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Application of fuzzy-logic to design fuzzy compensation controller for speed control system to reduce vibration of СВШ-250T drilling machine in mining industry

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ABSTRACT

The paper introduces fuzzy compensation control algorithm based on fuzzy logic to control the rotation speed in СБШ-250T drilling machine. The proposed solution uses an artificial neural network instead of a vibration measuring sensor to identify the amplitude and vibration frequency on a rotary drill. The vibration amplitude, vibration frequency and setpoint of the drilling speed are the input variables for the fuzzy logic unit. The fuzzy tool will diagnose the compensatory parameter δα with the target to reduce the vibration of the drilling equipment. The results were tested through modeling using Simulink_matlab tool. It can be applied to control system to improve control quality, and reduce vibration for СБШ-250T drilling machine, which is being operated on mines in Quang Ninh area.

1. Introduction

Nowadays, СБШ-250T type drilling machines are being widely used on mines in Quang Ninh – Vietnam. During the drilling process, the countersink is constantly in contact with the rock, it has different hardness and geological structure. The study found a suitable law or algorithm to adjust the drilling mode parameters (rotation speed and pressure) in complex geological conditions and specific mining environments in Vietnam to reduce vibration. Many scientists in the field of mining are interested in research.

Some previous studies of scientists in Vietnam also mentioned optimal control of drilling mode parameters based on object modeling (B.Y. Lee, H.S. Liu, Y.S. Tarng, 1998); (Claude E. Aboujaoude, 1991), which improves the control scheme of the system (Nguyen Thac Khanh, 2003) for 2 channels to control the

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rotation speed and axial pressure. In the doctoral thesis, the author Ngo Duc Thao proposed the solution to automate the drilling process based on the physical and mechanical properties of rock (Ngo Duc Thao, 1971). Currently, no research projects have been done to improve the control system to reduce vibration for rotary drilling machines in Vietnam.

The topics related to the field of study with the goal of reducing vibration for drilling machines have been in research all over the world. Jerome Rajnauth and Tennyson Jagai performed vibration measurement on drilling equipment, then the vibration signal was sent through FFT spectrum analysis to assess the vibration spectrum (Jerome Rajnauth and Tennyson Jagai, 2012) proposing a suitable algorithm to be embedded in the control system to reduce the vibration of the machine at the exploitation wells to a depth of hundreds of meters. In another study (Edward A. Branscombe, 2010) on PH120A (Rotary Blasthole Drill), Edward A. Branscombe applied DATAQ DI718 device to receive vibration measurement signals from an accelerometer sensor. This sensor set On the drill rod to experiment measure vibration of the machine in different geological conditions in iron ore mine. The measurement signal was also via FFT spectrum analysis. The author has established the relationship between amplitude, spectrum in different geological conditions and depths, and other drilling process relationships such as rotation speed, drill motor current, and drill bit depth. In another study, Stuart Jardine, Dave Malone and Mike Sheppard proposed an algorithm to control vibration reduction by measuring feedback signals from process parameters: voltage, current, and drill motor speed. Parameters put into the microprocessor to predict the speed feedback compensation signal. The difference between the set value and the speed compensation feedback value is used to adjust the PID controller's parameters (Stuart Jardine, Dave Malone and Mike Sheppard; 1994).

In general, many previous authors' studies show that there are many different approaches and solutions that can be embedded in existing control systems to reduce vibrations for drilling machines (Alexei A. Zhukovsky, 1982); (Claude E. Aboujaoude, 1991). Current studies in Viet Nam, due to technological limitations and the means to directly measure the hardness of rock and soil, have many technical disadvantages. The idea proposed to indirectly apply artificial neural networks to identify soil hardness through measuring the critical parameters of the process such as rotation speed and pressure to promise to bring positive results.

Based on the neural network's prediction information, it is possible to develop a fuzzy compensation algorithm (δα) to automatically compensate for the opening angle α in the thyristor control system to adjust the rotation speed to suit the properties of the rock. The proposed solution is checked through modeling the control system on the simulation software. The results confirm that the control system adapts and responds well to the mining process, reducing machine vibration, improving the control system's quality while ensuring a good working efficiency for the drilling equipment.

