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# Device for Failure Detection on Production Machines

**Radka Jírová [1*], Lubomír Pešík [1], Martin Sturm [2], Anett Maria Kupka [1]**

[1] Technical University of Liberec, Faculty of Mechanical Engineering, Studentska 2, 460 01 Liberec, Czech Republic
[2] University of Applied Sciences Zittau/Görlitz, Faculty of Mechanical Engineering, Theodor-Korner-Allee 16, 02763 Zittau, Germany

**Abstract:** Linear rolling systems are frequently used in industrial practice for the linear motion of machine parts or mechanical assemblies. Their reliability and prediction of possible failures are, during a production process, highly required to prevent production losses. Unfortunately, common diagnostic systems of linear rolling systems in industrial practice still fail in particular cases. Therefore, we designed an innovative solution for the diagnostic system based on a load-free part with a vibration sensor integrated into a carriage of the linear rolling system. A functional sample of diagnostics was produced, and vibrations measured on a loaded carriage and the diagnostic part in laboratory conditions were compared. Encouraging results were reached by time-domain analysis of measured data. On the diagnostic part, the damage appeared clearly, while on the loaded carriage, we did not observe any signs of damage.

**Keywords:** failure detection; linear rolling systems; vibrodiagnostics; wear

## 1. Introduction

Linear rolling systems realise a relative linear motion between two mechanical parts or assemblies. In practice, they are often used in production lines, requiring high reliability and predicting possible failures. It means securing the reliability of linear rolling systems.

Diagnostics of linear rolling systems is based on knowledge of rolling bearing diagnostics. In the diagnostics of rolling bearings, methods usually aim at a measurement of vibrations or acoustic emissions. Then, the measured data are analysed through an appropriate algorithm. The widely used algorithm transforms measured data by wavelet transform [1,2,3] and evaluates them using neural networks [4,5]. However, Japanese producer THK in the patent [6] mentioned that the design of linear systems might negatively influence the diagnostics based on measuring vibrations or noise intensity. Therefore, producers of linear rolling systems proposed diagnostics based on the end-cover deflection [7,8,9] that is significant for deep wear progression.

Lately, researchers and producers have focused on developing diagnostics based on evaluating measured vibrations through their RMS (root mean square) values in the context of lubrication level. Feng [10] explained the influence of lubrication on RMS and its distribution in the frequency domain. In the case described, neural networks are the suitable algorithm for the evaluation of RMS values comparing a defined threshold value [11]. Two patent applications [12,13] proposed that principle for the damage diagnostics of linear rolling systems. The producer THK and Schaeffler used an acceleration sensor to measure vibrations and evaluated RMS in the high-frequency band. When the threshold value is exceeded, the linear guide is relubricated, and the level of vibrations is measured again.

The current trend of linear rolling systems diagnostics is developing more auspicious input parameters for the diagnostics based on neural networks. Scientists



*** Corresponding author:** Radka Jírová, ***E-mail address:*** *radka.jirova@tul.cz*

compare the analysis of measured vibrations focused on, e.g. spectral analysis, crest factor [14] or spectrogram [15,16], considering different types of neural network algorithms [17].

Despite these efforts, linear rolling system diagnostics still does not appear reliable enough in industrial practice. In practice, several cases of significant damage to guiding profiles and rolling elements were noticed, in those measured vibrations did not exceed the threshold value. In industry, linear rolling systems are operated under varying conditions, which may disable the diagnostic function. Thus, the article describes an innovative method for the damage diagnostics of linear rolling systems.

## 2. Experimental Section

In the case of handling machines, linear rolling systems are frequently operated under enormous loads. These loads mainly relate to the mass inertia of transported goods. It might be recognised that external load influences measured vibrations in the way of damping them rapidly or exceeding them in orders by the machine's dynamical behaviour [18].

Thus, an innovative principle was developed as the linear rolling system with an integrated diagnostic system [19]. A load-free part was designed in the linear rolling system carriage with shared rolling elements. The external dynamical load is eliminated, and vibrations measured on the load-free part enable recognising the damage more easily (Fig. 1).

For verification of the proposed principle, a functional sample was produced and tested. The testing process was based on the simulation of operating conditions and guiding profile damage.

