Application of COMSOL Multiphysics in Thermal Effect Analysis of Electromagnetic Active Vibration Absorber

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Abstract. At present, there are some researches in the thermal analysis of electromagnetic absorbers. The heating principle of electromagnetic absorber magnetic circuit is analysed, and the finite element method is used to numerically solve the temperature field in the working process of electromagnetic vibration absorber. The magnetic circuit simulation model of electromagnetic vibration absorber is established in Comsol Multiphysics finite element analysis software. And the grid Division, simulation analysis of the vibration absorber magnetic circuit structure of the internal temperature distribution, you can get the vibration absorber magnetic circuit in the working process of the temperature field of two-dimensional distribution graphics and magnetic circuit structure of different parts of the temperature rise contrast chart. The conclusion provides some theoretical reference for the design and research of electromagnetic active vibration absorber.

1. Introduction

With the improvement of warship technology, the warship and civilian have been developing rapidly, and they have vibration characteristics due to the presence of power equipment. For warships, reducing hull vibration noise can reduce the possibility detected by the other ship sonar [1], and for civilian, mechanical vibration will affect the comfort of passengers, and further more excessive vibration can even cause machine and instrument equipment disordered, hull structure damage and so on. Dynamic Vibration Absorber is a good method to solve these problems. With the rapid development of computer and the application of fast Fourier transform algorithm, the absorber gradually turns to active vibration absorption. Compared with passive vibration absorption technology, active vibration absorption technology has greater flexibility and adaptability.

According to the different actuators, the active vibration absorber can be divided into the following common types: Electromagnetic power absorbers [2], magnetic levitation type power absorbers [3] and piezoelectric power absorbers [4]. The electromagnetic actuator is a kind of more traditional actuator, the frequency range is wide, and it can control the complex periodic vibration better, and its volume and output force characteristic can satisfy the actual engineering demand of the active vibration absorber.

But the modern vibration problem is more and more demanding for the vibration absorber, which requires the dynamic range of absorbers and the power to withstand more, the frequency response is wider and flatter, and the transient response is better. The vibration absorber is a kind of power exchange energy system, its electric energy converts to the output force, but during the conversion process, most of the electric energy in the current flows through the copper coil when the Joule effect is converted into heat, and the rotor and assembly body generate eddy heat. The coil and the moving subassembly are the heat source of the absorber, which transmits heat through different heat transfer
modes to the surrounding area. It will cause magnetic clearance, magnetic circuit, copper counterweight and shell components such as temperature rise even caused by high-frequency strong circuit coil and magnet overheating damage and other consequences, and usually, the main cause of damage to the absorber is high temperature that caused the magnet failure. So the research on the thermal effect of the absorber becomes very meaningful, and the conclusion provides a theoretical basis for the design and improvement of the electromagnetic active vibration absorber structure.

2. Introduction of Eddy Current effect
The coil is turned into alternating current, then the coil produces alternating magnetic field. As the conductor in the middle of the coil in the circumferential direction can be equivalent to a circle of circuit, as shown in figure 1, so in the direction of the conductor's circumferential can produce induction electromotive force and induced current, and the direction of electric currents along the circumference of the conductor circle is like a circle of the vortex. So in the entire conductor of electromagnetic induction and the occurrence of induction current phenomenon is known as eddy current phenomenon.

![Figure 1. Eddy current effect.](image)

The longer the outer perimeter of the conductor is, the higher the frequency of the alternating magnetic field is, the larger the eddy is.

The eddy currents inside the conductor also generate heat, in line with Joule's law. If the conductor's resistivity is small, then the eddy current is very strong, the heat generated is very big. The thermal effect of the current can increase the temperature of the iron core and the insulating material will be aged easily.

In the process of the electromagnetic active vibration absorber designed in this paper, the alternating current in the stator coil which is the main body of the coil assembly is used to generate alternating magnetic field, and the movement of the core of the actuator in the electromagnetic actuator in the transformation magnetic field inevitably has the problem of electric eddy current heating. These transient temperature fields will have a great influence on the operation of the equipment, what’s worse, the safety of the equipment will have unfavourable effects.

The purpose of the thermal field analysis is to calculate the temperature distributions of the model at different times under a certain frequency of current.

