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Simulation Research on Helicopter Airframe Vibration Reduction Based on Intelligent Control

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Abstract. Using parameterized dynamic Bingham model to describe the relationship between active control actuator movement and damping force. SIMULINK emulation module of nonlinear actuator movement characteristics and compared with test data has been achieved by adopting MTLAB. According to the active system of displacement, velocity, acceleration and the desired damping force, the control current inverse model has been obtained based on fuzzy control theory. The validity and correctness of the simulation model are verified by the test results of variable current inverse. Fixed frequency excitation and real flying helicopters floor vibration data are adapted respectively to simulation, and the damping effect of the control system is obtained through simulation analysis.

Keywords. Vibration reduction, intelligent control, dynamical model, fuzzy control theory, simulation

1. Introduction

Compared with other aircraft, helicopter has a unique configuration of the flight mechanism. During the mission period, the helicopter will be affected by the working environment, complex alternating aerodynamic load, different flight status and human operation coupling, resulting in large and variable vibration load in the working process, which makes the crew and equipment in a very bad vibration environment. At the same time, the characteristics of helicopter vibration are obvious. Firstly, it is typical periodic vibration $KN\Omega$ superposition with complex excitation [1]. Secondly, vibration amplitude and frequency changes are caused by different task profiles. Finally, the new variable speed rotor will also bring changes in the main vibration frequency [2]. Strong vibration not only reduces the comfort and efficiency of the crew, but also affects the performance of the equipment and weapon system, resulting in structural fatigue damage and affecting the stability and reliability of the helicopter. Therefore, it is of great practical and economic value to study how to reduce helicopter vibration effectively in real time. [3].

Helicopter vibration control is usually divided into three categories: reducing vibration load of vibration source [4] [5], reducing transmission of excitation force [6] and controlling vibration response of body [7]. According to the specific control mode, it is further divided into passive control and active vibration control [8]. With the rapid

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development of computer technology [9] and intelligent materials [10] [11], active vibration control technology that can adjust the control system is more and more favored. Active control is mainly divided into open loop and closed loop control, in which the control algorithm is the core of the key technology. In order to give full play to the advantages of active control, aiming at the characteristics of helicopter vibration, achieve real-time control and deal with vibration under different working conditions, time-domain algorithm closed-loop control has become a widely used control mode.

Aiming at the requirements of helicopter time-domain vibration control, this paper starts from the vibration active control device of a certain type of aircraft, and adopts the method based on fuzzy control and neural network theory [12] to build the logical relationship between controller output and controller input. Based on SIMULINK emulation module, the mathematical model of helicopter active vibration control has been built. The theoretical control effect of the proposed control model is verified by using the helicopter vibration test data under typical flight conditions as input (figure 1).

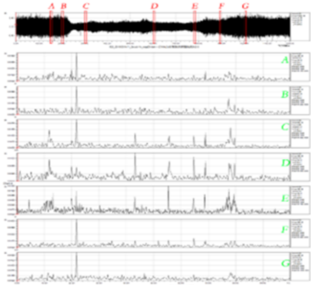

Figure 1. The characteristics of helicopter vibration

2. Actuator Modeling

2.1. Method

This paper adopts the magnetic rheological fluid(MRF) shock absorber for damper. The parameterized dynamic Bingham model is used to simulate the motion relationship, because it can use the characteristics of the MRF damper formula for the description of the system, and can accurately describe the performance of the damper. The damping of the MRF damper force F can be expressed as type:

$$F = f_y \times \tanh(a(\dot{x} + v_h \times \mathrm{sgn}(x))) + c_{po}\dot{x} + kx + f_0$$

In the above formula, c_{po} is viscous damping coefficient (N·s/m) . k is the elastic stiffness of the spring component (N/m) . f_y is the hysteresis proportional factor of the MRF damper. v_h is the half width of hysteresis of the MRF damper.α is the hysteresis slope proportional factor of the MRF damper: f_0 is the MRF bias force: x is the displacement of the damper hysteresis.

