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The 4th World Sustainability Forum
1 - 30 November 2014

http://www.sciforum.net/conference/wsf-4

World Sustainability Forum 2014 – Conference Proceedings Paper

Vibration Analysis for Environmental Sustainability

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Received: 20 August 2014 / Accepted: 9 October 2014 / Published: 1 November 2014

Abstract: Predictive maintenance has a significant impact on the environmental sustainability of an organization, by means of the increase in quality of the product, which allows the consumption of raw materials to be reduced. Vibration analysis is a predictive technique especially suitable for reciprocating and rotary machines; it consists of periodically recording the vibration level of the machine, as it increases when there are anomalies such as misalignment, unbalance, etc. In the manufacture of bearings for vehicles, the final vibration of the assembled bearing is one of the quality parameters analysed to ensure that the quality of the bearings are as desired. In external grinding processes vibrations appear which are generated by the process itself and not by flaws in the machine tool. These vibrations can cause defects which affect the quality of the workpieces produced. Nevertheless, analysis of process-induced vibrations is little studied in the literature. Vibration spectra are applied to distinguish problematic vibration frequencies from those that are not. Intercomparison of spectrums between similar machines and studies of the change over time of spectra or waterfall plots are used. This method considers the possible of establishing separate vibration limits in the machining of components so as to guarantee the quality of the final assembled product. The methodology exposed can contribute to increase the environmental sustainability of an industrial organization due that contribute to a more efficient use of resources.

Keywords: quality; self-induced vibrations; sustainability; bearing; spectral vibration analysis

1. Introduction

Organizations are increasingly concerned about contributing to environmental sustainability, and they may have specific sections or departments dedicated to environmental protection. Nevertheless, to date the effect that other areas, such as maintenance, can have on the matter has not been considered.

However, the application of optimal maintenance has important repercussions for the lifetime of assets and facilities, lengthening their use and contributing to the optimal use of resources. In maintenance policies applied by organizations we find:

- Corrective maintenance, or run to failure policy, is carried out after failure detection with the aim of returning the failed asset to an operational condition.
- Preventive maintenance is carried out at set intervals throughout the working life of the machine, with the aim of reducing the probability of problems or wear in the machine [1].
- Predictive maintenance is a maintenance policy based on measuring and recording intermittently or continuously (on-line) certain physical parameters associated with a working machine to obtain a diagnosis of anomalies and faults present in a machine and a prediction of the remaining life of the machine. There exist a number of predictive diagnostic techniques such as [2]: vibration analysis, process parameters, thermography, visual inspection, tribology, current spectrum, ultrasound, x-rays, penetrating liquids, etc. Other nondestructive testing techniques can be seen in NASA [3], or the American Society for Nondestructive Testing (ANST).

Predictive maintenance, unlike other maintenance policies, contributes to guaranteeing product quality, because the machines are operating without anomalies (such as excessive vibrations), that have a negative effect on quality. Guaranteeing product quality also contributes to a decrease in the consumption of raw materials and components, and the waste generated by faulty batches.

Among predictive techniques, vibration analysis is the most widely used in organizations due to its versatility of application to a variety of machines, and the number of faults that it can detect and diagnose.

In the manufacture of bearings for vehicles, the vibration of the assembled bearing is one of the quality parameters analysed to ensure that the lifetime of the bearing and the noise levels during operation are as expected. However, although vibration in machines is widely analysed in the literature, the vibrations produced by the processes themselves are not researched. This is because the process vibration and frequently mixed in and confused with the vibrations of the machines.

The problem analysed in this study is the appearance of chattered grinding surfaces [4]. Detection of chatter has been analysed in [5-11] while its removal is researched in [12-17]. Profile and surface roughness are applied as indicators of the quality of the bearing, as they affect its functional behaviour throughout their lifetime [18].

