EXAMINATION OF ACOUSTIC PROPERTIES OF A GEAR PUMP AFTER TOOTH ROOT UNDERCUTTING USING THE INDUCTION OF DECISION TREES

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Abstract: *Among cavity pumps used in hydraulic drive systems as energy generators, gear pumps are the most widespread. Apart from their numerous advantages from the point of view of noisiness and the delivery fluctuation coefficient, they are inferior to others. Steps are undertaken to decrease the noisiness. According to the research results, own acoustic parameters of the pump depend on the technology and performance quality as well as on the geometrical features of the tooth profile. The paper is restricted to the analysis of acoustic properties of an innovative gear unit after tooth root undercutting. Acoustic properties have been described with taking into consideration induction of decision trees and decision rules.*

Keywords: ACOUSTIC PROPERTIES, GEAR PUMP, INDUCTION TREES, OPTIMIZATION

1. Introduction

Hydraulic machines are one of the most widespread machine classes, without which it would be hard to imagine the functioning of modern industry and of society today. These machines can be divided into pumps, water turbines, hydrokinetic drives, mixers, water-jet drives, propellers etc., but also hydraulic transport, hydraulic drive and hydraulic steering, etc. [1-4]. Overflow machines form a wide group of systems. The work of overflow machines is most frequently based on two states: transient state (in which values of the system functions change in time) and steady state (the functions values do not change in time or change periodically). If the pump is the heart of a hydraulic system then the valve is the brain. Valves are used to perform a large variety of governing and controlling functions.

The noise is most effectively reduced through a combination of the two ways (the active way being the most effective of the two). Detailed studies have shown that the noisiness of the displacement pump is due to the flow of the working medium (Fluid Born Noise) and to the vibrations of its structural components (e.g. the unbalance of the rotating parts, excessive clearance in the moving joints, improper workmanship and assembly). The main causes of noise generation, having the most significant bearing on the sound pressure emission level, are the pressure fluctuation on the delivery side and the trapping of the fluid in gear wheel tooth spaces. In order to avoid such adverse phenomena, relief grooves and dampers are used to at least partially reduce the fluctuations generated by the pump (the passive method) [4, 12, 13]. Such measures, however, entail additional costs. The authors' own research has shown that the pump's acoustic parameters depend on the manufacturing technology, the quality of workmanship and the tooth profile geometry. The present study is limited to the analysis of the acoustic properties of a novel gear pump with tooth root relief, in particular with the use of a induction trees.

2. Tested pump

The designed and built prototype pump has a three-plate structure shown schematically in Fig. 1. The front plate (1) is used for mounting the pump on the drive unit. The middle plate (2) contains gear wheels, slide bearing housings and suction and forcing holes for connecting to a hydraulic system. The whole construction is closed with a rear plate.

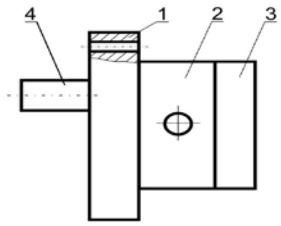

Fig. 1 *Three-plate design of gear micropump with external meshing. 1 – front (mounting) plate, 2 – middle (rest) plate, 3– rear plate, 4– driving shaft*

The tested prototype unit was designed in-house and manufactured by the Hydraulic Pumps Manufacturing Company Ltd. in Wrocław. The pump was designed having in mind the technological capacities of this company [10, 11]. The novelty of the prototype pump consists in the modification of the involute profile in its upper part through the so-called tooth root relief (undercut). The main meshing parameters for the pump with unit delivery q = 40 cm^3 are listed in the table below (Table 1).

Table 1: *Meshing parameters*

	Symbol	Unit	Value
Number of teeth	z	-	9
Modulus	m_0	[mm]	4.5
Pressure angle	α_0	[°]	20
Gear wheel width	b	[mm]	32.2

3. Measuring rig

The reverberation chamber (3) for acoustic testing meets standard ANSI S1.21-1972 and standard PN-85/N-01334 and can be used for the vibration and noise certification of machines and equipment. The chamber's sound insulating power against external noise in a frequency range of 20-20 kHz amounts to 50 dB. This insulating power ensures the elimination of disturbances originating from the drive system and from the hydraulic system supplying the tested pump. Figure 2 shows a schematic of the rig for the testing of acoustic parameters. For measurements the tested pump together with a microphone array was placed in a reverberation chamber.

