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Impact research of inverter power supply on the vibration noise source of the permanent magnet motor

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ABSTRACT

Popularization and application of the permanent magnet motor in all fields at such an alarming rate in recent years have been fundamentally resulted from high-speed advancement of power microelectronics industry, new motor control theory, power electronics technology and earth permanent magnet materials. Permanent magnet synchronous motor is endowed with high efficiency, low wastage, and power-saving, especially when compared with rare earth permanent magnet synchronous motor (REPMSM) and traditional electro-magnetic synchronous motor. Inverter, as the power control equipment to control alternating-current motor, can generally be operated by alteration of power supply frequency. When permanent magnet motor is powered by inverter, certain adverse effects can be generated on its vibration noise source, and experimental study has proved that inverter power supply is the largest origin of vibration noise source of permanent magnet motor. To find out the specific degree of influence and characteristic relation between them, the study has firstly introduced theoretical knowledge of permanent magnet synchronous motor, inverter and formula of air-gap field, then accomplishing the formula of spectral analysis and primary harmonic frequency by way of finite element calculation (FEM) and measured air-gap field, and afterwards taking permanent20KW disc magnet synchronous motor as object of study, three-dimensional concrete sound field data of disc permanent magnet motor and permanent magnet motor noisy data when powered by inverter can be calculated by finite element calculation (FEM), which lays a foundation for solution to problem of this kind in the future.

KEYWORDS

Permanent magnet motor; Inverter; Vibration noise; Finite element calculation (FEM); Three-dimensional sound field.

INTRODUCTION

The inventory of the motor in our country is considerably immense, but its required great power consumption and aging of equipment lead to increasingly lower efficiency of the motor, Nevertheless, permanent magnet synchronous motor has been growingly applied to various fields thanks to its abundant advantages, such as extremely high efficiency, relatively small volume, high power factor, great starting torque and good force and power indicators and temperature rise of low grade. permanent magnet synchronous motor, its excitation mainly provided by permanent magnet, enables the structure of the motor more simple and practical, with much cost of machining and assembly reduced, making potentially similar troublesome components of collecting ring and brush unnecessary, which on one hand, the operational reliability of the motor has been improved a great deal, and on the other hand, permanent magnet motor has enabled gradual elevation of the motor efficiency and power density with no exciting current and excitation loss. However, great many adverse factors[1] would occur in vibration noise source of permanent magnet motor when it is powered the inverter, and test has indicated that plenty of time-harmonic would be produced by stator current of permanent magnet when powered by the inverter, thus there exists plentiful harmonic in air gap magnetic field.

Because asynchronous motor is applied in large quantities before, most study on motor vibration noise focus on asynchronous motor, resulting in less study on permanent magnet synchronous motor[3, 4]. Currently, there are generally two approaches to the study on vibration noise of permanent magnet motor: analytical method and numerical simulation. For instance, pulse width modulation (PWM) control method, put forward by the American scholar, can perfectly reduce the noise of the permanent magnet motor[5]. This study adopts the analytical method, figuring out the formula[6] of air-gap magnetic field and harmonic frequency of permanent magnet motor in a definite manner.

THEORETICAL KNOWLEDGE

Inverter

The voltage and frequency standard of alternating current power supply employed in every country, either for homes or plants, is generally 200 v / 60 Hz (50 Hz) or 100 v / 60 Hz (50 Hz) and so on. Inverter is a device which converting alternating current of fixed voltage and frequency into the alternating current of variable voltage and frequency in accordance with the requirements. Sure enough, in order to produce the variable voltage and frequency, the equipment must firstly convert the alternating current of power supply into direct current (DC). The scientific term of the device converting direct current (DC) into alternating current (AC) is called inverter. the main device enabling variable voltage or frequency is “inverter”, thus the product itself is named “inverter”, that is, the so called “frequency converter”, which can not merely be applied in industrial production, but also in home appliances like motor (such as air conditioning, etc.), as well as fluorescent lamp, etc. Inverter for motor control can not only change voltage, also its alternation frequencies, while Inverter for fluorescent lamp is mainly used to adjust the frequency of power supply. The device for alternating current generation through the cell (direct current) installed in cars is also sold in the name of "inverter”. Working principle of the inverter is widely used in various fields, such as the computer power supply, and in the application, inverter is used to suppress the reverse voltage, power frequency fluctuation and the interruption of power supply at a certain moment.

The reason why inverter can convert operating frequency power supply into another frequency mainly lies in the fact that taking advantage of on-off power control device of power semiconductor, it can change the motor speed by adjusting the frequency, therefore also named variable voltage and variable frequency. In terms of the number of inverter, the growth rate of China's market maintains at 12-15%, and also it can be predicted that such a stable10% growth will continue at least until the next five years.

