Systematization Design of Linear Actuator by using CAE System

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Abstract - In this paper, we introduce the design method using CAE(Computer Aided Engineering) which is profitable in the compatibility and standardization of the developed product, and the reduction of construction time and price to develop and design a machine equipment.

Particularly, we select the standard model to design or develop from the large machinery to the super precision one, extract the peculiar characters of the model by the close analysis on the physical and technical part, the experiment for the characteristics of objective dimensions by analogical mathematical analysis for previous results, and can induce the design model demanded by user investigating optimal data in the design previous

We present the analogical algorithms and process method of design factors and restriction factors in the systematization design with computer. Then we analyze step functions for each systematization equipment and induce the process of technical data with actuator model.

1. Introduction

Machine equipment designers and developers is facing a variety of requirements from the customers such as functions, price and period of the manufacture from consumers. Although there are many methods of designing and developing them, you can choose the CAE applying for similarity theory to take advantages of the standardization and compatibility of developing products and of the reduction of the manufacture time and price.

In recent years, designers and developers are interested in the application of CAE because of low-cost computer system and the distribution of its related peripheral equipment. In order to design and develop from particularly super-sized machines to precision equipments, select a sample model and extract the peculiar characteristics through the close analysis on the physical and technical parts of it. We can preestimate the characteristic experiment for the magnitude to seek by means of analogical interpretation and draw the sample design the consumers need by verifying the optimum design data. For applying analogical interpretation, the characteristic analysis by analogical interpretation on each single medium at nonlinear factors should be complemented[1][2][3].

In this paper, designers and developers will come to learn the design technique easily applicable to international standards through product standardization based on the identical scheme or manufacture technique and learn how to apply similarity theory to design technique. After selecting the actuator as a model and designing it in miniature by similarity theory, find out the alternatives to correct the errors caused by comparing the estimated characteristic of the equipment with that of a trial product.

2.Similarity Consideration

In order to build up the systematization design of a linear actuator, make an analysis of thrust, speed, voltage, current, resistance and attenuation constant as systematization factors. these factors can be presented to different parameters in form of geometrical size. Each medium shaped in same species and products at same line must be calculated and designed at the process. When we estimate the characteristic or the machine in systematization layer, the series of its relationship can be settled by considering the characteristic of the provided model motor as one component.

$$\varphi = \frac{GH_2}{GH_1} = \frac{GH_1}{GM} = const. \qquad (1)$$

where,

GH_1 : the model and the classification machine of same character 1

GH_2 : the model and the classification machine of same character 2

GM : the model

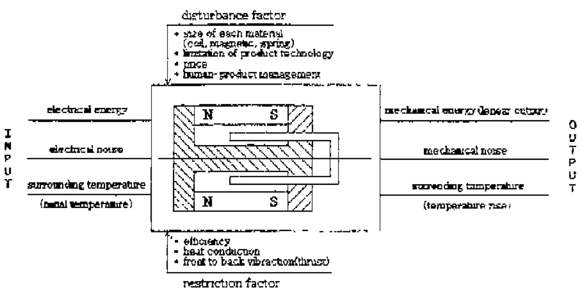

Fig. 1 The Input, Output and Indirect Medium of Linear Actuator

Fig. 1 shows the diagram of the input, output and indirect medium for the linear actuator.

The size of input can be given by the electrical energy, electrical noise(signal) and the initial operating condition (surrounding temperature) and the size of output can be appeared by the mechanical noise of the thrust and the attenuation constant and temperature rising caused by energy loss. Of course for this equation mechanical energy (thrust) and loss energy must be defined precisely, that is, similarity theory must be secured for all functions from the first to the end. Therefore linear mathematical technology based on fournetwork analysis must support it and similarity process for the model and product should be dealt with equally through all items. Generally, the similarity measure l^* representing the physical process of model and product applied is expressed as random measure l square[3].

$$l^* = \frac{\textit{physical amount of development product}}{\textit{physical amount of the model}} \qquad (2)$$

In case all parameters of the model and product are identical factors and classification series increases linearly, physical phenomenon and mathematical calculation must be described equally to factors applied to the model. To design with CAE the mathematical description about indirect medium including limitation factors and disturbance factors has to be given necessarily as showed in Fig1. Mathematical description for the indirect medium can estimates measure l^* by similarity theory for each medium and make the energy transformation system of motor apply to the fournetwork mathematical description.

