ІНФОРМАЦІЙНІ ТЕХНОЛОГІЇ

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TIME SERIES AND PROGNOSTICATION OF VIBRATION LEVEL FOR HYDROTREATERS

Abstract. This article is devoted to the problem of vibration level prognostication of hydrotreaters using the mathematical regression models that describe the time series with long or double long memory. The next problem investigation (using real data from Sayano-shushenskiy GES) shows that the processes, which describe the vibration level of hydrotreater's knot, might be represented effectively with mathematical ARCH and GARCH models. Authors developed the prognostication algorithm for vibration level of hydrotreater's knot that allows detect a long memory in time series with usage of Sugeno method, analyze a time series type, select time interval for prognostigation and using these results make a decision about working state of hydrotreater's knot.

Key words: time series, prognostication, vibration, ARIMA, GARCH.

Анотація. Ця стаття присвячена проблемі прогнозування рівня вібрації гідрогенераторів з використанням математичних регресійних моделей, які описують часові ряди з довгою чи подвійною довгою пам'яттю. Результати дослідження на реальних даних по Дністорвській ГЕС показали, що процеси, які описують рівень вібрації вузлів гідрогенератора, можуть бути представлені математичними моделями ARCH і GARCH. Автори розробили алгоритм, щоб виявити довгу пам'ять в часових рядах з використанням методу Сугено, проаналізувати тип часового ряду, вибрати часовий інтервал, на якому буде проводитись прогнозування, і, використовуючи ці результати, прийняти рішення, в якому робочому стані вузол.

Ключові слова: часові ряди, прогнозування, вібрація, ARIMA, GARCH.

Аннотация. Эта статья посвящена проблеме прогнозирования уровня вибрации гидрогенераторов с использованием математических регресионных моделей, которые описывают временные ряды с длинной или двойной длинной памятью. Результаты исследования на реальных данных по Днестровской ГЭС показали, что процессы, которые описывают уровень вибрации узлов гидрогенератора, могут быть представлены математическими моделями ARCH и GARCH. Авторы разработали алгоритм, чтобы обнаружить длинную память во временных рядах с использованием метода Сугено, проанализировать тип временного ряда, выбрать временной интервал, для которого будет осуществлятся прогнозирование, и, используя эти результаты, принять решение, в каком рабочем состоянии узел генератора.

Ключевые слова: временные ряды, прогнозирование, вибрация, ARIMA, GARCH.

Introduction

The task to provide monitoring of the vibration level of circulating parts for high-powered electric machines, especially hydrotreaters, is always actual because of the the details and knots are weared quickly [1]. Majority of stuff on the hydroelectric power stations behave indifferently to the necessity of permanent control of the vibration level. The tragedgy on August, 17, 2009 on Sayano-shushenskiy GES (6400 MVt) demonstrated this. However, from other side it became some positive pushing to develop and apply the monitoring systems of vibration state in the domestic hydroelectric power stations [1].

Such systems from the objective reasons are enough inert, because the low velocity of hydrotreaters circulation requires more time than for realization of every measuring cycle. Therefore the monitoring system is not able to provide an instantaneous reaction on damages appearance that cause the high vibration level and can result in emergency situations. It requires the protracted watching the vibration level of hydroelectric generators knots, analysis of reasons of possible damages appearance by taking into account of many factors, such as a water, temperature level, initial power and others like that.

This it is important to estimate the capacity of each knot or hydroelectric generator on the whole not only in current moment, but in the future too. For this reason a prognostication of vibration level is important and actual task during diagnosticating of hydroelectric generators knots.

The main reason of vibration are the mechanical vibrations and it is very hard to avoid them on practice, as they are caused by the dynamic processes, which are accompanied by the presence of admittances, gaps and superficial contacts of separate details of electric machines which arise up during the rotation of unstable elements and details [1, 2].

Even mechanical vibrations with small amplitude often cause the resonant vibrations of other knots, increase and become the substantial source of vibration. In relation to hydrotreaters the defects that are the reason of oscillation balance violation can be defined like as: rotor unbalance, violation of the supporting system inflexibility, defects of bearing, defects of electromagnetic origin, hydrodynamics violation [1].

