Performance Test Study on Electromagnetic Actuators

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Abstract: In this essay the operating principle of electromagnetic actuator is analyzed, and the mathematical model for the electromagnetic actuator is deduced. The performance testing setup for the electromagnetic actuator is constructed and the test data are analyzed by MATLAB. The result of the test shows that there exists certain differences between the theoretical calculation and the test result and the uncertainty of this kind of theoretical models must be taken into consideration when designing controllers.

1. Foreword

The actuator, as a power-providing device, is the key to the implementation of the active control. Actuators applied in control field nowadays are classified into two categories according to their working principles: one kind is the actuators realizing actuation on the basis of the material alertness; the other kind on the basis of the structure mechanism. Common actuators include the magnetostrictive actuator, the electromagnetic actuator, the hydraulic actuator, the electric actuator and etc. Electromagnetic actuators, compared with other kinds of actuators, have many advantages such as compact structure, little energy consumption, sensitive reaction, no contact friction, no lubrication, large adaption bandwidth, large displacement and output force, and therefore are widely used in engineering [1].

2. Working Principle of the Electromagnetic Actuator

The working principle of the electromagnetic actuator is that when a current flows through a conductor, the corresponding electromagnetic field emerges around it, and, at the same time, ferromagnetic substance near the magnetic will receive the corresponding attraction or repulsion, causing its mechanical movement. The electromagnet is the core of the electromagnetic actuator. The electromagnet can be divided into two major categories of direct current electromagnet and alternative current electromagnet according to the different exciting current. Dc electromagnet is the electromagnet excited by direct current and the magnetic flux through its magnetic circuit is constant flux without periodic variation. Ac electromagnet is the electromagnet excited by alternative current and the magnet flux through its magnetic circuit is alternating flux with periodic variation [2]. As the magnetic flux produced by dc electromagnet is constant, there is no magnetic hysteresis loss and therefore eddy current loss and electromagnetic lag is small and energy conversion efficiency is high. So the dc electromagnet structure is generally used in the electromagnetic actuator.

What is shown in figure 1 is the schematic diagram of the unidirectional electromagnetic actuator structure, which is composed of springs, armature, permeability magnetic materials and coil. At the beginning, the armature in on balance under its own gravity and spring force; when the excitation coil is energized, the armature will move under the combined action of the magnetic field suction and the spring force; the size of magnetic field force can be controlled by controlling the excitation current size, thereby adjusting the force on the armature [3]. Magnetic leakage and other factors neglected, when the coil is energized, the magnetic field force on the armature is as follows:

$$F(i,c) = \mu_0 A N^2 i^2 / 4c^2$$

μ_0、A、N、i、c in the formula are respectively vacuum magnetic permeability, iron core area, coil turns, excitation current and air gap.

Shown in figure 2 is the schematic diagram of the bidirectional electromagnetic actuator structure and the direction and the size of the magnetic field force on the armature is controlled by adjusting the size of the excitation current through the two coils [4].

Magnetic leakage and other factors neglected, when the coil is energized, the magnetic field force on the armature is as follows:

$$F = F_2 - F_1 = \frac{\mu_0 A N^2}{4}\left(\frac{i_0 + i_c}{c_0 - x}\right)^2 - \frac{\mu_0 A N^2}{4}\left(\frac{i_0 - i_c}{c_0 + x}\right)^2$$

μ_0、A、N、i_0、c_0、x in the forula is respectively vacuum magnetic permeability, iron core area, coil turns, excitation current at balance place, air gap at balance place and the armature displacement.

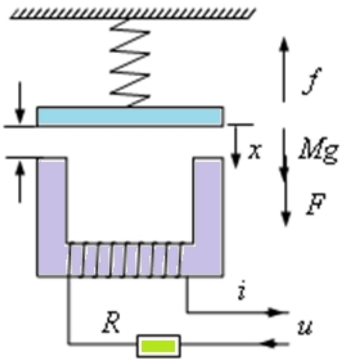

Fig 1. The schematic diagram of the unidirectional electromagnetic actuator structure

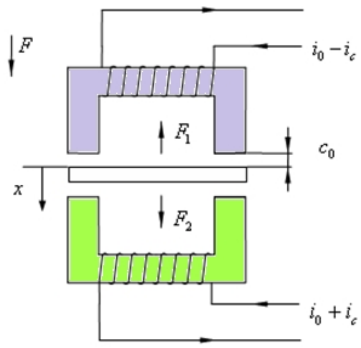

Fig 2. The schematic diagram of the bidirectional electromagnetic actuator structure

We can know from the above-deduced electromagnetic force expression, the electromagnetic force needed can be obtained by controlling the field current. But the above theoretical results are got under assumed conditions that magnetic flux leakage and magnetic resistance of permeability magnetic material and armature are ignored [5]. In fact, magnetic flux leakage and magnetic resistance always exist, and therefore it is necessary to do research on the relationship between the electromagnetic force and the field current from the angle of the experiment.

