Micro-Analysis of Electromagnetic Force Distribution in a Simple Actuator

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Abstract— ***In this paper a comprehensive analysis of micro force distribution on the surfaces of a simple actuator is presented. Knowledge of micro forces on electrical machine moving parts can be useful to have more understanding of machine's behavior. Some forces may be used in motion direction, some in opposite and some without any effect in motion. In this investigation, force distribution on four edges of a rectangular shaped plunger is presented and the points which have key effects on global force are compared on these four edges. Moreover this analysis has been extended to similar plunger with some holes on it. The results of this investigation can be completely generalized to Switched Reluctance Motors (SRM) and also other types of electrical machines. Using this analysis, designers can expertly increase effective motion force and reduce opposite and unused forces.***

Index Terms— **electromagnetic forces, electromagnetic devices, finite element methods**

I. Introduction

Electrical machines are used in various applications such as industrial, domestic, traction and many other applications. In the past, the investigation were done from macroscopic point of view, therefore in calculation of force or torque, the global values were considered and all of analysis and optimizations were done to improve the machines performance globally. Sometimes these were done with trial and error or sensitivity analysis methods. Microscopic analysis of forces in electrical machines can be helpful to identify the useful forces in electromagnetic devices. Maxwell stress tensor is one of the best methods to have force distribution on the machines body using the normal and tangential components of the field. This can help to increase or decrease force components within the change in shape of body and consequently change in field and force components.

Jiang et al. investigated force components in air gap of an electromagnetic device [1]and permanent magnet synchronous machines [2]. Moallem et al. have tried to find ways to improve the performance of IPMSM and SRM using micro force analysis [3]-[4]. They invented a new double stator switched reluctance motor construction which has higher torque density than traditional SR motors [5].

II. Machine Model and Force Calculation

Here, the terms macroscopic and microscopic forces are used and require definition. Macroscopic view of force calculation implies to calculating "net force" or briefly "force" acting on moving part globally. Microscopic view or "force distribution" implies the forces acted on small elements of moving part surface. In design of electrical machines, knowledge of force distribution can give enormous information to choose a smart shape optimization in order to increasing effective motion forces on body of machine. Knowledge of force distribution is also useful to reduce force and torque ripple, noise and vibration of machine by design optimization

Calculating force distribution needs accurate mesh and proper formulation in FEA especially in the points with intense change in field. In 2D problems, force distribution can be calculated from field component in the surfaces of body in post-processing step as follow.

$$f_t = B_n H_t$$
$$f_n = \frac{1}{2\mu_0}\left(B_n^2 - B_t^2\right). \quad (1)$$

B_n, B_t : Normal and tangential component of flux density (T)

f_n, f_t : Normal and tangential component of force density (N/m^2)

In order to obtain accurate results, the integration contour should be chosen the surface of rotor and the net force is the integration of force component on that surface.

Fig.1 shows the test model (Dimensions are in cm). The plunger has four edges which each edge is numbered from 1 to 4. Investigation is done on different six shapes of rotor. In each shape, five holes are considered near the rotor surface (o.1 cm below the surface). The shape of the holes and the rotor with holes are also shown in Fig 1.

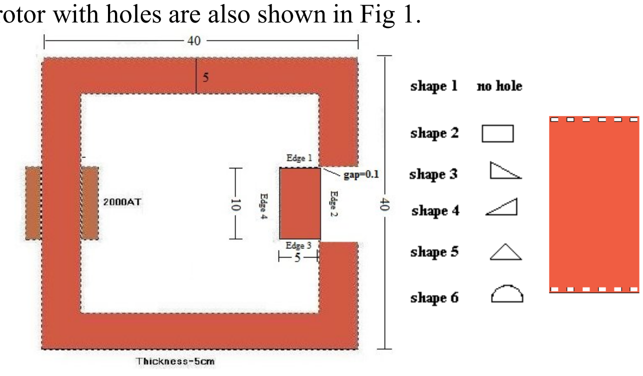

Fig. 1. Machine model and hole shapes considered in the rotor surface

III. Result and Analysis

Normal forces of edges 1 and 3, and tangential forces of edges 2 and 4 don't play any role in motion. These forces can also make noises and vibrations if there are small asymmetries in moving part shape or air gap which is inevitable in manufacturing process. The net force acted on plunger is the sum of normal forces on edges 2 and 4 and tangential force on edges 1 and 3.