Actuality

It should be noted that such defects arise up gradually, and the middle level of vibration grows during the protracted time period. Prognostication is carried out by different methods depending on the type of time series - stationary or non-stationary ones. The choice of that or other prognostication method is performed with the special criteria. An analysis shows that a hydrotreaters vibration is a non-stationary with so-called long memory and are characterized by the hyperbolical autocorrelation function. Therefore for its analysis there are inapplicable ordinary stationary and non-stationary methods [1, 2].

That is why authors offer the new prognostication method on the basis of time series with the so-called long memory. Long memory, or long-term dependence is property that describes the cross-correlation structure of high order time series. In case if a time series owns long memory, the dependence exists even between one from other supervisions remoted in time.

The time series Y_t is a time series with long memory, if there is a real number α, 0< α <1, and constant c > 0, and for them there is a condition $\lim_{k\to\infty} \frac{\rho_k}{c * k^{-\alpha}} = 1$, where ρ – an autocorrelation function and k – a lag number [2].

The long memory modelling using traditional autoregression processes with including of extremely plenty of lags is also possible (the autocorrelation will be in this case the sum of exponents). However such design does not allow to estimate the degree of time series persistency. As for persistent series roots of autoregression polynomials are pending to 1, that's why asymptotic distributions are bad approximations of distributions on final selections. It will cause the decresing of prognostication quality.

Aim and research task

Thus, the aim of this research is to increase of prognostication efficiency of hydrotreaters vibration state by the use of prognostication methods of time series with long memory.

The reseach task is to work out the prognostication algorithm of level of hydrotreaters vibration with the use of mathematical model for the analysis of time series with long memory.

Experimental part and obtained results

It should to work out a mathematical model for the analysis of time series with long memory and on its basis to build the stage-by-stage algorithm of prognostication of level of hydrotreaters vibration.

One of basic tasks of this work is a realization, verification and application of mathematical autoregression models with partly-integrated moving average (ARIMA) [3].

It is said that the time series Y_t is corresponded to the ARIMA process (p, d, q), if [2]:

$$\varphi(L)(1-L)^d y_t = \Theta(L)\varepsilon_t, \tag{1}$$

where

$$(1-L)^d = 1 - dL - \frac{\alpha(1-d)}{2!}L^2 - \frac{\alpha(1-d)(2-d)}{3!}L^3 - ... = \sum_{k=0}^{\infty}\frac{\Gamma(k-d)}{\Gamma(-d)\Gamma(k+1)}L^k =$$

$$= 1 - \sum_{k=0}^{\infty} c_k(d)L^k;$$

$0 < d < 1$, $c_1(d) = d$, $c_2(d) = \frac{1}{2}d(1-d)$,... i $\Gamma(z)$ means gamma function $\Gamma(z) = \int_0^{\infty} t^{z-1}e^{-t}dt$; $\Phi(L) = 1 - \psi_1 L - ... - \psi_p L_p; \Theta(L) = 1 + \theta_1 L + ... + \theta_q L_q$ – lag operators of auto regression and moving average processes; ε_t – «white noise».

ARIMA processes are the comfortable instrument of time series analysis, because they give an opportunity of simultaneous modelling the long and short memory effects [2, 3].

The casual processes that describe the level of hydrotreaters vibration are non-stationary of their origin. Thus it is actual to check up them in the long memory presence, and in such case to apply the mathematical ARIMA models for their modelling.

The research will be performed on the example of Dniester hydroelectric station hydrotreater for such knots: turbine bearing (TB), support bearing (SB), oil transceiver (OT), ventilators of VO3A and VO3B, that presented on Image 1 and signed by corresponding abbreviations.

The limit vibration norms for the electric machines with such power are set on vibrodisplacement (peak-to-peak) and depend on circulation velocity. For the rotor bearing the maximum vibrodisplacement norm is equal 160 mkm, and for the ventilators - 113 mkm.

