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APPROACH TO HYDROUNIT DEFECTS DEVELOPMENT FORECAST USING THE ARTIFICIAL NEURAL NETWORK

The paper suggests the structure and mathematical model of artificial neural network for automatic forecasting of hydrounits defects development. There had been considered some preliminary diagnostic conclusions.

Key words: *forecast of the defects development in hydrounits, artificial neuron net, amplitude - frequency – time spectrum.*

Introduction

Hydrounit is a pretty complex dynamic hydroelectromechanical system and mathematic description of vibroacoustic signal dependence on all factors which cause the vibration, is practically impossible.

Therefore, the hydrounit defects development forecast is done by the artificial neural netwok (ANN) which is an important component of the diagnostics and forecast subsystem of automatic system for diagnostics and forecast of hydrounits defects development(SADP - DHD) [1].

The subsystem for diagnostics and forecast of the defects development SADP - DHD contains two different neural networks: ANN for diagnostics of the existing defects and ANN for forecasting the defects development. This paper presents detailed consideration of ANN for forecasting, short characteristics of diagnostics ANN, also functional connections between both ANN are considered.

The input information, necessary for functioning of the subsystem for diagnostics and forecasting the defects development SADP - DHD are:

1. All values of vibroshifting, exceeding the allowed norm, on each of 4 vibrosensors (ВД1 - ВД4) within the specific time interval with fixed time of these values. These data enter the subsystem for diagnosing and forecast from the subsystem of current monitoring, which receives it from vibrosensors.
2. Amplitude-frequency – time spectra (AFTS), corresponding to each of the above vibro acoustic signals within the same time interval, formed by the program of the discrete wavelet- transformation (DWT). This program is a part of the subsystem for diagnostics and forecast [2-4].
3. Values of hydrogenerator load current within the same time interval with time fixing, which are supplied from sensor of current.
4. The values of water level in water reservoir within the same time interval with time fixing, which are supplied from sensor of level.

The initial diagnostics conclusions must correspond to the main factors [5], which cause the vibration of the hydrounit, namely: rotor non-equilibrium, violation of supporting structure rigidity, defects in turbine and thrust bearings; vibrations of electric machines of electromagnetic nature; violation of flow hydrodynamics.

The most spread types of ANN, used for modelling of complex technical systems, are Kokhonen networks, perceptrones, probabbilistic and fuzzy ANN, neural networks of adaptive resonance theory (ANN ART) etc [6,7].

At the same time, the heterogeneity of input data arrays, task complexity, significant uncertainty of expert evaluations lead to nonexpediency in using of standard types of ANN and require the development of heterogeneous non-standard neural nets.

ANN for diagnostics of the existing defects registers the availability of exceeding vibroshifting in the vibroacoustic signals and analyzes the cross-sections of AFTS which correspond to the time moments, registing the exceeding vibroshiftings. The diagnostics conclusions are made on the base of the analysis of these cross sections.

For more accurate analysis of these cross sections, the above -mentioned ANN conducts the allocation from AFTS the parameters, which are not directly connected with the defects of hydrounit, namely:

- background values of wavelet factors of each band of frequency at idle hydrounit;
- dependence of wavelet factors of each frequency band on hydrounit loading current;
- dependence of wavelet factors of each frequency band on water level in water reservoir.

It is known that the turbulent level is inversely proportional to water level in water reservoir, that is, the dependence is of hyperbolic character. Apart from that, there is a forcible argument, allowing to state that it is of non-linear character. The dependence of level of vibration on loading current is of proportional character and at first approximation it may be considered as a linear one.

During the research running of SADP-DHD the character of these dependences may be specified, but a priori, it may be written as

$$\left|d_j(H,I)\right| = D_{0j} + D_j + v_j I + \frac{1}{p_j + q_j H^2}, \qquad (1)$$

where H – water level in water reservoir; I – hydrogenerator loading current; $d_j(H,I)$ – function of dependence of wavelet factors of the j-th band on water level in water reservoir and load current; D_{0j} – averaged value of array of wavelet factors of the j-th frequency band at idle third hydrounit (background value); D_j – averaged value of the array of the wavelet factors of the j-th frequency band at maximum water level in water reservoir and idele operation of hydrogenerator; v_j – generalized numerical factor, which characterizes the dependence of wavelet factors of the j-th frequency band on load current; p_j, q_j – generalized numerical factors, which characterize the dependence of wavelet factors of the j-th frequency band on water level in the reservoir.

