

Marine main engine speed of rotation energy-saving control solution based on artificial neural network application

*Dmitry Piotrovsky*¹, *Sergey Podgorny*², and *Alexander Kukolev*²

¹ K.G. Razumovsky Moscow State University of Technologies and Management, 74 Zemlyanoy Val str., Moscow, 109004, Russian Federation.

² Kuban State Technological University, 2 Moskovskaya str., Krasnodar, 350072, Russian Federation.

Abstract. During operation and maintenance marine main engine is subjected to great variety of different impacts: climatic, operational, load impacts and others. Thus, object efficiency, being directly dependant on impacts overcome ability is known to be able to affect the major part of financial costs, related to the marine transport processes. Therefore, the marine shipping efficiency provision goal can be stated as vessel main engine propulsion plant reliability and operational condition maintenance together with external impacts influences minimization. One of the most significant marine propulsion plant influences is known to be sea water surface swell. However, it is known to be complicated in measurement as it requires some number of complicated devices to be installed outside the ships' hull. Such impacts are known to significantly affect object efficiency, leading to the list of undesirable results, such as speed of rotation fluctuations, increased fuel consumptions, increased vibrations and so on. This article gives an overview of one of the methods of combating significant speed of rotation fluctuations whilst ship rough sea navigation. The suggested algorithm is based on neural network structure integration as well as fuzzy logic controller integration into additional speed of rotation control system feedback link and can save up to 53,5 thousands of USD per year for the ship owner.

1 Introduction

The current moment of time defines the typical marine main engine speed of rotation limitation solution to be mechanical, electronic or logical fuel consumption limitation, often leading to significant efficiency drops as well as undesired temperature and vibration operation modes [1, 2, 10-14]. Such problem solution is often defined by measurement difficulties of some physical processes and values, e.g. marine main engine load. The latter is definitely affected by the list of impacts, namely: sea surface oscillation, propeller fouling, sea bottom masses shifts whilst moving within low depths and so on. The abstracted measurement can be performed, however it can lead to large financial expenses [1].

That is why, we have stated the following goal of the exploration, namely: to design the marine main engine speed of rotation control algorithm with the help of artificial neural

network and fuzzy logic control solutions for the stormy condition engine operation so that to minimize speed of rotation fluctuations amplitude.

2 Methods

Artificial network application in control impact adjustment can concern several specific features. First of all it is necessary to observe the control algorithm, which is illustrated in the figure 1.

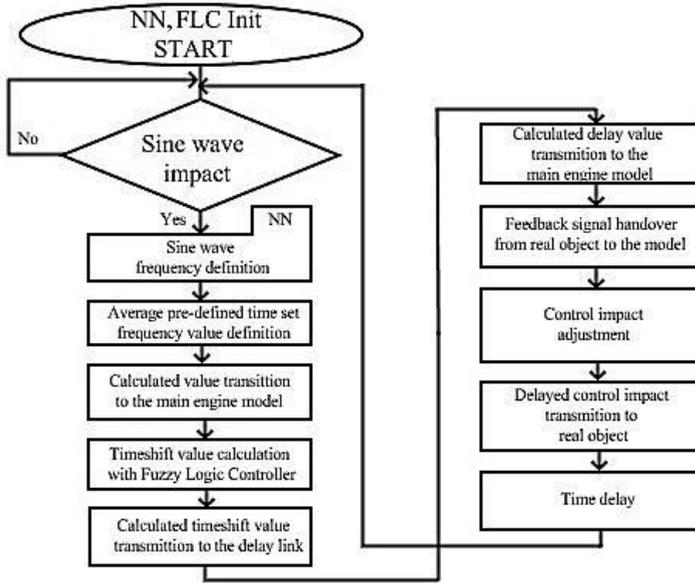


Fig. 1. Problem in question and marine main engine speed of rotation control algorithm

The algorithm concept is based on parallel operation of the main engine and the mathematical model of the main engine whilst vessel rough sea weather navigation. The control impact is calculated permanently both for real object and for the model. Besides, the continuous analog signal is permanently transmitted to the neural network, however it is subject to sampling, as the designed artificial neural network structure concerns input signal to be column-vector containing signal iterations (Figure 2). Each time sample refreshes input column-vector in accordance with the current engine speed of rotation value. Artificial neural network output signal in this case is known to be the calculated frequency value, which can be filtered or processed with the required accuracy.

