

# Design and Comparison of Axial Flux and Radial Flux Permanent Magnet Synchronous Motor for Robotic Joint Applications

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Nowadays the high torque density permanent magnet synchronous motors (PMSMs) are desired in a wide range of applications. The axial flux motor has receive intensive attention dur to its inherent merits in terms of high torque density and dynamic response. The multi-objective optimization was carried out for the two different topology motors, and their electromagnetic performance was compared.

**Index Terms**—axial flux PMSM, radial flux PMSM, electromagnetic performance, permanent magnet synchronous motors.

## I. INTRODUCTION

Recent years, with the rapid development of industrial robots and drones, the performance and technological development of motors[1-2] as the core component of transmission systems, will directly affect the motion state of the transmission system. In this field, the axial flux permanent magnet motors (AFPM) are gradually expanding their applications due to their unique motion characteristics and torque density advantages[3-5]. However, for small size motors in robotic joint application, due to the space limitation the traditional radial flux permanent magnet motors (RFPM) might be better in terms of torque density. There was no clear conclusion in the past literature to indicate in which scenarios AFPM offer better torque density.

In this paper multi-objective optimization of the topology structure was carried out for both type motors. The comparative analysis was conducted under no-load and load conditions. Finally, the guideline for motor design for robotic joint applications was provided.

## II. MODEL ANALYSIS

The model of the two motors are shown in Fig.1, with RFPM using a two-dimensional model and AFPM using a three-dimensional model. Both motors adopt a 24 slot 22 pole structure.

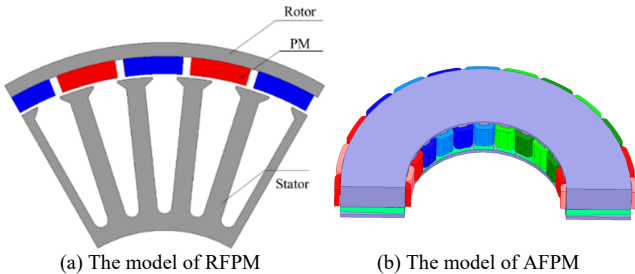


Fig. 1. The 24-slots/22-pole model the RFPM and AFPM.

In order to make two different topology motors comparable, it is necessary to ensure that the technical parameters of the motors are the same. The constraint conditions are as follows: a) the same motor material; b) the same motor volume; c) the

same current density. The main initial parameters of two motor is shown in Table I.

TABLE I  
MAIN DESIGN PARAMETERS OF TWO MOTORS

| Items (Unit)                               | RFPM | AFPM |
|--------------------------------------------|------|------|
| Rotor outer diameter (mm)                  | 98   | 98   |
| Axial length (mm)                          | 28   | 28   |
| Slot fill factor                           | 0.3  | 0.3  |
| Rated current density (A/mm <sup>2</sup> ) | 20   | 20   |
| Rated speed (r/min)                        | 3000 | 3000 |
| Rated torque (Nm)                          | 3.5  | 3.5  |

## III. ANALYSIS OF ELECTROMAGNETIC PERFORMANCE

The multi-objective optimization was carried out, the result was show in Fig.2. The points marked in red was the design adopted in this paper.

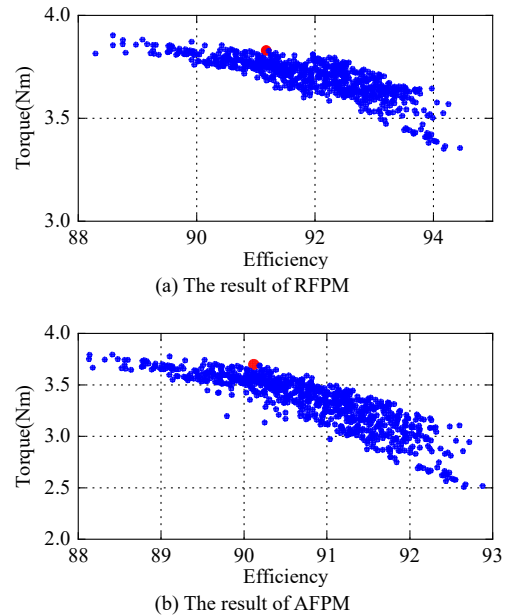


Fig. 2. The multi-objective optimization of RFPM and AFPM.

### A. Motor characteristics at unload condition

The no-load back electromotive force (EMF) is one of the main indicators for measuring the performance of a motor. By analyzing the waveform and values, the operating status and output voltage capability of the motor can be measured. Figure

2 shows the waveform of no-load line back electromotive force for AFPM motor and RFPM motor, with effective values of 29.1 V and 28.4 V, respectively. the voltage waveform distortion rates of RFPM and AFPM were calculated to be 2.4% and 3.9%, respectively.

