Vibration Research of Magnetically Controlled Saturated Reactor under AC and DC Excitation

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Abstract—Magnetically controlled saturable reactors (MCSRs) operate through changing the saturation degree of the magnetic-valves by applying different DC excitations. Due to the special structure and working mode of AC and DC excitation, the vibration of MCSRs is larger than that of the ordinary ones. It is generally believed that the core material shows different magnetization and magnetostrictive properties under different excitations. Therefore, the magnetization and magnetostriction curves of silicon steel under different DC bias are measured firstly in this paper. Then, an electromagnetic-mechanical coupled numerical model for MCSRs is presented based on the measured constitutive relations. Finally, the magnetic field and vibration of the MCSR under different DC bias are calculated, which provides the theoretical basis for vibration and noise reduction of MCSRs.

Measurements

In order to ensure the accuracy of vibration calculation, the magnetization and magnetostrictive properties under different DC bias of the non- oriented silicon steel are measured by the measurement system shown in Fig. 1. During the vibratiom calculation, the measured magnetization and magnetostriction curves are used.

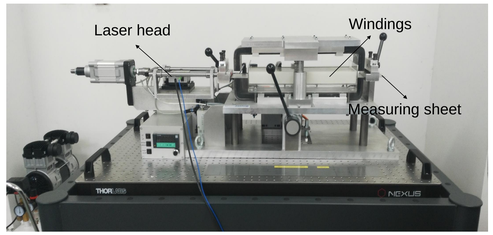

Fig. 1 Magnetization and magnetostrictive properties measurement system schematic diagram

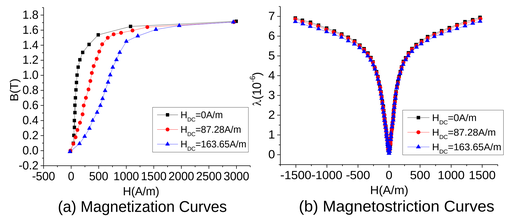

Fig. 2 magnetization and magnetostriction curves of silicon steel under different DC bias

Model

The total energy of MCSRs system consists of the magnetic field energy, the current potential energy, the potential energy on the magnetic field boundary, the magnetostrictive energy and the work of external forces:

$$I=\int_{\Omega_1}\left(\int_0^B \boldsymbol{H}\cdot \mathrm{d}\boldsymbol{B}\right)\mathrm{d}\Omega-\int_{\Omega_1}\left(\int_0^A \boldsymbol{J}\cdot \mathrm{d}\boldsymbol{A}\right)\mathrm{d}\Omega-\int_{\Gamma_1}\left(\int_0^A (\boldsymbol{H}\times\boldsymbol{n})\,\mathrm{d}\boldsymbol{A}\right)\mathrm{d}\Gamma+\int_{\Omega_2}\left(\sigma^T\cdot \mathrm{d}\boldsymbol{H}\right)\mathrm{d}\Omega+\int_{\Omega_2}\left(\int_0^\varepsilon \sigma\cdot \mathrm{d}\varepsilon\right)\mathrm{d}\Omega-\int_{\Gamma_2}\left(f^\Gamma\cdot u\right)\mathrm{d}\Gamma-\int_{\Omega_2}\left(f^\Omega\cdot u\right)\mathrm{d}\Omega$$

Based on the energy variational principle, the magnetic vector potential $\boldsymbol{A}$ and mechanical deformation $\boldsymbol{u}$ can be calculated by minimization of the total energy functional.

A single-phase MCSR is chosen to be studied in this paper, the structure of cores is shown in Fig. 3. The smaller areas of the two center columns are called magnetic-valves. By controlling the saturation degree of magnetic-valves, MCSRs can regulate the reactive power.

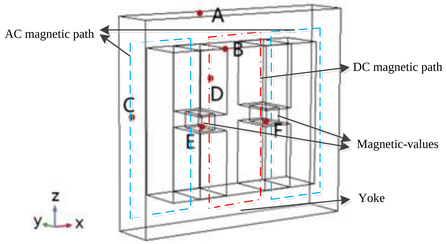

Fig. 3 The core structure of the single-phase MCSR

Vibration Analysis

Fig. 4 shows the magnetic flux distribution of the MCSR under different DC bias . By comparing Fig. 4(a), (c), (e) or (b), (d), (f), it can be seen that the magnetic flux density amplitude of the MCSR increases with DC bias. As shown in Fig. 4(c), (d), (e), (f), the distribution of magnetic flux density is asymmetrical when DC excitation is applied, and the asymmetrical characteristics is more and more obvious with the increase of DC bias. Furthermore, the magnetic flux density in the magnetic-values is bigger than that in other locations.