3. Establishment of thermal field model of electromagnetic absorber

3.1. The required theoretical part
While the vortices are formed between each of two baffles and the rear wall, it indicates that the grids result more vortices structure generation, meaning that the baffles make the flow field more complex. Points A~E are the velocity monitoring points during both the simulation of two kinds cavity models, and the velocity of these points are shown in table 1. It obviously shows that the velocity of the slotted hole monitoring points is smaller than the points of the opening hole. The system is solved by the equation of heat transfer equations, and the heat transfer equation is a parabolic partial differential equation, which describes the temperature distributions of specific regions in a given time:

$$\rho C_p \frac{\partial T}{\partial t} - \nabla \cdot (k \nabla T) = Q(T) \quad (1)$$
Among it, \( \rho \) is the density, \( C_p \) is the specific heat capacity, \( k \) is the thermal conductivity, and \( Q \) is induction heating.

The conductivity of copper \( \sigma \) is given by an expression:

\[
\sigma = \frac{1}{\rho_0 (1 + a(T - T_{ref}))}
\]  

(2)

Wherein, \( \rho_0 \) is a reference temperature of 293K resistivity, \( a \) is the temperature coefficient of resistivity, and \( T \) is the actual temperature in the field. The average time of induction heating is given by the following formula:

\[
Q = \frac{1}{2} \sigma |E|^2
\]  

(3)

Wherein, \( \sigma \) is electrical conductivity and \( E \) is electric field strength.

3.2. The establishment of simulation

(1) COMSOL Multiphysics is a finite element analysis software, the so-called finite element method is to divide the continuous model into a finite number of small modules, set up each module of the formula and solve them, then combine them. These modules represent the original model, so we can obtain the approximate solution of the continuous model. The following simulations are performed in Comsol Multiphysics.

Determine the physical field of the simulation: select "Heat Transfer-electromagnetic heat-Induction heating" module. The "Induction heating" interface combines all characteristics of the time harmonic "magnetic field" interface with the "heat Transfer" interface for induction and eddy current heating modeling. This predefined multi-physical field coupling adds electromagnetic power loss as a heat source, and the properties of the electromagnetic material vary with the temperature. This physical field interface is based on the assumption that the magnetic cycle time is shorter than the thermal time scale (adiabatic assumption).

The induction heating interface, a multiple physical field interface, is used to simulate induction heating and eddy current heating, which comprises a magnetic field interface and a solid heat transfer interface. The electromagnetic power loss is defined as a heat source by the preset coupling of multiple physical fields, and the properties of the electromagnetic material vary with the temperature.

Based on different licenses, the two-dimensional support for steady-state and transient simulations. In addition, the Frequency Domain field interface and the steady state solid heat transfer interface coupling, called the frequency domain-steady state, similar also has the frequency domain-instantaneous state and so on.

Constitutive physical Field Interface: The magnetic field interface is used to calculate the magnetic field and the current distribution in the coils, conductors and magnetic bodies. Depending on the license, the two-and three-dimensional support for steady-state, frequency-domain, and time-domain formats. When approaching the steady-state boundary, the frequency and time domain formats become increasingly uncomfortable, and you can extend the frequency range by adding a lower conductivity. The magnetic field interface solves the Maxwell equation using the magnetic vector potential format, and the scalar potential is used as the dependent variable for the coil.

Solid heat transfer is used to simulate heat conduction, convection and radiation. By default, solid heat transfer is activated in all domains, and it can contain other domain types, such as fluid fields. The temperature equation defined in the solid field corresponds to the differential form of the Fourier law and can include other contributions such as heat sources.

(2) Select the preset study of the Physical interface: "Frequency domain-instantaneous state". The frequency domain-transient study is used to calculate temperature variation over time, including the distribution of electromagnetic field in frequency domain. It is used in the model of physical field interface including induction heat, microwave heating, laser heating, inductively coupled plasma and
microwave plasma. For the plasma physical field interface, the temperature represents the electron temperature.

(3) Model establishment: In the research, focusing on the magnetic circuit part of the heat transfer, the rest of the part is not involved in the analysis, so the model only gives the magnetic circuit part. In Comsol Multiphysics, a two-dimensional axisymmetric geometrical model of the magnetic Circuit section shown in figure 3 is established, and the dimensions and specifications are determined according to the kind.

![Image of magnetic circuit model](image)

**Figure 2.** Two-dimensional axisymmetric model of magnetic circuit of electromagnetic absorber.

(4) Add material: According to the physical model of the addition of materials, the main materials are: the addition of circuit board materials to the model, copper coil, air, iron core and coil assembly body. The relative permeability, conductivity and relative permittivity are determined.

(5) Increase physical Field

1) In the “Field” field, add the “Ampere’s Law”: Maxwell-Ampere’s law formula is as follows:

\[ \nabla \times H - \frac{\partial D}{\partial t} = J \] (4)

The amount in the left side of the equation is the physical quantity describing the electromagnetic field, where \( D \) is the electric displacement vector \((C \cdot m^{-2})\), \( H \) is the magnetic field strength \((A \cdot m^{-1})\), and the right is the source of the excitation electromagnetic field, where \( J \) is the current strength \((A \cdot m^{-2})\).

