

# Analysis of Rotor Eccentricity Fault of Permanent Magnet Synchronous Motor for Electric Vehicle

Mai Liu

Hainan College of Economics and Business, Haikou, 571127, Hainan, China

**Keywords:** permanent magnet synchronous motor; static eccentricity; dynamic eccentricity; hybrid eccentricity; unbalanced magnetic pull force

**Abstract:** With the increasing demand for energy and awareness of environmental protection, the development of green economy has become the consensus of the whole society. New energy vehicle is playing an increasingly important role in the fast-growing automotive industry. Permanent magnet synchronous motor (PMSM) in new energy vehicle, especially electric vehicle in a wide range of applications. Rotor eccentricity faults are one of the common faults of PMSM. Based on the analysis of structure and rotor eccentric fault forms, the main influence of rotor eccentricity on PMSM is analyzed. The rotor eccentricity causes air gap magnetic density to change non-uniformly, resulting in an unbalanced magnetic pull. It further causes motor failures such as vibration, noise, increased losses, and mechanical damage. Generally, the motor cannot automatically return from the eccentric state to the non-eccentric state. Therefore, it is necessary to research the detection and diagnosis of rotor eccentricity fault, in order to find and take effective measures to prevent the increase of eccentricity.

## 1. Introduction

With the increasing demand for energy and awareness of environmental protection in economic and social development, new energy vehicle have become the focus of industry attention and research due to their advantages of environmental protection, economy, simplicity, and diverse energy sources[1]. Electric driving system is the heart of new energy vehicle, which directly affects the performance and economy of new energy vehicle. Driving motor is the key part of electric driving system. In early electric vehicle, DC motor has been used. Because of commutators and brushes, it is limited in maintenance, overload capacity and motor speed. AC induction motor is widely used in traditional industry. It has mature technology, simple structure, convenient maintenance and high reliability, but low efficiency, power density and poor adjustability. The application in electric vehicle is typical of Tesla, and there are also more common applications in vehicle with sufficient arrangement space such as buses. Switched reluctance motor has simple structure, small size and high reliability. Its overall efficiency is between AC motor and PMSM, but its torque fluctuation, noise and vibration are large [2].

PMSM has the characteristics of simple structure, good reliability, large torque, fast dynamic response, high operating efficiency, large power density, low vibration and noise [3]. Our country is rich in rare earth resources. It is of great significance for China's economic development to give full play to the advantages of resources, develop and apply high-performance permanent magnet materials, research and produce motors with rare earth permanent magnet. Therefore, as the core of driving system, PMSM is more and more increasingly used in electric vehicle.

## 2. Rotor Structure

Compared with AC induction motor, the structure of PMSM is mainly different from that of rotor. Figure 1 is the structure of PMSM.

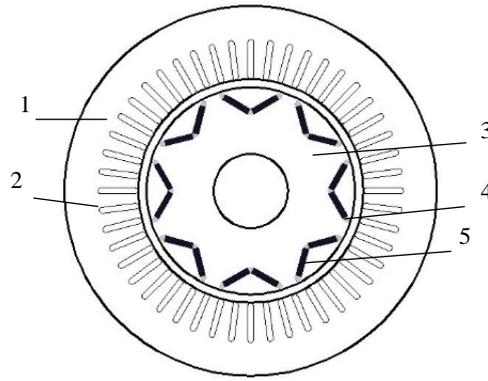


Fig.1 Structure of PMSM

1-stator core; 2-stator winding; 3-rotor core; 4-magnetic isolation slot; 5-permanent magnet

On the rotor of PMSM have permanent magnet poles. On the basis of the arrangement location of permanent magnet, there are mainly two types of motor rotor structure[4]. Surface permanent magnet rotor, subdivided into surface convex and surface embedded, is shown in Figure 2 (a) and (b). The surface convex type is provided with permanent magnet poles on the excircle surface of iron core. The surface embedded type has permanent magnet poles embedded in the excircle circumference surface of iron core. Interior permanent magnet rotor has a mounting slot inside the core for placing permanent magnets, as shown in Figure 2 (c). The structure has "one" type, "U" type, "V" type and so on.