Inverter is usually made of four parts of rectifier, and source inverter, controller and high capacitance. The specific function of each part is shown in TABLE 1 and system frame of inverter is as follows in Figure 1.

TABLE 1 : Functions of each part in inverter

Functional parts	Role
rectifier unit	Convert To alternating current of fixed working frequency into direct current
High capacitance	Store electric energy after conversion
Source inverter	Constitute electronic switch by collective tube array of high power switch, and convert direct current into square waves of different frequency, width and amplitude
Controller	Operate in line with the set procedures, control amplitude and pulse width of output pulse and enable motor driving by overlapping alternating current of approximate sine wave.

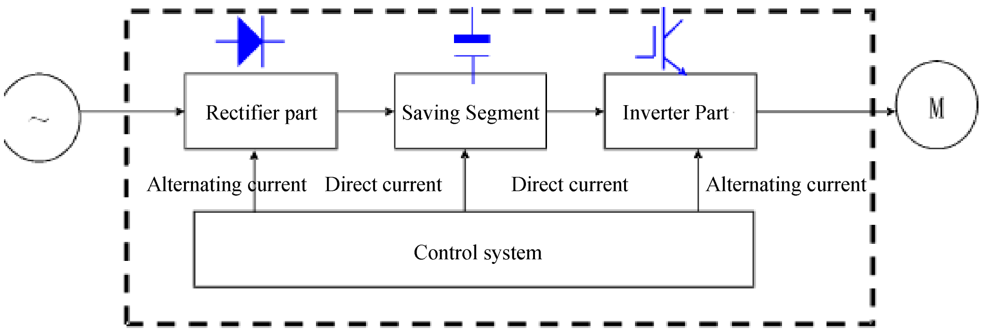

Figure 1 : Inverter system frame

Permanent magnet synchronous motor

Synchronous motor is alternating current motor, with the same stator windings with asynchronous motor. The reason why it is called synchronous motor consists in fundamentally consistent speed of rotor rotating of synchronous motor with that of rotating magnetic field generated by stator windings. There are in general three kinds of operation mode in synchronous motor: operations of generator, motor and compensator. Synchronous generator is widely applied in the modern hydropower, thermal power and nuclear power, while compensator and synchronous motor are also popularized in industrial and mining enterprises and power system.

The biggest difference between permanent magnet synchronous motor and common asynchronous motor can be rotor structure, for magnet pole is installed in the rotor of permanent magnet synchronous motor. Permanent magnet pole is installed on the circular surface of rotor iron core, known as the salience-type permanent magnet rotor. According to the principle of minimum reluctance, namely, the magnetic flux always close along the path of least resistance. By virtue of rotor rotation pulled by magnetic attraction, permanent magnet rotor will synchronously rotate with the rotating magnetic field produced by stator, but permanent magnet synchronous motor cannot directly start three-phase alternating, and the static rotor cannot never follow the rotating of magnetic field due to large rotor inertia and high-speed of magnetic field rotating. The permanent magnet synchronous motor, primarily used in frequency control, with the inverter output frequency from 0 ascending to working frequency when get started, the motor conducting synchronous rotation in line with inverter output frequency, is an excellent choice of variable frequency control motor.

Three-phase winding of permanent magnet synchronous motor is distributed on the stator, permanent magnet installed on the rotor. In the process of permanent magnet synchronous motor running, the stator and rotor remain the relative motion state all the time, and interactions between permanent magnet and windings, and among windings emerge, with complicated electromagnetic relations. Permanent magnet synchronous motor is powered by sine waves or square waves, setting up magnetic field by permanent magnet, with excellent high torque inertia ratio and high energy density[7]. Component of permanent magnet synchronous motor: stator (usually in the form of three phase winding), permanent magnetic steel rotor (main materials of NdFeB), position sensors, electronic transfer switch, etc., and the basic structure of permanent magnet synchronous motor is in Figure 2.

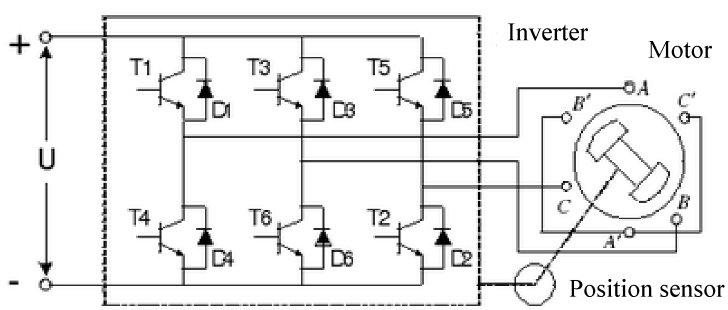

Figure 2 : Structure of permanent magnet synchronous motor

As can seen from the figure, there is a difference among magnetic circuit structure for specific duty of permanent magnet synchronous motor and other motors, which results in lots of distinctions between operating characteristics of the motor and control system. In general, based on the distinguished position of the permanent magnet on the rotor, permanent magnet synchronous motor can be basically divided into: surface permanent magnet synchronous motor and interior permanent magnet synchronous motor.