This value serves to define the control impact time-shift value with the help of fuzzy logic controller, which is further transmitted to the variable transport delay link, which alters the control impact. So that not to make the control system unstable the algorithm switches the feedback signal from real object to the model as well. Common concept model view is shown in figure 3.

The model contains following blocks [9]: Marine Main Engine (REAL), Marine Main Engine math model (MODEL), Artificial Neural Network for frequency calculation (NN), Fuzzy Logic Controller for impact time delay calculation (FLC), PID speed of rotation controller (PID), Transport Delay block, Sine Wave Builder and others.

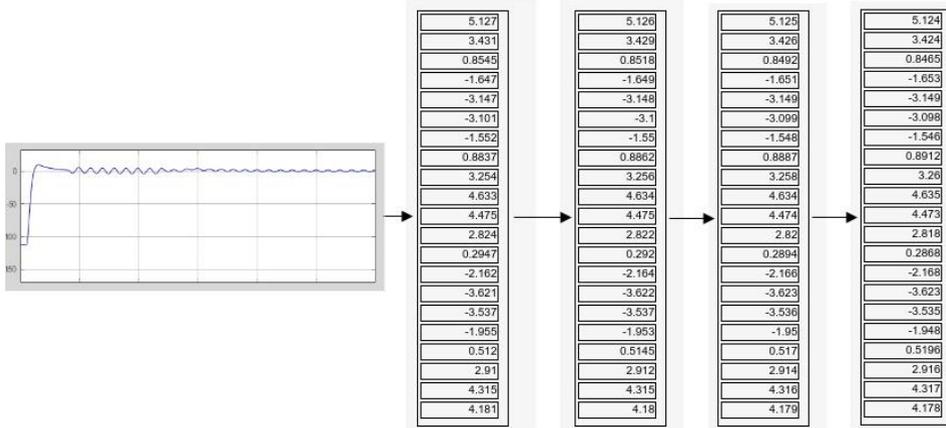


Fig. 2. Artificial neural network input column-vector calculation

The concept idea demonstration can be performed for the situation of 2-stroke engine operation under normal conditions with 75 RPM speed of rotation and sudden sine wave impact appearance, resulting in amplitude fluctuations with the pre-defined in Sine Wave Builder parameters frequency.

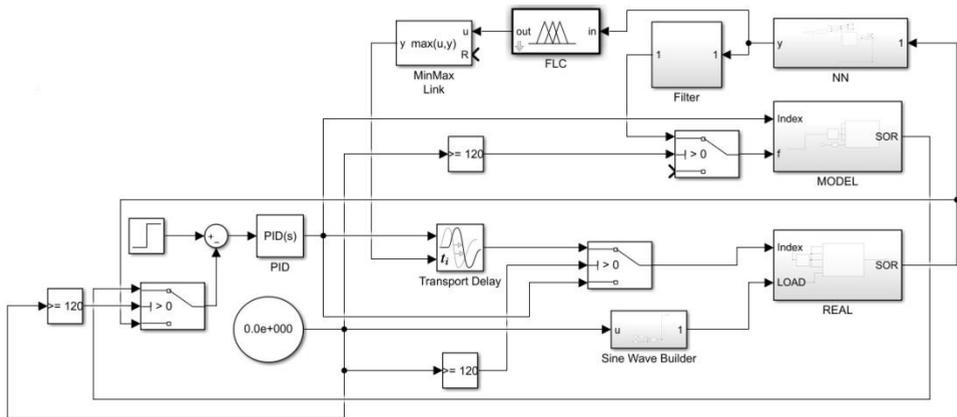


Fig. 3. Concept model of the modified marine main engine speed of rotation control system

The current control value error is known to be calculated as [3]:

$$eX = X_{setpoint} - X_{actual} \tag{1}$$

This value is further transmitted to the system PID-controller, which defines the control impact in accordance with the control principle [3]:

$$u = K_p \cdot eX + \frac{k_i}{T_i} \int_0^t eX dt + \frac{k_d}{T_d} \cdot \frac{deX}{dt} \tag{2}$$

The calculated control impact is then transmitted directly to the main engine– REAL Block (Transport Delay parameter is supposed to be zero), however the current speed of rotation value is processed by Neural Network (NN) as well and as soon as speed of rotation

value starts oscillating, neural network starts measuring its frequency, defining the load impact characteristics.

In accordance with the configuration and structure, neural network can define the impact frequency in the range of 0.05...0.145 Hz. However, current neural network configuration can generate some noisy or incorrect frequency values. Hence, the current feedback structure requires filter block to neutralize out-of-range values. The example of filtering can be represented for 0.1 Hz frequency definition (Figure 4a).

