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DETERIORATION OF DYNAMIC RAIL PAD CHARACTERISTICS

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SUMMARY

Impact loads applied to concrete sleepers, either due to the wheel flats of a train or rail abnormalities, may cause the sleepers to crack. The rail pads have been used to attenuate the effect of these impact loads on concrete sleepers and on the substructures in ballasted railway tracks. The rail pads experience high intensity loads due to wheel impacts and, as a result, the pad properties deteriorate during the service life. The consequences can be significant for the dynamic behaviour of railway tracks, interaction of vehicle and track, and impact forces on track components. However, there is currently no standard method available that can be used to evaluate the dynamic characteristics of the pads.

In this paper, the degradation of rail pad properties as a function of their in-service life is studied with a view of developing a technique for predicting the optimum period of track maintenance with regard to pad replacement. Identification of structural properties using methods of experimental modal analysis provides a means for investigation of the deterioration of dynamic pad characteristics. A technique using an instrumented impact hammer is employed in this study. The pad samples were collected from the railway lines in Sydney Electrified Network, Australia, which are operated by Rail Corporation New South Wales (RailCorp). Through testing of pads in a recently developed rail pad testing machine, the vibration responses were measured in the frequency range from 0 to 1000 Hz using the Bruel & Kjaer PULSE Vibration Analyser system. The analytical solution was derived to estimate the dynamic stiffness and damping constants of the worn pads from the obtained experimental data. The rates of deterioration based on limited data are proposed to predict the useful lifetime of pads and the period of pad replacement.

In this study, the type of rail pad used was the high-density polyethylene (HDPE) pad with 5.5 mm thickness. All worn pads were sourced from RailCorp tracks with approximately 22 MGT (million gross tons) annual tonnage. Based on linear regression analysis, it has been determined that at 20 kN preload (equivalent to PANDROL e-Clip fastening system clamping force) degradation of dynamic stiffness and damping is about 2.2 MN/m and 19.6 Ns/m per MGT, respectively, for the particular track conditions.

1. INTRODUCTION

In the design, construction and maintenance of railway track, it becomes more and more important to establish reliable engineering properties of the railway track components in their current state. Not only is this information typically required for numerical modelling of track structure to predict the response to a variety of dynamic loadings, but also its use in practical track works is critical. The dynamic properties of track components can be used as the structural health condition indicators to facilitate the processes of maintenance and replacement of the track components. Better understanding of the interaction between the service conditions and the dynamic properties of rail pads will facilitate the prediction of pads' service life and subsequent renewal periods of the

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railway track structures. However, it requires a number of dedicated testing methodologies to establish these properties and relationships to predict the degradation characteristics.

In Australia, the traditional ballasted track system is used throughout for transporting coal, cement, freight, and people. Rail pads are installed on rail seats in order to attenuate the dynamic forces from axle loads and wheel impacts, thus preserving concrete sleepers against cracking. Hence, rail pads is one of critical track components for which track engineers require knowledge of its dynamic parameters after a given number of years in service in the particular track conditions.

To help with making a decision about rail pad replacement, identification of their current condition could be performed. The relationship between the dynamic properties and the in-service conditions could provide the important information about the current performance of rail pads [1]. The “age” of the rail pads can be approximately established by multiplying the annual tonnage (usually in MGT) of the track by the number of years in service and taking into account the wheel load distribution factor. To determine the relationship between the dynamic characteristics of worn rail pads and their “age”, it is required to develop experimental techniques that would be capable of producing the dynamic pad parameters under controlled conditions similar to those in a real track.

There are currently many types of rail pads, such as high-density polyethylene (HDPE) pads, polyurethane pads, natural rubber pads, and resilient elastomer pads, all of which have different surface profiles and different properties [2]. An example of HDPE profile (5.5 mm thick, widely used in NSW Suburban Network) is illustrated in Figure 1. So far, there have been a number of studies on the dynamic characteristics of resilient pads [3,4,5]. Recently, Kaewunruen and Remennikov [6] have presented a simple and effective strategy for monitoring the structural health condition of rail pads. However, it has not been a great deal of studies on the degradation of rail pad characteristics at different ages.

