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An estimation of the state of consumption of a positive displacement pump based on dynamic pressure or vibrations using neural networks

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ABSTRACT

This paper describes the algorithms used to estimate the state of consumption of a pump based on dynamic pressure or vibrations. To create algorithms, the author used computational intelligence methods in the form of neural networks. In order to perform the analysis, data analysis systems were designed based on three neural networks: multilayer perceptron neural network (MLP), generalized regression neural network (GRNN) and probabilistic neural network (PNN). Processing of the input signal in the final result of the analysis consisted of several steps. First, the measurement data were preprocessed (delete constant component, normalization, standardization, reduction, fast Fourier transform (FFT), etc.), and training and test sets were prepared using the matrices with the expected system answers. The last step was the analysis, consisting of design data analysis systems based on artificial neural networks and their learning and testing. On the basis of the obtained results the effectiveness of neural networks and the methods of pre-processing of the signals applied to approximate the state of consumption of the displacement pump were evaluated. Design systems were evaluated based on accuracy (generated error) and complexity (number of parameters and training time) criteria. The main contribution of the paper is to design and compare methods for pre-processing the signal, and to design and compare the effectiveness of the three neural networks in the diagnosis consumption of a positive displacement pump.

1. Introduction

A modern engineer uses willingly other areas of science in solving technical problems. An example of this is the use of artificial neural networks [1] to diagnose the state of consumption of a pump [2,3]. It is a difficult problem to solve in a conventional way due to ignorance of the rules which govern it. However, using computational intelligence methods [4] one can easily deal with it. Artificial neural networks [5] with the ability to acquire knowledge during training and its generalization can learn the rules which approximate the state of consumption of a pump. The author used computational intelligence methods, including neural networks, for similar problems concerning the analysis of the signals from the electronic nose [6–8].

A pump [9,10] is an essential component of a hydrostatic system. It occurs in the conversion of the mechanical energy brought at the pump's shaft to drive motor energy in the form of pressure contained in the liquid stream pumped by the pump. The purpose of a pump is to obtain the greatest efficiency (minimizing energy loss) by achieving high operating pressures.

An important aspect when estimating the state of consumption of a pump is preliminary signal processing because the collected information is usually too complex and impossible to analyse without any data processing system. This is a problem similar to image analysis. The procedure of feature extraction is typically performed by standard pattern recognition methods (i.e. PCA – Principal Component Analysis; CLA – Cluster Analysis; TM – Template Matching; DFA – Discriminant Function Analysis; and TMLR – Transformed Multiple Linear Regression) or signal processing (i.e. Fourier or wavelet analyses; ANN – Artificial Neural Network; GA – Genetic Algorithm; and FL – Fuzzy Logic) [11,12].

The advantage of techniques based on computational intelligence (CI) methods [13] lies in the properties inherited from their biological equivalent [14], such as learning and generalization of knowledge (ANN [15]), a global optimization (evolutionary algorithms) and the use of imprecise concepts (FL) [16]. The very high popularity of ANN in recent years has contributed to a number of different types of structures, data flows, transfer functions of neurons and methods of training. When applying ANN to obtain

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maximum efficiency, the designer must demonstrate relevant experience realized in the selection of relevant parameters.

In this paper, the author focused on a comparison of signal pre-processing methods and a comparison of artificial neural networks [17]. An ANN has been used to analyse signals from a pump in the form of dynamic pressure and vibrations in order to approximate the states of consumption. The author has developed several data analysis systems. The software was written in MATLAB,[1] as it contains very extensive libraries of functions utilizing AI methods.

2. Pump

The measurements were performed on axial pistol positive displacement pump WPTO2-10. It is a positive displacement pump, axial, with multiple pistons, a hinged shield, and a constant angle of inclination (consistent performance). A photo of the pump is shown in Fig. 1, and a schema in Fig. 2.

Pumping liquid, in displacement pumps, is carried out by displacing the liquid from the working chambers by a suitably shaped element (e.g. a piston). Positive displacement pumps are characterized by a tightly sealed fluid-filled working chamber, so that the displacement of liquid from the compartment enables a concomitant significant increase in the liquid pressure. In pumps of this kind there are two working phases: suction – the moment of admission of liquid into the pump chamber under the influence of negative pressure; plunging – the moment of displacement of liquid from the pump chamber to the discharge space [18].

