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Petr Novak
Technical University of Ostravia

Jan Babjak
Technical University of Ostravia

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ROOF SUPPORT CONTROL IN LONGWALL TECHNOLOGY

Petr Novák and Jan Babjak

ABSTRACT: The article describes the structure of the selected Support Control System subsystems belonging to the automated longwall equipment complex. It shows some singularities resulting from the application conditions that must be taken into consideration while designing the particular control system, especially power restriction. It demonstrates how the relevant standards of ATEX regulation – coal mine with methane and coal dust explosion hazard – are taken into consideration. The structure of the automated longwall equipment complex is mentioned, emphasizing Support Control Unit (SCU) and meeting the intrinsic safety requirements. The article also describes the external module watch-dog, a communication subsystem, including the solution meeting the intrinsic safety requirements. The technical solution of low-input energizing of electro-hydraulic valves within the limited power conditions is presented.

INTRODUCTION

Modern technologies of black coal mining have necessitated application of automation in this area of human activity. One of the possibilities in mining is longwall technology. It involves a system of automated mining support consisting of a line (up to a few hundred) of hydraulic roof supports. This line forms a longwall where the mining equipment (shearer or coal plough) moves (see Figure 1). At the same time, the hydraulic roof supports ensure safe movement of persons operating and servicing the equipment. In connection with work in explosion-hazard areas (methane in the case of coal mines), increased requirements are placed on this equipment.

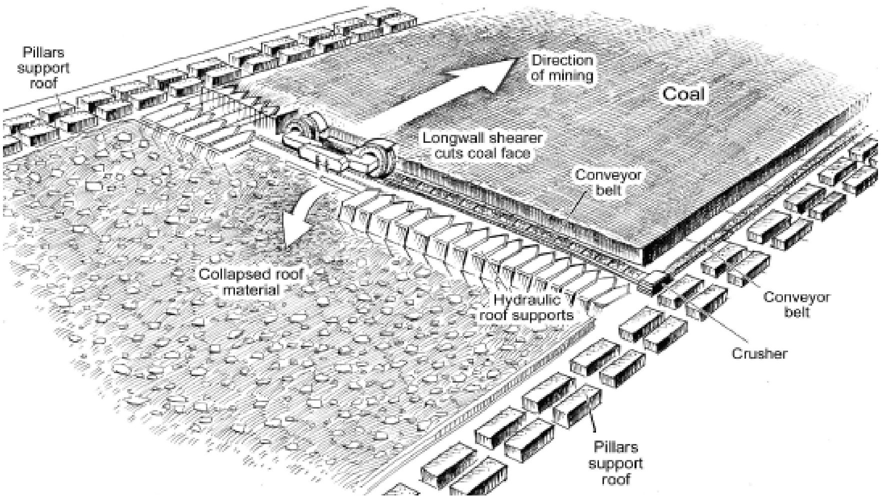

Figure 1 - A typical underground mining operation using longwall mining techniques

AUTOMATION

Automation is primarily based on the fact that by means of their hydraulic drives, hydraulic roof supports can move the track of the conveyor to the space left after drawing coal, and subsequently, the support can be pulled to the conveyor. Thus, the whole mine excavation (longwall) is gradually shifted in the direction of mining and simultaneously there is controlled caving at the back of the longwall.

For the operator of individual supports, the hydraulic medium is used and it is conveyed by arterial line to the individual parts of the support. Each support is equipped with electro-hydraulic valves controlling individual support functions (their number differs with respect to the facilities and the customer's

VŠB – Technical University of Ostrava, Faculty of Mechanical Engineering, Department of Robotics; E-mail: petr.novak@vsb.cz; Tel:+ 420 596993595

particular needs and ranges from 8 to 32 functions). For automated control of these electro-hydraulic valves, each support has its own embedded control module - Support Control Unit (SCU).

CONTROL SYSTEM OF AUTOMATED MINING SUPPORT

The control system for longwall mining technology consists of three parts. In the aboveground part of the mine there is a central computer, a Surface Monitoring System (SMS) intended for remote monitoring and administration of the equipment located underground. In the main gallery near the longwall (usually as a part of power-train) there is Headgate Control Unit (HCU), synchronizing the work of individual supports and the mining equipment itself. The last part of the control system is formed by Support Control Unit (SCU), one for each support – see Figure 2.