Figure 1: HDPE 5.5 mm pad

In this paper, a single-degree-of-freedom (SDOF) based method [5, 6] is adopted to evaluate the dynamic parameters of new and worn rail pads with the static preload condition. These are required for the analysis, design and maintenance of railway tracks. A SDOF dynamic model was utilised to fit the measured vibration responses in terms of acceleration. To measure vibration responses, the railhead or upper mass is struck by using an instrumented hammer. The frequency response functions (FRFs) obtained from modal testing measurements are best fit to estimate such parameters as the dynamic stiffness and damping of rail pads for different ages of pads.

There are many factors that would influence pad deterioration e.g. axle load, high rail vs low rail, speed, track irregularities, sand contamination, loss of toe load on clip, etc. At this stage, the research covers exclusively the effect of MGT amounts and preloads on the rail pad dynamic behaviours.

2. NOTATION

This technical paper makes use of symbols and other specialised nomenclature as defined as follows.

$H(f)$ = frequency response function (Nm/s^2)

f = loading frequency (Hz)

m = effective mass of rail or upper part (kg)

c_p = damping value of rail pad (Ns/m)

k_p = dynamic stiffness of rail pad (N/m)

3. MODAL ANALYSIS

The rail pad testing apparatus of the University of Wollongong has been designed and built as part of the CRC for Railway Engineering project. The machine simulates the SDOF dynamic system as shown in Figure 2. Remennikov and Kaewunruen [1] derived the analytical dynamic transfer function for the rail pads idealised as a simple mass-spring-damper SDOF system. The magnitude of the frequency response function $H(f)$ is given in terms of frequency f and dynamic properties of pads k_p and c_p by the following formula:

$$H(f)=\frac{1}{m}\frac{4\pi^2\left(\frac{m}{k_p}\right)f^2}{\sqrt{\left[1-4\pi^2\left(\frac{m}{k_p}\right)f^2\right]^2+\left[4\pi^2\left(\frac{m}{k_p}\right)\left(\frac{c_p^{\,2}}{k_p m}\right)f^2\right]}}$$

(Eq.1)

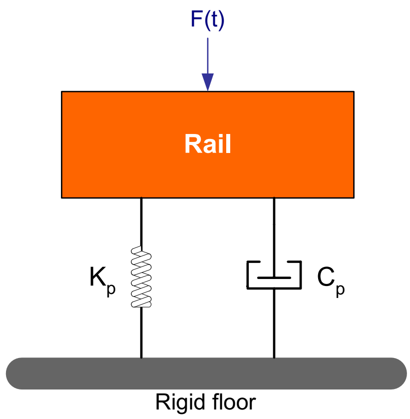


Figure 2: SDOF system (after [1])

Based on Eq.(1), these dynamic parameters can be extracted using modal testing measurements either in the laboratory or in the field.

4. WORN RAIL PADS

The rail pads were collected from a railway network operated by Rail Corporation (RailCorp) in Sydney electrified areas of New South Wales, Australia. Two groups of used rail pads, after 99 MGT (18 years in service) and 110 MGT (20 years in service), were evaluated. The tonnages were calculated with a reduction distribution factor of four (2 sides of about 50% re-distribution of the axle tonnages). This is the tonnage that the pad at the rail seat experiences. Figure 3 shows the samples of worn pads, HDPE 5.5mm, used in this study. The new pads of the same type, provided by PANDROL Australia, were tested using the identical technique.

5. EXPERIMENTATION

A base-isolated experimental rig for dynamic testing of rail pads (the so-called '*pad tester*') has been developed at the University of Wollongong. As shown in Figure 4, the lower steel block is rigidly mounted on a concrete foundation block. The upper steel block in movable in the vertical direction and represents the dynamic mass of the system. The rail pad is placed between two steel blocks and is preloaded by means of four force sensing bolts. The concrete block is isolated from surrounding noise by placing on the very soft rubber plate between the block and the strong floor representing the absolutely rigid foundation. An accelerometer is mounted on the upper steel block, as illustrated in Figure 4. An instrumented impact hammer is employed to impart excitation to the assembly of components ten times. The frequency response function (FRF) is then obtained using the PULSE dynamic analyser in a frequency range from 0 to 1,000 Hz. The coherence function is also obtained to evaluate the quality of FRF measurements, which were averaged from the 10 hits.