Let describe the construction of prognostication algorithm of hydroelectric vibration level with the usage of mathematical model for time series with long memory, that describe behavior of vibrodisplacement level in time. A result is a decision-making about the capacity state of all hydroelectric knots shown on Figure 1.

Stage 1. While decision-making about the capacity state of separate knot and hydroelectric generator on the whole a problem appears about the time interval selection, which will be used for prognostication of vibration level.

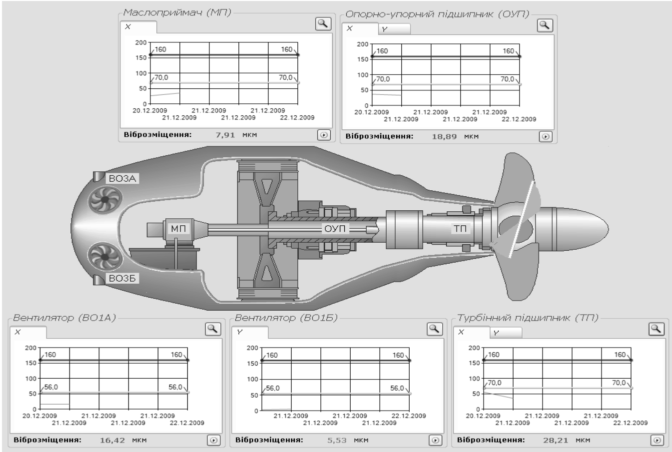

Image 1 – Detail view of hydroelectric generator knots

A time interval, that will be used for decision making, depends on current working state of knot. It is therefore necessary to define the special coefficient of estimation of the working knot state, that will be farther used for the calculation of time interval for prognostication. It can be determined as:

$$K_{pc} = \frac{\text{Vibrodisplacement norm}}{\text{current vibrodisplacement level}} * \alpha_1 + \frac{1}{K_T} * \alpha_2, \qquad (2)$$

where $\alpha_1 = \alpha_2 = 0.5$ – the priorities of indexes of the working separate knot state; K_m is an index of estimation of work terms [2, 3].

Regarding to the defined above index of current working knot status K_{pc} and normative documents mark, that planing capacity verifications of separate aggregates elements are conducted 1 time in half-year, then the prognostication interval T and decision-making can be determined as:

$$T = K_{pc} * 6 \ \ monthes. \qquad (3)$$

If index K_{pc} =1, it means that a knot is new and it is in good working state, then there is no need to check up it earlier planing verification there.

If K_{pc} < 1, it means that his working state not ideal, that is why there is need to perform prognostication of vibration level in an order to define the final wear of this knot. Because in this case there is need to repair it or even replace.

The Table 1 shows indexes of current working state for every knot, estimated for April, 2011. Using formula (3) the time intervals are calculated and they will be used for prognostication and decision-making about their capacity state. The efficiency verification of developed decision support system for the evaluation of the working state of hydroelectric generator knots was performed using the historical data accumulated during the year of verification (from April, 2011 for April, 2012) for behavior of vibration level on Dniester GES [2, 3].

Table 1 – Indexes of the knots working state and time intervals for decision-making

Knots	TB	SB	OT	VO3A	VO3B
K_{pc}	0,87	0,52	0,95	0,3	0,23
T, month	5,2	3,1	5,7	1,8	1,35

Stage 2. As a result of automatic classification on the basis of Sugeno algorithm [4] the time series type are defined, they describe the level of vibrodisplacement for every knot. In addition, a model that will be used for vibration level prognostication is chosen. The presence of long memory was detected for the knots of SB, VO3A and VO3B, that is why for their vibration level prognostication the ARIMA models will be used.

Stage 3. The vibrodisplacement level prognostication was performed for every knot and, using the worked out special criteria, the estimations of alternative decisions was calculated for every chosen knot of hydroelectric generator [3]. In particular graphic charts of the real and predict vibrodisplacement processes motion for the knots of SB, VO3A and VO3B are shown on Images 2 - 4.

