

# The performance comparison of 3 phase stepping motor by difference of construction

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## ABSTRACT

Until recently, 3- phase permanent magnet type stepping motor had not developed in use . On the other hand, AC motors or DC brushless motors in aiming high performance are mainly 3- phase type. Also permanent magnet type stepping motor is better for efficiency and linearity. Under such situation, Author has developed 3 kinds of different permanent type 3- phase stepping motors. They are HB(hybrid)type, RM(stator is same as HB but rotor is similar like PM ring magnet) type and claw pole cascade PM type. So, in this paper, firstly the advantages of 3 phase stepping motor are explained compared with 2 phase stepping motor. Then the performance comparisons are taken up among above 3 types with about same motor size.

## 1. INTRODUCTION

Permanent magnet type stepping motors such as HB and PM type are widely used in many applications for their better efficiency. In HB type stepping motors, 2 and 5-phases are used respectively for medium and high resolution purposes. If the number of phase is increased, the resolution and characteristics are improved, but increased number of phase results in the increase of stator pole, complicated manufacturing process and driving circuit accompanied by higher manufacturing cost.

In case of 3-phase motors, however, the number of stator poles can be reduced, and the structure of 6 poles, less than 8 poles which is widely used for 2-phase motors is available(shown in FIG1) .

Further, number of power supply terminals can be reduced also. In 3-phase motors, 3 terminals can be used compared with 4 terminals in 2-phase and 5 terminals in 5-phase motors, and further, the number of driving transistors can be reduced also (shown in Fig.1).

If the rotor of 3 phase HB type is replaced by Ring Magnet type rotor with back yoke, such 3 phase motor is named as RM type. RM type 3 phase motor has smooth rotation and high speed performance. There are two types for stepping motor construction as distribution type and cascade type for forming the stator phase. HB and RM type are the former. Construction of claw pole PM type stepping motor is the latter. Existing claw pole PM type is mainly 2 phase, however, 3 phase cascade claw pole PM type

is proposed as better performance actuator. These RM and PM type are also available for 3 terminal drive. From the consideration above, these permanent magnet type 3-phase stepping motors are understood to be superior in the point of cost-performance.