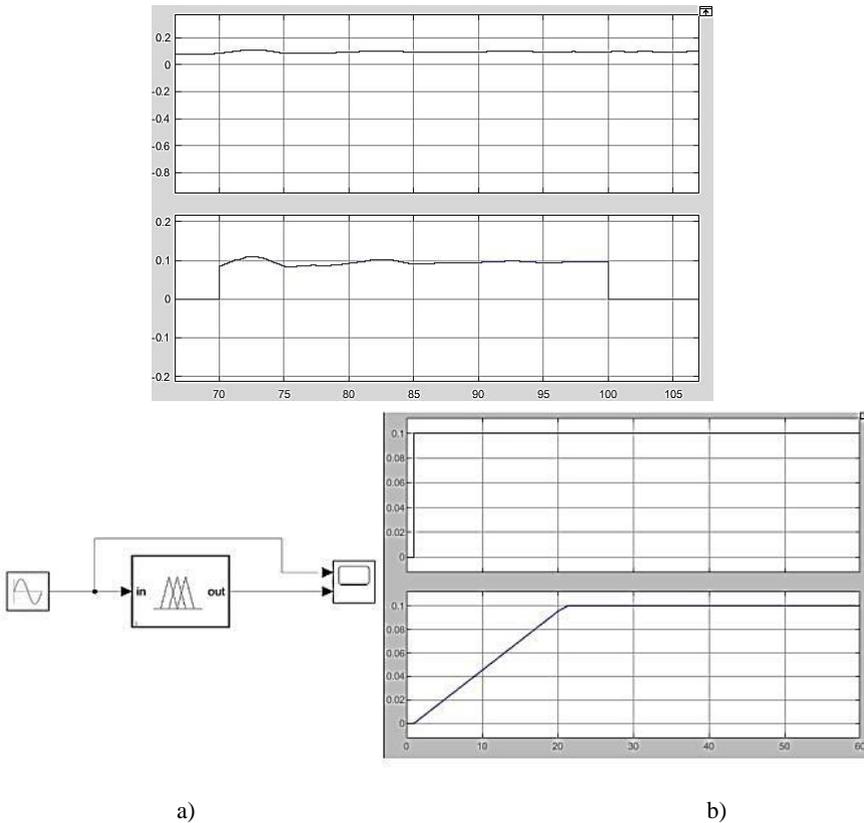


Fig. 4. Frequency signal filtering and mean value definition

The required average value definition for the period of time 70...100 s (Figure 4a) is performed with the help of Mean Value Definition block which calculates the output in accordance with the transfer function [4]:

$$W_{mvd} = \frac{0.05(1-e^{-20t})}{s} \quad (3)$$

The Mean Value Definition Block output signal characteristic for the 0.1 Hz frequency value can be represented as it is shown in Figure 4b i.e. the block fulfils input signal average value calculation for the period of 20 seconds, when this value is not equal to zero.

The obtained frequency value is used as input signal for the FLC block and is processed for the purpose of control impact time shift value calculation. Fuzzy logic theory allows to create controller operational parameters adjusting algorithms depending on controlled value deflection and its deflection speed. However, online controller operational parameters adjustment gives an opportunity to change over to the new technical processes control level.

Another fuzzy logic based control devices advantage is an opportunity to create conceptual device model and to modify it in accordance with the required functions and accuracy. Besides fuzzy logic devices are known to be easier in construction in comparison with classical analogs [5].

In accordance with the current research target it is necessary to state two important notes concerning the fuzzy logic controller operation: firstly, designed controller optimal operation requires continuous controller input signal presence; secondly, fuzzy set form $\langle x, \mu_A(x) \rangle_m$ (where x - is a set (open required to be non-empty) from the range 0.05...0.145 Hz, $\mu_A(x)$ - is represented as a membership function within the range 0...1) defines the complete range of input information, required for FLC operation [6].

As the result, the input information array generates limited fuzzy set A (*impact frequency 0.05 Hz*) = $\{\langle 0.05, 1 \rangle, \langle 0.1, 0.8 \rangle, \langle 0.15, 0.2 \rangle, \langle 0.2, 0 \rangle, \langle 0.25, 0 \rangle, \langle 0.3, 0 \rangle, \langle 0.35, 0 \rangle \dots\}$ in the real numbers range R. In accordance with this variety model plots membership function chart for the fuzzy set “*impact frequency 0.05 Hz*”.