2. Proposing rotation speed control system for drilling machine

2.1. Diagram of the proposed principle for the rotation speed control system

Diagram of the principle of controlling the rotation speed on СБШ-250Т drilling machines as shown in Figure 1 (Эксплуатационная документация, 2003); (Nguyen Chi Tinh and others. 2013).

In the control system of drilling machine СБШ-250Т, the signal setpoint U_{dk} is set directly by the driver in the cabin, through the controller ĐK to change the opening angle α. In the proposed system, the opening angle α will be compensated by the amount of δα through 2 devices (2 blocks) including:

+ Vibration sensor block: in the proposed modeling, it is replaced by Neural Network (Nguyen Phung Quang, 2004);(with the function of recognizing amplitude and vibration frequency after successful network training).

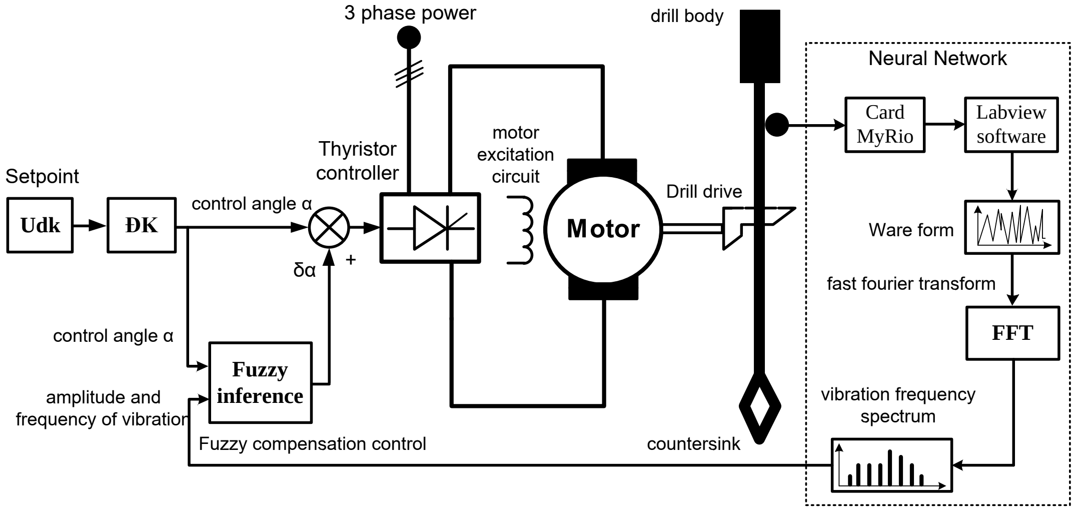

Figure 1. Principle diagram of rotation control of СБШ-250T drilling machine.

+ Fuzzy logic block (Nguyen Phung Quang, 2004): This function receives amplitude and frequency signals from the vibration measurement sensor to determine the appropriate compensation angle (δα) to reduce vibration.

In the control system of drilling machine СБШ-250T, the signal setpoint U_{dk} is set directly from the hand controlled by the driver in the cabin, through the controller to change the opening angle α. In the proposed system, the opening angle α will be compensated by the amount of δα through 2 devices (2 blocks) including:

+ Vibration sensor block: in the proposed modeling, it is replaced by Neural Network (with the function of recognizing amplitude and vibration frequency after successful network training).

+ Fuzzy logic block: This function receives amplitude and frequency signals from the vibration measurement sensor to determine the appropriate compensation angle (δα) to reduce vibration.

2.2. Building a neural network block to identify frequency and vibration amplitude

Neural networks are a very useful tool for identifying and controlling non-linear systems. The ability to self-study and update knowledge is an advantage that makes the network more and more knowledgeable and become smarter. That is the basis for building and developing an intelligent tool to predict the hardness and properties of rock and soil in reality, thereby evaluating the vibration ability of the machine.