3. Design and Experimental Consideration

3.1 Function Explanation

Fig. 2 shows the process of an iron core moving type actuator's action.

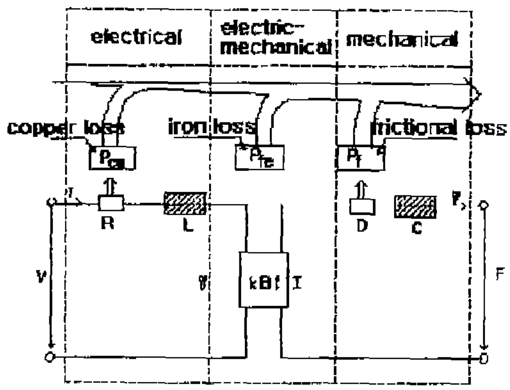

Fig. 2 Function process of moving core type actuator

Voltage V of the input makes current flow across the vibrator coil. Vibrator coil with winding number N makes resistance loss $P_{cu} = I^2R$ and state current arrival time (or electrical time constant) $\tau_e = L/R$ through resistance R and inductance L. When vibrator start moving in magnetic field of magnetic density B, counter electromotive force $kBlv$ is inducted across vibrator coil to keep voltage constant. If current flows across the wound wire, thrust F transmitting to axis and $kBlI$, energy relevant to the amount of mechanical loss, is produced. Iron loss(P_{fe}) occurred at this time come into existence only as vibrator coil is composed of material containing iron component. A bearing and vibrator in slit is proportioned to vibration number, so it acts as mechanical loss and the smaller the developing product is, more important its role is[4].

Linear actuator is a energy transfer machine connected by electrical mechanical, and mechanical process.

The formula for the thrust and voltage of the miniature linear vibration actuator is as follows

$$V = kBlv + \left(RI + L\frac{dI}{dt} \right) \tag{3}$$

$$F = kBlI - \left(m\frac{dv}{dt} + D \cdot v + c\int vdt \right) \tag{4}$$

3.2 Similarity Character Consideration

The similarity analysis on the vibrator vibration phenomenon shown by current I across the moving coil can be introduced by the transformation of equation(4),(5). Similarity measure, to find each character of the main action actuator consisted of the same elements with the geometrical similarity like the model, is as following.

$$F^*/v^* = k^*B^*l^*I^*/v^* = m^*/t^* = D^* = c^*t^* \tag{5}$$

We will find the mechanical constant reaching to the normal speed and the trust F , the one of the most important character of actuator. Here, the mass of the spring and vibrator decides the relation of the frequency and induces transformation equation (5) $m^*f^* = c^*/f^*$ from the equation of time $t^* = 1/f^*$, and from that, the natural frequency f_0 is

$$f^{*2} = \frac{c^*}{m^*} = f_0^{*2} \tag{6}$$

Here, thrust F can be calculated from the equation $m^*f^* = F/v^*$ and $v^* = f^*l^*$. That is,

$$F^* = f^{*2} \cdot m^* \cdot l^* \tag{7}$$

Thrust $F^* = l^{*4}$, occurring when the volume proportion of the same elements changes geometrically, has the amount of similarity measure. But the spring constant c in the equation (6) has a difficulty in confirming the entire similarity due to the elements and the manufacturing critical point in the case of the miniaturization.

