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RESEARCH METHODS AND TESTING STAND DEVELOPED TO EXAMINE VIBRATIONS GENERATED BY ROLLING BEARING

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Summary

The article presents research methods of rolling bearing vibration level measurement and evaluation of vibration measurement capability of Anderon meter STPPD developed at the Kielce University of Technology. In order to assess the measuring ability of Anderon meter STPPD comparative studies were performed. In these studies the noise tester MVH900 SKF - a standard instrument for measuring vibration, was adopted as a professional device. Analysis of the test results allow to reliably assess that both devices have comparable measurement capabilities.

Keywords: vibration level, rolling bearing, quality, anderon meter

METODY BADANIA POZIOMU DRGAŃ GENEROWANYCH PRZEZ ŁOŻYSKA TOCZNE ORAZ STANOWISKO BADAWCZE DO ICH PROWADZENIA

Streszczenie

W artykule przedstawiono metody badań poziomu drgań generowanych przez łożyska toczne oraz dokonano oceny zdolności pomiarowych stanowiska badawczego Anderometr STPPD opracowanego na Politechnice Świętokrzyskiej. W celu oceny zdolności pomiarowych Anderometru STPPD zostały przeprowadzone badania porównawcze. W badaniach tych za przyrząd wzorcowy przyjęto profesjonalne urządzenie do pomiaru drgań: noise tester MVH900 firmy SKF. Analiza wyników badań pozwoliła stwierdzić, że oba urządzenia dysponują porównywalnymi możliwościami pomiarowymi.

Słowa kluczowe: poziom drgań, łożyska toczne, jakość, anderometr.

1 INTRODUCTION

Roller bearings are commonly found in most of the mechanisms with rotating elements. From the users point of view parameters such as viability and reliability are of the utmost importance for the mechanisms in which they are assembled, a premature wear off or are damage of the bearing involves a time-consuming exchange, generating costs often disproportionate to the value of themselves (downtime, effort sharing etc.). This is particularly important in the case of large-size cylindrical parts [1, 2]. Strong competition on the bearing market forces producers to systematic improvement of their properties, which determine the vitality and comfort of use.

One of the most important rolling bearing parameters is the vibration level [3]. Measurements of vibration level generated by ball bearing allow the assessment production quality of new bearing. Vibration level analysis provides information about conditions of rolling bearing and allows to detect potential bearing faults [4-6]. Vibration analysis can be preventive tool used to monitoring wear level of bearing working in machine and if it necessary planned maintenance or replacement of bearing [7].

In literature there is information related to vibration model of rolling bearings [8, 9] but there is still limited details about construction and principle of working of measuring devices used to analyze vibration level of rolling bearing, particularly used in the industrial conditions [10].

2 EQUIPMENT FOR MEASURING THE VIBRATION LEVELS IN ROLLER BEARINGS

Just as the devices used by the leading rolling bearing manufacturers such as SKF, FAG or NSK, Kielce University of Technology designed and developed the measuring device Anderometr STPPD applied to measure the vibration level (Fig. 1). The device was made as a part of a project: "Development of methods for testing of rolling bearings in terms of modern requirements of products with higher operating parameters" by the

National Centre for Research and Development.

Anderometr STPPD is a device equivalent to the vibration levels measuring devices used by manufacturers of rolling bearings to monitor the level of quality of manufactured bearings. This follows from the objectives of the project under which the laboratory was created. According to which the laboratory works to support small companies producing equipment in which the bearings are used. The objective of the support is the optimization of bearings selection for applications under which they will work. The assumption is that Anderometr must meet the requirements of ISO 15242 [11,12] and be equipped with a velocity sensor. A sensor that will have parameters exactly defines by the standard, just for frequencies from 50 to 10 000 Hz.

The bearing industry has chosen for production testing a speed sensors for the following reasons:

– Velocity sensor is incomparably more comfortable to be used in devices applied to measure a series of bearings, ensuring an identical impact of the sensor on the tested bearing (preload spring provides a constant pressure of 200 g).To meet this specified conditions, piezoelectric sensors with low weight would have to be fixed to the bearing rings, which practically eliminate their suitability to be used in production lines and quality control positions.
– Acceleration sensors are more sensitive to vibrations of higher frequency in careful study of bearings low frequencies are also crucial (300 Hz).Without their analysis it is impossible to assess the impact of the basic parameters of accuracy of bearings, such as roundness or wave treadmill or pounding of the cage on the vibration levels.