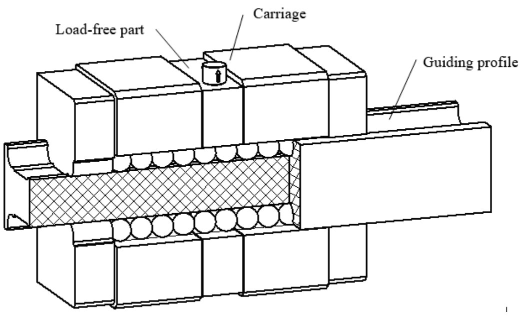


Figure 1: The linear rolling system carriage with the load-free part.

Laboratory testing was focused on evaluating vibrations measured on the load-free part of the functional sample. According to current knowledge, measurements were processed in the time domain.

The testing facility enabled the pressure loading of linear rolling systems by pneumatic springs. A linear motion was ensured by electromotor through a rope drive (Fig. 2). When testing, the guiding profile assembly moved by the velocity of v=0.42 $ms^{-1}$ and tested carriages, and the functional sample stood connected by pneumatic springs to the frame. The pressure load used for testing was F=18.5 kN.

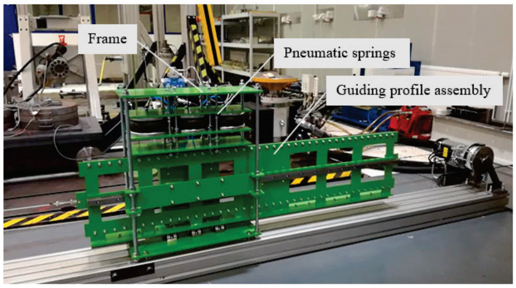


Figure 2: The testing facility.

The Hiwin linear rolling system, type RGH30CA ZAH, with rollers as rolling elements, was redesigned for the functional sample with the integrated load-free part (Fig. 3). The basic dynamic capacity of the Hiwin linear rolling system was C=39.1 kN, and the diameter of rollers dv=4 mm.

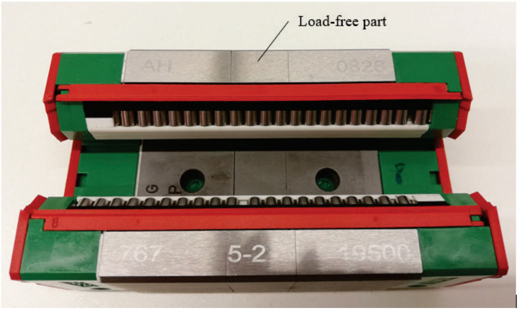


Figure 3: The functional sample.

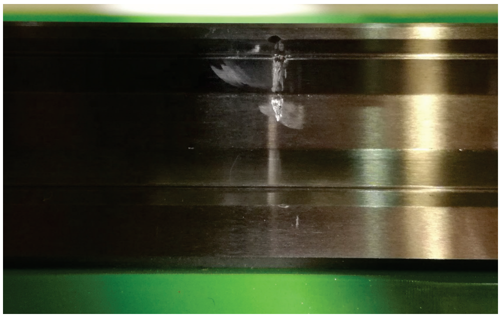

Figure 4: The simulated damage of the guiding profile.

Fig. 4 shows the guiding profile damage as a ground groove with a thickness of 1 mm on the contact surface. The damage represented a fatigue failure caused by contact pressure.

Vibrations on the load-free part and the carriage were measured using the 1-axis acceleration sensors that were placed according to the picture in Fig. 5. The 1-axis sensor of MMF producer, type MMF KS97.100, featured the range of ±60 g and the linear frequency range up to 13 kHz. The sampling frequency of measurement was set to 25 kHz.

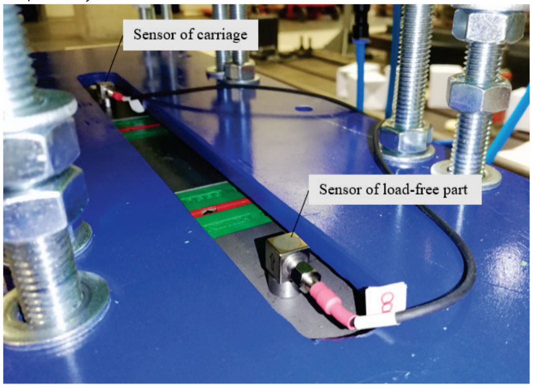


Figure 5: The placing of 1-axis acceleration sensors.