Developing a neural network depends on the quality and number of samples in the training process. Drilling process variables such as speed, force, and torque are important and are selected as inputs to the neural network. The output signal is amplitude and frequency of vibration.

+ Table of input and output data for network training, see table 1 (Le Ngoc Dung and Dang Van Chi, 2018).

+ Network design and training

The network is built based on the programming in m-file, including the network structure: the number of neurons layers, the number of neurons in the layers, the transfer function, deviations, etc... Perform the training process, training results are neural network diagram and deviation graph as shown in Figure 2, Figure 3 and Figure 4.

The result of checking the input and output data sets of the 3-layer network model [16 x 36 x 2] shows that the identification data sets are closely following the sample data sets. The newly established neural network had learned the set of input and output signals. The difference between the real value and the target value achieved after 652 generations (Epochs) training.

Table 1. Data for neural network training.

STT	Rock hardness	Spectrum (FFT)		Amplitude	Speed of drilling	Drilling force (F)	Torque M_c
	f_c	(rad/s)	(Hz)	(m/s^2)	(vòng/ph)	(ton)	(Nm)
1	13	1	0.16	0.3	50	30	260
2	12	3	0.48	0.65	63	27.5	218
3	11.5	5	0.8	0.35	70	25	185
4	11	10	1.6	0.15	75	24	183
5	10.5	15	2.4	0.23	78	23	172
6	10	18	2.88	0.2	84	20	165
7	9	26	4.16	0.75	90	17	156
8	8.5	31	4.96	0.25	96	15	153
9	8	35	5.6	0.2	102	13	134
10	7	40	6.4	0.15	107	12	121
11	6.5	55	8.8	0.1	110	10	102
12	6	60	9.6	0.02	123	9	91
13	5	82	13.12	0.05	132	8	83
14	4.5	100	16	0.03	138	7	82
15	4	120	19.2	0.05	145	6	75
16	3	140	22.4	0.03	150	5	67

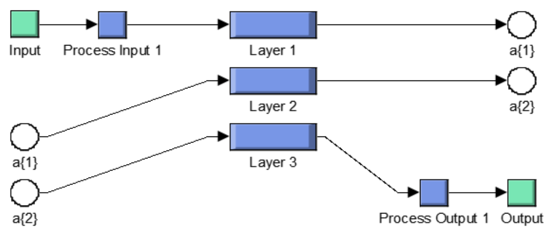

Figure 2. Reduced structure of 3 layers of the network.

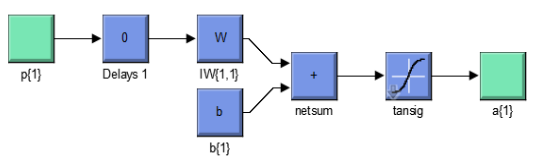

Figure 3. Input layer shortening structure of the network.

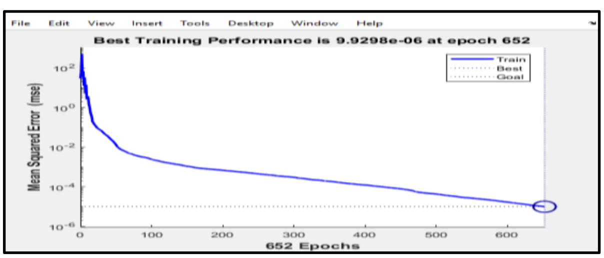

Figure 4. Deviations in neural network training.

2.3. Application of fuzzy-logic to design fuzzy compensation controller (δα)

\+ Defining input and output linguistic variables:

Input parameters:

1. Frequency f of the vibration signal, using 5 fuzzy sets: from (0.08 - 22.4) Hz.

2. Vibration amplitude, using 5 fuzzy sets: from (0.003 - 1.14) m/s2.

3. Control angle α, using 5 fuzzy sets: from (53.2o - 88.2o).

Output: compensating angle δα, using 5 sets of fuzzy words (-35o →+35o).