Based on the mechanical model test data of the MRF damper established by references, the following identification results are obtained through simulation:

Table 1. Parameter identification results of hyperbolic tangent model.

current/A	f_y	α	v_h	c_{po}	k	f_0
0	60. 4808	0. 4254	2. 3703	0. 2370	90. 8409	−0. 1476
0.3	242. 1297	0. 7681	4. 0533	3. 3476	89. 6654	−3. 7331
0.6	299. 9996	0. 5660	4. 1476	11. 5589	181. 5465	21. 9474
1.2	598. 1504	0. 5035	4. 5106	20. 9300	269. 9926	69. 0858

The table 1 shows that the parameters of MRF damper are associated with the current of input, and showed higher order related functional relations. In order to fit the above the line, using the cubic polynomial fitting. With α and v_h change with current is small, and the impact on the parameter is less than the other parameters, so here is not fitting the two parameters. Using 0.5658 and 3.7705 directly instead of these two parameters. Other parameters are in the following format:

$$Q = q_3 I^3 + q_2 I^2 + q_1 I + q_0$$

In the formula, Q is the parameter to be fitted. q_i is coefficients of various orders. I is input current.

Through the above relationship fitting, the remaining parameter fitting value is obtained as follows:

Table 2. Parameter fitting results.

order	f_y	c_{po}	k	f_0
0	60.5	0.2370	90.8	-0.1476
1	965.6	-4.3418	-263	-86.3252
2	-1456.8	59.3839	1037.1	290.4842
3	854.5	-34.4963	-577.9	-142.0565

The parameters identified above were brought back to the model and Simulink was used to establish the above simulation model. The simulation flow chart is as following:

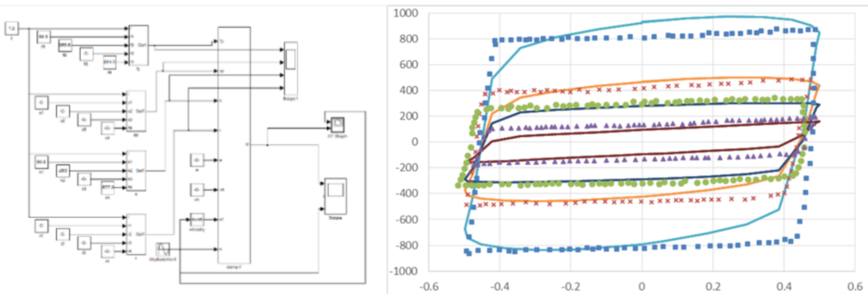

Figure 2. Simulation model for Simulink and comparison results.

Taking displacement as abscissa and damping force as ordinate, the force-displacement indicator curve of hyperbolic tangent model of MRF damper is showed in figure 2. And the simulation and test results of different current flow are compared.

Through the comparison between the Simulink simulation analysis and the test results, it can be seen that the simulation results of the hyperbolic tangent model are hysteretic curve. At the same time, it can get the bending degree, numerical value and position relationship of the graph are in good agreement with the test results. Test results and simulation hysteretic curve are proximate. It shows that the theory is feasible, and the hyperbolic tangent model can better describe the mechanical properties of the MRF damper.

2.2. Dynamical Modelling

The inverse model of the MRF damper is to obtain the control current of the damper according to the displacement, velocity, acceleration and expected damping force of the damper. The relationship between damping force and current, and its basic principle showed in figure 3.

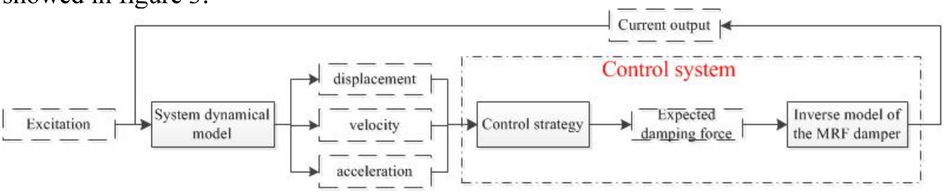

Figure 3. Control structure

Based on the existing positive model of the MRF damper, the inverse model of the damper is being built. However, the relationship between the damping force and current of the MRF damper model is complex and the inverse function is difficult to solve, so it is difficult to directly derive the inverse model. Another method to solve this problem is to use fuzzy method or neural network to get the inverse characteristics, according to the input and output characteristics of MRF damper.

