress of linear contact are as follows.

Semi-contact width,

\[ a = 2 \left( \frac{P R}{\pi E} \right)^{\frac{1}{2}} \]  

(1.1)

where \( P \) is the load on the unit length;

\( R \) is the effective curvature;
Chapter 1 Literature Survey

Figure 1.1 Contact of two curved bodies and force distribution

\[
\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}
\]

\(R_1\) and \(R_2\) are the principal radii of curvature of the two contact bodies

\(E\) is the contact modulus;

\[
\frac{1}{E} = \frac{1 - \nu_1^2}{E_1} + \frac{1 - \nu_2^2}{E_2}
\]

\(E_1, \nu_1\) and \(E_2, \nu_2\) are Young's modulus and Poisson's ratio of the two contact bodies respectively

Maximum contact pressure (Hertz stress),

\[
p_0 = \left( \frac{PE}{\pi R} \right)^{\frac{1}{2}}
\]  

(1.2)
Chapter 1 Literature Survey

Approach of the centres of two curved bodies,

\[
\delta = \frac{2P}{\pi} \left( \frac{1 - \nu_1^2}{E_1} \left( \ln \frac{4R_1}{a} + \frac{1}{2} \right) + \frac{1 - \nu_2^2}{E_2} \left( \ln \frac{R_2}{a} - \frac{1}{2} \right) \right)
\]  

(1.3)

Mean contact pressure

\[
p_{\text{mean}} = \frac{P}{2a} = \frac{\pi}{2} p_0
\]

(1.4)

Maximum shear stress

\[
\tau_{\text{max}} = 0.300 p_0
\]

(1.5)

The maximum shear stress locates in the neutral plane of the contact zone, and beneath the contact surface at the depth of 0.79 \(a\).

Pressure at the point \(x\) from the centre

\[
p = \frac{2P}{\pi al} \sqrt{\left(1 - \frac{x^2}{a^2}\right)}
\]

(1.6)

where, \(l\) is the contact length

The above formulae are often regarded as the Hertz equations.
1.1.2 Friction

Friction force is generally thought to be proportional to the normal load between the two contact bodies. Actually, friction force does not usually follow physical principles. Empirical formulae are usually employed to obtain the relationships.

Many studies focus on the friction force for sliding bodies. It is thought that friction force is due to interactions between the opposite asperities of the two sliding surfaces. The interaction is conventionally divided into two kinds: adhesion and deformation. Some asperities of the contact surfaces will adhere when a load applies on the two bodies. The adhesive junction will impede the motion of the two bodies, and will be broken when the motion takes place. Thus, the friction force is generated. The other interaction is from deformation or displacement of the contact surfaces, and in the macroscopic interaction, the harder surface ploughs grooves in the softer one.

K. L. Johnson studied the friction in rolling contact in detail[6]. He thought that all the motions between the two contact bodies can be divided into sliding, rolling and spinning. The resultant force transmitting any interface can always be resolved into a normal force, which acts along the direction of the common normal on the initial contact point of the two contact bodies, and a tangential force, which acts in the tangential plane. If the normal force is zero, the motion is defined as free rolling, otherwise it is called tractive rolling.

In free rolling, the contact stress and deformation can be calculated from the Hertz equations for the normal loading as shown in Equations 1.1 to 1.6.
Tractive rolling of elastic cylinders has been studied by F. W. Carter[7], H. Poritsky[8], K. L. Johnson[6] and R. D. Arnell[9]. In tractive rolling, in the contact zone, there is a central 'stick' area, and two outer 'slip' areas. The coexistence of zones of stick and slip is possible because of the deformable nature of the materials. Thus, if the normal force is kept constant and tangential force is increased steadily from zero, microslip begins at the edges of the contact zone and spreads inwards as tangential force increases; when the tangential force reaches the limiting value, tangential force times $\mu$ (coefficient of sliding friction), the two zones of slip meet in the centre and gross sliding occurs.

Rolling resistance also comes from adhesive and deformation losses, although the magnitude is much smaller. The resistance of free rolling arises mainly from a deformation loss, rather than an adhesion loss. It is confirmed that the resistance is influenced to only a small extent by the presence of lubricants, which would act to lower the adhesive contribution to the resistance. In tractive rolling, deformation loss is also the dominant factor of the resistance.

As an example of an elastic rolling contact[9], we consider a cylinder rolling freely on a plane under a normal load $P$ per unit length, as illustrated in Figure 1.2. The local pressure $p$, and the semiwidth of contact $a$ can be obtained from Hertz equations in 1.1.1. Considering a strip of width $dx$ at point $x$, we can see that, during forward compression of the contacting material, the normal force per unit length of the roller will be $pdx$. So, the moment about the centre of the cylinder is $pxdx$. Therefore, the total moment of the front half of the roller is

$$M = \int_0^a pxdx$$
If the cylinder rolls forward through a distance $x$, the elastic work done by this couple is given by

$$W = M\frac{x}{R}$$

$$= \frac{2Pax}{3\pi R}$$

Due to elastic hysteresis losses, not all the work in the forward half is recovered in the rear half and there is some dissipation of energy. Assuming the energy dissipated is $\varepsilon W$,
where $\varepsilon$ is a coefficient, smaller than 1. The loss should be the work of rolling resistance, if we think the deformation is the reason of rolling friction. Thus,

$$F_x = \varepsilon W$$

$$= \varepsilon \frac{2Pax}{3\pi R}$$

Furthermore, the coefficient of friction of rolling should be $\frac{F}{P}$. So,

$$\lambda = \frac{2\varepsilon a}{3\pi R} \quad (1.7)$$

1.1.3 Wear and wear catalogue

Wear is defined as "the progressive loss of substance from the operating surface of a body occurring as a result of relative motion at the surface"[10]. This "loss of substance" is of enormous economic importance. As an example, in 1978 National Bureau of Standards of United States reports that the loss of economy in United States from wear of material was about US$20 billion each year[11]. Another example is that the cost of wear from the British economy was estimated in 1988 to be about £2 billion[9].

Because of the uncertainty of friction and contact of two rolling and/or sliding materials, the wear condition usually can not be predicted in advance. The complexity in surface properties and interactions emphasises the difficulty of estimation of wear. It is generally agreed that the safe way to select materials to resist wear in a particular situation is on the
basis of tests first, realistic bench tests, and then field tests. Some wear parameters are usually described empirically.

Meanwhile, although there is much current research which is increasing the understanding of wear processes, it is probable that material selection will remain empirical for a foreseeable future. The importance of theoretical wear equations cannot be ignored, because they are useful to describe, explain and lead the actual application in industry. But the equations always contain factors which have to be determined by experiments.

Some researchers state that there are about 12 kinds of wear, each of which shows different symptoms and has different mechanism[12]. But conventional researchers just consider wear as one of the two groups: mechanical and chemical wear. It is commonly accepted that there are three major mechanisms in mechanical wear: adhesive wear, abrasive wear and surface fatigue. Corrosive wear is the typical chemical wear.

1. Adhesive wear

The real contact area between two materials is different from the nominated contact area. Only some asperities contact to subject the load between the two materials. When two materials contact and have relative motion, some strong welds may be formed at some asperity junctions and these welds must be sheared because of the continuous motion. If the shear of junction takes place away from the interface, a fragment of material is transferred from one surface to the other. Normally the softer material is transferred to the harder material, while occasionally the harder material is transferred to the soft one.
Three types of interferences of asperities can be concluded in the wear process. The blunter asperities allow the softer material to flow round them as a wave; this does not cause any removal of metal on the first pass, although, it may be removed on subsequent passes. The sharper asperities cause chips to be machined from the softer surface. Asperities of intermediate shapes cause a wedge of deformed material to form ahead of them at the start of sliding. The wedge effectively blunts the asperity, so that further material may flow round the wedge without removal, or it may intermittently displace the wedge, to form a new one.

Theoretical study of adhesive wear was firstly conducted by Archard in 1953[17]. He established a model for the contact area of the two materials. He assumed that each asperity is a hemisphere. Then he obtained the theoretical relationship for adhesive wear, which suggests that the volume of material worn is proportional to the sliding distance and the load, and inversely proportional to the hardness or yield pressure of the softer material.

In practice, the wear is usually proportional to the sliding distance and inversely proportional to the hardness of the softer material, but it is only in a certain range of conditions. When the load is too small or too big, the wear law is quite different. Especially, the upper limit of the load for the motion of the two materials, which is usually what researchers are interested, will cause an abrupt increase of wear.

2. Abrasive wear

Abrasive wear is considered as slight grinding in the surface of softer material. In two body abrasive wear, the harder surface slides on a relatively soft opposite surface, and
ploughs or cuts it. In three body abrasive wear, some hard particles trapping between the sliding surfaces cause one or both of the surfaces to be abraded. Some particles come from dirts and dusts in an industrial environment, while others are debris from corrosive wear of workpieces.

A simplified model can also be established to study the law of abrasive wear theoretically, which assumes that the abrasive particle has a conical shape, and the abraded surface is flat. From the theoretical study, it is found that the relationship between abrasive wear and the conditional factors is the same as in adhesive wear, which suggests that the volume of material worn is proportional to the sliding distance and the load, and inversely proportional to the hardness or yield pressure of the softer material in abrasive wear.

In practice, the situations are different. In two body abrasive wear, the harder surface must be relatively sharp, just like the abrasive machining of material. Surface roughness of the harder material definitely influences the abrasive wear. Small roughness of the harder material causes fine abrasive marks on the softer surface, which results in smaller wear. So, finished machining for the hard material is very important to decrease the abrasive wear.

Lubrication is very effective to reduce both the adhesive wear and abrasive wear, and to obstruct the growth of the wear. If the moving surfaces can be separated under an ideal lubricating condition, such as hydrodynamic and hydrostatic lubricating condition, both adhesive wear and abrasive wear will not occur. Without effective lubricant, if adhesive transfer takes place, both the worn surface and the transferred material can be roughened and work hardened such that adhesive wear will grow progressively in the process.
3. Fatigue wear

Macroscopic fatigue wear occurs at non-conforming loaded surfaces, such as those found in rolling contacts, whereas microscopic fatigue occurs at the contact between sliding asperities.

For rolling contact of two surfaces, circular compressive stress will cause large wear fragments, i.e., macroscopic fatigue. Because this kind of wear takes place rapidly which causes the part failure and almost no pre-symptom appears before the fragments are formed, this kind of wear is very critical. Therefore, useful life is often used to describe the fatigue wear rather than the wear rate. Even in very good lubricating condition, the fatigue wear due to subsurface shear also occurs in a distance below the contact surface. So, microstructural defect of the material, such as microcracks in the surface or subsurface, will accelerate fatigue. As a typical rolling contact element, bearing life is found to be inversely proportional to the cube of the load on it.

Microscopic fatigue takes place when two surfaces are in sliding contact. The elastic reactive force is formed to support both normal and tangential of the two contacting surfaces. Because of their height distribution and the contacting asperities are strained at different extents, the contact stresses generally vary from a low level of elastic stress up to the fracture stress of the weaker of the two contacting materials. The fracture stress can cause the formation of wear particles during a single interaction. The intermediate stresses which are above the fatigue limit and below the fracture stress will subject the asperity to a fatigue cycle. The accumulation of such cycles in continuous sliding will result in the formation of wear particles by local surface fatigue fracture.
4. Corrosive wear

Almost all the contact surfaces have corrosive wear, which cause the loss of the material. And the product of corrosive wear causes further wear of the contact surfaces. Corrosive wear always accompanies mechanical wear. The most common reason for corrosive wear is oxygen in the air.

It is not easy to precisely evaluate the rate of wear from the corrosive wear. The distribution of forces, the oxide film thickness and stabilities can influence the wear. It will depend on the corrosive environment, contact load, temperature distribution and the mechanical wear. So far, the prediction of corrosive wear rates still remain empirical.

It should be noted that oxidation of contact surfaces is often beneficial to wear, because the oxide film prevents metal-metal contact and thus mitigates the severe adhesion-enhanced wear which would otherwise occur. The contact surfaces remain smooth by the oxide film and the rate of wear is low.

1.1.4 Summary of wear equation and prediction

Many researchers in tribology have made much effort to find the relationships between wear and is relative variables and parameters[13], which is a common way for them to understand all the factors in a complex engineering process. If a clear equation can be obtained, it will be very easy and convenient to predict the engineering process. But unfortunately the equations for wear developed by these researchers can only be used in
a very limited and specific condition to predict the trend or to explain the influences between wear and the variables and parameters, as many other engineering problems. More than 300 equations for the friction and wear have been developed till now[14]. Some of these equations are based on physical modelling such as solid mechanics, while most are based on the combination of physical modelling and experimental study. Generally, the equations can not be applied to production with confidence[14], but they are meaningful for instructing design and production. Furthermore, the studies can also benefit the explosion of the “black box” in the future.

Bahadur summarised some equations in 1978[15]. Recently, R.G. Bayer wrote a chapter to deal with the wear prediction[16] and H.C. Meng and K. C. Ludema conducted a wide summary for the form and content of wear models and equations[14]. There are two general methods of modelling for the wear.

Empirical equations were applied for a long time. Typically empirical equations are valid only within a range of the test, but they are much more accurate in that range than theoretical equations. So, this kind of equation is still widely used now.

Volume loss may be expressed as one of the following three curves,

\[
\Delta V = \alpha t \quad (1.8)
\]
\[
\Delta V = \beta e^{\alpha t} \quad (1.9)
\]
\[
\Delta V = \frac{\beta}{\alpha} (1 - e^{-\alpha t}) \quad (1.10)
\]

where \(\Delta V\) is the volume loss, \(\alpha, \beta\) are constants and \(t\) is time of wear. Equation(1.8) describes the simple linear relationship between wear rate and time.
Equation (1.9) is the most commonly used empirical function, in which wear is a power function of time. Equation (1.10) is a complex equation, where $\beta$ is identified as "some characteristic of the initial surfaces."

Another common empirical equation describes the relationship among total weight loss and applied load, speed and time,

$$\Delta W = k F^\alpha V^\beta t^\gamma$$  \hspace{1cm} (1.11)

where $\Delta W$ is weight loss, $k$, $\alpha$, $\beta$ and $\gamma$ are constants. This is a common exponent empirical function.

After 1970, contact-mechanics were introduced to establish the equations of wear. They usually began from a model of contacting system, assuming simple relationships among working conditions. Topography of the contacting surfaces are taken into account in order to calculate the local region of contact.

The most famous equation is Archard equation,

$$W = k_s \frac{P}{p_m}$$  \hspace{1cm} (1.12)

where $W$ is the worn volume, $s$ is the sliding distance, $P$ the applied load, $p_m$ the flow pressure of the softer material, which is approximately proportional to hardness of the material. The ratio of $\frac{P}{p_m}$ is often taken as the real contact area, which is stated as a
constant related to the probability that an encounter of two asperities will produce a wear particle.

Some researcher also applied material failure mechanisms on modelling the wear.

1.1.5 Influence factors and variables of rolling wear

As described above, empirical equations for wear are far more accurate than theoretical equations in practice. The influence factors on rolling wear can be listed as below:

1. rolling velocity
2. load or pressure
3. time or rolling distance
4. materials properties of the two contacting bodies, such as density, hardness, Young's modulus, Poisson's ratio, critical strain and thermal conductivity,
5. lubrication condition
6. surface topography (roughness)
7. coefficient of friction
8. contact temperature
9. sliding/rolling ratio

The variables of friction and wear can be listed as below:

1. friction situation: friction force, rolling friction coefficient (rolling resistance coefficient)
2. wear: volume of loss (cross-sectional area of worn volume) or weight of loss, surface texture damage and debris
3. contact situation: vibration and rolling/sliding ratio

Therefore, the relationship among above influence factors and variables of rolling contact can reveal the tribological regularities in the rolling process.

1.2 Rolls in rolling mill

1.2.1 Classification of rolls in rolling mill

Rolls in a rolling mill may be classified in a number of ways. Rolls may be classified as their functions in mill, such as work rolls, backup rolls, process rolls and table rolls. They can also be classified as their materials of working surface, such as cast steel, forged steel, graphitic steel and cast iron rolls etc, as shown in Table 1.1[28].

Carbon in cast steel rolls ranges from 0.40 to 2.50 percent, in forged steel rolls from 0.50 to 1.50 percent and in graphitic steel from 1.50 to 2.50 percent. Carbon in cast iron ranges from 2.50 to 3.60 percent. Normally, silicon in rolls ranges from 0.2 to 2.5 percent, manganese is less than 2.5 percent, chromium less than 3.0 percent, nickel less than 5% and molybdenum less than 4%[1].
### Table 1.1 Classification of rolls according to the materials

<table>
<thead>
<tr>
<th>Material</th>
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<tbody>
<tr>
<td>Steel</td>
<td>Cast</td>
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<td></td>
<td>Forged</td>
</tr>
<tr>
<td></td>
<td>Normalised and tempered</td>
</tr>
<tr>
<td></td>
<td>Hardened and tempered</td>
</tr>
<tr>
<td></td>
<td>Graphitic</td>
</tr>
<tr>
<td>Cast iron</td>
<td>White or clear chill (no graphite)</td>
</tr>
<tr>
<td></td>
<td>Grain or indefinite chill (some graphite)</td>
</tr>
<tr>
<td></td>
<td>Gray (flake graphite)</td>
</tr>
<tr>
<td></td>
<td>Treated (inoculated)</td>
</tr>
<tr>
<td></td>
<td>Nodular (spheroidal, ductile)</td>
</tr>
<tr>
<td></td>
<td>Compacted</td>
</tr>
<tr>
<td>Special materials</td>
<td>Tungsten carbide coated rolls</td>
</tr>
<tr>
<td></td>
<td>Chromium plated rolls</td>
</tr>
<tr>
<td></td>
<td>High speed steel rolls</td>
</tr>
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### 1.2.2 Required properties of rolls

The final properties and performance of rolls depend not only on their chemical composition, but also on the heat treatment processes during their manufacture. In order to ensure work rolls to achieve their maximum useful life, it is necessary to select the optimum heat treatment parameters. The required properties of rolls vary according to different mill requirements. The properties of work rolls for a hot rolling mill should be:

1. wear resistance,
2. firecrack resistance,
3. spall resistance,
4. bending strength,
5. heat conductivity,
6. torsional strength,
7. fatigue strength,
8. hardness,
9. shear strength,
10. yield strength

Actually, the properties required differ in detail at various stages of the rolling line. For example, at the initial stage of rolling process the heat stock resistance and the general strength of the material are the major requirement of work rolls, but on the finishing stand, resistance to abrasion is the most important.

Backup rolls are subjected to extreme pressure in the contact area with work rolls. Work hardening occurs on each revolution and sub-surface shear failures can be developed, which can result in spalling[28]. The properties of backup rolls should be:

1. wear resistance,
2. fatigue strength,
3. tensile strength,
4. yield strength,
5. shear strength,
6. hardness
In the above properties, ductility is not included. The emphasis focuses on the strength and hardness of the rolls. However, ductility can decrease significantly with the increasing strength and hardness. Roll cracking susceptibility due to thermal fatigue and abnormal thermal shocks are mainly affected by fracture toughness, thermal conductivity, thermal expansion and ductility[1]. Hence, too high hardness does not always mean a good property for rolls and a compromise between strength and ductility should be examined.

1.2.3 Application of rolls

Cast iron rolls are widely used at finishing stands because of their high wear resistance. On the other hand, steel rolls are often used in primary and secondary mills. Because steel rolls are much stronger and tougher than iron rolls, they can withstand higher bending and torsional stresses. On the whole, various centrifugally cast steel base grades (adamites, C: 1.25-3.5%, Ni: 0.25-1.0 %, Si: 0.2-0.5 %, Mn: 0.45-0.7 %, P: <0.12%, Cr: 0.5-1.0 % and P: <0.05) can offer a better combination of resistance to mechanical stresses, thermal fatigue and wear. Therefore, adamites are chosen commencing with a hardness of 300 HB for the entry stands, and ending with a hardness of 420 HB for the finishing stands. In some modern mills, spheroidal iron is favoured for the intermediate stands, for it exhibits the strength of the higher carbon steel roll grades and the wear resistance of the alloy iron grades. Meanwhile, a high carbon steel or a graphitic steel would be a better material for deep groove rolls in the intermediate stands. This is because a steel roll can be heat treated to maintain a uniform hardness to a sufficient depth, which is much deeper than that with irons[1, 27, 28].
Nowadays, some special materials are introduced to manufacture rolls for the rolling process, such as tungsten carbide coated rolls, chromium plated rolls and high speed steel rolls.

1. Tungsten carbide coated rolls

The recent development in high velocity coatings comes from Browning Engineering Company with the introduction of AEROSPRAY, which is a High Velocity Air Fuel process. This kind of process produced the best tungsten carbide coating available today. Typically it produced a 88%WC/12%Co coating with a surface hardness of 1350Hv on forged steel work rolls[22]. However, this type of surface treatment is still in the experimental stage for cold rolling mill work rolls and benefits in productivity and cost performance must be established before this technology can be used in production[23].

2. Chromium plated rolls

Hardness of electrolytically deposited chromium exceeds 1000Hv, so it is used to improve the wear resistance of mechanical parts including rolls in rolling mill. Hard chromium plating was first used in work rolls in 1963 reported by B. Spencer et al[19]. It was found that chromium plated work rolls produced 4.2 times as much steel before the rolls needed replacing. At the same time chromium on the surface of work rolls made the surface smooth, so as to produce higher quality products. The wear rate of chromium plated rolls was 1/10 that of untreated rolls in their application. It is also found that electro-deposition of up to 10μm of chromium on textured work rolls has little effect on their surface roughness, but the better lubricating condition of the coating
reduces wear and damage resulting from grit, slugs and foreign material, as well as providing increased sticking resistance[20]. Although it is generally agreed that the wear resistance of chromium plated rolls is about 10 times greater than that of untreated rolls[21], the average production increase due to the chromium plated is about 2 to 3 times the production before plating because of work roll damage by welds, strip breaks, mill wrecks, etc.[20, 21]. This increased production has definite benefits and savings including improved product quality, reduced roll changes, less roll grinding and decreased minimum grinding depths, which means a much lower roll consumption, and an increase of total roll life in excess of 2 to 3 times that of untreated rolls.

Recently, another new technology was developed to densify the chromium plate. Hard chromium plate usually has a microcrack network and some porosity sufficient to allow corrosive fluids to penetrate to the interface between the mother material and chromium plate. The interface is attacked and thus causes debonding of the plating. It is possible to seal the porosity in the chromium plating with a densification process called C-RAMACHROME[66]. This process used a ceramic filler to seal the chromium plate, which improved the hardness and wear resistance of the surface. It was applied on some tension leveller rolls in BHP Co., which led to cost savings of about two thirds.

3. High speed steel rolls

High speed steel rolls as a composite with a core of common forged steel have been manufactured for many years, although they were limited to only very small work rolls used in cluster mills[24]. However, the recent development of bimetallic ingot casting by Hitachi Ltd has made it possible to manufacture work rolls large enough for four high tandem mills, and such rolls are now being tested in actual production mills[21].
We must be aware that, as the hardness and wear resistance of work rolls increases, grinding becomes more difficult, which not only increases grinding time but results in scratch type defects from loosened particles of the grinding wheel. Therefore, to grind such rolls, more expensive, high performance ceramic, diamond or Cubic Boron Nitride abrasive wheels must be used.

1.3 Hot roll wear modes

In the rolling process, faults of the whole production may come from roll, roll system, and general equipment. Roll defects are the most frequent and most expensive faults in normal rolling production.

The nature of in-service defects of the roll has not been comprehensively explained, and the actual extent of this problem is not quite clear. Some researchers consider that the main reason for this situation is the slow development of specific non-destructive-test technology for roll inspection equipment. So, the simulation experiment is a reasonable method for the study of roll defects. Wear of roll is a dominant factor in roll defects, and crack, spall, gnaw and pick-up all come from wear. In many cases, roll life is actually only 40 percent "service use", while the remaining 60 percent is for repair of damage[18]. This magnitude shows that the problem of heavy wear of the work rolls in rolling mills is very important in the steel industry.

Wear causes dimensional inaccuracy, especially in strip rolling. In section rolling the wear is seldom uniform in the process and affects the shape accuracy of product. In
addition, the deterioration of the roll surface in the finishing stand affects the surface of the products, which is especially detrimental when good surfaces are specified. Rectification of the work rolls involves considerable cost to restore their surface profile, as finish turning, grinding and roll changes downtime are all expensive items[25].

The modes of roll wear are mainly as follows,

1. banding caused by thermal fatigue and mechanical fatigue;
2. abrasion;
3. adhesion or sticking fatigue;
4. chemical corrosion;

All of these modes depend both on the material characteristics and the system interactions[1], so roll wear is a complex process. Complex interactions affect the wear conditions, for example, the loss of surface material may lead to loss of fit and alignment, with resultant changes in load, friction and sliding/rolling ratio, generating subsequent wear damage.

Many researchers found that the first two modes, namely banding and abrasion, are dominant in hot rolling mills[1, 2, 26, 27, 56].
1.3.1 Banding

Thermal fatigue is the most important factor of wear in the hot rolling process\[25,27\]. Large temperature differences exist between the rolled workpiece and rolls, causing heat flow from the workpiece to rolls through the contact zone. The outer layer of the rolls contacting the high temperature workpiece tends to expand, but it is prevented by the body of the roll which remains cold. If the temperature difference between the surface and the body of rolls is sufficiently great, large circumferential compressive stress is induced in the surface. When the outer layer is cooled by water spray, large tensile stress is also induced. These surface stresses are cyclic and have the same frequency as the rotation of the roll. They can be severe enough to exceed the yield stress of the roll material and cause the surface layer to deform plastically\[33\]. The result of these permanent surface strains is a mosaic-like pattern of surface cracks, often referred to by mill operators as "fire cracking". W. J. Williams\[34\] has shown that these cracks predominate in the directions normal and parallel to the roll surface. Sekimoto\[35\] found that the depth of the fire cracks is dependent upon the roll surface temperature and the depth of the surface layer which is heated to a high temperature.

Banding of rolls was introduced to describe the failure caused by thermal fatigue and mechanical fatigue. Banding failure is characterised by the formation of fine surface firecracks, followed by the formations and then peeling of a shiny black oxide. The peeled oxide layer often takes some roll metal with it, leaving a roughened surface unsuitable for further rolling. Banding is brought about by the tearing out of very small pieces of roll metal\[29, 60\]. DeBarbadillo and Trozzi studied 20 samples in detail including cast steel, grain iron, nodular iron and high-chromium iron during a 2-year
research program, and found that fire-cracks always occurred in the roll work surface but never on samples taken from outside of the roll work zone. Furthermore, they concluded that the banding was essential in the roll wear mechanism and proposed a five-stage mechanism[29]. The five-stage mechanism is from the generation of the crack to break-down from the roll surface, which is described as following.

In the first stage, the heating of the roll surface causes stress that is sufficiently high to reach the yield stress in the roll surface, and thus deform the roll surface plastically. When the roll is cooled, the surface contraction should initiate reverse plastic yielding. However, yielding does not occur in the reverse direction because the ductility of the roll material is not sufficient when the roll surface is cooled, and the roll material cannot withstand the high tensile stress during cooling. Hence the roll surface will crack, resulting in the fire-crack pattern.

The formation of fire-cracks changes the stress pattern abruptly during the rolling cycle. Stress arising from the roll pressure becomes more important since the thermal expansion of the surface layer is no longer constrained by the roll mass. In this second stage, transverse cracks are induced due to differential thermal expansion of the matrix and the carbides. This cracking can be considered as thermal fatigue on a microscopic scale.

In stage three, the roll surface becomes more irregular. Surface cracking pushes the surface to bulge up and causes small fragments to tilt. Transverse cracks begin to link with fire-cracks, permitting oxidation. The strength of the surface layer is reduced by the presence of cracks, resulting in the collapse of areas over discontinuity such as
graphite particles. The thermal conductivity is also reduced due to cracks, causing the roll surface to be hotter.

In stage four, the hot roll surface rapidly becomes covered with an oxide layer that adheres tightly to the roll surface. The oxide is plastically deformed under conditions of high temperature and compressive stress, but has little strength under the influence of tensile stress, and the fire-crack pattern of the roll is not covered by the oxide layer. The surface oxide may protect the roll from wear by reducing the heat transfer, but subsurface cracks continue to form and link up due to thermal stress and roll pressure.

The final break-down of the roll surface, during stage five, can occur in many ways. It can occur spontaneously or be stimulated by an outside force, such as shear stresses at the roll-bar interface. Often the first step is dislodgment of small pieces of roll material at the intersection of fire-cracks. These free pieces may abrade and penetrate the oxide layer and may be rolled back into the roll surface. When this process proceeds the surface layer is further weakened and later larger segments consisting of area defined by the fire-crack mesh may dislodge, carrying portions of roll material with them. The roll surface is at this stage greatly irregular, and rolling of defect-free products is no longer possible.

Several theoretical, empirical and experimental analyses of this thermal distribution have been published[49, 50, 51] to evaluate the thermal fatigue.
1.3.2 Abrasion

This type of wear results from the displacement of the softer of the two materials in sliding contact by an asperity of the harder material. It can also be due to a harder particle of foreign material which may become partly embedded in the softer material so that the hard particle behaves as a miniature cutting tool which ploughs grooves on the harder one of the two surfaces.

In hot rolling mills the abrasive wear is caused by rubbing contact between the rolls and the workpiece. Also, in the case of four-high stands, there will be some abrasion from contact of the back-up roll and work roll.

Hot strip mills are usually installed with scale breakers before the roughing stands and the finishing stands, so that the scale which is formed on delay table can be removed. But scale removal is rarely carried out within the finishing stands, so the scale formed between stands is rolled together with the stock. The scale layers which are hard and smooth, under the condition of high pressure in the roll gap, abrade the roll surface. Some researchers thought that this kind of three-body wear coming from oxide scales would be a common wear mode in hot rolling process[2, 11, 57]. A detailed classification of abrasion includes micro-ploughing, micro-cutting, micro-fatigue and micro-cracking.

In a multi-stand rolling mill the workpiece is accelerated as it passes through the stands, hence, the contact time for each revolution between the roll and the workpiece decreases till the final stand. The workpiece’s temperature also decreases from stand to stand,
reaching minimal at the final finishing stand. Hence, the total roll surface temperature attained in the roll gap diminishes along the mill. As thermal fatigue is a function of temperature and contact time, it is expected to be dominant in the roughing stand but having a smaller effect in the finishing stand. However, abrasion is a function of rolling load and speed, which gets its highest in the final stands. Shuaghnessy[32] reported from his metallurgical examination of roll surface structures, before and after rolling, that thermal fatigue is the primary cause of deterioration in the roughing and early finishing stands, and abrasion is the cause of deterioration in the finishing stand.

Other wear modes are also responsible in the rolling process. The outer layers of rolls endure large load cycles. Macroscopic mechanical fatigue must exist on the roll surfaces because of the circular compressed stresses. Fragments on the surfaces can be formed due to severe mechanical fatigue. Adhesive wear may be found in some situations. Usually some fragments of rolled materials stick or weld to the roll surfaces. Corrosion is common in the hot rolling process because of the high temperature, large stresses in the contact zone, and oxygen in the air.

There are some special phenomena found in the hot rolling process. Some researchers found that oxide scales at high temperature sometimes benefit the resistance to abrasive wear, because oxidation of some grades would produce a hard and smooth black magnetite scale film, which provided small friction coefficient between the rolls and rolled workpieces for some specific grades of rolls[61].
1.4 Influence factors of hot roll wear

Influence factors of rolling wear have been concluded in 1.1.5. On account of roll wear in the hot rolling process, the influence factors were summarised in Figure 1.3[1].

1. Rolling pressure

It is commonly accepted that wear rate is proportional to the normal pressure on roll surface. This is mainly because both adhesive wear and abrasive wear are proportional to the pressure. Cyclic stresses on the rolls surface result in material fatigue and other forms of surface deteriorations. Besides the mechanisms of cyclic softening and
corrosion fatigue, there is growing evidence of the damaging influence of tensile stress during the contact fatigue, leading to cracking and pitting.

Actual distribution patterns of the rolling load and stresses directly influence the uniformity and stability of wear. Hence, the design and control of load and stress distribution should ensure the uniform and stable wear of rolls in finishing stands.

2. Rolling temperature

The most important effect of rolling temperature is the formation of oxide scales in the hot rolling process. Researchers found that wear rate was different at different temperature.

Magnee pointed out wear was a maximum at 600°C dropping to a minimum at 900°C[62]. He explained his findings on the basis of the different scale composition and hardness at different temperature zones. The peak of wear corresponded to a high proportion of hard Fe$_3$O$_4$ and Fe$_2$O$_3$ at 600°C, while the minimum at 900°C was caused by soft FeO. Lundberg found that wear was a maximum at 900°C[30]. He explained that the scale growth increased rapidly when the temperature was above 900°C and the additional thickness of scale built up on the roll resulting in a actually lower surface temperature of the roll. The scale hardness was decreased at high temperature. So, the maximum wear was at 900°C. Savage recently presented the similar results that the wear was a maximum at 900°C to 950°C[59]. He explained this phenomenon based on the effect of temperature on scale growth and strength. At a temperature above 950°C the scale sheared internally which resulted in lower wear and friction. When the temperature was below 950°C, the scale was intact and wear
increased with increasing temperature as a result of roll softening, and harder abrasive oxides at the interface.

A. Ohnuki pointed out that the scale on cast steel and adamite roll transformed from magnetite to wustite when the temperature was high enough[61]. At above 650°C, the surface layer matrix was softened and deformed plastically. Therefore, he thought cast steel and adamite materials should be used in the temperature range 500°C to 650°C. For the same reason, grain cast iron rolls should be used between 600°C and 700°C.

Some researchers also found that friction was a function of rolling temperature. Roberts presented several linear relationships after citing many authors[63], which showed friction increased with temperature at 700°C to 1200°C. Ginzburg reported the contradictory findings[56], which showed that friction decreased linearly with temperature in the range of 700°C to 1250°C. Other researchers, including Lundberg and Savage, found that friction force had a peak at 900°C to 950°C[30, 59, 65]. Lundberg and Savage explained this phenomenon based on the same explanations for the wear peaks.

In a word, temperature is a dominating influence in hot rolling process. It directly influences the scales and thermal fatigue. It should be pointed out that thermal stresses are much more severe than the roll pressure, for example, thermal stress may be more than twice of the maximum roll pressure[2].
3. Cooling and lubrication

Efficient roll cooling and lubrication reduce the temperature variations of the roll, hence, decrease the probability of roll breakage and reduce the rate of deterioration of the roll surface. In consequence, efficient cooling and lubrication improve the surface finish of the product and impede the thermal crown which may improve the shape accuracy of the product.

Many researchers confirmed that significant decreases in roll wear had been achieved by use of lubricants, although some limitations were reported relating to their use at high temperature and the influence of hydrocarbon fluids, in particular, on roll performance. The lubricant will not only reduce metal/metal contact in the roll gap, it is also expected to reduce the heat transfer from the workpiece to the roll surface, minimising the thermally-induced stresses. It is also expected that the products of lubricant decomposition will plug surface cracks, inhibiting their further development. Nishizawa found from an actual rolling mill that rolling force was decreased by 10-20% and the roll wear was reduced by 70% when using a special kind of lubricant[64]. Several researchers, however, indicated that, lubrication sometimes paradoxically increased roll wear in the hot rolling process[31, 63].

Therefore, it can be concluded that the use of lubricant is marginal at the roughing stands where the workpiece is thick, heavily scaled, and rolled at a relatively low speed, whilst in the finishing stands the use of a lubricant is highly beneficial[25].
Chapter 2

Design of Hot Rolling Wear Test Rig
2.1 General Design

According to the aim of the experiments for hot rolling wear, the rolling wear test rig should have the following functions:

1. produce rolling contact
2. can work at ambient temperature and elevated temperature
3. simulate the hot rolling process as closely as possible
4. can measure friction and wear situation

2.1.1 Selection of test geometry

Though ASLE concluded 234 kinds of friction and wear rigs[52], most of them were based on sliding contact that can be applied for sliding wear test. Only multiple sphere and two roller wear test rigs, shown in Figure 2.1 and Figure 2.2, were adopted by some researchers for rolling wear test[48]. The former is mainly used for the study on ball bearings, while the latter is suitable for detecting the wear situation of two rolling contact couples such as roller bearings.

Two roller geometry can be used to simulate the rolling process. BHP in Australia and Lundberg in Sweden employed this kind of geometry to simulate rolling process and obtained some practical results[1, 2, 30]. But the contact condition of two rollers is different from the condition of the roll and the workpiece in the rolling mill. The workpiece should be treated as a plate rather than a cylinder.
Roller-on-disk geometry newly proposed in the thesis is shown in Figure 2.3. The roller and disk can rotate about their respective axes. Both the axes are fixed. The disk is driven positively. The rollers are driven passively by the friction force between rollers and the disk.

Another roller can be applied in this kind of geometry, as shown in Figure 2.3. We can use one new material roller, and use another reference roller to compare the wear and
friction characteristics of the two materials. This is better than the other test rigs with one specimen due to their inability to repeat the same test condition for different materials. We can also change the position of the roller on the disk to change the sliding/rolling ratio to study the influence of the sliding in experiments.

This geometry can guarantee the main wear object to be the rollers rather than the disk because the diameter of the disk is much greater than the diameter of the rollers. This kind of geometry is the closest and easiest way to simulate the practical situation of the rolling process so far. Until now we have not found any researcher applying this kind of geometry.

