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RESPONSE AND PREDICTION OF DYNAMIC CHARACTERISTICS OF WORN RAIL PADS UNDER STATIC PRELOADS

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Abstract

Rail pads are a major component of ballasted railway tracks. It helps attenuate the excessive dynamic stress from wheel/rail impact forces in order to prevent premature breakdown of other track components. Based on numerous analytical and numerical models, rail pad plays a crucial role on the dynamic behaviours of railway track. Over years, the rail pads have been worn by the services to carry either passenger or freight train operations. The characteristics of worn rail pads become imperative to maintenance unit as to plan the renewal schedule. Using methods of modal analysis, this paper adopts an instrumented hammer to excite an innovative rail pad test rig, modelled as an equivalent single degree-of-freedom system (SDOF), incorporating a rail pad as a resilient element. The test rig can allow the static preloads to the worn rail pads through the force sensing bolts up to 400 kN at a railseat. The vibration responses are then recorded using Bruel & Kjar PULSE system. The analytical SDOF dynamic model was applied to best fit the experimental modal measurements that were performed in a frequency range of 0-800 Hz. The curve fitting provides the dynamic parameters as the effective mass, dynamic stiffness, and dynamic damping constant, all of which are required for numerical modelling of a railway track. This would lead to a time-variable dynamic evaluation of dynamic behaviour of railway track.

1. INTRODUCTION

A significant factor driving the growth of both economy and society of any country around the world is transportation. It is commonly believed that the best and safest solution for transportation of either passenger or freight nowadays is the railway system. Among the modern types of railway tracks, the ballasted railway track is often used for those purposes in remote and rural area. The ballasted track gains advantage from its cost-effectiveness in construction, maintenance, and renewal. Esveld [1] also confirms that ballasted railway track has many advantages; for example, the construction costs are comparatively low, the maintenance and repair of track and its components are convenient, it has high damping characteristics and very good drainage properties, and noise and ground-borne vibrations can be controlled. By nature, loading conditions for railway tracks are of dynamic, impact force [2]. It has been found that wheel/rail interactions result in much higher-frequency and much higher-magnitude forces than simple quasi-static loads. These forces are often called as '*dynamic wheel/rail*' or '*impact*' forces. The typical impact loadings due to train and track vertical interaction has been presented in ref [3] with particular reference to the shapes of the typical waveforms of impact loads generally found in railway track structures. Accordingly, understanding the dynamic track responses is essential in order to evaluate the structural safety and service life of the railway track components. The ballasted railway track consists of two main groups including super-structure and sub-structure. The super-structure is made up of steel rails, the fastening systems and railway sleepers (or so-called 'railroad ties' in the US); whilst the ballast, sub-ballast, sub-grade and formation, form the sub-structure. Figure 1 illustrates the ballasted track components.

A rail pad is a major track component used in ballasted railway tracks worldwide. It is mostly made from a polymeric compound, rubber, or composite materials. The rail pads are installed on rail seats and designed to attenuate the dynamic stress from axle loads and wheel impact from either regular or irregular train movements. The wheel load from train passages and the rail fastening system provide dynamic and static preloading to the track, respectively. This wheel load pressing on the track causes local deformation and consequent preload on its components. The toe load can increase to as much as 150-200 kN when a wheel burn strikes the railhead [3, 4]. In most situations, dynamic responses of the railway tracks are directly associated with noise and wear problems in railway track environments. Due to a lack of information, the current numerical models or simulations of railway tracks mostly exclude the effect of preloading on the dynamic behaviour of rail pads, although it is evident that preloading has a significant influence on dynamic rail pad properties that affect the dynamic responses of railway tracks [5-8].