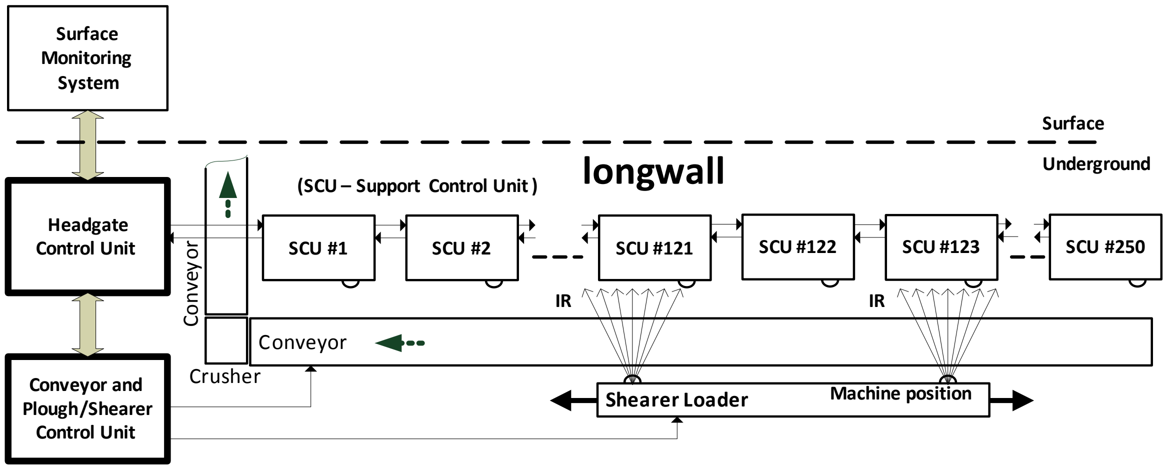

Figure 2 - Longwall – the control system hierarchy

These SCUs are designed in accordance with the relevant standards for work in the environment with explosion hazard based on ATEX Directive.
Described control system SCU is intended for use in environments with potentially explosive methane atmospheres – mines with "I M2 Ex ib I Mb" classification.

I	- Group I: Mines where methane may be present
M2 (Mb)	- Electrical parameters. These products are intended to be de-energised in the event of an explosive atmosphere.
Ex	- Explosive gas atmosphere
Ib	- Apparatus - which is adequately safe with one fault and a factor of safety of 1.5 is considered safe for use in less frequently hazardous areas (Zone 1).
Nothing	- For normal thermal conditions (-20 to +40°C) – not marked.

The type of protection" Intrinsic Safety" is based on the principle of current and voltage limitation within an electric circuit/unit. The energy from a power circuit capable of causing an explosive atmosphere to ignite is thus limited to such an extent that the surrounding explosive atmosphere cannot ignite as a result of sparks or inadmissible surface heating of the electrical components.

The type of protection "Intrinsic Safety" is particularly used in measurement and control technology, as no high currents, voltage and capacities are required here.

Intrinsic safety permits the use of conventional instrumentation cables and cases, thus reducing costs. The intrinsic safety technique is the only technique that permits live maintenance within the hazardous area without the need to obtain 'gas clearance' certificates. This is particularly important for instrumentation, since fault-finding on de-energised equipment is difficult.

Many international standards for intrinsic safety exist throughout the world. The most influential of these is the European Committee for Electrotechnical Standardization (CENELEC). There are several test laboratories authorized to issue approvals of intrinsic safety equipment to CENELEC standards. In North America, these regulations must be verified in each province, state or city since individual locations can differ in their installation and/or application of intrinsic safety. The same is true in Europe where regulations are subdivided into European (EU) and national requirements. The European standards define the general specifications and the detailed guidelines for methods of protection against explosion. The national requirements primarily contain installation requirements. Control module supply for the individual supports is realized by means of a mining power-supply unit in a flame proof enclosures. One unit is able to supply a group of 3-4 intrinsically safe SCUs, connected to a 12V supply branch in parallel - through internal barriers created by imbedded Zener diodes.

