Research on Simulation of Electromagnetic Field of DC Motor Based on Finite Element Analysis

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Abstract. With the continuous development of science and technology, the magnetic field distribution of DC motors is analyzed based on the finite element theory. These provide a theoretical basis and reliable basis for analyzing the working principle of DC motors and the further development and application of DC motors, establishing a reasonable non-linear model of DC motors, and applying a finite element analysis software to establish a simulation model of the electromagnetic field of DC motors. The characteristics of the electromagnetic field were analyzed during the start-up process, and the analysis results provided a theoretical basis and basis for the further optimization of the electromagnetic field of the DC motor.

1. Introduction

Compared with traditional electric excitation motors, modern permanent magnet motors have a simple structure and reliable operation; high efficiency; compared with recent DC motors and switched reluctance motors, permanent magnet DC motors have simple control systems and are easy to adjust the speed. Therefore, its application range is quite wide, from home appliances, portable electronic equipment, power tools to precision speed and position transmission systems that require good dynamic performance are widely used in DC motors [1].

DC motors are widely used in the fields of precision electronic instruments and equipment, industrial automation and modern household appliances. The study of performance analysis of permanent magnet motors has become a hot issue in the field of motors. Among the DC motor
performance analysis methods, there are DC motor analysis method, state equation simulation method, electromagnetic field analytical calculation method and electromagnetic field finite element numerical calculation method. The finite element numerical calculation of electromagnetic field is widely used in the analysis and calculation of various electrical equipment. It can comprehensively consider the nonlinearity of ferromagnetic materials and the changes of motor parameters. The finite element theory is used to analyze the prototype of the DC motor with complicated magnetic field distribution and changes, and the corresponding principle of the analysis results of the finite element theory is used to reflect the operation principle of the motor.

2. Finite element analysis model of electromagnetic field of DC motor

2.1. Structure and design parameters of DC motor

When a DC motor is running, the electromagnetic field distribution inside the motor is relatively complicated. To calculate this nonlinear magnetic field, the finite element method can be used to calculate the vector magnetic field in the magnetic field [3].

Meshing is the basis of the finite element method. The quality of the meshing not only affects the calculation time, but also affects the calculation accuracy. However, a high-quality grid depends on whether the density of each cell is reasonable and whether there are enough nodes in the grid. The finite element analysis software we use uses triangular mesh elements by default, and adopts a pyramid-shaped meshing setting [4]. Users do not need to participate in meshing to get correct calculation results. During the design process, you only need to set the maximum side length of the grid element to perform adaptive grid division. You can also set the maximum number of grid elements to prevent excessively large division units from occupying memory resources. The size determines the density of the grid. Therefore, when the computing resources allow, the maximum length of the element side is selected for adaptive meshing [5].

\[
\frac{D_{i+1}^2 n_L L}{P} = \frac{P_g}{\alpha_i K_i K_y A B_{ij}}
\]

(1)

\[K_p=0.92+(3.2/W)\]

(2)

\[kB = 2.5 + k_e \sum_{s=1}^{e} \left( \frac{AB_{s} \xi_{s}}{B_{s}} \right)^{a_{h}}\]

(3)

\(D_i\) is the inner diameter of the stator; \(L\) is the length of the iron core; \(n_L\) is the rated speed; \(P\) is the calculated power; take \(1.25 \times P_N = 187.5\) W; \(\alpha_i\) is the polar arc coefficient; \(A\) is the electrical load; \(K_p\) is the air gap magnetic field waveform Coefficient; \(K_{W}\) is the fundamental winding coefficient, concentrated winding is used in this electromagnetic scheme; \(B_{\delta}\) is the average air gap magnetic density, which is mainly determined by the selected permanent magnetic material.

2.2. Selection of magnetic materials

At present, the magnetic materials used in DC motors are mainly ferrite and neodymium iron boron permanent magnet materials. The DC motor can increase the air gap magnetic flux by increasing the thickness of the magnet and the magnetic supply area. The rotor pole is made of relatively weak magnetic material, and the magnetic load is relatively low, which makes the cogging torque and output torque fluctuation of the motor relatively small, which can reduce the noise of the motor and achieve a smoother operation of the motor. Far more than ferrite, more than 10 times the price of ferrite. Therefore, if the size of the motor permits, it is more appropriate to select ferrite as the magnetic material in the permanent magnet DC motor for the fan.
2.3. *Choice of magnet shape and size design*