In this study, the dynamic parameters of both new and worn PANDROL HDPE 5.5 mm pads were obtained using the rail pad tester. For comparison, the preloading bolt system was employed to control the static preload of 20 kN on the rail pads. The frequency response functions (FRFs) of the new and worn pads at different ages are presented in Figure 5.

Note that the preload on the pads was fixed to 20 kN, which corresponds to the clamping force of two railclips.

a) after 99 MGT in service on RailCorp track

b) after 110 MGT in service on RailCorp track

Figure 3: Worn rail pads

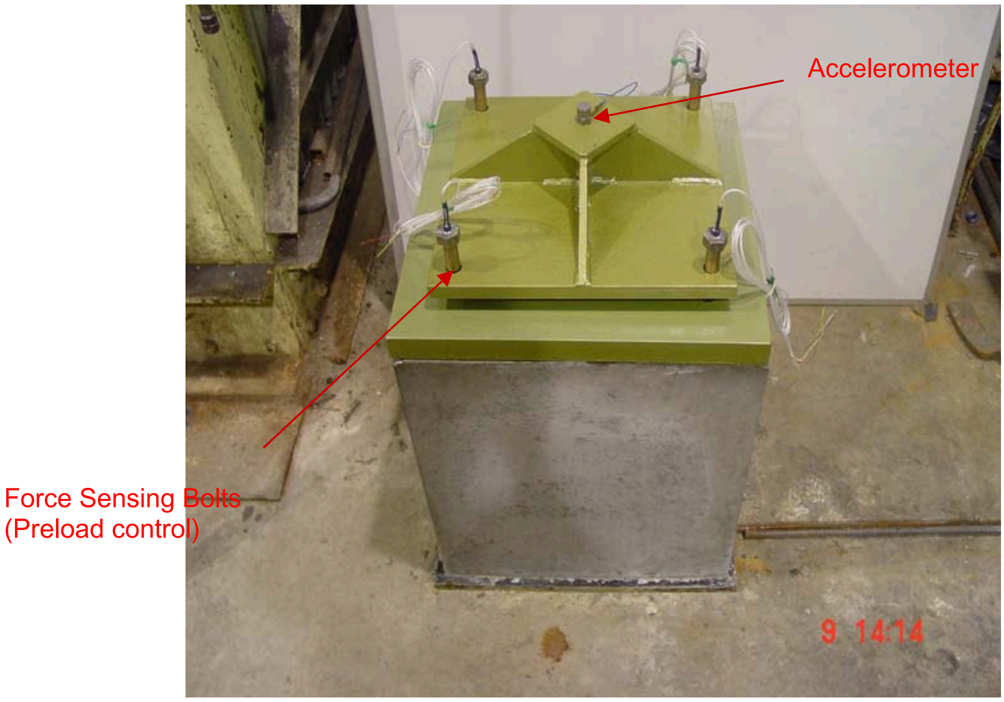
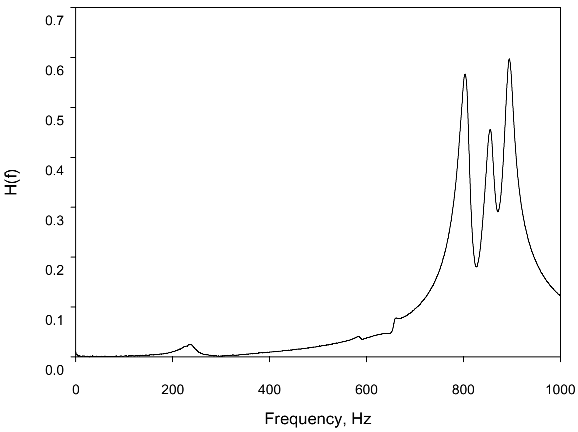
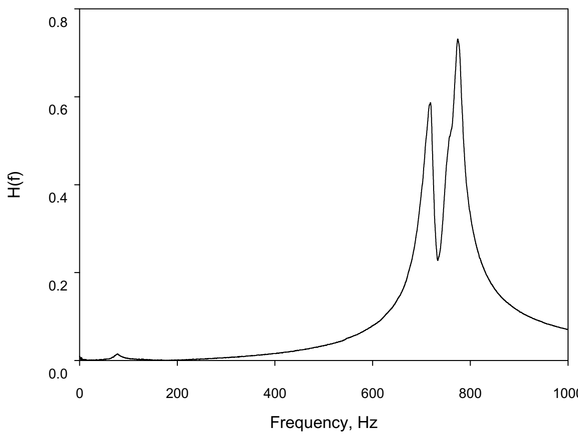