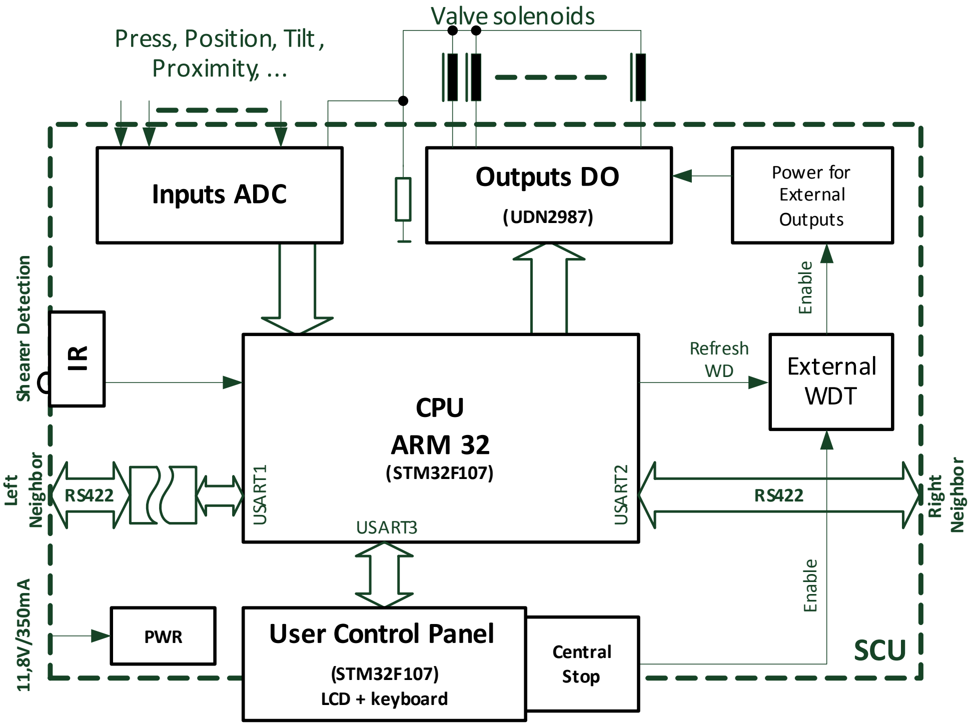

Figure 3 - Schematic diagram of the SCU

Maximum power take-off on each of these devices is defined by standards EN 60079-11 and EN 60079-25 and for a developed system it corresponds to the current of 350 mA at supply voltage 12V (11,8V). This current is limited by a fuse in the unit, which ensures that even in case of the particular device failure, power take-off will not reach the value that could cause thermal impact with a hazard of initiating ignition or explosion. It is necessary to realize that this current supplies both the SCU control system itself and all the action members (solenoids of electro-hydraulic valves) and sensors. This must be considered while selecting them, and also in the way the action members (up to 32) with power take-off approx. 120/60 mA a piece are controlled (see below). Typically used sensors are: absolute sensor monitoring the movable cylinder position, hydraulic pressure sensors, IR sensor for detecting the plough in front of the particular SCU, inclinometer(s), induction contactless position sensors and possibly SCU wireless receiver remote control.

CONTROL SYSTEM SAFETY

Safety of intrinsically safe devices is ensured by several different means. On the supply side, the device is equipped with protective fuse and intrinsically safe barrier. Mutual data communication between individual sections is realized by means of metallic interface RS422 with opto-isolation of individual sections, which eliminates potential fault currents, equalizing the differences in potential in individual parts of the longwall with separate power supply – see Figure 4. If an appropriate technical device (jumper wire) is used, the conception of the power supply system enables to distribute supply voltage from the neighbouring device (on the left). One source thus typically supplies 3 – 4 SCUs.

The control system is also equipped with local stop button for the corresponding part of the longwall, which ensures that within the defined area of the button activation, all support motion functions will be immobilized. This action on a particular support(s) cuts off supply of an individual action members. This shutdown will be realized both through the control logic (by means of activating the corresponding control microprocessor subroutine) and independently – by activating logical circuits outside the control processor. This enables safe shutdown also in case of a control processor fault in the particular section.