Vibration spectra are used to distinguish problematic vibration frequencies from those that are not; the techniques used are intercomparison of spectrums between similar machines and waterfall plots. This research considers the possibility of establishing vibration band limits in the machining of components so as to guarantee the quality of the final assembled product.

Firstly, the characteristics of the experimental system used are shown; next the results obtained for automotive bearings are described.

2. Experimental System

The measurement systems used in this study are made up of: vibration analyzer IRD 890 Mechanalysis, accelerometer 970 from Mechanalysis, and the databases for the storage and manipulation of vibration data are the 7090 system of IRD Mechanalysis and ODYSSEY system from Entek-IRD. To evaluate the quality of the bearing, measurement devices model Talyrond 31 and an analogue Federal device, calibrated by certified bodies; this equipment is available in the normal manufacturing areas of the company.

1. Level 0. Null chattering.
2. Level 1. Intermediate chattering.
3. Level 2. Severe chattering with significant widths of displacement.

Standard ANSI B89.3.1-1972 was applied to carry out the tests.

The design of the experiment followed a classical approach, considering all the interactions, and applying variance analysis systematically. As a result of the experimental design, 25 tests were carried out with two different machines dedicated to the same manufacturing process.

3. Results and Discussion

Vibrations can occur in displacement, velocity and acceleration. These magnitudes can be shown against time and against frequency, in the latter case they are spectra. The Fourier Theorem states that any periodic signal can be decomposed as a combination of pure sinusoidal waves, whose frequencies are multiples of a fundamental frequency, giving a spectrum in frequency [19], using the Fast Fourier Transform (FFT) algorithm. FFT allows a time vibration signal to be transformed into components characterized by an amplitude and a frequency.

Vibration spectra were gathered in order to identify the vibration frequencies that cause poor quality. Since there are no studies in the literature about the maximum permissible values and their frequencies, the concept of spectral intercomparison between similar machines, and a waterfall analysis, have been used.

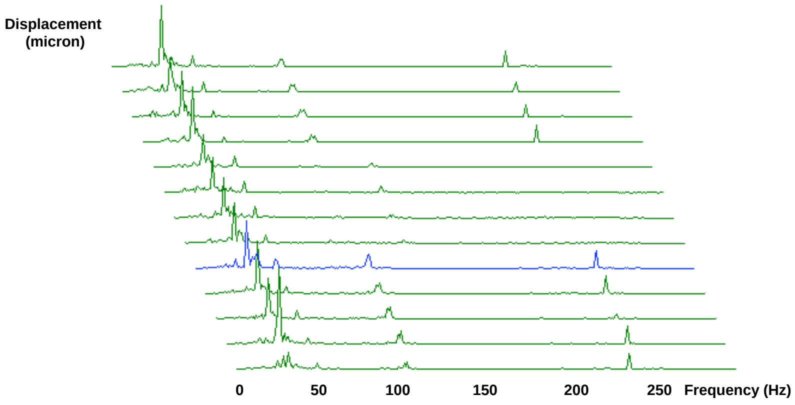
The spectral intercomparison consists in a comparison of spectra from different machines performing the same process and with similar operating variables, while the waterfall is a graph with the successive spectra shown as a function of the variation of the machine velocity.

Therefore, a set of experiments was performed on two similar machines to determine whether the process-induced vibrations allow spectral comparisons to be made to show which are the operating conditions that affect the appearance of loss of quality.

The variables included in the experimental design are: the two grinding machine-tools, the grinding wheel diameter, the rotational speed of the grinding wheel and, as output variables, high frequency displacement and the quality of the process assessed according to the presence of high frequency chattering and low frequency chattering. The choice of these variables has been made after a series of prior experiments which can be seen in [20].