The chamber is made from two similar irregular polyhedrons, one of which is placed in the other. The walls of the chamber are made of solid brick while its inner plasters are made of cement mortar.

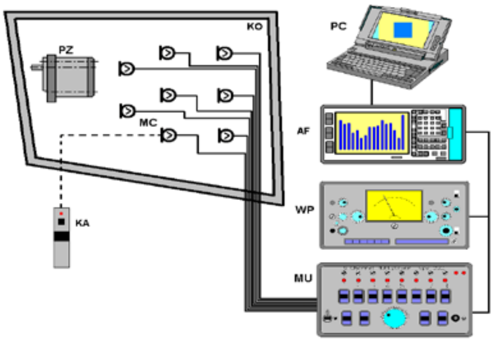

Fig. 2 *Block diagram of gear pump noisiness measuring rig: KA-calibrator, MC-eight free sound field microphones, MU-multiplexer, WP-instrumentation amplifier, AF-two-channel frequency analyzer, PC-computer, PZ-gear pump, KO-chamber*

Reverberation chamber

The chamber is made from two similar irregular polyhedrons, one of which is placed in the other. The walls of the chamber are made of solid brick while its inner plasters are made of cement mortar (Figures 3). Standing waves have been eliminated owing to the different dihedral angles and the concrete plasters. The uniformity of sound field distribution in the chamber is good, being within acceptable limits starting with the octave midband frequency of 125 Hz. Eight constant measuring points have been fixed in the chamber on the basis of sound field distribution studies. In conformance with the above standards, the microphones have been fixed at a height of 1.3 m from the floor.

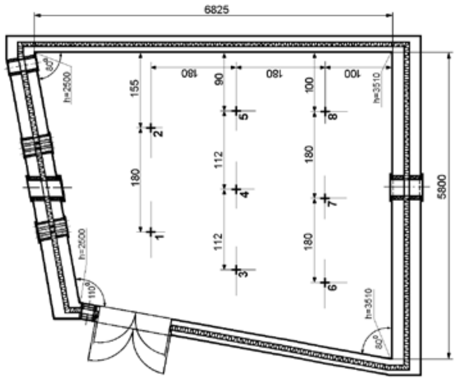

Fig. 3 *Reverberation chamber*

The equipment setup for measuring the noise of the gear pump placed in the diffusion sound chamber is shown in Fig. 4. Measuring microphones were positioned in eight points. The sound pressure level readings taken from them were averaged. For data reading the measuring microphones were selected by means of the multiplexer, and the sound pressure level with the spectrum was stored in the two-channel analyzer memory. The data were edited using a PC and the *B&K* type *5306* software.

Fig. 4 *A gear pump in the acoustic chamber*

4. Acoustic research

Acoustic measurements of an experimental version of the pump respectively for the value of discharge pressure p_t: 0, 2, 4, ..., 30 [MPa] and the frequency f: 25÷20k [Hz] have been obtained in the analysis. Table 2 shows exemplary acoustic measurements of a gear pump after tooth root undercutting for $p_t = 12$ MP. Figure 5 presents the value of the acoustic pressure level L_m, corrected acoustic pressure level L_A, acoustic power level L_p and corrected acoustic power level L_{pA} in the function of discharge pressure p_t at a constant rotational speed of a pump shaft n = 1500 rpm.

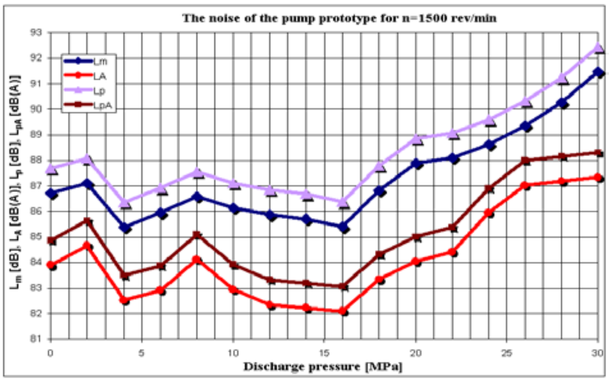

Fig. 5 *The noise of the gear pump after tooth root undercutting for nominal rpm.*

Figures 6 and 7 present a tertian and an octave spectrum of the gear pump after tooth root undercutting for nominal discharge pressure and nominal rotational speed.