In the STPPD a SG 4.3 sensor was use. This sensor was develop by the FAG company. SG4.3 is an induction sensor, the characteristics of the sensor are shown in fig. 2 and 3.The sensor is made of very light coil of wire ϕ 30 μm wound on an aluminum sleeve, suspended on a flat springs in a strong magnetic field. The sensor collects vibration from the outer ring of the bearing, with ensured controlled pressure from the spring. This sensor isn't commercially available. It can be only purchased with a very expensive complete measuring device. Both the sensors and the devices are offered by major manufacturers of bearings (SKF, NSK, FAG).

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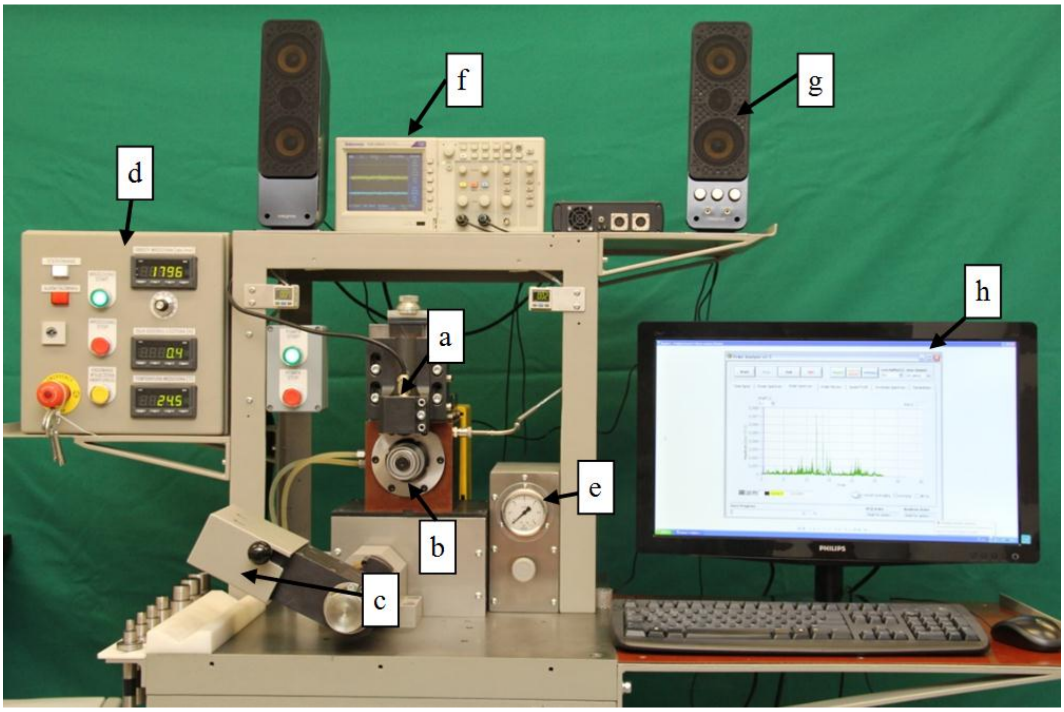

Figure1. Equipment for measuring the vibration levels, AnderometrSTPPD located in the Research Laboratory of Roller Bearing in Kielce University of Technology. Where: a – research probe; b - research spindle; c - axial load (air pressure); d - control panel; e - gauge; f - an oscilloscope; g - speakers; h - control and data analysis.