3 Performance Testing Apparatus Design

The electromagnetic performance of the electromagnetic actuator is directly manifested by the variation patterns of the electromagnetic coil current and electromagnetic force of electromagnetic actuators. To test the electromagnetic performance of electromagnetic actuator, the special electromagnetic performance testing system, which is shown in figure 3, is designed and it is mainly composed of the following parts: MTS testing machine, dc regulated power supply, power-driven circuit, current sensor, force sensor, PCMA308 acquisition card, notebook computers and dasp5.0 software [6].

4 Test Data Analysis

Test data are instantly instored in the computer through PCMA308 acquisition card and dasp5.0 software; the test results are analyzed by using MATLAB with the built-in curve fitting toolkit.

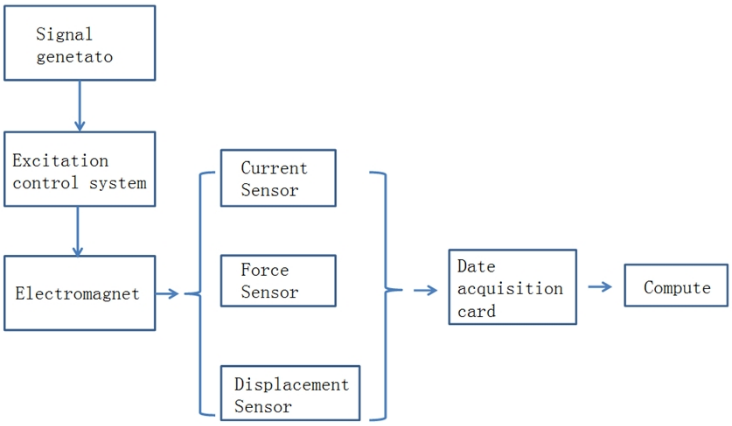

Fig 3. Electromagnetic actuators characteristic test system

4.1 Relationships between the Electromagnetic Force and the Exciting Current

When magnetic gap is fixed, the electromagnetic force is proportional to the square of the coil current. This result is achieved when we ignore the magnetic resistance and the magnetic flux leakage of the magnetic conductor and the hypothesis is that the magnetic circuit is unsaturated and the magnetic field lines are equally distributed in the magnetic circuit [7]. According to the analysis of test data, if we fit the test data by using a quadratic power function $F = Ai(t)^2$, the effect is very poor or even can't fit. In fact, there is always magnetic resistance and the magnetic flux leakage in the magnetic conductor and there is always the mechanical friction in the actuator, so it is more reasonable to fit the test data by using the formula $F = ai(t)^{b_1} + b_2$, b_2 representing the mechanical friction force of the actuator, as shown in figure 4.

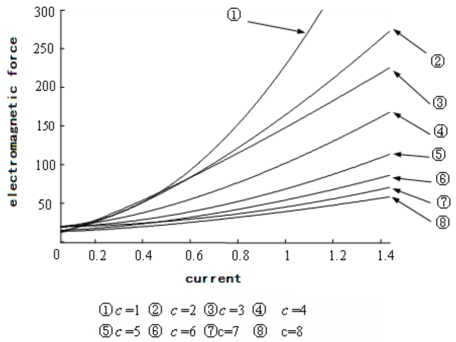

Fig 4. The relation curve of different air gap between electromagnetic force and exciting current

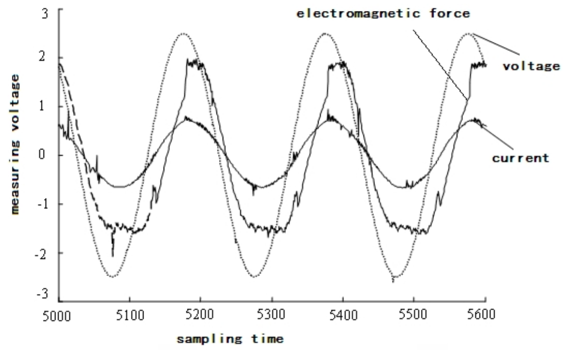

Fig 5. The sine response of voltage

4.2 Dynamic Test

Test method: measure the output waveforms of the current and force when the changes with different frequency and amplitude while the magnetic gap is stable in 4 mm [8].

When the magnetic gap is fixed in 4 mm, the input voltage is sine signal the amplitude and the frequency of which are 2.5 V f 5 Hz respectively [9]. The responses of the current and the electromagnetic force are shown in figure 5; from it we can find that the current and the voltage basically have no phase difference but that there is a lag in the response of the electromagnetic force and this strictly conforms to the actual system [10].

5. Conclusion

Test results show that when the air gap is very small, coupling coefficient variation range is quite large and theoretical model is rough; when the air gap is more than 1 mm, the test result and the theoretical model are in good agreement, but still there is certain deviation. Enlightenment from the theoretical analysis and the experimental results is: on one hand, we should try to reduce friction force or use non-contact structure in the design of the electromagnetic actuator as well as to minimize magnetic flux leakage and iron losses in the design of magnetic circuit; on the other hand, when researching the electromagnetic actuator control strategy, we should take model uncertainty into consideration so as to design controllers with better performance.

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