The hyperbolic tangent model can dynamically reflect the nonlinear characteristics of the damper. But the hyperbolic tangent model is difficult to use the first method to build the inverse model, because there are many parameters and the model expression is complex. In this paper, neural fuzzy is used to fit the nonlinear mapping and obtain the inverse model of the hyperbolic tangent model.

MATLAB Neuro-Fuzzy Designer is used to build the inverse model of MRF damper.

In order to verify the accuracy of the inverse model, the same excitation is provided to the positive model and the inverse model of the MRF damper. And then a current is introduced to the positive model of the damper. The damping force output by the positive model is regarded as the damping force input by the inverse model, and the current value of the input positive model is compared with the current value output by the inverse model. If the two currents have the same size, the inverse model is accurate, otherwise, the inverse model is not accurate.

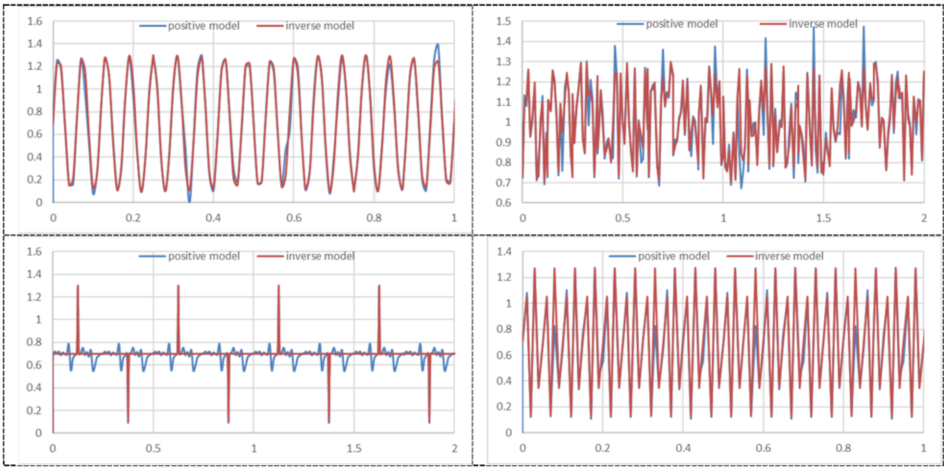

Figure 4. Comparison between the positive model and the inverse model

Tested are conducted with sine, random, pulse and sawtooth current variation. Compared with the positive model and inverse model simulation results in **Figure 4**, it can be seen from the positive model and the inverse model are proximate. The output current of the inverse model coincide with the input current, when the input electric current is a sine wave. The inverse model is more accurate under sinusoidal current trends. As can be seen from the figure comparison, when the input current of the positive model is random, pulse or sawtooth wave, the output current of the inverse model and the input current of the positive model are the same at most simulation times, but cannot completely coincide. This difference comes from the selection of training samples during the training model. The small number of samples is a cause of the difference. Another reason is the defects of neural fuzzy fitting for hysteresis characteristics.

In general, the error between the input current and output current is small, and the inverse model is considered accurate within the allowable range. In this paper, the neural fuzzy inverse model of the hyperbolic tangent is adopted.

3. Vibration Control Simulation

Considering the damping characteristics of the vibration isolation platform, the system dynamics equation of MRF damper is built. Transform dynamics equation into the state space equation. Simultaneous control hardware system and the vibration isolation platform, get the mathematical model for the closed-loop controlled system. In order to keep the motion system stability, 0.2% structural damping is added.

3.1. Results of Periodic Excitation Control

Considering the level of the helicopter rotor vibration characteristics and its influence, selected 5-60 Hz displacement excitation for the input. The spatial rigid body kinematics and dynamics equation of vibration reduction platform have been obtained, including design parameters.

Based on rigid body dynamics equation of vibration reduction platform, the dynamic response and sensitivity have been analysis. Through calculation and analysis, the key factors affecting the natural frequency and other characteristics of the vibration reduction system were obtained. At the same time, the control effect of the system is obtained by using the control rate from the training.