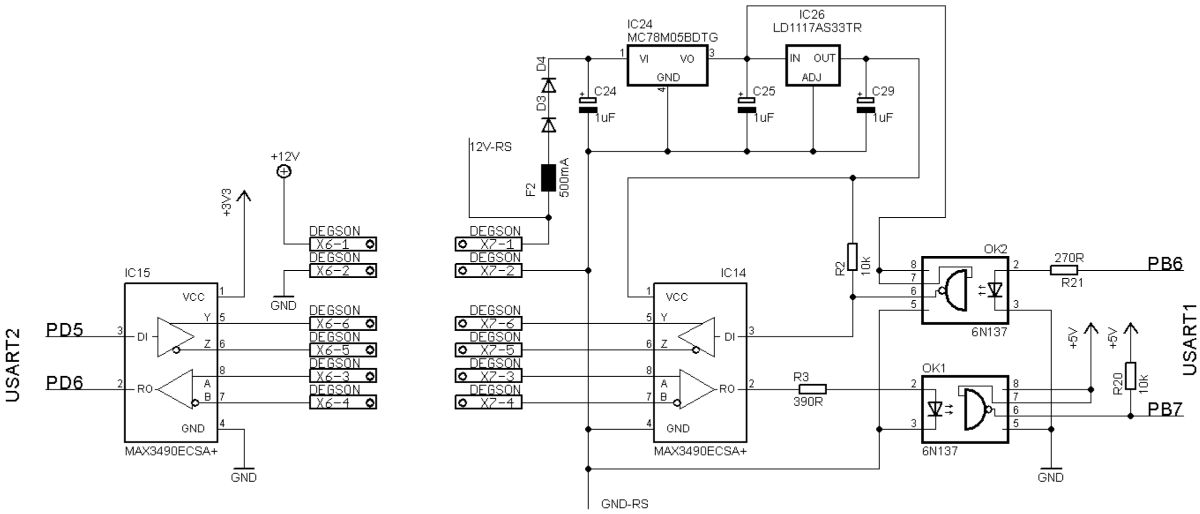

Figure 4 - Circuit of communication subsystem between SCU (optical isolation)

Information on emergency out activation is also transferred by data line to adjacent supports, whose shutdown is, however, only ensured by the SCU logic of the corresponding support.

Another safety element is a set of separate monitoring circuits (Watchdog), which monitors proper function of SCU control processor and in the case of a fault, it can deactivate support also without the need to press the local stop button – see Figure 5.

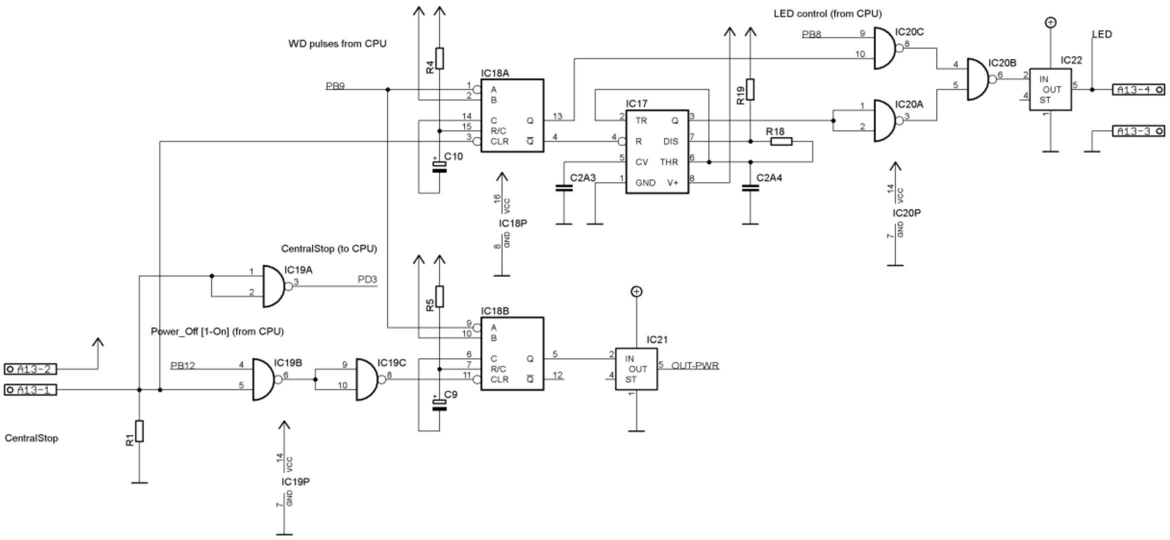

Figure 5 - Example of the external independent watchdog and warning light controller

COMMUNICATION

Communication between the longwall HCU and the SCU's (up to 250 units), and mutual communication among SC Us is realized by means of a full duplex galvanically separated bus with the interface RS422, brought from one SCU to the adjacent one, each SCU forming a transparent reciprocal communication bridge.