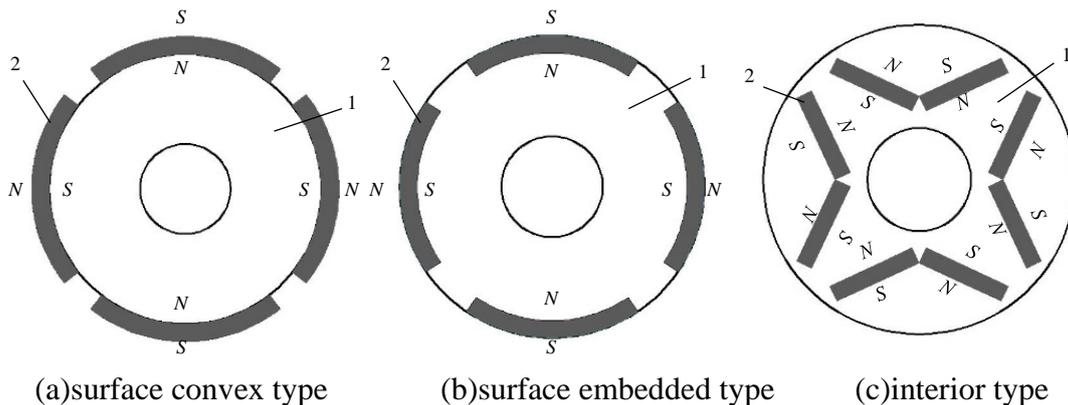


Fig.2 Permanent magnet rotor structure

1-permanent magnet pole; 2-rotor core

Surface permanent magnet rotor has no reluctance torque during operation, so it can not adjust the weak magnetic field. The speed range and mechanical strength is small, which can't meet the requirement of mechanical structure. When the motor runs at high speed, the surface of permanent magnet poles will bear large centrifugal force. Interior permanent magnet rotor has complex structure and high cost, but it has the advantages of high air gap flux density, large torque, large output range, large mechanical strength, easy control of weak magnetic field, and strong anti-demagnetization ability. Therefore, interior permanent magnet rotor structure is often used in PMSM of electric vehicle.

### 3. Rotor Eccentricity Fault Forms

The fault types of PMSM can be split into electrical fault and mechanical fault. The main electrical faults are stator winding turn to turn short circuit and permanent magnet loss of excitation. The main mechanical faults are rotor eccentricity and bearing damage. Among them, mechanical faults account for about 60%, and most of mechanical faults will lead to rotor eccentricity. Rotor eccentricity fault is that the air gap between stator and rotor is asymmetrical beyond allowable range. The errors in manufacturing and assembly process make any motor have a certain degree of

eccentricity. In industry, 10% eccentricity is usually used as the allowable range, 20% eccentricity is unacceptable, and more than 50% eccentricity should be discontinued immediately [5].

The plane model of PMSM under normal conditions is shown in Figure 3 (a). Rotor eccentricity can be divided into three forms[6]. The first is static eccentricity, the center of rotor and stator are offset. When rotated, the rotor rotates around the center of rotor, and the eccentric position does not change with rotation. The static eccentricity plane model is shown in Figure 3 (b). The second is dynamic eccentricity. As shown in Figure 3 (c), the center of rotation is concentric with the stator, the rotor center and rotation center are offset. The eccentric position transforms with the rotation of rotor. The third is hybrid eccentricity, which is a superposition of static eccentricity and dynamic eccentricity. The rotor center does not coincide with the stator center. While the rotor rotates around the rotor center, the rotor center rotates around a point that does not coincide with the center of stator. Hybrid eccentricity is shown in Figure 3 (d).

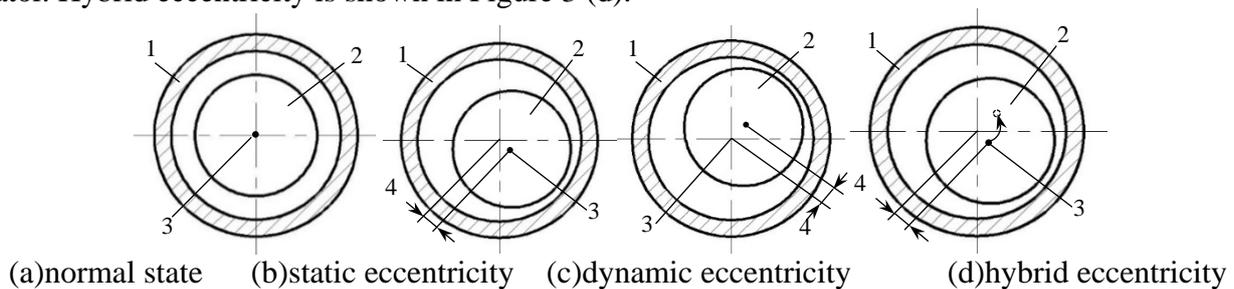


Fig.3 Rotor eccentricity diagram

1-stator; 2-rotor; 3- rotation center; 4-eccentricity

In practice, the eccentricity of rotor is complex and changeable, it also includes axially inclination, shaft bending, and the like. In order to simplify the analysis, the above three eccentric states are usually adopted. Hybrid eccentricity has both static eccentricity and dynamic eccentricity, which is closest to the actual eccentricity.