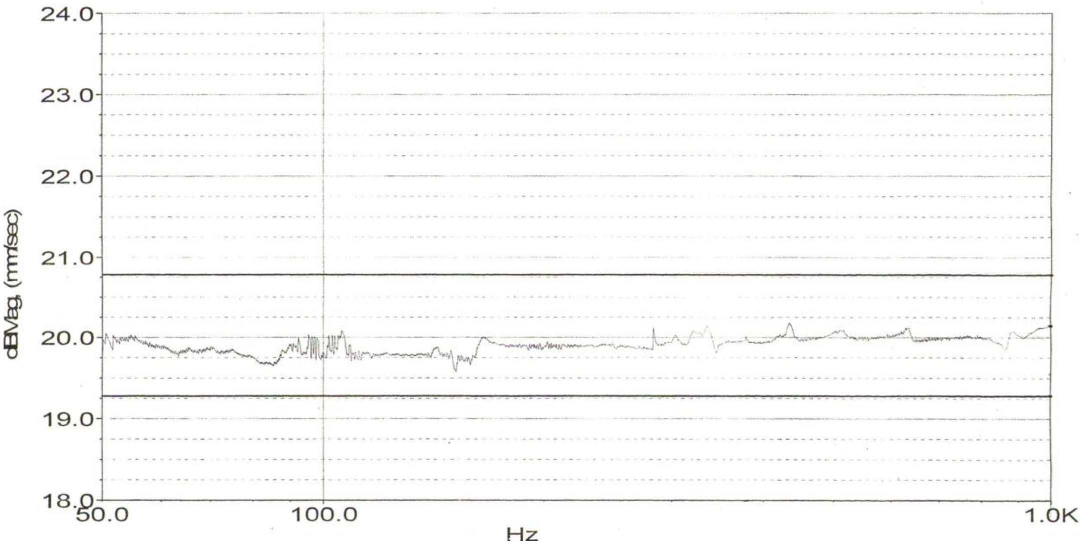

Figure. 2. Characteristics of the vibration sensor (range 50 - 1 000 Hz).

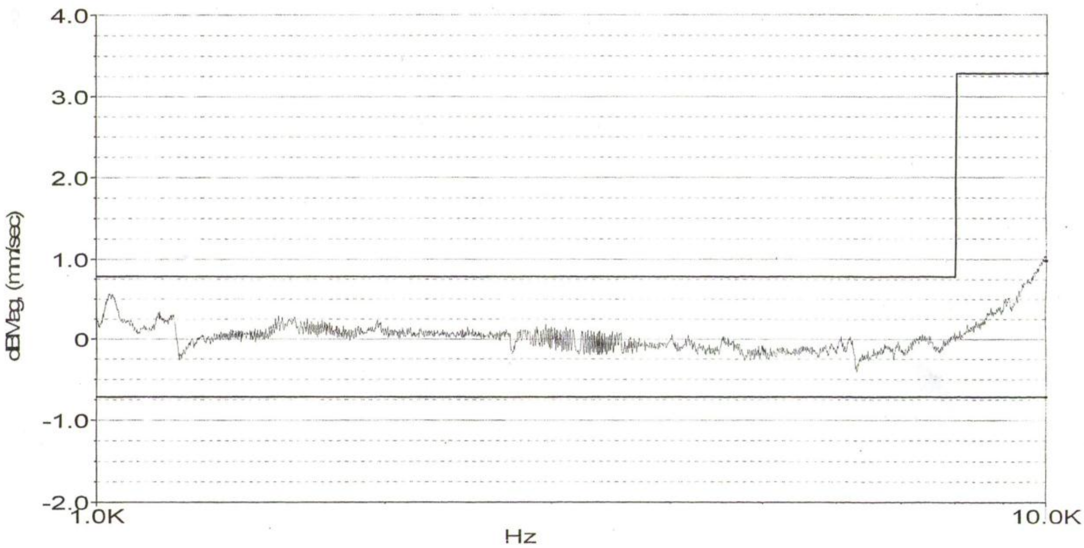

Figure3. Characteristics of the vibration sensor (range 1 000 - 10 000 Hz).

Otheradvantages of this sensor are:

a) a function of frequency is the most flat - i.e. Sensitivity (mV / G or mV / mm / s) is relatively constant for both low (below 300 Hz) and high (above 5 kHz) frequency, which allows to significantly simplify the construction measurement amplifier;
b) low input impedance of the sensor (approx. 30 Ohm) is beneficial due to the suppression of interference and ease in matching the input impedance and sending the signal;
c) the ability to work with low-gain signal;
d) measurement of low frequencies (even in the vicinity of 30Hz);

The next element of the design is the measuring device is the hydrodynamic bearing of the spindle with its body mounted on the measuring probe. In the probe the vibration sensor is fixed. Everything is mounted on the main plate of the body to which are attached the other components of the device. Additionally on the main plate the pneumatic pressure module is assembly (see Fig. 4), the module has a precisely set test load and bracket shelves on which measuring equipment are placed: speakers and control panel. To the main body the machine drive unit is attached, air maintenance unit for pneumatic pressure and control box.