2.1.2 Outline of the wear test rig

A pin-on-disk wear test rig which is in existence in the Department of Mechanical Engineering is selected to be modified for the roller-on-disk wear test method. The Ø395 disk is driven by a direct current motor with a thyristor drive and variable velocity control unit while a roller is on the disk contacting with its taper surface. Because the velocities of two ends of the roller in its axial direction are different, the roller is designed to be a tapered roller. The tapered roller is held on a support beam with two bearings and is driven by the friction force between the roller and the disk. Roller support beam is connected to a couple of holding blocks with a shaft, thus the contact angle of roller and disk can be adjusted. Two linear bearings link the holding blocks and a big holding frame on the top in the friction force direction. The holding frame can rotate about a pulley shaft fixed further away from the centre of the disk. The shaft can support another holding frame and roller, thus the test rig is capable of
testing two kinds of material at the same time. Load is applied to the roller by dead weights. Friction force, temperature, vibration, acoustic emission signal, wear of the roller, and the disk and the roller velocities can be measured with corresponding sensors. The outline drawing of the rig is shown in Figure 2.4. The photograph of the test rig is shown in Figure 6.1 in Chapter 6.

Figure 2.4  Outline of the wear test rig
2.1.3 Input and output parameters of the rig

In order to evaluate the effect of main variables on rolling wear process, the following parameters are chosen for the test rig:

(1) materials
   material of the roller is AS1204-250 (mild steel),
   material of the disk is 253MA, which is a hard and heat-resistant steel.

(2) temperature:
   maximum temperature 700°C

(3) pressure (or load):
   0—160 MPa
   Load can simply be evaluated with the Hertz Equation. For example, when the Young's modulii of the materials of the roller and the disk are 200 GPa (mild steel) and 350 GPa (253MA), both Poisson's ratios are 0.3 while the pressure is 160 MPa, the maximum load is 34 kg for the rig.

(4) speed (or rolling distance):
   1—4.5m/s
   This speed is referred to the normal hot rolling speed.

The following output variables will be obtained to study the wear and friction features at high temperature:
(1) coefficient of friction
(2) wear rate of the roller:
   loss of mass
   change of the diameter
(3) vibration of the roller
(4) surface damage
(5) sliding/rolling ratio
(6) acoustic emission signal

2.2 Heating and insulating design

2.2.1 Heating method

Hot rolling wear test is based on elevated temperature on the rolling surface. Heating disk is selected because it is similar to the hot rolling process and implemented more easily, although the heating area is larger and the cost may be more than heating the roller.

Heating the disk can be divided into two methods. The first method is outside heating method. For example, the disk can be heated with an induction coil near the disk but without contacting the disk. It is easy to mount this heating device but the heat efficiency will not be low and the cost will be very high. The second method is internal heating method. Heating elements such as heating pipe or electric resistance wire can be embedded inside the disk.
We simply select electric resistance wire inside the disk, because it is the fastest and cheapest way. Electric resistance wire is embedded in a ceramic plate for heating the top disk to the maximum of 800°C. Electric brushes (slip rings) are used to conduct the electric power into the disk because the disk is spinning, and insulation material is used to avoid a large amount of heat spreading to other directions and concentrate the heat to the top disk.

The outline drawing of the heating disk, heating element and insulation material is shown in Figure 2.5.

### 2.2.2 Heating disk design

The material of heating disk is 253MA heat-resistant steel, which can function properly up to 1175°C. The 253MA steel is an austenitic chromium-nickel steel alloyed with nitrogen and rare earth metals. The grade is characterised by high creep strength, very good resistance to carburisation and good structural stability at high temperatures. Mechanical properties at high temperature are listed in Appendix A.

The outer diameter of the disk is 395, inner diameter is 300, and the thickness is 3mm.

As shown in Figure 2.5, the disk is mounted by 8 long screws on the base disk, and there is some clearance between the screws and the holes on the ceramic plate and supporting disk, so the expansion of the disk at high temperature is not too restricted by the screws. The disk actually is a ring which can decrease the distortion caused by the unbalance of expansion.
Figure 2.5  Outline of heating disk, heating element and insulation board
2.2.3 Heating element

A five-meter-long electric heating element is embedded in the groove of ceramic plate to heat the top disk. The plate is made of a special machinable ceramic. Some small and short hard ceramic beads are placed between the element and disk to isolate electrical power.

2.2.4 Insulation design

Heating insulation is very important for the overall heating device. Good insulation is the first factor to be considered to achieve very high temperature for the test rig. Because the spindle, linking disk and base disk are made from steel, insulation method must be considered to reduce significant heat loss through these steel disks and the spindle. The bearings for the spindle also require good heating insulation from the heating zone.

Kaowool ceramic fibre board is selected for heating insulation. Kaowool ceramic fibre is produced from refractory fibre compositions specially developed to give rigid, self-supporting forms. The maximum service temperature of the board selected for the test rig is 1260°C. The thermal conductivity of this kind of board is quite small. Typically it is less than 0.2 W/mK at 1000°C, and it is about 0.07 W/mK at 200°C.

Because Kaowool ceramic fibre board is very soft, it can not stand heavy load. So, some spacers and a supporting disk are introduced to support the load. The machinable ceramic board is used to mount the electric element and support the
heating disk directly. The ceramic board can isolate the electricity from electric element and insulate some heat as well.

Three layers of Kaowool ceramic fibre paper are implemented in the heating groove. They are located between the bottom and two sides of the groove and the element to decrease the heat diffusion downward and sideward.

To decrease the loss of heat near the specimen disk and decrease the heating influence to the other parts in the test rig, almost all the top and side surfaces of the disk are completely enveloped by Kaowool fibre board.

2.3 Electric brushes design

Because the heating element is spinning together with the disk, electric brushes are applied to lead the electric power to the element. The outline drawing of the electric brushes is shown in Figure 2.6.

Two electric brushes are fixed to the frame of the wear test rig. Brushes contact two commutators respectively. The two commutators spin with the base disk. The small commutator is a cylinder, while the big one is a ring. The centre of both commutators is the same as the centre of heating disk.

The load capacity of the electric brushes is determined by the material, the contact area of brushes and commutators, and the contact force between the brushes and commutators. Better material couple for electrical brushes and commutators is
graphite and copper. Because the graphite is soft and is self-lubricated, it can contact the copper properly. The normal current permitted per square centimetre is 5 to 12 Ampere for this kind of couple.

The electric brushes locate near the spinning centre of the disk to decrease the brush wear and the vibration of the contact surface. Commutations are made of copper, while brushes are made of graphite. Cylindrical brushes are pressed by two springs and held by two seamless pipes. A hard and heat-resistant board is used to support the two commutators and insulate the electricity as well, and hold the brushes. This kind of material can work at 500°C.

The maximum electric current should be more than 80 Ampere, and the corresponding diameter of brushes is designed to be 42 mm. If load capacity is assumed to be 6 Amp/cm² conservatively, the current permitted by the brushes is

\[ I = \pi \times \left( \frac{42}{20} \right)^2 \times 6A \]
\[ = 83A \]

The contact force between brushes and commutators is adjusted to be 2.5kg–3.5kg by the two springs according to the recommended value of 17.5 kN/m².

Figure 2.7 shows the photograph of the electric brushes and the heating disk.
Figure 2.6 Electric brushes
2.4 Roller and its support design

Roller and its support are shown in Figure 2.8. Roller is held by a support shaft, and the shaft is fixed by two bearings, so the roller can rotate about its centre line. Bearings are mounted in a block which is connected with a support beam. The support
beam links to a holding block through a shaft. Two linear bearings connect the holding block and a frame, which can rotate about a pivot. The holding block and frame are kept level. The load is applied on the holding block to provide the required pressure between the roller and heating disk, as shown in Figure 2.4. The roller is fixed by a long bolt in the hollow support shaft. In such a way, the roller can be replaced conveniently by another one after severe wear or for check in an experiment.
Figure 2.9 is the photograph of the holding frame in the rig.

Figure 2.10 shows the geometry of the roller. To ensure no relative sliding in its axial direction when the roller rolls on the disk, the roller is designed as a tapered roller. The front end of the roller is 165 mm away from the centre of spinning disk. The
diameter of front end is 19 mm, so the taper should be $2 \times \arctan \frac{19/2}{165} \approx 6.59^\circ$. A long supporting arm is designed to provide space for the capacitance sensor.

Figure 2.11 is the photography of the roller and its support beam. As mentioned above, the maximum load is approximately 34 kg. The roller support beam is designed to be about 38 mm wide and 12 mm thick, and the distance between two bearings to be about 30 mm and the internal diameter of the bearings to be 20 mm. Therefore, the strength of the beam and the roller is sufficiently strong and the deflection of the support beam, the support shaft and the roller should be very small.

![Figure 2.10 Geometry of the roller](image-url)
Figure 2.11  The roller and its support beam
The groove ball bearings are mounted far from the hot rolling contact surface. They are IT6 accuracy, with an internal clearance of C5 to allow for the expansion of the shaft. They can work properly up to 360°C. The Molykote high temperature grease is filled into the bearings for lubrication, which can work at 290°C.

2.5 Consideration of parameter measurement

The temperature of rolling surface, change of diameter of roller, friction force, acoustic emission signal, spinning velocity of roller and disk will be measured during the process of wear. Mechanical mounting of the sensors is discussed in this chapter. Electrical characteristic and selection of sensors will be discussed in Chapter 4.

2.5.1 Capacitance sensor

A capacitance sensor, Px305-HB made by Lion Precision Co., is applied to measure the change of diameter of the roller, and velocity and acceleration of vibration. The tip of the sensor just faces the top generating line of the roller.

The tip of the sensor is modified to make the sensor sensitive and prevent the original tip of the sensor from being damaged by over heat, as will be discussed in Chapter 4. Two additional tips are used connecting to the original probe of the sensor, as shown in Figure 2.12. One is the guarded tip from the manufacturer of the sensor, and the other is newly designed with a smaller head. A spring is used to make the new tip to contact the guarded tip properly. A ceramic pipe is put between the tip cap and the small core shaft to insulate the two components.
Figure 2.12 Modification of probe of Px305-HB capacitance sensor
The head of the protective cap is reshaped to be concave to fit the tapered surface of the roller.

### 2.5.2 Thermocouple

The temperature of rolling surface is measured by a K type thermocouple, which is held by a spring beam to make the junction point to contact the top surface of the spinning disk. The diagram is shown in Figure 2.13. Thermocouple can be replaced conveniently when the junction is worn.

![Diagram of Thermocouple Mounting](image-url)
2.5.3 Load cell

A load cell, SM-100 made by Interface Inc., is mounted in the direction of the relative movement of the roller and the heating disk. It connects to the top holding block of roller support beam and the swing holding frame, as shown in Figure 2.9. There are two linear bearings on the holding block connecting with the holding frame, which can swing about a pivot on the rig base. The swing frame is kept level. The friction force between the roller and disk transfers from the roller to its support beam and through the holding block to the load cell.

2.5.4 Optoelectrical sensors

Spinning velocities of the roller and the disk are measured by two optoelectrical sensors to determine the sliding proportion of the roller.

As shown in Figure 2.8, a thin disk is mounted on the rear of the roller support shaft to measure the spinning velocity of the roller. An optoelectrical sensor detects the slot on the speed measurement disk and transfer to pulse signal. Then the spinning velocity can be calculated.

Another optoelectrical sensor is mounted on the bottom of the rig to measure the spinning velocity of the heating disk. It detects the 24 slots on the measurement disk which is connected on the bottom end of the main shaft of the rig.
2.5.5 Acoustic emission sensors

An acoustic emission (AE) sensor is mounted on the roller support frame to get the acoustic emission signal caused by the wear of the roller. Vaseline has not been used but can be applied between the sensitive tip of the sensor and the measurement surface, which guarantees better transfer of acoustic emission signal. The contact force is applied by a soft spring on the back of the sensor. The sensor should be located near the roller to measure the wear characteristics of the roller. But because of the high temperature of the roller, the sensor has to be located a little bit far from the roller. The sensor is a high temperature sensor, which can operate up to 500°C.

2.6 Cooling design

High temperature is obtained on the top of the heating disk and the surface of the roller to simulate contact between the roller and hot steel product. Some insulating measures are taken to prevent heat in the heating zone from dissipating to the spindle and circumferential directions, as discussed in 2.2.4. But the temperature surrounding the roller support bearings, capacitance sensor and optoelectrical sensor for roller speed is still very high. High temperature will influence the working condition of bearings, the accuracy of sensors, and even damage the bearings and sensors.

Cooling is considered in structure design. To protect bearings, five dissipate flanges are designed at the front part of the roller support shaft, and the bearings are mounted far from the roller, as shown in Figure 2.8 and Figure 2.9. The probe of the
capacitance sensor is extended to decrease the temperature of the original tip of the sensor. The optoelectrical sensor for roller rotary speed is mounted at the opposite end of the roller support shaft to prolong its life at lower temperatures.

Air forced cooling is also used to cool the bearings and sensors. There are five cooling nozzles to cool the bearings and sensors. Air cooling system block diagram is shown on Figure 2.14.

A compressed air nozzle blows the flanges of the roller support shaft in the opposite rotary direction. A small air nozzle blows the optoelectrical sensor for the roller speed measurement to decrease the temperature.

The shaft of bearings is a hollow shaft. As shown in Figure 2.8, compressed air can go through the hollow shaft from the end of the linking bolt, then blows out from 24 small cooling holes in the front end near the roller and front bearing. There are 16 holes in the axial direction in the support block of bearings. Compressed air goes into
one hole from the rear of the block to the front of the block. Then through a circle slot, it blows into another 15 holes at the rear of the block.

The original probe, guarded tip and newly designed tip of capacitance sensor are covered by a cooling pipe with a compressed air inlet on it. Compressed air blows from the top of the original tip to the end of the new tips, then to the side direction from an outlet to the flanges of the roller support shaft. Therefore, the cooling air affects less on the temperature of the roller, but decreases the temperature of flanges. There are also 4 holes on the extension pipe of the sensor, and there is large space between the pipe and the extension rod, as shown in Figure 2.13. Therefore, it will only transfer small quantity heat to the original probe.

The air pressure is 0.5 MPa-1 MPa and the maximum designed cooling air velocity is 10m/s. The diameter of nozzles is about 4mm, so the total flow rate is 2.2 m³/hr.
Chapter 3

General Design of Measurement and Control System
3.1 Measurement and control system based on computer

The application of the microcomputer allows evolution and development of the measurement and control system. Powerful software functions in this kind of system may include data acquisition, simulating instruction panel, instrumentation and device control, database management, and graphic display and output. This kind of "intelligent" measurement and control system can offer increased reliability and flexibility, through non-end-loop monitoring, built-in diagnosis, regular internal calibration and prompting of inexperience of operators where necessary.

Researchers have shown that the design of the human-computer and machine-computer interfaces can make a substantial difference in performance, accuracy, speed, learning time and user satisfaction for a computerised system. So, interface design plays an important role in the system. Actually, interface design is the main task for a measurement and control system based on a computer, because sensors, instruments and control devices are usually available directly from the manufacturers. Interface design for machine measurement and control is a combined knowledge of mechanical engineering, microelectronics, computer engineering and electrical engineering.

For the design of an experimental system, a commercial computer system is usually adopted. Commercial computer, commercial data logging and control board and some accessory function boards, even commercial software platform are implemented. The development period is short and interface hardware work is relatively simple for this
kind of system. The measurement and control system for the hot rolling wear test falls into this kind of system. Machine-computer interface includes analog, digital input and output interfaces, which implements the compatibility of analog, digital and switch signals, such as amplifiers, filters, opto-electrical isolators and power drivers. Human-machine interface includes hardware and software work. Because commercial computer provides mouse, keyboard and powerful CRT display, generally operational panel is substituted by a mouse, keyboard and CRT. Therefore, human-computer interface work is mainly focused on software design.

All error can be classified into systematic error and random error. Some systematic errors, such as non-linearity and instrument fixed offset, can be eliminated easily in a computer based system. Appendix B shows detailed analyses on the accuracy of measurement.

### 3.2 Real-time programming

Because the hot rolling wear test involves the actual process measurement and control, the real-time programming technology should be applied. The common phenomena nowadays is that engineering programming for measurement and control in various industries is based on the implementation of functions, while the reliability and anti-interference of the system have not been paid sufficient attention.

Usually the industrial application program is designed by specific industrial engineers, who are not professional software engineers. They do not have systematic programming background. On the other hand, professional software engineers are
generally skilled in system software or application software for calculation, database management, which does not involve non-standard external devices which exist in the measurement and control system. As concluded in the last section, the majority of the human-machine interface work of an experimental system is software design relative to actual industrial condition. Therefore, professional software engineers are not skilled in real-time programming. Industrial engineers should emphasise the real-time technology for programming.

A fundamental property of a real-time program is that some or all of its inputs come from the outside world synchronously with respect to any work that the program is already doing. The program must be able to interrupt its current activity immediately and then execute some predefined code to capture or respond to that input, which is often a fleeting, transient signal. The capture of new data, in turn, may trigger the running of one or more other urgent programs that were waiting for input. This means the priority of tasks decides their running. Finally, the computer is able to resume its original activity. Therefore, a real-time system is a time-constraint system, which can respond rapidly to the outside condition. The application of a real-time program makes the system reliable. It is safer to use the robust real-time organisation for practical industry process measurement and control.

The need to interrupt one part of a real-time application to perform data capture and some prior functions forces a particular organisation method in such a program. Real-time applications must be written as a series of separated component programs that can execute concurrently. This kind of organisation is often called multitask processing system.
A real-time system is not only based on the real-time programming. Actually, it is the combination of real-time hardware and real-time software. Real-time software costs less, but takes more time in running. In principle, any software function can be implemented by hardware, and vice versa. So, it is a better way to apply more real-time software rather than real-time hardware if the running speed is tolerated for the application system. Wide applications of high speed computer and other microelectrical devices make the substitution of hardware by software more feasible.

3.3 Calibration method

3.3.1 Calibration method

The whole measuring chain including sensors, instruments, signal conditioners and A/D converter can be calibrated at the same time and directly converted to digital values to increase the accuracy of the system. With a suitable processing method in the calibration and application of the calibrating data, the system can eliminate constant systematic error and minimise variable systematic error. So a suitable calibration method makes the measurement more accurate.

A direct digital table calibrating method is introduced in the measurement and control system. Firstly, link all the measuring chain from the sensor to the analog-digital board in the computer. Apply the given physical values on the sensor and obtain digital reading from the A/D board by the computer. The calibrating data can be obtained in a specific measuring range. A suitable interpolation method is applied to get all the physical values corresponding to every set of digital values that the A/D
Chapter 3 General Design of Measurement and Control System

A/D converter can obtain, for example, 4096 values for 12 bit A/D converter and 256 values for 8 bit A/D converter. These interpolated calibrating data can be stored in a file or just in a digital table which is easier, much faster and more accurate to search for the corresponding physical values when the system is in use later.

This type of calibrating method does not depend on the actual physical relationships in the measurement chain and their characteristics. Complex transferring properties of every element in the chain have no influence on the direct digital table calibrating method.

The following errors can be eliminated by this calibrating method:

- nonlinearity of sensors, amplifiers and signal conditioners
- output offset of sensors, amplifiers and signal conditioners
- gain error of amplifiers

Only stability (output drift) of sensors, amplifiers and conditioners, and quantisation error influence the measurement accuracy. As mentioned before, if the bit is selected properly, the quantisation error can be omitted.

Therefore, nonlinearity and output offset and gain error need not be considered in detail in a computer-based measurement system accompanied with a direct digital table calibrating method.

Furthermore, some variable systematic errors such as output drift can be decreased or even eliminated by regular on-line correction of a normal point of the measurement value. Usually before the experiment starts, some measured physical properties are
kept to normal values, but the calibrating values at that time may not be the normal values because of the output drift of the elements on the measuring chain. Forcing the calibrating values to be the normal values by offsetting the calibration table can guarantee a smaller drift coming from the change of conditions, such as temperature.

3.3.2 Calibration curve fitting and interpolation

For a series of experimental points, if their data are accurate, it is better to obtain a prediction curve passing through all the given data points. It is known that a polynomial of degree \( n - 1 \) can be made to pass through \( n \) given points. However, when large numbers of data points are involved, polynomial of very high degree results in creating the possibility of extreme fluctuations in polynomial values between data points. Such a curve is obviously not a good approximation of an actual function, even though it does pass through all of the data points. Usually a smooth curve from the cubic spline fit can provide a good approximation of an actual function[53].

In the cubic spline fit, it is assumed that the approximating function between any two adjacent data points is a third-degree polynomial. A cubic spline fit is made smooth by ensuring that the first and second derivatives of the overall function \( y(x) \) are continuous functions, that is, \( y'(x) \) and \( y''(x) \) are continuous functions.

End conditions of the spline should be specified before the resulting equations can be solved. For the calibrating system used for the hot wear test rig, four kinds of end conditions are discussed as follows:
(1) case 1: In this case, the assumption is made that the rate of change of the slope of the approximating cubic spline at each end of the data points is zero. Since this corresponds to the actual rate of change in the slope of a draft’s spline, it is referred to as a natural spline fit.

(2) case 2: Here, the assumption is made that the second derivatives at the end data points are the same as those at the points adjacent to the ends, which generally provides more curvature in the approximating curve near the end data points than case 1 does.

(3) case 3: In this case it is assumed that the second derivatives at the end points are linear extrapolations of those at the two nearest data points.

(4) case 4: In case 1, the fitting curve usually flattens a little bit near the ends since a drafter’s spline is straight beyond the last buckle at each end. In case 3, on the other hand, the end conditions sometimes provide too much curvature near the end points. Therefore, case 4 is introduced to combine the two end conditions. In this case, the second derivatives at the end data points are half of the linear extrapolations of those at the two nearest data points.

The detail of the formulae and the solution of the above interpolation methods can be found in Reference 53.

For the wear rig, the calibrating experimental points of load cell, displacement from capacitance sensor, thermocouple and acoustic emission RMS can be obtained accurately. Therefore, in the program developed cubic spline fitting is used to get the
entire calibrating curve. The four cases discussed above are embedded in the calibrating subprogram, while fitting curves are clearly displayed for the operator to compare and select suitable end conditions.

3.4 General design of the system

The block diagram of the measurement and control system is shown in Figure 3.1. The sensors used in the system are listed in Table 3.1.

<table>
<thead>
<tr>
<th>sensor</th>
<th>parameters measured</th>
</tr>
</thead>
<tbody>
<tr>
<td>capacitance sensor</td>
<td>change of diameter of the roller (wear),</td>
</tr>
<tr>
<td></td>
<td>displacement of roller vibration</td>
</tr>
<tr>
<td>capacitance sensor</td>
<td>velocity of vibration of the roller</td>
</tr>
<tr>
<td>capacitance sensor</td>
<td>acceleration of vibration of the roller</td>
</tr>
<tr>
<td>thermocouple</td>
<td>temperature of the contact surface of the disk and the roller</td>
</tr>
<tr>
<td>force sensor</td>
<td>friction force</td>
</tr>
<tr>
<td>AE sensor</td>
<td>acoustic emission caused by wear</td>
</tr>
<tr>
<td>velocity sensor</td>
<td>roller rotary velocity</td>
</tr>
<tr>
<td>velocity sensor</td>
<td>disk rotary velocity</td>
</tr>
</tbody>
</table>

MacInstrument and SoftPanel are used for previous adjustment of the system. These two softwares come along with the MacAdios II data logging board from the manufacturer.
Figure 3.1 Block diagram of measurement and control system
Analog signals from these sensors and pulse signals from velocity sensors are transmitted to a data acquisition and control board MacAdios II Board which is connected to a Macintosh computer. The power of heating device and DC motor drive unit are controlled by the computer directly. In this way, the test rig can operate automatically. Because rolling wear test is a time-consuming process, it is necessary to automatically control the test process.

A specified rolling wear measurement and control software environment is designed, which can carry out all the data acquisition, variable analysis and condition monitoring and process control with clear picture display and convenient operation. The software bases upon QuickBasic and TurboDrivers. TurboDrivers is a linkage of assembly language of the 68000 CPU and high-level language such as QuickBasic which can be embedded in the complied software.

Experimental system will automatically stop after a pre-set period of wear, and will be forced to an emergency stop if an accident occurs. The condition of the rig and program execution is monitored and some faults can be diagnosed, while some anti-interference methods are also applied in the system.
Chapter 4

Hardware Design of Measurement and Control System
A MacAdios II board in the Macintosh Computer is employed to measure and control the system. Interfaces are designed to link all the sensors, and monitoring and control devices to the MacAdios II board.

The load is applied with dead weights according to the requirements in advance. The analog signals from sensors of displacement (vibration), friction force, temperature, AE RMS and the pulse signals of velocities are transmitted to the board which is connected to a Macintosh II cx computer. These signals can be obtained in the process of rolling wear.

### 4.1 Data logging board

The MacAdios II board is a multiple-function board for data acquisition and control compatible with Macintosh computer bus which is made by GW Instrument Company. It has 12-bit A/D, 12-bit D/A, digital input and output ports. The board details are referred in Appendix C.

All the analog signals are fed into the A/D converter. They are,

- change of roller diameter,
- velocity of roller vibration,
- acceleration of roller vibration,
- friction force,
- root-mean-square of acoustic emission,
temperature of disk

Two pulse signals are fed into the counter/timer of the board. They are,

- velocity of the disk,
- velocity of the roller

And some switching signals are input to and output from the board to set up some conditions or implement some controls for the system.

Then friction coefficient can be obtained from the friction force and the load applied by dead weights, which can be written as,

$$\mu = \frac{F_f}{W}$$

where, $\mu$ is friction coefficient between the roller and the disk
- $F_f$ is friction force of the roller
- $W$ is load on the roller

Sliding/rolling ratio can be obtained from the velocity of the disk and the roller, which can be written as,

$$\lambda = \frac{V_{sliding}}{V_{rolling}} \times 100\%$$

$$= \frac{V_{disk} - V_{roller}}{V_{disk}} \times 100\%$$
\[ \lambda = (1 - \frac{n_{\text{roller}} \times D_{\text{roller}}}{n_{\text{disk}} \times D_{\text{disk}}}) \times 100\% \] (4.2)

where, \( \lambda \) is the sliding/rolling ratio

\( V_{\text{rolling}} \), rolling linear velocity

\( V_{\text{sliding}} \), sliding linear velocity

\( V_{\text{disk}} \), disk velocity at the middle contact point between the disk and the roller

\( n_{\text{disk}} \), the spinning velocity of the disk

\( D_{\text{disk}} \), diameter of disk at the middle contact point between the disk and the roller

\( V_{\text{roller}} \), roller velocity at the middle contact point between the disk and the roller

\( n_{\text{roller}} \), spinning velocity of the roller

\( D_{\text{roller}} \), diameter of roller at the middle contact point between the disk and the roller.

### 4.2 Analog interface design

The outline of analog interfaces is shown in Figure 4.1 in the next page.

#### 4.2.1 Sensors and instruments

There are four analog sensors in the system to measure the following parameters.

(1) Diameter change and vibration of the roller
Diameter change and vibration of the roller in the rolling process are measured on-line with an accurate capacitance sensor. The sensor is mounted on the roller support frame which has a rigid connection with the roller. The vibration from the motor and the main shaft plate will not influence the measurement, nor will the flatness error and the heat deformation of the disk.

![Block diagram of analog interfaces of the system](image)

**Figure 4.1** Block diagram of analog interfaces of the system
Capacitance sensor works on the principle that the electrical capacitance $C$ depends on the area $A$, the distance $s$ and the dielectric constant $\varepsilon$ of the material between the electrodes, according to the equation,

$$C = \varepsilon \frac{A}{s} \quad (4.3)$$

Then capacitance $C$ can be determined from the equation,

$$I = \frac{Q}{C} \quad (4.4)$$

where, $I$ is electric current, $Q$ is electric charge.

For the capacitance sensor, $A$ is the active area on the tip of the probe, $s$ is the gap between the tip and the measured surface.

The sensitivity of capacitance to the gap can be calculated from Equation (4.5):

$$\frac{dC}{ds} = -\varepsilon \frac{A}{s^2} \quad (4.5)$$

A newly designed tip with a smaller head connects the protective tip, as shown in Figure 2.12. The introduction of the two additional tips is because of two reasons. The first reason is that the probe operates at a very high temperature. Two additional tips increase the length of the whole probe to protect the original tip from melting. The second reason is that the accuracy of the original sensor is not sufficient. The smaller head of the newly designed tip can make the resolution of the sensor smaller.
From Equation (4.5), we note that the variation of capacitance with the gap $s$ is nonlinear (hyperbolic), thus the percentage change in $s$ from a chosen "neutral" position must be small if good linearity is expected to achieve. But as discussed in 3.3, digital table calibration method can eliminate this kind of error for a computerised system.

The displacement, velocity and acceleration of vibration of the roller can be obtained from the sensor and its conditioning module. The specification of the capacitance sensor and its module is as follows,

Manufacturer: Lion Precision Co.
Model: Sensor: Px305-HB
Module: DMT-2M
Original range: ±0.010 inch
±0.25 mm
Sensitivity: 1V/0.001 inch
System linearity: 0.015%

The change of the diameter and the vibration of the rolling process can be distinguished by filters. The high frequency section of the displacement is the vibration of the roller, while the low frequency section of the displacement is the change of diameter of the roller.

The signal conditioner Module DTM-2M is used with the capacitance sensor. The module is used to condition and amplify the low-level signal from the sensor. It can supply the master oscillator excitation voltage for the sensor and amplify the output,
and can also obtain the velocity and the acceleration outputs by embedded hardware differentiation circuits.

Moreover, the roller can be assembled and disassembled conveniently, so the wear rate of the roller can be measured in term of the loss of mass.

(2) Friction force

The friction force will be measured with a load cell mounted on the top holding frame far from the heat zone. The friction force between the roller and the disk can be transferred from the roller support frame and holding blocks to the sensor. The specification of the load cell is as follows,

Manufacturer: Interface Inc.
Model: SM-100
Rated capacity: 100 lbs
Excitation voltage: 10VDC

(3) Temperature

A thermocouple, which maintains constant contact with the top surface of the disk, is used to measure the temperature of the disk. The K-type thermocouple, whose measurement range is from 0-1200°C, is selected because the temperature in the experiment can be up to 700°C-800°C.
An Eurotherm Model 91e thermocontroller (thermo-control unit) is employed to control the temperature combined with the thermocouple. The temperature required can be set on the control panel of the controller. Then the controller acquires the temperature signal and outputs the control signal to switch on or off the power of the heating device. The control strategy is proportional-integral-derivative (PID) control, which is the well-known controller used in industrial practice. The transfer function of the controller is,

\[ G_c(s) = K_P + K_D s + \frac{K_I}{s} \]

where \( K_P \), \( K_I \) and \( K_D \) are proportional constant, integral constant and derivative constant. Actually, a PD controller would add damping to the system, but the steady-state response is not affected, while a PI controller could add damping and improve the steady-state error at the same time, but the rise time and settling time are penalised. This leads to the motivation of using a PID controller so that the best proportion of each of the PD and PI controllers are utilised. The parameters including the above constants can be adjusted by applying a secret key on the panel to prevent misoperation.

The thermocontroller can detect if the sensor circuit fails or not. If the input is open circuit or the signal is out of the selected sensor's range, then the output power level is forced to be 0% and sensor-failure message will be displayed. The solid-state relay output is used to isolate the power control from the measurement circuit and can be used for power driving.
Because 80A current contactor is used to switch on and off the transformer for the heating element, the heating cycle time (the minimum switch on and off time) should be adjusted more than 5 seconds. Meanwhile, the ramping of the heating control should be short, or just without ramping.

After tuning the controller to make the control process both stable and sensitive, the main parameters are shown in Table 4.1.

Table 4.1 Parameters set for EUROTHERM 91e temperature controller

<table>
<thead>
<tr>
<th>Mnemonic</th>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>ProP</td>
<td>proportional band</td>
<td>4</td>
</tr>
<tr>
<td>Int.t</td>
<td>integral time constant</td>
<td>60</td>
</tr>
<tr>
<td>dEr.t</td>
<td>derivative time constant</td>
<td>100</td>
</tr>
<tr>
<td>OFSt</td>
<td>calibration offset</td>
<td>0</td>
</tr>
<tr>
<td>H.ct</td>
<td>heat cycle time</td>
<td>10 seconds</td>
</tr>
<tr>
<td>SP.rr</td>
<td>setpoint ramp rate</td>
<td>OFF</td>
</tr>
<tr>
<td>SP.Hi</td>
<td>setpoint high limit</td>
<td>0 °C</td>
</tr>
<tr>
<td>SP.Lo</td>
<td>setpoint low limit</td>
<td>800 °C</td>
</tr>
</tbody>
</table>

(4) Acoustic emission

The 4610 Smart Acoustic Monitor is used to obtain the acoustic emission signal from the sensor which is mounted on the support frame of the roller. The instrument is a computer based instrument. It has a programmable gain amplifier and can conduct some processing of the acoustic emission signal, such as root-mean-square, event
count and total counts. The output of RMS of the signal will be fed into the data logging board.

The specification of the instrument is as follows,

Manufacturer: Physical Acoustics Corporation

<table>
<thead>
<tr>
<th>Sensor:</th>
<th>Model:</th>
<th>PAC S9521</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>75kHz, resonant</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Preamplifier:</th>
<th>Model:</th>
<th>1227B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>20dB, 50-400kHz</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>AE instrument:</th>
<th>Model:</th>
<th>4610</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dynamic range:</td>
<td></td>
<td>88dB</td>
</tr>
<tr>
<td>Frequency response:</td>
<td>1kHz—700kHz</td>
<td></td>
</tr>
<tr>
<td>Gain resolution:</td>
<td>20—80dB, 1dB steps</td>
<td></td>
</tr>
<tr>
<td>Event time out:</td>
<td>400 μs</td>
<td></td>
</tr>
<tr>
<td>Alarms:</td>
<td>events, counts, total counts, RMS</td>
<td></td>
</tr>
<tr>
<td>Energy processor:</td>
<td>5MHz maximum frequency</td>
<td></td>
</tr>
<tr>
<td></td>
<td>65535 maximum count</td>
<td></td>
</tr>
<tr>
<td></td>
<td>16M total counts</td>
<td></td>
</tr>
<tr>
<td>RMS signal:</td>
<td>0.10s time constant</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.01 voltage</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Panel:</th>
<th>Display:</th>
<th>LCD 16 characters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Keyboard:</td>
<td>16 keys</td>
<td></td>
</tr>
</tbody>
</table>

Some other instruments are used in the experiments. For example, Surtronic 3 portable profilometer made by Rank Taylor-Hobson Co. is used to measure the
surface roughness of the roller and the disk. An accurate balance with the resolution of 0.01 gram is used to measure the weight of the roller and the disk.

### 4.2.2 Signal conditioners and interface circuits

Figure 4.2 is the photography of some interface circuits for analogue signals.

![Figure 4.2 Some interface circuits for analogue signals](image)

(1) Instrumentation amplifier

The instrumentation amplifier is different from a common amplifier which is optimised for performance. An instrumentation amplifier is a committed “gain block”
that measures the difference between the voltages existing at its two input terminal and amplifies the difference by a precisely set gain. It has a high input impedance, low offset and drift, low nonlinearity, stable gain and low effective output impedance. The typical structure of instrumentation amplifier is shown in Figure 4.3, which is a well-known three-op-amp configuration. Amplifiers 1 and 2 provide united gain to the common mode signal and amplifier 3 acts as a differential amplifier.

![Figure 4.3 Typical instrumentation amplifier structure](image)

The AD524 amplifier in the system is a product of Analog Device Company, which has a three-op-amp configuration. As a complete amplifier the AD524 does not require any external components for fixed gains of 1, 10, 100 and 1000. For other gain settings between 1 and 1000 only a single precise resistor is required.

For the signal conditioning of thermocouple, another amplifier AD595 of Analog Device Company is used in the measurement and control system. It is a monolithic thermocouple amplifier with cold junction compensation, which is specially designed for Type K (chrome-alumel) thermocouple. It is pre-calibrated by laser trimmed
resistor in the chip. It also includes a thermocouple failure alarm signal that indicates if one or both thermocouple leads become open.

(2) Amplifier box

The amplifier box is made including several amplifiers and one excitation voltage for the system. The high precision integrated circuit amplifier AD524 is used, with a zero adjustment circuit.

There is one more sensor excitation voltage in the box, which is for load cell. The voltage is 5VDC, ±0.05%. There are 5 more amplifiers in the box for the load cell, thermocouple, capacitance sensor and its modular (displacement, velocity and acceleration). Amplifying gain and programmable gain set in the MacAdios II board are in Table 4.2.

<table>
<thead>
<tr>
<th>signal</th>
<th>input</th>
<th>output</th>
<th>amplifier gain</th>
<th>programmable gain</th>
</tr>
</thead>
<tbody>
<tr>
<td>load cell</td>
<td>0—30mV</td>
<td>-10V—+10V</td>
<td>200—1000</td>
<td>1</td>
</tr>
<tr>
<td>thermocouple</td>
<td>0—50mV</td>
<td>-10V—+10V</td>
<td>100—500</td>
<td>1</td>
</tr>
<tr>
<td>displacement</td>
<td>-5V—+5V</td>
<td>-10V—+10V</td>
<td>1—5</td>
<td>1</td>
</tr>
<tr>
<td>velocity</td>
<td>-2V—+2V</td>
<td>-10V—+10V</td>
<td>2—20</td>
<td>1</td>
</tr>
<tr>
<td>acceleration</td>
<td>-2V—+2V</td>
<td>-10V—+10V</td>
<td>2—20</td>
<td>1</td>
</tr>
</tbody>
</table>

All the amplifiers have differential input with wide offset adjustment, the accuracy of which is less than 0.02%, while the gain is easily adjusted in a certain range with the change of gain resistor. Constant offset circuits are used for the load cell and
thermocouple, because the outputs of the instrument are uni-polar and the input of MacAdios board is set to be bi-polar.

### 4.3 Digital interface design

The outline of digital interface is shown in Figure 4.4. Velocity signals, protective signals, monitoring signals and power control signals are connected to the MacAdios II board.

![Block diagram of digital interface of the system](image)

**Figure 4.4 Block diagram of digital interface of the system**

### 4.3.1 General design

The low-cost MacAdios DBO Digital Breakout Unit made by GW Instrument Company provides screw-terminal access to digital input, digital output and clock
signals on MacAdios hardware systems. LEDs show the status of each digital data bit in the unit.

