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Procedia Manufacturing 41 (2019) 516–522

Procedia MANUFACTURING

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8th Manufacturing Engineering Society International Conference

Development of a shape specification based on the waviness parameter of tapered roller bearing

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Abstract

Tapered roller bearings can accommodate high radial loads as well as high axial loads. The manufacturing process consists of rings machining processes and components assembly, followed by an intense quality control. In this contribution, a study of the parameters of influence in the inspection procedure has been carried out. The main objective of this work is to develop a shape specification using real parts and to optimize the process of specification development. This requires to study the influence of several parameters in the inspection and to determine how they affect the waviness specification.

Keywords: tapered roller bearing; roundness; waviness; raceway; inner ring; outer ring; UPR; harmonic analysis; harmonic amplitude; ovality; triangulation; RONt;

1. Introduction

Bearing manufacturing is a high precision technology, where material composition, hardness and micrometric dimensions need to be ensured to reach the product requirements [1, 2]. The faults due to manufacturing error, surface roughness, waviness, misaligned races, and off-size rolling elements are categorized under distributed defect. All of

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Peer-review under responsibility of the scientific committee of the 8th Manufacturing Engineering Society International Conference.

them affect the fatigue that is the predominant mode of failure in rolling element bearings; the life of bearings is governed by its rolling contact fatigue life [3].

Surface waviness describes features varying in size from the roughness cutoff wavelength up to the full circumference of the bearing raceway. Surface waviness features are sufficiently large that they do not play a role in the contact between the surfaces. The primary effect of such features is to introduce extra vibration into the bearing mechanism as the moving parts periodically encounter, and are displaced by, the same surface deviations [4]. Behzad et al. [5] have proposed the stochastic model with the capability of predicting vibrations for known defective conditions. Knowledge of the waviness of the bearing surfaces enables predictions of the vibration frequencies and amplitudes to be made [5-8].

The main goal of the work is the development of a specification that covers the need for inspection of tapered roller bearing, regarding shape geometrical parameters. The specification should take into account the waviness defects of the bearing rolling surfaces to restrict the vibrations generated in operation. Rolling surfaces of the tapered roller bearings, also known as raceways, are indicated in Figure 1.

Currently, other manufacturers (of bearings, or revolution elements) may have specified the variables discussed, but there is not much information in the state of the art on how they have obtained them. This paper presents a methodology, based on both empirical measurements and a mathematical model, which can serve as a reference for other manufacturers.

The realization of this study is the basis for developing an internal manufacturing specification that determines the validity of products manufactured by grinding. It is then necessary to investigate the influence of waviness and propose tools to control it during the manufacturing process.

In order to create an internal specification, it is necessary to leverage a deep knowledge about the order of magnitude of the error that is currently occurring. Therefore, an exhaustive study of the waviness error that is generated and considered valid in the current production has been carried out. Geometrical data of manufactured parts has been collected after their measurement during the validation process. During the investigation, almost a thousand measurements of the manufacturing lines have been processed to obtain a sample size with reasonable confidence levels. Additionally, more than a hundred integral measurements have been carried out in the roundness measurement machine, corresponding to finished part numbers from other bearing manufacturers in order to carry out a wider benchmarking.

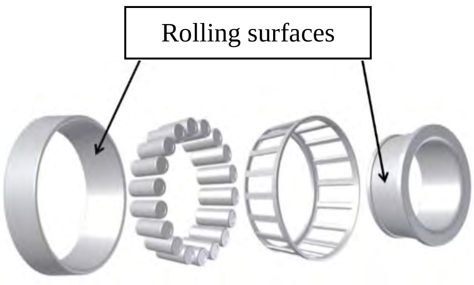

Fig. 1. Rolling surfaces of a tapered roller bearing.

2. Methodology

2.1. Specification definition

During bearing manufacturing, waviness error in tapered roller bearing raceways is measured in two different ways: harmonic analysis and out-of-round error with a roundness measurement system, as well as ovality and triangulation measurement systems. The first method is used to validate the manufacturing process and the second to monitor process deviations during manufacturing.

