Design of a Single-phase Asynchronous Motor under the Wide Voltage and Realization of MATLAB Program

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Abstract. In a single-phase power supply system with the relatively large range of voltage fluctuation, an ordinary single-phase asynchronous motor is difficult to run normally. In order to solve this question, a new type of single-phase asynchronous motor running in the wide voltage range is proposed. In this paper, the design of a single-phase asynchronous motor with the wide voltage operation is analyzed theoretically. MATLAB design program for general wide voltage single-phase asynchronous motor is given, and then the practical application of the program is verified by examples.

1. Introduction

The single-phase capacitor starting and running asynchronous motor needs to run in the single-phase power supply, with the advantages of simple structure, low cost and low noise, and has good starting and running performance, high power factor and efficiency characteristics. It’s widely used in industrial and agricultural production and people's daily life. In the remote areas, far from the power supply center, the power supply quality is poor and the voltage fluctuation is very big, so that the motor cannot run normally and is even burned in low voltage. Therefore, the asynchronous motor which can run in the wide voltage range is not only a great development potential, but also has considerable economic and social benefits.

The voltage regulator and other stable voltage devices are proposed in the paper [1], but it is uneasy to be popularized and difficult to guarantee the motor run normally, because the voltage regulator also has a voltage operating range, and its capacity is three times than that of the motor power, and the price is very expensive. A voltage adjustable single-phase motor with some taps in the main coil is given in the paper [2], which can be controlled by mechanical type shift switches. The motor can run normally in different power supply area, but the structure of the motor is complex, and it is difficult to be widely used in the application.

In this paper, similar to common single-phase motor in the structure, the single-phase capacitor starting and running asynchronous motor has a new winding structure with high efficiency, high power factor and other characteristics, to make it run in the wide voltage better. Combined with the structure of the motor, the design theory is given in the paper. To extend the application of the single phase motor running in the wide voltage, the electromagnetic design program of the motor is written, the design of the motor running in the voltage between 140V and 260V and the power of 750W, is given in the paper to provide support for it.

2. Motor design

To guarantee the motor running in the wide voltage range, its starting torque multiples should be greater than 0.8, and the magnetic field distribution between the motor air gap and stator or rotor yoke should be reasonable, the current of the main winding and auxiliary winding should be not more than the maximum current of the line.

2.1 Motor winding

If the single-phase capacitor starting and running asynchronous motor had equal magnetic

potential between the main winding and auxiliary winding and the current phase difference were 90 degrees, the magnetic field of the motor would be round. At this time, the motor harmonic magnetic potential is minimal, but the main winding and auxiliary winding current is changing with the change of the motor load. Compared with three-phase motor, the magnetic field of the single-phase asynchronous motor is an elliptical magnetic field and has more harmonics. In order to effectively weaken and even eliminate the high harmonics of the elliptical magnetic field, a special winding is given in the paper to improve the starting and running performance of the motor. The Y2-225S-4 motor with the concentric winding and a special form of sine winding at the same level of performance are designed respectively, core, wire gauge, the number of series conductor per pole is equal [3]. The comparison of motor performance is shown in table 1.

Table 1 Performance comparison between a special form of sine winding and the general winding

motor performance	efficiency /%	power factor /%	blocking torque /multiple	temperature /K	noise /(dB(A))	vibration /(mm/s)	wire weight /kg
general winding	92.06	87.48	2.08	78.44	83.9	2.6	23.15
sine winding	92.11	86.77	2.49	66.10	83.5	2.4	21.05

From table 1, it can be seen that the special sine winding can not only effectively reduce the high harmonics of the air gap magnetic field and improve the efficiency of the motor, but also its temperature, noise and vibration have some improvement. In addition, in the case of the same structure, the copper content of the motor windings is reduced by nearly 10%, which effectively reduces the manufacturing cost of the motor. The torque of the motor is much higher than the common winding, which is advantageous to the motor running in the wide voltage range.

2.2 Number and groove of stator and rotor of motor

The influence of the stator and rotor slot of the squirrel cage asynchronous motor is analyzed in the paper, concerning on the synchronous additional torque, the asynchronous additional torque, the additional loss, the electromagnetic vibration and noise [4]. A complete summary of the number of stator and rotor slots for some common small single phase induction motors is given. Taking into account all aspects of factors, the better groove matching of stator and rotor in bipolar single phase motor includes 18/12、24/17、24/18、24/30、24/31, that of four polar includes 24/16、24/30、36/26、36/42、36/44.

The number of stator slots should be firstly chosen before choosing the groove matching of rotor and stator. Generally speaking, the slot number will be increased with reduction of the leakage reactance of induction motor, and harmonic magnetic field has also weakened, which is favorable for the performance of the motor. If the stator had too much slots, the slot insulating would occupy more space, leading to high tooth flux density, and the motor performance would become poor. In addition, the slot pitch of the motor become small, die hard, the mechanical strength becomes lower, easy to damage. For the rotor, the rotor vortex is reduced gradually by increasing the number of slots, but the number of slots must be matched with that of the stator. The choice of motor groove is mainly depended on the power, efficiency and power factor of the motor. For the micro motor, the stator and rotor slot of the motor generally chooses the parallel teeth pear shaped groove.