The structure diagram for the fuzzy inference set in the Matlab is shown in Figure 5.

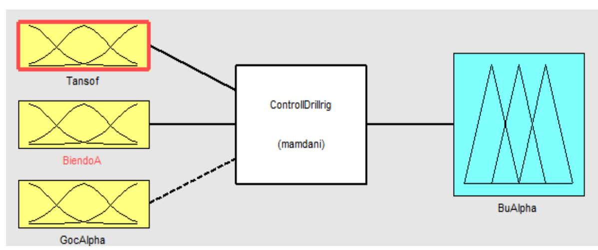

Figure 5. Schematic structure for the fuzzy inference.

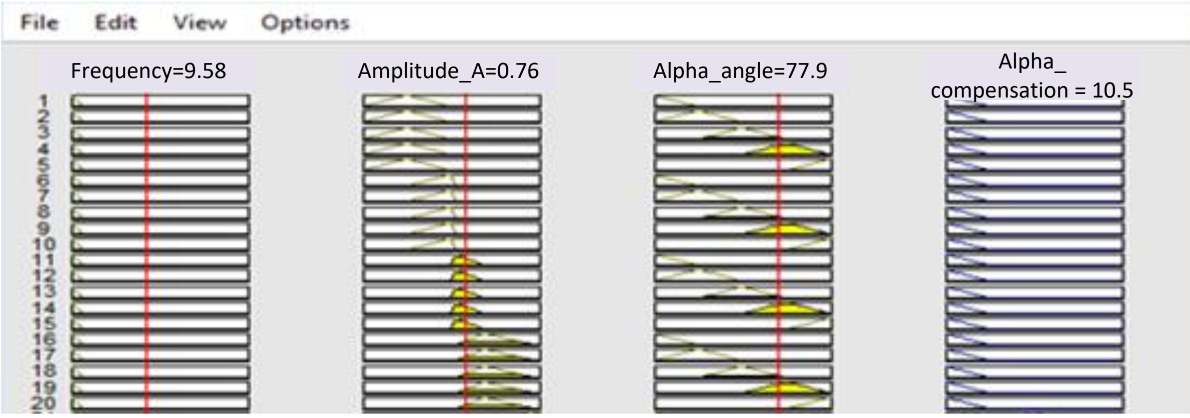

Figure 6. Test results of fuzzy inference output offset δα.

+ Composition law and defuzzification methods

Non-linear transmission relation of fuzzy prediction system with three input variables and one output variable, it is collected according to expert data, and data table 1 has a total of 125 clauses constituted by law:

If $Freq_f$=$Freq_{fi}$ and Ampl_A=Ampl_A_i and Alpha=$Alpha_i$ then Alpha_comp= Alpha_$comp_j$

The fuzzy inference set is installed with the Max-Min component device. The inference is performed according to the Min law. The fuzzy inference is performed according to the Max law, defuzzification average method focus.

+ Simulation results in the Matlab as shown in Figure 6.

3. Applying Neural network and Fuzzy logic to model the rotary channel control system on drilling machine СБШ-250T

After successfully developing two sets of Neural network and Fuzzy logic tools, it will be saved in Simulink Matlab's library for research and modeling. From the proposed principle diagram (Figure 1), the control system modeling was implemented, in which the motor model was developed (Nguyen Chi Tinh al. 2013), linking blocks together and running. (Figure 7).

Test results in operating conditions with different hardness soils, systems with and without compensation, results achieved with control quality and vibration reduction objectives for the device. Figure 8 and Figure 9 show the results of model tests at different depths. The red is the amplitude and frequency of vibration with the current controller, blue is the amplitude and frequency of vibration to compensate fuzzy controller. Observing the