The characteristics of the SG 4.3 sensor shown in Figure. **2** and Figure**3**. Charts inFigure. 2 and Figure3have been prepared by the manufacturer of the vibration sensor and are accurate response to the requirements of ISO 15242, standardizing the requirements that must be met in order to be approved for use by the manufacturer of rolling bearings. Such a presentation of the results of the qualification tests is to demonstrate that the flatness of the characteristics of up to 1000 Hz and from 1000 to 10 000 Hz is included in the area specified by the norm.

The spindle bearing is intended to provide a constant speed, very precise rotation and may not apply to the test node any additional vibrations.

Highly placed requirements in this regard can only be met by using sliding bearing arrange spindle on an oil film or an air cushion. These spindle is lubricated by the oil under pressure, which is provided by the oil pump. Adopted motor speed is 1800 min^{-1} by definition Anderon, as a measurement unit. The device can operate at different speeds (eg. for large bearings are used at 700 min^{-1}, or for very small bearings 3600 min^{-1}, but the speed measurement is then performed in mm/s), however, due to the structure of the spindle, which is bearing on a hydrodynamic slide bearing obtain high speed is impossible. On the other hand another type of bearing, outside pneumatic, would significantly limits the ability of the test load, inflict their own vibration levels (particularly when assessing the quality of small dimensions bearings) which could significantly affect the results of measurements.

Spindle unit with the air pressure module and setting module of the test load are shown in Fig. 4. The measuring probe has to ensure the sensor stiff position relative to the spindle shaft, to be able to maintain a constant pressure to the outer ring of the tested bearing. In order to enable adjustment position of the sensor to a changing with the size of the spatial position of the bearing point of its application, the probe is equipped with horizontal and vertical slides, which, after obtaining the desired position is blocked.

Studies level of bearing vibration is carried out under an axial load. Axially strained ball bearing works at a specified clearance. By maintaining constant contact of rolling elements with the raceways of the bearing we get a stable rotation, with allows the measurement of the vibration levels generated by the bearing. In other words, the measurement of the bearings under axial load eliminates interference from the unloaded rolling elements. Pressing force has an influence on the results, so it is normalized and, for each bearing size specified. It should be reproducibly and precisely adjusted.It is important to point out that the device does not test the bearings in terms of future applications, only examines the vibration level in the conditions specified by the norm.

In order to meet this requirement the measuring device has a pneumatic pressure module. The module consists of a rotating body installed pneumatic actuator. On its piston rod is mounted with replaceable joint, three-toed heads, equipped with flexible fingers pinch. The design of the module allows the rotation of adjustable angle, move away and repeatedly push it back the module to the working position.

The precise positioning of the module in the spindle axis enables regulating mechanism actuator position in the coordinates in the right position. The adjustment is done by changing the distance from the axis of the cylinder axis of rotation of acting as a polar coordinate, the angle is determined position shaft, on which rests the shoulder after going to the working position. The exact value of the pressure force is regulated by a potentiometer, located on the precise air pressure gauge in the cylinder actuator. The value of clamping force is read (in units of force [N]) on the digital display located on the control panel.