Therefore, we apply the equation $f^* = \sqrt{\frac{c^*}{m^*}} = \frac{1}{l^*}\sqrt{\frac{E^*}{e^*}}$ instead of the $f^* = 1$ [2].

where,

E^* : the spring constant, ρ^* : volume density

The mechanical time constant τ_m reaching to the normal speed is obtained from the equation (5).

$$m^* v^* t^{*-1} = k^* B^* l^* I^* \qquad (8)$$

Here, the similarity measure $k^* = 1$ for the constant k^*, therefore, $\tau_m^* = m^* v^* / B^* l^* I^*$ from the equation (8) in the case of the normal speed $v^* = 1$. The mechanical time constant is

$$\tau_m^* = \frac{l^{*3}}{B^* l^* I^*} = l^{*2} B^{*-1} I^{*-1} \qquad (9)$$

when we use the some elements used in the model and action actuator which has geometrical similarity $R^* = l^{-1}$, $B^* = 1$, $\tau_m^* = l^{*2} B^{*-1} I^{*-1}$ from the equation (9) when the normal speed v^* is in the steady-state $I^* = l^{*2}[B^*]$. In the case of the miniaturization of the actuator, $R^* = 1/l^{*0.93}$ [5], therefore, the amount of the current transformation is

$$I^* = l^{*1.86} \qquad (10)$$

In the case of the miniaturization of model motor with the equation (10), (9) using the mechanical time constant $\tau_m^* = l^{*2} \cdot l^{*-1.86} = l^{*0.14}$, the mechanical time constant reaches the normal speed in the short time at the proportion of the length measure l^* and in the case of the large-sized model motor, it reaches to the normal speed with waking time. In the case of the ready state driving voltage V, $V^* = 1$, and $I^* = l^*$, therefore, the mechanical time constant is $\tau_m^* = l^{*2} \cdot l^{*-1.86} = l^{*0.14}$, so the mechanical time constant is $\tau_m = l^{*2} \cdot l^{*-0.93} = l^{*1.07}$ from the equation (9) and is proportioned to time in the growth curve. When comsumer's requirement is that the driving current I has to stay constant, the mechanical time constant $\tau_m = l^{*2}$ in the equation (9). In this case, according to each driving condition, when we predict the time of actuator reaching to the normal speed, we can represent it like Fig. 3.

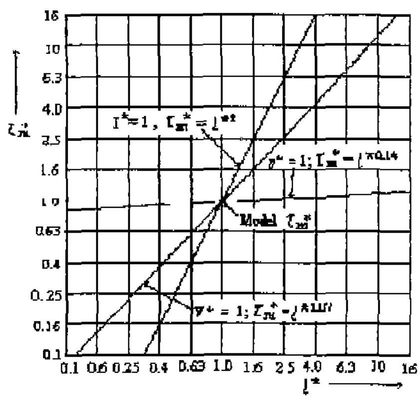

Fig. 3 The transition curve of mechanical time constant τ_m for reach by normal speed by operating term

3.3 Experiment Consideration and Analysis

Model and input voltage of the action actuator for oscillation frequency is shown table 1.

Table 1 Input voltage and oscillation frequency

Input Voltage [V]	Oscillation frequency	
	Model	Action
3	832	1289
4	1014	1558
5	1220	1783
6	1385	2132
7	1504	2395
8	1680	2584
9	1795	2760

The characteristic curve of input voltage oscillation frequency for model actuator (full length 107㎜, stator's external diameter 50㎜, stator's internal diameter 33.3㎜, vibrator's external diameter 11.7㎜) and action actuator($l^* = 0.6$) is shown in Fig. 4.

As input voltage is constant ($V^* = 1$), oscillation frequency(speed) is in proportion to $\frac{1}{l^*}\left[\frac{1}{B^* k^*}\right]$. The model and the action actuator were manufactured under totally similar condition, so $B^* = 1$, $k^* = 1$ and $1/l^*$ has a value of 1/0.6 of model speed.