Disk spinning velocity is measured with an opto-electrical sensor mounting on the bottom of the disk spindle. Another opto-electrical sensor is used to measure the velocity of the roller. The outputs of the sensors are pulse signal, and are regulated and conditioned to be compatible with TTL level. Then the velocities will be obtained through a counter/timer. Two velocity sensors and their interfaces are shown in Figure 4.5. From the two velocity sensors the sliding/rolling ratio can be determined.

![Figure 4.5 Velocity sensors and interfaces block diagram](image)

The power of DC motor and heating device in the test rig are controlled by the computer. Because the power is about 9 kW, some protective signals and control circuit monitoring signals are employed to make the system reliable and safe. The control and monitoring block diagram is shown in Figure 4.6.
4.3.2 Digital interface circuits

The digital input and output circuit is shown as Figure 4.7 in the next page. J1 is the digital input and output socket on the MacAdios II Board. High voltage output modules are Opto22-OAC5A whose operation voltages are 24VAC-240VAC. High voltage input modules are Opto22-IAC5 series. The digital input and output modules Opto22 series provide a low-cost, high-performance means of switching on and off large device as well as inputting information from switches and sensors.
Figure 4.7 Digital input and output circuit
These modules translate AC or DC voltage levels from field devices into signals with which the MacAdios digital input port is compatible. The modules isolate MacAdios II board from the external electrical transients, accidental short circuits and excessive voltages.

The AM9513A counter/timer works in frequency measurement mode. Channel 3 is used as the gating timebase for the input of gate controlling of channel 1 and channel 2. Channel 1 and channel 2 are used for measuring of velocity.

A contactor box is used for switching on and off the power of the DC motor and heating device for software time trigger, soft-button or an accident, and is controlled by the computer and micro-switches. A micro-switch is used to turn off the power of the motor when the hood is open. Another micro-switch is mounted on the triangle steel to turn off the power of the motor when the roller supporter is broken accidentally. While some signals are input to the computer to monitor the work condition of the rig.

Figure 4.8 shows the power control circuit of the DC motor and heating device. The circuit can work in two states: control work state and test state. In control work state, the power is controlled by the computer, while in the test state the power is controlled by the operator. Contactor Ch is applied for switching on and off the power of the large transformer of the heating element. The temperature is controlled by an Eurotherm thermocontroller.
Contactor Cm is applied for switching on or off the power of thyristor drive and control unit for the motor of the rig. The velocity is adjusted manually on the panel of the drive and control unit. Two intermediate relays are used for driving the contactors of the motor and the heating device. The requirements of intermediate relays and contactors are as follows,

![Power control circuit diagram](image)

**Figure 4.8 Power control circuit**

intermediate relays controlling voltage (coil voltage): 240VAC
contact voltage: 240VAC

contactors
controlling voltage (coil voltage): 240VAC
contact voltage: 415VAC
contact current: 30A

The control flows of the motor and the heating device are shown in Figure 4.9 and Figure 4.10 respectively. The control strategy of the power is implemented in the software of the system.

In motor test condition, motor control contactor is activated, then the motor is controlled by the operator directly. In motor control condition, the computer can automatically distinguish this condition and conduct suitable prompt and control. The velocity of motor is always controlled by the thyristor unit, while its stop is controlled by the computer in motor control condition. Protective hood and roller supporting frame condition are monitored in the process. If the hood is open, or the roller supporting frame is broken, the system will issue warning and stop.

In heating device test condition, heating device is controlled by a thermocontroller. Its SSR output drives the intermediate relay, then control the large transformer of the heating device. The limit of the temperature is set by the operator on the small panel of the thermocontroller. In heating device control condition, the heating process is also controlled by the thermocontroller, while its on and off states are controlled by the computer. When the time required is over, a fault is detected or the parameter is over threshold, the heating process will be terminated automatically.
motor test

switch to TEST on the panel

Rm is activated

Cm is activated

motor is controlled by control unit

motor control

switch to CONTROL on the panel

check SI1 (SO1 is inactive)

SI1 has voltage? yes in TEST condition, warning

no

waiting, soft-button START is pushed? yes activate SO1

no

check SI1, has voltage? yes hood is not closed, warning

no

Rm is activated

Cm is activated

motor is controlled by control unit

some parameters (vibration, force) over threshold?

no

yes

time is over?

no

soft-button PAUSE/STOP is pushed? yes

no

check SI1, has voltage? yes

no

roller supporting frame is broken?

no

hood is open, warning

Inactivate SO2, stop heating

Inactivate SO1, stop motor

Inactivate SO1, stop motor

soft-button GO ON is pushed?

yes

no

soft-button STOP is pushed?

yes

no

Figure 4.9 Control flow of the motor
heating device test

- switch to TEST on the panel
- heating device is controlled by thermocontroller
  - temperature
  - PID control
  - SSR output for power
    - control Rhc

- control Rh
- control Ch

heating device control

- switch to CONTROL on the panel
- check SI2 (SO2 is inactive)
  - SI2 has voltage?
    - yes, in TEST condition, warning
    - no
  - waiting, soft-button START is pushed?
    - no
    - yes, activate SO2
- heating device is controlled by thermocontroller
  - time is over?
    - yes
    - parameters are over threshold or an accident occurs?
      - yes, warning
      - no
    - no
- inactivate SO2, stop heating device

Figure 4.10  Control flow of the heating device

Figure 4.11 is the photograph of the computer interface box for the power control and the temperature controller.
4.4 Data logging board configuration and interface channel assignment

4.4.1 Data logging board configuration

The MacAdios II board has several modes of operation, which can be selected by positioning user-configurable jumpers. The following items are selected by jumpers,
The configuration of the board for the jumpers related to the system is shown in Table 4.3. The other condition of the setting is also listed in the table.

### Table 4.3 Configuration of MacAdios II board

<table>
<thead>
<tr>
<th>selection</th>
<th>jumper</th>
<th>setting in the system</th>
<th>other setting</th>
</tr>
</thead>
<tbody>
<tr>
<td>A/D input mode</td>
<td>W1b-W1a, W2b-W2a, W3b-W3a</td>
<td>16 channels single-ended</td>
<td>8 channels differential input</td>
</tr>
<tr>
<td>A/D input range</td>
<td>W40b-W40a, W41b-W41a</td>
<td>bipolar -10V to +10V</td>
<td>unipolar 0 to +10V</td>
</tr>
<tr>
<td>A/D data coding</td>
<td>W30b-W30a, W31b-W31a</td>
<td>two’s complement</td>
<td>straight binary</td>
</tr>
</tbody>
</table>

Upon the above configuration, the readout of analog digital converter is from -2048 to +2047 corresponding to the input range from -10V to +10V.

### 4.4.2 Interface channel assignment

Connection J2 on the MacAdios II board is used for analog input and output connections. Analog digital converter channel and pin assignments are shown in Table 4.4.
Table 4.4 Analog digital converter channel assignments

<table>
<thead>
<tr>
<th>A/D converter channel</th>
<th>pin numbers (J2)</th>
<th>analog signal</th>
</tr>
</thead>
<tbody>
<tr>
<td>A/D Channel 0</td>
<td>high: 3</td>
<td>friction force</td>
</tr>
<tr>
<td>A/D Channel 1</td>
<td>high: 5</td>
<td>change of roller diameter</td>
</tr>
<tr>
<td>A/D Channel 2</td>
<td>high: 7</td>
<td>velocity of roller vibration</td>
</tr>
<tr>
<td>A/D Channel 3</td>
<td>high: 9</td>
<td>acceleration of roller vibration</td>
</tr>
<tr>
<td>A/D Channel 4</td>
<td>high: 11</td>
<td>root-mean-square of acoustic emission</td>
</tr>
<tr>
<td>A/D Channel 5</td>
<td>high: 13</td>
<td>temperature</td>
</tr>
</tbody>
</table>

Analog common: J2.1, 2
Digital common: J2.29, 34
+5V supply: J2.22, 300mA available to the user

Connection J1 on the MacAdios II board is used for digital input/output and time-related digital input/output connections. Digital channel assignments are shown in Table 4.5.

Table 4.5 Digital channel assignments

<table>
<thead>
<tr>
<th>digital input/output channel</th>
<th>pin number (J1)</th>
<th>digital signal</th>
</tr>
</thead>
<tbody>
<tr>
<td>DI Channel 0</td>
<td>18</td>
<td>monitoring of motor control</td>
</tr>
<tr>
<td>DI Channel 1</td>
<td>16</td>
<td>monitoring of heating device control</td>
</tr>
<tr>
<td>DI Channel 2</td>
<td>14</td>
<td>spare</td>
</tr>
<tr>
<td>DO Channel 7</td>
<td>3</td>
<td>motor control</td>
</tr>
<tr>
<td>DO Channel 6</td>
<td>5</td>
<td>heating device control</td>
</tr>
<tr>
<td>DO Channel 5</td>
<td>7</td>
<td>spare</td>
</tr>
</tbody>
</table>

Digital common: J1.1, 30, 32, 33, 34, available to user
Vcc: J1.2
Counter/timer channel assignments are shown in Table 4.6. The details are shown in Figure 4.6.

**Table 4.6 Counter/Timer channel assignments**

<table>
<thead>
<tr>
<th>Counter/timer channel</th>
<th>pin number (J1)</th>
<th>function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Counter/Timer Channel 1 input</td>
<td>21</td>
<td>velocity signal of spindle</td>
</tr>
<tr>
<td>Counter/Timer Channel 2 input</td>
<td>27</td>
<td>velocity signal of roller</td>
</tr>
<tr>
<td>Counter/Timer Channel 3 output</td>
<td>26</td>
<td>time base output</td>
</tr>
<tr>
<td>Counter/Timer Channel 1 gate</td>
<td>23</td>
<td>gate control from C/T Ch.3</td>
</tr>
<tr>
<td>Counter/Timer Channel 2 gate</td>
<td>29</td>
<td>gate control from C/T Ch.3</td>
</tr>
</tbody>
</table>
Chapter 5

Software Design of Measurement and Control System
5.1 General design

GW Instrument Company has produced several commercial data acquisition softwares accompanied with MacAdios board which have flexible and versatile display and analysis functions. They are general softwares which are expected to be suitable for most of data acquisition system. However, they lack specific and variable data acquisition functions for a specific system, and cannot realise required switching input detection, analog value judgement, software filter and power control output. Complex automatic acquisition and control processes cannot be implemented by these kinds of commercial softwares.

In this thesis an integrated software environment for the hot rolling wear test is established to conduct complete experimental manipulation. The entire experimental process is carried out under the supervision of the integrated software, from calibration of the instruments and sensors, to the data analysis and display. The specified measurement and control software can carry out all the data acquisition, parameter analysis and condition control with clear picture display and user-friendly operation. It is based upon QuickBasic and TurboDrivers software. QuickBasic has versatile picture function and is easy to debug. It can make excellent work for not-very-rapid measurement and control system. However QuickBasic is difficult to access the hardware directly. TurboDrivers is a linkage for assembly language of MC68000 CPU and advanced language such as QuickBasic which can be embedded in the compiled software. It can access the built-in ROM calls of Macintosh toolbox. Thirteen I/O routines can be called from several programming languages in it. TurboDrivers interact directly with MacAdios data acquisition hardware. The user only needs to specify the
options such as sample rate, number of channels and display mode to the TurboDrivers software. It can accelerate the software running and decrease the assembly language programming for the hardware. Functions of the 13 TurboDrivers routines are shown in Table 5.1.

<table>
<thead>
<tr>
<th>number</th>
<th>routine</th>
<th>function</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>DIGITIZE</td>
<td>input from up to 8 multiplexed A/D channels</td>
</tr>
<tr>
<td>2</td>
<td>FASTIO</td>
<td>input or output one channel at high speeds</td>
</tr>
<tr>
<td>3</td>
<td>INOUT</td>
<td>perform I/O with 1 to 4 channels</td>
</tr>
<tr>
<td>4</td>
<td>CKSETUP</td>
<td>configure clock output</td>
</tr>
<tr>
<td>5</td>
<td>CKCONTROL</td>
<td>control clock output</td>
</tr>
<tr>
<td>6</td>
<td>CWRITE</td>
<td>write to a device on the MacAdios board</td>
</tr>
<tr>
<td>7</td>
<td>CREAD</td>
<td>read from a device on the MacAdios board</td>
</tr>
<tr>
<td>8</td>
<td>SETAD</td>
<td>set MacAdios II A/D gain and channel</td>
</tr>
<tr>
<td>9</td>
<td>SETDOUTBIT</td>
<td>set or clear a specific digital output bit</td>
</tr>
<tr>
<td>10</td>
<td>PDSETUP</td>
<td>initiate period measurement</td>
</tr>
<tr>
<td>11</td>
<td>PDCONTROL</td>
<td>read result of period measurement</td>
</tr>
<tr>
<td>12</td>
<td>FQSETUP</td>
<td>initiate frequency measurement</td>
</tr>
<tr>
<td>13</td>
<td>FQCONTROL</td>
<td>read result of frequency measurement</td>
</tr>
</tbody>
</table>

Real-time programming is applied in the software system. Multiple window strategies, menu and sub-menu functions, soft buttons, clear figure and word display, on-line help and prompt, pre-testing, Watchdog timer monitoring, dialogue and mouse activity, time passage trapping and program executive error trapping are used in this software.
The integrated software includes five modules corresponding to the five main functions of the experimental system as shown in Figure 5.1. The main functions of the five modules are described as follows.

**Modes of the measurement and control software**

- **MacAdios II Diagnosis**: check the hardware of the MacAdios II board and TurboDrivers software
- **Calibration**: calibrate the sensors, instruments, amplifiers and the A/D converters
- **Pre-adjustment**: adjust the temperature of disk and the velocity of the spindle
- **Experiment**: measure and control the experiments
- **Simulation**: simulate the experimental processes

![Figure 5.1 Five modules of the software](image)

(1) **MacAdios II Diagnosis**

This module is used to check the hardware of the MacAdios II board and the interface software of TurboDrivers. A/D converters check D/A converters, and vice versa, and the in-circuit amplifiers are checked as well. Digital input and output and timer/counter input and output are also checked in this module.
(2) Calibration

All the measurement chains including sensors, instruments, signal conditioners and A/D converters are calibrated. The calibrating data will be analysed and calibrating files are produced, which will be automatically called in experiment and simulation processes.

(3) Pre-adjustment

Pre-adjustment is conducted before the experiment, such as heating the disk to the required temperature and changing the velocity of spindle (disk). This module is for measurement, indication and control of the pre-adjustment process.

(4) Experiment

The experimental processes of the high temperature wear test rig can be measured and controlled automatically in this module. This is the default mode if the MacAdios II board exists in the computer. It has powerful processing functions, such as digital low-pass filter and bad-data eliminator, test rig condition monitoring based on parameter measuring with both fixed threshold and dynamic threshold judgement, software error recognition and Watchdog software process monitoring. It also has very friendly interfaces with operators, such as clear and flexible figure displays, display scale and scroll change buttons, parameter edit fields, menu functions, soft control buttons and message feedback window.

(5) Simulation
Chapter 5 Software Design of Measurement and Control System

It is used to simulate the experimental process without the support of the hardware. This is the default mode when the MacAdios II board does not exist in the computer. This mode is also useful for reviewing the results of the finished experiments.

On-line help and prompt are always available on the CRT. Operations which are used frequently and should be responded quickly are triggered by soft buttons or shortcut keys. One-touch trigger makes these operations easier and quicker. Almost all the screen displayed and currently active window can be sent to the printer or saved as a postscript file for later calling. It is useful for the calibration, pre-adjustment and experiment processes. For example, the screen display and currently active window can be transferred into Microsoft word processing series software.

The integrated software for the test rig is listed in Appendix D.

5.2 MacAdios board diagnosis process

This module checks and diagnoses almost all of the channels of the hardware of the MacAdios II board and the interface software of TurboDrivers. A/D converter and its in-circuit amplifiers, D/A converter, digital input and output, timer/counter input and output are checked in this module.

The general flowchart of the process is shown as Figure 5.2.
This module must be executed when the measurement and control system has been disconnected from the wear test rig. At first, it checks what kind of MacAdios II board is installed in the computer. Then the hardware connections are required for the further checks. The checks for the different functional components are designed to be carried out mutually. For example, A/D converters read the output of D/A converters. If the mutual check is accurate or right, it is believed that both of the components are accurate or right, because it is impossible that both of the mutual check hardware are inaccurate or faulty and the mutual check are accurate or right at the same measurement point. No extra chips and components are required in this kind of check.
Therefore, accurate diagnosis can be obtained in the process and this kind of method is reliable.

Figure 5.3 is the screen copy when MacAdios II Diagnosis menu is selected from Experiment or Simulation module. Figure 5.4 is the screen copy when the kind of board is detected.

In the module, there are mainly three sub-modules: A/D and D/A check sub-module, digital input and output check sub-module and timer/counter check sub-module.
EXPERIMENTS FOR HOT ROLLING WEAR

<table>
<thead>
<tr>
<th>Experiment Series</th>
<th>Experiment Date</th>
<th>Redraw Step (pts)</th>
<th>Interval (s)</th>
<th>Trigger Time (sec)</th>
<th>Pressure (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>00174</td>
<td>07-19-96</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature (C)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rolling Speed (m/s)</td>
<td>mild steel</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

STOP 100:00 MINS LEFT

Figure 5.4 Screen copy when checking the kind of MacAdios II board

MacAdios II Diagnosis

WHAT KIND OF BOARD?

This section checks what kind of MacAdios II board is installed.

Please enter slot number where the board is installed.
The slot number should between 0 and 6.

Cread() sensed a MacAdios II or MacAdios/SE board is installed.

Do you want to go on the check?

YES  NO

5.2.1 A/D and D/A check

This sub-module checks analog-digital converter and digital-analog converter mutually at the same time. The connections between the input of analog-digital converter and the output of digital-analog converter are illustrated in Figure 5.5.

The flowchart of the sub-module is shown in Figure 5.6. The programmable gain amplifier is also checked in the process. When the gain is at 1, D/A outputs from -10V
to +10V, or -2048 to +2047 digitally with incremental step of 1V or 204.8 digitally. The input read from A/D converter via programmable amplifier should approach the value D/A outputs. When the gain is set at 10, D/A outputs from -1V to +1V, or -205 to +205 digitally with incremental step of 0.1V or 20.48 digitally. The input read from the A/D converter via programmable amplifier should approach 10 times of the D/A outputs.

Figure 5.7 is a screen copy for the MacAdios II board when the gain is set at 1 and both channel 0 and 1 of D/A converter output -2048. At this time, all the channels of A/D converter read -2047 or -2048. This means the accuracy of the A/D and D/A converters and amplifier at this measurement point is reasonable, and the accuracy is just 1 least significant bit (LSB). Figure 5.8 shows the screen copy when D/A converter outputs 1638.
Figure 5.7 Flowchart of A/D and D/A check subroutine

Figure 5.9 shows the screen copy when D/A converter outputs -164 and the gain of programmable amplifier is set at 10. It is also found that the accuracy of A/D and D/A converters and programmable gain amplifier of the board is reasonable.

Push NEXT VALUE button to continue the analog output and input check for next value. Push NEXT CHECK to check the digital input and output ports.
Experiment Series: 00174
Experiment Date: 07-19-96
Temperature(C): 800
Material: mild steel
Rolling Speed(m/s): 1.2

Are you ready to test? Please check all the instruments before start.

STOP 100:00 MIN LEFT
START CONT P/STOP

MacAdios II Diagnosis
A/D AND D/A CHECK

Cread(), Cwrite() and SetAD will also be checked. D/A 12 bit->A/D 12 bit
Setting to bi-polar analog and differential input for A/D.

DA0->AD0, AD1, AD2, AD3
pin J2 23->3, 5, 7, 9 and low 4,6,8,10-> analog common 2
DA1->AD4, AD5, AD6, AD7
pin J2 24->11, 13, 15, 17 and low 12,14,16,18-> analog common 2

when Gain=1, D/A output range -10V...+10V, -2048...+2047,
A/D input range should be the same as D/A output.

DA0  AD0  AD1  AD2  AD3
-2048 -2047 -2048 -2048 -2048

DA1  AD4  AD5  AD6  AD7
-2048 -2047 -2046 -2046 -2046

Figure 5.8 Screen copy when D/A outputs 1638 and the gain is 1
Chapter 5  Software Design of Measurement and Control System  

EXPERIMENTS FOR HOT ROLLING WEAR

<table>
<thead>
<tr>
<th>Experiment Series</th>
<th>Date</th>
<th>Temperature(C)</th>
<th>Material</th>
<th>Rolling Speed(m/s)</th>
<th>Experiments for Hot Rolling Wear</th>
</tr>
</thead>
<tbody>
<tr>
<td>00174</td>
<td>07-19-98</td>
<td>800</td>
<td>mild steel</td>
<td>1.2</td>
<td></td>
</tr>
</tbody>
</table>

Are you ready to test? Please check all the instruments before start.

STOP 100:00 MINS LEFT

START  CONT.  P/STOP

MacAdios II Diagnosis

A/D AND D/A CHECK

Cread(), Cwrite() and SetAD will also be checked. D/A 12 bit --> A/D 12 bit
Setting to bi-polar analog and differential input for A/D.
DA0 --> AD0, AD1, AD2, AD3
pin J2 23 --> 3, 5, 7, 9 and low 4, 6, 8, 10 --> analog common 2
DA1 --> AD4, AD5, AD6, AD7
pin J2 24 --> 11, 13, 15, 17 and low 12, 14, 16, 18 --> analog common 2
when Gain = 10, D/A output range = -1V_+1V, -205_+205,
A/D Input range should still be = -2048_+2047.

DA0  AD0  AD1  AD2  AD3
-164 -1638 -1637 -1637 -1635

DA1  AD4  AD5  AD6  AD7
-164 -1635 -1638 -1637 -1637

Figure 5.9  Screen copy when D/A outputs -164 and the gain is 10

5.2.2 DI and DO check

This sub-module checks one 8-bit digital input and one 8-bit digital output ports in MacAdios II board mutually at the same time. The connections between the input and output of digital signals are illustrated in Figure 5.10.

The flowchart of the sub-module is shown in Figure 5.11. The input value should be the same as the output value. 0H, FFH, 55H and AAH are 00000000B, 11111111B, 01010101B and 10101010B in binary code. Thus each bit of the input and output ports is checked twice.
Figure 5.10 Connections of DI/DO check for MacAdios II diagnosis

Figure 5.11 Flowchart of DI/DO check
Figure 5.12 is a screen copy of the check. Push NEXT VALUE button to the next output and input. Push NEXT CHECK to check the timer/counter.

![Screen copy of DI/DO check](image)

**MacAdios II Diagnosis**

DI AND DO CHECK

Cread(), Cwrite() and SetDoutbit will also be checked.

DO--->DI

D00,D01,D02,D03,D04,D05,D06,D07--->D10,D11,D12,D13,D14,D15,D16,D17

17, 15, 13, 11, 9, 7, 5, 3, 1, 8, 6, 4

The digital common pins are 1, 30, 32, 33 and 34 on J1

Digital Output: OH

Digital Input: OH

**5.2.3 Timer/counter check**

This sub-module checks the timer/counter in the MacAdios II board mutually at the same time. There are three ports in the timer/counter. The connections of timer/counter are illustrated in Figure 5.13. Timer 2 outputs pulse signal as the input signal of Timer 1, and Timer 3 outputs timebase signal for Timer 1 to calculate the frequency. Therefore, only part of the functions of the timer/counter are checked in the sub-module.
Figure 5.13 Connections of Timer/Counter check

Figure 5.14 Flowchart of timer/counter check
The flowchart of the sub-module is shown in Figure 5.14. Input value should be the same as the output value. A screen copy of the check is shown in Figure 5.15. Push NEXT VALUE button to check the next output and input. Push FINISH CHECK button to finalise all check process.

![Screen copy of Timer/Counter check](image-url)
5.3 Calibration process

This module calibrates all the sensors, instruments, signal conditioners and A/D converters. The programmable gain on the MacAdios II board can be set properly in the process. The calibration data and programmable gain will be saved automatically in the corresponding files, which will be loaded in the experiment and pre-adjustment modules.

According to the above analysis, the most accurate way to calibrate is calibrating the whole measurement chain at one time. Calibration data table file is obtained directly in this kind of method.

In this measurement system, friction force coming from the load cell, displacement (change of diameter of the roller) coming from the capacitance sensor, acoustic emission RMS coming from AE sensor and temperature coming from thermocouple are calibrated directly. After the displacement from capacitance sensor is calibrated, the velocity and acceleration coming from the instrument accompanying the capacitance sensor can be calibrated. This means channel 0, 1, 4 and 5 are calibrated directly, then channel 2 and 3 are calibrated later.

The general flowchart of the calibration process is shown as Figure 5.16.

The screen is mainly divided into 6 zones: menu zone, parameter edit zone, current A/D value display zone, prompt zone, button zone, and calibrating point and curve display zone, as shown in Figure 5.17.
CALIBRATION MODE

start

prompt to check no

MacAdios II board exist?
yes

open calibration window and set menu edit fields, soft buttons and figure zone

Channel 0 selection

Ch 0,1,4,5

read A/D and get current input physical value from keyboard in edit field

display A/D value and data points in figure zone

get A/D data pair? no

finish calibration? no

yes

get a record

set to spline end condition case 1

sort and cubic spline interpolation

change to other end condition

display fitting curve

satisfy? no

write to calibrating file

yes

4 channels finished? no

next channel?

yes

exit calibration?

no

yes

exit

CI
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Figure 5.16 General flowchart of calibration mode
Figure 5.17 Screen setting in calibration module
When channel 0, 1, 4 and 5 are calibrated, the system reads the A/D values of a specific channel and displays the points on the screen of the computer. The operator adjusts the sensor from the beginning to the end in the measurement range, and inputs the physical value of the sensor to the edit zone on the keyboard of the computer. Thus, a series of data pairs of physical values and the readings of A/D values can be obtained. The calibration data pairs can be seen on the screen. Because the calibration process can be controlled accurately, cubic spline interpolation is conducted for the four channel signals. The interpolation curve is displayed based on the end condition case 1 cited before. If the curve is not satisfied, the interpolation for end condition of case 2, 3 or 4 will be conducted. When the calibration curve is satisfied, the calibration data table will be written into the calibration file.

When channel 2 and 3 are calibrated, the system works in the process of running of the test rig. The system acquires the A/D value of displacement as well as velocity and acceleration at the same time. The physical values of velocity and acceleration can be obtained by deriving the displacement physical value, which is calibrated by the above method. Therefore, the calibration points for velocity and acceleration can be obtained and are displayed on the screen. This process can be shown in Figure 5.18. Because of the long chain of the calibration, the calibration data pairs may not be very accurate. So software low pass filter is employed and “noisy-data” are eliminated and polynomial interpolation is conducted for the velocity and acceleration calibration. The fitting curve is displayed on the screen and the order of the polynomial can be changed if the fitting curves are not satisfied. As the other channels, the calibration data table will be written in the calibration file if the calibration curve is satisfied. Because it is difficult to ensure the calibrating points to cover the entire range which the measurement and control system will operate, both interpolation and extrapolation are applied in the program.
Since the measurement range of 12-bit A/D converter on the board is set to -10V—+10V and its output is two's complement code, the digital range of the A/D is from -2048—+2047. Therefore, each calibration file has 4096 data, the position of each datum in the file specifies the physical value of this channel. For example, the first datum in the file specifies the physical value corresponding to the digital input value of -2048 (-10V input), and the 4096th datum in the file specifies the physical value corresponding to the digital input value of 2047 (+10V input).

As an example, some screen copies of the calibration procedure of load cell are shown in the following pages.
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Figure 5.19 shows the start of the calibration of load cell. The operator can change the maximum and minimum calibrating values, A/D converter on-board programmable gain, calibrating file name and current physical value. The system can automatically change the horizontal coordinate of the figure to fit the whole figure display zone. Push START button to start calibration, push NEXT button to change to the next channel calibration, or push EXIT button to exit calibration process.

![Test Rig Calibration](image)

**Test Rig Calibration**

ADO: FRICTION FORCE (LOAD CELL)

Max physical value: 200
Min physical value: 0
Calibration file: force.cal1
Programmable gain: 10
Current value: 0

A/D CONVERTER

Please adjust the max and min physical values of the signal and the programmable gain on the board, then push START. Push NEXT for the next channel. Push EXIT to end calibration.

Figure 5.19 Screen copy when start the calibration process

When push START button, the point corresponding to the current physical value and A/D value is displayed on the figure zone as a blinking square as shown in Figure 5.20. We need to adjust the load for the sensor, and enter the physical value of the load in the edit zone, then push CONT. button to get this data pair as a calibrating point and display this point as a small hollow square, and continue the above procedure. The RESTART button is pushed to conceal the previous calibration of this channel and
restart a calibration procedure. When the operator gets enough data pairs and the data pairs cover the majority of the measurement range, push FINISH to finalise this calibration.

Cubic spline interpolation is employed to get the calibrating table explained before in the full measurement range. Natural spline fit (case 1) is the default method to get the interpolating data. The interpolating curve is displayed in the figure zone. If the interpolation is not satisfied, push METHOD to select the other end conditions and the interpolation curve is displayed again, as shown in Figure 5.21. The four kinds of end conditions described in Section 3.4.2 are employed in turn for the operator to check. When the operator is satisfied with an interpolation curve, push SAVE to save the curve as the calibrating table in the calibration file to finalise the calibration of the channel, as shown in Figure 5.22.
Figure 5.21 Screen copy of interpolating curve of the calibrating points

Figure 5.22 Selecting interpolating method and saving calibration table
The default calibration file names for each channel is shown in Table 5.2.

<table>
<thead>
<tr>
<th>No.</th>
<th>A/D channel/signal</th>
<th>calibration file name</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>friction force</td>
<td>force.cali</td>
</tr>
<tr>
<td>2</td>
<td>displacement from capacitance sensor</td>
<td>dsplsmt.cali</td>
</tr>
<tr>
<td>3</td>
<td>RMS of acoustic emission</td>
<td>AErms.cali</td>
</tr>
<tr>
<td>4</td>
<td>thermocouple</td>
<td>tmprt.cali</td>
</tr>
<tr>
<td>5</td>
<td>velocity from capacitance sensor</td>
<td>vlct.cali</td>
</tr>
<tr>
<td>6</td>
<td>acceleration from capacitance sensor</td>
<td>aclrt.cali</td>
</tr>
</tbody>
</table>

When the calibrations of all the channels are finished, this module automatically switches to experimental process.

### 5.4 Pre-adjustment process

The temperature of disk and velocity of spindle should be adjusted to the required values before the actual experiments. This module is used for the pre-adjustment and check of some devices of the test rig. The control signals for motor and heating device can also be checked. It is also useful for the check of almost all the input channels and output channels, including A/D converter, amplifiers, sensors, instruments, switching input devices and switching control output devices.

The general flowchart of the process is shown as Figure 5.23.
PRE-ADJUSTMENT MODE

start

MacAdios II board exist? yes

at working status? yes

open pre-adjustment window

set menu, parameter display zone and soft buttons

no button pushed? yes

sample all signals and filter

display temperature, disk velocity, roller velocity and friction force, etc.

manually start motor, adjust disk velocity

change heating device or motor control

finish adjustment

stop motor

record the input values of displacement and force channels as zero datum of measurement

close window and menu

END

Figure 5.23 Flowchart of pre-adjustment process
The disk temperature, disk velocity, friction force, displacement of roller diameter, acoustic emission RMS, and spinning velocity of roller are displayed in this module for check.

A group of data from each A/D channel are sampled first. Then all the data are sorted and only the middle value in the group is taken into account as the real value. Physical value of the channel is calibrated from the real value. This kind of digital filter method is very powerful for strong interference data group, because the sharp peak and valley of the signal from interference could not influence the middle value if the number of sample is big enough and the sample and calculating speed is permitted.

A sample of screen copy is shown as Figure 5.24. The operator can implement the control of motor and heating device by pushing soft control buttons on the screen.

![Figure 5.24 Screen copy of pre-adjustment process](image-url)
When the temperature approaches the required value, adjust the velocity of disk to the required velocity. Then operator can push soft button to finalise the pre-adjustment process. As shown in Figure 5.25, the system instructs operator to keep the holding block of roller from contacting with load cell, so the reading of force should be zero. If it is not zero, record this value as the zero datum, and then deduct it from the reading of A/D converter to get the accurate value of friction force. Wear of diameter of roller is considered in the system, which is expressed by the difference of displacements from the beginning of the experiment. Thus the datum value is recorded at the end of pre-adjustment and before the experiment.

![Figure 5.25 Screen copy of the end of pre-adjustment process](image-url)
5.5 Experimental/simulation process

The softwares for experimental and simulation processes are almost the same. The difference is that the simulation process just carries out the functions similar to the experimental process without concerning with the outside hardware inputs. It neither waits for switching input, just obtains analog values directly and rapidly from an existing experimental data file rather than from real-time A/D converter, nor produces an experimental data file.

5.5.1 Screen Setting

The screen can be mainly divided into five zones, as shown in Figure 5.26.

(1) menu zone

This zone is used to select suitable menu zone function. The details of the menu setting will be discussed in the following section.

(2) parameter edit zone

Some parameters relating to running of the software are displayed, and can be edited and modified in this zone. There are 10 parameters in this zone. They are: Experiment Series, Experiment Date, Temperature (°C), Material, Rolling Speed (m/s), Pressure (MPa), Trigger Time (min), Interval (s), Redraw Step (pts), and Weight (N). The interval is the circle of recording time, and the redraw step is the interval pixel to redraw figures when resuming display.
Figure 5.26 Screen setting of experimental and simulation processes
Chapter 5 Software Design of Measurement and Control System

(3) condition and prompt zone

The running condition of the experimental or simulation process is displayed in this zone. Some messages are also displayed in this zone, which provide some information of the experiment, such as prompt for operation and warning message. Time is also displayed in this zone to indicate the time left for the current experiment.

(4) button operation zone

Some soft buttons are set here to trigger the suitable operations. There are 7 buttons in this zone, including three control buttons and four display setting change buttons.

Three control buttons are: Start button, Pause/Stop button and Continue button. There are four display setting change buttons. The Horizontal coordinate scale increasing button and Horizontal coordinate scale decreasing button can change the display range of horizontal coordinate. The smallest range is 10 minutes, then 20 minutes, 30 minutes, 60 minutes, 120 minutes, 180 minutes, 240 minutes, 360 minutes, 480 minutes, 600 minutes. The Horizontal coordinate scroll left button and Horizontal coordinate scroll right button can scroll the figure(s) displayed by a unit. The unit is determined by a scroll rate set by scroll rate menu, which may be 1/6, 1/4, 1/3, 1/2, 2/3, 5/6 of the display range and the whole display range. Two figures scroll simultaneously if in the two figure display mode.

(5) figure zone

This is the largest zone on the screen. One experimental curve figure or two experimental curve figures can be displayed in this zone. In each figure, two
experimental parameters can be displayed. The parameters displayed on the figure(s) can be set in the menu function by the operator.

5.5.2 Menu Setting

There are 8 groups of menu for the experimental system. They are: System, Mode, Fig11, Fig12, Fig21, Fig22, Display, and Scroll rate. Each menu has its own pull-down submenu. Using the mouse to pull down the submenu will trigger a desired function. The menu and submenu are described as follows,

(1) System menu

Some basic system operations are selected in this menu. The 6 groups of submenu and their functions are save, print screen:, print window, Resume screen (shortcut key: R), reset, Pause/stop (shortcut key: P), Quit (shortcut key: Q).

When the integrated measurement and control system quit normally, the parameters and some settings of the system are written to the HOTWEAR.CONFIG file, which will be re-called for the following experiments.

(2) Mode menu

This menu is used to convert to a suitable mode as desired by the operator. Experimental and its subsidiary functions are included. They correspond to the five functions of the software: experiment, simulation, calibration, MacAdios II diagnosis: and pre-adjustment.
(3) Fig. 11 menu

The left vertical coordinate of the first figure or the only figure displayed in the figure zone is selected in this menu. One of nine experimental parameters can be selected to be displayed in this coordinate. The parameters are change of diameter, friction coefficient, sliding/rolling ratio, AE RMS, friction force, velocity of spindle, velocity of roller, velocity of vibration and acceleration of vibration. The change of diameter is the default coordinate.

(4) Fig. 12 menu

The right vertical coordinate of the first figure or the only figure displayed in the figure zone is selected in this menu. One of nine experimental parameters, the same as in Fig. 11 menu, can be selected to be displayed in this coordinate. The friction coefficient is the default coordinate.

(5) Fig. 21 menu

The left vertical coordinate of the second figure displayed in the figure zone is selected in this menu. One of nine experimental parameters, the same as in Fig. 11 menu, can be selected to be displayed in this coordinate. The sliding/rolling ratio is the default coordinate.

(6) Fig. 22 menu
The right vertical coordinate of the second figure displayed in the figure zone is selected in this menu. One of nine experimental parameters, the same as in Fig. 11 menu, can be selected to be displayed in this coordinate. The AE RMS is the default coordinate.

(7) Display menu

This menu is used for selecting and changing display modes, in which one parameter figure, two parameter figures or original data can be displayed in the figure display zone. Figures scrolling and resealing can also be triggered in the menu. They include first figure (shortcut key: ft 1), second figure (shortcut key: ft 2), both figures (shortcut key: ft 3), original data (shortcut key: ft 4), scroll left (shortcut key: ft [), scroll right (shortcut key: ft ]), decrease scale (shortcut key: ft ;) and increase scale (shortcut key: ft ').

When the original data display mode is selected, no figure is displayed in the figure zone, but original data is displayed instead. This is usually used for checking the input and output status.

(8) Scroll rate

Horizontal coordinate scroll rate of the figures displayed is selected in this submenu, which is applied when the horizontal scroll left or right button is pushed, or the equivalent menu is selected. Scroll rate is set referring to the horizontal display range. For example, if the scroll rate is set to be 1/2, when the scroll left button is pushed, the figure(s) will move left by half of the display window to allow inspection of the
figure(s) at different time. The scroll rate can be 1/6, 1/4, 1/3, 1/2, 2/3, 5/6 of the whole horizontal display window and the whole window.