This dependence is determined only for those frequency bands, for which wavelet factors increase with water level drop or with the increase in load current. For the frequency bands, which do not respond neither to water level nor to current, the only D_{0j} is allocatedof AFTS.

Consequently, the AFTS of all the vibrosignals from the DWT program and the parameters H, I, D_{0j}, D_j, v_j, p_j, q_j from ANN of the existing defects diagnostics enter the input of ANN of defects development forecast.

General ANN structure for forecast the hydrounit defects development

The ANN structure for forecast the hydrounit defects development is stipulated for as a two-layer structure and is presented in Fig. 1.

The number of input neurons in this ANN equals $4M+1$.

The first ANN layer contains $4M$ neurons. Each of them receives the wavelet factors of the definite frequency band from the corresponding input neuron as well as the corresponding parameters H, I, D_{0j}, D_j, v_j, p_j, q_j from the ANN for diagnostics of the existing defects.

The first layer neurons are intended for formation the trends of each frequency band of AFTS of each of four vibrosignals. The maximum (as for the absolute magnitude) value of the wavelet factor is chosen for construction trend from each AFTS line, corresponding to the separate data stack and half-minute time interval.

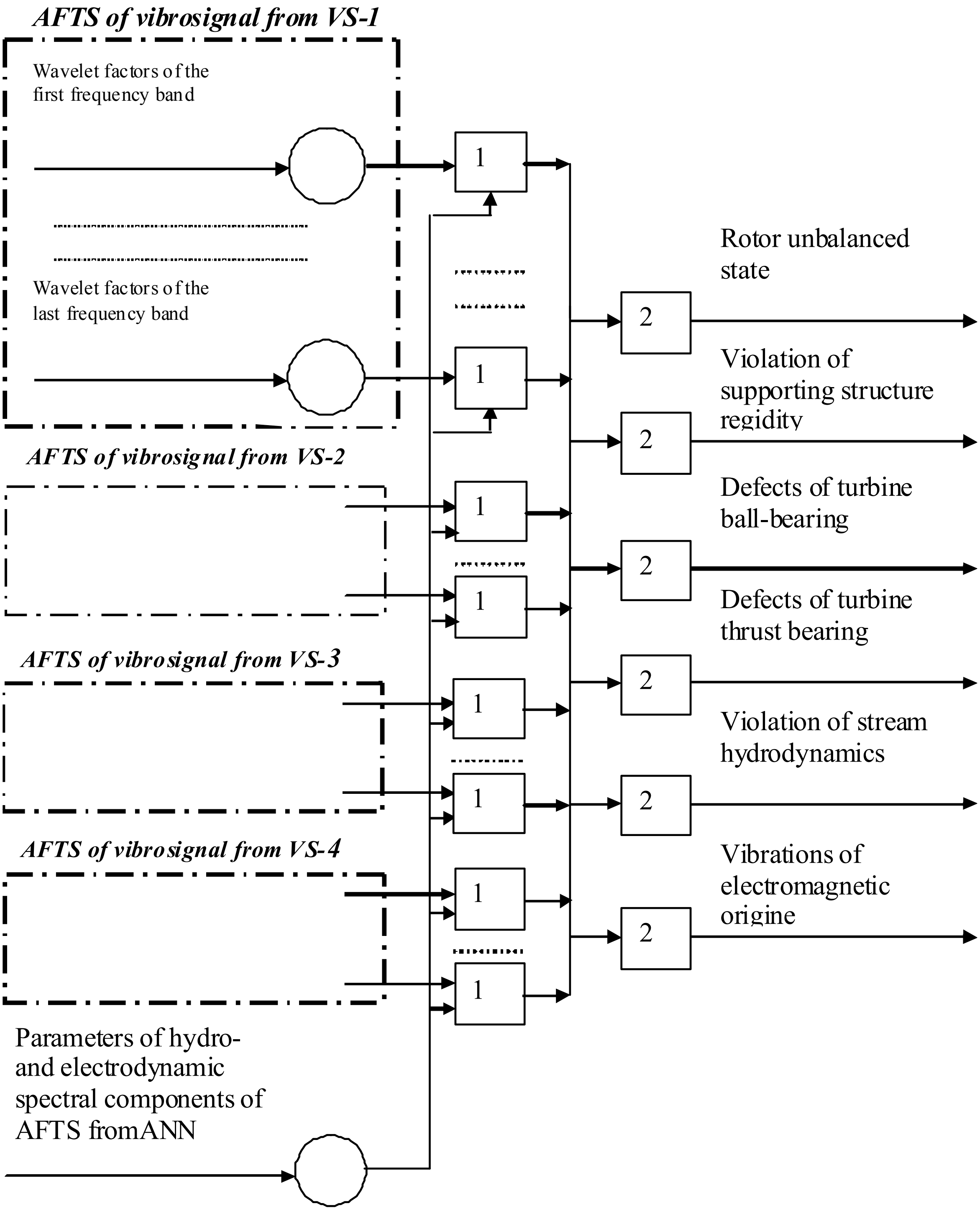

Fig. 1. ANN structure for the forecast of hydrounits defects development

This trend shall be further analyzed within the relatively long period of time (for example, 24 hours, but the time interval duration must be specified during the research run of the SADP-DHD). If the analysis results show steady increase in maximum value of wavelet factors of some frequency bands of AFTS, then these trends are transferred to the input of the neurons of the second layer of ANN together with parameters H, I, D_{0j}, D_j, v_j, p_j, q_j of the corresponding frequency bands.