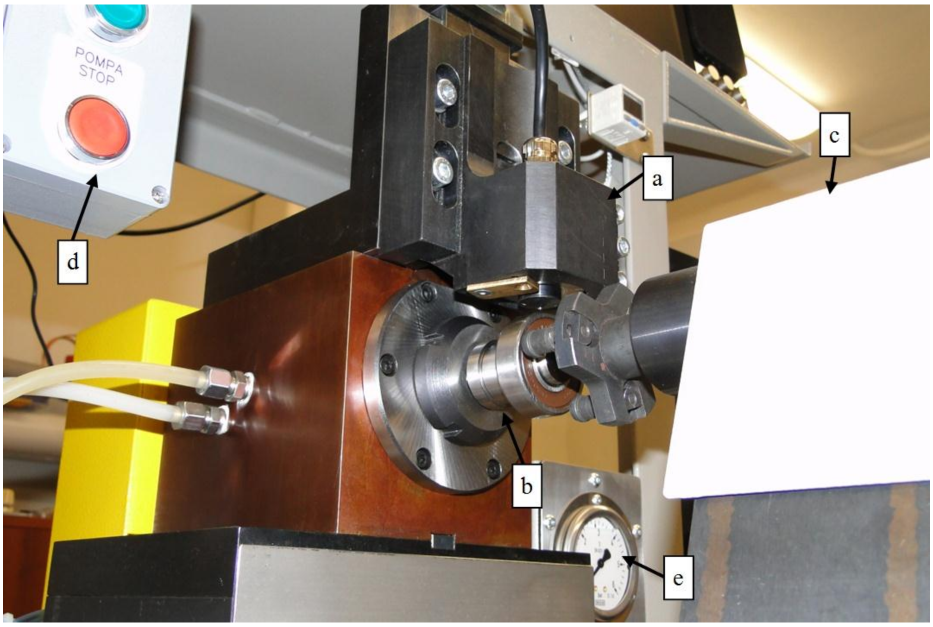

Fig. 4. Equipment for measuring the vibration levels, AnderometrSTPPD located in the Research Laboratory of Roller Bearing in Kielce University of Technology. Where: a – research probe; b - research spindle; c - axial load (air pressure); d - control panel; e – gauge

Drive unit consists of a motor placed on a special anti-vibration construction and belt drive. The motor with a inverter control is equipped with independent cooling fan, allowing him to work at low revs. Although the post is mainly to work in the standard speed of 1 800 min^{-1} is capable of operation at a speed of 700 min^{-1}, used sometimes when evaluating very large bearings. The module is intended to provide stable performance of the device at constant speed test. The permitted standard deviation is within ± 0.2%. Rotation measured by the spindle shaft are monitored and corrected. The power transmission module ensures stable operation of the spindle, and consequently tested bearing.

The signal from the vibration sensor is amplified and filtered by pre-measuring amplifier designed specifically for the needs of the position. A unique feature is its multigrade, allowing you to select the degree of amplification depending on power source. This allows a larger resolution at a very low level of vibration, which should enable greater accuracy of measuring the vibration levels of very high quality bearings. Standard solutions do not allow for practical detect quantitative differences when comparing bearings, in which the vibration levels of in individual frequency bands falls below one Anderona. The amplifier has seven degrees amplification which are selected automatically by the device software (from 250 to 25 000 times), which allows for high device resolution important with low vibration. The signal from the amplifier is divided into three parallel tracks, which are directed on an analog-to-digital card for further processing into oscilloscope and speaker - the acoustic assessment.

Although the construction of Anderometr is known, to build such a device that meets the high demands a precision, both in terms of mechanical and electronic isn't an easy task. Anderometr built at Kielce University of Technology has its own, unique solution in terms of strengthening the measurement signal (as mentioned earlier), a unique device software allows a standard evaluation of vibration in three frequency bands, FFT spectrum analysis and is developed in terms of assessing which part of the placenta is responsible for increasing the level of vibration and/or displays damage. In addition, the device has an innovative solutions in terms of mechanical design. Pneumatic clamping, providing repeatable test load, it has been reported to protect on 03.12.2012 as "Axial load thrust rolling bearings, especially in a device for measuring the vibration level" and received a positive decision on 26.10.2015.

3 DESCRIPTION OF THE ANDEROMETER SOFTWARE

The program ANDEROMETER [13] developed by the staff of Kielce University of Technology, serves to support the rapid measurement of vibration emitted by bearings according to ISO 15242-1 [11] and ISO 15242-2 [12]. The software can run on operating systems: Windows XP, Windows Vista and Windows 7.

The program allows you to:

• set the measuring range of the amplifier,
• change measuring ranges of the measuring card,
• constant measurement of the spindle speed,
• with real-time waveform signal of the vibration sensor,
• with real-time amplitude spectrum of the sensor signal
• continuous measurement of vibration levels in the full range of frequencies and bands specified by the standard,
• averaged measurement of vibration values in a given period of time,
• calibration of the measurement path.

The program works with research station for measuring and analyzing vibration bearings. ANDEROMETER software processes the received signal, filters it, and divided into three bands:

- Low (LB) from 50 to 300 [Hz]
- Medium (MB) from 300 to 1800 [Hz]
- High (HB) from 1800 to 10 000 [Hz].

Each band is evaluated separately and carries information about the accuracy of certain geometry parameters raceways and rolling elements, blemishes and selected properties of the lubricant.

Bearings defects have the greatest impact on the level of vibration in certain frequency bands:

a) Low frequency LB:
   – the difference in size of the balls;
   – imperfections resulting from the processing of turning;
   – instability of cage;
b) Medium frequency MB:
   – deformation of the bearing balls;
   – wave treadmill;
   – instability of cage;
c) High frequency HB:
   – roughness of the track;
   – roughness of the balls;
   – instability of cage;
   – contamination.