## 3. Results and Discussion

The diagnostic function of the proposed diagnostic principle was verified via the testing in laboratory conditions. On the contact surface of the guiding profile, the groove was ground for the damage simulation. Then, the vibrations were measured and analysed on the load-free part and the carriage in the time domain.

The time graph in Fig. 6 shows the carriage crossing over the simulated damage. Major amplitudes of measured acceleration may be recognised at a time period of TBA with parameters of time $t_A$=2.59326 s and $t_B$=2.61268 s.

$$T_{BA} = t_B - t_A = 0.019\,s \qquad (1)$$

These major amplitudes belong to the changed status of the rolling element from non-loaded to loaded status. In contrast, amplitudes of acceleration related to the simulated damage are hidden in the vibration noise.

The time graph in Fig. 7 illustrates the load-free part crossing over the simulated damage. In the measured signal, parameters of major $T_{42}$ and minor $T_{31}$ acceleration amplitudes of $t_1$=1.95636 s,

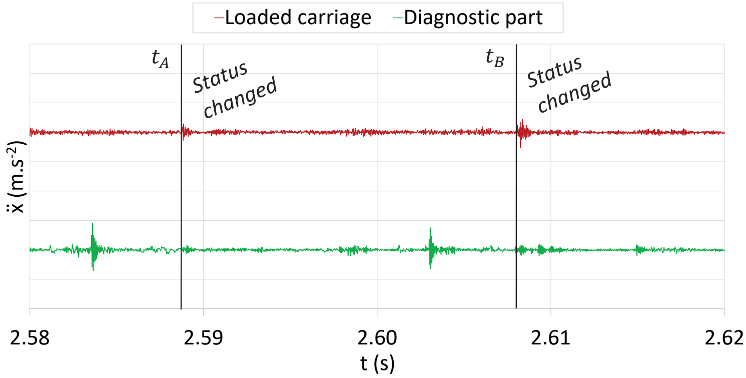


Figure 6: The time graph of acceleration by the carriage crossing over the simulated damage: Ordinate tick marks 100 ms$^{-2}$.

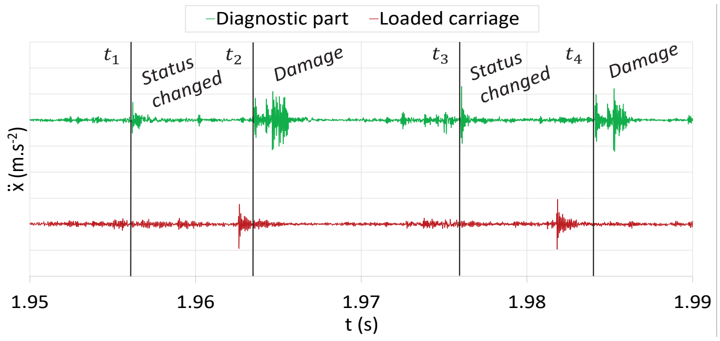


Figure 7: The time graph of acceleration by the load-free part crossing over the simulated damage: Ordinate tick marks 100ms$^{-2}$.

$t_2$=1.96376 s, $t_3$=1.97620 s and $t_4$=1.98432 s may be detected.

Referring to the time graph, major amplitudes of acceleration with the time period of $T_{42}$ belong to the vibrations excited by the simulated damage. In the measured vibrations, minor amplitudes of acceleration $T_{31}$ may be observed. These minor amplitudes are related to the changed status of the rolling element by crossing over from the load-free part to the carriage of the functional sample.

$$T_{42} = t_4 - t_2 = 0.0206\,s \quad (2)$$

$$T_{31} = t_3 - t_1 = 0.0198\,s \quad (3)$$

The time period of major and minor amplitudes equal approximately to the damage time period of the guiding profile, $T_{42} \cong T_{31} \cong T_{Dp}$.

Through a length of the load-free part l=15mm, the number of rolling elements n in contact with one raceway of the guiding profile may be calculated.

$$n = l / d_v = 3.75 \quad (4)$$

The result indicates 3 or 4 rolling elements in contact with the raceway each time. Respecting the preload of linear systems, by crossing one specific rolling element over the damage, the remaining rolling elements might absorb excited vibrations. By reducing the number of rolling elements in contact with the guiding profile, significant acceleration amplitudes that belong to the vibrations excited by the simulated damage were reached.