## 2. FEATURES OF 3-PHASE TYPE STEPPING MOTOR

### 2-1. COMPARISON WITH 2-PHASE MOTOR

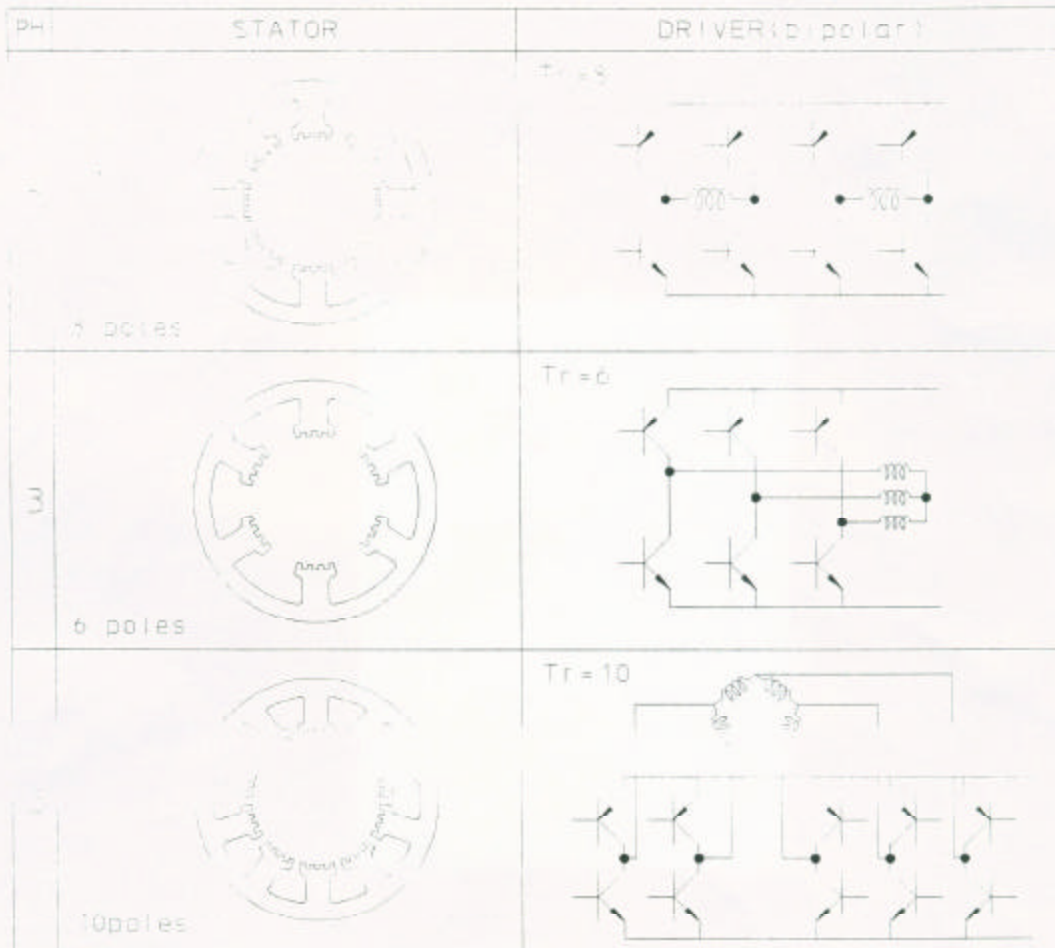


FIG.1 Distribution type stator and driver

Comparison with 2-phase motor is taken up for better understanding of 3-phase motor as follows.

1) Step angle  $\theta_s$  is given by  $\theta_s = 180^\circ / P_H \cdot N_r$  (where  $P_H$  : number of phase,  $N_r$  : number of rotor teeth)

Therefore, 3-phase motor is better for getting small angle than 2-phase motor.

2) Maximum holding torque of 2phase excitation for 3 phase motor is  $\sqrt{3}T_1$ , and 2 phase is  $\sqrt{2}T_1$ , (where  $T_1$  : 1 phase excitation torque) . So 3-phase motor is more effective for resultant torque.

- 3) Torque ripple for changing phase is smaller for 3-phase motor than that of 2-phase motor due to  $\pi/3$  phase shift against that of  $\pi/2$  for 2 phase motor.
- 4) Torque difference of continuous 2 steps for half step drive is smaller for 3-phase motor than that of 2-phase motor (torque ratio of 3-phase half step drive is 1:1.15, where that of 2-phase is 1:1.41) .
- 5) Star winding connection of 3-phase motor is available with 3 terminals drive and number of transistor for drive circuit is 6 less than 8 of 2-phase motor(FIG.1). It means there is the possibility to become cheaper than that of 2-phase motor if quantity of use becomes large in future.
- 6) Vibration torque in continuous rotation for 3-phase motor is smaller than that of 2-phase motor. Because 3<sup>rd</sup> harmonics for magnetic flux and current are both cancelled due to 3 phase constructin.

## 2-2. TORQUE ANALYSIS

Torque analysis is reviewed with influence of space harmonic components.

Gap permeance  $P(\theta)$  is composed only of odd number harmonics to be shown by the equation (1) below.

$$P(\theta) = P_0 (K_1 \sin \theta + K_3 \sin 3\theta + K_5 \sin 5\theta + K_7 \sin 7\theta) \quad (1)$$

Torque T by IBL law is :

$$T = KIP(\theta) \quad (2)$$

[where K:constant, I:current]

Space harmonic component for RM type in equation (1) is smaller than that of HB type so RM type is suitable for smooth rotation. Because space harmonic component also time harmonics contained in current generates vibration torque.