In terms of the surface permanent magnet synchronous motor, permanent magnet usually is located in the outer surface of the rotor core in tiles form, with significant characteristics of the equal main inductance of direct axis to quadrature axis ; while the permanent magnet of interior permanent magnet synchronous motor is situated inside the rotor, pole shoe made up of ferromagnetic materials is formed between surface of permanent magnet and inner circle of stator core, which can protect the permanent magnets, with important features of unequal main inductance of direct axis to quadrature axis. Therefore, the performance of these two motors is various.

Formula of air-gap magnetic field

In general, if impact of core magnetic circuit reluctance on air-gap magnetic field of permanent magnet motor not taken into consideration, formula of air gap flux density can be calculated by formula (1).

$$b(\theta,t) = f(\theta,t)\lambda(\theta,t) \quad \textbf{(1)}$$

In formula: $f(\theta,t)$ stands for the air-gap magneto motive force, while $\lambda(\theta,t)$ represents the air-gap permeance.

If permanent magnet motor is powered by inverter, the total air-gap magnetic potential of air-gap magnetic field is generally composed of four parts of base-wave magnetic potential, rotor-harmonic wave magnetic potential, stator-harmonic magnetic potential and time-harmonic wave magnetic potential, in which nail-harmonic magnetic potential is the biggest problem which causes permanent magnet motor vibration noise. Specific formula of air-gap magnetic field is shown as k in formula (2):

$$\begin{aligned} f(\theta,t) &= F_0\cos(p\theta - w_0 t - \varphi_0) + \\ &\sum F_v \cos(vp\theta \pm w_0 t - \varphi_v) + \\ &\sum F_\mu \cos(\mu p\theta - \mu w_0 t - \varphi_\mu) + \\ &\sum F_k \cos(p\theta \pm w_k t - \varphi_k) \end{aligned} \quad \textbf{(2)}$$

In the formula, $\sum F_\mu \cos(\mu p\theta - \mu w_0 t - \varphi_\mu)$ would occur in permanent magnet motor in a special sense when powered by inverter, and its frequency of harmonic magnetic field are closely linked to the switching frequency of the inverter. The increase of the vibration noise of permanent magnet motor is basically led by electromagnetic exciting force wave generated by its frequency.

ANALYSIS OF VIBRATION NOISE OF PERMANENT MAGNET MOTOR

Object of study - disc permanent magnet synchronous motor

In order to obtain more accurate test data, we chose a 20 kw disc permanent magnet synchronous motor as the study object, to analyze the influence degree of inverter on vibration noise of permanent magnet motor, and the parameters is shown in TABLE 2.

TABLE 2 : The parameters of the disc permanent magnet motor

Project	Parameter
Rated power P	20 kw
Rated frequency f	82.5 Hz
Rated speed n	450r/min
Motor phase number m	6
Stator slot number Z	24
pole pairs p	11
Stator outer diameter D1	410 mm
Stator inner diameter D2	250 mm

Finite element calculation and analysis of three-dimensional sound field

In order to obtain the three-dimensional sound field data of disc permanent magnet motor, finite element calculation is carried out, thereby to analyze the specific impact characteristics of inverter power supply on vibration noise of permanent magnet motor. A specific parameter is set in calculation: in order to better simulate the inverter and the power supply way of sine wave, we will load harmonic current of 3 kHz sine wave current and switching frequency into the stator winding. Calculated result is figured out through the adoption of A weighting sound pressure level as noise to reflect the effects of noise loudness on the human ear. Frequency spectrogram of sound pressure level of permanent magnet motor noise when powered by sine wave and inverter can be obtained through finite element calculation, as shown in Figure 3, Figure 4:

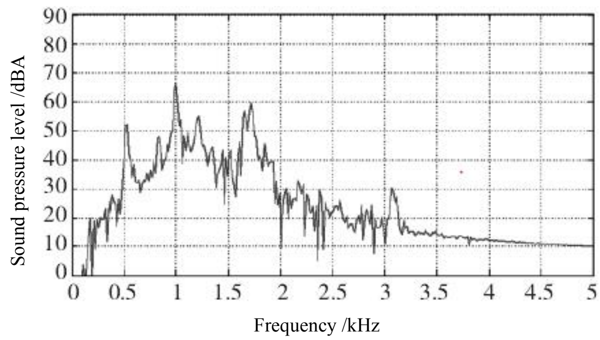

Figure 3 : Frequency spectrogram of sound pressure level of permanent magnet motor noise when powered by sine wave