The installation method of the DC motor on the rotor of the permanent magnet DC motor can be divided into surface mount type and built-in type. In the design, because it is used in a ventilator, the rotation speed is not high. Therefore, considering the manufacturing cost and the complexity of the process, the surface-mounted rotor structure with low cost, simple process and easy to optimize is selected. The finite element analysis software we use uses triangular mesh elements by default, and adopts a pyramid-shaped meshing setting. Users do not need to participate in meshing to get correct calculation results. During the design process, you only need to set the maximum side length of the grid element to perform adaptive grid division. You can also set the maximum number of grid elements to prevent excessively large division units from occupying memory resources. The size determines the density of the grid. Therefore, when the computing resources allow, the maximum length of the element side is selected for adaptive meshing. The maximum number of mesh elements is not set. Set the maximum side length of the unit to 1mm where the magnetic field changes less, such as DC motors, stator and rotor cores of motors, etc., which can be divided larger; set the maximum side length of the unit to 0.1mm where the magnetic field changes greatly, such as The air gap grid of the motor should be densely divided, so that the calculation time can be saved without affecting the calculation accuracy.

![Figure 1. Research on Electromagnetic Field of DC Motor](image)

2.4. *No-load Back-EMF of Electromagnetic Field of DC Motor*

Due to the electromagnetic induction between the DC motor and the armature winding at no load, the no-load back-EMF is generated, which is one of the important parameters of the motor. Because it is not possible to improve the power factor by adjusting the state of the DC motor's electromagnetic field, that is, adjusting the excitation, it is important to select a suitable no-load back-EMF in the motor design process. It can reduce the stator current and the amount of permanent magnet materials. The role of improving the efficiency of the motor provides a reliable guarantee for the optimal design of the later motor.

3. *Analysis of electromagnetic field of DC motor based on finite element theory*

3.1. *Pre-processing stage*

Create a solid model in the finite element theory: pay attention to the selection of the coordinate system, the setting of the system units, especially the unity of the unit when conducting electromagnetic analysis, such as MKS. Because it is a two-dimensional plane analysis of the
electromagnetic field, the unit type is PLANE53. Through the bottom-up modeling and the mapping method after rotating the work plane, the basic geometry is constructed, and then the related operations are used to obtain the required physical model of the motor. Define the material properties: 4 materials need to be defined. Hc needs to be defined by vector, the above-defined material properties are assigned to the corresponding Motor geometric area, and finally, the commands are used to fuse the areas with specific attributes.

3.2. Analysis of electromagnetic field loss of DC motor

The basic iron consumption of the electromagnetic field of the DC motor accounts for 68.46% of the total iron consumption, while the no-load stray loss accounts for 31.54% of the total iron consumption. Among the factors that cause no-load stray losses, the increase in iron loss caused by shear processing accounts for the largest proportion, reaching 56%; the non-sinusoidal distribution of air gap magnetic fields, small hysteresis loops, and stator yoke generated by DC motors The increase of iron loss caused by partial rotation magnetization was the second, which was 40.3%. The proportion of no-load stray losses caused by other factors is small. Among them, the stator, rotor core, and DC motor losses caused by the armature magnetic field generated by the stator no-load current when powered by sine wave voltage are related to the pole slot coordination and air gap length of the motor; The partial leakage magnetic field and the end leakage magnetic field generated by the no-load current generated by the sine wave voltage supply cause small losses in nearby metal structures, which is related to the structure of the calculated motor using an aluminum casing and an endless pressure plate. 3) According to the location of the no-load stray loss, the no-load stray loss in the stator core of the motor is about 53.2W, which accounts for nearly 96.8% of the total no-load stray loss; DC motors, rotor cores The loss is 1.5W, which accounts for 2.7% of the total no-load stray loss; the rest is the loss in the metal structure of the motor, which is only about 0.05%.

3.3. Simulation study of DC motor

Simulation research: Simulation is an important step in the finite element calculation process, and it directly affects the accuracy of the calculation. The denser the mesh, the higher the accuracy of the solution, but the more time it takes to process. The finite element theory provides an intelligent meshing tool that can automatically control the meshing, automatically encrypt at the air gap, and obtain a relatively satisfactory required accuracy.