## 3. Construction of 3 phase stepping motor

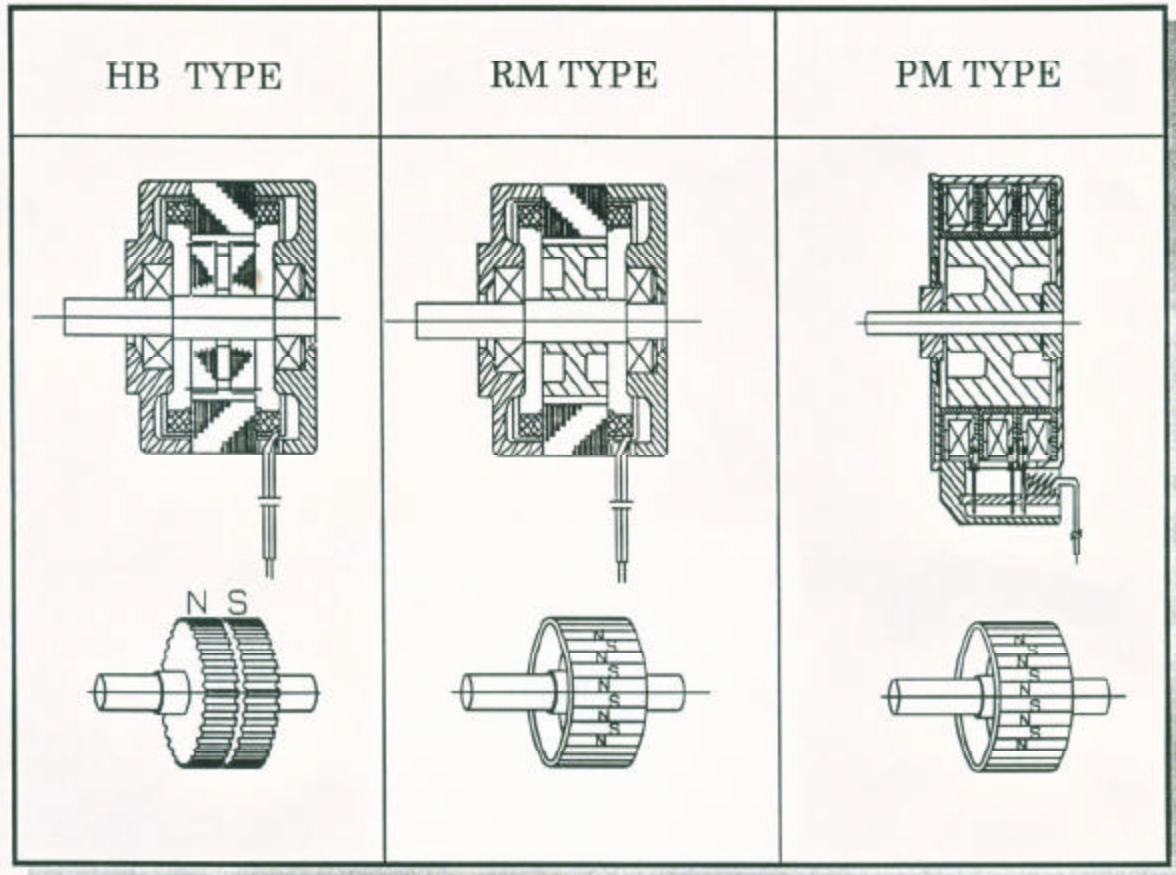
FIG.2 shows the constructions for 3 kinds of 3 phase permanent type stepping motor. They are HB, RM and PM type. Advantage and disadvantage are discussed hereafter.

### 3-1. HB type 3 phase stepping motor

HB type is same construction as 2 phase except stator. Number of main poles of stator for 3 phase is multiple of 3 as ,6,9,12<sup>1)</sup> . 6 main pole stator is used for step angle 3.75 deg.(Nr=16). 12 main pole stator is used for 1.2 deg(Nr=50) and and 0.6 deg(Nr=100) in actual products.

Advantage of HB type is high torque at low speed ,so this motor is suitable to use at low speed like less than 1000rpm,also direct drive is available if step angle is small like 0.6 deg. Disadvantage of HB type compared with RM or PM type is high vibration at low speed range.

FIG2. Construction of 3 phase stepping motor



### 3-2. RM type stepping motor

The rotor of RM type is similar to PM type. Different point from PM type is that RM type needs back yoke in inside of rotor ring magnet. Stator is exactly same as HB type. Following features are expected for RM type against HB type. 1) Magnetic flux distribution of rotor is sinusoidal wave, so suitable for smooth rotation. 2) Magnetic flux path is 2 dimensional which means perpendicular surface to shaft only. HB type takes axial direction also. So RM type is short magnetic path and smaller in loss. 3) Air gap face area between stator teeth and rotor teeth is 2 times larger than HB. 4) Inductance of RM type is smaller than HB because of no iron on surface of rotor.

### 3-3. PM type stepping motor

Stator for each phase is located to axial direction so this type structure is called as cascade type. Stator coil is bobbin wound type and stator is claw pole type. So cost of this motor is cheapest among three. Cost of PM type compared with HB or RM type by same size is roughly half. Star or delta connection is available like HB or RM type.

#### 4. Performance comparison

##### 4-1. Dynamic torque comparison among 3 types

FIG.3 shows dynamic torque comparison among 3 types with same step angle of 3.75 deg. by roughly same 42mm size. These data shows that HB type is high torque at low speed. On the other hand, RM type is lower torque at low speed, but higher torque at high speed of more than 1500pps.