The research concept defines the fuzzy sets quantity, here being equal to the possible frequency values, i.e. 20.

Classical fuzzy logic structure operation is known to be based on trial-and-error method [7] and generally consists of [8]: initialization, i.e. the system’s operational specification, inputs and outputs determination; the fuzzy sets for the inputs determination (fuzzification of the input variables); the rule sets determination; application of the fuzzy operator in the antecedent; implication of the antecedent to the consequent, aggregation of the consequents across the rules, defuzzification.

However, the above mentioned fuzzy logic algorithm can be carried out in different ways, as it includes several parameters, which must be fixed or specified, for instance Mamdani, Tsukamoto, Larsen, Sugeno modifications and so on [7]. In the current research we have tried to use Sugeno algorithm with triangle-form membership functions. In this case it was possible to built fuzzy model with the help of Neuro Fuzzy Designer add-on for MATLAB software (Figure 5); membership functions in this case were represented in the following manner:

$$\begin{aligned}
 f_{mid} = \left\{ \begin{array}{l} 0, f < 0.06 \\ \frac{x-0.06}{0.1-0.06}, 0.06 < f < 0.1 \\ \frac{0.135-x}{0.135-0.1}, 0.1 < f < 0.135 \\ 0, f > 0.135 \end{array} \right\} \quad f_{low} = \left\{ \begin{array}{l} 1, f = 0.05 \\ \frac{0.14-x}{0.14-0.05}, 0.05 < f < 0.14 \\ 0, f > 0.14 \end{array} \right\} \\
 f_{high} = \left\{ \begin{array}{l} 0, f < 0.055 \\ \frac{x-0.055}{0.145-0.055}, 0.06 < f < 0.1 \\ 1, f = 0.145 \end{array} \right\} \quad (4)
 \end{aligned}$$

Fuzzification in this case is performed with the help of all the system input variables determination i.e. all the input signal values $V = \{a_1, a_2, \dots, a_n\}$. Sugeno fuzzy logic control method defines the set of rules form to be as follows [7]:

Rule #n: If $\langle \beta_1 \text{ is } \alpha \rangle$ & $\langle \beta_2 \text{ is } \alpha \rangle$, then $\langle \omega = \varepsilon_1 \cdot a_1 + \varepsilon_2 \cdot a_2 \rangle$, where ε_1 и ε_2 - are real values, ω - output linguistic variable.

In this case number of rules is set by the number of fuzzy input variable values, i.e. calculated frequency values. Further action is set to be each production rule $\langle \beta_1 \text{ is } \alpha \rangle$ processing where α is used as a membership function $\mu(x)$ argument. This procedure defines $\mu(x)$ quantitatively, which becomes the result of fuzzification stage.

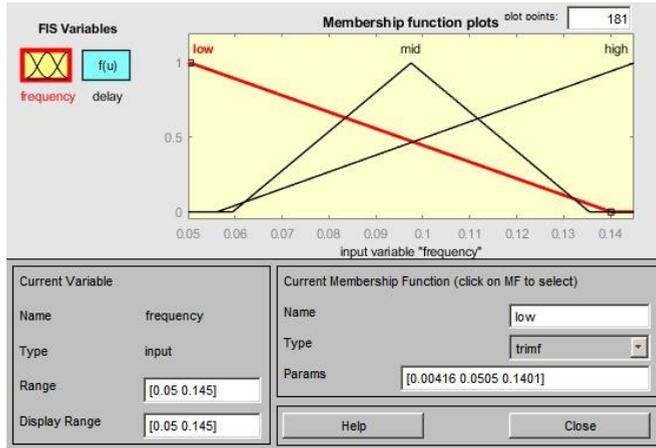


Fig.5. Neuro Fuzzy Designer software application for the purpose of control impact time delay value definition

We have used And method to be algebraic production method [8]:

$$T(\mathcal{A} \wedge \mathcal{B}) = T(\mathcal{A}) \cdot T(\mathcal{B}) \tag{5}$$

whilst Or method was set to be algebraic sum method [8]:

$$T(\mathcal{A} \vee \mathcal{B}) = T(\mathcal{A}) + T(\mathcal{B}) - T(\mathcal{A}) \cdot T(\mathcal{B}) \tag{6}$$

Sugeno method defines Implication and Aggregation methods to be minimum and maximum values definition methods with corresponding formulas [8]:

$$\mu^{\wedge}(y) = \min\{c_i, \mu(y)\} \tag{7}$$

$$T(\mathcal{A} \vee \mathcal{B}) = \max\{T(\mathcal{A}), T(\mathcal{B})\} \tag{8}$$

As for defuzzification method, we have tried to use weighted average method, defined by the formula [8]:

$$y = \frac{\sum_{i=1}^n c_i \cdot w_i}{\sum_{i=1}^n c_i} \tag{9}$$

where n - total active rules quantity, which possess w_i as output linguistic value.