### 5.5.3 General operation process

General process of the experimental and simulation processes is shown in Figure 5.27.

A configuration file is employed to configure the integrated software system, which may be changed in the experimental period and should be kept for the future use. The configuration file is a ASCII code file, therefore it can be edited by Simpletext and other general document edit software. Every parameter is separated by a comma ",". Generally, a new configuration will be written in the file, which will be called for the following experiment. The serial number of experiment will automatically have an increment by one in the software in the experimental mode if the stop trigger time is run out, otherwise it will remain the same. In simulation mode, the serial number is always the same. There are 24 parameters including numbers and texts in the configuration file. The name of configuration file is "hotwear.config". It should locate in the same folder with the system software.

The "second function" of the Macintosh computer is employed to calculate the time of experimental process, such as recording interval and the stop trigger time. The "second function" is the second past from the midnight, which is an internal timer of the computer provided by the Macintosh hardware. The software inquires the "second function" to obtain the time past in the current experiment. It does not use the interruption to leave more interruption sources and accelerate the program execution. It does not use software timer to eliminate the influence of accumulated error.
EXPERIMENT
SIMULATION

start

system initialised

yes

MacAdios board in the computer?

set to EXPERIMENT mode

get location of the board
hardware initialisation

no

set to SIMULATION mode

set error trap

get system configuration parameters hotwear.config

menu setting: System, Mode, Fig.11, Fig.12, Fig.21, Fig.22, Display and Scroll rate

message feedback field setting

control button setting

display button setting

edit field setting

figure display zone setting and grid net displaying

experimental status, time left display zone setting

ESI
reset Watchdog timer trap

menu event? yes menu manipulation

no

dialogue event? yes dialogue manipulation

no

work status? yes pass 1 second? yes get time passed and display time left

no

simulation mode? yes reach an interval? no

no

sample from analogue channels and timers

read data from previous file

simulate measurement

obtain the middle value for each A/D channel

obtain the middle value for Timer 1 and 2

threshold detection, accident judgement
Figure 5.27 Flowchart of experimental/simulation process software
It should be pointed out that though the recording interval is based on every second, the sample of the signals is carried out consecutively. Thus, the software can obtain the condition of the wear test rig very quickly.

Many event flags, condition indicators and task states are employed in the system to control the program branches.

The following files should be in the same folder with the application program "WEAR",

(1) interface support software: TurboDrivers(TM), TurboDrivers Interface
(2) application program configuration record: hotwear.config
(3) calibration data files: force.cali, dsplsmt.cali, AErms.cali, tmprt.cali, vlct.cali, and aclrt.cali, as shown in Table 5.2
(4) simulating data file (if running in simulating mode): 900000

The normal screen displayed is shown in Figure 5.26. Two parameter curves in one figure can clearly be seen in the screen. Four parameters can be seen in two-figure display mode, shown in Figure 5.28.
Sometimes the original data display mode is more convenient. It is the most transparent to the measurement and control devices. All the A/D current values, filtered values and physical values after calibration, and some calculating values are displayed in the screen. There are four specific control buttons, which only appear when the original data display mode is selected. They are motor on, motor off, heat on and heat off. Therefore the control of motor and heating can be modified anytime in this mode, temporarily suspending the automatic control of the normal process. The control outputs for the motor and heating device are also indicated from this kind of circle buttons. Furthermore, the monitoring signals of motor and heating device are indicated on the screen. Figure 5.29 is a screen copy of this mode.

![Figure 5.28 Screen copy of two-figure display mode](image_url)
Real time Watchdog trap is set in the process, which is used to prevent the software dropping into endless loop by accident. A backup timer, usually called Watchdog timer, is running when the system works normally. The primary software resets the timer periodically. Failure to set the timer causes the backup to resume the control and interrupt the working of the primary software. In the system, the real time clock interruption is employed as the Watchdog timer. The primary software can set and reset the timer. If the timer trap is found, the system must be abnormal. Then the system will enter into a protective control condition.

In the control circle, menu and dialogue events are scanned first. Menu manipulation may terminate experimental/simulation mode and transfer to another mode if Mode menu is selected. Usually it is just a condition change or a task execution.
Dialogue events include two aspects: soft button and parameter edit field operation. Keyboard operation triggers the change of the parameters in edit field. TAB key is used to change one parameter editing to another one. Soft buttons may trigger control or display operation. Control button handling is quite important for the control flow of the system, which will be explained in the next section.

The system keeps acquiring the input from analog channels and timers and obtains the sample data as frequently as possible in an interval without any limit. Then at the end of an interval, the middle value of each channel is picked up as the real value. This kind of filter method is quite powerful to eliminate many erupt peak or valley interferences. The new data are inserted into the sorted queue dynamically, which decreases the response speed to dialogue, menu and outside monitoring and control signals. Only when the time reaches the display pixel of the horizontal coordinate, the parameters are calibrated and displayed on the screen, which can also increase the running speed of the software.

Dynamic and static threshold judgements for some input channels can detect overload of friction force, or out of range of the displacement sensor as soon as possible.

When the time is up to the preset stop trigger time, the system is forced to stop and all the experimental data and configuration data are written into corresponding files.

The flowchart of the handling of control buttons is shown in Figure 5.30. The handling determines the whole control flow of the system. It mainly implements the handling of START, CONT. and P/STOP buttons. System status are divided into work, pause and stop status. Push START to start an experiment, push P/STOP to pause it. Then push
P/STOP once more to stop the experiment, or push CONT. to continue the experiment. All the buttons can trigger different operations at any system status, accompanying with on-line prompt and condition display. Fault operation is tolerant and correct operation is prompted.
output signals to stop motor and heating device

B2

timer off and clear timeleft

close experimental data file and append configure file

set stop status

B3

status display

return

B2

P/STOP button? no

work status

yes

timer stop

invalid operation prompt

output signals, only stop motor

set pause status

Figure 5.30 Flowchart of control button handling

For example, when the system is working, pushing CONT. will not influence the running of the system. "invalid operation" is displayed in the prompt zone. When the system is stop (not in pause status), push CONT. will cause a prompt "START for a new test, CONT. to continue the test". If go on to push START, "START for an incremented series, STOP to enter a new series" is displayed on the prompt zone. Then push START to start a new experiment with a incremented serial number, or push STOP to enter a new serial number in edit field so as to start a new experiment.
Chapter 6

Experiments and Discussions
All the experiments were conducted in the high temperature rolling test rig. The rig and computer interface circuit box are shown in Figure 6.1. The Macintosh computer with MacAdios II board and interface terminal boards are shown in Figure 6.2.
The motor and heating device control cabinet, transformer and cooling air tank are shown in Figure 6.3.

Figure 6.3 Power control of the rig and cooling air tank
The experimental procedure follows these steps:

1. Adjust the three screws on the top of the support beam to change the angle of the support beam and the roller to make the roller and the disk contact evenly in the full length of the roller at high temperature;

2. Run Pre-adjustment Module in the integrated software. Adjust the micrometer at the end of the capacitance sensor to change the position of the probe tip, so as to set the sensor in measuring range;

3. Adjust the supporting nut on the support beam protective stand on the triangle beam to support all the holding block, the support beam and the roller to separate the roller from the disk;

4. Manually start the motor then use the computer to control the motor and to turn on the heating device;

5. When temperature approaches the required temperature, manually switch on the cooling air supply;

6. After the temperature approaches the required temperature once more, loosen the supporting nut on the triangle beam to release the load on the holding block, the
supporting arm and the roller to the top of the disk, and apply dead weight required on
the top of the holding block;

7. Keep the rig running for a period of time to achieve steady state condition;

8. Stop the motor, obtain measuring datum point for the capacitance sensor and
eliminate zero drift of the load cell by adjusting the position of the tip of the capacitance
sensor to ensure the readout to be 100-250 μm, then separate the holding block of the
support beam from the load cell for a period of time;

9. Finish pre-adjustment and transfer to Experimental Module automatically. Enter
experimental parameters, such as stop trigger time, record interval, and load on the
roller, then start the experiment;

10. In the experimental process, the operator can pause, then continue, or stop the
experiment at anytime, can select any display mode and variables displayed on the
screen, and can modify some experimental parameters. The screen and window can also
be printed or saved. The condition of the rig is in-process monitored, and some faults
will cause the rig to stop to protect the system;

11. When it reaches the stop trigger time, the system automatically stops and all the
experimental data and information are saved in an experimental file.
6.2 Preliminary test of the rig

Preliminary experiments were carried out to test the experimental system.

Calibrations of sensors are referred to Appendix E. It usually takes about 30 minutes to heat the disk to 700°C. The heating curve is referred to Appendix F. After the rig has run about half an hour at the required temperature, the temperatures of the capacitance sensor and optoelectrical sensor for roller velocity remain stable. For example, when the rig runs for 20 minutes after 700°C, the output of the capacitance sensor is shown in Figure 6.4. In the following 20 minutes, the sensor is stable. The standard deviation of error $\sigma$ in the last 10 minutes is 0.70 $\mu$m. Therefore, the precision at this measurement point can be estimated as $4\sigma$, i.e., 2.8 $\mu$m.

![Figure 6.4 Output of the capacitance sensor after 20 minutes at 700°C](image)
When the rig runs 30 minutes after reaching 700°C, the temperatures of some parts in the rig are listed in Table 6.1. The list represents the highest temperatures though the rig keeps running for extra four hours, which means that heat balance can be obtained in thirty minutes after reaching the required temperature. As the bearings are designed to be able to work at 360°C and the grease at 290°C, the cooling system enables the bearings to work properly. The load cell and capacitance sensor are under 70°C, therefore they work in the allowed temperature range.

<table>
<thead>
<tr>
<th>position of measurement</th>
<th>temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>original tip of capacitance sensor</td>
<td>55°C</td>
</tr>
<tr>
<td>middle of cooling pipe</td>
<td>95°C</td>
</tr>
<tr>
<td>top of cooling pipe</td>
<td>50°C</td>
</tr>
<tr>
<td>velocity measuring disk</td>
<td>70°C</td>
</tr>
<tr>
<td>optoelectrical sensor mounting beam</td>
<td>70°C</td>
</tr>
<tr>
<td>roller support beam</td>
<td>65°C</td>
</tr>
<tr>
<td>bearing holding block</td>
<td>110°C</td>
</tr>
<tr>
<td>roller</td>
<td>430°C</td>
</tr>
</tbody>
</table>

Two preliminary experiments were conducted in the following conditions,

1. roller material: mild steel
2. temperature: 700 °C
3. pressure between the roller and the disk: 90 MPa
Rolling speed of the first experiment was 1.4 m/s and the experiment lasted 150 minutes. The experimental curve for the change of diameter of roller is shown in Figure 6.5, and the friction force is shown in Figure 6.6.
Because the roller is made of normal mild steel (AS 250), the wear is severe. Change of
diameter is about 60µm in 150 minutes. It is found that the curve is not quite good. Due
to three pauses of the rig in the experimental process, the heating balance was
interrupted and the long tips of the capacitance sensor and support beam of the roller shrank. The shrinking length of the long tips of the sensor must be longer than that of the support beam since their volume and heat capacity are smaller and they transfer heat quickly. Therefore, pauses caused the transient readout of displacement to be smaller. We found this kind of situation in BC, DE, and FG sections, which correspond to the time from 35 to 45 minutes, 80 to 90 minutes, and 140 to 145 minutes. Because all the pauses only took about 1 or 2 minute stop of the heating device, the heating balance resumed in 10 minutes.

Heating device cutoff circuit automatically stops the heating device when the motor stops or the protective mesh covering the test rig is open. This circuit causes the heating interrupted by the pauses in the experiment, which results in a transient heating balance when the experiment continues. It also takes time to resume the required temperature in pre-adjustment process, for example, in step 9 of the experimental process described in Section 6.1.

It is also found that wear of the roller is very uneven in the direction of the length of the roller, as shown in Figure 6.7. Only about 60 percent of the surface in the front end of the roller wore in the 150-minute experiment. This is because the high temperature causes the disk to warp upwards, as shown in Figure 6.8. Anyway, the expansion due to the high temperature cannot be released in the inner part of the disk, but expansion in the outer part of the disk can be free if there is no restriction from the screws. Though long screws, loose connection and big mounting holes are considered in the design of the rig to allow for expansion of the disk, it seems that the screws still restrict the expansion.
The warpage also influences the flatness of the disk at high temperature, and results in vibration of the rig and more wear of the roller. Uneven wear makes it difficult to measure the diameter of the roller. So the mounting angle of the capacitance sensor should be adjusted properly. The angle of the tapered roller is designed to be 6.59°.
After the severe wear the angle at the front end of the roller is 15.4°. Thus, the distorted angle of the disk in the experiment is 4.3°. The warpage caused the contact zone concentrating on the front end of the roller which make the diameter of the roller decrease quickly in the early period of the experimental process, as shown in Figure 6.5.

No water is applied in the experiment. The average of friction coefficient is about 0.06, which almost remains the same during the experimental process. The surface of roller is still smooth after the experiment. But from 50 to 100 minutes, shown as BC section in Figure 6.6, the friction force measured is smaller than the whole trend. It could be due to the fact that the linear bearings linking the support beam and holding frame were not smooth enough in this period. The friction force in the bearings decreased the contact force to the load cell.

The instability of the measurement also comes from the diameter runout of the roller and unflatness of the disk due to thermal distortion. The runout of the roller is shown in Figure 6.9, which is measured by the capacitance sensor when the roller is mounted in the rig. The runout results from the following reasons:

1. roundness of the tapered surface of the roller;
2. concentricity of the tapered surface and the bearing surfaces of the roller;
3. roundness and concentricity of the bearing mounting holes;
4. concentricity of the inner and outer rings of bearings, clearance of bearings

The major factors should be the first two reasons. The maximum runout is about 0.1 mm, which directly influences the measurement of the diameter of the roller. Although
the digital filter is employed in the software, it is still difficult to eliminate the influence from such a large runout.

Then the tapered angle of the roller was modified to be 15.4°, which is equal to the angle after wear in the 150-minute experiment to improve the measurement of diameter of the roller. The linear bearings were readjusted, and low viscosity grease was applied instead of the high viscosity one, and cleaning the rolling ball races to allow free running of the bearings. Then another 180-minute experiment was conducted uninterrupted. The rolling speed in this experiment was 2.0 m/s. Experimental curves for the change of diameter of roller and friction coefficient are shown in Figure 6.10 and Figure 6.11.
Chapter 6 Experiments and discussions

Figure 6.10 Change of diameter of roller in 180-minute test
### EXPERIMENTS FOR HOT ROLLING WEAR

<table>
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<th>01010</th>
<th>Weight (N):</th>
<th>200</th>
</tr>
</thead>
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<td>Redraw Step(pts):</td>
<td>1</td>
</tr>
<tr>
<td>Temperature(°C):</td>
<td>600</td>
<td>Interval (s):</td>
<td>60</td>
</tr>
<tr>
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<td>Trigger Time(min):</td>
<td>180</td>
</tr>
<tr>
<td>Rolling Speed(m/s):</td>
<td>2.0</td>
<td>Pressure(£Pa):</td>
<td>90</td>
</tr>
</tbody>
</table>

This experiment ends
next series number will be 01010

STOP 180:00 TIME LEFT

**Figure 6.11 Friction coefficient in 180-minute test**
It is found that wear is about 70 μm in the whole experimental process. The measurement curve is more stable than the last set of experiment, because of no pause in the process. Friction coefficient also remains the same in the experiment, with a little bit higher at the end of the experiment. The friction coefficient curve is more stable than last experiment because the linear bearings are smoother than before.

6.3 Experiments and discussions

6.3.1 Experiments

The second experiments were conducted under the following conditions:

1. temperature: 700°C;
2. pressure between the roller and the disk: 135 MPa;
3. velocity of the roller: 2.20 m/s;
4. angle of the tapered roller: 15.4°

The diameter runout of the newly-machined roller was measured before the experiment, which was about 0.04, better than previous one. The experimental curves for the change of the diameter of the roller and friction coefficient in the first 120-minute experiment are shown in Figure 6.12. The curves for the acoustic emission and sliding/rolling ratio are shown in Figure 6.13.

The diameter changed quickly at the beginning of the experiment because the contact of the roller and the disk was not even. After a few minutes, the contact condition became
better and the wear became stable. The total change of the diameter of the roller is about 30 μm in the stable period.
Figure 6.13 RMS of acoustic emission and sliding/rolling ratio in the first 120-minute experiment
The friction coefficient became a little bit larger in the entire trend. However, at the beginning of the experiment, the friction coefficient was larger than the normal value. This is probably due to the fact that the roller and the disk contacted unevenly at the beginning of the process.

The RMS of acoustic emission was larger at the start of the experiment, then decreased to a relatively stable value. This can also be explained by the uneven contact of the roller and the disk. All the load focused on the small contact zone between the roller and the disk. The deformation of the material definitely produced stronger physical energy, which made the RMS of acoustic emission larger. Near the end of the experiment, acoustic emission increased to a larger level. This is because more significant wear of roller produced more energy.

The weight and the surface roughness of the roller were also checked before and after the experiment. The total loss of the roller is about 190 mg. The surface roughness was Ra 0.54 before the experiment, then it was Ra 0.71 after the experiment. The surface roughness of the disk changed from Ra 2.4 to Ra 2.7 in the experiment.

Some small pitting can be viewed in the surface of the roller after the experiment. The distribution of the pitting was uniform on the surface of the roller. There were many scales left on the contact zone of the disk. As shown in Figure 6.14, the scales were shiny and bright. They were crispy and hard. The largest size of scales was about 3 mm X 3 mm, whilst the majority of the scales ranged from 0.5 mm to 2 mm. The thickness of the scales was from 8 μm to 20 μm.
Two more continuous 120-minute experiments were conducted after the first 120-minute experiment. The overall changes within the 120-minute periods of the diameter of the roller, friction coefficient, sliding/rolling ratio, RMS of acoustic emission, weight loss of the roller, surface roughness of the roller are shown in Figure 6.15 to Figure 6.20.
Chapter 6 Experiments and discussions

Figure 6.15 Change of the diameter of the roller

Figure 6.16 Friction coefficient curve
Figure 6.17 Sliding/rolling ratio curve

Figure 6.18 AE RMS curve
Figure 6.19  Weight loss curve of the roller

Figure 6.20  Surface roughness curve of the roller
6.3.2 Discussions

It is found that the change of the diameter of the roller, the RMS of acoustic emission, weight loss of the roller and the surface roughness of the roller increased when the wear was more severe. Sliding/rolling ratio in the experiment could not provide effective information of the wear. Friction coefficient reduced sharply at the beginning of the experiment because of the uneven contact of the roller and the disk during the running-in process. When the surfaces had bedded with a larger area of contact, the coefficient of friction stabilised and increased slightly.

The surfaces of the roller and the disk were checked in detail using a microscope. Pitting was more severe on the surface of the roller after the third 120-minute experiment. Figure 6.21 and Figure 6.22 show the pitting on the roller. The size of pitting is about 0.04 mm × 0.04 mm to 0.15 mm × 0.15 mm. Scales on the disk seemed to be smaller than those in the first 120-minute experiment. The size became about 0.25 mm to 1 mm.

Figure 6.21 Surface of the roller after wear (X 150)
Figure 6.22 Surface of the roller after wear (X 150)

Figure 6.23 and Figure 6.24 show the disk surface before wear and after the experiments. After cleaning the top of the disk, it is also found that some scales were embedded in the disk material, as shown in Figure 6.24. A scale in the middle down part of the figure stuck to the disk. Ploughing marks of abrasive wear can also be seen. The material on the surface flowed and smeared.

Figure 6.23 Surface of the disk before wear (X 150)
The pitting on the roller and scales on the disk result from the severe wear associated with banding due to thermal and mechanical fatigue in the continuous high temperature and stress cycling[29,60].

The high temperature between the roller and the disk gradually causes an oxide layer to build up on the roller surface. At first, the hard layer is smooth, and uniform on the roller surface, which acts as a solid lubricant and protects the roller from wear. However, the layer is very crispy, and there are significant thermal and mechanical fatigue, as well as unequal stresses on the roller surface, which lead to subsequent building up and releasing of the oxide layer on the roller surface. When the layer releases from the roller, it may bite and peel off some roller material. This produces pitting on the roller surface[36].

The oxide layer is formed gradually, therefore it is very thin. Then it breaks out on the top surface of the disk, referred to as scales. Because the roller presses the same
position of the disk periodically, the oxide layer is accumulated and pressed tightly. At
the early period of wear, oxide layer is uniform on the roller surface, so releasing of the
layer is not severe. Thus, in the experiments, the pitting of the roller was rare and the
scales were large and thin after the first 120-minute experiment. Pitting could not be
seen on the roller surface. Scales were about 0.5-3 mm large and 8-20 μm thick, as
shown in Figure 6.14. When the releasing of the layer is severe, scales are pressed
together and become fragmented because they are crispy. Then the scales become
smaller and thicker. After the third 120-minute experiment, severe pitting existed on the
roller surface, which could be observed by eyes. Scales were about 0.5-1.0 mm large
and 15-40 μm thick, smaller and thicker than those before wear.

Because the disk is made from a high-temperature-resistant stainless steel, the oxidation
of the disk is not severe. The total weight loss of the roller in the experiments was 580
mg. But the weight of the disk changed from 1146.20 g to 1146.15 g in the
experiments. So, the weight loss was very little, only about 50 mg.

In conclusion, in the experiments, the dominant wear mode was banding caused by
thermal fatigue and mechanical fatigue, which caused the pitting on the roller surface
and scales left on the disk surface.

The experiment has shown that the roller-on-disk test rig can be used in the study of
friction and wear at high temperature. The detailed studies can be carried out by another
project in the near future.
Chapter 7

Conclusions and Recommendations
7.1 Conclusions

1. Study on roll wear in the hot rolling process is very important, because roll wear not only costs significantly but also influences dimensional and shape accuracies of products.

2. It is found that the roller on disk wear geometry has been a novel concept to simulate the rolling process so far, and the high temperature rolling wear test rig can be used for simulation of roll wear in hot rolling process. It can provide different sliding/rolling ratio by moving the position of the roller on the disk. The geometry can also be used to test two specimens at the same time, which is more useful to test different materials than other test rigs with one specimen.

3. It is a feasible way to obtain high temperature by using electrical brushes and commutators to heat the rotating disk, and applying Kaowool ceramic board to insulate the heat.

4. Air coolant system and special coolant structure design in the rig have been proved to be effective in protecting sensors and bearings.

5. Hardware design for the measurement and control of the test rig, including sensor selection, analogue signal conditioning, power signal isolation, motor and heating device control, and protective circuits, demonstrates good performance in the experimental process.
6. Integrated software specially developed for the test rig was proved to be versatile and effective. The entire experimental process can be carried out under the supervision of the software, from data logging board diagnosis, sensor calibration, simulation of experiment and pre-adjustment before experiment, to actual experiment.

7. The dominant wear mode in the experiments is adhesive wear. There is a possibility of wear due to banding which is the continuous building up and releasing of the oxide layer on surface of the roller caused by high temperature, thermal and mechanical fatigue.

8. Clear fire-cracking is not found in the experiment. It may be because the fact that no water spray was applied in the test rig.

9. Acoustic emission signal can be used to detect the wear process, whilst sliding/roller ratio cannot provide effective information in the experiments.

7.2 Recommendations for future work

From the above analyses and experiments, some modifications should be conducted in the rig to achieve better performance. Suggestions are as follows:

1. More power is expected for the heating device to obtain higher temperature. It is recommended to use a larger but shorter heating element to increase the power.
2. Electric brushes and commutators should be relocated further from the heating disk to decrease oxidation of copper, and hence they should be shielded as much from the heat as possible.

3. Omit the heating device cutoff circuit to keep the heating device on when pausing the experiment.

4. Decrease significant warpage of heating disk. We can increase the thickness of the disk and decrease the width of the disk ring, and can modify the mechanical device on the supporting beam of the roller to make the roller and the warping disk contact more evenly over the roller width.

5. Need to introduce water cooling to the roller to simulate rolling process, and computer can control it on- or off-operation.

6. Using hydraulic jack to apply the load, which can be controlled by the computer.

7. Two rollers with different materials should be tested at the same time to provide qualitative and quantitative indications of their wear and friction characteristics.

8. Different roll bite lubricants should be applied in the experiment.
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Appendices
Appendices

Appendix A  Properties of 253MA steel

Mechanical properties of 253MA heat-resistant steel at high temperature are listed in Table A.1, and modulus of elasticity is shown as Table A.2.

<table>
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<th>Table A.1</th>
<th>Mechanical properties at high temperature of 253MA</th>
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<table>
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<tr>
<th>Table A.2</th>
<th>Modulus of elasticity of 253MA</th>
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<td>1000</td>
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Appendix B  Discussion on accuracy of measurement

The basic causes of inaccuracies in the measurement of physical properties by sensors are the physical characteristics of the sensors and signal conditioners themselves, especially with respect to manufacturing tolerances and changes of characteristics of usage and time, and by any mechanical or electrical connections that are present.

Some vocabulary for measurement and error should be clarified before an error analysis is considered.

All errors can be classified into two categories according to their performances: systematic error and random error. If the quantity and direction of errors in the process concerned are fixed or vary according to a specific rule, these errors are called systematic errors. Furthermore, if the quantity and direction of the errors are fixed, they are called constant systematic errors, such as zero offset of an instrument. Whereas if the systematic errors vary in the process, for example, zero drift of an instrument, they are called variable systematic errors. On the other hand, if the quantity and direction of all the errors do not agree exactly, these errors are called random error. The total error is the standard sum of systematic error and random error and can be written in the following form,

\[ e_{total} = \sqrt{e_{system}^2 + e_{random}^2} \]  

(A.1)

where, \( e_{total} \) is the total error of a measurement system

\( e_{system} \) is the systematic error
Accuracy is the closeness of measurement value to the true value. If an experiment has small systematic error, it is said to have high accuracy. Precision is the closeness of grouping of measurement values. If an experiment has small random error, it is said to have high precision.

Accuracy describes the amount of systematic error or the bias of measurement value distribution. It is usually denoted to be the difference between the measurement value and the "true" value which is always an average value of a large number of samples in practice. Precision describes the amount of random error, or measurement value dispersion, or sometimes is called estimated uncertainty. It is usually denoted to be the standard deviation or precision index.

Accuracy and precision are obviously different concepts. A measurement may be accurate but not precise, while another measurement may be precise but not accurate.

Systematic error mainly comes from,

- calibrating error
- experimental condition which is different from calibration condition
- imperfect technique or measurement theoretic error
- human error

Random error mainly comes from,
error of judgement
fluctuating experimental condition
small disturbance of mechanical and electrical system

It is very difficult to decrease the random error. The only way is to enhance the performance of measurement system and improve the measurement condition. In the past years, there have been many improvements in sensor design and manufacturing technology along with the development of various techniques to reduce these errors. These methods are expensive because additional special electronic circuits are needed and each circuit is usually designed for only one class of sensors. And these methods generally have been limited to a certain extent by current technology. Systematic error, on the other hand, may be decreased by suitable methods, because it either remains constant or varies according to a rule. The normal way to eliminate the constant systematic error is the opposite offset or zero-adjustment before using system. Regular opposite offset in the process of running the system is a common way to decrease the variable systematic error, in which some subsidiary hardware and software will be needed.

In the measurement and control system based on microcomputer where the output of the sensors will be transferred into a computer, digital table calibrating method and its combination with regular on-line zero offset correction is a good method to obtain the accurate values of physical properties.

For dial indicator instrument, non-linearity is a systematic error, which is a typical imperfect technique error. Much work has been done in the past to improve the linearity of sensor, amplifier and instrument, since the relationship between the physical value and the sensing value is usually not linear. But non-linearity is not a factor to influence the
measurement accuracy in computer based measurement system. Human error is not a factor of measurement accuracy, either. And regular on-line zero offset correction can also minimise the error caused by a difference of experimental conditions. The important factors for this kind of system are the sensitivity and the stability of the measurement system which cause random error.

Application of A/D converter introduces quantisation error, which is generally determined by the bit of A/D. For example, the error for 8-bit A/D converter is ±0.2%, and the error for 12-bit A/D converter is ±0.012%. High bit A/D converter is much more expensive than low bit A/D converter. So, the bit of A/D converter should be low upon the permission of accuracy. The bit of A/D can be selected to guarantee the quantisation error less than one third to one fifth of the random error. Then, the quantisation error will influence the measurement very slightly according to Equation A.1.

For example, if the quantisation error is 1/3 of the random error, the total error will be,

\[ e_{total} = \sqrt{e_{quantisation}^2 + e_{random}^2} \]

\[ = e_{random} \sqrt{\left(\frac{1}{3}\right)^2 + 1^2} \times 100\% \]

\[ = 105.4\% \ e_{random} \]

therefore the quantisation error only increases 5.4% of the total error. If the quantisation error is 1/4 of the random error, the total error will increase 3.1%, while if the quantisation error is 1/5 of the random error, the total error will increase 2.0%. So, one third to one fifth of the random error is the most economic value for additional error including quantisation error.
Appendix C  Properties of MacAdios II data logging board

The MacAdios board is a high-performance, data-acquisition card designed for the Apple Macintosh. It can reside in any available Macintosh II slot and communicates via the Macintosh II or SE through the system bus. The Macintosh II uses a scaled-down version of NuBUS to interface to peripheral cards. The NuBUS is a 32-bit high-speed bus specified by the IEEE document P1196. The MacAdios only uses basic transfer modes: 16 bit reads and 16 bit writes.

There are four major resources provided by the MacAdios board: A/D system, D/A system, the timer, and the digital input and output ports. The A/D system allows the user to read analog data into the Macintosh II. A/D converter is the most important component in the system, which takes an analog signal and, using a successive approximation method, generates a digital representation of the signal. The analog signal is fed to the A/D converter via an input buffer amplifier and a sample-hold circuit. The amplifier is a programmable-gain amplifier. The sample-hold circuit holds the signal steady as the converter acquires a new analog signal. AMD9513 timer chip controls all of MacAdios timing functions. It sets the sample rate, trigger time, length of sample, and experiment clock outputs. There are 8-bit digital input and 8-bit digital output ports. Each output can drive 10 TTL loads, and the input can accept standard TTL signals.

The main features of MacAdios board are as follows:

A/D: 12 bit

16 channels with single-ended or 8 channels with differential input
7μs sample period, sample and hold circuit

linearity: ±1LSB

software selectable gains:
1 for ±10V or 0—10V input
10 for ±1V or 0—1V input
100 for ±0.1V or 0—0.1V input

optional Multiplexer daughter boards for more channels

D/A: 12 bit

2 channels

output ranges: ±10V or 0—10V at 10 mA

accuracy: ±0.02%

linearity: ±1LSB

DO: 8 channels, TTL compatible

DI: 8 channels, TTL compatible

C/T: AM9513A counter/timer chip

15 bits

3 channels

TTL compatible

operation modes: event counting, frequency measurement, pulse-width measuring (0—7MHz)
pulse output, time-proportional output
Appendix D List of integrated software

MacAdios II board is used in the software, which can be inserted in any bus slot

The following files should be in the same folder with the application program:
1: interface support software: TurboDrivers(TM), TurboDrivers Interface
2: application program configuration record: hotwear.config
3: calibration data file: force.cali(#13), dsplsmt.cali(#14), AErms.cali(#15),
   tmprt.cali(#16), vlcrt.cali(#17), aclrt.cali(#18)
4: simulating data file (if running in simulating mode): 900000

Configuration in MacAdios II board
A/D input mode: 16 channels, single-ended
A/D input range: bipolar
A/D data coding: two's complement
A/D Channel 0: Friction force
A/D Channel 1: Displacement from capacitance sensor
A/D Channel 2: Velocity from capacitance sensor
A/D Channel 3: Acceleration from capacitance sensor
A/D Channel 4: RMS of Acoustic emission
A/D Channel 5: Temperature
DI 0: Monitoring of motor control
DI 1: Monitoring of heating device
DO 0: Motor control
DO 1: Heating device control
C/T 1: Velocity of disk
C/T 2: Velocity of roller

Button setting for Experiment/Simulation module
button 1: start
Appendices

'button 2: cont.
'button 3: p/stop
'button 4: scale -
'button 5: scale +
'button 6: scroll left
'button 7: scroll right
'button 8: first figure (used for 25' CRT)
'button 9: second figure (used for 25' CRT)
'button 10: both figures (used for 25' CRT)
'button 11: motor on (used for original data display mode)
'button 12: motor off (used for original data display mode)
'button 13: heat on (used for original data display mode)
'button 14: heat off (used for original data display mode)

'File name and number
'file #1: hotwear.config
'file #2: series$, experimental data file
'file #11: simulating calibration data file (used in calibration module)
'file #12: calibration data file when generated (used in calibration module)
'file #13-file #18: calibration data file of A/D channels, see above

=================================================================
' =
'=================================================================
'
SYSTEM INFORMATION

'=================================================================
'sh=system(6) 'get screen height
'sw=system(5) 'get screen width

cls
chnmb%=6
chnmb%=2
'dbg
dim fixlimit(5), dynmcfract(5), ystart(9), yfull(9)
'dim adv%(chnmb%+1), ad%(chnmb%,120), sum(chnmb%), middle(chnmb%), dat%(chnmb%,960)
dim adv%(8), sum(6), middle(6), dat%(6,960)
dim admid%(7), ad%(7,960)

'if interval is 60s, maximum experimental time is 16 hours. If long time is expected,
'please change interval longer. For example, 120s interval for 32 hours.
nn%=41
'sample points for each record of the parameters
DIM addd%(nn%),adff%(nn%),adtt%(nn%)
'GOTO readcali

'get the fixed threshold and dynamic coefficient
FOR i%=0 TO 4
  READ fixlimit(i%), dynmcfract(i%)
NEXT i%

DATA -200,2,4000,2,4000,2,4000,2,4000,2,4000,2
fixlimit(0)=-350 'for 10kg dead weight
fixlimit(0)=-500 'for 20kg dead weight
'get y start, full range, and figure display parameters
FOR i%=1 TO 9
  READ ystart(i%), yfull(i%), k(i%),d(i%)
NEXT i%

'change of diameter of roller
DATA 0, 450,0.11,0
'friction coefficient
DATA 0, 0.4,0.0001,0
'sliding rolling ratio
DATA 0, 1.2,0.000293,0
'AE rms
DATA 0, 50,0.0125,0
'friction force
DATA 0, 20,0.005,0
'velocity of spindle
DATA 0, 5,0.0012,0
'velocity of roller
DATA 0, 5,0.0012,0
'velocity of vibration of roller
DATA 0, 10,0.0025,0
'acceleration of vibration of roller
DATA 0, 10,0.0025,0

ProgramStart:
SH%=480
'get the screen pixles 640*480
SW%=640
slot%=2
simu%=0 'experimental mode
vk=1
vkk=1
firstpoint%=255 'first sample point flag

color definition
black:33 white:30 red:205 green:341 Cyan:273 Magerte:137
color1%=69 'yellow
color2%=409 'blue

noreDaw%=255
wd%=6
motoron%=0
heaton%=0
fileopen%=0
count%(1)=0
count%(2)=0
sqc%=0
sqc1%=0
d1=341
d2=19
dc1#=3.14159#*d1/24/10000
dc2#=3.14159#*d2/10000
dc12#=dc1#/dc2#

WINDOW 1,(1,21)-(SW%-1,SH%-1),3
WINDOW 1

FOR i%=1 TO 9
' ac(i%)=ac(i%)=9/16*k(i%)*SH%/(yfull(i%)-ystart(i%))
ac(i%)=9/16*SH%/(yfull(i%)-ystart(i%))
bc(i%)=-9/16*SH%*(d(i%)-ystart(i%))/(yfull(i%)-ystart(i%))+(21/32+1/5)*SH%
' PRINT k(i%);d(i%);ac(i%);bc(i%)
NEXT i%

' If the screen is 14 inches(640*480 pixies), the default basic textsize is 9.
' If the screen is 25 inches(1152*870 pixles), the default basic textsize is set to be 12.
IF SW%>1000 THEN size=12 ELSE size=9
Appendices

' previous setting for display
fy1%=1     'fy11 coordinate set to be parameter 1
fy12%=2     'fy12 coordinate set to be parameter 2
fy21%=3     'fy21 coordinate set to be parameter 3
fy22%=4     'fy22 coordinate set to be parameter 4

fg1%=255     'figure 1 enable
fg2%=0       'figure 2 disable

y11title$="change of diameter"
y11unit$="(um)"
y12title$="friction coefficient"
y12unit$=""
y21title$="sliding/rolling ratio"
y21unit$=""
y22title$="AE RMS"
y22unit$="(mV)"

start:
LIBRARY "TurboDrivers Interface"
GOTO init     ' for debugging
count1%=0
count2%=0
er%=0
'Display a prompt information of the measuring and controlling system
h%=200
w%=400
WINDOW 10,,((SW%-w%)/2,(SH%-h%)/4)-((SW%-w%)/2+w%,(SH%-h%)/4+h%),2

setR: title$="HOT ROLLING WEAR TEST"
TEXTFONT 0
TEXTSIZE 16
MOVETO (WINDOW(2)-WIDTH(title$))/2,20     'center title$
PRINT title$
TEXTFONT 3
TEXTSIZE 12
SetRect r%(1),10,30,w%-5,h%-15
m$="*
Department of Mechanical Engineering"+CHR$(13)
m$=m$+" University of Wollongong, 1995"+CHR$(13)+CHR$(13)
m$=m$+" This program is used for measuring and controlling of the hot rolling "
m$=m$+"wear test rig."

m$=m$+CHR$(13)+CHR$(13)
m$=m$+" Misoperation of the system may cause fatal damage of the wear test rig!"
m$=m$+" Are you permitted to use this system?"
Textbox  m$,,r%(1),0
BUTTON  1,1,*YES*, (170,170)-(230,190),1
d%=DIALOG(0)
WHILE d%<>1 AND d%<>6
d%=DIALOG(0)
WEND
WINDOW CLOSE 10
' detect where the MacAdios board locates

value%=999
er%=-1

GOTO init

FOR i%=0 TO 6
    CALL cread (0,21,VARPTR(value%),i%,er&+2*ErrorIndx)
    IF value%=0 OR value%=16 THEN findslot
NEXT i%