## 4. Conclusions

The diagnostics of linear rolling systems is currently based on measuring vibrations and evaluating the RMS value in the context of the threshold value. In industrial practice, several cases of failure without exceeding the threshold value of vibrations were registered. Therefore, the innovative principle of diagnostics based on decreasing the external load through the load-free part integrated into the linear system carriage was proposed. Then, the functional sample with the load-free part was designed. In the load-free part, the major amplitudes related to the simulated damage were registered.

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## References

[1] C. Mishra, A. K. Samantaray, G. Chakraborty, Rolling element bearing fault diagnosis under slow speed operation using wavelet de-noising, Measurement, vol. 103 (2017). doi: 10.1016/j.measurement.2017.02.033.

[2] L. Zheng, A. Ming, W. Zhang, T. Liu, F. Chum Y. Li, Fault feature extraction and enhancement of rolling element bearings based on maximum correlated kurtosis deconvolution and improved empirical wavelet transform, Applied Science, vol. 9 (2019). doi: 10.3390/app9091876.

[3] X. Zhang, J. Zhu, Y. Wu, D. Zhen, M. Zhang, Feature extraction for bearing fault detection using wavelet packet energy and fast kurtogram analysis, Applied Science, vol. 10 (2020). doi: 10.3390/app10217715.

[4] M. He, D. He, Deep learning based approach for bearing fault diagnosis, IEEE Transactions on Industry Applications, vol. 53 (2017).

[5] R. W. Rong, T. F. Ming, Research on rolling element bearing fault diagnosis based on genetic algorithm matching pursuit, IOP Conference Series: Materials Science and Engineering, vol. 283 (2017). doi: 10.1088/1757-899X/283/1/012009.

[6] THK Co. Ltd., Condition-detecting device, method, and program, and information-recording medium, granted patent EP1598569B1 (23.8.2011).

[7] THK Co. Ltd., Rolling guide device with breakage prediction function, patent application JP2012193803A (11.10.2012).

[8] HIWIN TECHNOLOGIES Corp., Linear guideway capable of detecting abnormal circulation state, granted patent US10436254B1 (8.10.2019).

[9] HIWIN TECHNOLOGIES Corp., Linear guideway, granted patent US10508691B1 (17.12.2019).

[10] H. Feng, R. Chen, Z. Wang, Feature extraction for fault diagnosis based on wavelet packet decomposition: An application on linear rolling guide, Advances in Mechanical Engineering, vol. 10. doi: 10.1177/1687814018796367.

[11] J. Zhong, K. Yang, Failure prediction for linear ball bearings based on wavelet transformation and self-organising map, Proceedings of 2018 IEEE 4th Information Technology and Mechatronics Engineering Conference, Chongqing, Peoples Republic China, 14-16th December 2018, p 34-38.

[12] THK Co. Ltd., Method for diagnosing rolling guide device status, granted patent JP6747757B2 (26.8.2020).

[13] Schaeffler Technologies Ag. & Co. Kg., Method for lubricating a linear guide, patent application DE102017113720A1 (27.12.2018).

[14] P. Chommuangpuck, T. Wanglomklang, J. Srisertpol, Fault detection and diagnosis of linear bearing in auto core adhesion mounting machines based on condition monitoring, Systems Science & Control Engineering, vol. 9

(2021). doi: 10.1080/21642583.2021.1895901.

[15] M. S. Kim, J. P. Yun, S. Lee, P. Park, Unsupervised anomaly detection of LM guide using variational autoencoder, The XIth International Symposium on Advanced Topics in Electrical Engineering, Bucharest, Romania, 28-30th march 2019.

[16] M. S. Kim, J. P. Yun, P. Park, An explainable convolutional neural network for fault diagnosis in linear motion guide, IEEE Transactions on Industrial Informatics, vol. 17 (2021).

[17] D. Hong, S. Bang, B. Kim, Unsupervised condition diagnosis of linear motion guide using generative model based on images, IEEE Access, vol. 283 (2017). doi: 10.1109/ACCESS.2021.3084602.

[18] R. Jirova, L. Pesik, Dynamical load of linear rolling guides, MM Science Journal, vol. June (2020), pp. 3943-3949. doi: 10.17973/MMSJ.2020_06_2020014.

[19] Skoda Auto a. s., Linear rolling guide with integrated diagnostic equipment, granted patent CZ308232B6.