The test results are presented in real time on the screen, both in digital form and in the form of graphs. Assessed on the device is also subject to the sound produced by the placenta, which suitably enhanced, given by the audio system. Researcher hackneyed in the acoustic emission of the rolling bearings, can accurately assess their condition, together with an indication of what sort of defects or damage present in the test sample.

In addition to assessing the level of vibration spectrum analysis software enables the sensor signal in real time or with a predetermined time interval, spectral analysis envelope and recording the results.

Below Fig. 5 shows the main software interface ANDEROMETER, along with marked its basic functional windows.

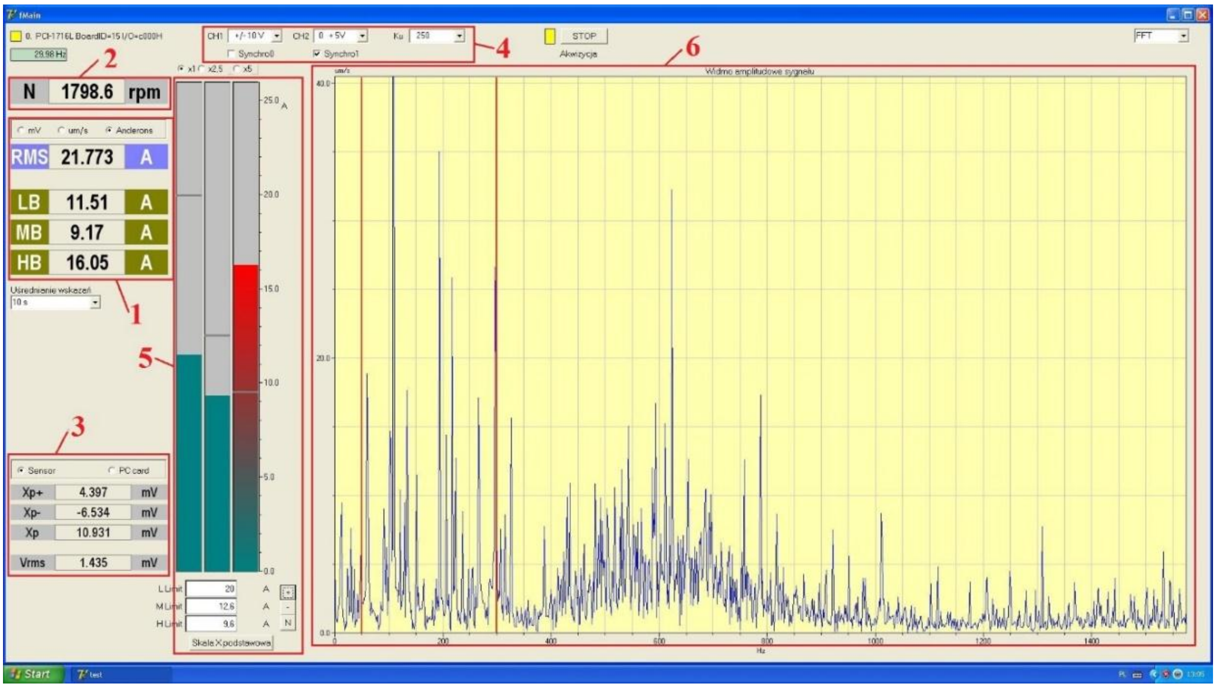

Fig 5. The main software interface ANDEROMETER: 1 noise indicators, 2-spindle speed, 3-voltage, 4- measuring range of the measuring card, 5- analog indicators of the noise floor, 6-amplitude spectrum.

The effective values of vibration tested bearing in the standard frequency bands with a choice of vibration units are displayed on indicators stroked the frame (1). Markings when rates further define the effective values of vibration in the corresponding frequency ranges, ie. RMS - full frequency range, LB - low frequency range, MB - mid range, HB - high frequency range.