3. Theoretical analysis

The motor can run at the low voltage, it should have a relatively large starting and maximum torque at rated condition. According to the knowledge of the motor, the maximum torque of the motor is

$$T_m = \pm \frac{m_1 p}{\omega_1} \cdot \frac{U_1^2}{2c_1[\pm r_1 + (x_1 + c_1 x_2^{'})^2]} \quad (1)$$

The starting torque of the motor is

$$T_{st} = \frac{m_1 p}{\omega_1} \cdot U_1^2 \cdot \frac{r_2^{'}}{(r_1 + c_1 r_2^{'})^2 + (x_1 + c_2 x_2^{'})^2} \quad (2)$$

In the above equation, U_1-phase voltage; r_1, $r_2^{'}$, x_1, $x_2^{'}$-phase resistance and leakage reactance of the stator and rotor; m_1-phase number; ω_1-synchronous angular frequency; p-pole number of motor; c_1-correction factor.

In general, the motor winding resistance value is relatively small, its influence is small for the torque of the motor. According to above equation (1) and (2), in the case of the same power supply voltage, frequency, motor phase number and frequency, the maximum torque and the rated torque of the motor will become smaller, because of the greater the maximum torque and rated torque. By the equation (2), in a certain range, the starting torque is increased by increasing the rotor resistance. Therefore, the leakage reactance and resistance value of the stator and rotor can be changed by changing the structure of the stator and rotor of the motor. In addition, the rotor chute structure can effectively restrain harmonics, improving the motor starting and operation performance.

4. Program design

The motor design program is a large and complex engineering, and the single -phase double value capacitor asynchronous motor running in the wide voltage is more complex, so a process of the MATLAB electromagnetic design program is from easy to difficulty, and gradually improving. The motor design procedure is mainly composed of the main and some subroutine programs [5].

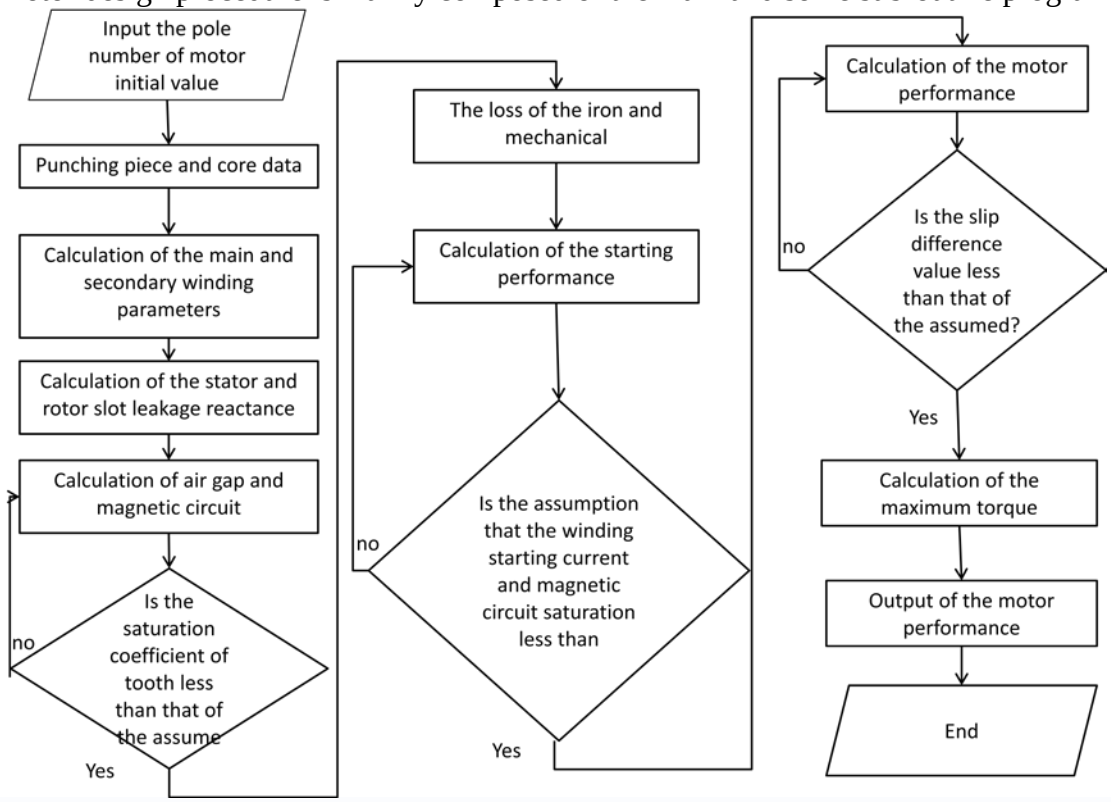

Fig. 1 Electromagnetic calculation process for the single-phase double value capacitor induction motor in the wide voltage

According to the flow chart, the accuracy of the main program is ensured by the calculation of the case. Different from the ordinary single-phase double value capacitor asynchronous motor, the design of the motor running in the wide voltage is different between the rated voltage and the

running voltage. In addition, when calculating the starting and running performance of the motor, it is necessary to pay special attention to distinguish between the starting capacitor and running capacitor.