Each SCU has its own 1-byte address (ID) and for the sake of simplicity, it is assumed that it forms a regular line from 1 to 250 for the purpose of this text. (However, for operational reasons, it is not always the case in practice). The basic structure of the telegram is showed and explained in Figure 6. The telegram heading is the telegram type: order, request, and reply. The listener corresponds to SCU ID address, where the telegram is sent. The talker corresponds to the sender of the telegram. It is followed by detailed information concerning the message type - message code and possibly data message 4 – 32 bytes long (it depends on message code). The whole telegram is finished by a 4-byte checksum CRC-32 (Ethernet). If the accepted telegram is not related to it (Listener ≠ ID) – it will simply start forwarding it to the adjacent SCU – see Figure 7.

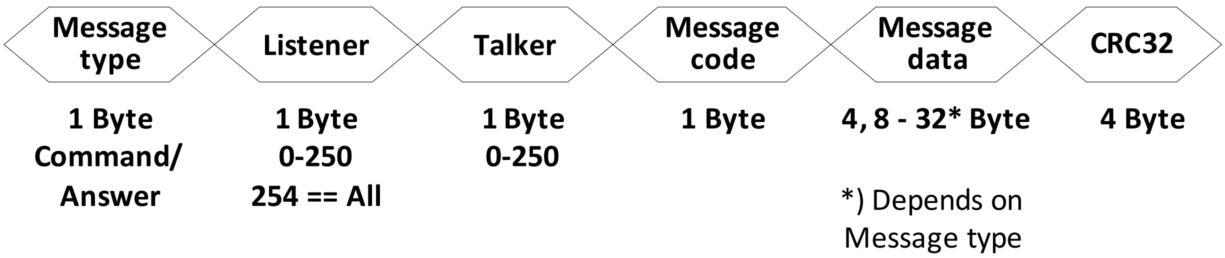

Figure 6 - Telegram structure

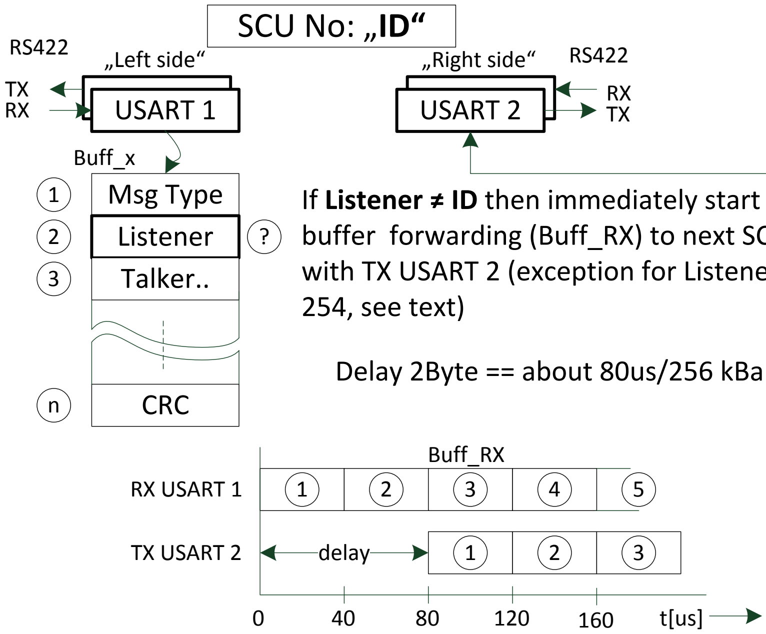

Figure 7 - Communication (only one direction is illustrated)

If the particular telegram concerns this SCU, it is processed after having been completely accepted and according to its type, it responds or forwards the message like in the above mentioned case. The address Listener == 254 is assigned for addressing all SCUs simultaneously – e.g. at the request concerning the current position and direction of the shearer loader machine.

In reality, e.g. in the longwall with 250 SCUs, the longwall HCU can communicate with the 250th SCU by gradually transferring the telegram from the 1st SCU to the last, the 250th one. The potential response to the particular order/request will proceed in the opposite direction. At the same time, SCUs can communicate mutually (typically in an automated mode).