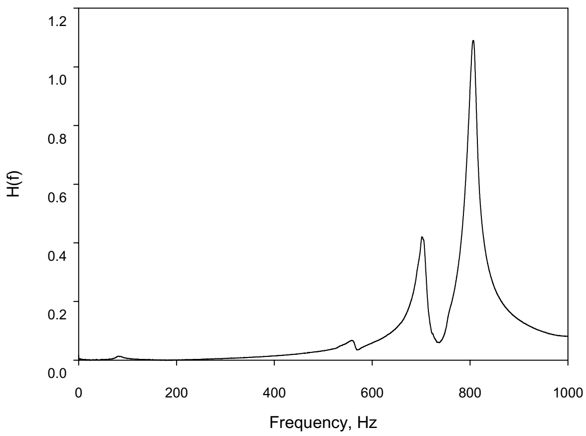
Figure 4: Detailed View of Rail Pad Tester



a) new pad



b) after 99 MGT in service on RailCorp track



c) after 110 MGT in service on RailCorp track

Figure 5: FRFs of new and used rail pads under 20 kN preload

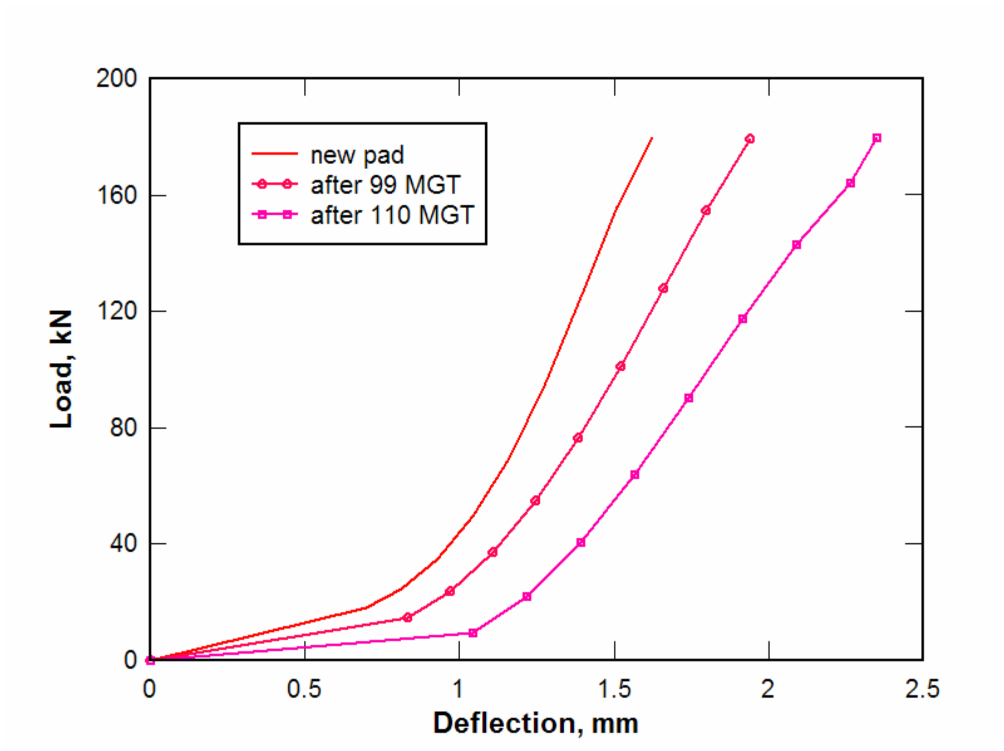


Figure 6: Load-deflection curves of rail pads

6. RESULTS

To evaluate the static stiffness of the pads, the new and worn pads were tested using incremental preload. By means of force sensing bolts, the static behaviour of rail pads was determined. The nonlinear load vs. deflection curves for three groups of pads are shown in Figure 6. By comparing the slopes of the load vs. deflection curves one can see that the static stiffness degrades with the increased age of pads. The level of energy absorption by the new and worn pads, as represented by the hysteresis loops in the static load-deflection curves, is still being investigated and will be reported later.