#### 4. Effect of Rotor Eccentricity Fault on Motor

When the rotor of PMSP is eccentric, it will directly lead to the variety of the air gap width between rotor and stator. The air gap is no longer uniform, which makes the magnetic field in the air gap change obviously. On the deviating side of rotor, the width of air gap is reduced, the magnetic resistance is reduced, the magnetic pressure drop is also reduced, and the magnetic field strength is intensity increased. And, the width of the rotor offset side air gap becomes larger, the magnetic resistance becomes larger, and the magnetic field strength decreases. Therefore, in the rotor deflection side, the magnetic density will be significantly larger than that in the rotor deviating side, and with the increase of rotor eccentricity, the disparity of magnetic field strength in difference regions becomes more pronounced.

Electromagnetic force is the source of electromagnetic torque. According to Maxwell's electromagnetic force calculation formula [7], the magnetic density under each magnetic pole is uniformly distributed in non-eccentric state. The radial electromagnetic forces are the same, and the opposite counteracts each other. When eccentric faults occur, the radial electromagnetic force under each magnetic pole changes obviously. At the position perpendicular to the eccentric direction, the air gap width caused by eccentricity changes little, so the air gap magnetic density does not change much. Radial electromagnetic force changes very little and can be neglected. On the deflecting side of rotor, the eccentricity increases the air gap magnetic density, and the radial electromagnetic force increases significantly. On the off-side of rotor, the radial electromagnetic force is significantly reduced. As the degree of eccentricity increases, the degree of change in the radial electromagnetic force also increases. The eccentricity fault causes a difference between the radial electromagnetic forces on the deflecting side of rotor and that on the off-axis side, which forms an unbalanced magnetic pull force and pointing toward the deflecting side. The unbalanced magnetic tension makes the rotor torque fluctuate, increases the vibration and noise of the motor, causes wear or

fracture of the bearing, reduces the mechanical strength and fatigue life of rotor, and also exacerbates the degree of eccentricity and causes damage to the motor.

In addition, the stator teeth with larger air gap under eccentric fault are subjected to less electromagnetic force, so the strain is smaller. The stator teeth with smaller air gap are subjected to larger electromagnetic force, so the strain is larger. When dynamic eccentricity occurs, the magnitude of electromagnetic force on the stator teeth depends on the position of rotor, and the strain fluctuates between the maximum and minimum. The change of stress and strain can easily lead to mechanical damage of stator teeth.

Furthermore, the non-uniformity of air gap magnetic density will increase the motor losses. PMSM losses mainly include iron core loss, copper loss and mechanical loss. Iron core loss is affected by magnetic field of motor. Rotor eccentricity fault causes a change of harmonic magnetic field in air gap. On the rotor deflecting side, eccentricity increases the iron loss in each region. On the rotor off-axis side of the, the iron loss decreases in each region. Overall, the total iron consumption increases with the increase of eccentricity. It can be seen that when the motor rotor is eccentrically faulty, the efficiency of motor is reduced. In addition, rotor eddy current loss is a key factor affecting the temperature rise of motor rotor. The increase in rotor temperature with the change of rotor loss is very obvious, which leads to the loss of magnetism of permanent magnet due to high temperature [8].

## 5. Conclusion

In this paper, based on the research of PMSM structure and fault forms, the influence of eccentric fault on motor is analyzed carefully. The rotor eccentricity makes air gap magnetic field of PMSM not uniform anymore, which leads to unbalanced magnetic pull force and increases loss, and then brings the problems of torque ripple, vibration, noise and wear of mechanical structures. Because the direction of unbalanced magnetic pull force is basically the same as that of eccentricity of rotor, the pull force acts on the deviating side along the radial direction, which increases the degree of the eccentricity. Generally, the motor cannot automatically return from the eccentric state to the non-eccentric state. Therefore, if effective measures are not discovered and taken in time, the gradual increase of eccentricity will eventually lead to friction collision between rotor and stator surface, which will damage stator and rotor surface, thereby further aggravating the problem. Therefore, the research on rotor eccentricity fault is of great significance to the stable and safe operation of PMSM.

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