The second layer of ANN contains 6 neurons, each of which corresponds to one of the factors, causing vibration.

Each neuron of the second layer receives all the growing frequency band trends as well as data on possible dependence of these bands of corresponding AFTS on hydrodynamic and electrodynamic factors, and background spectral characteristics.

Each neuron of the second layer determines the level of faithfulness of the fact, that the cause for increase of wavelet factors is the typical vibration factor, corresponding to this neuron.

It is obvious that this ANN works only when there is at least one growing trend.

Mathematical model, algorithm and software realization of ANN for the forecast of hydrounit defects development

As it had been mentioned above, the neurons of the first layer are intended for construction of the trends of wavelet factors of each AFTS frequency band for each of four vibrosignals within the definite time intervals. Each trend T_{ij} is a numerical set, that is, it may be written as

$$\forall i = 1, 4\ \forall j = 1, M\ \forall r = 1, N \left(T_{ij} = \left\{ \left| d_{ij1}^{max} \right|, \left| d_{ij2}^{max} \right|, \ldots, \left| d_{ijr}^{max} \right|, \ldots \left| d_{ijN}^{max} \right| \right\} \right), \quad (2)$$

where N – number of input data stacks with volume of 32768 values, received from the vibrosensors within the preset time interval; $\left| d_{ijr} \right|$ – maximum absolute value of wavelet factor of the j-th frequency band of AFTS of the i - th vibrosignal, corresponding to the r-th stack of input data.

Then each trend is analyzed in order to reveal the stable increase in absolute maximum values of wavelet factors.

The criterion of evaluation of such an increase during the test run of SADP – DHD may be specified, but a priori, is taken as:

$$\frac{\sum_{r=1}^{N} \left| d_{ijr}^{max} \right|}{N} - \frac{\sum_{r=1}^{\frac{N}{2}} \left| d_{ijr}^{max} \right|}{\frac{N}{2}} > \varepsilon\,, \quad (3)$$

where ε – parameter, which characterizes the degree of trend increase.