The subroutine is built to realize the computer to handle the curves or charts of the processing, including the relevant data of the query, the curve drawing, the input and output functions, etc. For the calculation of the magnetic flux leakage of the stator and rotor and the choice of the sinusoidal winding scheme, obtained by the complex mathematical formulas, it can be expressed by the original mathematical formulas. For like silicon steel sheet magnetization curve, they cannot use mathematical formula accurate expression, the interpolation function can realize the objective by the similar points in the experience or experimental data. The wire specification has the corresponding national standard, its diameter and the cross section can be obtained by the approximate query.

The calculating results of the program can be directly generated by the file read and write I/O command function. For a variable that needs guarantee the small error between the assumption and the saturation coefficient of the tooth, the MATLAB of the while..... end is used in the loop statement control, the loop statement and if determine is also achieved [6].

5. Case calculation

According to the manufacturer's requirements, the single-phase double value capacitor asynchronous motor, designed to the motor with the power 750W, the rated voltage 220V, can run in the voltage 140V and 260V, and the relevant indicators meet the national requirements. According to a single-phase asynchronous motor with the similar power, the motor stator is selected as 36 slots, the rotor is 44 slots, the pole number is 4 poles, and the stator slot is selected as the parallel slot. The winding form is selected as a special form of sinusoidal winding.

After the repeated testing, the main dimensions of the single-phase double value capacitor asynchronous motor are determined: the stator outer diameter is 89.5mm, the inner diameter is 89mm, the outer diameter is 23mm, the inner diameter is 152mm and the stator core is 84.5mm. Under the premise of ensuring the rated output power, when the motor running in the 140V voltage, its starting torque is 0.88, the maximum torque is 1.08, which fully meets the requirements of the motor soft start. When running in the 260V voltage, its starting torque is 3.09, the maximum torque is 4.13. Through the performance calculation of the motor, it can reliably run in the voltage range between 140V and 260V, and the main and auxiliary winding currents meet the national standard GB/T4706.1-2005 wire load current value, other performance index can also meet the national standards. The mechanical properties of the single phase double value capacitor asynchronous motor at three voltages are shown in Figure 2. From the diagram, it can be seen that the mechanical characteristics of the designed motor are basically consistent with the simulation results.

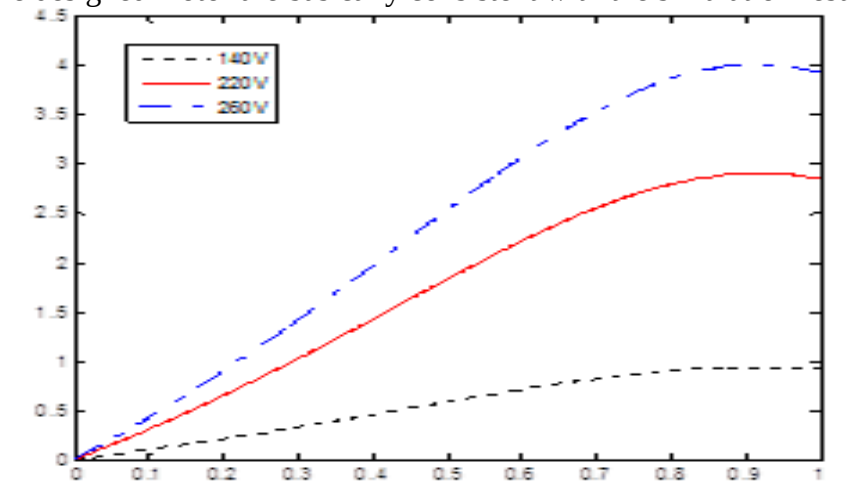

Fig. 2 Mechanical properties of the single phase double valued capacitor asynchronous motor

6. Summary

The computer aided design is an inevitable trend of the motor design. Because of the specific characteristics of the motor structure, the complexity of the magnetic field and the special requirements of the motor performance, It is determined that the design can be accomplished only by means of computer language. The influence of the new type sine winding of the motor is analyzed and the design of the single-phase asynchronous motor is studied in this paper. The whole design idea of MATLAB programming is given in the paper. The example analysis shows that the program has good practical value.

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