Optimization of the CEDM Coil and Housing

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1. Introduction

The Control Element Drive Mechanism (CEDM) is an electro-mechanical device to provide a controlled linear motion for the control element assembly. Reliable operation of the CEDM is very important because its failure directly causes shutdown of a nuclear power plant. As far as the reliability of the CEDM is concerned, the CEDM coil has been an important issue as its failure has been reported several times.

The failure was caused by high temperature of the coil. One of the main heat sources of the coil is the copper loss produced by the input current of the coil itself. Therefore, it has been required to develop a CEDM with low power consumption.

There has been an effort to improve the performance of the CEDM by increasing the thickness of the coil housing [1]. However, it increased the total volume of the CEDM. In this paper, a design optimization method to improve the performance of the CEDM without increasing the total volume of the CEDM is introduced.

2. Modeling and analysis

A 2D axisymmetric model of the CEDM has been developed using Maxwell[2] as Fig. 1. The gap between the upper lift magnet and upper latch magnet is modeled to be closed and the other gaps are modeled to be open to describe the hold mode condition.

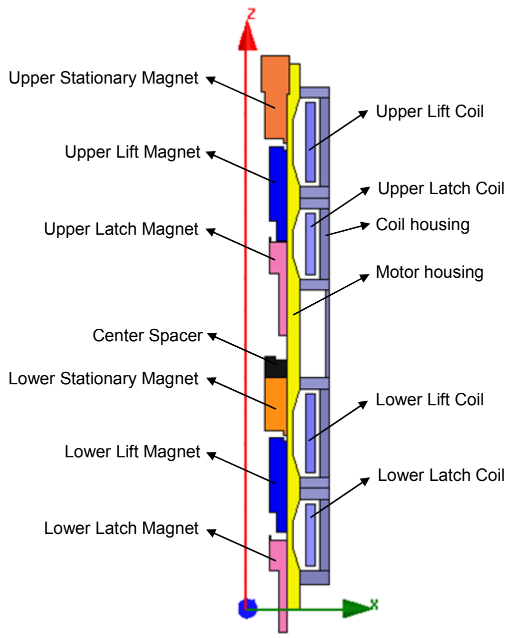

Fig. 1. Analysis model

Non-linear characteristic of magnetic material is considered by applying the B-H curve of the CEDM components as shown in Fig. 2.

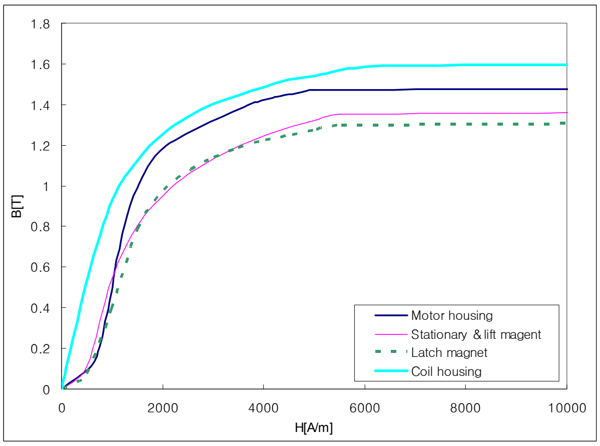

Fig. 2. B-H curves

All the other design parameters are constrained as the same with the conventional design except the two dimensions. Fig. 3 shows the design parameters to be optimized, the outer radius of the latch coil and the inner radius of the latch coil housing. Since the distance between the coil and the coil housing is constrained as well, the two dimensions are related as below.

$$dr = \Delta r_{o,coil} = -\Delta r_{i,housing} \quad (1)$$

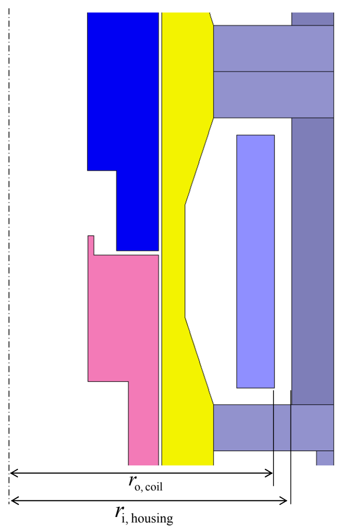

Fig. 3. Design parameters to be optimized

Two cases were analyzed. For the first case, input excitation (ampere-turns) for latch coil is fixed as the conventional one. For the second case, increased input excitation is applied to the latch coil assuming the turns of latch coil winding can be increased linearly to the coil area as below.

$$new\ turns = old\ turns \times \frac{new\ coil\ area}{old\ coil\ area} \qquad (2)$$

Analyses are performed for the two cases by increasing the outer radius of the coil up to 0.25 inch with increment of 0.05 inch.

