Computer aided design of amorphous alloy permanent magnet motor

Ping Chen¹, Tingting Qi², Ning Zuo³ and Zexuan Wang⁴

¹Civil Aviation College, Shenyang Aerospace University, Shenyang, Liaoning, 110136, China
²Civil Aviation College, Shenyang Aerospace University, Shenyang, Liaoning, 110136, China
³Civil Aviation College, Shenyang Aerospace University, Shenyang, Liaoning, 110136, China
⁴Civil Aviation College, Shenyang Aerospace University, Shenyang, Liaoning, 110136, China

Corresponding author’s e-mail: 20160020@sau.edu.cn

Abstract. Amorphous alloy is a kind of double green soft magnetic material with high saturation magnetic induction, low coercive force, low loss, high stability and other excellent properties. Instead of cold rolled silicon steel sheet, it can reduce the loss and improve the efficiency of the motor to a great extent. Combined with the characteristics of amorphous alloy and based on the design theory of permanent magnet motor, this paper uses the MATLAB software to write the electromagnetic design program of amorphous alloy permanent magnet synchronous motor, which has the characteristics of visual parameter input, rapid electromagnetic calculation, and convenient man-machine interaction. An example is given to verify the reliability of the program.

1. Introduction

In recent years, environmental problems have become increasingly serious, and it has become a global consensus to practice the concept of energy conservation, emission reduction, green and low-carbon sustainable development. For motors, improving the manufacturing process and developing stator and rotor with new materials are important steps in the manufacture of energy-efficient motors[1]. Amorphous alloy material, with its excellent soft magnetic properties, can be used as the motor core instead of silicon steel sheet, so as to realize the design requirements of high efficiency, energy saving and lightweight of motor, which has become a research hotspot at home and abroad[2]. Liu et al.[3] used the finite element analysis method to analyze the amorphous alloy and silicon steel motor in detail, and the results showed that the use of amorphous alloy material can reduce the loss and improve the efficiency. S. Okamoto et al.[4] measured the core loss of amorphous alloy motors by experiment and numerical calculation. The results showed that the core loss can be reduced by about half compared with the conventional stator using silicon steel plates.

The properties of amorphous alloy are different from those of silicon steel sheet, so it is necessary to redesign the electromagnetic design part of amorphous alloy motor. P.R. et al.[5] put forward a program for designing the computer sub-account of the radial flux permanent magnet motor and
verified the accuracy of the program by using finite element analysis. Mazgaonkar, N. et al.\cite{6} designed the motor using electromagnetic coupling and analyzed and optimized it using the global response surface method.

In this paper, MATLAB software is used to program the amorphous alloy electromagnetic calculation program, and APP Design module is used to achieve visual input of parameters, which is easy to operate and convenient for human-computer interaction.

2. About amorphous alloy motor design

2.1. Properties of amorphous alloy materials

The amorphous alloy adopts ultra-rapid cooling and solidification technology, which can directly cool from high-temperature liquid steel to amorphous thin strip products at the rate of millions of per second. The atoms are arranged orderly too late when the alloy solidifies, so that the solid alloy is a long-range disordered structure. This special structure makes it have excellent magnetic properties, mechanical properties and corrosion resistance\cite{7}. The saturated magnetic induction intensity of amorphous alloy is close to that of silicon steel sheet, at the same time, permeability and resistivity is far higher than that of silicon steel sheet, when frequency increasing, silicon steel sheet of the motor magnetic meeting sharply reduced, and the iron base amorphous alloy decrease the amplitude of small to ignore, this shows that the frequency of the larger application places using iron-based amorphous alloy stator core has more advantages\cite{8}.

In the electromagnetic design program of amorphous alloy permanent magnet motor, the magnetization curve and loss characteristic curve of amorphous alloy material need to be consulted. In this paper, interpolation method is used to fit the characteristic curve. As shown in Figure 1 and Figure 2.

![Magnetization curve of amorphous alloy](image1.png)

![Amorphous stator loss curve](image2.png)

Figure 1. Magnetization curve of amorphous alloy

Figure 2. Amorphous stator loss curve

2.2. Electromagnetic design method

The main tasks of permanent magnet synchronous motor electromagnetic design include determining motor rating parameters, selecting permanent magnet material and permanent magnet rotor magnetic circuit structure, designing stator and rotor dimensions and winding design. Then use the formula for the initial design scheme for performance check and adjust some design parameters of the motor, until the motor electromagnetic design conform to the requirements of the technical and economic indicators\cite{9}.