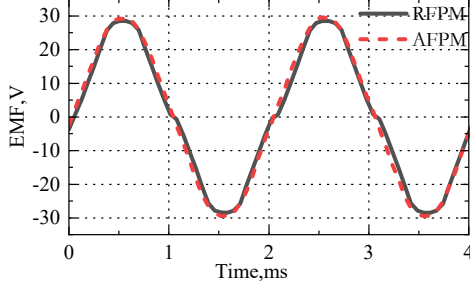


Fig. 2. The EMF of the RFPM and AFPM.

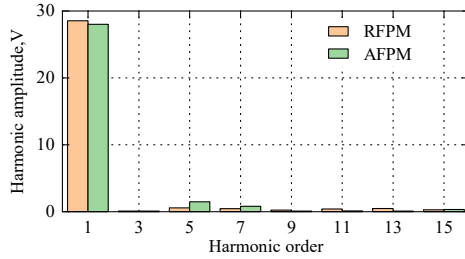


Fig. 3. Harmonic amplitude of line voltage of the RFPM and AFPM.

The peak to peak values of cogging torque for two different motor structures are 135mN and 41mN, respectively, with RFPM motor having smaller cogging torque.

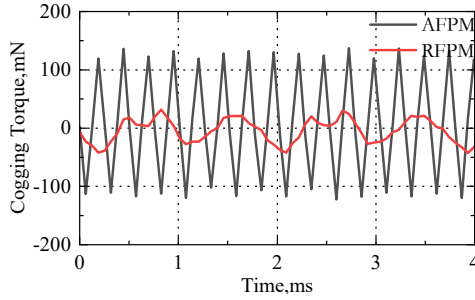


Fig. 4. Cogging torque comparison of the two models

#### B. Performance at different current density

As shown in Fig. 4, under different currents, the torque performance of AFPM motor is better than that of RFPM motor, with a 6.7% increase, which is consistent with the comparison of back electromotive force in no-load characteristics.

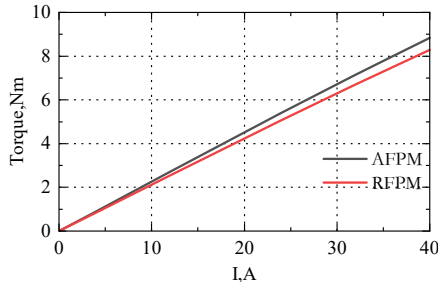


Fig. 5. Average torque of the two motors at different current.

At the same current density, the torque ripple of AFPM is 5.8%, while that of RFPM is 4.1%, mainly due to the presence

of more harmonic components in the air gap magnetic field of AFPM.

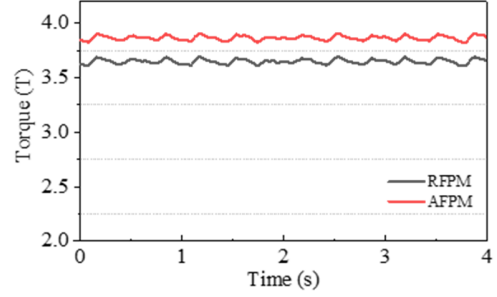


Fig. 6. Torque comparison of the two models at rated current density.

From Table II and Fig. 2, it can be seen that generating the same magnitude of back electromotive force requires more permanent magnets for the AFPM motor. In addition, due to the longer end of the AFPM winding, the weight of the winding is also greater. The longer end will require more space for installation in the housing design of the AFPM motor.

TABLE II  
MATERIAL WEIGHT OF EACH PART OF THE MOTOR

| Item (Unit)         | RFPM | AFPM |
|---------------------|------|------|
| Stator corer(g)     | 426  | 416  |
| Rotor core(g)       | 135  | 217  |
| Permanent magnet(g) | 100  | 65   |
| Winding(g)          | 221  | 192  |
| Total(g)            | 882  | 890  |

From the above discussion, it can be seen that at the same size, AFPM motors can provide greater torque, but they are slightly heavier and have larger cogging torque, which requires greater dynamic balancing of the motor. At the same time, it should be noted that in practical situations, AFPM motors require a larger air gap to ensure mechanical safety, and further expansion of the air gap may have a negative impact on torque density.

#### IV. CONCLUSIONS

This paper compared and analyzed the no-load and load performance of AFPM and RFPM motors under the same working conditions. The AFPM motor offer better torque density in the penalty of higher torque ripple.

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