Basic fuzzy logic control structure can be represented as follows (Figure 6). In this case we consider the controlled object to be marine 2-stroke main engine together with fuel supply control equipment. Feedback sensor is concerned to be artificial neural network together with fuzzy logic controller.

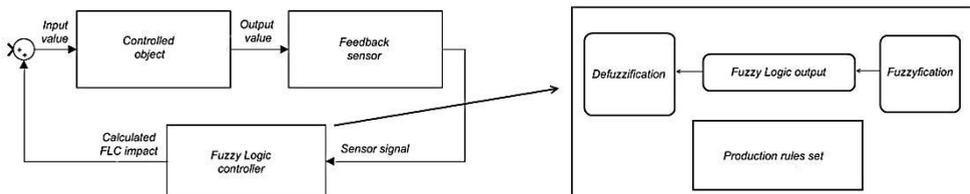


Fig. 6. Basic fuzzy logic control system structure

Thus, it is necessary to set up the exploration goal to be calculation of the impact transport delay value t (Figure 7a). That is why we consider Fuzzy Logic Controller output value to be measured in seconds.

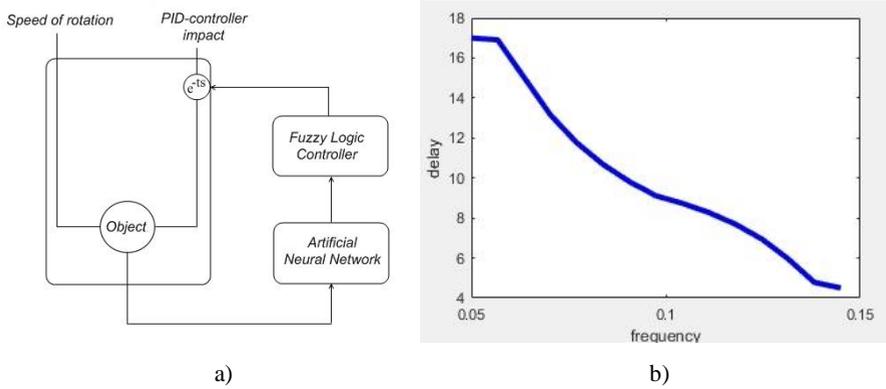


Fig. 7. Functional description of the suggested concept control system configuration and relation between the transport delay value and sine wave impact frequency

We consider defuzzification process to be finished as soon as each of input linguistic values will be characterized with calculated numerical values, being represented in the following manner:

$$\begin{aligned}
 t_{low} &= 4.5 \text{ sec} \\
 t_{mid} &= 9.5 \text{ sec} \\
 t_{high} &= 17 \text{ sec}
 \end{aligned}$$

Hence, it becomes possible to plot the following chart, describing the relation between input frequency value and output (Figure 7b).

The obtained fuzzy structure can calculate the transport delay time value so that to compensate sine marine water wave impact of the 2-stroke ship main engine. The FLC operation can be demonstrated with the help of input sine wave, entering FLC with an amplitude being equal to maximum main engine impact frequency value (Figure 8).

In accordance with the obtained chart, the obtained structure can solve the marine sine wave impact problems with the predefined accuracy, allowing to automatically adjust the transport delay block timeshift parameter value. Artificial network reaction is known to be calculated continuous sine wave impact frequency value, being obtained by main engine speed of rotation value fluctuations processing. The structure uses several additional filtering and processing blocks. For instance, the calculated frequency filtering block allows the structure to process optimal calculated frequency values, also defining average and extreme frequency values over all the period of impact-presence operation. This filtered value enters FLC as well as Sine wave builder model (which is integrated in the MODEL block in Figure 3).