3. Results and discussion

Fig. 4. shows the result of magnetic force. For the case of fixed turns, the magnetic force decreases as the outer radius of the coil increases because the reluctance of the coil housing increases. The decrease slope of the magnetic force becomes steeper as the radius of coil increases since the coil housing becomes saturated more and more.

For the case of increased turns, the magnetic force shows the maximum value at the radius increment of 0.15 inch, which is the optimized point. This result can be explained as follow:

As the outer radius of the coil increases, more ampere-turns can be applied to the coil area and it produces higher magnetic force. However, the reluctance of the coil housing increases as the inner radius of the coil housing increases, which result in lower magnetic force to be produced. The effect of higher ampere-turns is more dominant until the radius increment reaches 0.15 inch. After the radius increment reaches 0.15 inch, the coil housing become saturated significantly and the effect of the coil housing thickness reduction becomes more dominant.

Fig. 5. and Fig. 6. show the flux distribution for the case of increased turns with conventional design and the radius increment of 0.25 inch, respectively. They show that the coil hosing is saturated significantly as the coil housing thickness is reduced.

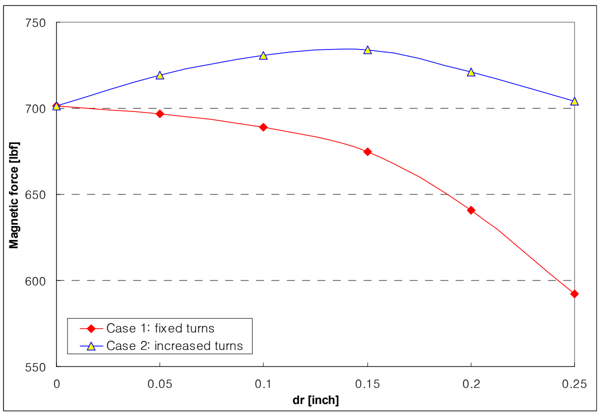

Fig. 4. Magnetic force result

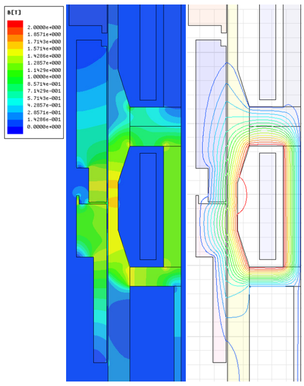

Fig. 5. Flux distribution for the case of conventional design

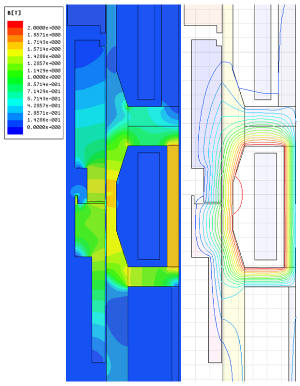

Fig. 6. Flux distribution for the case of increased turns (dr=0.25 inch)

4. Conclusion

In this paper, the CEDM coil and housing were optimized by parametric study using FEM analysis. Magnetic force increased around 5% by applying the optimized design of the CEDM coil and its corresponding ampere-turns.

This result can also be used to design a new CEDM which generates lower heat since it is possible to reduce the input current without deteriorating the magnetic force. Although the total resistance of the coil increases by applying higher turns, this concept is still available because the heat generation due to the copper loss decreases in proportion to the square of the current reduction while it increases linearly with the resistance.

Additional benefit from the new design is expected in respect of heat transfer. The coil housing is exposed to cooling air. Therefore, the operating temperature of the coil is expected to be lower as the thickness of the coil housing is reduced.

REFERENCES

[1] Hyun Min Kim, In Young Kim and Il Kon Kim. Electromagnetic Analysis of the Magnetic Jack Type Control Element Drive Mechanism, Proc. of the 17th SMiRT, 2003

[2] MAXWELL 2D V.12 User's Manual, ANSOFT Inc. 2008