LOCATE 10,15
PRINT " No MacAdios Board in Slot 0-6! Or the board installment is not OK."
LOCATE 12,30
PRINT " Please check the hardware."
LOCATE 14,23
PRINT " You can only simulate the experiments now."

simu%=255

BUTTON 1,1,"GO ON", (300,240)-(360,260),1
d%=DIALOG(0)
WHILE d%<>1 AND d%<>6
d%=DIALOG(0)
WEND
GOTO mainmenu

findslot:
slot%=i%

' initialization of the hardware
' if simulation skip the initialization

init:
    GOSUB initialization

'slot%=i%
mainmenu:
  GOSUB menusetting

  ' Condition feedback dialogue field setting. at the upper right corner

  '------------------------------------------
  TEXTSIZE size
  x1%=SW%*28.5/40
  y1%=SH%*6/200
  x2%=SW%*39/40
  y2%=SH%*16/200
  LINE (x1%-3,y1%-3)-(x2%+3,y2%+3),,b
  SetRect r%(2),x1%,y1%,x2%,y2%
  n$="Are you ready to test? Please check all the instruments before start."
  Textbox n$,r%(2),1

  'Get system last configure variables and timeleft from the associate files
  '------------------------------------------
  'ON ERROR GOTO errorhandle  ' no configure file, get default values
  'for debugging

  erl1:
  OPEN "hotwear.config" FOR INPUT AS #1
  INPUT #1, series$,temperature$,material$,rollingspeed$,pressure$,trigger$
  INPUT #1,interval$,redRAWStep$,Weight$,ss,v3,v4,v5,v6,v7,v8
  INPUT #1,xstart%,xfull%
  INPUT #1,w1,w2,w3,w4,secondNmb2&
  INPUT #1,secondNmb&
  CLOSE #1

  IF simu%=255 GOTO simufile
  ' Time is not left, then start a new experiment with a sequence number
  ' If timeleft is not zero, go on the last experiment
  workstatus%=0
  IF secondNmb&=0 THEN
    status$=" STOP "
    stopstatus%=255
    series$=RIGHT$(STR$(VAL(series$)+100001 &),5)
  ELSE
    status$="PAUSE "

pausestatus%=255
ENDIF
GOTO title

simufile:
  series$="90000"
  status$=" STOP 
  stopstatus%=255
  trigger$="240"
  interval$="2" "=>60"
  xstart%=0
  xfull%=240
  secondNmb%=0
  redrawStep$="2"

'The title of experiments
--------------
title:
TEXTSIZE size*1.5
TEXTFONT 3
TEXTFACE 1
MOVETO (SW%-WIDTH("EXPERIMENTS OF HOT ROLLING WEAR"))/2-100,SH%*1/30
PRINT "EXPERIMENTS FOR HOT ROLLING WEAR"

'EXPERIMENTAL CONTROLLING BUTTONS AND TIME LEFT DISPLAYED
-----------------------------------------------
MOVETO SW%*72/100-6,SH%*13/100   'status display field
TEXTSIZE size*1.2
TEXTFACE 1
TEXTFONT 1
PRINT status$

TEXTFONT 1
TEXTFACE 0

TEXTSIZE size*1.5
MOVETO SW%*72/100+WIDTH("      "), SH%*13/100
  minutLeft%=INT(VAL(trigger$)-secondNmb&/60)
  secondLeft%=(VAL(trigger$)*60-secondNmb&) MOD 60
PRINT RIGHT$(STR$(minutLeft%+1000),3);";";
Appendices 202

PRINT RIGHT$(STR$(secondLeft%+100),2);

TEXTSIZE size
TEXTFACE 1
TEXTFONT 1
PRINT * TIME LEFT*

'-----------------------------------------------------------------------------------------------------------------
'EXPERIMENTAL VARIABLES DISPLAYED ON EDIT FIELDS WHICH CAN BE MODIFIED
'-----------------------------------------------------------------------------------------------------------------
TEXTSIZE size
TEXTFACE 0
TEXTFONT 1
x=SW%/40
y=SH%/12

MOVETO x,y
PRINT *Experiment Series:*
x1=x+WIDTH("Experiment Series: ")
EDIT FIELD 1, seriesS, (x1,y-size-1)-(x1+5*size, y),2

y=y+SH%/40
MOVETO x,y
PRINT *Experiment Date:*
date1$=LEFT$(DATE$,6)+RIGHT$(DATE$,2)
EDIT FIELD 2, date1$, (x1,y-size-1)-(x1+5*size, y),2

y=y+SH%/40
MOVETO x,y
PRINT *Temperature(C):*
EDIT FIELD 3, temperature$, (x1,y-size-1)-(x1+5*size, y),2

y=y+SH%/40
MOVETO x,y
PRINT *Material:*
EDIT FIELD 4, material$, (x1,y-size-1)-(x1+5*size, y),2

y=y+SH%/40
MOVETO x,y
PRINT *Rolling Speed(m/s):*
EDIT FIELD 5, rollingspeed$, (x1,y-size-1)-(x1+5*size, y),2
Appendices

x = SW% * 10 / 40
x1 = x + WIDTH("Experiment Series: ")
MOVETO x,y
PRINT "Pressure (MPa):"
EDIT FIELD 6, pressure$, (x1,y-size-1)-(x1+5*size, y), 2

y = y - SH% / 40
MOVETO x,y
PRINT "Trigger Time (min):"
EDIT FIELD 7, trigger$, (x1,y-size-1)-(x1+5*size, y), 2

y = y - SH% / 40
MOVETO x,y
PRINT "Interval (s):"
EDIT FIELD 8, interval$, (x1,y-size-1)-(x1+5*size, y), 2

y = y - SH% / 40
MOVETO x,y
PRINT "Redraw Step (pts):"
EDIT FIELD 9, redrawStep$, (x1,y-size-1)-(x1+5*size, y), 2

y = y - SH% / 40
MOVETO x,y
PRINT "Weight (N):"
EDIT FIELD 10, Weight$, (x1,y-size-1)-(x1+5*size, y), 2

LINE (SW%/40-5,SH%/12-size-8)-(x1+5.5*size, SH%/12+SH%/10+5),,b

'-------------------------------------------------------------
THREE CONTROLLING SOFT BUTTONS
'-------------------------------------------------------------

TEXTSIZE size
TEXTFACE 0
TEXTFONT 1
x = SW% * 28 / 40 + 5
y = SH% * 15 / 100
xbutton = SW% * 7 / 100 + 6
ybutton = SH% * 5 / 100
BUTTON 1, 1, "START", (x, y)-(x+xbutton, y+ybutton), 1
x = x + xbutton + SW% * 1/60
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BUTTON 2,1,"CONT.", (x,y)-(x+xbutton,y+ybutton),1
x=x+xbutton+SW%*1/60
BUTTON 3,1,"P/STOP", (x,y)-(x+xbutton,y+ybutton),1
Pushed = 0

'HORIZONTAL SCALE CHANGE BUTTONS

TEXTFACE 1
x=SW%*10/20
y=SH%*15/100
MOVETO x,y
PRINT * Horizontal Scale*
x=SW%*11/20-25
xx=SW%*11/20+25
y=SH%*16/100
BUTTON 4,1,"<",(x,y)-(x+30, y+15),1
BUTTON 5,1,">",(xx,y)-(xx+30, y+15),1

'HORIZONTAL SCROLL CHANGE BUTTONS

x=SW%*10/20
y=SH%*8/100
MOVETO x,y
PRINT "Horizontal Scroll"
x=SW%*11/20-25
xx=SW%*11/20+25
y=SH%*9/100
BUTTON 6,1,"<",(x,y)-(x+30, y+15),1
BUTTON 7,1,">",(xx,y)-(xx+30, y+15),1
TEXTFACE 0

'DISPLAY SELECTION BUTTONS

IF SW%<1000 GOTO coordinate ' for 14 inches CRT, not display the buttons
x=SW%*12/20
y=SH%*10/100
MOVETO x,y
PRINT "Display Selection"
Appendices

\[ x = \text{SW} \times \frac{12}{20} \]
\[ y = \text{SH} \times \frac{12}{100} \]

BUTTON 8,1,"First figure",(x,y)-(x+\text{WIDTH}("First figure")+10, y+\text{size} \times 1.5),3
BUTTON 9,1,"Second figure",(x,y+size \times 2)-(x+\text{WIDTH}("Second figure")+10, y+size \times 3.5),3
BUTTON 10,2,"Both figures",(x,y+size \times 4)-(x+\text{WIDTH}("Both figures")+10, y+size \times 5.5),3

'-------------------------------
'DISPLAY NET AND COORDINATE NAMES
'-------------------------------
'default selection is displaying the first figure
coordinate:
    windowwifract=1
    GOSUB windownet2
    
    GOSUB windownet3

'horizontal scale display
    GOSUB horizontalscale
'=================================================================================
'
' WORKING PROGRAM
'
'=================================================================================

'working loop

DIALOG ON
MENU ON
TIMER ON

'open calibration files
IF Chnmb%=2 GOTO chnl2
  OPEN *aclrt.cali* AS #18 LEN=4
  FIELD #18, 4 AS prmt$(3)
  OPEN *vict.cali* AS #17 LEN=4
  FIELD #17, 4 AS prmt$(2)
  OPEN *AErms.cali* AS #15 LEN=4
  FIELD #15, 4 AS prmt$(4)
chnl2:
  OPEN *dsplsmt.cali* AS #14 LEN=4
  FIELD #14, 4 AS prmt$(1)
  OPEN *force.cali* AS #13 LEN=4
  FIELD #13, 4 AS prmt$(0)
  OPEN *tmprt.cali* AS #16 LEN=4
  FIELD #16, 4 AS prmt$(5)

WHILE 1
  ON MENU GOSUB domenu
  ' ON TIMER(wd%) GOSUB WatchDog
  ON DIALOG GOSUB doDialog
  a$=INKEY$
  IF LEN(a$)=0 GOTO conditionMT
  IF ASC(a$)<>16 GOTO conditionMT
  buttonpushed%=3
  GOSUB DoControlbutton
conditionMT:
  IF workstatus%<=255 THEN nextloop
  'no working status, next loop
  SELECT CASE simu%
  CASE 0
GOSUB measure 'experimental mode to measuring
CASE ELSE
  GOSUB Simu measure 'simulating mode to get data from file
END SELECT

IF simu%=255 GOTO simuwk1

secondpass&=TIMER
  IF secondpass&<>0 GOTO nomidnight
  IF midnight%=255 GOTO nomidnight 'only adjust the timer once
    timebase&=timebase-&86400&
    midnight%=255
  GOTO nomidnight
simuwk1:
  smp%=smp%+1
  GOTO simugo1

nomidnight:
  smp%=INT(secondNmb&/VAL(interval$)) 'sample series number, interval number
simugo1:
  scd%=secondNmb&-smp%*VAL(interval$) 'second left in a sample interval
  IF secondpass&<=timebase& GOTO endseconds

'just pass 1 second
  timebase&=timebase&+1
  secondNmb&=secondNmb&+1

  trigger%=VAL(EDIT$(7))
  minutLeft%=INT(trigger%–secondNmb&/60)
  secondLeft%=(trigger%*60–secondNmb&) MOD 60

MENU OFF 'temporarily suspend menu and dialog trapping
DIALOG OFF
TEXTSIZE size*1.5
MOVETO SW%*72/100+WIDTH(* *), SH%*13/100
PRINT RIGHT$(STR$(minutLeft%+1000),3);*:*
PRINT RIGHT$(STR$(secondLeft%+100),2)
TEXTSIZE size
MENU ON
DIALOG ON 'turn menu and dialog trapping on
IF simu% = 255 GOTO simuwk2

n$ = STR$(scd%)
Textbox n$, r%(2), 1

IF scd% < VAL(interval$) - 1 THEN endseconds
' reach another interval, draw the curves on screen
' get the middle value for each channel, get the two frequency values
mid% = (sqc% + 1) \ 2
midforce% = (sqc% + 1) \ 10
admid%(0) = ad%(0, midforce%)
FOR i% = 1 TO 5
    admid%(i%) = ad%(i%, mid%)
NEXT i%

' get the middle value for Timer1 and 2
mid% = (sqc1% + 1) \ 2
admid%(6) = ad%(6, mid%)
admid%(7) = ad%(7, mid%)

n$ = "0:" + STR$(admid%(0)) + " 1:" + STR$(admid%(1))
' C/T No:" + STR$(sqc1%)
Textbox n$, r%(2), 1
'dbg

IF fg0% <> 255 GOTO nodspldt1

MOVETO 410, 175
PRINT admid%(0); " *
MOVETO 410, 195
PRINT admid%(1); " *
MOVETO 410, 215
PRINT admid%(2); " *
MOVETO 410, 235
PRINT admid%(3); " *
MOVETO 410, 255
PRINT admid%(4); " *
MOVETO 410, 275
PRINT admid%(5); " *
MOVETO 410, 295
PRINT admid%(6); " *
moveto 410,315
print admid%(7); " 

nodspld1:
'calibrate the data
IF Chnmb%=2 GOTO chnl21
GET #18, admid%(3)+2049 'acceleration
phyvall(3)=CVS(prmt$(3))
GET #17, admid%(2)+2049 'velocity
phyvall(2)=CVS(prmt$(2))
GET #15, admid%(4)+2049 'AE
phyvall(4)=CVS(prmt$(4))

chnl21:
GET #14, admid%(1)+2049 'displacement
phyvall(1)=CVS(prmt$(1))
GET #13, admid%(0)+2049 'friction force
phyvall(0)=CVS(prmt$(0))
GET #16, admid%(5)+2049 'temperature
phyvall(5)=CVS(prmt$(5))

goto clrsqc

for u%=0 to 5
  for v%=0 to sqc%
    ad%(u%,v%)=0
  next v%
next u%

for u%=6 to 7
  for v%=0 to sqc1%
    ad%(u%,v%)=0
  next v%
next u%

clrsqc:
  sqc%=0  'the sequence number of sample in an intervals
  sqc1%=0
'calibration

if fg0%<>255 goto nodspldt11
' phyvall(6)=count%(1)*dc1#
phyval!(6)=admid%(6)*dc1#
phyval!(7)=count%(2)*dc2#
phyval!(7)=admid%(7)*dc2#

MOVETO 520, 175
PRINT phyval!(0); " N "
MOVETO 520, 195
PRINT phyval!(1); " um "
MOVETO 520, 215
PRINT phyval!(2); " m/s "
MOVETO 520, 235
PRINT phyval!(3); " m/s/s "
MOVETO 520, 255
PRINT phyval!(4); " mV "
MOVETO 520, 275
PRINT phyval!(5); " dgr "
MOVETO 520, 295
PRINT phyval!(6); " m/s "
MOVETO 520, 315
PRINT phyval!(7); " m/s "

PRINT " 0"; " um "
PRINT phyval!(0)/VAL(Weight$);

IF admid%(7)=0 GOTO nodspldtm

PRINT admid%(6)/admid%(7)*dc12#;

nodspldtm:
PRINT "N/A"

nodspldt111:

'write physical values to the experimental data file
IF Chnmb%=2 GOTO chnl2skp

LSET dat2$=MKS$(phyval!(2))
LSET dat3$=MKS$(phyval!(3))
LSET dat4$=MKS$(phyval!(4))
LSET dat5$=MKS$(phyval!(5))

chnl2skp:
LSET dat0$=MKS$(phyval!(0))
LSET dat1$=MKS$(phyval!(1))
LSET dat6$=MKS$(phyval!(6))
LSET dat7$=MKS$(phyval!(7))
PUT #2, smp%+1
GOTO timecheck

simuwk2:
phyval!(0)=CVS(dat0$)
phyval!(1)=CVS(dat1$)
phyval!(6)=CVS(dat6$)
phyval!(7)=CVS(dat7$)
GOSUB onlinedraw

'IF secondNmb& MOD 60>VAL(interval$) GOTO endSeconds
'PRINT "onlinedraw"

timecheck:
'to the trigger time?
   IF secondNmb&<60*trigger% THEN drawfigure
'time is coming, stop
'output control signal and change the output buffer
'close data file, append configure file to data file
secondNmb&=0
workstatus%=0
stopstatus%=255
pausestatus%=0
BEEP
BEEP
series$=RIGHT$(STR$(VAL(EDIT$(1))+100001&),5)
n$="This experiment ends"+CHR$(13)
n$=n$+"next series number will be "+series$
Textbox n$,r%(2),1
x=SW%/40+W/DTH("Experiment Series: ")
y=SH%/12
EDIT FIELD 1,series$,(x,y-size-1)-(x+5*size, y),2
status$=" STOP "
MOVETO SW%*72/100-6,SH%*13/100
TEXTSIZE size*1.2
TEXTFACE 1
PRINT status$
TEXTSIZE size
TEXTFACE 0
GOTO endseconds
drawfigure:
    GOSUB onlinedraw

endseconds:
'PRINT " "
nextloop:
WEND

'-------------------------------------
doDialog:
    SELECT CASE DIALOG(0)
    CASE 1
        buttonpushed%=DIALOG(1)
        IF buttonpushed%<=3 OR buttonpushed%>10 THEN 'display button pushed
            GOSUB DoControlbutton
        ELSE 'control button pushed
            GOSUB DoDisplaybutton
        END IF
    CASE 2
        editfield=DIALOG(2)
        EDIT FIELD editfield
    CASE 7 'tab pressed
        editfield=editfield MOD 10+1
        EDIT FIELD editfield
    CASE ELSE
    END SELECT
RETURN
'sample from the A/D channels and accident judgement, 
'insert the new data in the sorted queue
'AD value to

measure:
FOR u%=0 TO Chnmb%-1 
   CALL cread (u%,0,VARPTR(adv%(u%)),slot%, VARPTR(er%))
NEXT u%
CALL cread (5,0,VARPTR(adv%(5)),slot%, VARPTR(er%))
IF adv%(0)<fixlimit(0) GOTO troubleST

IF fg0%<>255 GOTO nodspldt
' TEXTSIZE size
MENU OFF
   MOVETO 280, 175 
   PRINT adv%(0); " 
   MOVETO 280,195 
   PRINT adv%(1); " 
   MOVETO 280,215 
   PRINT adv%(2); " 
   MOVETO 280,235 
   PRINT adv%(3); " 
   MOVETO 280,255 
   PRINT adv%(4); " 
   MOVETO 280,275 
   PRINT adv%(5); " 
MENU ON

nodspldt:
IF smp%<>0 THEN normaljudge
'the first interval, just fixed threshold accident judgement
   FOR u%=0 TO Chnmb%-1 
      IF u%>=5 GOTO passcheck1
      IF adv%(u%)>fixlimit(u%) THEN troubleSt
   NEXT u%
   passcheck1:
   GOTO passcheck2
normaljudge:
'fixed threshold accident judgement, and dynamic threshold judgement for the first 5 Chs
FOR u%=0 TO Chnmb%-1
    IF u%=5 GOTO passcheck2
    ' IF adv%(u%)>fixlimit(u%) THEN troubleSt
    ' IF adv%(u%)>dynmcfract(u%)*middle(u%) THEN troubleDy
NEXT u%
passcheck2:

'store data in ad( , ) sguently from small to big
FOR u%=0 TO 5
    IF sqc%<>0 GOTO  bubble 1
    ad%(u%,0)=adv%(u%)
    GOTO norm1
bubble1:
    FOR v%=0 TO sqc%-1
        IF adv%(u%)<ad%(u%,v%) THEN tomove
    NEXT v%
    GOTO  write 1
tomove:
    FOR w%=sqc%-1 TO v% STEP -1 'move all the data back by one position
        ' which are bigger than the new one
        ad%(u%, w%+1)=ad%(u%, w%)
    NEXT w%
write1:
    ad%(u%, v%)=adv%(u%) 'write the new data on right position
norm1:
    NEXT u%
sqc%=sqc%+1

CALL Fqcontrol(1,3,VARPTR(count%(1)),slot%,VARPTR(er%))
IF er%=16 GOTO timenoenough00
CALL Fqsetup(1,3, 10000,slot%,VARPTR(er%))

CALL Fqcontrol(2,3,VARPTR(count%(2)),slot%,VARPTR(er%))
IF er%=16 GOTO timenoenough00
CALL Fqsetup(2,3, 10000,slot%,VARPTR(er%))

FOR u%=6 TO 7
IF sqc1%<>0 GOTO bubble2
    ad%(u%,0)=count%(u%-5)
GOTO norm2
bubble2:
    FOR v%=0 TO sqc1%-1
        IF count%(u%-5)<ad%(u%,v%) THEN tomove2
    NEXT v%
GOTO write2
tomove2:
    FOR w%=sqc1%-1 TO v% STEP -1 'move all the data back by one position
        'which are bigger than the new one
        ad%(u%, w%+1)=ad%(u%, w%)
    NEXT w%
write2:
    ad%(u%, v%)=count%(u%-5) 'write the new data on right position
norm2:
NEXT u%

IF fg0%<>255 GOTO nodspl2
    MOVETO 280,295
    MENU OFF
    PRINT count%(1); " 
    MOVETO 280,315
    PRINT count%(2); "
    MENU ON
nodspl2:
    sqc1%=sqc1%+1
timenoenough00:
RETURN

CALL Fqcontrol(1,3,adv%(Chnmb%),slot%,VARPTR(er%)) 'input from timer 1, gate 3
CALL Fqcontrol(2,3,adv%(Chnmb%+1),slot%,VARPTR(er%)) 'input from timer 2, gate 3
RETURN

' SIMULATING MEASUREMENT
Simumeasure:

'get data from the data file in dat0$--dat6$

GET #2, smp%+1

IF Chnmb%=2 GOTO chnl2skp1

phyval(2)=CVS(dat2$)
phyval(3)=CVS(dat3$)
phyval(4)=CVS(dat4$)
phyval(5)=CVS(dat5$)

chnl2skp1:

phyval(0)=CVS(dat0$)
phyval(1)=CVS(dat1$)
phyval(6)=CVS(dat6$)
phyval(7)=CVS(dat7$)

n$=STR$(smp%)+" "+STR$(CVI(dat0$))+" "+STR$(CVI(dat1$))

Textbox n$,r%(2),1

RETURN

troubleST:

'STOP motor AND heating device

CALL setDoutbit(7,1,slot%,VARPTR(er%))
CALL setDoutbit(7,1,slot%,VARPTR(er%))
CALL setDoutbit(6,1,slot%,VARPTR(er%))
CALL setDoutbit(6,1,slot%,VARPTR(er%))

force=adv%(0)

STOP

RETURN

troubleDy:

RETURN
Appendices

```
'===============================================
'       DRAWING
'===============================================
'draw at the next second after one interval
onlinedraw:
fdata(1)=phyval!(1)            'change of diameter
fdata(2)=phyval!(0)/VAL(Weight$)  'friction of coefficient
IF phyval!(7)=0 GOTO zerovlct
    fdata(3)=phyval!(6)/phyval!(7)  'sliding rolling ratio
zerovlct:
fdata(4)=phyval!(4)            'AE rms
fdata(5)=phyval!(0)            'friction force
fdata(6)=phyval!(6)            'velocity of spindle
fdata(7)=phyval!(7)            'velocity of roller
fdata(8)=phyval!(2)            'velocity of vibration
fdata(9)=phyval!(3)            'acceleration of vibration

IF fg0%=255 GOTO displaydata
IF windowwifact=.5 GOTO drawfigures
'draw one figure
IF fg1%<>255 GOTO drawfig2
'draw figure 1, fy11: yellow, fy12: blue, from xstart to xfull
    IF smp%/60*VAL(interval$)<xstart% OR smp%/60*VAL(interval$)>xfull% GOTO endfig1
        xfig%=SW%/8+(smp%/60*VAL(interval$)-xstart%)*480/(xfull%-xstart%)
        y11fig%=bc(fy11%)-fdata(fy11%)*ac(fy11%)
        y12fig%=bc(fy12%)-fdata(fy12%)*ac(fy12%)
    n$=STR$(smp%)+" *+STR$(fdata(fy11%))+" *+STR$(fdata(fy12%))+" *+STR$(y11fig%)+" *+STR$(y12fig%)
    n$=n$+" *+STR$(bc(fy11%))+" *+STR$(ac(fy11%))
    n$=n$+" *+STR$(bc(fy12%))+" *+STR$(ac(fy12%))
    Texbox n$,r%(2),1
    IF firstpoint%<>255 GOTO drawline1
        firstpoint%=0
        last11%=y11fig%
        last12%=y12fig%
        lastx%=xfig%
drawline1:
            LINE (lastx%, last11%)-(xfig%,y11fig%),color1%
            LINE (lastx%, last12%)-(xfig%,y12fig%), color2%
        last11%=y11fig%
        last12%=y12fig%
```

---

The provided text appears to be a segment of a computer program, possibly written in a language like Basic or similar, that deals with drawing on a screen. It includes various calculations and instructions for displaying different parameters, such as change of diameter, friction of coefficient, sliding rolling ratio, AE rms, friction force, velocity of spindle, velocity of roller, velocity of vibration, and acceleration of vibration. The program uses variables and functions to manipulate these values and display them on the screen in specific colors and positions.
lastx%=xfig%
endfig1:
   GOTO endonlinedraw

drawfig2:
   'draw figure 2, fy21: yellow, fy22: blue, from xstart to xfull
   drawfig2:
      IF smp%/60*VAL(interval$)<xstart% OR smp%/60*VAL(interval$)>xfull% GOTO endfig2
         xfig%=SW%/8+(smp%/60*VAL(interval$)-xstart%)*480/(xfull%-xstart%)
         y21fig%=bc(fy21%)-fdata(fy21%)*ac(fy21%)
         y22fig%=bc(fy22%)-fdata(fy22%)*ac(fy22%)
      
      n$=STR$(smp%)+" *+STR$(fdata(fy11%))"+" *+STR$(fdata(fy12%))"+" *+STR$(y11fig%)+" *+STR$(y12fig%)
      n$=n$+" *+STR$(bc(fy11%))"+" *+STR$(ac(fy11%))
      n$=n$+" *+STR$(bc(fy12%))"+" *+STR$(ac(fy12%))
      'Textbox n$,r%(2),1
      IF firstpoint%<>255 GOTO drawline2
         firstpoint%=0
         last21%=y21fig%
         last22%=y22fig%
         lastx%=xfig%
      drawline2:
         LINE (lastx%, last21%)-(xfig%,y21fig%),color1%
         LINE (lastx%, last22%)-(xfig%,y22fig%), color2%
         last21%=y21fig%
         last22%=y22fig%
         lastx%=xfig%
endfig2:
   GOTO endonlinedraw
drawfigures:
   'draw two figures
   'draw figure 1, fy11: yellow, fy12: blue, from xstart to xfull
   drawfigure1:
      IF smp%/60*VAL(interval$)<xstart% OR smp%/60*VAL(interval$)>xfull% GOTO endfig12
         xfig%=SW%/16+(smp%/60*VAL(interval$)-xstart%)*240/(xfull%-xstart%)
         y11fig%=bc(fy11%)-fdata(fy11%)*ac(fy11%)
         y12fig%=bc(fy12%)-fdata(fy12%)*ac(fy12%)
      IF firstpoint%<=255 GOTO drawline121
         firstpoint%=0
         last11%=y11fig%
         last12%=y12fig%
         lastx1%=xfig%
      drawline121:
LINE (lastx1%, last11%)-(xfig%,y11fig%),color1%
LINE (lastx1%, last12%)-(xfig%,y12fig%), color2%
last11%=y11fig%
last12%=y12fig%
lastx1%=xfig%

draw figure 2,
   xfig%=SW%/2+xfig%
   y21fig%=bc(fy21%)-fdata(fy21%)*ac(fy21%)
   y22fig%=bc(fy22%)-fdata(fy22%)*ac(fy22%)
IF firstpoint%<>255 GOTO drawline122
   firstpoint%=0
   last21%=y21fig%
   last22%=y22fig%
   lastx2%=xfig%
drawline122:
   LINE (lastx2%, last21%)-(xfig%,y21fig%),color1%
   LINE (lastx2%, last22%)-(xfig%,y22fig%), color2%
   last21%=y21fig%
   last22%=y22fig%
   lastx2%=xfig%
endfig12:
   GOTO endonlinedraw

displaydata:
'only display the data, the names are displayed in redraw subroutine
endonlinedraw:
   RETURN
Appendices

REDRAWING
from Horizontal Scroll, Horizontal Scale, Fig.11, Fig.12, Fig.21
Fig.22 and Display Mood Change (first, second and both)

redraw:

TIMER OFF
IF fg0%=255 GOTO redisplaydata
BUTTON CLOSE 11 'motor and heating control buttons disable
BUTTON CLOSE 12
BUTTON CLOSE 13
BUTTON CLOSE 14

firstpoint%=255
LINE (0, SH%/5+2)-(SW%,SH%),30,bf
drawstep%=VAL(EDIT$(9))
GOSUB horizontalscale

' if no figure display skip here
IF fg1%<>0 GOTO ccc
  windowwifract=1 'the second figure
  GOSUB windownet3full
  GOSUB redrawfig2
  GOTO drawend
ccc:
IF fg2%<>0 GOTO ccc1
  windowwifract=1 'the first figure
  GOSUB windownet2
  GOSUB redrawfig1
  GOTO drawend
ccc1:
  windowwifract=.5 'both figures
  GOSUB windownet2
  GOSUB windownet3
  GOSUB redrawfig12
  GOTO drawend

redisplaydata:
LINE (0, SH%/5+2)-(SW%,SH%),30,bf
LINE (5,100)-(632,450),b
LINE (7,102)-(630,448),b
DATA AND CONDITION OF EXPERIMENT

CURRENT DATA

FILTERED DATA

PHYSICAL VALUE

ADO (friction force)
AD1 (displacement)
AD2 (velocity of vibration)
AD3 (acceleration of vibration)
AD4 (RMS of AE)
AD5 (temperature)
CT1 (velocity of disk)
CT2 (velocity of roller)
Change of diameter of roller
Coefficient of friction
Sliding and rolling ratio

IF workstatus% = 255 GOTO motorison
BUTTON 11,1,"MOTOR ON",(50,390)-(160,410),3
BUTTON 12,2,"MOTOR OFF",(50,420)-(160,440),3
GOTO heatcondition
motorison:
BUTTON 11,2,"MOTOR ON",(50,390)-(160,410),3
BUTTON 12,1,"MOTOR OFF",(50,420)-(160,440),3

'heating is on when working and pause status
heatcondition:
IF stopstatus%=255 GOTO heatisoff
BUTTON 13,2,"HEAT ON",(220,390)-(330,410),3
BUTTON 14,1,"HEAT OFF",(220,420)-(330,440),3
GOTO conditiondspl

heatisoff:
BUTTON 13,1,"HEAT ON",(220,390)-(330,410),3
BUTTON 14,2,"HEAT OFF",(220,420)-(330,440),3

conditiondspl:
'detect the condition of motor and heating device
'get the digital input

MOVETO 380, 403
PRINT "The motor is ";
TEXTFACE 1

MOVETO 470, 403
PRINT "RUNNING ";
GOTO htd<tab>ct
m<tab>ts<tab>tp:
PRINT "STOPPED ";

htcdt:
TEXTFACE 0
MOVETO 380,433
PRINT "The heating device is ";
TEXTFACE 1

MOVETO 525, 433
PRINT "ON ";
GOTO cdtfnsh
htoff:
PRINT "OFF ";
cdtfnsh:
REWIND

drawend:
RETURN

redrawfig1:
'draw figure 1, fy11: yellow, fy12: blue, from xstart to xfull
'if not start and a new experiment, skip the redrawing

IF noreDaw%=255 GOTO endRedraw1

tt%=(INT((xfull%-xstart%)/480)+1)*drawstep%
FOR i%=xstart%/VAL(interval$)*60 TO smp% STEP tt%
  IF i%/60*VAL(interval$)>xfull% THEN RETURN
getvalue1:
  GET #2, i%+1
IF Chnmb%=2 GOTO chnl2skp2
phyval!(2)=CVS(dat2$)
phyval!(3)=CVS(dat3$)
phyval!(4)=CVS(dat4$)
phyval!(5)=CVS(dat5$)
chnl2skp2:
phyval!(0)=CVS(dat0$)
phyval!(1)=CVS(dat1$)
phyval!(6)=CVS(dat6$)
phyval!(7)=CVS(dat7$)

SELECT CASE fy11%
  CASE 1
    fdata(1)=phyval!(1)
  CASE 2
    fdata(2)=phyval!(0)/VAL(Weight$)
  CASE 3
    IF phyval!(7)=0 GOTO zerovlctl
    fdata(3)=phyval!(6)/phyval!(7)
zerovlctl:
    fdata(3)=0
  CASE 4
    fdata(4)=phyval!(4)
  CASE 5
CASE 6
fdata(6)=phyval!(6)
CASE 7
fdata(7)=phyval!(7)
CASE 8
fdata(8)=phyval!(2)
CASE 9
fdata(9)=phyval!(3)
END SELECT

xfig%=(SW%/8+(i%*VAL(interval$)/60-xstart%)*480/(xfull%-xstart%))
y11fig%=bc(fy11%)-fdata(fy11%)*ac(fy11%)

IF firstpoint%<>255 GOTO drawline111
last11%=y11fig%
lastx%=xfig%
drawline111:
    LINE (lastx%, last11%)-(xfig%,y11fig%),color1%

SELECT CASE fy12%
    CASE 1
        fdata(1)=phyval!(1)
    CASE 2
        fdata(2)=phyval!(0)/VAL(Weight$)
    CASE 3
        IF phyval!(7)=0 GOTO zerovlct2
            fdata(3)=phyval!(6)/phyval!(7)
    zerovlct2:
        fdata(3)=0
    CASE 4
        fdata(4)=phyval!(4)
    CASE 5
        fdata(5)=phyval!(0)
    CASE 6
        fdata(6)=phyval!(6)
    CASE 7
        fdata(7)=phyval!(7)
    CASE 8
        fdata(8)=phyval!(2)
    CASE 9
        fdata(9)=phyval!(3)
END SELECT
Appendices

```
y12fig% = bc(fy12%) - fdata(fy12%) * ac(fy12%)
IF firstpoint% <> 255 GOTO drawline112
last12% = y12fig%
firstpoint% = 0
drawline112:
    LINE (lastx%, last12%) - (xfig%, y12fig%), color2%
    last11% = y11fig%
    last12% = y12fig%
    lastx% = xfig%
nextpoint1:
    NEXT i%
endRedraw1:
    noreDaw% = 0
    RETURN

redrawfig2:
    ' draw figure 2, fy21: yellow, fy22: blue, from xstart to xfull
    ' if not start and a new experiment, skip the redrawing
    IF noreDaw% = 255 GOTO endRedraw2
    tt% = (INT((xfull% - xstart%) / 480) + 1) * drawstep%
    FOR i% = xstart% / VAL(interval$) * 60 TO smp% STEP tt%
        IF i% * VAL(interval$) / 60 < xstart% GOTO nextpoint2
        IF i% / 60 * VAL(interval$) > xfull% THEN RETURN
    getvalue2:
        GET #2, i% + 1
    IF Chnmb% = 2 GOTO chnl2skp22
    phyvall(2) = CVS(dat2$)
    phyvall(3) = CVS(dat3$)
    phyvall(4) = CVS(dat4$)
    phyvall(5) = CVS(dat5$)
    chnl2skp22:
    phyvall(0) = CVS(dat0$)
    phyvall(1) = CVS(dat1$)
    phyvall(6) = CVS(dat6$)
    phyvall(7) = CVS(dat7$)
SELECT CASE fy21%
    CASE 1
```
fdata(1)=phyval!(1)

CASE 2
fdata(2)=phyval!(0)/VAL(Weight$)

CASE 3

IF phyval!(7)=0 GOTO zerovlct22
    fdata(3)=phyval!(6)/phyval!(7)
zerovlct22:
    fdata(3)=0

CASE 4
    fdata(4)=phyval!(4)

CASE 5
    fdata(5)=phyval!(0)

CASE 6
    fdata(6)=phyval!(6)

CASE 7
    fdata(7)=phyval!(7)

CASE 8
    fdata(8)=phyval!(2)

CASE 9
    fdata(9)=phyval!(3)

END SELECT

xfig%=SW%/8+(i%*VAL(interval$)/60-xstart%)*480/(xfull%-xstart%)
y21fig%=bc(fy21%)-fdata(fy21%)*ac(fy21%)

IF firstpoint%<>255 GOTO drawline211
    last21%=y21fig%
    lastx%=xfig%

drawline211:
    LINE (lastx%, last21%)-(xfig%,y21fig%),color1%

SELECT CASE fy22%

CASE 1
    fdata(1)=phyval!(1)

CASE 2
    fdata(2)=phyval!(0)/VAL(Weight$)

CASE 3

IF phyval!(7)=0 GOTO zerovlct23
    fdata(3)=phyval!(6)/phyval!(7)
zerovlct23:
    fdata(3)=0

CASE 4
    fdata(4)=phyval!(4)
CASE 5
    fdata(5)=phyval!(0)

CASE 6
    fdata(6)=phyval!(6)

CASE 7
    fdata(7)=phyval!(7)

CASE 8
    fdata(8)=phyval!(2)

CASE 9
    fdata(9)=phyval!(3)

END SELECT
    y22fig%=bc(fy22%)-fdata(fy22%)*ac(fy22%)
    IF firstpoint%<>255 GOTO drawline212
        last22%=y22fig%
        firstpoint%=0

drawline212:
        LINE (lastx%, last22%)-(xfig%,y22fig%),color2%
        last21%=y21fig%
        last22%=y22fig%
        lastx%=xfig%

nextpoint2:
    NEXT i%
endRedraw2:
    noreDaw%=0
    RETURN

'------------------------------------------------------------
redrawfig12:
    'draw figure 1 and 2, fy11 and fy21: yellow, fy12 and fy22: blue, from xstart to xfull
    'if not start and a new experiment, skip the redrawing