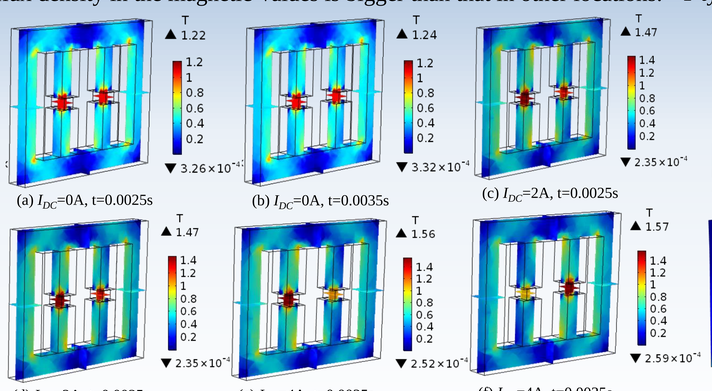

Fig. 4 Magnetic flux density amplitude distribution of MCSR cores

The stress distribution under different DC bias of the MCSR is shown in Fig. 5. By comparing Fig. 5(a), (c), (e) or (b), (d), (f), it can be seen that the stress amplitude of the MCSR also increase with the DC bias. Meanwhile, Fig. 5 shows that the distribution of stress is asymmetrical when there is DC bias, which is similar to the magnetic flux density distribution. Apart from that, the stress concentration areas are located at the magnetic-valves, the surfaces of the lower and upper yokes and the T-type contact surfaces of the columns and the yokes.

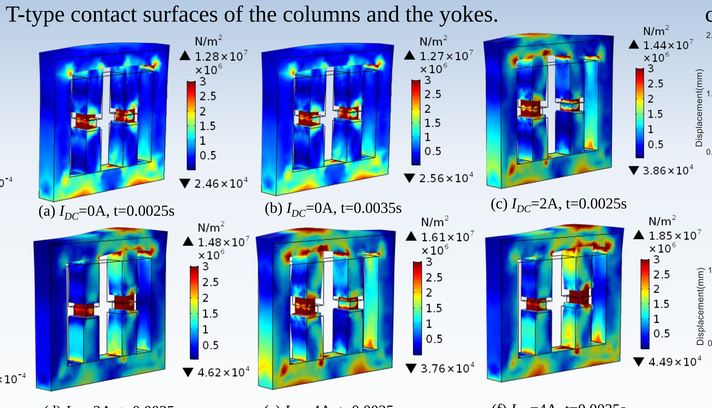

Fig. 5 Stress amplitude distribution of MCSR cores

The locations A, B, C, D, E and F, shown in Fig. 3, are chosen to analyze the influence of different DC bias on MCSR vibration. As shown in Fig. 6, the displacement amplitude increases with the DC bias, and the increase degree of the different parts of the MCSR is not the same. Meanwhile, the periods of vibration is changed from 0.01s to 0.02s gradually with the increase of DC bias. Apart from that, the vibration at magnetic-valves and the T-type contact surfaces of the columns and the yokes is the most serious.

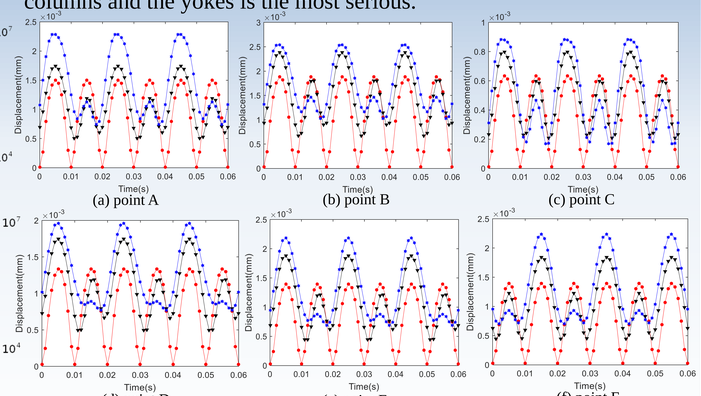

Fig. 6 The relationships between displacement and time under different DC bias

Conclusion

From the computation results, it can be seen that the magnetic flux density, displacement and stress of the MCSR all increase with DC bias, and the increased degree of different locations of the MCSR is not same. Furthermore, the vibration at magnetic-valves and the T-type contact surfaces of central columns is the most serious.. Thus, the vibration reduction work should be concentrated on magnetic-valves and T-type contact surfaces of columns and the yokes.