The issue considered by the author of the work was the consumption of the positive displacement pump, which influenced the exploitation of the pump's components. Impurities in the working fluid cause 80% of the hydraulic system's failure. They cause accelerated wear of the abrasive mating surfaces of the elements remaining in relative motion [18].

The disadvantage of the pump WPTO2-10 is the load of the piston by a significant radial force (derived from the interaction of the shield) transmitted to the rotor shaft and radial bearing. The distribution of the forces operating on individual elements of the pump indirectly determines their damages [18].

Those elements most exposed to the load are the roller bearings, which determine the stability of the pump. This pump has three such bearings. The shaft has bearings on one side, two ball bearings, because it transmits significant radial and axial forces [18].

3. Measurements

One measurement for each state of consumption of the pump lasted 1 s and contains 49 999 samples. The measured signal was from the dynamic pressure and the vibration sensors. The resulting measurements related to the four states of pump consumption: 0%, 20%, 50% and 80%. Table 1 shows the matrices in which the data was collected and in Table 2, the data are described in detail in subsequent processing steps.

4. Preprocessing

The present study used two methods of pre-processing of data: for time domain and for frequency domain. Preliminary signal processing consisted of appropriate manipulation of data in order to best separate the different states of consumption of the pump. Depending on the analysed signal (dynamic pressure or vibration) and the method used (time domain or frequency domain) the subsequent processing steps were different. An important element was to divide the raw signal (49 999 samples) into smaller fragments (25 fragments for each consumption of the pump) to form training and test sets. All the preprocessing stages performed on the measurement data for the dynamic pressure and vibrations for the time and the frequency domain are described in Table 3 and shown in Figs. 3 and 4. As a result 100 vectors built of 100 elements were obtained, which are used as input data for all the developed and evaluated AI systems.

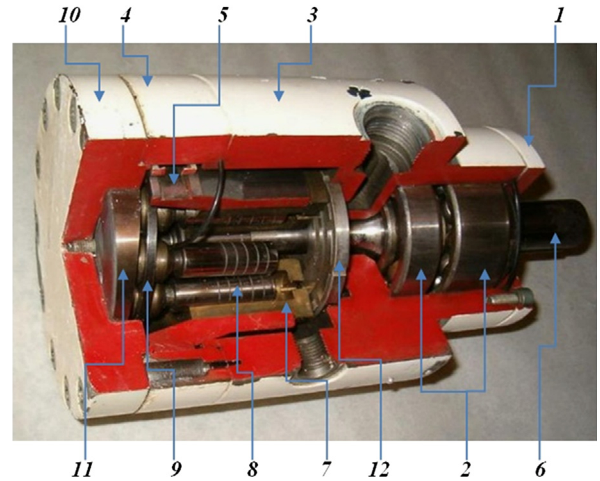

Fig. 1. Pump WPTO2-10 (cross-section): 1 – lid; 2 – bearings; 3 – body; 4 – side dish; 5 – outer race of the bearing rotor; 6 – shaft; 7 – rotor; 8 – pistons; 9 – separator; 10 – lid; 11 – shield with a constant inclination angle; and 12 – shield of timing gear [18].

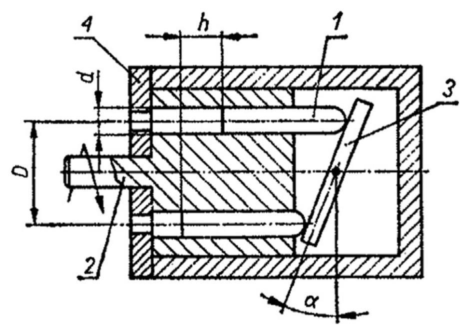

Fig. 2. Schema of axial piston pump with hinged shield: 1 – piston; 2 – shaft and rotor; 3 – shield; 4 – distributor plate; D – distance between the pistons; d – diameter of the piston; and h – the maximum displacement of the piston [18].

At the start, of the dynamic pressure and vibration waveforms, was excised 30 initial and final samples, due to errors at the beginning and end of the measurement.

The pre-processing of data (for dynamic pressure and the vibrations) consisted of removal of the constant component, normalization to the range of -1 to 1, standardization (mean value equal to 0 and standard deviation equal to 1), the transition from the time domain to the frequency domain (FFT) and excision of the appropriate fragments (25 fragments for each state of consumption of the pump, a total of 100 fragments) of the entire waveform.

5. Data separation

The next stage of the processing of the measurement data was to visualize the separation of signals in order to identify the best method for further analysis. The parameters influencing the

[1] MATLAB version R2010a.