At present, the electromagnetic calculation methods for PMSM mainly include equivalent magnetic circuit method, equivalent magnetic network method and finite element method. Xu et al.\cite{10} proposed a simple and accurate magnetic field calculation model for three-phase 12/10-pole AFFSPM motor design.
based on equivalent magnetic circuit method. Zhang et al. established an equivalent magnetic network model for a new transversal flux permanent magnet synchronous motor, and converted the three-dimensional magnetic circuit of the transversal flux motor into a two-dimensional one, thus simplifying the calculation process of the magnetic circuit. The calculation results of time-step finite element method are accurate, but in the early stage of design, the design parameters need to be adjusted frequently, which takes a long time. In this paper, the equivalent magnetic circuit is chosen as the basic method for electromagnetic design of amorphous motor. Magnetic circuit method has the advantages of simple model and quick solution, which is of great reference value in the early stage of motor design.

The equivalent magnetic circuit model of permanent magnet motor equates the permanent magnet to the source of magnetomotive force, deduces the equivalent circuit, and establishes the analytic formula expressed by the per-unit value, which can simplify the expression and make analysis more convenient. Figure 3, Figure 4 shows the equivalent magnetic circuit in terms of a per-unit value.

![Figure 3. Magnetic flux source](image)

![Figure 4. Magnetomotive force source](image)

When analyzing the equivalent magnetic circuit, when the magnetic circuit of the permanent magnet is unsaturated, the no-load and load working points of the permanent magnet can be directly solved by simultaneous equations, and then the magnetic flux value of each part can be obtained. The formula is as follows:

Total flux provided by permanent magnet:

$$\Phi_{m0} = h_m B_r A_m \times 10^{-4}$$  \hspace{1cm} (1)

Magnetic flux leakage:

$$\Phi_{\sigma0} = h_m \text{\sigma}_m B_r A_m \times 10^{-4}$$  \hspace{1cm} (2)

Air gap flux per pole:

$$\Phi_{\delta0} = \frac{b_m B_r A_m}{\text{\sigma}_m} \times 10^{-4}$$  \hspace{1cm} (3)

Where, $h_m, h_m$ is the no-load working point of the permanent magnet; $B_r$ is the remanence density; $A_m$ is the cross-sectional area of each magnetic flux; $\sigma_m$ is the no-load magnetic leakage coefficient.

Under normal circumstances, the magnetic circuit of the permanent magnet is saturated, and then the iterative equation should be used to solve the problem.

3. **Amorphous alloy electromagnetic design software**

3.1. **Input Interface design**

In the process of amorphous alloy motor electromagnetic design, need to enter as many as dozens of initial design parameters, the computer in this article, the input parameter to classify organizations, in accordance with the regulations of the design personnel to establish three input interface, including
rated data and technical requirements, input interface, the stator and the rotor parameter input interface. Take the stator parameter input interface as an example, as shown in the figure 5. The slot type can be selected by the drop-down frame, and the slot size of the stator can be input according to the slot type schematic diagram.

3.2. Data output Settings
Electrical engineers want to get graphic and report displays an intuitive design result. For this purpose, the designed program data output part is stored in the form of TXT file. Add the callback function of the calculation button, create a new text file using the fopen function, and use the fprintf function to write the data to the text file.

4. Application instance
The electromagnetic calculation program of amorphous alloy designed in this paper is applied to carry out electromagnetic calculation on an amorphous alloy permanent magnet motor. The rated parameters of the motor are shown in Table 1. After input the rated parameter and the main dimensions of the motor on the parameter input interface, the motor can be calculated by calculation. Program execution end, the calculation results in the form of TXT text output, can be directly accessed. The calculated results are shown in the table 2. The results show that the design meets the performance requirements.

| Table 1. Motor rating parameter |
|--------------------------------|
| **Rated power** | **Number of phase** | **Rated line voltage** | **Rated frequency** | **Number of poles** | **Rated efficiency** | **Rated speed** |
| 15kW | 3 | 380V | 50Hz | 2 | 93.5% | 1500r/min |
Table 2. Calculation result

| Stator tooth magnetic density | Stator yoke density | No load counter emf | The total loss | The output power | Efficiency |
|------------------------------|--------------------|--------------------|--------------|-----------------|------------|
| 1.4891T                      | 1.4904T            | 226.52V            | 959.85W      | 13037W          | 93.15%     |

5. Conclusion

In this paper, according to the characteristics of amorphous alloy materials, using the method of equivalent magnetic circuit of amorphous alloy motor electromagnetic calculation. With the help of APP design module of MATLAB software, amorphous alloy electromagnetic design APP was developed, which finally realized an APP with convenient human-computer interaction, fast calculation and independence from the desktop. The accuracy of the electromagnetic Design program through examples, provide reference for the Design of the amorphous alloy permanent magnet motor.

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