Icon (2) represents the spindle speed. According to the recommendations of ISO 15242-1 [11], measurements should be performed at the speed of 1800 rev / min, while deviation from this speed should not be greater than ± 0.2%. That's why software is designed so that the deviation exceeds the limits of standard changes the background color of the indicator to red. The icons presented in the frame (3) show the voltage at the output of the sensor or at the input of measuring card. However, in the central part of the main interface with windows measuring range measuring card (4). In order to make a rapid assessment of vibration level in different frequency bands placed analog gauges (5). Below these indicators are three editing window for entering the limit, limit values of vibration levels specified by the manufacturer receiving condition or needs of the recipient. Exceeding the limit values declared vibration levels will change the color of the indicator. Window (6) shows a graph of the amplitude spectrum of the signal output from the sensor in real time. Additionally, you can choose here waveform chart measured in time.

4 THE RESULTS OF THE EQUIPMENT VERIFICATION

The level of vibration is a parameter which is concentrated rich information about bearings quality, allowing for its multidimensional assessment. Each bearing descending from the production line to test the level of vibration, deciding to release him for further operations process.

For comparative verification tests selected professional equipment used for measurement of vibration by bearing manufacturers - noise tester MVH900 SKF. The parameters of STPPD and MVH 900 should be very similar, despite the use of differentiated cell structure, various embodiments of measuring circuits (amplifiers, measuring cards, etc.) and with quite different software. Comparative test presented in this article is intended to demonstrate these similarities. The tests were carried out on bearings: 6202 ZZ and 6206 ZZ. Due to the multitude of factors that determine the level of vibrations generated by the placenta and their instability, the results of measurement of this parameter are scatter. A significant dispersion of the results exhibit bearing from the same batch as well as measurements made on a single bearing. Large differences can be observed by changing the measurement location on the circumference of the outer ring. In carrying out the test verification unit attempts to minimize the impact of these factors on the obtained results. It was decided to perform tests on a single bearing from each group and the measurements will be performed with the same orientation of the outer ring to the vibration sensor.

Research was carried out for each of three frequency bands (LB, MB and HD) as a standard are assessed separately. The MVH900 was adapted as the reference device. The results obtained were processed statistically. A typical set of results is shown in tables 2 and 3. These results have been developed according to the criteria described in the literature [14], measurement accuracy:

$$DM = \left|\bar{w}_{\Delta z} \pm t_j \cdot s\right|_{max} \cdot 100\% \qquad (1)$$

where:
$\bar{w}_{\Delta z}$ - the average value of measurement error;
t_j - the Student t distribution;
s – Standard deviation.

5 SUMMARY AND CONCLUSIONS

Measurement of vibrations generated by the rolling bearings is especially important for their users because it carries very important information about the quality of their performance and therefore their functionality and expected durability. All major manufacturers of rolling bearings have in their inventory devices for vibration measurement. Most of them are installed in automatic assembly lines, allowing for the elimination of defective pieces already on the production line.

Due to the fact that they devices for vibration measurement are highly specialized equipment, their price is relatively high. Few manufacturers use in their products bearings are able to afford the cost of purchase of equipment to test the bearings for measurement of vibration. The use of equipment bearing manufacturers is limited and often quite impossible.

Anderometr STPPD, developed in Kielce University of Technology, enables the provision of services for measurement of bearing vibration, allowing for a reliable assessment of their suitability for applications with specific quality requirements.

Results of comparative test have shown that the maximum measurement accuracy DM obtained for medium frequency band for both types of examined bearing (see tab. 1 and 2). While for the bearing types 6202ZZ minimum measurement accuracy DM calculated for high frequency band (see tab. 1), whereas for bearing 6206ZZ the lowest measurement accuracy indicated for low frequency band (see. tab 2). However measurement accuracy DM obtained for all frequency band generaly fall within 30%. This values are satisfactory.

Table 1. Results of comparative tests.