    IF noreDaw%=255 GOTO endRedraw12
        tt%=((INT((xfull%-xstart%)/240)+1)*drawstep%
    FOR i%=xstart%/VAL(interval$)*60 TO smp% STEP tt%
        IF i%*VAL(interval$)/60<xstart% GOTO nextpoint12
        IF i%/60*VAL(interval$)>xfull% THEN RETURN

    getvalue12:
        GET #2, i%+1
    IF Chnmb%=2 GOTO chnl2skp212
    phyval!(2)=CVS(dat2$)
    phyval!(3)=CVS(dat3$)
phyval!(4)=CVS(dat4$)
phyval!(5)=CVS(dat5$)
chnl2skp212:
phyval!(0)=CVS(dat0$)
phyval!(1)=CVS(dat1$)
phyval!(6)=CVS(dat6$)
phyval!(7)=CVS(dat7$)
'------------------------
'draw figure 1
SELECT CASE fy11%
  CASE 1
    fdata(1)=phyval!(1)
  CASE 2
    fdata(2)=phyval!(0)/VAL(Weight$)
  CASE 3
IF phyval!(7)=0 GOTO zerovlct121
    fdata(3)=phyval!(6)/phyval!(7)
zerovlct121:
    fdata(3)=0
  CASE 4
    fdata(4)=phyval!(4)
  CASE 5
    fdata(5)=phyval!(0)
  CASE 6
    fdata(6)=phyval!(6)
  CASE 7
    fdata(7)=phyval!(7)
  CASE 8
    fdata(8)=phyval!(2)
  CASE 9
    fdata(9)=phyval!(3)
END SELECT
  xfig%=-SW%/16+(i%*VAL(interval$)/60-xstart%)*240/(xfull%-xstart%)
  y11fig%=-bc(fy11%)-fdata(fy11%)*ac(fy11%)
IF firstpoint%<>255 GOTO drawline1211
    last11%=y11fig%
    lastx1%=xfig%
drawline1211:
    LINE (lastx1%, last11%)-(xfig%,y11fig%),color1%
SELECT CASE fy12%
CASE 1
  fdata(1)=phyval!(1)
CASE 2
  fdata(2)=phyval!(0)/VAL(Weight$)
CASE 3
  IF phyval!(7)=0 GOTO zerovalct22
  fdata(3)=phyval!(6)/phyval!(7)
zerovalct22:
  fdata(3)=0
CASE 4
  fdata(4)=phyval!(4)
CASE 5
  fdata(5)=phyval!(0)
CASE 6
  fdata(6)=phyval!(6)
CASE 7
  fdata(7)=phyval!(7)
CASE 8
  fdata(8)=phyval!(2)
CASE 9
  fdata(9)=phyval!(3)
END SELECT

y12fig%=-bc(fy12%)-fdata(fy12%)*ac(fy12%)
IF firstpoint%<>255 GOTO drawline1212
  last12%=y12fig%
drawline1212:
  LINE (lastx1%, last12%)-(xfig%,y12fig%),color2%
  last11%=y11fig%
  last12%=y12fig%
  lastx1%=xfig%

'draw figure 2
SELECT CASE fy21%
  CASE 1
    fdata(1)=phyval!(1)
  CASE 2
    fdata(2)=phyval!(0)/VAL(Weight$)
  CASE 3
    IF phyval!(7)=0 GOTO zerovalct212
fdata(3)=phyval!(6)/phyval!(7)

zerovlct212:
  fdata(3)=0
  CASE 4
    fdata(4)=phyval!(4)
  CASE 5
    fdata(5)=phyval!(0)
  CASE 6
    fdata(6)=phyval!(6)
  CASE 7
    fdata(7)=phyval!(7)
  CASE 8
    fdata(8)=phyval!(2)
  CASE 9
    fdata(9)=phyval!(3)
END SELECT

xfig% = SW%*9/16+(i%*VAL(interval$)/60-xstart%)*240/(xfull%-xstart%)
y21fig% = bc(fy21%)-fdata(fy21%)*ac(fy21%)
IF firstpoint%<>255 GOTO drawline2112
  last21%=y21fig%
  lastx2% = xfig%

SELECT CASE fy22%
  CASE 1
    fdata(1)=phyval!(1)
  CASE 2
    fdata(2)=phyval!(0)/VAL(Weight$)
  CASE 3
    IF phyval!(7)=0 GOTO zerovlct232
    fdata(3)=phyval!(6)/phyval!(7)

zerovlct232:
  fdata(3)=0
  CASE 4
    fdata(4)=phyval!(4)
  CASE 5
    fdata(5)=phyval!(0)
  CASE 6
    fdata(6)=phyval!(6)
  CASE 7
fdata(7)=phyval!(7)

CASE 8
fdata(8)=phyval!(2)

CASE 9
fdata(9)=phyval!(3)

END SELECT

y22fig%=bc(fy22%)-fdata(fy22%)*ac(fy22%)

IF firstpoint%<>255 GOTO drawline2122

last22%=y22fig%

firstpoint%=0

drawline2122:

LINE (lastx2%, last22%)-(xfig%,y22fig%),color2%

last21%=y21fig%

last22%=y22fig%

lastx2%=xfig%

nextpoint12:

NEXT i%

endRedraw12:

noreDaw%=0

RETURN

'nextpoint11:

' IF i%>=xfull%+tt% GOTO nextpoint1
'

i%=xfull%

' GOTO getvalue1
'MENU HANDLING

domenu:

    menuID=MENU(0)
    menunumber=MENU(1)
    TEXTFACE 0
    n$= "Menu " + STR$(menuID) + STR$(menunumber)
    Textbox n$,r%(2),1

    MENU
    ON menuID GOSUB dosystem, domode, dofig11, dofig12, dofig21, dofig22, dodisplayselection, doscrollrate
    TIMER OFF
    RETURN

dosystem:

    ON menunumber GOSUB dosave, doprintS, doprintW, doresume, nothing, doreset, dopstop, endexperiment
    RETURN

    dosave:
    RETURN

    doprintS:
    n$= "The screen is being printed. Please change the orientation of paper."
    Textbox n$,r%(2),1
    'when the rig is running, this operation is not permitted.
    IF workstatus%<>255 THEN goon1
    n$="This operation is abort when the rig is running"
    Textbox n$,r%(2),1
    RETURN

goon1:
    TIMER STOP
    PrintScreen 0,0
    TIMER ON
    RETURN

doprintW:
    n$= "The screen is being printed. Please change the orientation of paper."
    Textbox n$,r%(2),1
IF workstatus%<>255 THEN goon2
n$="This operation is abort when the rig is running"
Textbox n$,r%(2),1
RETURN

goon2:
  TIMER STOP
  printWindow 1,3
  TIMER ON
  RETURN

do.resume:
  TIMER OFF
  GOSUB resumeScreen
  GOSUB redraw
  RETURN

'-----------------------
resumeScreen:
' Message feedback dialogue field setting
TEXTSIZE size
x1%=SW%*28.5/40
y1%=SH%*6/200
x2%=SW%*39/40
y2%=SH%*16/200
LINE (x1%-3,y1%-3)-(x2%+3,y2%+3),,b
SetRect r%(2),x1%,y1%,x2%,y2%
Textbox n$,r%(2),1

'The title of experiments
TEXTSIZE size*1.5
TEXTFONT 3
TEXTFACE 1
MOVETO (SW%-WIDTH("EXPERIMENTS OF HOT ROLLING WEAR"))/2-100,SH%*1/30
PRINT *EXPERIMENTS FOR HOT ROLLING WEAR*

MOVETO SW%*72/100-6,SH%*13/100
TEXTSIZE size*1.2
TEXTFONT 1
PRINT status$

TEXTFACE 0
TEXTSIZE size*1.5
MOVETO SW%*72/100+WIDTH(" "), SH%*13/100
trigger$=EDIT$(7)
  minutLeft%=INT(VAL(trigger$)-secondNmb&/60)
  secondLeft%=(VAL(trigger$)*60-secondNmb&) MOD 60
PRINT RIGHT$(STR$(minutLeft%+1000),3);".;
PRINT RIGHT$(STR$(secondLeft%+100),2);

TEXTSIZE size
TEXTFACE 1
TEXTFONT 1
PRINT " TIME LEFT"

TEXTFACE 0
TEXTFONT 1
x=SW%/40
y=SH%/12

MOVETO x,y
  PRINT "Experiment Series:"
  y=+y+SH%/40
MOVETO x,y
  PRINT "Experiment Date:"
  y=+y+SH%/40
MOVETO x,y
  PRINT "Temperature(C):"
  y=+y+SH%/40
MOVETO x,y
  PRINT "Material:"
  y=+y+SH%/40
MOVETO x,y
  PRINT "Rolling Speed(m/s):"
  x=SW%*10/40
MOVETO x,y
  PRINT "Pressure(MPa):"
  y=+y-SH%/40
MOVETO x,y
  PRINT "Trigger Time(min):"
  y=+y-SH%/40
MOVETO x,y
  PRINT "Interval (s):"
  y=+y-SH%/40
MOVETO x,y
PRINT "Redraw Step(pts):"
y=y-SH%/40
MOVETO x,y
PRINT "Weight (N):"
LINE (SW%/40-5,SH%/12-size-8)-(x1+5.5*size, SH%/12+SH%/10+5),,b

TEXTFACE 1
x=SW%*10/20
y=SH%*15/100
MOVETO x,y
PRINT "Horizontal Scale"
y=SH%*8/100
MOVETO x,y
PRINT "Horizontal Scroll"

TEXTFACE 0
TEXTFONT 1
TEXTSIZE size
RETURN

'-----------------
nothing:
RETURN

doreset:
IF workstatus%<>255 THEN goon3
n$="This operation is abort when the rig is running"
Textbox n$,r%(2),1
RETURN
goon3:
GOTO ProgramStart
RETURN
dopstop:
buttonpushed%=3
GOSUB DoControlbutton
RETURN

'-------------------
domode:
ON menunumber GOSUB doexperiment, dosimulation, doboardTest, dopreAdjustment, docalibration
RETURN

doeperiment:
  IF workstatus%<>255 THEN goon4
  n$="This operation is abort when the rig is running"
  Textbox n$,r%(2),1
  BEEP
  RETURN
  goon4:
    MENU 2,1,2
    MENU 2,2,1
    MENU 2,3,1
    MENU 2,4,1
    MENU 2,5,1
  simu%=0
  RETURN

dosimulation:
  IF workstatus%<>255 THEN goon5
  n$="This operation is abort when the rig is running"
  Textbox n$,r%(2),1
  BEEP
  RETURN
  goon5:
    MENU 2,1,1
    MENU 2,2,2
    MENU 2,3,1
    MENU 2,4,1
    MENU 2,5,1
  simu%=255
  RETURN

doboardTest:
  IF workstatus%<>255 THEN goon6
  n$="This operation is abort when the rig is running"
  Textbox n$,r%(2),1
  BEEP
  RETURN
  goon6:
    MENU 2,1,1
dopreAdjustment:
  IF workstatus%<>255 THEN goon7
  n$="This operation is abort when the rig is running"
    Textbox n$,r%(2),1
  BEEP
  RETURN

goon7:
  MENU 2,1,1
  MENU 2,2,1
  MENU 2,3,1
  MENU 2,4,2
  MENU 2,5,1
  adjustment
  GOSUB menusetting

'resume screen
  GOSUB resumeScreen
  MENU ON
  ON MENU GOSUB domenu
  RETURN

docalibration:
  IF workstatus%<>255 THEN goon8
  n$="This operation is abort when the rig is running"
    Textbox n$,r%(2),1
  BEEP
  RETURN

goon8:
  MENU 2,1,1
  MENU 2,2,1
MENU 2,3,1
MENU 2,4,1
MENU 2,5,2
calibration (simu%)
GOSUB menusetting
'resume screen
GOSUB resumeScreen
' GOSUB redraw
MENU ON
ON MENU GOSUB domenu
RETURN

dofig11:
FOR i%=1 TO 9
    MENU 3,i%,1
NEXT i%
firstpoint%=255
ON menunumber GOSUB f11,f12,f13,f14,f15,f16,f17,f18,f19,
    MENU 3,fy11%,2
GOSUB redraw
RETURN

'y11 definition
f11:
fy11%=1
y11title$="change of diameter"
y11unit$="(um)"
RETURN

f12:
fy11%=2
y11title$="friction coefficient"
y11unit$=""
RETURN

f13:
fy11%=3
y11title$="sliding/rolling ratio"
y11unit$="" RETURN

f14:
fy11%=4
y11title$="AE RMS"
y11unit$="mV"
RETURN

f15:
fy11%=5
y11title$="friction force"
y11unit$="N"
RETURN

f16:
fy11%=6
y11title$="velocity of spindle"
y11unit$="m/s"
RETURN

f17:
fy11%=7
y11title$="velocity of roller"
y11unit$="m/s"
RETURN

f18:
fy11%=8
y11title$="velocity of vibration"
y11unit$="m/s"
RETURN

f19:
fy11%=9
y11title$="acceleration of vibration"
y11unit$="m/s/s"
RETURN

'----------------------------------------
dofig12:
FOR i%=1 TO 9
    MENU 4,i%,1
NEXT i%
firstpoint%=255
    ON menunumber GOSUB f111,f112,f113,f114,f115,f116,f117,f118,f119
    MENU 4,fy12%,2
    GOSUB redraw
    RETURN
'y12 definition
f111:
    fy12%=1
    y12title$="change of diameter"
    y12unit$="(um)"
    RETURN
f112:
    fy12%=2
    y12title$="friction coefficient"
    y12unit$=""
    RETURN
f113:
    fy12%=3
    y12title$="sliding/rolling ratio"
    y12unit$=""
    RETURN
f114:
    fy12%=4
    y12title$="AE RMS"
    y12unit$="mV"
    RETURN
f115:
    fy12%=5
    y12title$="friction force"
    y12unit$="N"
    RETURN
f116:
fy12%=6
y12title$="velocity of spindle"
y12unit$="m/s"
RETURN

f117:
fy12%=7
y12title$="velocity of roller"
y12unit$="m/s"
RETURN

f118:
fy12%=8
y12title$="velocity of vibration"
y12unit$="m/s"
RETURN

f119:
fy12%=9
y12title$="acceleration of vibration"
y12unit$="m/s/s"
RETURN

'-----------------------------------------------
dofig21:
FOR i%=1 TO 9
    MENU 5,i%,1
NEXT i%
firstpoint%=255
    ON menunumber GOSUB f21,f22,f23,f24,f25,f26,f27,f28,f29
    MENU 5,fy21%,2
GOSUB redraw
RETURN

'y21 definition
f21:
fy21%=1
y21title$="change of diameter"
y21unit$="(um)"
RETURN
f22:
fy21% = 2
y21title$ = "friction coefficient"
y21unit$ = ""
RETURN

f23:
fy21% = 3
y21title$ = "sliding/rolling ratio"
y21unit$ = ""
RETURN

f24:
fy21% = 4
y21title$ = "AE RMS"
y21unit$ = "mV"
RETURN

f25:
fy21% = 5
y21title$ = "friction force"
y21unit$ = "N"
RETURN

f26:
fy21% = 6
y21title$ = "velocity of spindle"
y21unit$ = "m/s"
RETURN

f27:
fy21% = 7
y21title$ = "velocity of roller"
y21unit$ = "m/s"
RETURN

f28:
fy21% = 8
y21title$ = "velocity of vibration"
y21unit$ = "m/s"
RETURN
Appendices

f29:
fy21%=9
y21title$="acceleration of vibration"
y21unit$="m/s/s"
RETURN

 dofig22:
 FOR i%=1 TO 9
 MENU 6,i%,1
 NEXT i%
 firstpoint%=255
 ON menunumber GOSUB f211,f212,f213,f214,f215,f216,f217,f218,f219
 MENU 6,fy22%,2
 GOSUB redraw
 RETURN

'y22 definition
f211:
fy22%=1
y22title$="change of diameter"
y22unit$="(um)"
RETURN

f212:
fy22%=2
y22title$="friction coefficient"
y22unit$=""
RETURN

f213:
fy22%=3
y22title$="sliding/rolling ratio"
y22unit$=""
RETURN

f214:
fy22%=4
y22title$="AE RMS"
y22unit$="mV"
RETURN

f215:
y22%=5
y22title$="friction force"
y22unit$="N"
RETURN

f216:
y22%=6
y22title$="velocity of spindle"
y22unit$="m/s"
RETURN

f217:
y22%=7
y22title$="velocity of roller"
y22unit$="m/s"
RETURN

f218:
y22%=8
y22title$="velocity of vibration"
y22unit$="m/s"
RETURN

f219:
y22%=9
y22title$="acceleration of vibration"
y22unit$="m/s/s"
RETURN

'----------------------------------------

dodisplayselection:
firstpoint%=255

ON menunumber GOSUB firstfig, secondfig, bothfig, original, nothing, sleft, sright, ssmall, sbig
RETURN

'----------------------------------------
firstfig:

MENU 7,1,2
MENU 7,2,1
MENU 7,3,1
MENU 7,4,1
fg0%=0
fg1%=255
fg2%=0
windowwifact=1
GOSUB redraw
RETURN

secondfig:

MENU 7,1,1
MENU 7,2,2
MENU 7,3,1
MENU 7,4,1
fg0%=0
fg1%=0
fg2%=255
windowwifact=1
GOSUB redraw
RETURN

bothfig:

MENU 7,1,1
MENU 7,2,1
MENU 7,3,2
MENU 7,4,1
fg0%=0
fg1%=255
fg2%=255
windowwifact=.5
GOSUB redraw
RETURN

original:

MENU 7,1,1
GOSUB redraw
RETURN

sleft:
    GOSUB scrollLeft
    RETURN

sright:
    GOSUB scrollRight
    RETURN

sbig:
    GOSUB scallncrs
    RETURN

ssmall:
    GOSUB scalDcrs
    RETURN

doscrollrate:
FOR i%=1 TO 7
    MENU 8,i%,1
NEXT i%

ON menunumber GOSUB scr16, scr14, scr13, scr12, scr23, scr56, scr1
MENU 8,scr%,2
RETURN

scr16:
    scrollfract=6
    scr%=1
    RETURN

scr14:
    scr%=2
    scrollfract=4
RETURN

scr13:
  scr%=3
  scrollfrac=3
RETURN

scr12:
  scr%=4
  scrollfrac=2
RETURN

scr23:
  scr%=5
  scrollfrac=1.5
RETURN

scr56:
  scr%=6
  scrollfrac=1.2
RETURN

scr1:
  scr%=7
  scrollfrac=1
RETURN
CONTROL BUTTONS HANDLING

only modify setup and status, do not execute screen display and data file operation, but execute rapid control output

DoControlbutton:

TEXTFONT 1
TEXTFACE 0

IF fg0%<>255 GOTO noonoffbutton
    IF buttonpushed%=11 GOTO motoron1
    IF buttonpushed%=12 GOTO motoroff1
    IF buttonpushed%=13 GOTO heaton1
    IF buttonpushed%=14 GOTO heatoff1
GOTO noonoffbutton

motoron1:
    BUTTON 11,2
    BUTTON 12,1
    CALL setDoutbit(7,0,slot%,VARPTR(er%))
RETURN

motoroff1:
    BUTTON 11,1
    BUTTON 12,2
    CALL setDoutbit(7,1,slot%,VARPTR(er%))
RETURN

heaton1:
    BUTTON 13,2
    BUTTON 14,1
    CALL setDoutbit(6,0,slot%,VARPTR(er%))
RETURN

heatoff1:
    BUTTON 13,1
    BUTTON 14,2
    CALL setDoutbit(6,1,slot%,VARPTR(er%))
RETURN

noonoffbutton:
    IF stopstatus% <>255 THEN PauseOrWorking
'stop status
IF buttonpushed%<>1 THEN continuebtn
'start button
n$= "START is pushed"
Textbox n$,r%(2),1

IF secondNmb&>0 THEN nonew 'if a new test has started
startworking:
'series number has been +1 at the beginning of the software or at the begining
'of the time interrupt routine
noreDaw%=0 'redrawing enable
timebase&=TIMER
'open new file
series$=EDIT$(1)
interval$=EDIT$(8)
IF simu%=255 GOTO skiphere
OPEN series$ FOR OUTPUT AS #2
CLOSE #2
skiphere:
IF Chnmb%=2 GOTO ch2file
OPEN series$ AS #2 LEN=32
fileopen%=255
FIELD #2, 4 AS dat0$,4 AS dat1$,4 AS dat2$,4 AS dat3$,4 AS dat4$,4 AS dat5$,4 AS dat6$, 4 AS dat7$
GOTO endopen
ch2file:
OPEN series$ AS #2 LEN=16
fileopen%=255
FIELD #2, 4 AS dat0$,4 AS dat1$,4 AS dat6$,4 AS dat6$,4 AS dat7$
endopen:
'output control signal and change the output buffer
CALL setDoutbit(6,0,slot%,VARPTR(er%))
CALL setDoutbit(7,0,slot%,VARPTR(er%))
motoron%=255
heaton%=255
workstatus%=255
stopstatus%=0
pausestatus%=0
firstpoint%=255
midnight%=0
CALL Fqsetup(1,3, 10000,slot%,VARPTR(er%))
CALL Fqsetup(2,3, 10000,slot%,VARPTR(er%))

LINE (0, SH%/5+2)-(SW%,SH%),30,bf
drawstep%=VAL(EDIT$(9))
GOSUB redraw
GOTO endbutton

GOSUB horizontaiscale
IF fg1%<>0 GOTO ccconline
  windowwifract=1 'the second figure
GOSUB windownet3full
GOTO drawendonline

ccconline:
  IF fg2%<>0 GOTO ccc1online
    windowwifract=1 'the first figure
GOSUB windownet2
GOTO drawendonline

ccc1online:
  windowwifract=.5 'both figures
GOSUB windownet2
GOSUB windownet3

drawendonline:
  GOTO endbutton

nonew:
  n$= "START for a new test"+CHR$(13)
  n$=n$+"CONT. to continue the test"
  Textbox n$,r%(2),1
WHILE 1
  TIMER ON
  IF DIALOG(0)<1 THEN w1
  SELECT CASE DIALOG(1)
  CASE 1
    GOTO newtest1
  CASE 2
    GOTO continueworking
  CASE 3
    GOTO endbutton
  CASE ELSE
END SELECT
w1:
WEND

newtest1:
n$= "START for an increased series"+CHR$(13)
n$=n$+"P/STOP to enter a new series"
Textbox n$,r%(2),1
WHILE 1
  TIMER ON
  IF DIALOG(0)<>1 THEN newtest2
  SELECT CASE DIALOG(1)
  CASE 1
    series$=RIGHT$(STR$(VAL(EDIT$(1))+100001&),5) 'series number +1
    x=SW%/40+WIDTH("Experiment Series: ")
    y=SH%/12
    EDIT FIELD 1,series$,x,y-size-1)-(x+5*size, y),2
    secondNmb&=0
    GOTO startworking
  CASE 2
    GOTO newtest2
  CASE 3
    n$="P/STOP is pushed."
   Textbox n$,r%(2),1
   secondNmb2&=secondNmb&
   secondNmb&=0
   workstatus%=0
   stopstatus%=255
   pausestatus%=0
   GOTO endbutton
  CASE ELSE
    END SELECT
newtest2:
WEND

continuebtn:
  IF buttonpushed%<>2 THEN endbutton
  'CONT. pushed
continuebtn2:
  IF secondNmb&=0 THEN newtest9
  'if a new test has started
continueworking:
timebase$=TIMER

'open this file
IF fileopen%=255 THEN fileopened
IF Chnmb%=2 GOTO ch2file1
OPEN series$ AS #2 LEN=32
fileopen%=255
  FIELD #2, 4 AS dat0$,4 AS dat1$,4 AS dat2$,4 AS dat3$,4 AS dat4$,4 AS dat5$, 4 AS dat6$, 4 AS dat7$
GOTO fileopened
ch2file1:
OPEN series$ AS #2 LEN=16
fileopen%=255
  FIELD #2, 4 AS dat0$,4 AS dat1$,4 AS dat6$,4 AS dat7$
fileopened:

'output control signal and change the output buffer
CALL setDoutbit(6,0,slot%,VARPTR(er%))
CALL setDoutbit(7,0,slot%,VARPTR(er%))
IF fgO%=0 GOTO chgbtn2
BUTTON 11,2
BUTTON 12,1
BUTTON 13,2
BUTTON 14,1
chgbtn2:
motoron%=255
heaton%=255
  workstatus%=255
stopstatus%=0
pausestatus%=0
midnight%=0
GOTO endbutton

newtest9:
  n$= "START for a new test"+CHR$(13)
  n$=n$+"CONT. to continue the test"
 Textbox n$,r%(2),1
WHILE 1
  TIMER ON
  IF DIALOG(0)<>1 THEN w3
  SELECT CASE DIALOG(1)
  CASE 1
GOTO newtest91
CASE 2
secondNmb&=secondNmb2&  ' second counter number
GOTO continueworking
CASE 3
GOTO endbutton
CASE ELSE
END SELECT
w3:
WEND

newtest91:
n$= "CONT. for a decreased series"+CHR$(13)
n$=n$+"P/STOP to enter a new series"
Textbox n$,r%(2),1
WHILE 1
  TIMER ON
  IF DIALOG(0)<>1 THEN newtest92
  SELECT CASE DIALOG(1)
  CASE 1
    GOTO newtest92
  CASE 2
    series$=RIGHT$(STR$(VAL(EDIT$(1))+99999&),5)  'series number -1
    x=SW%/40+WIDTH("Experiment Series: ")
y=SH%/12
    EDIT FIELD 1,series$,(x,y-size-1)-(x+5*size, y),2
    secondNmb&=0
    GOTO continueworking
  CASE 3
    n$="P/STOP is pushed."
   Textbox n$,r%(2),1
    secondNmb2&=secondNmb&
    secondNmb&=0
    workstatus%=0
    stopstatus%=255
    pausestatus%=0
    GOTO endbutton
  CASE ELSE
  END SELECT
newtest92:
WEND
PauseOrWorking:

IF workstatus% THEN working

'working status

'pause status

IF buttonpushed% = 2 THEN continuebtn2

'continue working

IF buttonpushed% = 1 THEN startpush

'P/STOP pushed

stopworking:

secondNmb2& = secondNmb&

secondNmb& = 0

n$ = "P/STOP is pushed."

Textbox n$, r%(2), 1

'close this file, append configure file to data file

CLOSE #2

fileopen% = 0

'output control signal and change the output buffer

CALL setDoutbit(6,1, slot%, VARPTR(er%))

CALL setDoutbit(7,1, slot%, VARPTR(er%))

IF fgO% = 0 GOTO chgbtn3

BUTTON 11,1

BUTTON 12,2

BUTTON 13,1

BUTTON 14,2

chgbtn3:

motoron% = 0

heaton% = 0

CALL Fqsetup(1,3, 10000, slot%, VARPTR(er%))

CALL Fqsetup(2,3, 10000, slot%, VARPTR(er%))

workstatus% = 0

stopstatus% = 255

pausestatus% = 0

GOTO endbutton

startpush:

' BEEP

'go on working

GOTO nonew
working:
IF buttonpushed%<=3 THEN invalidop  'START or CONT. pushed
pauseworking:
output control signal and change the output buffer
close this file, append configure file to data file
CLOSE #2
fileopen%=0
CALL setDoutbit(6,0,slo%,VARPTR(er%))
CALL setDoutbit(7,1,slo%,VARPTR(er%))
IF fg0%=0 GOTO chgbtn4
BUTTON 11,1
BUTTON 12,2
BUTTON 13,2
BUTTON 14,1
chgbtn4:
motoron%=0
heaton%=255
n$="P/STOP is pushed."
Textbox n$,r%(2),1
workstatus%=0
stopstatus%=0
pausestatus%=255
GOTO endbutton
invalidop:
n$="invalid operation"
Textbox n$,r%(2),1
endbutton:
IF workstatus%=255 THEN status$=" WORK "
IF stopstatus%=255 THEN status$=" STOP "
IF pausestatus%=255 THEN status$="PAUSE "
MOVETO SW%*72/100-6,SH%*13/100
MENU OFF
DIALOG OFF
TEXTSIZE size*1.2
TEXTFACE 1
TEXTFONT 1
PRINT status$
TEXTSIZE size
TEXTFACE 0
MENU ON
DIALOG ON
RETURN
DISPLAY BUTTONS HANDLING

'only modify setup and status, do not execute screen display and data file operation, but execute rapid control output

DoDisplaybutton:
SELECT CASE buttonpushed%
CASE 4
    GOSUB scalDcrs
CASE 5
    GOSUB scalincrs
CASE 6
    GOSUB scrollLeft
CASE 7
    GOSUB scrollRight
CASE ELSE
END SELECT
RETURN

'SCALE DECREASE is pushed

scalDcrs:

xfull%=xfull%−60
IF xfull%−xstart%>240 THEN xfull%=xfull%−60 :GOTO scal
IF xfull%−xstart%<60 THEN
    IF xfull%−xstart%=0 THEN
        xfull%=xfull%+30
    ELSEIF xfull%−xstart%>-50 THEN
        xfull%=xfull%+50
    ELSE
        BEEP
        xfull%=xfull%+60
    END IF
ELSE
    END IF
RETURN
END IF
ELSE
END IF

scal:

n$= "Decreasing horizontal scale to"+STR$((xfull%−xstart%)/60)+"hour(s)"
Textbox n$,r%(2),1
GOSUB redraw
RETURN

'SCALE INCREASE is pushed
-

scalincrs:

    xfull%=xfull%+60
    IF xfull%+xstart%>240 THEN xfull%=xfull%+60
    IF xfull%-xstart%<120 THEN xfull%=xfull%-30
    IF xfull%-xstart%<60 THEN xfull%=xfull%-20
    n$= "Increasing horizontal scale"+STR$((xfull%-xstart%)/60)+"hour(s)"
   Textbox n$,r%(2),1
GOSUB redraw
RETURN

'SCROLL LEFT is pushed
-

scrollLeft:
    'scroll a fracture of current display
    xxx%=(xfull%-xstart%)/scrollfract
    xfull%=xfull%+xxx%
    xstart%=xstart%+xxx%
    n$= "Left scrolling"
   Textbox n$,r%(2),1
GOSUB redraw
RETURN

'SCROLL RIGHT is pushed
-

scrollRight:

    xxx%=(xfull%-xstart%)/scrollfract
    xfull%=xfull%-xxx%
    xstart%=xstart%-xxx%
    IF xstart%>=0 THEN endofscroll
    xfull%=xfull%-xstart%
    xstart%=0
    BEEP

endofscroll:
    n$= "Right scrolling"
   Textbox n$,r%(2),1
GOSUB redraw
RETURN
endexperiment:

IF simu%=255 THEN endexp

series$=EDIT$(1)
temperature$=EDIT$(3)
material$=EDIT$(4)
rollingspeed$=EDIT$(5)
pressure$=EDIT$(6)
trigger$=EDIT$(7)
interval$=EDIT$(8)
redrawStep$=EDIT$(9)
Weight$=EDIT$(10)

'Save the configure

OPEN "hotwear.config" FOR OUTPUT AS #1
WRITE #1,series$,temperature$,material$,rollingspeed$,pressure$,trigger$
WRITE #1,interval$,redrawStep$,Weight$
WRITE #1,ss,v3,v4,v5,v6,v7,v8
WRITE #1,xstart%,xfull%
WRITE #1,w1,w2,w3,w4,secondNmb2&
WRITE #1,secondNmb&
CLOSE #1

CLOSE #2 'close data file
endexp:

END
Appendices

---

' MENU SETTING

---

menusetting:

    LINE (0, SH%/5+2)-(SW%,SH%),30,bf  'clear window

MENU  1,0,1,"System"
MENU  1,1,1,"save"
MENU  1,2,1,"print screen"
MENU  1,3,1,"print window"
MENU  1,4,1,"Resume screen"
        cmdkey 1,4,"R"
MENU  1,5,0,"-
MENU  1,6,1,"reset"
MENU  1,7,1,"Pause/stop"
        cmdkey 1,7,"P"
MENU  1,8,1,"Quit"
        cmdkey 1,8,"Q"

MENU  2,0,1,"Mode"
MENU  2,1,2,"Experiment"
MENU  2,2,1,"simulation"
IF simu%=0 GOTO epmt

    MENU  2,1,1,"Experiment"  'simulating situation
    MENU  2,2,2,"simulation"

epmt:

MENU  2,3,1,"MacAdiosll diagnosis"
MENU  2,4,1,"pre-adjustment"
MENU  2,5,1,"calibration"

MENU  3,0,1,"Fig.11"
MENU  3,1,2,"change of diameter"
MENU  3,2,1,"friction coefficient"
MENU  3,3,1,"sliding/rolling ratio"
MENU  3,4,1,"AE RMS"
MENU  3,5,1,"friction force"
MENU  3,6,1,"velocity of spindle"
MENU  3,7,1,"velocity of roller"
MENU  3,8,1,"velocity of vibration"
MENU  3,9,1,"acceleration of vibration"
Appendices

MENU 4,0,1,"Fig.12"
MENU 4,1,1,"change of diameter"
MENU 4,2,2,"friction coefficient"
MENU 4,3,1,"sliding/rolling ratio"
MENU 4,4,1,"AE RMS"
MENU 4,5,1,"friction force"
MENU 4,6,1,"velocity of spindle"
MENU 4,7,1,"velocity of roller"
MENU 4,8,1,"velocity of vibration"
MENU 4,9,1,"acceleration of vibration"

MENU 5,0,1,"Fig.21"
MENU 5,1,1,"change of diameter"
MENU 5,2,1,"friction coefficient"
MENU 5,3,2,"sliding/rolling ratio"
MENU 5,4,1,"AE RMS"
MENU 5,5,1,"friction force"
MENU 5,6,1,"velocity of spindle"
MENU 5,7,1,"velocity of roller"
MENU 5,8,1,"velocity of vibration"
MENU 5,9,1,"acceleration of vibration"

MENU 6,0,1,"Fig.22"
MENU 6,1,1,"change of diameter"
MENU 6,2,1,"friction coefficient"
MENU 6,3,1,"sliding/rolling ratio"
MENU 6,4,2,"AE RMS"
MENU 6,5,1,"friction force"
MENU 6,6,1,"velocity of spindle"
MENU 6,7,1,"velocity of roller"
MENU 6,8,1,"velocity of vibration"
MENU 6,9,1,"acceleration of vibration"

MENU 7,0,1,"Display"
MENU 7,1,2,"first figure only"
   cmdkey 7,1,"1"
MENU 7,2,1,"second figure only"
   cmdkey 7,2,"2"
MENU 7,3,1,"both figures"
   cmdkey 7,3,"3"
MENU 7,4,1,"original data"
Appendices

```
cmdkey 7,4,"4"
MENU 7,5,0, "*
MENU 7,6,1,"scroll left"
cmdkey 7,6, [*
MENU 7,7,1,"scroll right"
cmdkey 7,7, "]*
MENU 7,8,1,"decrease scale"
cmdkey 7,8, ";"
MENU 7,9,1,"increase scale"
cmdkey 7,9, ":"

MENU 8,0,1,"Scroll rate"
MENU 8,1,1,"1/6"
MENU 8,2,1,"1/4"
MENU 8,3,1,"1/3"
MENU 8,4,2,"1/2"
MENU 8,5,1,"2/3"
MENU 8,6,1,"5/6"
MENU 8,7,1,"1"

scr%=4
scrollfract=2
' get the last scroll rate, set
RETURN
```
INITIALISATION OF THE HARDWARE

initialization:

value% = 999
er% = -1

'DO protective value
outputvalue% = 255
CALL cwrite(147, 80, outputvalue%, slot%, VARPTR(er%))

'AD gain setup
CALL SetAD(0, 1, slot%, VARPTR(er%)) 'ch0
CALL SetAD(1, 1, slot%, VARPTR(er%)) 'ch1
CALL SetAD(2, 1, slot%, VARPTR(er%)) 'ch2
CALL SetAD(3, 1, slot%, VARPTR(er%)) 'ch3
CALL SetAD(4, 1, slot%, VARPTR(er%)) 'ch4
CALL SetAD(5, 1, slot%, VARPTR(er%)) 'ch5
CALL SetAD(6, 1, slot%, VARPTR(er%)) 'ch6
CALL SetAD(7, 1, slot%, VARPTR(er%)) 'ch7

'start frequency measuring
'it will cost about 10 seconds to get the accurate value of the two channels
CALL Fqsetup(1, 3, 10000, slot%, VARPTR(er%))
CALL Fqsetup(2, 3, 10000, slot%, VARPTR(er%))

RETURN
ERROR HANDLING

errorhandle:
SELECT CASE ERL
CASE 10
  GOTO Getdefault  'configure file can not found
CASE 55
  GOTO fileopen  'reentre the file of No.2
CASE 9
  GOTO Subscript  'subscript out of range
CASE ELSE
  TEXTFONT 3
  TEXTSIZE 10
  TEXTFACE 0
  n$= "Unknown ERROR:"+STR$(ERR)+"  ERROR LINE: "+STR$(ERL)
  Textbox n$,r%(2),1
  STOP
END SELECT

'  goto trouble

Fulldisk:
  STOP

fileopen:
  RESUME NEXT

Subscript:
  STOP

'  get system default values if the configure file can not be found

Getdefault:
  timeleft=0
  series$="00001"
  temperature$="800"
  material$="mild steel"
  rollingspeed$="2.0"
  pressure$="100"
trigger$=*120*
interval$=*120*
x2start=0
x2full=60
 y21start=0
 y21full=40
 y22start=0
 y22full=20
x3start=0
x3full=60
 y31start=0
 y31full=.02
 y32start=0
 y32full=.4

RESUME windowscreen
WATCHDOG

' Stop all equipment
' Write file
BEEP
BEEP
n$ = "WatchDog works! There must be some trouble!"
Textbox n$, r%(2), 1
END
SCREEN DISPLAY MOOD