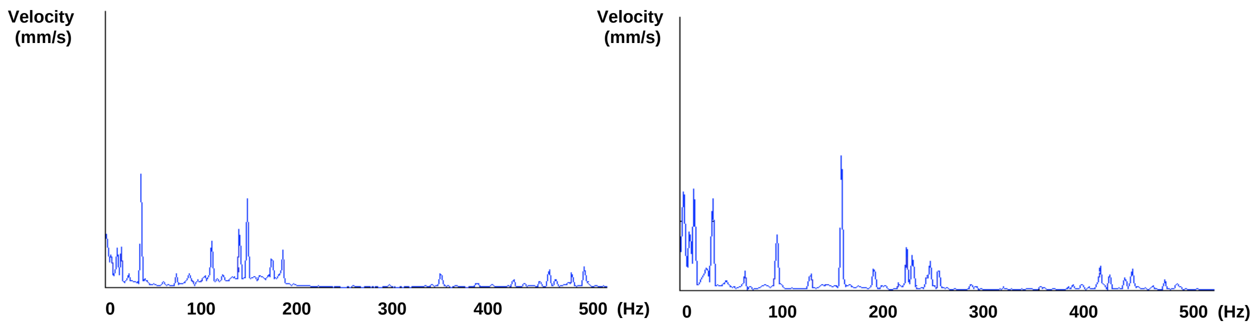
The waterfall plots of Figure 1 represent the spectral characteristics in displacement, in the chosen range of frequencies for the grinding process in the outer raceway. It can be seen that the frequency of appearance of vibration peaks is maintained, showing that the processes retain spectral identity if the process variables are not modified. From the spectral identity obtained it is possible to define vibration bands and so quantify the vibration content in each of them.

Figure 1. Waterfalls plots.



Next we see whether two identical machines have different spectral identities for different processes. The comparison of spectra measured in velocity of the two different grinding processes obtained from two different machines is shown in Figure 2, where the differences in amplitude and frequency for each type of process can be seen.

Figure 2. Spectra from two identical machines in different grinding processes.



At the experimental stage, spectra are obtained throughout the life of the grinding wheel, as well as the development of chattering in the manufactured components. It is observed that low-frequency vibration is heavily influenced by the diameter of the grinding wheel. Random high-frequency spectral components are also observed. Therefore, two vibration bands will be taken:

- From 1Hz to 44 Hz.
- From 44 Hz to 250 Hz.

The experimental results for high frequency displacement lead to the hypothesis that this variable is related to problems with quality in the processes. A variance analysis was carried out to verify this hypothesis [21] which gave as a result the possibility of establishing a monitoring band for high frequency displacement, entre 44 Hz and 250 Hz, which allows the stability of the process with respect to the resulting quality to be guaranteed.

Once the maximum admissible high-frequency vibration displacement values are known, limit spectra can be defined, controllable cycle by cycle, and even connected to continuous vibration data acquisition devices so that the machines can adjust their parameters and avoid the frequency band that is sensitive to problems of quality.

4. Conclusions

Grinding processes produce induced vibrations that depend on the process variables. These self-excited vibrations are independent of the input variables, the amplitudes and frequencies of the vibrations, and the chattering assessed in the workpieces.

Spectral intercomparison is a technique used to detect problems of quality in grinding processes; this is done by taking high-frequency displacement spectra. The high-frequency vibration is of the same order even in different machines working on the same piece, which suggests that this variable is linked to self-excited vibrations during tool-workpiece contact. For each process it will be possible to define a given high-frequency band where the displacements should be controlled to guarantee operation with stable quality.

Spectral identity and intercomparison allow monitoring bands to be defined, in which the spectral activity indicates the imminent appearance of quality problems in the parts being ground. In the process analysed this band lies between 44 Hz and 250 Hz.

The methodology described favours the environment by preventing quality problems in the parts being ground; this leads to more efficient use of resources as it avoids batches of defective parts. These defective batches have used energy, raw materials, components, etc., which in the end have been wasted. This also causes a problem of disposal of the defective parts, as in many cases they cannot be remanufactured.

Conflict of Interest

The authors declare no conflict of interest.

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