Experimental measurement error for the 6202ZZ bearing vibration level [A]								
LP	Parameter		STPPD	MVH900	STPPD	MVH900	STPPD	MVH900
			LB		MB		HB	
1	Cardinality n_s		30	30	30	30	30	30
2	Averagevalue $\bar{x}$		3,46	3,61	1,54	1,69	1,13	1,19
3	Standard deviation $\boldsymbol{s}$		0,2747	0,1964	0,0774	0,0662	0,0547	0,0403
4	Mean square error arithmetic mean of a series of measurements s_r		0,0502	0,0359	0,0141	0,0121	0,0100	0,0074
5	The expanded uncertainty of the measurement U_p		0,5385	0,3850	0,1516	0,1297	0,1071	0,0789
6	Expandeduncertainty U		0,0983	0,0703	0,0277	0,0237	0,0196	0,0144
7	Limiting error of the measurement $s_{max}\%$		4,35 %	2,98 %	2,75 %	2,14 %	2,64 %	1,85 %
8	Comparison of variance two populations F		1,40		1,17		1,36	
9	The average value of measurement error $\bar{w}_{\Delta z}$		-0,0402		-0,0853		-0,0468	
10	The confidence interval for the mean, when $\gamma_s = 0{,}95$	$\bar{w}_{\Delta zmin}$	-0,1141		-0,0671		-0,0955	
		$\bar{w}_{\Delta zmax}$	-0,0564		-0,0264		0,0618	
12	The variance in the sample s^2		0,0061		0,0036		0,0028	
13	MeanDeviations s		0,0784		0,0602		0,0527	
15	The confidence interval for a method single error α	*min*	0,0376		0,0609		0,1237	
		max	0,2082		0,1544		0,1573	
16	Measurement accuracy		**20,02 %**		**20,82 %**		**15,44 %**	

Table2. Results of comparative tests.

Experimental measurement error for the 6206ZZ bearing vibration level [A]								
LP	Parameter		**STPPD**	**MVH900**	**STPPD**	**MVH900**	**STPPD**	**MVH900**
			LB		MB		HB	
1	Cardinalityn_s		30	30	30	30	30	30
2	Averagevalue$\bar{x}$		6,84	6,78	3,91	4,74	3,84	3,91
3	Standard deviation$s$		0,1651	0,1990	0,2752	0,2399	0,2110	0,1494
4	Mean square error arithmetic mean of a series of measurements s_r		0,0301	0,0363	0,0503	0,0438	0,0385	0,0273
5	The expanded uncertainty of the measurementU_p		0,3236	0,3900	0,5346	0,4703	0,4137	0,2928
6	Expandeduncertainty$U$		0,0591	0,0712	0,0985	0,0859	0,0755	0,0535
7	Limiting error of the measurement$s_{max}\%$		1,32 %	1,61 %	3,86 %	2,77 %	3,01 %	2,09 %
8	Comparison of variance two populations F		1,21		1,15		1,41	
9	The average value of measurement error$\bar{w}_{\Delta z}$		0,0103		-0,1722		-0,0117	
10	The confidence interval for the mean, when$\gamma_s = 0{,}95$	$\bar{w}_{\Delta zmin}$	-0,0512		-0,2748		-0,0955	
		$\bar{w}_{\Delta zmax}$	0,0719		-0,0695		0,0618	
12	The variance in the sample s^2		0,0016		0,0058		0,0047	
13	MeanDeviation$s$		0,0394		0,0760		0,0688	
15	The confidence interval for a method single error α	*min*	0,0701		0,0170		0,1237	
		max	0,0908		0,3102		0,1573	
16	Measurement accuracy DM		**9,08 %**		**31,02 %**		**15,73 %**	

The results of the verification tests allow to conclude that AnderometrSTPPD has a comparable measurement capabilities in relation to the device MVH900 SKF, which is a product of one of the leading manufacturers of bearings and devices for the diagnosis of the world.

In the next step of research the wider groups of different types of rolling bearings will be examined. Furthermore comparative test with another devices used to measure vibration level of rolling bearings will be carried out.

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Prof. dr hab. inż. Stanisław Adamczak, dr h.c., pełni funkcję Rektora Politechniki Świętokrzyskiej w Kielcach. Jego zainteresowania naukowe obejmują podstawy metrologii i metrologię wielkości geometrycznych. Jest członkiem wielu organizacji i stowarzyszeń naukowych, m.in. Komitetu Metrologii i Aparatury Naukowej PAN. W swoim dorobku ma ponad 200 publikacji i 120 referatów, jest także autorem lub współautorem szeregu patentów.
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Absolwent Wydziału Metalurgicznego AGH w Krakowie. Obecnie pracownik Katedry Technologii Mechanicznej i Metrologii na Politechniki Świętokrzyskiej w Kielcach. Wiele lat pracował w przemyśle łożyskowym, gdzie zajmował się badaniami łożysk tocznych oraz konstrukcją i eksploatacją urządzeń do oceny i badań własności eksploatacyjnych łożysk. Aktualnie kontynuuje swoje zainteresowania zawodowe, biorąc udział w realizacji projektów prowadzonych przez Politechnikę Świętokrzyską.
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