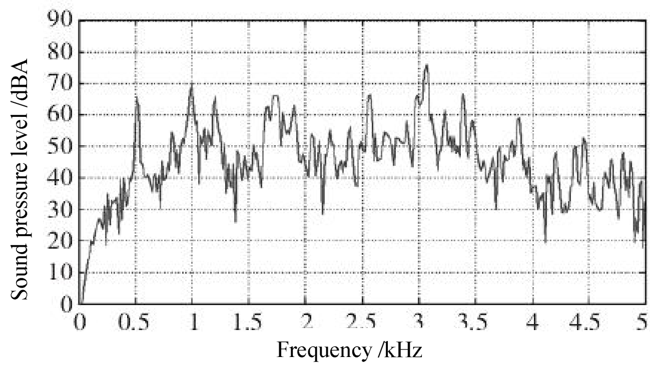

Figure 4 : Frequency spectrogram of sound pressure level of permanent magnet motor noise when powered by inverter

Judging from Figure 3, noise peak of permanent magnet motor mainly concentrates on low-frequency stage, and it can be concluded by analysis that mutual interaction between stator harmonic magnetic field and rotor harmonic magnetic field generates electromagnetic noise of permanent magnet motor when powered by sine wave supply. Furthermore, frequency and amplitude of stator harmonic magnetic field and rotor harmonic magnetic field harmonic will greatly influence the vibration noise of permanent magnet motor, and it can be seen that if you are to reduce its impact, the most effective means is to improve the frequency and amplitude of stator harmonic magnetic field and rotor harmonic magnetic field.

While in Figure 4, it shows that these peak values are generated by the intermodulation between base wave and current harmonic, when the pressure value of the permanent magnet motor and harmonic components in some columns all appear in the switching frequency of 3 KHZ. In addition, as a result of these noise peaks in the sensitive range of 1 to 6 KHZ, it can be seen that the vibration noise when powered by the inverter is obviously greater when compared with sine wave power supply.

Noise test analysis of inverter power supply

To get more accurate data of noise of the disc permanent magnet motor, we choose noise vibration test system produced by Denmark B&K Company. Measured results of noise vibration test are shown in Figure 5:

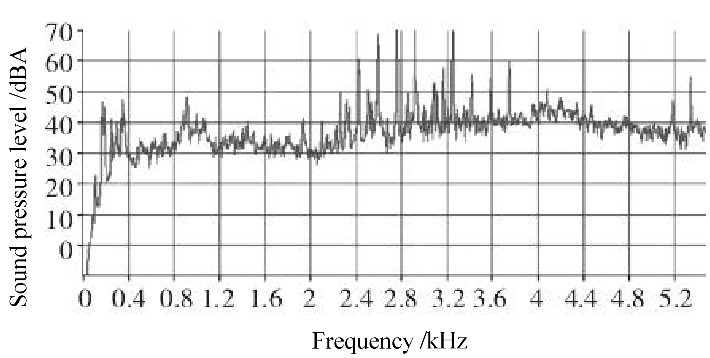

Figure 5 : Frequency spectrogram of noise vibration when powered by inverter by actual measurement

By Figure 5, it can be determined that the vibration noise of permanent magnet motor is prone to produce a series of noise values near the inverter switching frequency, and testing has found that noise frequency, analysis formula and finite element calculation are fundamentally consistent, thus it can be summarized that components of vibration noise when powered by inverter can be accurately estimated by the above two methods, which has laid a foundation for future investigation.

CONCLUSION

It can be seen that there are not merely vibration noise of low frequency in permanent magnet synchronous motor, but also a great many vibration noises of high frequency related to the carrier frequency of inverter.

The study has made testing and analysis of related parameters variation of permanent magnet motor when powered by inverter through the analytic method.

Through theoretical analysis and the research data, the following measures can be taken to reduce the effects of inverter power supply on vibration noise of permanent magnet motor.

(1) Harmonic near the switch frequency of inverter ought to be eliminated, for vibration noise of permanent magnet motor is primarily associated with it;

(2) To reduce the inevitable vibration noise of two times the base frequency of permanent magnet motor, number of poles in permanent magnet motor can be increased from the source design so as to increase the order numbers of rotating force wave.

(3) With a view to eliminate the harmonic magnetic potential of the stator, double lap winding and increase of slot numbers per pole and per phase can be adopted in the stator winding.

Permanent magnet synchronous motor has been everywhere either in modern industrial production or in daily life, since it is equipped with benefits of high efficiency, simple structure and energy saving, etc. With regard to the application fields in years to come, there would be a qualitative alteration in permanent magnet motor, which would be enhanced in aspects of energy saving with high efficiency, electromechanical integration and high performance in a continuous manner, in order to meet the increasingly demanding application requirements.

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