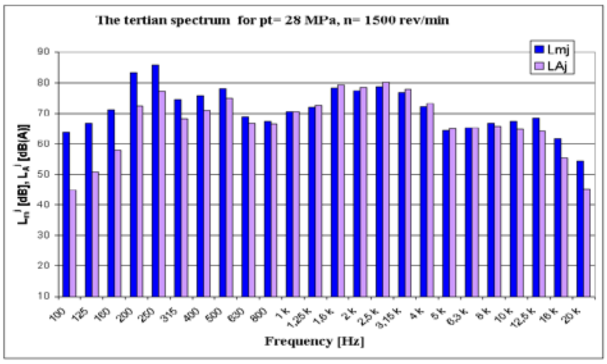

Fig. 6 *The tertian spectrum of an experimental unit for nominal pressure and rotational*

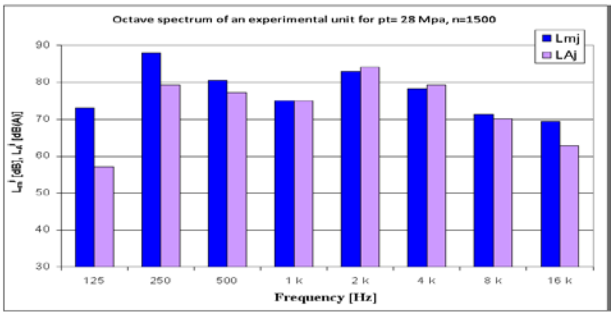

Fig. 7 *The octave spectrum of an experimental unit for nominal pressure and rotational speed*

The dominant level in the whole scope of discharge pressures is present in case of an octave of the centre frequency equal to 2k Hz. Table 2 compares data gathered for an experimental unit and the pump PZ4-32 TKs 186.

Table 2: *Meshing parameters.*

p_t [MPa]	Pump test $L_{A(1)}^{2000}$	PZ4-32 TKs 186 $L_{A(2)}^{2000}$	ΔL_A^{2000}
6	74,7 [dB]	79,5 [dB]	4,8 [dB]
12	74,8 [dB]	79,5 [dB]	4,7 [dB]
18	78,2 [dB]	83,6 [dB]	5,4 [dB]
24	81,0 [dB]	83,0 [dB]	2,0 [dB]
28	82,9 [dB]	83,6 [dB]	0,7 [dB]

Figure 8 compare a corrected level of the acoustic pressure L_A, and the corrected level of the acoustic power L_{pA} of an experimental unit and pump PZ4-32 TKs 186.

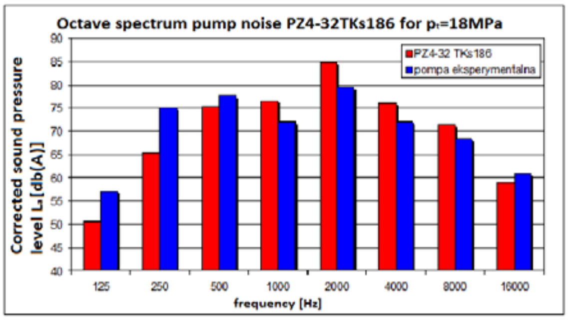

Fig. 8 *The octave spectrum of an experimental unit and pump PZ4-32 TKs 186*

5. Discrete methods of identification and classification of acoustic signal

The classification is an important stage in the analysis of acoustic properties. In this stage, properties characteristic for signals of particular microphones are compared with each other. On the basis of obtained results a decision concerning the classification of the signal properties to a given group is made [5] Among the most often applied methods of recognising acoustic signals are: HMM (Hidden Markov Models) , VQ (Vector Quantization), LVQ (Learning Vector Quantization), SOM (Self- Organising Maps), ANN (Artificial Neural Network), GMM (Gaussiab Mixture Models) [14, 16], SVM (Support Vector Machines). In addition, there are classifiers based on the induction of decision trees, ML-HMM (Maximum Likelihood Hidden Markov Model) [6, 7, 8]. In a general case, the classification includes two stages: creating of patterns for recognition and identification.