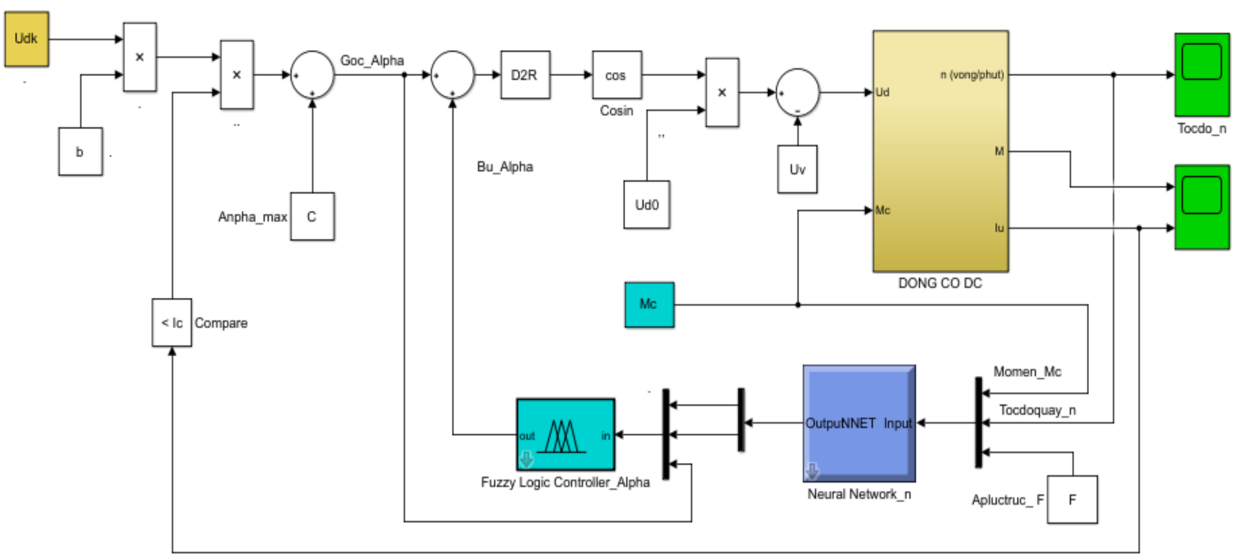

Figure 7. Simulation of the rotating channel on the СБШ-250T drilling machine.

peak amplitudes at different frequencies of 0.1 Hz, 1.5Hz, 3.7 Hz, 5.2 Hz, 7.85 Hz (at a depth of 3 m) and 0.2 Hz, 0.4 Hz, 3.8 Hz, 4.2 Hz all show the reduced effect vibration level ranges from 20% - 60%.

4. Conclusion

The paper presents research and development of two tools, neural network and fuzzy logic to build a fuzzy controller embedded into the current control system to control rotation speed and reduce vibration, including:

+ Training a neural network to determine the properties of rock by amplitude and vibration frequency.

+ Developing fuzzy logic to determine the complementary value.

+ Summarizing and model the rotation speed control system to apply the fuzzy compensation controller, comparing and evaluating with the current controller in use.

