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The contribution to the analysis of the run up test

Vladimír Dekýš¹,* Pavol Novák¹, Ondrej Dvouletý¹, Leszek Radziszewski²

¹University of Žilina, Faculty of Mechanical Engineering, Univerzitná 8215/1, 010 26 Žilina, Slovakia
²Kielce University of Technology, Al. Tysiąclecia Państwa Polskiego 7, 25-314 Kielce, Poland

Abstract

The article deals with analysis of possible applications easing by Short Time Fourier transformation, in determining the natural frequencies and damage to the monitored equipment. We have focused on the problem when the maximum speed of the equipment at start-up is limited due to the excitation of resonances around this maximum speed. If we are concerned about the frequency region near resonance and above this, and when we do not want to risk damage to the equipment when passing through resonance, then the solution can be complicated. Our solution is based on the use of the excitatory properties of harmonic frequencies generated by the system to build a facility in the desired frequency range. The procedure was applied to solve reducing vibration of the structure in the steel mills and the extension of the interval of possible use of frequencies in production.

Keywords: run-up; STFT; resonance; natural frequency; ODS

1. Introduction

Increasing production is often achieved by increasing working speed machines and thus to increase speed drives. This leads to the increase of the dynamic load and a part of the technology to increase the vibration. This case, however, can also reduce the life of the construction elements, and the reliability of the device arrangement as a whole, but also an increase of the effects of excitation of the machine on the supporting building structure and the other machines in the vicinity. There may be a situation where some of the excitation frequency technology closer to the natural frequency of the system. Although it was not necessary to solve the problem in the past, at the desired
operating speeds increase, the situation may change significantly. Then knowledge of natural frequencies is an important element in assessing the increase in speed.

Real systems have more degrees of freedom, corresponding to the respective natural frequency. It is often sufficient to solve the problem for the lowest natural frequency. However, it is useful to note that if the technology has been operated a certain time, then there has been a degradation of some of its parts, as the increase in speed can occur synergistic effect. As a result, the resulting damage may occur to a greater extent the effect of excitatory forces associated with the speed-frequency drive and also with its higher harmonics.

In the following sections we will deal with determining the natural frequencies. The above problem can be solved in several ways. One of them is verified using a suitable numerical model, another way is to set your own or resonant frequency, using experimental methods. The choice is often based and economic, technical conditions and time-consuming solutions [1–4].

2. A description of the problem

Our concern is vertical rolling mill in hot rolling mills. The device is composed of a steel structure, a DC electric motor 500 kW, bevel gearbox, three-stage spur gearbox and rolling cassette itself (Fig. 1). The connecting shafts with claw couplings are used to power transmission between engine, bevel gear and three-stage spur gearbox. The cassette is driven by a cardan shaft.

Rolling mill was operated at a process speed, which corresponded to a motor speed \( n_1 \). Vibration equipment was at these speeds acceptable. The user wanted a rolling mill operating at a higher process speed, corresponding to motor speed \( n_2 \), \( n_1 < n_2 \). However, at the speed \( n_3 \), \( (n_1 < n_3 < n_2) \), there was a massive increase in vibration. The high level of vibration in \( n_3 \) defended the continuation of the trial operation of the rolling stand to the desired speed \( n_2 \), the high risk of accidents. Described condition caused need for knowledge resonance frequency of the system. Knowledge of resonance conditions and the natural frequency is significant, but it's only a partial solution. The objective is to operate the plant in a desired speed range, i.e., eliminating or reducing vibration technology in this range. This paper is limited to experimental solution. Time for preparation and performance measurements was limited to a short period determined by the duration of the maintenance or planned repairs of technological equipment.
3. A solution

Completely solve the problem of determining natural frequencies consisted of experimental and numerical part. It is therefore appropriate elected experimental methods in order to permit a comparison of experimental and numerical results based on the current status and thus subsequently verified numerical model used to simulate the structural modifications.

To solve the problem, we exclude the use of modal hammer and modal exciter. The reason was the short time given to the operator, after which he may have been made above tests, produce suitable dedicated stand for flexible suspension exciter and the like. Some of the problems are avoidable by using bump tests, during this type of construction is exciting after impact as a piece of wood in the machine (low crest factor, the excitation of the lower frequencies) when they are not measured by the input data and the excitation is measured and evaluated as the response data. Then, based on the peaks in the output signals are determined excited resonance frequencies, this type of measurement, however, we did not use, for reasons of standardization of the amplitude of the output signal. This method of measurement does not reject, on the contrary, we can be considered a simple solution for that is sufficient and single-channel analyzer, but in a particular case, we used it only as a complementary way.