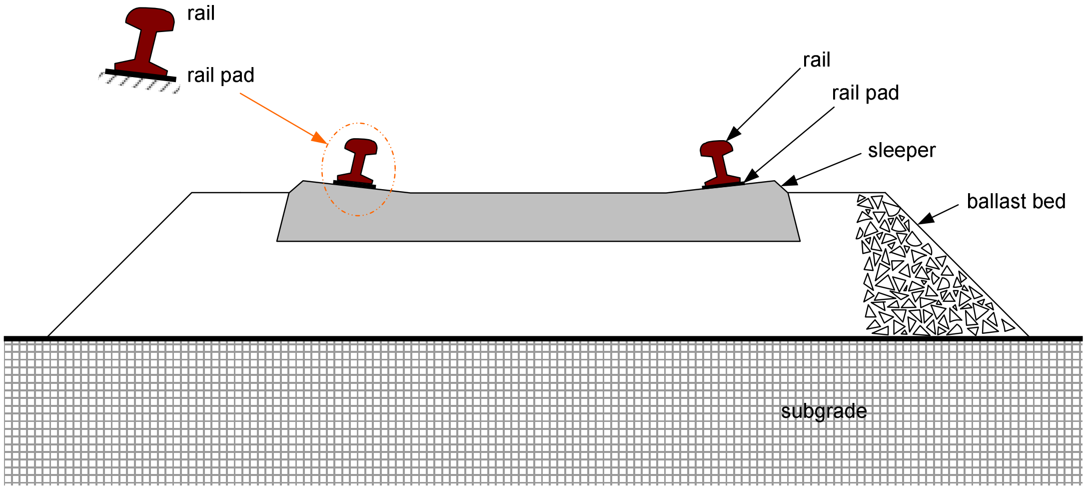


Figure 1 Typical ballasted track structure

Figure 2 HDPE rail pad (5.5mm thick)

There are currently many types of rail pads such as high-density polyethylene (HDPE) pads, resilient rubber pads, and resilient elastomer pads, all of which have different surface profiles and distinctive engineering properties. Figure 2 features the selected type of pads, namely the HDPE rail pads. This type of rail pad is extensively used in New South Wales' railway network. The dynamic behaviour of rail pads is generally represented by two key parameters: dynamic stiffness and damping coefficient. Sometimes, more variables are needed and a nonlinear dynamic model or so-called '*state-dependent viscoelastic model*' might be adopted. To obtain such properties, the dynamic testing of rail pads in the laboratory or on the track is required. From the dynamic response measurements, both linear and nonlinear properties can be estimated by optimizing the objective formulations of the desired dynamic model. Modeling rail pads as a '*spring and viscous dashpot in parallel*' seems to be a very practical means for the railway industry. The parameters can be obtained conveniently, and this model is often applied to various studies on vertical vibrations of railway tracks [6-11]. A number of publications have recently addressed the dynamic characteristics of resilient pads [12-17]. From the literature, the single-degree-of-freedom (SDOF) dynamic model of rail pads has been used in a number of investigations as well. The instrumented hammer impact technique is widely used in this kind of tests due to its proven effectiveness and mobility. Most of the above-mentioned studies discuss the effects of loading frequency that tend to induce potential problems to railway tracks (e.g., noise, wear, etc). It has been shown that the loading frequency may increase the dynamic stiffness of rail pads, and plays a significant role in the level of damping provided. However, the influence of large preloads on the degraded pads, which might cause problems to the track environment, has not yet been investigated.

In this paper, a SDOF-based method is adopted to evaluate the dynamic parameters of worn rail pads with various preload conditions. These are required for the design and maintenance of railway tracks. A SDOF dynamic model was utilised to fit the measured vibration responses in terms of acceleration. The instrumented hammer impact technique is adopted in order to benchmark with the field trials [18-19]. Figure 3 demonstrates the test setup of the rail pad tester developed at the University of Wollongong. This test rig takes advantage of the modern force sensing bolt that can resist large loads up to 100kN each. An analytical solution for a frequency response function was used to best fit the vibration responses. Vibration response records were obtained by impacting the upper segment with an instrumented hammer. In this paper, the effective mass, dynamic stiffness and damping of resilient-type rail pads are obtained from the least-square optimisation of the frequency response functions (FRFs) obtained from the modal testing measurements. The demonstrations provided focus on the response and prediction of dynamic characteristics of worn pads.

2. EXPERIMENTAL OVERVIEW

In this study, an innovative pad tester has been developed based on the SDOF dynamic system as illustrated in Figure 4. Remennikov and Kaewunruen [15] derived an analytical dynamic transfer function of 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 by:

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

Based on Eq.(1), these dynamic parameters can be extracted using modal testing measurements either in the laboratory or in the field. Note that the rail pads are deteriorated in relation to the quantity of train passage (MGT) and the nonlinearity in FRFs is negligible.