Tree induction as classifiers of acoustic signals

A decision tree is a structure which has ordinary properties of trees in the meaning assigned to the tree in the information technology, so it is a structure composed of nodes from which branches come to other nodes or leaves. It is convenient to define tree structures in a recursive way. Assuming that a given branch X on which attributes a_1, a_2 ,..., a_n and the set of notions C of the category C are determined:

1. The leaf containing any category label $d \in C$ is a decision tree.

2. If t: $X \rightarrow R_t$ is a test made on the values of attributes of examples with a set of possible results $R_t = \{ r_1, r_2, \dots r_m \}$ are decision trees, then the node containing the test t , from which m branches come out, given that for i== 1, 2, ..., m branch i corresponds to the result r_i and leads to the tree T_i, is a decision tree.

For any node of n decision tree, by t_n we mean a test connected with it, and for each of its possible results $r \in R_t$ by $n_{[r]}$ node or child leaf, to which the n branch related to the r result leads from the node. The notation described above is presented in Figure 9.

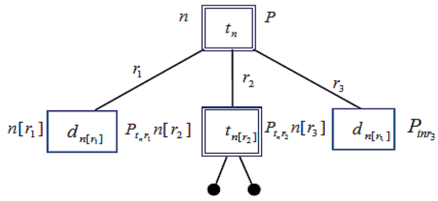

Fig. 9 *A sample query "query-by-example" to the decision-making system*

Information included in the set of training examples is equal to:

$$I(E) = -\sum_{i=1}^{|E|} \frac{|E_i|}{|E|} \cdot \log_2 \left(\frac{|E_i|}{|E|} \right)$$

where:

E - the set of training examples

$|E_i|$ - the number of examples which describe i object

$|E|$ - the number of examples in the training set E

The expected value of information after the division of the set of examples E into subsets $E^{(m)}, m = 1, \dots, |V_a|$, for which the attribute a has the value V_m, determined as [15]:

$$I(E,a) = \sum_{m=1,K,|V_a|, E^{(m)} = \emptyset} \frac{|E^{(m)}|}{|E|} \cdot I\left(E^{(m)}\right)$$

where:

$|E^{(m)}|$ - the number of examples after the division of the set E in relation to the value m of a given attribute,

$|E|$ - the number of examples in the training set E.

Figure 10 presents preliminary signals processing without a filter for 8 microphones in the whole range of values of discharge pressure that is 2-30 MPa.

a) b)

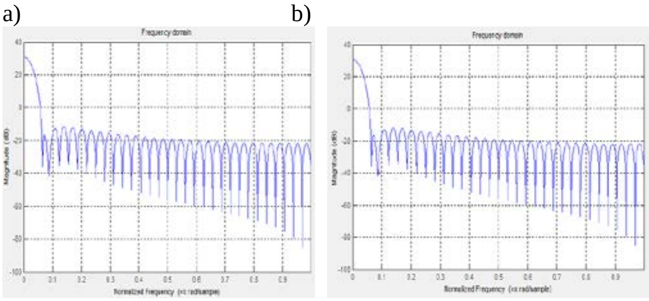

Fig. 10 *Initial processing of the signals for the four microphones: a)1. b)3*

A method of analysing a frequency spectrum has been chosen as a parametrisation method. The method using this rule is called the Burg method, the implementation of which is included among others in the range "Signal Processing Toolbox" of the Matlab programme [9]. The figure 11 shows the spectrogram for 2 microphones.

a) b)