In addition, the user know that the device vibrates at run-up, so as experimental vibration analysis has been selected measuring vibration during this run-up up to the operating speed $n_1$ (Fig. 2). Based on the first measurement were found in the spectra of the vibration harmonics rotation speed of the motor (Fig. 3). The dominant peak at harmonics may be due to various phenomena, e.g. unbalance, misalignment, looseness, gear problems in the transmission or the like. Although the presence of harmonics is significant, in that moment, we did not seek its causes but we used them to detect the resonant frequencies. Even though the maximum engine speed during run-up test were only $n_1$, a value less than the required speed $n_2$, harmonics present during run-up managed to excite resonance in the system and around required speed $n_2$.

The measurements were performed using 12 channel systems cDAQ National Instrument, the NI 9234 modules with simultaneous data collection, accelerometers B&K 4507B004 and optical tachometer PLT200. Data were collected LabVIEW software system (NI). Collected data can be processed in Diadem software (LabVIEW) and MEscopeVES (Vibrant Technology).

![Fig. 2 Measuring vibration during run-up up to the operating speed $n_1$, steady state and run-down, speed profile and measure signal – acceleration of vibration.](image-url)
Fig. 3. A vibration spectrum with harmonics.

Fig. 4. The colormap of run-up, decreasing curve ~ resonance, vertical line ~ harmonics.

Fig. 5. The zoom of waterfall graph with red curve of resonance frequency.
The measurements are processed by using of Short Time Fourier Transform (STFT) in the form of a color maps (Fig. 4) or waterfalls (Fig. 5). On the horizontal axis are plotted speeds in multiples of the input shaft speed as orders \((n\text{-}\text{order} = n \cdot n_1, \text{in Hz})\). Around curves in the form of hyperbole corresponding resonance in the system, vertical lines correspond to the harmonic speed frequency. For better deduction resonant frequencies have been created in the waterfall display cuts through rational multiples speed frequency (Fig. 6).

This practice has been identified resonant frequency of the system. For completeness, it should be noted, is not merely measure the run-up, but in the steady state were obtained data for operation deflection shapes (Fig. 7). All these experimental data both complement each other and are used for verification prepared FEM model. The same problems by using FEM are described in [5–9]. Subsequently, on the basis FEM model (Fig. 1) was made design changes. One of these changes was elimination example waveform shown in Fig. 7, changing the stiffness of the supports angle gear. Subsequent tests confirmed the possibility of increasing the operating speed \(n_2\), not to excite resonance at speed \(n_3\) and reduce the level of vibration of the object.

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**Fig. 6.** Determine the resonant frequency at 31Hz in the cut for 1.96 order from waterfall graph.

**Fig. 7.** The operation deflection shape at 31,3Hz, rotate bevel gearbox around z-axis.
4. Conclusion

The article was presented a method for determining resonance frequencies of start-up equipment. This method was chosen on the basis of a quick acquisition of the necessary data and ease of use of an existing control system at start-up, which ensures reproducibility. It is to be noted that when the run-up, reflected in the resonance system these frequencies which are sufficiently excited by the system itself. Since it was a system in which the present excitation associated with the revolutions of the input shaft (speed-frequency) and with a harmonic of, and are excitable resonant frequencies well above that speed-frequency.

After startup device to the desired speed then become stable operation and during this mode data are collected for analysis of operating modes of vibrations. The presence of harmonics is possible to detect the mode shapes of vibrations excited by the presence of harmonics. This was the case of equipment which is already in operation some time and we can assume that the ongoing degradation mechanisms are manifested by the presence of harmonics in the excitation spectrum.

From the experimental point of view was an appropriate use of the properties of damaged or worn-out equipment. It is appropriate to point out that the term was used by harmonics in terms of integer multiples of the fundamental speed frequency, but if the device were damaged bearings, then the excitation can also occur on the positive real multiples of that frequency.

From the user point of view which wants to reduce vibration device is significant that the measurable response system requiring the presence of a sufficient excitation. If eliminated or reduced excitation, then we can expect the elimination or reduction in the level of vibration that is related to resonance. Then, it is appropriate to adopt a strategy for reducing the vibration device under no design changes, such as when there is a shifting of the natural frequencies, but the elimination of the excitation sources.

However, there is real to compromise, since it eliminates all the excitation sources can be time consuming and expensive (for example, in terms of ambiguity of transformation relations between the plurality of failure or negative state, and a set of symptoms of these conditions), and only structural change can really (but perhaps only temporarily, however) reduce the level of vibration.

We are of the opinion that the current problem is described not only in terms of reducing the vibration technology equipment itself but also in terms of reducing the excitation base concrete structures.

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References