't= Figure 1 display module for half and full displays

windoww1t2:
TEXTFACE 0
ww2=SW%*windowwifract
wh2=SH%*3/4
FOR i=1 TO 7
   LINE (ww2/8+ww2/8*(i-1), wh2/8+SH%/5)-(ww2/8+ww2/8*(i-1), wh2*(1-1/8)+SH%/5)
   LINE (ww2/8, wh2/8+wh2/8*(i-1)+SH%/5)-(ww2*(1-1/8), wh2/8+wh2/8*(i-1)+SH%/5)
NEXT i

horititle$="Time (min) ", MOVETO (ww2-WIDTH (horititle$))/2, wh2*(1-1/30)+SH%/5
PRINT horititle$

y11title2$=y11unit$+" (yellow)"
MOVETO 10,wh2/10+SH%/5-13
PRINT y11title$
MOVETO 10,wh2/10+SH%/5
PRINT y11title2$

y12title2$=y12unit$+" (blue)"
MOVETO WW2-WIDTH (y12title$)-15,wh2/10+SH%/5-13
PRINT y12title$
MOVETO WW2-WIDTH (y12title2$)-15,wh2/10+SH%/5
PRINT y12title2$

'vertical scale
ymid=(yfull(fy11%) - ystart(fy11%))/2
MOVETO ww2*1/8-WIDTH(STR$(ystart(fy11%)))-20,wh2*7/8+SH%/5+5
PRINT ystart(fy11%)
MOVETO ww2*1/8-WIDTH(STR$(ymid))-20,wh2*4/8+SH%/5+5
PRINT ymid
MOVETO ww2*1/8-WIDTH(STR$(yfull((fy11%)))-20,wh2*1/8+SH%/5+5
PRINT yfull(fy11%)

ymid=(yfull(fy12%) - ystart(fy12%))/2
MOVETO ww2*7/8+10,wh2*7/8+SH%/5+5
PRINT ystart(fy12%)
MOVETO  ww2*7/8+10,wh2*4/8+SH%/5+5
PRINT ymid
MOVETO  ww2*7/8+10,wh2*1/8+SH%/5+5
PRINT yfull(fy12%)
RETURN

'Figure 2 display module for full display
'-------------------------------------------------------------
windowet3full:
TEXTFACE 0
ww2=SW%*windowwifract
wh2=SH%*3/4
FOR i=1 TO 7
  LINE (ww2/8+ww2/8*(i-1), wh2/8+SH%/5)-(ww2/8+ww2/8*(i-1), wh2*(1-1/8)+SH%/5)
  LINE (ww2/8, wh2/8+wh2/8*(i-1)+SH%/5)-(ww2*7/8, wh2/8+wh2/8*(i-1)+SH%/5)
NEXT i
horititle$="Time (min)"
MOVETO (ww2-WIDTH (horititle$))/2, wh2*(1-1/30)+SH%/5
PRINT horititle$

y21title2$=y21unit$+" (yellow)"
MOVETO 10,wh2/10+SH%/5-13
PRINT y21title$
MOVETO 10,wh2/10+SH%/5
PRINT y21title2$
y22title2$=y22unit$+" (blue)"
MOVETO WW2-WIDTH (y22title$)-15,wh2/10+SH%/5-13
PRINT y22title$
MOVETO WW2-WIDTH (y22title2$)-15,wh2/10+SH%/5
PRINT y22title2$

'vertical scale
ymid=(yfull(fy21%)-ystart(fy21%))/2
MOVETO  ww2*1/8-WIDTH(STR$(ystart(fy21%)))-20,wh2*7/8+SH%/5+5
PRINT ystart(fy21%)
MOVETO  ww2*1/8-WIDTH(STR$(ymid)))-20,wh2*4/8+SH%/5+5
PRINT ymid
MOVETO  ww2*1/8-WIDTH(STR$(yfull(fy21%)))-20,wh2*1/8+SH%/5+5
PRINT yfull(fy21%)
ymid=(yfull(fy22%)-ystart(fy21%))/2
MOVETO \(ww2*7/8+10,wh2*7/8+SH\%/5+5\)
PRINT ystart(fy22%)
MOVETO \(ww2*7/8+10,wh2*4/8+SH\%/5+5\)
PRINT ymid
MOVETO \(ww2*7/8+10,wh2*1/8+SH\%/5+5\)
PRINT yfull(fy22%)
RETURN

'Figure 2 display module for half display

windownet3:
TEXTFACE 0
ww2=SW\%*windowwifract
wh2=SH\%*3/4
FOR i=1 TO 7
   LINE (ww2*9/8+ww2/8*(i-1), wh2/8+SH%/5)-(ww2*9/8+ww2/8*(i-1),
         wh2*(1-1/8)+SH%/5)
   LINE (ww2*9/8, wh2/8+wh2/8*(i-1)+SH%/5)-(ww2*15/8, wh2/8+wh2/8*(i-1)+SH%/5)
NEXT i

horititle$="Time (min)"
MOVETO (WW2-WIDTH(horititle$))/2+ww2, wh2*(1-1/30)+SH%/5
PRINT horititle$

y21title2$=y21unit$+" (yellow)"
MOVETO 10+ww2,wh2/10+SH%/5-13
PRINT y21title$
MOVETO 10+ww2,wh2/10-SH%/5-13
PRINT y21title2$
y22title2$=y22unit$+" (blue)"
MOVETO ww2+ww2-WIDTH(y22title$)-15,wh2/10+SH%/5-13
PRINT y22title$
MOVETO ww2+ww2-WIDTH(y22title2$)-15,wh2/10+SH%/5
PRINT y22title2$

'vertical scale
ymid=(yfull(fy21%)-ystart(fy21%))/2
MOVETO ww2*9/8-WIDTH(STR$(ystart(fy21%)))-20,wh2*7/8+SH%/5+5
PRINT ystart(fy21%)
MOVETO ww2*9/8-WIDTH(STR$(ymid))-20,wh2*4/8+SH%/5+5
PRINT ymid
MOVETO ww2*9/8-WIDTH(STR$(yfull(fy21%)))-20,wh2*1/8+SH%5+5
   PRINT yfull(fy21%)
ymid=(yfull(fy22%)-ystart(fy22%))/2
MOVETO ww2*15/8+10,wh2*7/8+SH%5+5
   PRINT ystart(fy22%)
MOVETO ww2*15/8+10,wh2*4/8+SH%5+5
   PRINT ymid
MOVETO ww2*15/8+10,wh2*1/8+SH%5+5
   PRINT yfull(fy22%)
RETURN

'Horizontal scale display for both half and full displays
'---------------------------------------------------------------
horizontalscale:
TEXTFACE 0
xmid%=xstart%+(xfull%-xstart%)/2
MOVETO ww2/8-WIDTH(STR$(xstart%))/2,wh2*7/8+SH%5+20
   PRINT xstart%
MOVETO ww2*4/8-WIDTH(STR$(xmid%))/2,wh2*7/8+SH%5+20
   PRINT xmid%
MOVETO ww2*7/8-WIDTH(STR$(xfull%))/2,wh2*7/8+SH%5+20
   PRINT xfull%

' The second scale, it is useless for the only one figure
MOVETO ww2*9/8-WIDTH(STR$(xstart%))/2,wh2*7/8+SH%5+20
   PRINT xstart%
MOVETO ww2*12/8-WIDTH(STR$(xmid%))/2,wh2*7/8+SH%5+20
   PRINT xmid%
MOVETO ww2*15/8-WIDTH(STR$(xfull%))/2,wh2*7/8+SH%5+20
   PRINT xfull%
RETURN
Draw a window

SUB drawwindow(id%, title$, high%, wide%, type%, fractwide!, fracthigh!) STATIC
  SELECT CASE ABS(type%)
    CASE 1
      overt%=18
      overb%=2
    CASE 2
      overt%=8
      overb%=8
    CASE ELSE
      overt%=0
      overb%=0
  END SELECT
  LEFT%=SYSTEM(5)*fractwide!
  top%=SYSTEM(6)*fracthigh!
  'top%=peekw(&HBAA)+overt%*fracthigh!+(SH%-(peekw(&HBAA)+high%+overb%))*fracthigh!
  WINDOW id%, title$, (LEFT%, top%)-(LEFT%+wide%, top%+high%), type%
END SUB
Appendices

'==============================================
'\nPrintWindow
'==============================================
' n\% = window ID number.
' type\% = window type.
' If 1<type\%<7 then the window frame and contents are printed,
' otherwise only the contents.
'
SUB printWindow(n\%,type\%) STATIC
max&=FRE(-1) 'compact memory
    max&=(4+(WINDOW(2)+21)*2*INT((WINDOW(3)+36)/16))/4+1
IF max&>32767 OR max&*4+26>FRE(0) THEN BEEP:EXIT SUB
DIM win&(max&)
saved%=WINDOW(0)
WINDOW n\%
l\%=-1
T\%=-1
b\%=WINDOW(3)+1
r\%=WINDOW(2)+1
SELECT CASE type\%
CASE 1,7
    T\%=T\%-18
    r\%=r\%+15
CASE 2
    T\%=T\%-7
    l\%=-8
    b\%=b\%+6
    r\%=r\%+6
CASE 3
    b\%=b\%+1
    r\%=r\%-1
CASE 4
    b\%=b\%+1
    r\%=r\%+1
CASE 5
    T\%=T\%-18
CASE 6
    T\%=T\%-18
    b\%=b\%-1
    r\%=r\%-1

CASE ELSE
    T%=0
    l%=0
    b%=WINDOW(3)-1
    r%=WINDOW(2)-1
END SELECT
    GET (l%,T%)-(r%,b%),win&
    max&=FRE(-1)  'compact memory
    OPEN "lpt1:prompt" FOR OUTPUT AS #10
    WINDOW OUTPUT #10
    PUT (0,0),win&
    CLOSE #10
    ERASE win&
    WINDOW saved%
END SUB
' If x% and y% are nonzero, then the output is scaled to x% wide and y% high.

SUB PrintScreen(x%, y%) STATIC
    max& = FRE(-1) ' compact memory
    ' calculate array size
    max& = (4 + (479 + 1) * 2 * INT((639 + 16) / 16)) / 4 + 1
    ' If not enough memory, then beep and exit
    IF max& > 32767 OR max& * 4 + 26 > FRE(0) THEN BEEP : EXIT SUB

    DIM pt%(1), screen&(max&)
    LocalToGlobal pt%(0) ' Find screen origin relative to window (0,0)
    GET (-pt%(1), -pt%(0)) - (639 - pt%(1), 479 - pt%(0)), screen &
    max& = FRE(-1) ' compact memory
    OPEN "ipt1:.prompt" FOR OUTPUT AS #10
    WINDOW OUTPUT #10
    IF x% <> 0 AND y% <> 0 THEN PUT (0, 0) - (x%, y%), screen & ELSE PUT (0, 0), screen &
    CLOSE #10
    ERASE pt%, screen &
END SUB
Appendices

'=====================================================================
'(= Hardware test subroutines
'=====================================================================

SUB hardwaretest STATIC

MENU 1,0,1,"System"
MENU 1,1,1,"Print screen"
MENU 1,2,1,"print window"
'MENU 1,3,0,"-"
'MENU 1,4,1,"Quit"
'
        cmkey,1,4,"Q"

FOR i%=2 TO 8
    MENU i%,0,0,""
NEXT i%

MENU ON

ON MENU GOSUB domenuTest

SW%=640
SH%=480
h%=345
w%=500
WINDOW 9,,((SW%-w%)/2,(SH%+h%)-10)-((SW%-w%)/2+w%,(SH%+h%)-10+h%),2
title$="MacAdios II Diagnosis"
TEXTFONT 0
TEXTSIZE 16
MOVETO 30,20 'center title$
PRINT title$
TEXTFONT 3

SetRect r%(3),10,30,w%-5,h%-15
m$=CHR$(13)+CHR$(13)+"This section checks all the functions of the MacAdios board and"
+CHR$(13)
m$=m$+"TurboDrivers which the measuring and controlling system will use."
+CHR$(13)
+CHR$(13)

m$=m$+"Some hardware setting and preparation will be required. "
m$=m$+CHR$(13)

p$="Do you want to go on the check?"

Textbox m$,,r%(3),1
TEXTFACE 1
LOCATE 14,6
PRINT "ARE YOU SURE YOU HAVE DISCONNECTED THE WEAR TEST RIG?"
LOCATE 16,4
PRINT "OR THE FOLLOWING CHECK PROGRAM WILL CAUSE SOME DAMAGE!"
TEXTFACE 0

DIALOG OFF
WINDOW 9
BUTTON 1,1,"YES", (180,310)-(230,330),1
BUTTON 2,1,"NO", (280,310)-(330,330),1
d%=DIALOG(0)
WHILE d%<>1 AND d%<>6
d%=DIALOG(0)
WEND
IF DIALOG(1)<>1 GOTO endhardTest
BUTTON CLOSE 0

'start check

MENU ON
'check what kind of board is installed in the computer
'-------------------------------------------------------------
Slotprompt:
n$=CHR$(13)+"WHAT KIND OF BOARD?"+CHR$(13)+CHR$(13)
n$=n$+"This section checks what kind of MacAdios II board is installed."+CHR$(13)+CHR$(13)
n$=n$+"Please enter slot number where the board is installed."+CHR$(13)
n$=n$+"The slot number should between 0 and 6."+CHR$(13)+CHR$(13)

slotnumber1:
Textbox n$,r%(3),1

slotnumber:
LOCATE 14, 20
  INPUT "Slot number: ", slot%
  IF slot%<0 OR slot%>6 THEN slotnumber1

value% = 999
er% = -1
CALL cread (0,21,VARPTR(value%),slot%,er&+2*ErrorIndx)

IF value%=0 THEN
    m$=n$+"Cread() return ed an error code"+STR$(value%)+CHR$(13)
    m$=m$+"while sensing what kind of MacAdios ll board is installed"+CHR$(13)+CHR$(13)
    TextBox m$,r%(3),1
    GOTO slotnumber
ELSEIF value%=2 OR value%=18 THEN
    m$=n$+"Cread() sensed a MacAdios ll/16 board is installed."+CHR$(13)+CHR$(13)
ELSEIF value%=0 OR value%=16 THEN
    m$=n$+"Cread() sensed a MacAdios ll or MacAdios/SE board is installed."+CHR$(13)+CHR$(13)
ELSEIF value%=1 OR value%=17 THEN
    m$=n$+"Cread() sensed a MacAdios ll/Jr board is installed."+CHR$(13)+CHR$(13)
ELSE
    m$=n$+"The board in the slot specified is not a MacAdios ll board or not any board in this slot. Please check carefully."+CHR$(13)+CHR$(13)
    TextBox m$,r%(3),1
    BEEP:BEEP
    GOTO slotnumber
ENDIF

m$=m$+p$
    TextBox m$,r%(3),1

BUTTON 1,1,"YES", (130,310)-(230,330),1
BUTTON 2,1,"NO", (280,310)-(380,330),1
d%=$DIALOG(0)
WHILE d%<>1 AND d%<>6
d%=$DIALOG(0)
WEND
IF DIALOG(1)<1 GOTO endhardTest
BUTTON CLOSE 0

'AD and DA check
Adda:
m$="A/D AND D/A CHECK"+CHR$(13)+CHR$(13)

m$=m$+"Cread(), Cwrite() and SetAD will also be checked."
m$=m$+"D/A 12 bit-->A/D 12 bit"+CHR$(13)
m$=m$+"Setting to bi-polar analog and differential input for A/D."+CHR$(13)
Appendices

\[
\begin{align*}
\text{DA0} & \rightarrow \text{AD0}, \text{AD1}, \text{AD2}, \text{AD3} \\
\text{pin J2} & \rightarrow 3, 5, 7, 9 \text{ and low 4, 6, 8, 10} \\
\text{DA1} & \rightarrow \text{AD4}, \text{AD5}, \text{AD6}, \text{AD7} \\
\text{pin J2} & \rightarrow 11, 13, 15, 17 \text{ and low 12, 14, 16, 18} \\
\text{when Gain}=1, \text{ D/A output range} & \rightarrow -10V_+10V, -2048_+2047 \\
\text{A/D input range} & \text{ should be the same as D/A output}.
\end{align*}
\]

\[
\begin{align*}
textbox{n$}, r%(3), 1 \\
\text{advalue}$% & = 999 \\
\text{LOCATE} & 15, 6 \\
\text{PRINT} & \text{"DA0"} \\
\text{LOCATE} & 15, 20 \\
\text{PRINT} & \text{"AD0"} \\
\text{LOCATE} & 15, 30 \\
\text{PRINT} & \text{"AD1"} \\
\text{LOCATE} & 15, 40 \\
\text{PRINT} & \text{"AD2"} \\
\text{LOCATE} & 15, 50 \\
\text{PRINT} & \text{"AD3"} \\
\text{LOCATE} & 18, 6 \\
\text{PRINT} & \text{"DA1"} \\
\text{LOCATE} & 18, 20 \\
\text{PRINT} & \text{"AD4"} \\
\text{LOCATE} & 18, 30 \\
\text{PRINT} & \text{"AD5"} \\
\text{LOCATE} & 18, 40 \\
\text{PRINT} & \text{"AD6"} \\
\text{LOCATE} & 18, 50 \\
\text{PRINT} & \text{"AD7"} \\
\end{align*}
\]

\[
\begin{align*}
\text{set AD gain}=1 \\
\text{FOR i%}=0 \text{ TO 7} \\
\end{align*}
\]
CALL SetAD(i%,1,slot%, VARPTR(er%))
NEXT i%

'write DA output
FOR i%=0 TO 10
value%=409.6*i%-2048
CALL cwrite (145,64, value%,slot%,VARPTR(er%))
CALL cwrite (145,72, value%,slot%,VARPTR(er%))
LOCATE 16,6
PRINT value%
LOCATE 19,6
PRINT value%

'read AD input
BUTTON 1,1,"NEXT VALUE", (130,310)-(230,330),1
BUTTON 2,1,"NEXT CHECK", (280,310)-(380,330),1
adda1:
FOR k%=0 TO 3
CALL cread (k%,0,VARPTR(advalue%),slot%,VARPTR(er%))
LOCATE 16,19+k%*10
'TEXTSIZE 20
PRINT advalue%
TEXTSIZE 12
CALL cread (k%+4,0,VARPTR(advalue%),slot%,VARPTR(er%))
LOCATE 19,19+k%*10
'TEXTSIZE 20
PRINT advalue%
TEXTSIZE 12
NEXT k%

d%=DIALOG(0)
IF d%<>1 AND d%<>6 GOTO adda1
d%=DIALOG(0)
IF DIALOG(1)<1 GOTO outloop
NEXT i%

outloop:
BUTTON CLOSE 0

'write D/A=0 for protection
CALL cwrite (145,64, 0,slot%,VARPTR(er%))
CALL cwrite (145,72, 0,slot%,VARPTR(er%))

'gain=10 check again
'n$=m$+"when Gain=10, D/A output range -1V_+1V, -205_+205, "+CHR$(13)
n$=n$+"A/D input range should still be -2048___2047."+CHR$(13)

Textbox n$,r%(3),1

LOCATE 15, 6
PRINT "DA0"
LOCATE 15, 20
PRINT "ADO"
LOCATE 15, 30
PRINT "AD1"
LOCATE 15, 40
PRINT "AD2"
LOCATE 15, 50
PRINT "AD3"

LOCATE 18, 6
PRINT "DA1"
LOCATE 18, 20
PRINT "AD4"
LOCATE 18, 30
PRINT "AD5"
LOCATE 18, 40
PRINT "AD6"
LOCATE 18, 50
PRINT "AD7"

'set AD gain=10
FOR i%=0 TO 7
    CALL SetAD(i%,10,slot%, VARPTR(er%))
NEXT i%

'write DA output
FOR i%=0 TO 10
value% = 40.96*i% - 204.8
CALL cwrite (145, 64, value%, slot%, VARPTR(er%))
CALL cwrite (145, 72, value%, slot%, VARPTR(er%))
LOCATE 16, 6
PRINT value%
LOCATE 19, 6
PRINT value%

'READ AD input
BUTTON 1,1, "NEXT VALUE*, (130,310)-(230,330), 1
BUTTON 2,1, "NEXT CHECK*, (280,310)-(380,330), 1

adda2:
FOR k% = 0 TO 3
    CALL cread (k%, 0, VARPTR(advalue%), slot%, VARPTR(er%))
    LOCATE 16, 19 + k% * 10
'TEXTSIZE 20
PRINT advalue%

TEXTSIZE 12
CALL cread (k% + 4, 0, VARPTR(advalue%), slot%, VARPTR(er%))
LOCATE 19, 19 + k% * 10
'TEXTSIZE 20
PRINT advalue%

TEXTSIZE 12
NEXT k%

d% = DIALOG(0)
IF d% <> 1 AND d% <> 6 GOTO adda2
d% = DIALOG(0)
IF DIALOG(1) <> 1 GOTO outloop1
NEXT i%

outloop1:
BUTTON CLOSE 0

'WRITE D/A=0 FOR PROTECTION
CALL cwrite (145, 64, 0, slot%, VARPTR(er%))
CALL cwrite (145, 72, 0, slot%, VARPTR(er%))

'RESET AD GAIN=1
FOR i% = 0 TO 7
    CALL SetAD(i%, 1, slot%, VARPTR(er%))
Appendices

NEXT %

'Digital input and output check

digitinout:

m$="DI AND DO CHECK"+CHR$(13)+CHR$(13)

m$=m$+"Cread(), Cwrite() and SetDoutbit will also be checked."+CHR$(13)+CHR$(13)

m$=m$+"DO-->DI"

m$=m$+"DO0.D01.D02,D03,D04,D05,D06,D07-->

m$=m$+"DI0,DI1,DI2,DI3,DI4,DI5,DI6,DI7"+CHR$(13)

m$=m$+"pin number on J1"+CHR$(13)

m$=m$+"The digital common pins are 1, 30, 32, 33 and 34 on J1"

Textbox m$,r%(3),1

LOCATE 14, 20
PRINT "Digital Output:

LOCATE 17,20
PRINT "Digital Input:

value%=0
valuehex$="0H"

BUTTON 1,1,"NEXT VALUE", (130,310)-(230,330),1

BUTTON 2,1,"NEXT CHECK", (280,310)-(380,330),1

dido1:
GOSUB writeread

d%=DIALOG(0)
IF d%<>1 AND d%<>6 GOTO dido1
IF DIALOG(1)<=1 GOTO outloop2

value%=255
valuehex$="FFH"

dido2:
GOSUB writeread

d%=DIALOG(0)
IF d%<>1 AND d%<>6 GOTO dido2
IF DIALOG(1)<=1 GOTO outloop2
value%=85
valuehex$="55H"
dido3:
GOSUB writeread
d%=DIALOG(0)
IF d%<>1 AND d%<>6 GOTO dido3
IF DIALOG(1)<1 GOTO outloop2

value%=170
valuehex$="AAH"
dido4:
GOSUB writeread
d%=DIALOG(0)
IF d%<>1 AND d%<>6 GOTO dido4
IF DIALOG(1)<1 GOTO outloop2

outloop2:
BUTTON CLOSE 0
CALL cwrite(147,80,0,slot%,VARPTR(er%)) 'write 0 to output port
GOTO timercountertest

't sub used for write and read for the digital I/O port
writeread:
'write DO
CALL cwrite(147,80,value%,slot%,VARPTR(er%))
LOCATE 14, 40
PRINT valuehex$

'read DI
CALL cread(146,8,VARPTR(value%),slot%,VARPTR(er%))
LOCATE 17,40
PRINT HEX$(value%)"H"
RETURN

-----------------------------------------------------------------
timercountertest:
m$="COUNTER/TIMER CHECK"+CHR$(13)+CHR$(13)
m$=m$+"Ckcontrol(), CkSetup(), Fqcontrol() and FqSetup will also be checked."+CHR$(13)
Timer 3 outputs timebase signal to GATE for Timer 1. *+CHR$(13)

Timer 2 outputs pulse signal as the input signal of Timer 1. *+CHR$(13)

Timer 1 measures the signal.*+CHR$(13)+CHR$(13)

OUT3-->GATE1  OUT2-->IN1 *+CHR$(13)

J1 26--> 23  J1 31--> 21*+CHR$(13)+CHR$(13)

Textbox m$,r%(3),1

time base set to be 1s

```
CALL Cksetup(3,10000,50,50,slot%, VARPTR(er%)) 'ch 3, 10000us, Hi 50(0.5s), Lo 50(0.5s)
IF er%<>0 THEN PRINT "ERROR for output 1";er%
CALL Ckcontrol(1,4,slot%,VARPTR(er%)) 'mood 1: arm timer output, ch 3—4
IF er%<>0 THEN PRINT "ERROR for output 2";er%
LOCATE 13,22
PRINT "The Base time is 1 second"
```

frequency output set to be from 10_160Hz

count%=0

```
fqu%=5000
FOR i%=1 TO 6
    CALL Cksetup(2,10,fqu%,fqu%,slot%, VARPTR(er%)) 'frequency signal output from 2
    IF er%<>0 THEN PRINT "ERROR for output 3";er%
    CALL Ckcontrol(1,2,slot%,VARPTR(er%)) 'mood 1: arm timer output, 10us range base
    IF er%<>0 THEN PRINT "ERROR for output 4";er%
    LOCATE 15,20
    PRINT "Output signal:"
    fqu1%=100000&/fqu%/2
    LOCATE 15,40
    PRINT fqu1%"Hz"
ENDFOR
```

```
BUTTON 1,1,"NEXT VALUE", (130,310)-(230,330),1
BUTTON 2,1,"FINISH CHECK", (280,310)-(380,330),1
fqu%=fqu%/2
```

```
counttimer:
    CALL Fqsetup(1,3,1000, slot%, VARPTR(er%)) 'input 1, gate from 3, 1000ms period
    IF er%<>0 THEN PRINT "ERROR for output 5";er%
    LOCATE 17,20
    PRINT "Input signal:"
```

```
fqagain:
```
CALL Fqcontrol(1, 3, VARPTR(count%), slot%, VARPTR(er%))  'input 1, gate from 3
IF er%=16 THEN fqagain  'count incompletely, once more
LOCATE 17,40
PRINT count%*"Hz"

d%=DIALOG(0)
IF d%<>1 AND d%<>6 GOTO counttimer
d%=DIALOG(0)
IF DIALOG(1)<>1 GOTO endtimertest

NEXT i%

delimTest:
CALL Ckcontrol(2,6,slot%,VARPTR(er%))  'mood 2: stop timers output, ch2 and 3

endhardTest:

'DO protective value
outputvalue%=255
CALL cwrite(147,80,outputvalue%,slot%,VARPTR(er%))

BUTTON CLOSE 0
WINDOW CLOSE 9
END SUB

domenuTest:
   menunumber=MENU(1)
   MENU
   ON menunumber GOSUB doprintSt,doprintWt
RETURN

doprintSt:
   PrintScreen 0,0
RETURN

doprintWt:
   printWindow 9,2
RETURN
'=========================================================================
' Calibration
'=========================================================================
SUB calibration (simu%) STATIC
DIM a#(48), b#(48), C#(48), s#(48), z#(48), x#(50), y#(50), h#(49), ypp#(50)
' for spline interpolation calculation

DIALOG OFF

MENU 1,0,1,"System"
MENU 1,1,1,"Print screen"
MENU 1,2,1,"print window"

FOR i%=2 TO 8
    MENU i%,0,0,"
NEXT i%

MENU ON
ON MENU GOSUB domenuCali

SW%=640
SH%=480
h%=440
w%=600
WINDOW 8,,((SW%-w%)/2,(SH%-h%)-10)-((SW%-w%)/2+w%,(SH%-h%)-10+h%),2

title$="Test Rig Calibration"
TEXTFONT 0
TEXTSIZE 16
MOVETO 30,20  'center title$
PRINT title$
TEXTFONT 3
TEXTSIZE 12

SetRect r%(3),10,30,w%-5,h%-15
m$=CHR$(13)+CHR$(13)+"This section checks all the sensors, instruments, "+CHR$(13)
m$=m$+"signal conditioner and A/D converters or timer/counters."+CHR$(13)+CHR$(13)
m$=m$+"The calibrating results will be got and will be"+CHR$(13)
m$=m$+"automatically written in the calibrating file"+CHR$(13)
m$=m$+"which the measuring and controlling system will use."+CHR$(13)
m$=m$+CHR$(13)

m$=m$+"AD0, AD1, AD4 and AD5 will be calibrated directly"+CHR$(13)
m$=m$+"AD2 and AD3 will be calibrated after AD1 calibration."+CHR$(13)+CHR$(13)

m$=m$+"Do you want to go on?"
Textbox m$, r%(3), 1

WINDOW 8

BUTTON 1, 1, "YES", (220, 310)-(270, 330), 1
BUTTON 2, 1, "NO", (320, 310)-(370, 330), 1
d%=DIALOG(0)
WHILE d%<>1 AND d%<>6
d%=DIALOG(0)
WEND
IF DIALOG(1)<1 GOTO endCalibration
BUTTON CLOSE

'start check
MENU ON
TEXTSIZE 11
advalue%=999
er%=-1
slot%=2

Textbox "", r%(3), 1

'set panel
'for Ch. 0

a$="AD0: FRICTION FORCE(LOAD CELL)"
b$="FRICTION FORCE (N)"
chn%=0

p$=CHR$(13)+"Please adjust the max and min physical values of the signal and the programmable gain on the board, then push START."+CHR$(13)
p$=p$+"Push NEXT for the next channel."+CHR$(13)
p$=p$+"Push EXIT to end calibration."+CHR$(13)

q$=CHR$(13)+"Change the input value and write the value in the edit field,"
q$=q$+"then push the CONT. for the following point."+CHR$(13)
Appendices

q$=q$+"Push RESTART to renew calibration."+CHR$(13)
q$=q$+"Push FINISH to finish the calibration."

r$=CHR$(13)+CHR$(13)+"Programmable gain set up error!"+CHR$(13)
r$=r$+"The gain can only be 1,10 or 100."

s$=CHR$(13)
s$=s$+"Push SAVE to write calibration file."+CHR$(13)
s$=s$+"Push RESTART to renew calibration."+CHR$(13)
s$=s$+"Push METHOD for a new end condition of cubic spline interpolation method."

T$=CHR$(13)+"The calibrating data is written to the calibration file."+CHR$(13)
T$=T$+"Please be patient."+CHR$(13)
T$=T$+"Push NEXT to stop to next channel."+CHR$(13)
T$=T$+"Push RESTART for renew calibration."+CHR$(13)

maxp$="200"
minp$="0"
calfile$="force.cali"
gain$="10"
crtvalue$="0"

Clbrtstt:
TEXTSIZE 14

MOVETO 30,50
PRINT a$

TEXTSIZE 12
MOVETO 20,80
PRINT "Max physical value:"
MOVETO 20,100
PRINT "Min physical value:"
MOVETO 20,120
PRINT "Calibration file:"
MOVETO 20,140
PRINT "Programmable gain:"
MOVETO 20,160
PRINT "Current value:"
MOVETO 20,190
PRINT "A/D CONVERTER"
MOVETO 40,205
PRINT "VALUE"

EDIT FIELD 11,maxp$,(155,67)-(250,82),2
EDIT FIELD 12,minp$,(155,87)-(250,102),2
EDIT FIELD 13,calfile$,(155,107)-(250,122),2
EDIT FIELD 14,gain$,(155,127)-(250,142),2
EDIT FIELD 15,crtvalue$,(155,147)-(250,162),2

MOVETO 150,200
TEXTSIZE 28
PRINT "0000"

TEXTSIZE 9
MOVETO 400,430
PRINT b$
MOVETO 310,430
PRINT "Min"
MOVETO 560,430
PRINT "Max"

caa:
SetRect r%(4), 15,240,250,350
LINE (12,237)-(253,353),.b
TEXTSIZE 11
Textbox p$,r%(4),1

'resume screen
TEXTFONT 0
TEXTSIZE 16
MOVETO 30,20 'center title$
PRINT title$
TEXTFONT 3
TEXTSIZE 14

MOVETO 30,50
PRINT a$

TEXTSIZE 12
MOVETO 20,80
PRINT "Max physical value:"
MOVETO 20,100
PRINT "Min physical value:"
MOVETO 20,120
PRINT "Calibration file:"
MOVETO 20,140
PRINT "Pragrammable gain:"
MOVETO 20,160
PRINT "Current value:"
MOVETO 20,190
PRINT "A/D CONVERTER"
MOVETO 40,205
PRINT "VALUE"

TEXTSIZE 9
LINE (306,1)-(598,420),30,bf
FOR i%=0 TO 6
   LINE (310,4+i%*102.5)-(580,4+i%*102.5)
   LINE (310+i%*67.5,4)-(310+i%*67.5,414)
NEXT i%

MOVETO 285,16
PRINT "2048"
MOVETO 295,220
PRINT "0"
MOVETO 280,410
PRINT "-2048"

BUTTON 1,1,"START", (20,390)-(70,420),1
BUTTON 2,1,"NEXT", (105,390)-(155,420),1
BUTTON 3,1,"EXIT",(190,390)-(240,420),1

caa1:
WHILE 1
SELECT CASE DIALOG(0)
   CASE 1
      d% = DIALOG(1)
      IF d% = 1 GOTO going 'start button pushed
      IF d% = 3 GOTO endCalibration
IF d%=2 GOTO nextchnl
CASE 2
   editfield=DIALOG(2)
   EDIT FIELD editfield
CASE ELSE
END SELECT
WEND

going:
' start button pushed
maxp=VAL(EDIT$(11))
minp=VAL(EDIT$(12))
calfile$=EDIT$(13)
gain%=VAL(EDIT$(14))
TEXTSIZE 9
MOVETO 310,430
   PRINT minp
MOVETO 560,430
   PRINT maxp
TEXTSIZE 11
IF gain%=1 OR gain%=10 OR gain%=100 GOTO going1
BEEP
Textbox r$,r%(4),1
GOTO caal

going1:
Textbox q$,r%(4),1
BUTTON  1,1,"CONT.", (20,390)-(70,420),1
BUTTON  2,1,"RESTART",(102,390)-(158,420),1
BUTTON  3,1,"FINISH",(190,390)-(240,420),1
'set AD gain
   CALL SetAD(chn%,gain%,slot%,VARPTR(er%))
   Xc=270/(maxp-minp)

j%=0
smp:
j%=j%+1
WHILE 1
   'read AD
Appendices

sum=0
FOR i%=1 TO 40
    CALL cread (chn%,0,VARPTR(advalue%),slot%,VARPTR(er%))
    sum=sum+advalue%
NEXT i%

averg%=sum/40  '+500*j%  'debuging

crtvalue=VAL(EDIT$(15))
x=crtvalue*Xc+310
y=414-(averg%+2048)/10
LINE (x-4,y-4)-(x+4,y+4),33,bf

MOVETO 150,200
TEXTSIZE 28
PRINT averg%;" "
'REIGHT$(STR$(averg%+10000),4)

FOR k%=1 TO j%-1
    x1=y#(k%)*Xc+310
    y1=414 -(x#(k%)+2048)/10
    LINE (x1-2,y1-2)-(x1+2,y1+2),33,b
NEXT k%

FOR i%=0 TO 6
    LINE (310,4+i%*102.5)-(580,4+i%*102.5)
    LINE (310+i%*67.5,4)-(310+i%*67.5,414)
NEXT i%

SELECT CASE DIALOG(O)
    CASE 1
        d%=DIALOG(1)
        IF d%=1 GOTO going2  'cont button pushed
        IF d%=3 GOTO getcali  'finish one calibration
        IF d%=2 GOTO caa     'restart the calibration
    CASE 2
        editfield=DIALOG(2)
        EDIT FIELD editfield
    CASE ELSE
        END SELECT
        LINE (x-4,y-4)-(x+4,y+4),30,bf
WEND

going2:
'get a record and display
'note the variable x#() and y#() changed here
   LINE (x-4,y-4)-(x+4,y+4),30,bf
   y#(j%)=crtvalue
   x#(j%)=averg%
GOTO smp

'sort and cubic spline interpolation
getcali:
   n=10
   IF simu%<>255 GOTO bubbleCali
   GOTO bubbleCali

'simulating calibration
   n=11
   OPEN "!", #11, "clbrt.simu"
   cy=maxp/20
   FOR i=1 TO n
      INPUT #11, x#(i), y#(l)
      y#(i)=y#(i)*cy
   NEXT i
   CLOSE #11

bubbleCali:
   FOR i%=1 TO n
      FOR j%=1 TO n
         IF x#(i%)<=x#(j%) GOTO noswap
         SWAP x#(i%),x#(j%)
         SWAP y#(i%),y#(j%)
      NEXT j%
   NEXT i%
   endcon=0

getcali1:
   maxp=VAL(EDIT$(11))
   minp=VAL(EDIT$(12))
   Xc=270/(maxp-minp)
   endcon=endcon+1
   IF endcon<5 GOTO getcali2
   endcon=1
getcali2:
'resume screen
TEXTFONT 0
TEXTSIZE 16
MOVETO 30,20 'center title$
PRINT title$
TEXTFONT 3
TEXTSIZE 14

MOVETO 30,50
PRINT a$

TEXTSIZE 12
MOVETO 20,80
PRINT "Max physical value:"
MOVETO 20,100
PRINT "Min physical value:"
MOVETO 20,120
PRINT "Calibration file:"
MOVETO 20,140
PRINT "Programmable gain:"
MOVETO 20,160
PRINT "Current value:"
MOVETO 20,190
PRINT "A/D CONVERTER"
MOVETO 40,205
PRINT "VALUE"

TEXTSIZE 9
LINE (306,1)-(598,420),30,bf
FOR i%=0 TO 6
  LINE (310,4+i%*102.5)-(580,4+i%*102.5)
  LINE (310+i%*67.5,4)-(310+i%*67.5,414)
NEXT i%