For communication speed of 256 kBauds, the time lag in forwarding the telegram within one SCU is 2Byte, which corresponds to about 80µs – see Figure 7. The maximum time lag between sending by the talker and accepting by the listener will be in the situation when the telegram/message from HCU is sent to the last one, e.g. 250th SCU. In this case, the time lag is compliant with the necessary control dynamics and it is 250 x 80µs = about 20ms.

CONTROLLING SOLENOID FOR THE ELECTRO-HYDRAULIC VALVE

The significant element of the hydraulic roof support control system is a group of electro-hydraulic valves which are energized from the SCU. In some phases, the mining technology requires simultaneous function of several of these electromagnetic units, therefore it is necessary to ensure their minimum consumption. For this purpose, it is possible to use the solenoid coil property; the coil requires multiple-higher current for bringing the coil core closer, compared to the current which is sufficient for keeping it in an active position.

Electronic circuit realizing the above mentioned current limitation is usually integrated directly in the solenoid body. The principle of the solution is based on using series resistance in the batch with the coil; when it is switched on, the resistance is spanned by a semiconductor element for a moment. This interval can be determined by changing the value of R-C member parts for the used timing circuit of the 555 type – see Figure 8. As the graph below shows, this procedure enables the value of the necessary current to be lower for the active valve up to one half (from the initial value 115mA to 56mA) – see Figure 9.

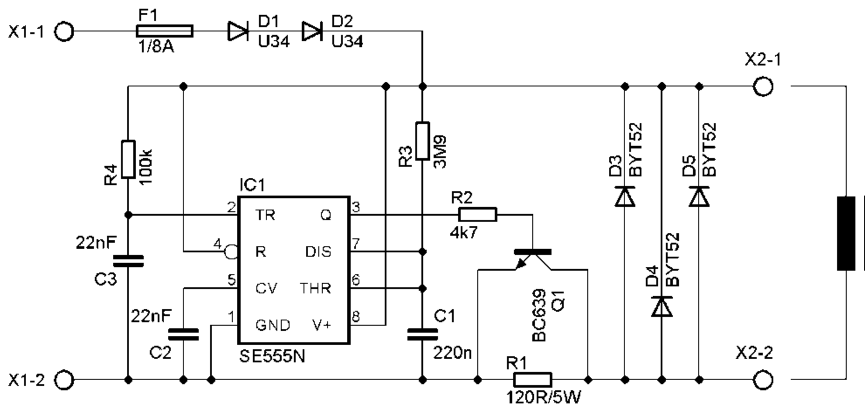

Figure 8 - Electronics of the solenoid

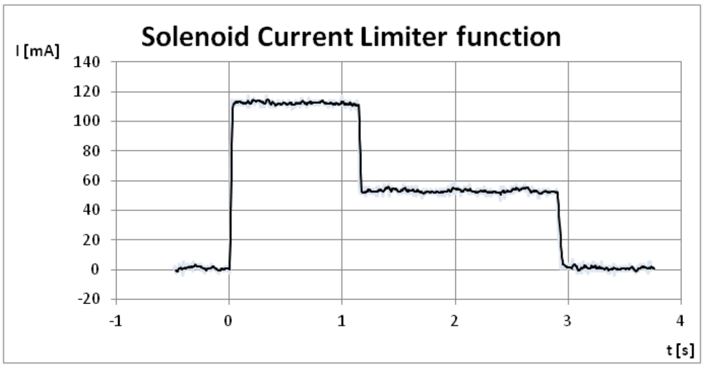

Figure 9 - Current time response of the energised solenoid

This time is necessary for safe mechanical repositioning of the valve and its stabilization in an active position. Owing to this, it is technically possible to energize 3-4 solenoids simultaneously from an intrinsically safe system with limited power; the solenoids are switched gradually with a time lag approx. 1.2 s.

SOFTWARE SAFETY

While developing software for mining equipment control systems, it is necessary to consider and respect safety requirements and requirements for functioning in all the possible conditions and failure states. The programmers have a number of recommendations at their disposal on how to proceed while creating and subsequently testing the control application. One of the universally accepted standards (however, not required by the regulations) includes a set of rules, originally issued by "Motor Industry Software Reliability Association" under the title MISRA-C. It is a set of guidelines for the programmer resulting in code safety, transferability and reliability within the context of integrated systems programmed mainly in the ISO C language (There is also a set of guidelines for MISRAC++).

