Mechanical Systems and Signal Processing 24 (2010) 1138–1160

Contents lists available at ScienceDirect

Mechanical Systems and Signal Processing

journal homepage: www.elsevier.com/locate/jnlabr/ymssp

Statistical quality control through overall vibration analysis

Mª Carmen Carnero [a,*], Rafael González-Palma [b], David Almorza [b], Pedro Mayorga [b], Carlos López-Escobar [c,d,e]

[a] University of Castilla-La Mancha, Technical School of Industrial Engineering, Avda. Camilo José Cela s/n, 13071 Ciudad Real, Spain
[b] University of Cádiz, Technical School of Industrial Engineering, Calle Chile 1, 11002 Cádiz, Spain
[c] University of Cádiz, School of Work Sciences, Calle Duque de Nájera 6, 1002 Cádiz, Spain
[d] Electrical Technology Institute (ITE), Avenida de Juan de la Cierva 24, parque tecnológico de Valencia, 46980 Valencia, Spain
[e] Aluminum Company of America (ALCOA), Paseo de la Castellana 95, Edificio Torre Europa, 28046 Madrid, Spain

A R T I C L E I N F O

Article history:
Received 24 October 2008
Received in revised form
4 September 2009
Accepted 11 September 2009
Available online 25 September 2009

Keywords:
Machine tool
Vibration analysis
Quality
ANOVA

A B S T R A C T

The present study introduces the concept of statistical quality control in automotive wheel bearings manufacturing processes. Defects on products under analysis can have a direct influence on passengers' safety and comfort. At present, the use of vibration analysis on machine tools for quality control purposes is not very extensive in manufacturing facilities.

Noise and vibration are common quality problems in bearings. These failure modes likely occur under certain operating conditions and do not require high vibration amplitudes but relate to certain vibration frequencies. The vibration frequencies are affected by the type of surface problems (chattering) of ball races that are generated through grinding processes.

The purpose of this paper is to identify grinding process variables that affect the quality of bearings by using statistical principles in the field of machine tools. In addition, an evaluation of the quality results of the finished parts under different combinations of process variables is assessed. This paper intends to establish the foundations to predict the quality of the products through the analysis of self-induced vibrations during the contact between the grinding wheel and the parts. To achieve this goal, the overall self-induced vibration readings under different combinations of process variables are analysed using statistical tools. The analysis of data and design of experiments follows a classical approach, considering all potential interactions between variables. The analysis of data is conducted through analysis of variance (ANOVA) for data sets that meet normality and homoscedasticity criteria. This paper utilizes different statistical tools to support the conclusions such as chi squared, Shapiro–Wilks, symmetry, Kurtosis, Cochran, Hartlett, and Hartley and Krushal–Wallis.

The analysis presented is the starting point to extend the use of predictive techniques (vibration analysis) for quality control. This paper demonstrates the existence of predictive variables (high-frequency vibration displacements) that are sensible to the processes setup and the quality of the products obtained. Based on the result of this overall vibration analysis, a second paper will analyse self-induced vibration spectrums in order to define limit vibration bands, controllable every cycle or connected to permanent vibration-monitoring systems able to adjust sensible process variables identified by ANOVA, once the vibration readings exceed established quality limits.

* Corresponding author. Tel.: +34 926 295300x3863; fax: +34 926 295361.
E-mail address: Carmen.Carnero@uclm.es (M.C. Carnero).

0888-3270/$ - see front matter
doi:10.1016/j.ymssp.2009.09.007

Acronyms

μm-H	high-frequency displacements
μm-L	low-frequency displacements
cpm	cycles per minute
ED	experimental design
g	unit of acceleration caused by the force of gravity (9.8 m/s^2)
H_0	null hypothesis
H_1	research hypothesis
Hz	hertz
Lob A	high-frequency chattering (very-fast movements of the dial indicator on turning the part).
Lob B	low-frequency chattering (slow movements of the hands of the dial indicator on turning the part).
P	values the significance level of a statistical test
RMS	root mean square
rpm	revolutions per minute
SQC	statistical quality control
W	Shapiro–Wilks test

1. Introduction

Periodically, the mass media report on the appearance of defective lots not detected during the manufacturing process and that therefore have come to the market. On occasions, the announced quantities are extremely high and the manufacturers face high losses in expenses of review and substitution of elements. This type of problem is usual in the automotive market, where volumes manufactured are high.

The appearance of this type of situation persists in spite of the existence of agreements of quality coordinated between manufacturers and suppliers, as well as rigorous statistical systems of internal quality control, which assure the maintenance of processes within the quality levels established. In some cases, the nature of the quality problems makes their control complex, especially when the product specifications are tight.

In this paper, condition monitoring-technologies are applied to the study of the mechanical behaviour of high-precision processes and then extend the concept of predictive maintenance to quality control. The aim is to discover the nature of vibrations generated by the process itself to detect early symptoms that indicate a separation from the quality zone objective, as well as to determine which are the variables that induce the vibration most suitable for predicting quality problems.

It must be considered that at the moment there are very few companies that apply vibration analysis to machine tools in the periodical control of quality insurance. At present, the study of vibration analysis induced by the process is a subject that is almost unexplored.

Specifically, one of the major quality problems in the bearings industry is the occurrence of noises when bearings are in certain functioning conditions. The existence of this fault does not need very big amplitudes but it conditions the frequency of the vibration, which has been determined by the type of chattering obtained in the manufacturing processes of their tracks of tread.

Harris [17] defines that the roundness of a part on a certain section is correct when a point exists in this section from which all the points of the periphery are halfway, this point being the center of the circle. When the section is not totally circular, the part is considered to be out of roundness and this is specified as the difference in distance between the outlying points and the center. In Fig. 1, the degree of deviation of the roundness is the value r_2-r_1, that is, the difference between the maximum and minimum radii.

When a part is manufactured by a machine tool, the profile obtained is of an irregular type in the rolling tracks and in the rolling elements (see Fig. 2); this will affect the durability and operation of the bearing.

Chattering has a decisive influence on the final vibration of the bearing; its importance depends on the number of existing lobes and their depth. Besides, the problem is greater when taking into account that the final vibration is the result of the combined effect of roundness of rolling tracks, balls, superficial finishes of all surfaces and assembly conditions. This may lead to the manufacturing of noisy bearings if certain natural frequencies are excited, which is especially uncomfortable in automotive wheel bearings.

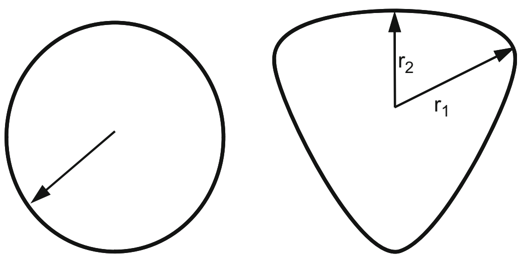

Fig. 1. Examples of profiles. Circular profile r_2-r_1=0 Profile with chattering of order 3 (3 lobes).