MOVETO 285,16
PRINT "2048"
MOVETO 295,220
PRINT "0"
MOVETO 280,410
PRINT "-2048"
MOVETO 310,430
PRINT minp
MOVETO 560,430
PRINT maxp
TEXTSIZE 11

cubic spline interpolation
FOR i%=1 TO n
   PRINT x%(i%),y%(i%)
   x=(y%(i%)*Xc+310)
   y=414-(x%(i%)+2048)/10
   CIRCLE (x,y),3
NEXT i%
xmin#=x%(1)
xmax#=x%(n)
deltx=10
cubicspline:
    FOR i=1 TO n-1
        h#(i)=x#(i+1)-x#(i)
    NEXT i

    FOR i=1 TO n-2
        s#(i)=6!*(y#(i+2)-y#(i+1))/h#(i+1)-6!*(y#(i+1)-y#(i))/h#(i)
    NEXT i

    FOR i=1 TO n-3
        C#(i)=h#(i+1)
        a#(i+1)=C#(i)
    NEXT i

    FOR i=1 TO n-2
        b#(i)=2!*(h#(i)+h#(i+1))
    NEXT i

    IF endcon=1 GOTO endl
    IF endcon=2 GOTO end2
    IF endcon=3 GOTO end3
    IF endcon=4 GOTO end4

   end2:
    b#(1)=b#(1)+h#(1)
    b#(n-2)=b#(n-2)+h#(n-1)
    GOTO endl

   end3:
    b#(1)=(h#(1)+h#(2))*(h#(1)+2!*h#(2))/h#(2)
    a#(n-2)=(h#(n-2)*h#(n-2)-h#(n-1)*h#(n-1))/h#(n-2)
    b#(n-2)=(h#(n-2)+h#(n-1))*(2!*h#(n-2)+h#(n-1))/h#(n-2)
    GOTO endl

   end4:
    b#(1)=(h#(1)+h#(2))*(h#(1)+4!*h#(2))/(2!*h#(2))
    C#(1)=(2!*h#(2)*h#(2)-h#(1)*h#(1))/(2!*h#(2))
Appendices

\[ a^{(n-2)} = \frac{(2! \cdot h^{(n-2)} \cdot h^{(n-2)} - h^{(n-1)} \cdot h^{(n-1)})}{(2! \cdot h^{(n-2)})} \]
\[ b^{(n-2)} = \frac{(h^{(n-2)} + h^{(n-1)}) \cdot (4! \cdot h^{(n-2)} + h^{(n-1)})}{(2! \cdot h^{(n-2)})} \]

\begin{align*}
\text{end1:} \\
& n = n-2 \\
& \text{NM1 = n-1} \\
& \text{FOR } i = 1 \text{ TO NM1} \\
& \quad b^{(i+1)} = b^{(i+1)} - a^{(i+1)} \cdot c^{(i)}/b^{(i)} \\
& \quad s^{(i+1)} = s^{(i+1)} - a^{(i+1)} \cdot s^{(i)}/b^{(i)} \\
& \text{NEXT } i \\
& z^{(n)} = s^{(n)}/b^{(n)} \\
& \text{FOR } i = 1 \text{ TO NM1} \\
& \quad i = n-1 \\
& \quad z^{(i)} = (s^{(i)} - c^{(i)} \cdot z^{(i+1)})/b^{(i)} \\
& \text{NEXT } i \\
& n = n+2 \\
& \text{IF endcon = 1 GOTO end11} \\
& \text{IF endcon = 2 GOTO end12} \\
& \text{IF endcon = 3 GOTO end13} \\
& \text{IF endcon = 4 GOTO end14} \\
\text{end11:} \\
& \quad ypp^{(1)} = 0! \\
& \quad ypp^{(n)} = 0! \\
& \text{GOTO endfnsh} \\
\text{end12:} \\
& \quad ypp^{(1)} = z^{(1)} \\
& \quad ypp^{(n)} = z^{(n-2)} \\
& \text{GOTO endfnsh} \\
\text{end13:} \\
& \quad ypp^{(1)} = (z^{(1)} \cdot (h^{(1)} + h^{(2)}) - z^{(2)} \cdot h^{(1)})/h^{(2)} \\
& \quad ypp^{(n)} = (z^{(n-2)} \cdot (h^{(n-2)} + h^{(n-1)}) - z^{(n-3)} \cdot h^{(n-1)})/h^{(n-2)} \\
& \text{GOTO endfnsh} \\
\text{end14:} \\
& \quad ypp^{(1)} = (z^{(1)} \cdot (h^{(1)} + h^{(2)}) - z^{(2)} \cdot h^{(1)})/(2! \cdot h^{(2)}) \\
& \quad ypp^{(n)} = (z^{(n-2)} \cdot (h^{(n-2)} + h^{(n-1)}) - z^{(n-3)} \cdot h^{(n-1)})/(2! \cdot h^{(n-2)}) \\
\text{endfnsh:} \\
& \text{FOR } i = 2 \text{ TO } n-1 \\
& \quad ypp^{(i)} = z^{(i-1)}
PRINT ypp#(i);
NEXT i

SELECT CASE endcon
CASE 1
   ss$="Finish. End condition: natural spline fit."+CHR$(13)
CASE 2
   ss$="Finish. End condition: 2ed deriv. equal to adjacent points."+CHR$(13)
CASE 3
   ss$="Finish. End condition: extrapolated 2ed deriv. at ends"+CHR$(13)
CASE 4
   ss$="Finish. End condition: average of natural fit and extrapolated 2ed deriv. at ends"
   +CHR$(13)
END SELECT

ss$=ss$+s$
Textbox ss$,r%(4),1
BUTTON 1,1,"SAVE", (20,390)-(70,420),1
BUTTON 3,1,"METHOD",(190,390H245,420),1

xx=-2038
splinet:
   IF xx>=xmin# GOTO sp1
   i=1
   GOTO getyy
sp1:
   IF xx<=xmax# GOTO sp2
   i=n-1
   GOTO getyy
sp2:
   FOR i=1 TO n-1
      IF xx>=x#(i) AND xx<=x#(i+1) GOTO getyy
   NEXT i
getyy:
   YY1#=ypp#(i)/6*((x#(i+1)-xx)^3/h#(i)-h#(i)*(x#(i+1)-xx))
   YY2#=ypp#(i+1)/6*((xx-x#(i))^3/h#(i)-h#(i)*(xx-x#(i)))
   YY3#=y#(i)*(x#(i+1)-xx)/h#(i)+y#(i+1)*(xx-x#(i))/h#(i)
   yy#=YY1#+YY2#+YY3#
   IF yy#>maxp OR yy#<minp GOTO psp
   x=yy#*Xc+310
   y=414-(xx+2048)/10
PSET (x,y)
psp:
   xx=xx+deltx
   IF xx>2048 GOTO endspline
SELECT CASE DIALOG(0)
CASE 1
   d%=DIALOG(1)
   IF d%=3 GOTO getcali1 'another calibration method
   IF d%=2 GOTO caa 'restart the calibration
CASE ELSE
END SELECT
GOTO spline1
endspline:
TEXTSIZE 11
WHILE 1
SELECT CASE DIALOG(0)
CASE 1
   d%=DIALOG(1)
   IF d%=1 GOTO writecalifile 'yes button pushed
   IF d%=3 GOTO getcali1 'another calibration method
   IF d%=2 GOTO caa 'restart the calibration
CASE 2
   editfield=DIALOG(2)
   EDIT FIELD editfield
CASE ELSE
END SELECT
WEND
writecalifile:
Textbox T$,r%(4),1
BUTTON 1,1,"NEXT", (20,390)-(70,420),1
BUTTON 3,1,"EXIT",(190,390)-(245,420),1
TEXTSIZE 9
LINE (306,1)-(598,420),30,bf
FOR i%=0 TO 6
   LINE (310,4+i%*102.5)-(580,4+i%*102.5)
   LINE (310+i%*67.5,4)-(310+i%*67.5,414)
NEXT i%
MOVETO 285,16
PRINT "2048"
MOVETO 295,220
PRINT "0"
MOVETO 280,410
PRINT "-2048"
MOVETO 310,430
PRINT "\text{min}\ p"
MOVETO 560,430
PRINT "\text{max}\ p"
TEXTSIZE 11

'cubic splining interpolation
FOR i%=1 TO n
' \hspace{1em} \text{PRINT } x#(i%),y#(i%)
\hspace{1em} x=y#(i%)\times Xc+310
\hspace{1em} y=414-(x#(i%)+2048)/10
\hspace{1em} \text{CIRCLE } (x,y),3
\hspace{1em} NEXT i%

'calculation calibration points and write to file
calfile$=EDIT$(13)
OPEN calfile$ FOR OUTPUT AS #12
CLOSE #12
OPEN calfile$ AS #12 LEN=4
FIELD #12,4 AS yy$
\hspace{1em} xx%=-2047

spline11:
IF xx%>=xmin# GOTO sp11
i=1
GOTO getyy1
sp11:
IF xx%<=xmax# GOTO sp21
i=n-1
GOTO getyy1
sp21:
\hspace{1em} \text{FOR } i=1 \text{ TO } n-1
\hspace{1em} \text{IF } xx%>=x#(i) \text{ AND } xx%<=x#(i+1) \text{ GOTO } getyy1
\hspace{1em} \text{NEXT } i
getyy1:
\hspace{1em} YY1#=ypp#(i)/6*((x#(i+1)-xx%))/h#(i)-h#(i)*(x#(i+1)-xx%)
YY2# = yp#(i+1)/6*((xx%-x#(i))\(3/h#(i)-h#(i)\)*(xx%-x#(i)))
YY3# = y#(i)\((x#(i+1)-xx%)/h#(i)+y#(i+1)*(xx%-x#(i)))/h#(i)

yy# = YY1#+YY2#+YY3#

IF yy# > maxp THEN yy# = maxp
IF yy# < minp THEN yy# = minp

yy = yy#

LSET yy$ = MKS$(yy) 'write into calibration file
PUT #12, xx%+2049

x = yy*Xc+310
y = 414-(xx%+2048)/10
PSET (x, y)

xx% = xx%+1 'debugging
IF xx% > 2048 GOTO endspline1 'debugging

SELECT CASE DIALOG(0)
CASE 1
  d% = DIALOG(1)
  IF d% = 1 GOTO stopwrt 'next button pushed
  IF d% = 3 GOTO endcalibration1 'restart the calibration
CASE 2
  editfield = DIALOG(2)
  EDIT FIELD editfield
CASE ELSE
END SELECT
GOTO spline11
endspline11:
CLOSE #12

stopwrt:
'close file and change to next channel
CLOSE #12

-------------------------------
nextchnl:

SELECT CASE chn%
CASE 0
  GOTO tochn1
CASE 1
  GOTO tochn4
CASE 4
    GOTO tochn5
CASE ELSE
    GOTO tochn23
END SELECT

tochn1:
a$="AD1: DISPLACEMENT(CAP SENSOR)"
b$="DISPLACEMENT(um)  "
chn%=1
maxp$="440"
minp$="0"
calfile$="dsplsmt.cali"
gain$="1"
crtvalue$="0"
GOTO Clbrtstt
tochn4:
a$="AD4: AE RMS(AE SENSOR)"
b$=" AE RMS (V)"
chn%=4
maxp$="10"
minp$="0"
calfile$="AErms.cali"
gain$="1"
crtvalue$="0"
GOTO Clbrtstt
tochn5:
a$="AD5: TEMPERATURE(THERMOCOUPLE)"
b$=" TEMPERATURE(degree)"
chn%=5
maxp$="1000"
minp$="0"
calfile$="tmprt.cali"
gain$="1"
crtvalue$="0"
GOTO Clbrtstt
tochn23:
a$="AD2: VELOCITY OF DIAMETER"

b$="VELOCITY(m/s)"

chn%=2

maxp$="3"

minp$="-3"

calfile$="vlct.cali"

gain$="1"

crtvalue$="0"

p$=CHR$(13)+"Please adjust the max and min physical values of the signal and the programmable gain on the board,"
p$=p$+" then push START. Note: it will automatically start the motor"+CHR$(13)
p$=p$+" Please adjust the velocity and the load in the process,"
p$=p$+" Push EXIT to end calibration."+CHR$(13)

q$=CHR$(13)+"Now the programme is calibrating automatically. "
q$=q$+"Keep it going at least more that 5 minuts. "
q$=q$+"Push the STOP to stop the motor but keep the calibration going."+CHR$(13)
q$=q$+"Push RESTART to renew calibration."+CHR$(13)
q$=q$+"Push FINISH to finish the calibration."

CLS

TEXTFONT 0

TEXTSIZE 16

MOVETO 30,20  'center title$

PRINT title$

TEXTFONT 3


cali23:

TEXTSIZE 14

MOVETO 30,50  'center title$

PRINT a$


TEXTSIZE 12

MOVETO 20,80  

PRINT "Max physical value."

MOVETO 20,100

PRINT "Min physical value:"

MOVETO 20,120

PRINT "Calibration file:"
PRINT "Programmable gain:"
' MOVETO 20,160
   PRINT *
   EDIT FIELD CLOSE 15
   BUTTON CLOSE 0
   EDIT FIELD 11, maxp$,(155,67)-(250,82),2
   EDIT FIELD 12, minp$,(155,87)-(250,102),2
   EDIT FIELD 13, calfile$,(155,107)-(250,122),2
   EDIT FIELD 14, gain$,(155,127)-(250,142),2
   EDIT FIELD 15, crtvalue$,(155,147)-(250,162),2

MOVETO 20,190
   PRINT "A/D CONVERTER"
MOVETO 40,205
   PRINT "VALUE"
MOVETO 150,200
   TEXTSIZE 28
   PRINT "0000 "
   TEXTSIZE 9
   MOVETO 400,430
   PRINT b$
   MOVETO 310,430
   PRINT "Min"
   MOVETO 560,430
   PRINT "Max"
   caa23:
   SetRect r%(4), 15,240,250,350
   LINE (12,237)-(253,353)"b
   TEXTSIZE 11
  Textbox p$,r%(4),1
   TEXTSIZE 9
   MOVETO 400,430
   PRINT b$
   MOVETO 310,430
   PRINT "Min"
   MOVETO 560,430
   PRINT "Max"
   FOR i%=0 TO 6
      LINE (310,4+i%*102.5)-(580,4+i%*102.5)
      LINE (310+i%*67.5,4)-(310+i%*67.5,414)
   NEXT i%
MOVETO 285,16
    PRINT "2048"
MOVETO 295,220
    PRINT "0"
MOVETO 280,410
    PRINT "-2048"

BUTTON 1,1,"START", (20,390)-(70,420),1
BUTTON 2,1,"EXIT", (190,390)-(240,420),1

caa123:
WHILE 1
    SELECT CASE DIALOG(0)
    CASE 1
        d%=DIALOG(1)
        IF d%=1 GOTO going23
        IF d%=2 GOTO endCalibration
    CASE 2
        editfield=DIALOG(2)
        EDIT FIELD editfield
    CASE ELSE
    END SELECT
    WEND

    going23:
    'start button pushed
    OPEN "dsplsmt.cali" AS #12 LEN=4
    FIELD #12,4 AS yy$

    maxp=VAL(EDIT$(11))
    minp=VAL(EDIT$(12))
    callfile$=EDIT$(13)
    gain%=VAL(EDIT$(14))
    TEXTSIZE 9
    MOVETO 310,430
    PRINT minp
    MOVETO 560,430
    PRINT maxp
    TEXTSIZE 11
IF gain%=1 OR gain%=10 OR gain%=100 GOTO going123
BEEP
Textbox r$,r%(4),1
GOTO caa123

going123:
'start motor
Textbox q$,r%(4),1
BUTTON 1,1,"STOP", (20,390)-(70,420),1
BUTTON 2,1,"RESTART", (102,390)-(158,420),1
BUTTON 3,1,"FINISH", (190,390)-(240,420),1
'set AD gain
CALL SetAD(chn%,gain%,slot%,VARPTR(er%))
Xc=270/(maxp-minp)

j%=0
smp23:
  j%=j%+1
  WHILE 1
  'read AD
  sum=0
      CALL cread (chn%,0,VARPTR(advalue%),slot%,VARPTR(er%))
      'klklklklk
      CALL cread (1,0,VARPTR(advalued%),slot%,VARPTR(er%))
      'displacement
      GET #12, avergd%
      dsplcm=CV!(yy$)
  'get integration of displacement to crtvalue
      x=crtvalue*Xc+310
      y=414-(averg%+2048)/10
      LINE (x-4,y-4)-(x+4,y+4),33,bf
  MOVETO 150,200
  TEXTSIZE 28
  PRINT averg%," 
  'RIGHT$(STR$(averg%+10000),4)
FOR k%=1 TO j%-1
  x1=y#(k%)Xc+310
  y1=414-x#(k%)/10
LINE (x1-2,y1-2)-(x1+2,y1+2),33,b
NEXT k%
FOR %i=0 TO 6
  LINE (310,4+i%*102.5)-(580,4+i%*102.5)
  LINE (310+i%*67.5,4)-(310+i%*67.5,414)
NEXT i%
SELECT CASE DIALOG(0)
  CASE 1
    d%=DIALOG(1)
    IF d%=1 GOTO going223  'cont button pushed
    IF d%=3 GOTO getcali23  'finish one calibration
    IF d%=2 GOTO caa23  'restart the calibration
  CASE 2
    editfield=DIALOG(2)
    EDIT FIELD editfield
  CASE ELSE
    END SELECT
    LINE (x-4,y-4)-(x+4,y+4),30,bf
  END SELECT
  LINE (x-4,y-4)-(x+4,y+4),30,bf
WEND

going223:
'get a record and display
'note the variable x#() and y#() changed here
  LINE (x-4,y-4)-(x+4,y+4),30,bf
  y#(j%)=crfvalue
  x#(j%)=averg%
  GOTO smp

' sort and cubic spline interpolation

IF chn%=3 GOTO endCalibration
' for acceleration calibration
a$="AD3: ACCELERATION OF DIAMETER"
b$="ACCELERATION(m/s/s)"
chn%=3
maxp$="5"
mnp$="-5"
calfile$="aclrt.cali"
Appendices

```plaintext
gain$="1"
crtvalue$="0"
GOTO cali23

endcalibration1:
  CLOSE #12
endCalibration:
  WINDOW CLOSE 8
  WINDOW 1
  ERASE a#, b#, C#, s#, z#, x#, y#, h#, ypp#
  DIALOG ON
  END SUB

readcali:
  OPEN *califorce* AS #12 LEN=4
  FIELD #12,4 AS yy$
  FOR i=10 TO 4090 STEP 100
    GET #12, i
    yy=CVS(yy$)
    PRINT i, yy
  NEXT i
  CLOSE #12
  END

domenuCali:
  menunumber=MENU(1)
  MENU
  ON menunumber GOSUB doprintSc,doprintWc
  RETURN

doprintSc:
  PrintScreen 0,0
  RETURN

doprintWc:
  printWindow 8,2
  RETURN
```
Prepare adjustment

Just three parameters here are considered, including friction force, displacement and temperature

SUB adjustment STATIC

DIM adff%(50), addd%(50), adtt%(50)

d1=341
d2=19
dc1#=3.14159#*d1/24/10000
dc2#=3.14159#*d2/10000

DIALOG OFF

MENU 1,0,1,"System"
MENU 1,1,1,"Print screen"
MENU 1,2,1,"print window"

FOR i%=2 TO 8
    MENU i%,0,0,""
NEXT i%

MENU ON
ON MENU GOSUB domenuAdjst

MENU ON
ad%=999
er%=-1
slot%=2
count1%=0
count2%=0

'stop motor and heating device
CALL setDoutbit(6,1,slot%, VARPTR(er%))
CALL setDoutbit(7,1,slot%, VARPTR(er%))

SW%=640
SH%=480
Appendices 310

h% = 440
w% = 600
WINDOW 7, ((SW%-w%)/2, (SH%-h%)-10)-((SW%-w%)/2+w%, (SH%-h%)-10+h%), 2
title$ = "Rig Pre-adjustment"
TEXTFONT 0
TEXTSIZE 16
MOVETO 30, 20 'center title$
PRINT title$
TEXTFONT 3
TEXTSIZE 12

SetRect r%(3), 10, 30, w%-5, h%-15
m$ = CHR$(13)+CHR$(13)+"This section is used for adjustment and check"+CHR$(13)
m$ = m$ + " of some devices before the actual experiments."
+CHR$(13)
m$ = m$ + "The temperature of disk and velocity of the spindle"+CHR$(13)
m$ = m$ + "should be adjusted to the required values."
+CHR$(13)
m$ = m$ + "All the control signals and status signals can also be checked."
+CHR$(13)
m$ = m$ + CHR$(13)+"Please be patient for the measurement of velocities of disk and roller"
+CHR$(13)
m$ = m$ + CHR$(13) + CHR$(13)
m$ = m$ + "Do you want to go on?"
Textbox m$, r%(3), 1

WINDOW 7

BUTTON 1, 1, "YES", (220, 310)-(270, 330), 1
BUTTON 2, 1, "NO", (320, 310)-(370, 330), 1
d% = DIALOG(0)
WHILE d% <> 1 AND d% <> 6
d% = DIALOG(0)
WEND
IF DIALOG(1) <> 1 GOTO endAdjustment1
BUTTON CLOSE 0

'start check
Textbox " ", r%(3), 1

'set panel
LINE (28, 40)-(560, 42), b
TEXTSIZE 22
MOVETO 30, 70
Print "Temperature (dgr):"
Moveto 30,105
Print "Disk Velocity (m/s):"
Moveto 30,140
Print "Friction Force (N):"
Moveto 30,175
Print "Change of Roller Diameter (um):"
Moveto 30,180
Print "Velocity of Vibration of Roller (m/s):"
Moveto 30,205
Print "Acceleration of Vibration of Roller (m/s²):"
Moveto 30,210
Print "Acoustic Emission RMS (mv):"
Moveto 30,245
Print "Roller Velocity (m/s):"

Textfont 0
Textsize 12
Moveto 90,295
Print "Motor Control"
'button 1,1, "ON", (90,310)-(130,340), 1
'button 2,2, "OFF", (150,310)-(190,340), 1
button 1,1, "motor on", (100,305)-(210,325), 3
button 2,2, "motor off", (100,330)-(210,350), 3

Moveto 330,295
Print "Heating Device Control"
'button 3,1, "ON", (360,310)-(400,340), 1
'button 4,2, "OFF", (420,310)-(460,340), 1
button 3,1, "heating on", (350,305)-(520,325), 3
button 4,2, "heating off", (350,330)-(520,350), 3

Textsize 14
Textfont 1
Textsize 12
Moveto 80,375
Print "Would you like to continue the pre-adjustment or exit the adjustment?"
Button 5, 1, "CONT.", (180,390)-(230,420), 1
Button 6,1, "EXIT", (320,390)-(370,420), 1
'set timebase signal to timer 1 and 2
'time base set to be 1s: ch3,10000us, Hi 50(0.5s), Lo 50(0.5s)
'CALL Cksetup(3,10000,50,50,slot%,VARPTR(er%))
'CALL Ckcontrol(1,4,slot%,VARPTR(er%)) 'mood1: armtimer output, ch3->4

'set AD gain
slot%=2

CALL SetAD(0,1,slot%,VARPTR(er%))  'friction force gain: 1
CALL SetAD(1,1,slot%,VARPTR(er%))  'wear gain: 1
CALL SetAD(2,1,slot%,VARPTR(er%))  'velocity of vibration gain: 1
CALL SetAD(3,1,slot%,VARPTR(er%))  'acceleration of vibration gain: 1
CALL SetAD(4,1,slot%,VARPTR(er%))  'rms of AE gain: 1
CALL SetAD(5,1,slot%,VARPTR(er%))  'temperature gain: 1

'open calibration files
'OPEN "force.cali" AS #13 LEN=4
'OPEN "dsplsmt.cali" AS #14 LEN=4
'OPEN "tmprt.cali" AS #16 LEN=4
FIELD #13, 4 AS prmt$(0)
FIELD #14, 4 AS prmt$(1)
FIELD #16, 4 AS tt$

adjstttt:
'setup frequency measurement first, it will cost about 10 seconds to get the
accurate value of the two input 1 and 2
CALL Fqsetup(1,3,10000,slot%,VARPTR(er%))
CALL Fqsetup(2,3,10000,slot%,VARPTR(er%))

WHILE 1
SELECT CASE DIALOG(O)
  CASE 1
    d%=DIALOG(1)
    IF d%=1 GOTO motoron
    IF d%=2 GOTO motoroff
    IF d%=3 GOTO heatingon
    IF d%=4 GOTO heatingoff
IF d%=5 GOTO ajtfnsh
IF d%=6 GOTO endAdjustment
CASE ELSE
END SELECT

'FOR i=1 TO 400
'NEXT i

TEXTSIZE 22
CALL Fqcontrol(1,3,VARPTR(count1%),slot%,VARPTR(er%))
IF er%=16 GOTO timenoenough1
vlct=INT(count1%*dc1#*1000)/1000
MOVETO 430,105
PRINT vlct;"*
CALL Fqsetup(1,3,10000,slot%,VARPTR(er%))

timenoenough1:

CALL Fqcontrol(2,3,VARPTR(count2%),slot%,VARPTR(er%))
IF er%=16 GOTO timenoenough2
vlct=INT(count2%*dc2#*1000)/1000
MOVETO 430,245
PRINT vlct;"*
CALL Fqsetup(2,3,10000,slot%,VARPTR(er%))

timenoenough2:

'detect the motor and heating control key again to reduce the response time
SELECT CASE DIALOG(O)
CASE 1
d%=DIALOG(1)
IF d%=1 GOTO motoron
IF d%=2 GOTO motoroff
IF d%=3 GOTO heatingon
IF d%=4 GOTO heatingoff
IF d%=5 GOTO ajtfnsh
IF d%=6 GOTO endAdjustment
CASE ELSE
END SELECT

nn=41
FOR i%=1 TO nn
    CALL cread(0,0,VARPTR(ad%),slot%,VARPTR(er%)) 'friction force
    adff%(i%)=ad%
    'PRINT ad%;
    CALL cread(1,0,VARPTR(ad%),slot%,VARPTR(er%)) 'displacement
    addd%(i%)=ad%
    'PRINT ad%;
    CALL cread(5,0,VARPTR(ad%),slot%,VARPTR(er%)) 'temperature
    adtt%(i%)=ad%
    'PRINT ad%
NEXT i%

'detect the motor and heating control key again to reduce the reponse time
SELECT CASE DIALOG(O)
    CASE 1
        d%=DIALOG(1)
        IF d%=1 GOTO motoron
        IF d%=2 GOTO motoroff
        IF d%=3 GOTO heatingon
        IF d%=4 GOTO heatingoff
        IF d%=5 GOTO ajtfnsh
        IF d%=6 GOTO endAdjustment
    CASE ELSE
        END SELECT
END SELECT

'get the middle value of friction force
FOR i%=1 TO (nn+1)/2
    FOR j%=i% TO nn
        IF adff%(i%)<=adff%(j%) GOTO noff1
        SWAP adff%(i%), adff%(j%)
    NEXT j%
NEXT i%
GET #13, adff%((nn+1)/2)+2049
MOVETO 430,140
PRINT INT(CVS(prmt$(0))*10+.5)/10;"
d%=DIALOG(1)
IF d%=1 GOTO motoron
IF d%=2 GOTO motoroff
IF d%=3 GOTO heatingon
IF d%=4 GOTO heatingoff
IF d%=5 GOTO ajtfnsh
IF d%=6 GOTO endAdjustment
CASE ELSE
END SELECT

'get the middle value of displacement
FOR i%=1 TO (nn+1)/2
    FOR j%=i% TO nn
        IF addd%(i%)<=addd%(j%) GOTO nodd1
            SWAP addd%(i%), addd%(j%)
    NEXT j%
NEXT i%
GET #14, addd%((nn+1)/2)+2049
MOVETO 430,175
PRINT INT(CVS(prmt$(1)));" 

'detect the motor and heating control key again to reduce the response time
SELECT CASE DIALOG(0)
    CASE 1
        d%=DIALOG(1)
        IF d%=1 GOTO motoron
        IF d%=2 GOTO motoroff
        IF d%=3 GOTO heatingon
        IF d%=4 GOTO heatingoff
        IF d%=5 GOTO ajtfnsh
        IF d%=6 GOTO endAdjustment
    CASE ELSE
        END SELECT

'get the middle value of temperature
FOR i%=1 TO (nn+1)/2
    FOR j%=i% TO nn
        IF adtt%(i%)<=adtt%(j%) GOTO nottl
            SWAP adtt%(i%), adtt%(j%)
    NEXT j%
NEXT i%
NEXT j%
NEXT i%
GET #16, adtt%((nn+1)/2)+2049
MOVETO 430,70
PRINT INT(CVS(tt$));: *
GOTO ww

CALL cread(2,0,VARPTR(ad%),slot%,VARPTR(er%)) 'velocity
MOVETO 430,180
PRINT ad%

CALL cread(3,0,VARPTR(ad%),slot%,VARPTR(er%)) 'acceleration
MOVETO 430,205
PRINT ad%

CALL cread(4,0,VARPTR(ad%),slot%,VARPTR(er%)) 'AE rms
ww:
MOVETO 430,210 'default value of AE
PRINT 0

WEND

motoron:
BUTTON 1,2
BUTTON 2,1
CALL setDoutbit(7,0,slot%, VARPTR(er%))
GOTO adjststt

motoroff:
BUTTON 1,1
BUTTON 2,2
CALL setDoutbit(7,1,slot%, VARPTR(er%))
GOTO adjststt

heatingon:
BUTTON 3,2
BUTTON 4,1
CALL setDoutbit(6,0,slot%, VARPTR(er%))
GOTO adjuststt

heatingoff:
BUTTON 3,1
BUTTON 4,2
CALL setDoutbit(6,1,slot%, VARPTR(er%))
GOTO adjuststt

ajtfnsh:
'get the displacement value and force value as the base value
'to decrease the zero drift.
BUTTON CLOSE 0
LINE (54,273)-(536,432),30,bf
TEXTSIZE 12
SetRect r%(6),83,282,507,423
pr$="Eliminating zero drift now."+CHR$(13)
pr$=pr$+CHR$(13)+"Please adjust position of tip of capacitance*
pr$=pr$+"sensor to ensure the readout to be 40-80 um."
pr$=pr$+CHR$(13)+"Please move the support block of roller arm*
pr$=pr$+"apart from the load cell at least 2 seconds,"
pr$=pr$+"then push the FINISH button."
Textbox pr$,r%(6),1

BUTTON 7,1, "FINISH", (250,390)-(300,420),1

'stop heating device and motor when eliminating zero drift
CALL setDoutbit(6,1,slot%, VARPTR(er%))
CALL setDoutbit(7,1,slot%, VARPTR(er%))

WHILE 1
SELECT CASE DIALOG(0)
CASE 1
    d%=DIALOG(1)
    IF d%=7 GOTO finishAdjustment
CASE ELSE
END SELECT

TEXTSIZE 22

CALL Fqcontrol(1,3,VARPTR(count1%),slot%,VARPTR(er%))
IF er%=16 GOTO timenoenough12
vlct=INT(count1%*dc1#*1000)/1000
MOVETO 430,105
PRINT vlct;" *
CALL Fqsetup(1,3,10000,slot%,VARPTR(er%))

timenoenough12:

CALL Fqcontrol(2,3,VARPTR(count2%),slot%,VARPTR(er%))
IF er%=16 GOTO timenoenough22
vlct=INT(count2%*dc2#*1000)/1000
MOVETO 430,245
PRINT vlct;" *
CALL Fqsetup(2,3,10000,slot%,VARPTR(er%))

timenoenough22:

nn=41

FOR i%=1 TO nn
   CALL cread(0,0,VARPTR(ad%),slot%,VARPTR(er%)) 'friction force
   adff%(i%)=ad%
   CALL cread(1,0,VARPTR(ad%),slot%,VARPTR(er%)) 'displacement
   addd%(i%)=ad%
   CALL cread(5,0,VARPTR(ad%),slot%,VARPTR(er%)) 'temperature
   adtt%(i%)=ad%
NEXT i%

'get the middle value of friction force
FOR i%=1 TO (nn+1)/2
   FOR j%=i% TO nn
      IF adff%(i%)<=adff%(j%) GOTO noff
      SWAP adff%(i%), adff%(j%)
   NEXT j%
NEXT i%
GET #13, adff%((nn+1)/2)+2049
MOVETO 430,140
PRINT INT(CVS(prmt$(0))*10+.5)/10;"
baseff# = CVS(prmt$(0))

SELECT CASE DIALOG(0)
    CASE 1
        d% = DIALOG(1)
        IF d% = 7 GOTO finishAdjustment
    CASE ELSE
    END SELECT

'get the middle value of displacement
FOR i% = 1 TO (nn+1)/2
    FOR j% = i% TO nn
        IF addd%(i%) <= addd%(j%) GOTO nodd
        SWAP addd%(i%), addd%(j%)
    nodd:
    NEXT j%
NEXT i%
GET #14, addd%((nn+1)/2)+2049
MOVETO 430,175
PRINT INT(CVS(prmt$(1)));" 

'get the middle value of temperature
FOR i% = 1 TO (nn+1)/2
    FOR j% = i% TO nn
        IF adtt%(i%) <= adtt%(j%) GOTO nott
        SWAP adtt%(i%), adtt%(j%)
    nott:
    NEXT j%
NEXT i%
GET #16, adtt%((nn+1)/2)+2049
MOVETO 430,70
PRINT INT(CVS(tt$));" 
GOTO www
CALL cread(2,0,VARPTR(ad%),slot%,VARPTR(er%))  'velocity
MOVETO 430,180
PRINT ad%

CALL cread(3,0,VARPTR(ad%),slot%,VARPTR(er%))  'acceleration
MOVETO 430,205
PRINT ad%

CALL cread(4,0,VARPTR(ad%),slot%,VARPTR(er%)) 'AE rms

www:
MOVETO 430,210 'default value
   PRINT 0
WEND

finishAdjustment:
endAdjustment:
'stop heating device and motor before exit
CALL setDoutbit(6,1,slot%, VARPTR(er%))
CALL setDoutbit(7,1,slot%, VARPTR(er%))

endAdjust:
'close calibration files
'CLOSE #13 'friction force
'CLOSE #14 'displacement
'CLOSE #16 'temperature

endAdjustment1:
WINDOW CLOSE 7
WINDOW 1
DIALOG ON
ERASE adff%, addd%, adtt%
END SUB

domenuAdjst:
   menunumber=MENU(1)
   MENU
   ON menunumber GOSUB doprintSc,doprintWc
RETURN

   doprintSc:
   'PrintScreen 0,0
   'RETURN

   doprintWc:
   'printWindow 8,2
   'RETURN

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Appendix E  Calibrations of sensors

All analogue sensors were calibrated before the experiment. Calibration process was implemented by the integrated software specially designed for the high temperature rolling wear test rig. For each sensor, the whole measurement chain from the physical analogue value (input of the sensor) to digital value (read from A/D converter) was calibrated together.

E.1 Calibration of the load cell

The measurement range of the load cell SM-100 is 100lbs, which is equivalent to 445N. However the largest friction force in the rig is estimated to be less 200N. Thus the sensor is calibrated from 0-200 N. The programmable gain of the amplifier in Macintosh board is set as 1. In the calibrating process, the load cell is mounted vertically and some dead weights are used to apply compressive load on it. The calibration curve is illustrated in Figure A.1. The curve has been cubic-spline-interpolated.

E.2 Calibration of the thermocouple

K-type thermocouple is employed to measure the temperature of contact zone of the roller and the disk. The highest temperature it can measure is more than 800°C. Because the junction of the two wires can not be made very small, and the temperature of
contacting point with the rotating disk is different to the temperature on real junction, the calibration curve is different to the standard property curve of K-type thermocouple.

Figure A.2 shows the calibration curve after cubic spline interpolation. A standard digital thermometer TES 1310 is used to calibrate the thermocouple, whose accuracy is 3%±1°C. This thermometer has a very thin and flat probe which can measure temperature of the object very quickly and sensitively.

E.3 Calibration of the capacitance sensor

Because the exclusive modification of the probe of the capacitance sensor, the characteristic relationship between input and output is quite different to that of the original design of the product. Figure A.3 shows the calibration curve. The relationship is far from linearity. The head of the protective cap has been reshaped to be a concave surface to fit the tapered surface of the roller.
Figure A.1 Calibration curve of load cell SM-100
Figure A.2 Calibration curve of the thermocouple
Figure A.3 Calibration curve of the capacitance sensor
Appendix F  Control curve of temperature

The disk is controlled to be a fixed temperature for the rolling experiments. The actual control curve for 700°C is shown in Figure A.4. It takes 25 minutes to reach the heat balance when the air cooling system is off. Then the cooling system is on before the roller is released onto the rotating disk. It will spend about 10 more minutes to reach the new heat balance at 700°C.

![Temperature control curve](image_url)
Appendix G  Transfer of printing figure

The integrated software can print the screen or active window in the process of an experiment. It can also produce printing file and save the file. In order to recall the file in commercial softwares, such as Microsoft word processing serial softwares, the procedure of transfer should follow three steps:

Step 1, pull down the System menu in the integrated software, and select the print screen or print window submenu to trigger the print command. Then LaserWriter Page Setup window pops on the screen. Change Pager to A4 to suit for the screen print or others for different active windows, change orientation of paper and select Lager Print Area in the Options triggering window if printing screen, because the screen is set to be 14" CRT. After the setting, the corresponding LaserWriter control window pops on the screen. Select the Color/Grayscale as the print mood rather than Black & White, and select PostScript File as the destination rather than Printer. Then the image of the screen or the window in the integrated software is saved as a postscript file. This kind of file occupies a large space in the disk.

Step 2, use Ghostscript to open and view the postscript file and then save it as a PICT file. PICT file occupies relative small space in the disk.

Step 3, insert PICT file into Microsoft word processing software. For example, use the insert picture menu function in Word. Now we can use the embedded drawing editing module in Microsoft word processing software to edit it. In Word, we can firstly rescale it then rotate the drawing of the screen or the window to obtain a satisfactory drawing.