With this in mind, the specification defines the following parameters: on the one hand, harmonic amplitude limits and on the other hand, ovality and triangulation limits.

These bearing specifications, generally, are divided into several ranges of bearing dimensions, for example, the bore diameter for inner rings or outer diameter for outer rings.

2.1.1. Harmonic amplitude specification

In order to get useful and quantifiable information from the roundness profile of a bearing raceway, the harmonic analysis is one of the best options. Figure 2 shows the maximum (b) and minimum (a) deviations from the theoretical profile (1). By applying the Fourier Transform to the raceway shape wave, this analysis shows amplitude of the specified number of harmonics, which is possible to specify.

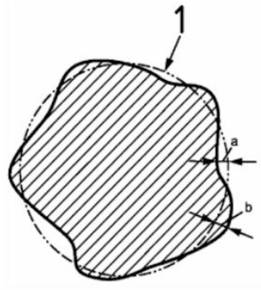

Fig. 1: Example of roundness profile with waviness deviation

For example, if a bearing raceway presents a remarkable undulation error related to a determined number of undulations per revolution (UPR), the amplitude of the harmonic component corresponding with the same number of UPR will be notable. Therefore, harmonic analysis is able to detect all of the periodic roundness errors among certain filtering limits.

Due to the impossibility of individually specify the value of each harmonic component, they have been classified into five ranges, as shown in table 1.

2.1.2. Ovality, triangulation and RONt

Apart from the harmonic amplitude specification but created from it, a new *Ovality and triangulation specification* has also been developed. During manufacturing, this specification is used by the monitoring system of the roundness parameter, which measure the standard defined values of ovality and triangulation.

Additionally, in order to have a complementary control system, a new specification of the *RONt* parameter has been developed (out-of-roundness, defined in the reference ISO standard 3162). It is the *RONt for oval and triangular forms specification*.

2.2. Geometrical form study

The goal of the study is to collect enough data to determine with confidence the specification values. The current Fersa manufacturing errors data as well as benchmarking bearings errors data are gathered in this study.

2.2.1. Manufacturing lines study

The roundness profile and harmonic analysis of grinded inner and outer ring raceways is the core of the study, measured with a *Talyrond 365* and processed with a *harmonic analysis software.* This study has processed data of five months of manufacturing different bearings sizes and in three different manufacturing lines. For extreme ranges, it has been necessary to extrapolate data.

The scope of the study has reached a total amount of 538 sample size processed data divided into four ranges of outer rings and 387 units in three ranges of inner rings. With these sample sizes, it has been possible to get confidence levels around 90-95% and 80-90% for outer and inner ring, respectively, with maximum allowed errors of 0.05 micrometers in long wavelength ranges and 0.02 and 0.01 micrometers in short wavelength ranges.

2.2.2. Benchmarking study

The same measurements have been carried out in several finished references of manufacturers such as Timken, SKF, NTN and FAG. As the sample size has been a limitation, the universe size is infinite and the samples are from different manufacturers, the confidence levels are around 40-50%. Hence, it is not possible to extract accurate data but indicative values.

3. Performances and results

Three parameter groups have been specified from the study results: harmonic amplitude, ovality and triangulation and *RONt*.

3.1. Harmonic amplitude data selection

The results of the study in arithmetical mean form are distributed in tables similar to the table 1. The values are divided in inner and outer rings, and Fersa and others manufacturers results are similar.

Table 1. Harmonic amplitude measurements ranges

.Bore diameter [mm]		Harmonic amplitude [μm] / N of harmonic				
Over	To	2	3	4 ⩽ N ⩽ 7	8 ⩽ N ⩽ 50	N > 50
30	50	0 - 10	0 - 5	0 - 2	0 - 1	0 - 1
50	80	0 - 10	0 - 5	0 - 2	0 - 1	0 - 1
80	120	0 - 10	0 - 5	0 – 2	0 - 1	0 - 1

The requirements used to select the specification values are the following:

1. Specified limit values to be among the 90th and the 95th percentile of current manufacturing error values.
2. Specified limit values equal or lower than the 90th percentile of other manufacturers.
3. Values fixed to increase linearly.