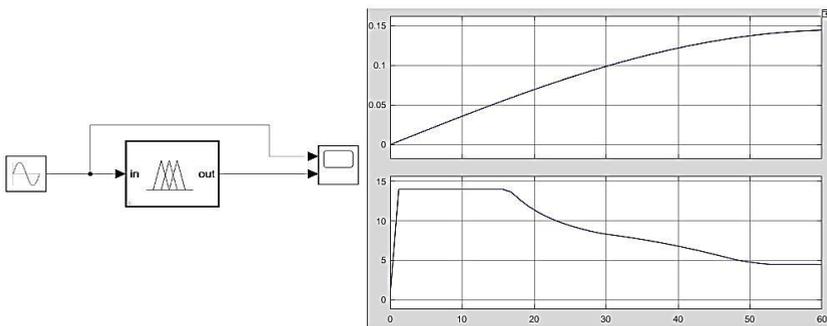


Fig. 8. Fuzzy logic controller operation for the case of input frequency increase

Output MODEL value is then transmitted into PID-controller, which calculates and adjusts the control impact, however it is processed not directly to the main engine, but through transport delay unit with its own timeshift parameter, which is adjusted with the help of FLC operation. Thus, 2-stroke marine main engine operation under 75 RPM speed of rotation within rough sea weather and stormy sea surface condition can be adjusted with the help of the developed structure in accordance with the figure 9.

2-stroke marine main engine operation is simulated by its start up and speed of rotation increase up to 75 RPM and then at 40 sec simulation time sudden sine wave impact appearance. The system initiates start operation delay so that to confirm steady amplitude and frequency sine wave impact fluctuations. In this example it is set to 120 s, after which control feedback change over is fulfilled so that to process model reaction for the defined sine wave impact. Simultaneously measured with NN frequency value signal is transmitted directly to the impact modeling unit and then after impact calculation directly to the main engine model, making model control value alternating with the calculated frequency and amplitude (Figure 10).

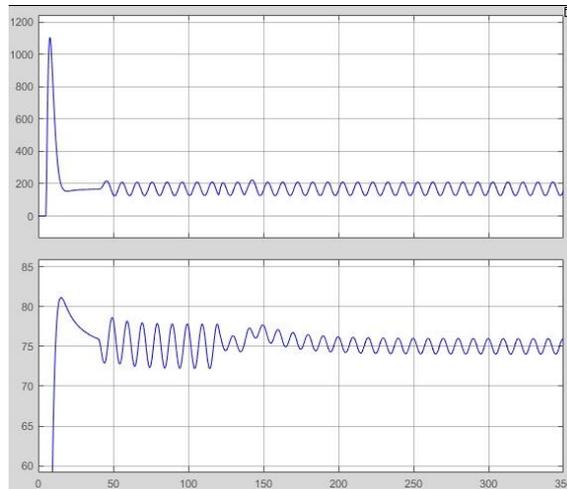


Fig. 9. Two-stroke marine main engine operation under 75 RPM speed of rotation within rough sea weather navigation

3 Results

The plotted in the figure 10 chart shows main engine model control value fluctuations amplitude increase, which appears from PID-controller impact and load impact superimposing.

From this moment of time current control value magnitude is transmitted to the PID-controller not from real object, but from the model; however, calculated control impact value is transmitted to the real object, being time-shifted by the t parameter of transport delay block $e^{-t \cdot s}$.

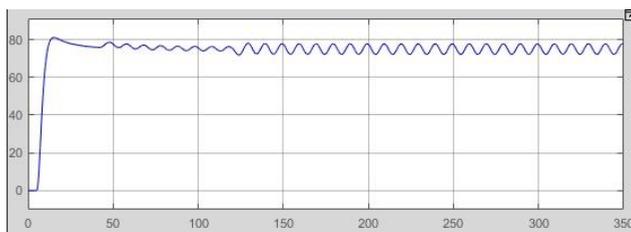


Fig. 10. Main engine model control value fluctuations amplitude increase for the case of rough sea weather navigation

4 Discussion

Useful described algorithm feature is obvious to be significant speed of rotation fluctuations amplitude decrease as well as unacceptable vibration, what results in significant piston and cylinder arrangement resource increase, financial and material costs drop and so on. Namely, the above mentioned structure can decrease speed of rotation fluctuations amplitudes down to 35% of the actual operational value for 75 RPM speed of rotation engine operation. In this case we consider piston rings load decrease as well as cylinder liner wear and oil consumption. Much depends on service personnel knowledge and experience, however, within the current prices for the large bore diesel engine MAN B&W 6S90 type, running in severe storm conditions 70% of time per year, the suggested structure can save up to 53,5 thousands of USD and 150 hours of maintenance time and undesirable standstills.

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