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)

Figure 3 Innovative rail pad tester

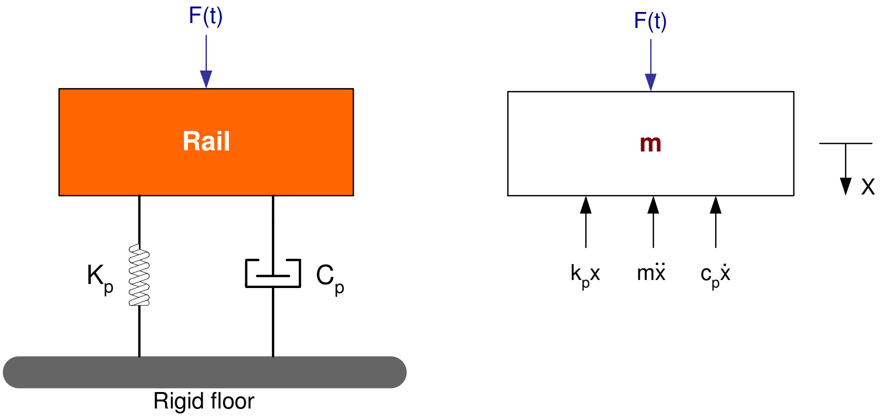


Figure 4 SDOF system

2.1 Worn rail pads

The rail pads were collected from a railway network operated by Rail Corporation (RailCorp) in 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. Figure 2 shows this type of rail pad, HDPE 5.5mm, used in this study. The new pads of the same type, provided by PANDROL Australia, were tested using the identical technique.

2.2 Experimentation

A base-isolated experimental rig for dynamic testing of rail pads (so-called '*pad tester*') has been developed at the University of Wollongong [15]. As shown in Figure 3, the test rig consists of a concrete block that supports steel mass, preloading bolt system, and a rail pad. The concrete block is isolated from surrounding noise by placing on the very soft rubber plate between the block and strong floor representing the absolutely rigid foundation. An accelerometer is installed on the upper steel mass, as illustrated in Figure 3. An instrumented impact hammer is employed to impart excitation to the assembly of components for 10 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.

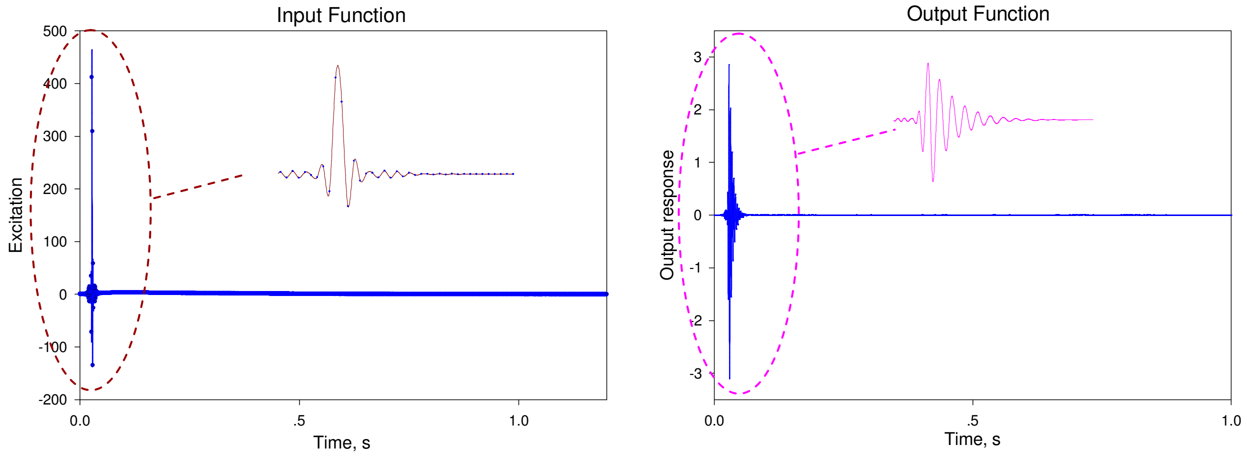
In this study, the dynamic parameters of both new and worn PANDROL HDPE 5.5 mm pads (flat type) were obtained using the test rig. The preloading bolt system was employed to control the static preload on the rail pads. The dynamic response and frequency response function (FRF) of the new pad, subject to 20kN preload, are presented in Figure 5. Note that the company's recommended properties are usually based on a 20 kN preload, representing the clamping load from the fastening system (PANDROL e-Clip system)

3. RESULTS AND DISCUSSIONS

Variations of the incremental preload during excitation have been statistically detected for about 1%-4% of each instant preload during the tests. The excitation was given through the impact hammer and the frequency response function was obtained using PULSE after each preloading. Figure 6 shows the examples of curve fitting using DataFit [20].