3.3.1. Simulation analysis of DC motor. Adding boundary conditions: Imposing boundary conditions on the outer diameter of the casing and the inner diameter of the armature satisfies the first type of boundary conditions, that is, the finite element theoretical boundary conditions. Loading: According to the winding connection of 4 pole 16 slot permanent magnet DC motor, add the current calculation in the corresponding rotor slot to get the current density. For example, add negative current density on
plus positive current density. The windings in the other slots are on the geometric neutral line, so the current density is zero. Solution: The finite element theory provides three solvers, a wavefront solver, a conditional conjugate gradient (PCG) solver, and a Jacobian conjugate gradient solver. Among them, for solving models, wavefront solvers are commonly used, and the other two are more suitable for solving large models.

**Figure 3.** Simulation Modeling of Electromagnetic Field of DC Motor

3.3.2. Flow motor simulation post-processing stage. The post-processing results can be obtained through post-processing and calculated. The finite element theory provides powerful post-processing functions, such as magnetic field lines, contour lines, vector display, magnetic force, and magnetic torque can all be obtained by post-processing or calculation, especially the path operation can be performed through the general post-processor, which is about to be required. The field quantity is mapped to a specified path, and the air gap magnetic flux density of the electromagnetic field is distributed along the circumferential direction of the air gap. The abscissa is the length in the circumferential direction of the air gap, and the ordinate is the air gap magnetic flux density value. The armature response at load reduces part of the air gap magnetic density; it can also be seen that an approximate sinusoidal waveform can be obtained after excluding each harmonic.

**Figure 4.** Graphic analysis of electromagnetic field simulation of DC motor
3.4. DC Motor Simulation Summary

Through the finite element analysis of the electromagnetic field of the permanent magnet motor, the magnetic field lines of the motor are evenly distributed, and the magnetic leakage phenomenon is less obvious, which meets the design requirements and is more reasonable. It can be seen from the color distribution that the magnetic density of each part of the motor is strong, the magnetic field is strong around the air gap, the magnetic leakage phenomenon of the motor is not obvious, and there is no local oversize phenomenon in each part. Through the finite element analysis of the transient electromagnetic field of the permanent magnet DC motor under no-load and load, the simulation results have obtained the magnetic force lines, magnetic flux density, reluctance torque and back-EMF curve diagrams. The electromotive force and winding current are analyzed, which can reduce the electromagnetic torque ripple caused by the number of stator slots and the cogging effect, which can greatly improve the design accuracy of the motor and provide a scientific and powerful basis for optimizing the design of the motor.

![Figure 5. Simulation Research on Electromagnetic Field of DC Motor Based on Finite Element Analysis](image)

4. Conclusion

We have established a simulation model of the DC motor and completed the simulation study of the DC motor. The simulation results accurately reflect the magnetic field lines, magnetic flux density, and current density distribution of the DC motor, and provide a basis for further design and research of the motor. After the finite element theory analysis and post-processing, the important parameters of the motor can be obtained intuitively, and the starting process of the motor is simulated, which is in line with the actual operation law. These studies have certain practical significance for reducing the design cost of permanent magnet motors in the later stage, reducing vibration during startup, reducing operating noise, and improving motor performance and efficiency. The results obtained by the application of finite element software analysis not only ensure the high accuracy of the finite element analysis, but also greatly reduce the calculation amount, which has great theoretical reference value for subsequent work.
References

[1] Li Qunnv, Zou Jingxian, Zhang Zehui. Optimal design of DC moto. Journal of Shanghai University of Electric Power, 2016, 6, 23, pp. 15-21.

[2] Liu Ruifang. Research on performance analysis method of permanent magnet motor based on numerical calculation of electromagnetic field. Nanjing: Southeast University, 2016, 6, 23, pp. 12-16.

[3] Chen Yunyun, Zhu Xiaoyong, Quanli, et al. Optimal design and performance analysis of doubly salient permanent magnet dual stator motor based on parameter sensitivity. Journal of Electrical Engineering Technology, 2017, 10, 14, pp. 160-167.

[4] Chen Yunyun, Quan Li, Zhu Xiaoyong, et al. Optimal design of double salient-pole permanent magnet dual-rotor motor and analysis of its electromagnetic characteristics. Chinese Journal of Electrical Engineering, 2018, 5, 12, pp. 1912-1921

[5] Liu Ruifang, Yan Dengjun, Hu Minqiang. Time step finite element analysis of field-circuit coupling motion of permanent magnet brushless DC motor. Chinese Journal of Electrical Engineering, 2017, 4, 10, pp. 59-64