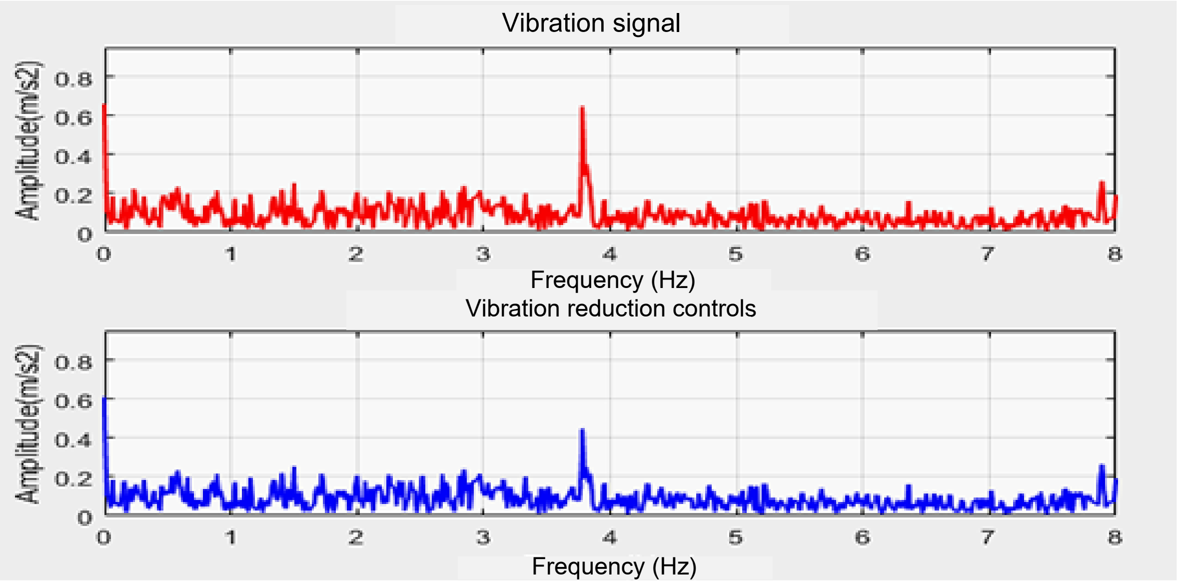

Figure 8. Test results on the model at a depth of 3 m.

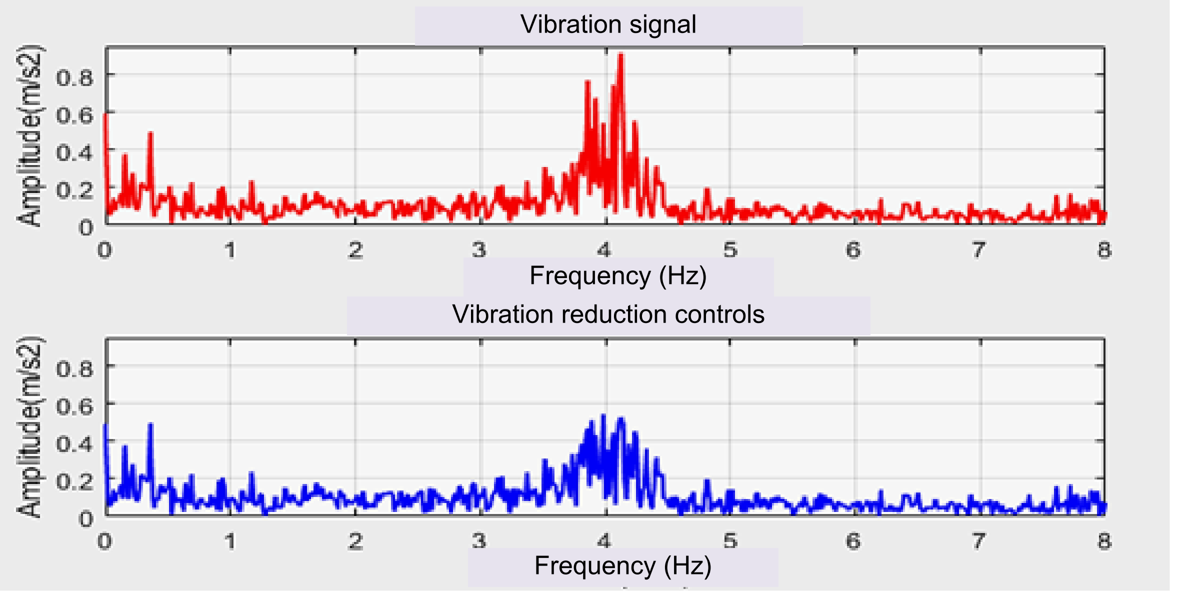

Figure 9. Test results on the model at a depth of 6 m.

+ The research results were tested on the simulation model, evaluated by the control system's quality criteria, the vibration reduction criteria on the machine. The results allow the controller's application to the actual drill operation.

+ The research results confirm that the application of neural networks and fuzzy logic to improve the quality of control and reduce vibration for drilling machines is a reasonable solution in non-linear power transmission systems.

+ Proposing to continue evaluating the fuzzy compensation control system's stability and sustainability through simultaneous control of force and rotation speed.

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