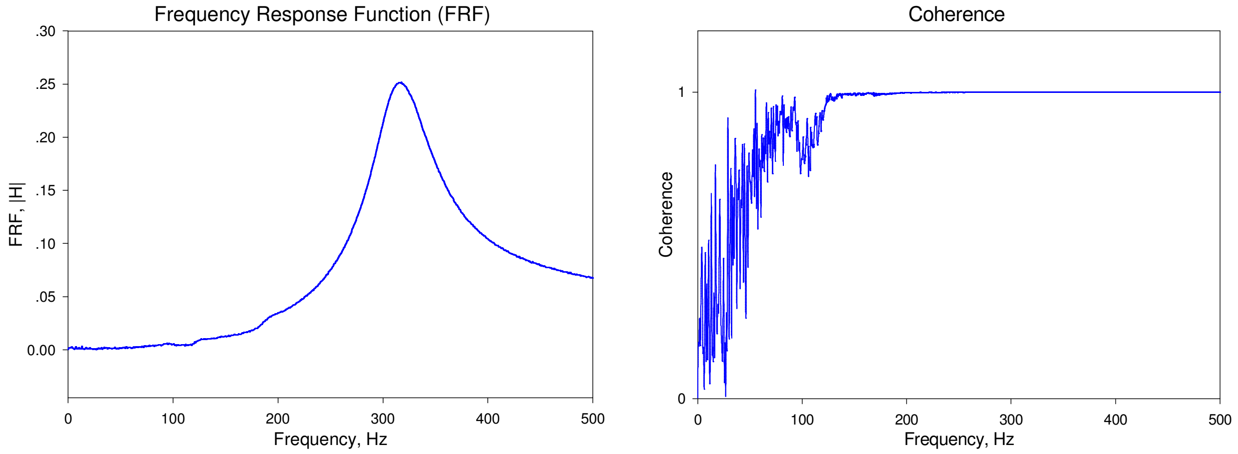
Both new and worn pads had incremental preloads applied to them. By means of force sensing bolts, the static behaviors of rail pads can be determined. It appears that the stiffness of rail pads increases with static preload as the slope of the curve becomes much steeper in the large loading region. However, when comparing worn pads, it can be seen that the stiffness reduces with the age of the pad. New pads seem to have the highest energy absorption capacity, while the level of the energy absorption diminishes with the age of used rail pads. Figures 7 and 8 show the determined dynamic stiffness and damping of worn rail pads under preloads using the curve fitting approach. The maximum correlation indices of curve fitting were found to have less than 4% error for all pads.

It appears that the stiffness and damping coefficients of aged pads are gradually reduced. The relationships between resonance frequency and preload, and between dynamic stiffness and preload are promising. At this stage, the aged pad data are available only for three different ages. Using linear regression analysis for the results at 20 kN preload, the dynamic stiffness can be estimated to deteriorate at the rate of about 2.18 MN/m per 1 MGT (or 12 MN/m per year), while the damping value reduces at about 19.63 Ns/m per 1 MGT (or 108 Ns/m per year). However, it can be seen that the damping values fluctuate in a limited range. This is because the aged rail pads have been compressed greatly from long service and consequently they are stiff but worn.



a) transient forcing function

b) transient dynamic response



c) FRF

d) coherence function

Figure 5 Vibration response measurements using impact instrumented hammer

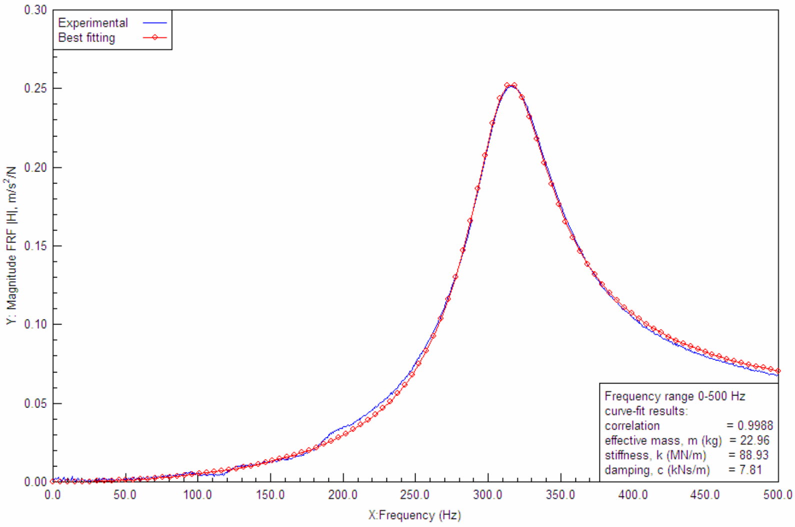


Figure 6 Best curve fitting using DataFit

It is also found that once the preloading is high enough, its influence on the damping constant of this type of rail pad becomes insignificant. These findings will be further investigated by a more comprehensive study of rail pads of different ages in the near future.