The value of the ε must be specified during test run of ADP-DHD, but at the beginning it may be taken as equal 10% of the average value of wavelet factor of the trend, that is:

$$\varepsilon = 0.1 \cdot \frac{\sum_{r=1}^{N} \left| d_{ijr}^{max} \right|}{N}\,, \quad (4)$$

After the analysis, all the trends T_{ij} with stable increase in wavelet factors (and only they) together with parameters H, I, D_{0j}, D_j, v_j, p_j, q_j enter the second layer of ANN. Let us mark these trends as $T_{ij}^{\uparrow}$.

Each neuron of the second ANN layer must perform the following procedures:

1. First it is necessary to determine the set Z, which contains the last element of each increasing trend

$$\forall \left| d_{ijN}^{max} \right| \in T_{ij}^{\uparrow} \left(\left| d_{ijN}^{max} \right| \in Z \right). \quad (5)$$

2. Then, for each element of the Z set it is necessary to separate the background, hydrodynamic and electrodynamic spectral components from the components caused other factors, namely:

– for the first four neurons, which characterize directly the mechanical defects of the hydrounit; it is done according to the formula:

$$\forall k = 1,4\, \forall \left| d_{ijN}^{max} \right| \in Z \left(d_{kij}^{*} = \left| d_{ijN}^{max} \right| - D_{0ij} - v_j I - \frac{1}{p_{ij} + q_{ij} H^2} \right); \tag{6}$$

– for the 5th neuron which must test the flow hydrodynamic violation, it is possible to write

$$\forall \left| d_{ijN}^{max} \right| \in Z \left(d_{5ij}^{*} = \frac{1}{p_{ij} + q_{ij} H^2} \right); \tag{7}$$

– for the 6th neuron which must test the electrodynamic component of vibration, it is possible to write

$$\forall \left| d_{ijN}^{max} \right| \in Z \left(d_{6ij}^{*} = v_j I \right). \tag{8}$$

3. The next step is the normalization of all the d_{kij}^{*} elements, which is done according to the formula

$$\forall k = 1, 6\, \forall \left| d_{ijN}^{\max} \right| \in Z \left(d_{kij}^{norm} = \frac{d_{kij}^{*}}{\sum\limits_{k,i,j} d_{kij}^{*}} \right). \tag{9}$$

4. The index of probability of PV_k factor, which corresponds to the k-th neuron, is determined as

$$\forall k = 1, 6\, \forall \left| d_{ijN}^{max} \right| \in Z\, \forall j \in Q_k \left(PV_k = \sum_{i,j} w_{ki} d_{kij}^{norm} \right). \tag{10}$$

Analyzing the above -mentioned expressions it is easy to note, that the absolute values of reliability indices will be insignificant and it will lead to certain inconveniencies during their analysis. Therefore, it is expedient to introduce the relative level of reliability RV_{kt} according to the formula

$$RV_{kt} = \frac{PV_{kt}}{\max\left(PV_{1t}, PV_{2t}, PV_{3t}, PV_{4t}, PV_{5t}, PV_{6t}\right)}. \tag{11}$$

Consequently, the final diagnostic conclusion can be formulated as a set of values of probability levels of different vibration factors $\{RV_1, RV_2, RV_3, RV_4, RV_5, RV_6\}$.

Let us consider some examples, received by means of software, realized according to the above - mentioned algorithm.

Fig. 2 presents the trend of the 7th frequency band of AFTS vibrosignal, received from vibrosensor VS1 (turbine ball bearing)

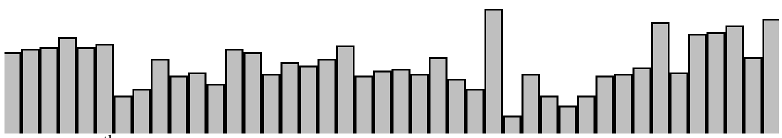

Fig. 2 Trend of the 7th frequency band of the AFTS vibrosignal, received from vibrosensor VS1

Even without the use of criterion (3) it is seen that this trend is practically unchanged and there is no necessity in transferring it to the neurons of the second layer of ANN. Trend, presented in Fig.2 is of greater interest.