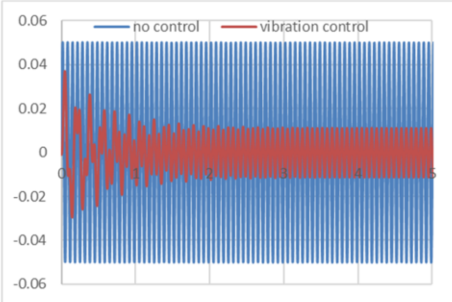

Figure 5. The control effect for periodic excitation

The Simulink simulation results showed that the intelligent control system can achieve the effect of stable control amplitude in about 10-20 cycles, for the periodic excitation system. It can be clearly seen from Figure 5 that the control system does consistently reduce the vibration by more than 80%.

In addition, the vibration response results of the system under excitation of different frequencies are analyzed. According to the result curve, the vibration level dramatic decline when the excitation frequency is far away from the natural frequency of the system. However, when the excitation frequency is close to the natural frequency, the control efficiency of intelligent vibration control system decreases obviously, and the control rate is only about 40%.

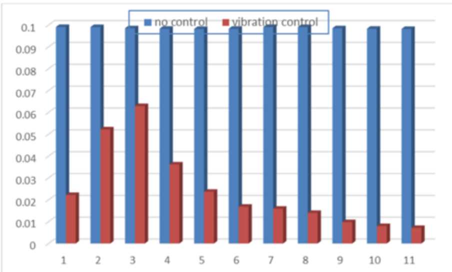

Figure 6. The control effect of different periodic excitation

3.2. Real Excitation Simulation Results

The helicopter real flight characteristics were used to model the dynamic system. Based on the mathematical model of the closed-loop controlled system, the two different flight conditions, stable flight and maneuvering flight, has been built. Take the cabin vibration level as a goal, the neural networks control is applied for single frequency vibration control.

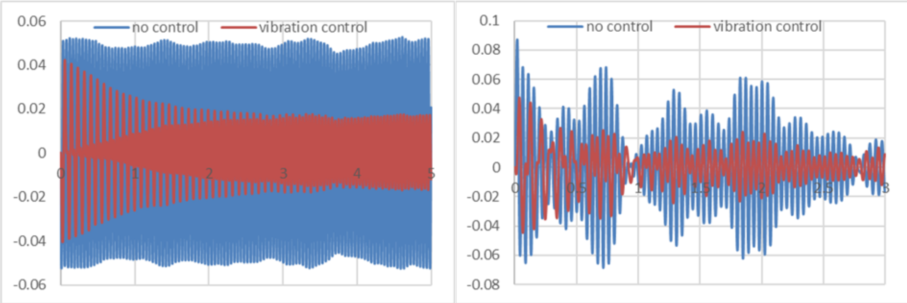

Figure 7. The control results for stable flight and maneuvering flight

According to the control results, even stable flight, doped with other frequency excitation because there are many interference excitation in the real flight process. Which makes the incentive is not steady sine signal and the resulting two effects. Firstly, the control convergence process slows down, from the original 10-20 cycles, increase about 25 cycles: Otherwise, the vibration isolation efficiency is lower, the peak-to-peak value comparison shows that convergence after vibration reduction efficiency of about 72.8% on average.

It can be seen from the control results of the excitation in the maneuvering flight that the excitation amplitude changes greatly. And the intelligent control system can follow the change of the external excitation well to achieve better control effect. However, compared with the stable flight state, the control rate is reduced, and the average vibration reduction efficiency is about 50%-65% after 25 cycles.

4. Conclusions

Aiming at vibration reduction requirements of helicopter body, the dynamic model of active control system was established based on Simulink simulation analysis method and Neuro-Fuzzy Designer control method, and the validity of the model was verified by using different current input. The control system was simulated by periodic excitation and measured helicopter flight excitation respectively. The results of this study showed that:

(1) The control system dynamic model is established and validated with the test date.

(2) The control system has a good control effect on fixed frequency excitation far away from the natural frequency, achieving stable control effect in about 10-20 cycles, and the control rate can reach 80%.

(3) For real flight excitation, the vibration control rate is about 72.8% in stable flight, and the vibration reduction efficiency is reduced to 50%-65% in maneuvering flight state.

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