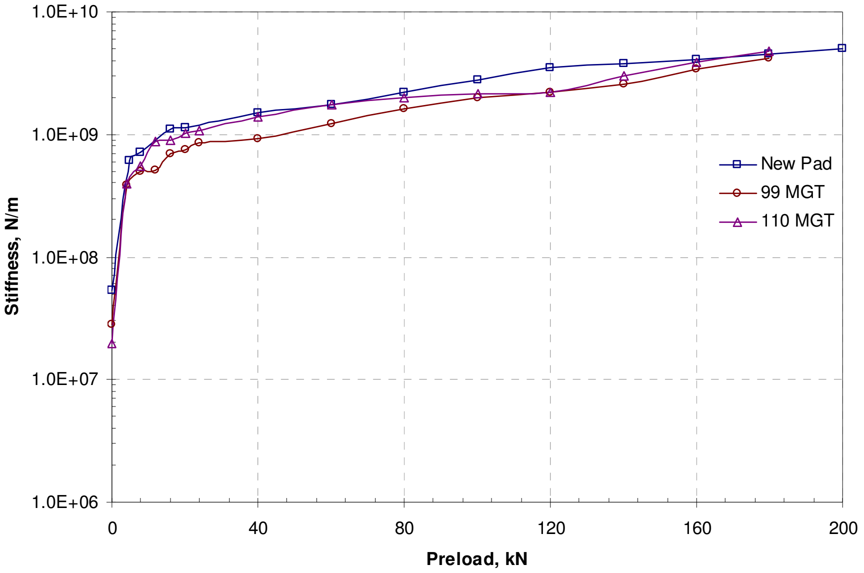


Figure 7 Effect of preload on dynamic stiffness of rail pads

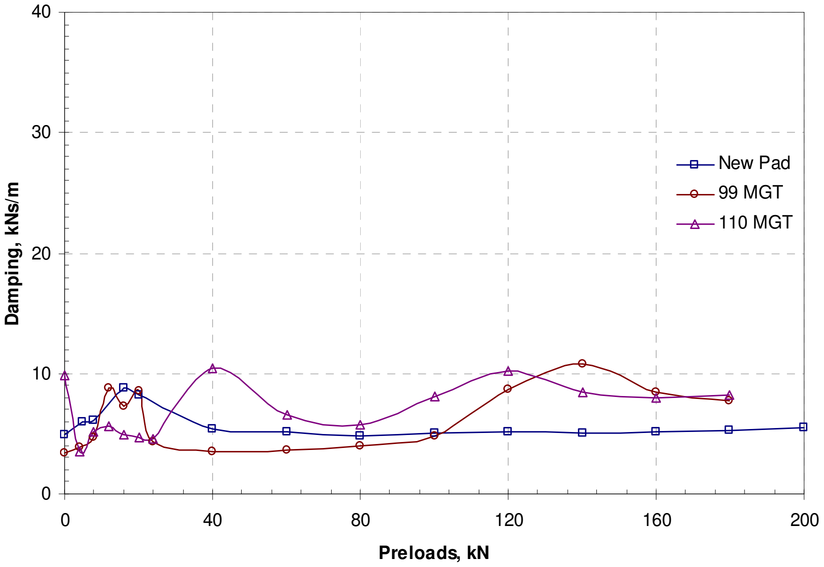


Figure 8 Effect of preload on dynamic damping of rail pads

4. CONCLUDING REMARKS

Dynamic properties of structural/mechanical components can be used for a number of applications to railway track dynamics such as analysis, modeling, and, as presented in this paper, monitoring the structural degradation rate. Presented in this paper are the response and prediction of the dynamic characteristics of worn rail pads, as the key indicator for the structural degradation rate of rail bearing pads. The dynamic characteristics of rail pads, such as resonance frequency, dynamic stiffness, and damping values, have been highlighted. Based on the linear regression of the results, it can be approximated that the per-MGT rate of rail pad degradation in terms of dynamic stiffness is about 2.18 MN/m and the rate for the damping is approximately 19.63 Ns/m. It should be noted that this type of pad is a high-density polyethylene (HDPE) pad with 5.5 mm thickness. Nonetheless, this information is imperative to track maintenance and renewal divisions in order to make decisions and plan optimum track implementation. In addition, RailCorp Sydney NSW and Queensland Rail agree to provide the University of Wollongong more worn pads for further investigations. Further investigation about the condition assessments of a variety of rail pads with different ages, the degradation rates, and the optimum renewal period will be presented in the near future.