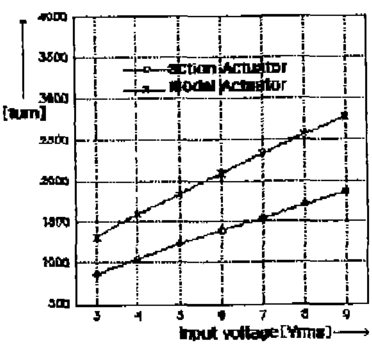

Fig. 4 Curve of the voltage and oscillation

In Fig. 4, it is almost equal to the theoretical values but has some nonlinear factors and speed value up to 1/0.65. This seems to be as a result of the technical problem of manufacturing process.

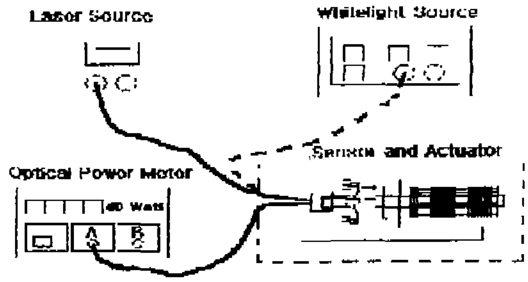

Fig. 5 Experimental system to measure the characteristic curve of a moving actuator

The experimental equipment to measure the characteristic curve of a moving actuator is shown in Fig. 5

The results of measuring moving state for on-off operating state of the model are given in Fig. 6. As shown in Fig.6, with the characteristic curve reaching the steady-state, the miniaturized one reaches the steady-state faster than the model does, but the error of 0.6ms degree comparing to the theoretically estimated value, 3ms, occurred. This problem is also caused by the inconsistency of manufacturing process like the friction coefficient of the motor axis.

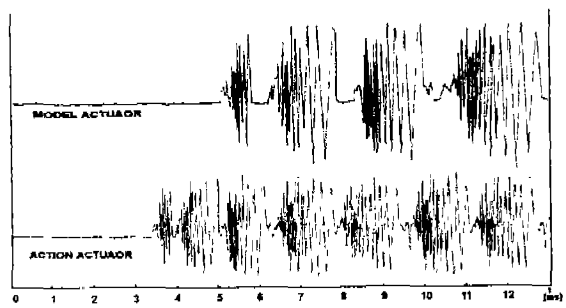

Fig. 6. Characteristic curves for the on-off operating state of a moving actuator

The magnitude of thrust being in proportion to current rise ration increases, as the characteristic curve between operating current and thrust at a constant voltage($V^* = 1$) is Fig.7.

The theoretical value proportioned to thrust $F^* = I^{*2}$ has some deviation, but refers to almost same value in similarity.

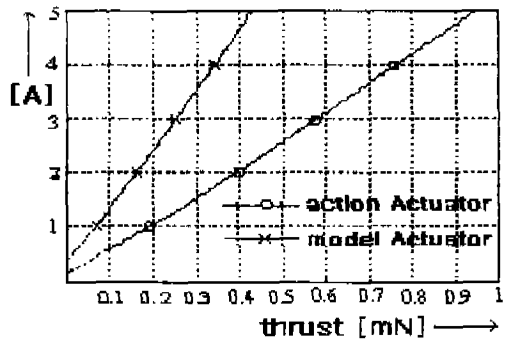

Fig. 7. Current and thrust character curves

4. Conclusion

As we have discussed, we can realize that designing on computers with design appling similarity theory is available and preestimate the character of working apparatus we want in size according to results. The difference in measure results from the processing machine and characteristic curves exists due to manufactory technical problems on the direct medium. The vibration of 8-V input voltage was 8 % and dynamic character in unload had error of 20%, but we can Figure out more accurate expectation character with the systematic program through separate catalog and data base, as appling this paper's result, we can obtain results closer to theoretical values through the experiment and the manufacture of appliance product and the designing using several data about the product of the related factories.

Even though there are not enough technical engineers in the small medium industries, they can develop the design technique on their products with the designing method using PC, and can accomplish the production improvement and cost reduction and early proficiency of the engineers with the standardization of products and systematization design.

5. REFERENCES

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