The best-curve-fitting optimisation approach is utilised to extract the structural parameters of rail pads such as dynamic stiffness and damping values. By using the analytical formulation for frequency response function (FRF) associated with a SDOF system in Equation (1), the best fitting of the experimental measurements of FRFs can be done based on the least squares method. The curve-fitting algorithms are generally available from many of either general or scientific computational software packages (e.g. MATLAB, Mathematica, Maple), or by using specialised curve-fitting computer codes (e.g. DataFit). Figure 7 demonstrates the curve fitting performed by the computer program DataFit [7].

Table 1 shows the changes of the resonance frequencies for the new and worn pads. It can be seen that the resonance frequencies of the worn pads are from 5 to 15 percent lower that those of the new pads. It should be noted that the fluctuating result reflects the fact that rail pads that have been collected at different locations perform differently even in the same area. Also, Table 1 presents the changes of the dynamic properties of the rail pads determined using the curve fitting approach. The values of stiffness and damping were averaged from the results for three sampling pad tested. The maximum correlation error of curve fitting was found to be less than 4% for all pads.

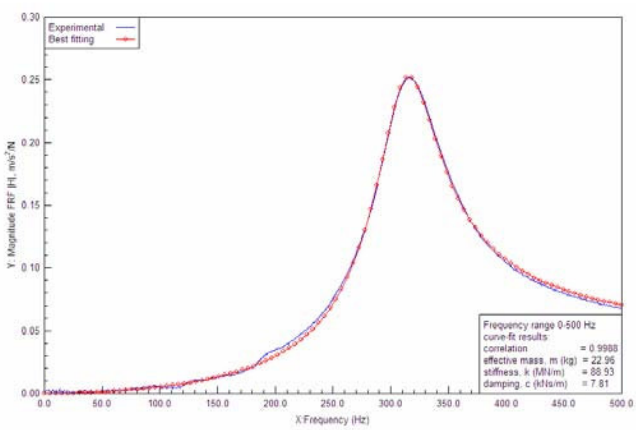


Figure 7: Best curve fitting of single FRF

Table 1 Deterioration of rail pad characteristics (HDPE5.5mm)

Age of Pads	Frequency (Hz)	Damping, C (kNs/m)	Stiffness, K (MN/m)
New	841	8.3	1,200
99 MGT (18 years)	718	8.0	750
110 MGT (20 years)	804	4.6	1,000

From Table 1, it appears that the stiffness and damping characteristics of the worn pads gradually deteriorate with increased age. At this stage, the data on the worn pads are only available for three age groups. The more rigorous statistic data will be obtained. Using linear regression analysis, the dynamic stiffness is predicted to deteriorate with the rate of about 2.2 MN/m per 1 MGT, while the damping coefficient reduction is about 19.6 Ns/m per 1 MGT. It should be noted that the more comprehensive study of the attenuation characteristics of the worn pads under impact loads is currently under way.

7. CONCLUSION

Dynamic properties of the structural components can be used for monitoring the structural system health and the rate of deterioration. Experimental modal analysis is a non-destructive testing methodology, which has proven to be a fast and effective test method for identification of the dynamic stiffness and damping constant of the components of railway track including the rail pads. This paper presents the details of the rail pad testing device for the experimental assessment of the dynamic parameters of all kinds of rail pad types. Using this device, the deterioration of dynamic pad characteristics has been studied.

The dynamic characteristics of rail pads, such as the resonance frequency, dynamic stiffness, and damping constants have been determined for the new and worn pads. It should be noted that all tested pads were of high-density polyethylene (HDPE) type with 5.5 mm thickness collected from a RailCorp track. Based on the linear regression analysis of the available results, it has been found that the rate of deterioration of the dynamic stiffness and the damping constant for the particular track conditions is about 2.2 MN/m and 19.6 Ns/m per MGT, respectively. This information could be important for track maintenance engineers in order to make decisions about the replacement periods for the rail pads.

Further studies are required that involve more pad types and samples of various ages in order to evaluate the relationships between the rate of deterioration of dynamic pad characteristics and the attenuation effects on impact load, tensile and compressive strain in concrete sleepers.

8. ACKNOWLEDGEMENT

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