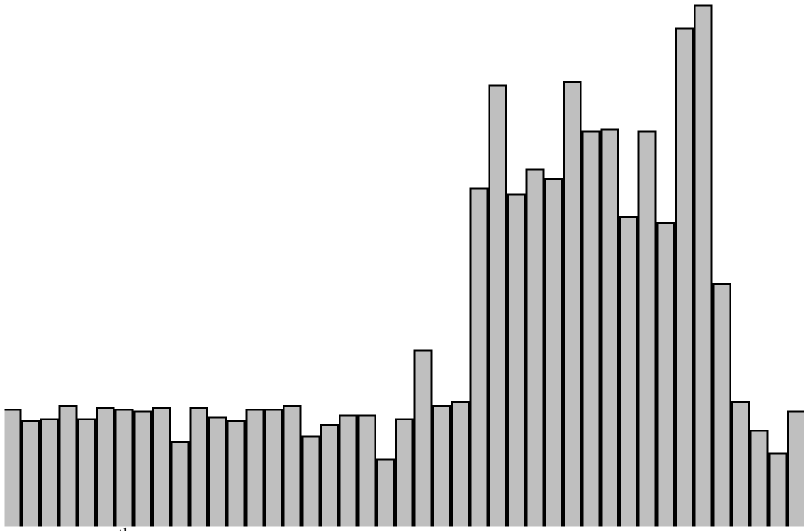

Fig. 3. Trend of the 9th frequency band of AFTS vibrosignal, received from the vibrosensor VS1

In this case it is expedient to transfer this trend to the second layer of neurons and research the reason for its increase, since it may be caused by temporal water level drop in the reservoir or an increase in load current of the hydrogenerator.

Analogical situation (even better expressed) is observed in the trend of the 10 frequency brand of vibrosignal from VS3 (Fig.4)

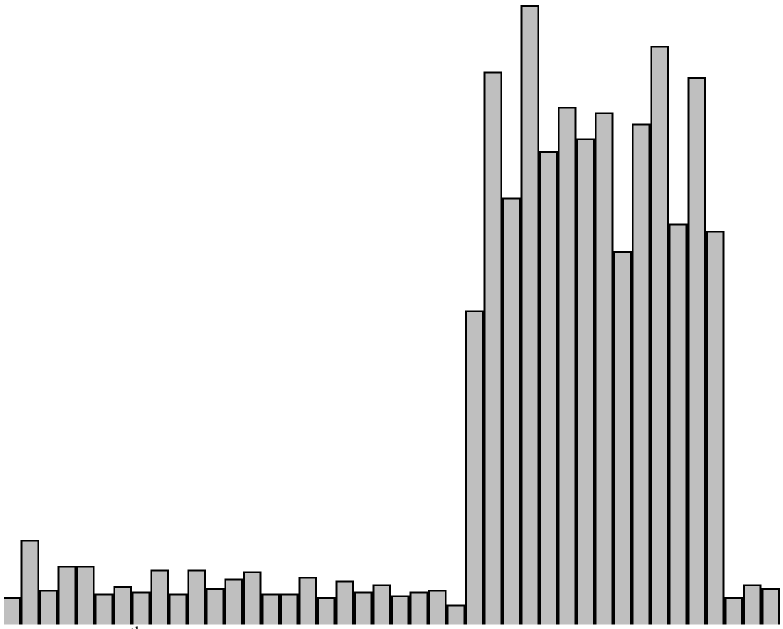

Fig. 4. Trend of the 10th frequency band of AFTS vibrosignal, recieved from vibrosensor VS3.

Conclusions

1. There had been suggested two layers non standard heterogeneous ANN to forecast the development of the hydrounit defects, the main input information for which is the AFTS of vibroacoustic signals of hydrounits.

2. The exceptional difficulty of the hydrounit as a dynamic hydroelectromechanic system stipulates for the significant uncertainty of a priori expert evaluations, concerning the dependencies of AFTS vibroacoustic signals on the factors which cause vibrations.

3. Therefore the procedures of training and self-training of ANN must be conducted within the whole period of test run of SADP-DHD.

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