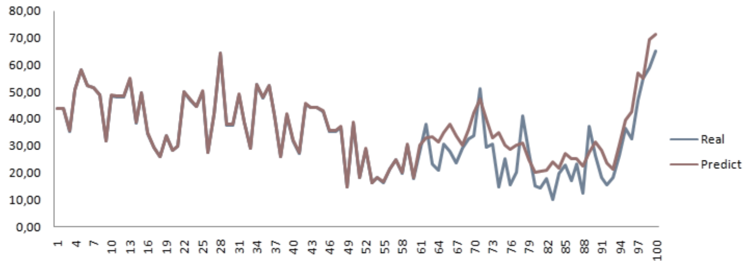

Image 2 – Time series chart for SB knot

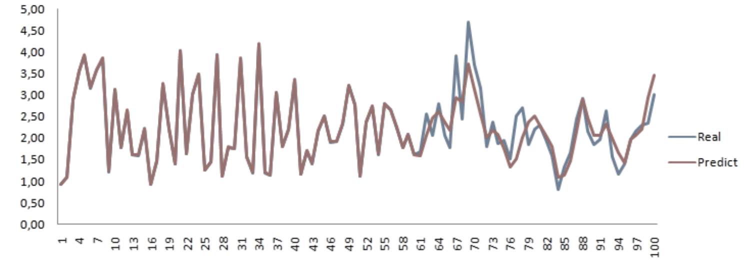

Image 3 – Time series chart for VO3A knot

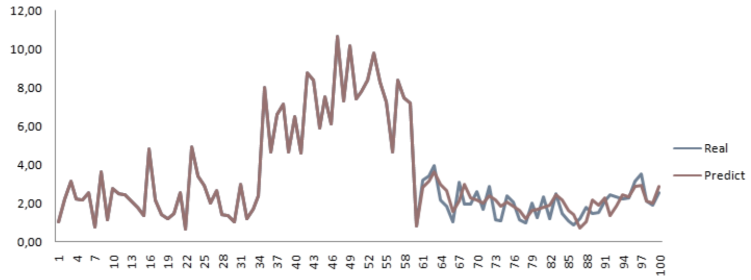

Image 4 – Time series chart for VO3B knot

Stage 4. In an order to show that the developed model gives the best results for prognostication, comparing was performed for a few known mathematical models. For comparison time series that describes behavior of SB knot, was selected, and following criteria for model estimation: mean-square error, absolute middle error and sum of errors squares. The results of errors calculation are shown in the table 2.

Table 2 – Model estimation indexes or time series

Mathematical model	Mean-square error	Absolute middle error	Sum of errors squares
Random walk	0.4771	0.3064	0.5232
ARIMA (0,1,0)	0.3093	0.2949	0.4221
ARIMA(0,d,0) – ARCH(1,ξ,1)	0.1768	0.2587	0.3858
ARIMA(0,d,0) – GARCH(1,ξ,1)	0.1701	0.2534	0.3298

This table demonstrates, that developed model gives the best indexes of quality of time series with long memory prognostication.

Stage 5. As a result of vibrodisplacement prognostication for each of knots and, having regard to the row of the special criteria, authors got following decisions about every knot state taking into account their vibration characteristics. In Table 3 columns represent the chosen hydroelectric generator knots, rows - defined alternatives, and the value in a cell represents this alternative estimation for the chosen knot.

Table 3 – Alternative decision estimates of knot working state

Alternatives	TB	SB	OT	VO3A	VO3B
Working state	0.15	0.65	0.55	0.09	0.58
Need examination	0.66	0.12	0.18	0.84	0.19

After the results are analyzed, it may concluded, that it is needed to plan the examination of SB and VO3B knots in chosen time intervals.

Conclusions

The article describes the high efficiency of ARIMA mathematical models applying for vibration level prognostication of hydroelectric generators knots, that is described by a time series with long memory. In addition authors represent the specially developed algorithm that includes following stages: to select time interval for prognostication, to detect the time series type and long memory presence, to predict vibration level using the ARIMA mathematical model of, to estimate models errors, to make decision about the knots working state.

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