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REFERENCES

[1] Esveld C, *Modern Railway Track*, The Netherlands MRT Press, 2001.

[2] Standards Australia, “Railway track material - Part 14: Prestressed concrete sleepers” *Australian Standard: AS1085.14-2003*, 2003.

[3] Remennikov AM and Kaewunruen S, “A review on loading conditions for railway track structures due to wheel and rail vertical interactions”. *Progress in Structural Engineering and Materials*, invited, (2006).

[4] Cai, Z. “Modelling of rail track dynamics and wheel/rail interaction”. *Ph.D. Thesis*, Department of Civil Engineering, Queen’s University, Ontario, Canada, 1992.

[5] Grassie, S.L. and Cox, S.J. “The dynamic response of railway track with flexible sleepers to high frequency vertical excitation”. *Proceedings of Institute of Mechanical Engineering Part D* 24: 77-90, (1984).

[6] Wu, TX. and Thompson, DJ. “The effects of local preload on the foundation stiffness and vertical vibration of railway track”. *Journal of Sound and Vibration* 215(5): 881-904, (1999).

[7] Kaewunruen, S and Remennikov, AM, “Sensitivity analysis of free vibration characteristics of an in-situ railway concrete sleeper to variations of rail pad parameters”. *Journal of Sound and Vibration*, 298(1-2), 453-461, (2006).

[8] Kaewunruen, S and Remennikov, AM, “Effect of improper ballast tamping/packing on dynamic behaviors of on-track railway concrete sleeper”. *International Journal of Structural Stability and Dynamics*, 7(1), 167-177, (2007).

[9] Knothe, K., Grassie, S.L. “Modelling of railway track and vehicle/track interaction at high frequencies”. *Vehicle System Dynamics* 22(3-4): 209-262, (1993).

[10] Fenander, A. “A fractional derivative railpad model included in a railway track model”. *Journal of Sound and Vibration* 212(5), 889-903, (1998).

[11] De Man, A.P. “DYNATRACK: A survey of dynamic railway track properties and their quality”. *Ph.D. Thesis*, Faculty of Civil Engineering, Delft University of Technology, The Netherlands, 2002.

[12] Maes, J., Sol, H., “Guillaume, P. Measurements of dynamic railpad properties”. *Journal of Sound and Vibration* 293(3-5): 557-565, (2006).

[13] Grassie, S.L. “Resilient railpads: their dynamic behavior in the laboratory and on track”. *Proceedings of Institute of Mechanical Engineering Part F: J. of Rail and Rapid Transit* 203: 25-32, (1989).

[14] Van’t Zand, J. “Assessment of dynamic characteristics of rail pads”. *Railway Engineering International 1994 Edition* 23(4): 15-17, (1993).

[15] Remennikov, A., Kaewunruen, S. “Determination of dynamic properties of rail pads using instrumented hammer impact technique”. *Acoustics Australia* 33(2): 63-67, (2005).

[16] Remennikov, A., Kaewunruen, S., Ikaunieks, K. “Deterioration of dynamic rail pad characteristics”. *Conference of Railway Engineering 2006*, Apr 30 - May 3, Melbourne, Australia, 173-179, (2006).

[17] Carrascal, IA., Casado, JA., Polanco, JA., Gutierrez-Solana, F. “Dynamic behavior of railway fastening setting pads”. *Engineering Failure Analysis* 14(2): 364-373, (2007).

[18] Kaewunruen, S., Remennikov, A.M. “Non-destructive testing (NDT): A tool for dynamic health monitoring of railway track structures”. *Materials Australia* 39(6): 14-16, (2006).

[19] Kaewunruen, S., Remennikov, A.M. “Field trials for dynamic characteristics of railway track and its components using impact excitation technique”. *NDT & E International,* in press, (2007).

[20] DataFit, *User’s Manual*, Oakdale Engineering, Oakdale, PA, USA, 2005

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