Therefore, specified values show the following trend:

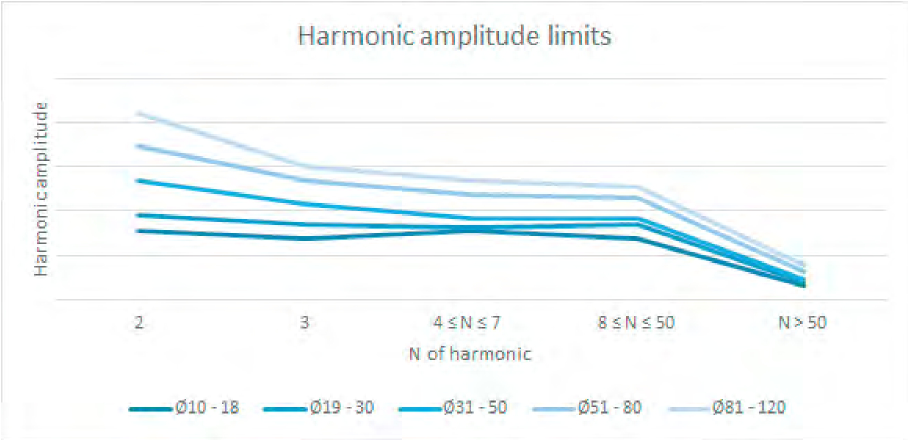

Fig. 2: Harmonic amplitude limits trend

3.2. Ovality and triangulation specification. Harmonic relations

These two values are derived from the *harmonic amplitude specification*. The relation between the harmonic component and the form error is obtained as follows.

1. Ovality to 2nd harmonic relation

Theoretically, the relation of an oval shape and its harmonic component amplitude is shown in the following scheme. It relates the amplitude error a, the *RONt* error and ovality, respectively. Nevertheless, this relation implies a perfect oval shape with no more errors. Therefore, a corrective ovality factor f_O has to be included to the relation equations.

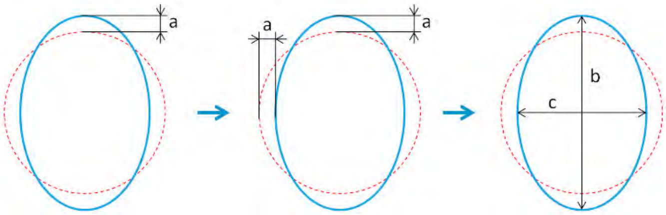

Fig. 4: Ideal relation between ovality (∇Δd) (and RONt) and harmonic amplitude

$$\nabla\Delta d = f_o \cdot (b - c) = f_o \cdot 4 \cdot a \quad (1)$$

The value of the factors has been calculated by processing data of amplitude and ovality measurements.

2. Triangulation to 3rd harmonic relation

The same procedure has been followed to get this relation, although the demonstration is a bit more complex and includes trigonometric relations as well as some simplifications. Real pieces are not ideal and therefore two factors are calculated: outer ring triangulation factor f_{tO} and inner ring triangulation factor f_{ti}.

$$\nabla\Delta d = \Delta d + \nabla d = f_{to/i} \cdot 6 \cdot a \quad (2)$$

3.3. RONt specification

The specification of this roundness error is also derived from the *harmonic amplitude specification*, and the theoretical relation has been shown in 3.2. *RONt* is an alternative parameter for measuring roundness deviation and can easily be evaluated in the laboratory by using roundness measurement systems. For this reason, it is interesting to use this parameter to identify ovality and triangulation deviations, which are the two most common errors.

This specification defines two different *RONt* limit values: one for predominant oval deviation pieces and the other for predominant triangular deviation pieces. Both the influence of the error on the bearing performance and the relationship between the harmonic amplitude of the error and the *RONt* value are different between ovality and triangulation. Therefore, two values are specified with their corresponding corrective factors.

RONt relation for oval pieces, with corrective ovality factor f_O.

$$RONt = f_o \cdot (a + a) = f_o \cdot 2 \cdot a \tag{3}$$

RONt relation for triangular pieces, with corrective triangulation factor f_{tR}.

$$RONt = f_{tR} \cdot (a + a) = f_{tR} \cdot 2 \cdot a \tag{4}$$

Thanks to these relations, it has been possible to specify ovality and triangulation limits on the one hand and *RONt* limits on the other hand, as shown in tables 2 and 3.