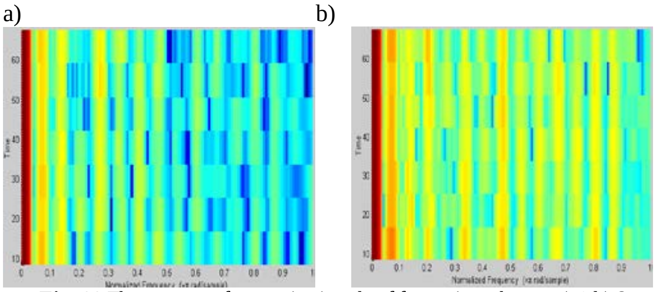

Fig. 11 *The spectra of acoustic signals of four microphones a) 1 b) 8*

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The classification by means of induction trees has been made separately for acoustic pressure L_m, frequency *kHz* and discharge pressure *MPa*, as output attributes (wy): L_m(wy), *kHz* (wy), *MPa* (wy). Input attributes (we) are the values of acoustic measurements registered from 8 microphones: microphones**1**(we), microphones**2**(we), microphones**3**(we), microphones**4**(we), microphones**4**(we), microphones**5**(we), microphones**6**(we), microphones**7**(we), microphones**8**(we). As a result of the analysis, induction trees have been generated for each parameter L_{mj}, p_t [Mpa], f [Hz].

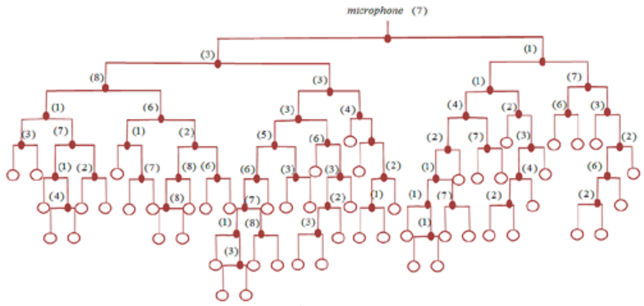

Fig. 12 *The induction tree for the acoustic pressure L_m – without trimming*

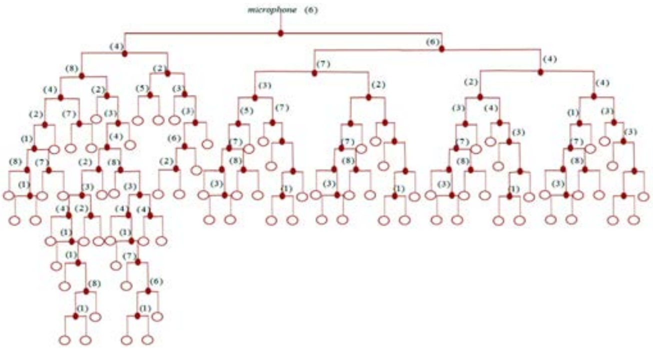

Fig. 13 *A simplified induction tree for the frequency f [Hz]- the number of examples forming the tree graph- 4, tree trimming- 40%*

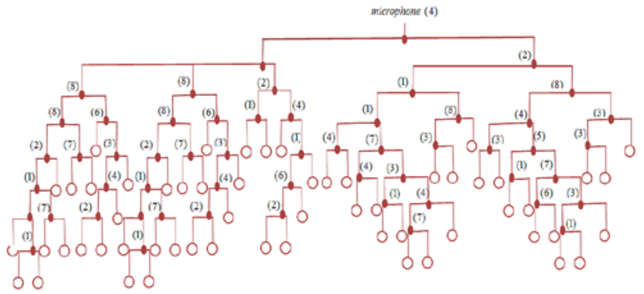

Fig. 14 *A simplified induction tree for the discharge pressure p_t [Mpa]- the number of examples forming the tree graph-4, tree trimming-25%*

The induction tree determines the degree of importance of the attribute from the most important one placed in the root, through classification of any example. The most important acoustic signal generated by the value of the discharge pressure is present in the microphone 4- in accordance with the tree from Figure 14 whilst the most important acoustic signal influenced by the change of frequency is generated on the microphone 6- in accordance with the tree from Figure 13. In accordance with the tree from Figure 12, the most important signal influencing the value of the acoustic pressure is the signal registered on the microphone 7.

6. Conclusions

In a decision tree, nodes store tests checking values of example attributes and leaves store categories assigned to them. For each of possible test results, there is one branch coming from a node to a subtree. In this way, it is possible to represent any attributes of the hypothesis admissible for a given set. All operations were made in the real time during normal exploitation of the gear pump. On the basis of the results received from the inference mechanism, resulting from the correlation between acoustic signals measured in a continuous manner and model signals placed in the data base, there would be identification of the influence of particular signals from microphones on the chosen parameters of the gear pump after tooth undercutting

7. Bibliography

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