Microprocessor control systems and their software are also considered in the IEC60335 standard, dividing the equipment reliability into three categories:

- Class A – the equipment safety does not depend on software
- Class B – the equipment safety depends also on software
- Class C – software also ensures prevention from special risks (e.g. explosion)

For the development of the mining section control system, it is necessary to consider the requirements for Class B category (Class C category safety is intended for special applications and, besides other things, it is ensured e.g. by redundant check while using more CPUs and it is not necessary for support control applications).

If the application safety depends on electronic components, it must stay safe even after two consecutive defaults. The software is not taken into account for the first failure: the application must be safe with one hardware failure and MCU not operating under reset or CPU not operating properly. Annex Q of IEC60335 defines precisely in which conditions a class B software is required (see Figure 10)

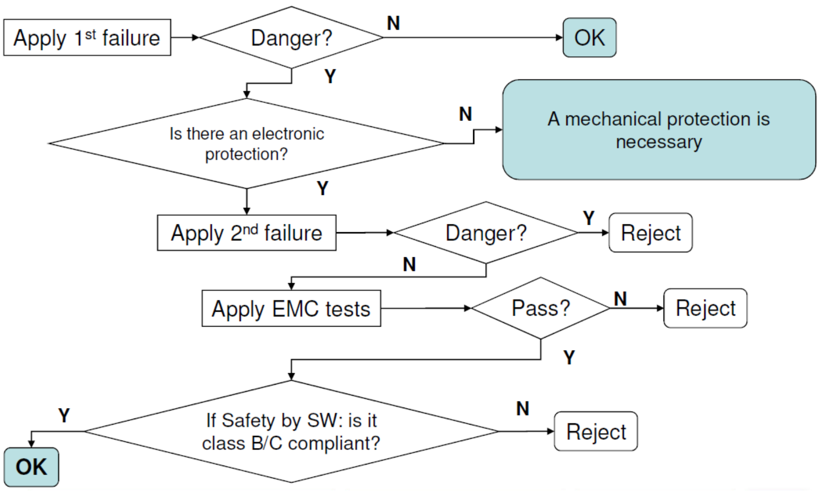

Figure 10 - IEC60335 test flow diagram (simplified)

For developing control system in compliance with these requirements, the producer of the microcontroller usually offers both software and hardware tools.

- Hardware standpoint – Dual watchdog architecture on chip (one has its own independent clock (Resistor - Capacitor oscillator based), the other is windowed). Both are started by hardware (option byte in flash, not depend on software). Dual internal RC oscillators and versatile clock circuitry allows frequency deviations detection.
- Software standpoints – Class B self-diagnostics routines for microcontroller (RAM, Flash and core integrity testing).

Application of these tools enables the creation of a control system which can ensure defined behaviour (mainly safe shutdown) after detecting various faults in the equipment electronics, like the CPU programmed memory damage and other problems (interference, power supply drop, processor hourly signal failure). Testing can be carried out in two modes:

- At power-up
  - CPU registers self-test
  - Watchdog self-test (even if not directly required by the standard)
  - Flash integrity check with a 16-bit CRC
  - RAM function test (using March C –algorithm)

- External clock frequency measurement
- A "self-test start up" including function calls and logical sequence monitoring

- During run-time
  - CPU registers self-test
  - Transparent RAM functional test (March C and March X algorithm available)
  - External Clock frequency measurement
  - Stack overflow monitoring (even if not directly required by the standard)

A number of these tests are supported by some ARM processors from both a technical and a software standpoint. Safe software must be able to detect the above mentioned problems and respond in a defined, programmed way, to ensure safe shutdown, to alert the operators or possibly to carry out automatic restart and assess whether the problem lingers on.

CONCLUSIONS

The article described the construction of the control system intended for the hydraulic roof support control used in longwall mining techniques – see Figure 1. It specified the ATEX requirements for a coal mine with methane and coal dust explosion hazard. The SCU control system is designed as intrinsically safe. It also characterized the conception of the external Watchdog Timer (WDT) circuit monitoring SW run and controlling the action members – electro-hydraulic solenoids – supply. As far as energising electro-hydraulic valves is concerned, the article described how they are controlled with reduced consumption. It also characterised the communication subsystem on the basis of the bus RS422, including the telegram format with CRC securing. The telegrams are transferred among up to 250 SCUs with emphasis on minimisation of time lags.

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