FEA is implemented for each six shapes with proper consideration on meshing and formulation. In post-processing, field components at each edge are extracted separately, and normal and tangential forces of each edge are calculated. At each edge, the components of field at 5000 nodes are extracted. Then each edge is divided into ten parts and the sum of forces in each part is calculated. Fig.2 shows the force of this ten parts on edge 1 in x direction exactly on the rotor surface for two positions (xp=0 means that plunger is at the entry position). It is evident that the normal force on this edge (in y direction) is ineffective on motion. Shape 1 demonstrates the rotor without any hole. As it can be seen in Fig 1-a and Fig 1-b for shape 1, most of the force is acted on the tip of moving part near the stator in both positions and there is no x directional value on the other parts of rotor surface. Certainly, normal forces can also be investigated similarly from noise and vibration viewpoint on this edge. With punching holes in the moving party, this stresses can be distributed among the moving surface. On this edge, equal B_t and B_n can make higher tangential force if the flux is entered with 45 degrees angle by changing the shape of the holes. Hole shapes and positions in moving body and rotor position directly affect the produced force. These holes may improve performance in some positions and deteriorate in others and so position of plunger must changed in adequate small steps and in each step the analysis should be done again. Also the number of holes on rotor surface, their distance from surface and their dimensions should be investigated in the same fashion.

Fig 2-c and 2-d show the force component on edge 2. This edge is also divided into ten parts. On this edge normal forces are important in motion and tangential forces can also be investigated for noise and vibration analysis. In this edge, for all shapes of the moving part, the force components are inserted to the first and last part near the corners of rotor. The shapes could not affect on the distribution of force components. Punching some holes near this edge maybe helpful for more force distribution. Decreasing B_t and increasing B_n is the key method for increasing the normal force on edge2.

If these holes can produce forces in several parts of the surface in motion direction, without reducing the forces of effective parts (part 10 in edge 1 and parts 1 and 10 in edge 2), it is be helpful to have higher force density for this device.

Becase of symmetry of this device, force and field component on edge 3 and edge 1 are similar. On edge 4, fields and forces are almost negligible and is not presented.

IV. CONCLUSION

In this paper, a comprehensive analysis of field and force components on a linear reluctance device is presented. Six different shapes of rotor is considered and advantages and disadvantages of each one will be discussed in full version of this paper. With similar studies we can investigate microscopic force effects on other machines. This is of great importance to increase the knowledge of reshaping the electrical machine in order to get higer specific torque or to reduce their noise and vibration.

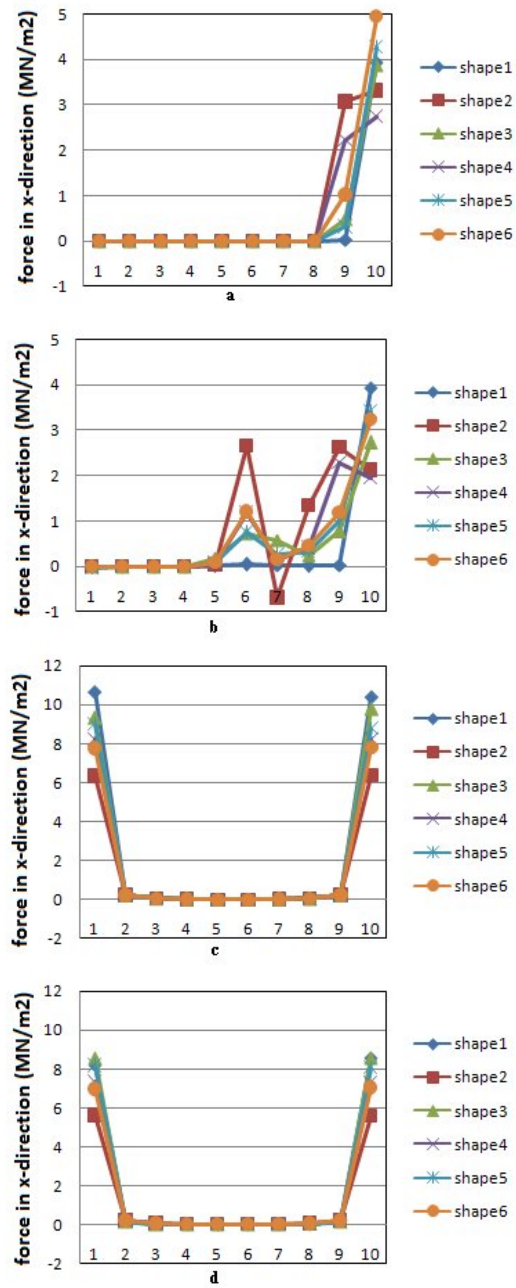

Fig. 2. Force stress in motion direction on edges 1 and 2 in 2 positions.
a) edge1, px=0.5, b) edge1, px= 2.5, c)) edge2, px=0.5, b) edge2,px= 2.5

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