Table 2. Ovality and triangulation specification

Bore diameter / Outer diameter [mm]		Ovality (µm)	Triangulation (µm)
Over	To		
10	30	1 - 4	1 - 4
30	80	3 - 7	2 - 6
80	150	4 - 10	3 - 9
150	250	5 - 12	4 - 10

Table 3. RONt specification

Bore diameter / Outer diameter [mm]		Oval form	Triangular form
Over	To	RONt (µm)	RONt (µm)
10	30	1 - 3	1 - 3
30	80	2 - 5	3 - 6
80	150	3 - 6	4 - 7
150	250	4 - 8	5 - 9

Finally, it is necessary to emphasize that the main reason for the need to include correction factors is that a bearing is never perfectly oval or perfectly triangulated. Its errors of form are in fact a sum of different errors. These errors can affect and distort a measure of ovality / triangulation or of RONt, and to take it into account in the specification it is necessary to define these correction factors, whose values are determined by empirical experience and by trigonometric calculations.

On the other hand, the reason why in the specification of RONt the values are separated according to whether the piece has a predominantly oval or triangulated shape, is because both ovality and triangulation are two errors that have a large influence and in a different way on how the other errors affect the final piece. The values of these correction factors (f_o, f_{tR}, f_{to} and f_{ti}) are greater than one.

4. Conclusions

The presented work shows the methodology followed to develop a shape specification based on the undulation of the tapered roller bearings as well as the results obtained. Both Fersa and benchmarking bearings have been taken into account to select the specified values, in order to achieve the highest quality level. Three groups of parameters have been specified: harmonic amplitude, total roundness error and ovality and triangulation. The first two groups are used in the laboratory validation process and the last one has been implemented for manufacturing supervision.

Future work includes relating harmonic amplitude to vibrations, which influence bearing performance, and waviness errors to manufacturing parameters. In addition, this specification paves the way to attribute noise levels to different bearing categories.

References

[1] El-Thalji, I.; Jantunen, E. A summary of fault modelling and predictive health monitoring of rolling element bearings. Mechanical Systems and Signal Processing, 2015, 60–61, 252–272, 10.1016/j.ymssp.2015.02.008.

[2] Liu, J.; Shao, Y.; Qin, X. Dynamic simulation for a tapered roller bearing considering a localized surface fault on the rib of the inner race. Proceedings of the Institution of Mechanical Engineers, Part K: Journal of Multi-body Dynamics Institution of Mechanical Engineers, 2017, 231(4), 670-683, 10.1177/1464419317695171.

[3] Sadeghi F, Jalalahmadi B, Slack T S, Raje N, Arakere N K. A review of rolling contact fatigue. ASME Transactions on Tribology 2009; 131:041403-1-15.

[4] Lancaster, A.; Dury, M. Measurement of the surface texture in Large Roller Bearings. NPL Management Limited, Good practice Guide No.148. 2017.

[5] Behzad, M.; Bastami, A.R. and Mba D. A New Model for Estimating Vibrations Generated in the Defective Rolling Element Bearings. ASME J. Vibration Acoustic. 2011. 133(4), 41011.

[6] Wardle F P 1988 Vibration Forces Produced by Waviness of the Rolling Surfaces of Thrust Loaded Ball Bearings Part 1: Theory Proc. Inst. Mech. Eng. Part C J. Mech. Eng. Sci. 202 305–12.

[7] Wardle F P 1988 Vibration Forces Produced by Waviness of the Rolling Surfaces of Thrust Loaded Ball Bearings Part 2: Experimental Validation Proc. Inst. Mech. Eng. Part C J. Mech. Eng. Sci. 202 313–9.

[8] Meyer L D, Ahlgren F F and Weichbrodt B 1980 An Analytic Model for Ball Bearing Vibrations to Predict Vibration Response to Distributed Defects J. Mech. Des. 102 205.