2) Add "multi-turn coil" in “Field” field: Multi-turn coils satisfy the following hypothetical equations

\[ J_e = \frac{NI_{coil}}{A} e_{coil} \] (5)

wherein, \( J_e \) is the external current, \( N \) is the coil turn number, \( I_{coil} \) is the coil current, \( A \) is the coil conductor cross-sectional area, and \( e_{coil} \) is the planar outside unit vector.

(6) Grid division: In the model, due to the different boundary conditions, the process and complexity of each component are different, and in the interior of the magnetic circuit due to different parts, different locations of the structural characteristics and various needs of the solution (such as in small size and the critical position of two regions), the tiny monocular divided is also different. As shown in figure 2, where the structure is simpler and the local change scope is small, the grid is larger, and the grid is smaller where the structure is more complex and the adjacent position varies greatly more meticulous [5].
4. Solution of partial thermal analysis of magnetic circuit

The principle of magnetic circuit analysis has been described in front of the electromagnetic absorber a constant power, heat generation in the iron core caused by eddy current effect in alternating magnetic field, which immediately diffuses through the shell, air and other heat conduction. In the study, the thermal distribution of the electromagnetic actuator is effectively analyzed in the magnetic circuit structure.

In the analysis process, the iron core is the only heat source, heat transfer process contains solid heat transfer and radiation heat transfer. Over time, the temperature of the core gradually increased, heat was diffused into the magnetic circuit system by thermal radiation. Then heat transfer in solid is achieved in the magnetic circuit system. So temperature of the whole system gradually increased. The analysis method of this paper chooses transient thermodynamic analysis, and the general equation of analysis is:

$$[C][\dot{T}]+[K][T]=[Q]$$

In the formula: $[K]$ is the coefficient matrix, including thermal conductivity coefficient, thermal convection coefficient and thermal radiation coefficient and shape coefficient, $[C]$ is the specific heat matrix, considering the increase of energy in the system, $\{T\}$ represents the temperature vector of each node, $\{\dot{T}\}$ is the derivative of the temperature to time of the node, and $\{Q\}$ is the heat flux vector of the node, including thermal generation.

Table of material parameters used in the study:

| Part          | Relative permeability | Conductivity (S/m) | Atmospheric heat Capacity (J/(kg*K)) | Density (kg/m$^3$) | Coefficient of thermal Conductivity (W/(m*K)) |
|--------------|----------------------|-------------------|-------------------------------------|-------------------|---------------------------------------------|
| Copper coil  | 1                    | 5.998e7           | 385                                 | 8960              | 400                                         |

The transient solution is done by setting the required research time, time step and frequency.

The results of the analysis are as follows: The transient analysis by the coupling of multiple physical fields. Figure 4 and figure 5 are the three-dimensional temperature distribution chart of the magnetic circuit structure in 1800s and 3600s respectively, which intuitively indicates that the internal temperature of electromagnetic active vibration absorber is different, as the temperature rises. According to figure 6 and figure 7 respectively, 1800s, 3600s magnetic circuit structure of the two-dimensional contour distribution of the temperature, the temperature of iron core is the highest, and the outer surface is the room temperature 293K (20°C). From the graph and the legend, it can be seen that there are obvious differences in the electromagnetic active vibration absorber’s different parts. Figure 8 is the temperature rise curve of iron core over time.
From figure 4 to figure 8, the current in the simulation is 2 A and the frequency is 40Hz. It can be seen from the graph that the temperature increases gradually as the working time increases, and the temperature grows slowly and tends to stability. When the active vibration absorber continues to work up to 3600s, the electromagnetic part of the heating temperature up to 311K (38°C), when the temperature exceeds 150 degrees, permanent magnet will be demagnetized, and coil insulation layer will melt, so the vibration absorber continued to work 3600s still can maintain a very good working condition.
5. Conclusion
By using the induction heating module in the heat transfer of COMSOL Multiphysics, the thermal effect of the magnetic circuit structure is analyzed and the temperature distribution of different components inside the magnetic circuit structure is obtained. Iron core has the highest temperature, followed by the copper coil. The results require us to consider temperature range when selecting the active vibration absorber material. So that it can get rid of adverse effects on the working state of components caused by too high temperature and burns and other hazards on the operators. The longer the working time, the higher the temperature, so it is necessary to consider the process of cooling the active vibration absorber in the subsequent design process, and create a good working environment. The study of the thermal effect of the magnetic structure of the active vibration absorber provides some reference for the material selection in the production, and has some reference value for the research and development of the active vibration absorber.

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