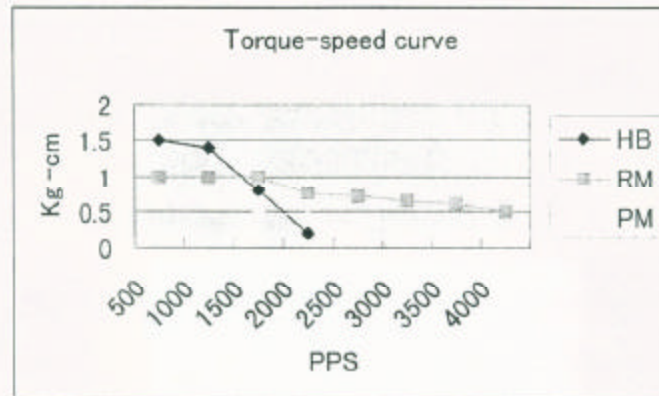


FIG.3 Dynamic torque comparison

PM type is low torque for whole speed range, however, this motor's air gap is larger than other two types. Also sleeve metal is used against ball bearing, and a little bite shorter for length than that of HB and RM type. So motor cost is cheapest one by including bobbin wound coil and press forming claw pole stator construction. Above data are measured by 24V, 2 phase excitation, so 4000pps corresponds to 2500 rpm.

##### 4-2. Torque and vibration comparison between 2 phase and 3 phase PM type

FIG.4 and FIG.5 is comparison data between 2 phase and 3 phase PM type for torque-speed curve and vibration-speed curve respectively with same size 54mm stator-25mm long and same size rotor at 24V. In put power is controlled as same value. Step angle is 7.5 deg for 2 phase and 3.75 deg. for 3 phase type. FIG.4 shows torque at low speed as less than 800 rpm for 2 phase type is higher than that of 3 phase type. However torque at high speed as more than 800 rpm for 3 phase type is higher than that of 2 phase type. FIG.5 shows vibration at low speed as less than 500 rpm is improved roughly more than 50% by 3 phase type. So 3 phase PM type is suitable actuator for wide range speed application than 2 phase PM type.

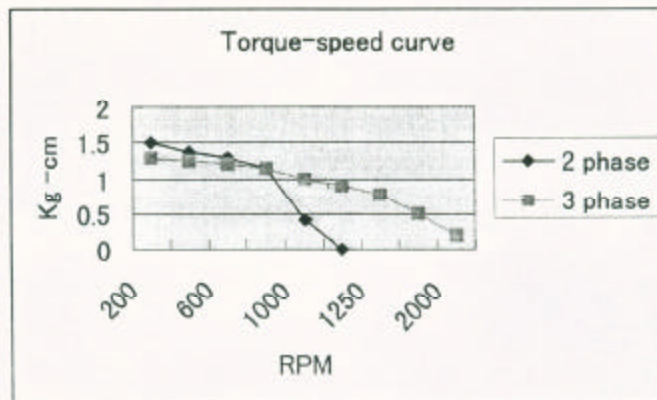


FIG.4 Dynamic torque comparison with 2 and 3 phase PM type

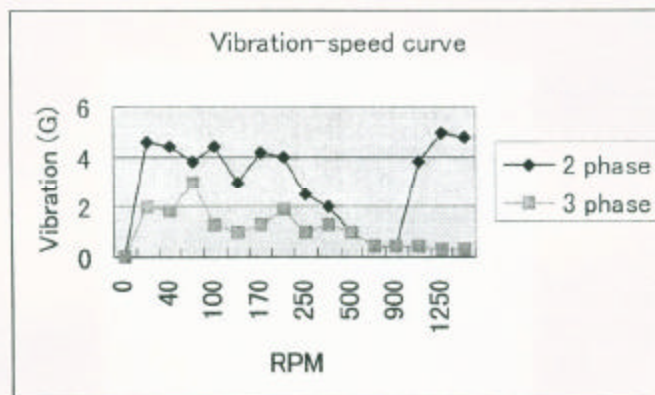


FIG.5 Vibration comparison with 2 and 3 phase PM type

#### 5. Conclusion

- 1) Features of 3 phase permanent magnet type stepping motor have cleared by the view point of comparison with 2 phase permanent magnet type stepping motor.
- 2) 3 different types 3 phase permanent magnet stepping motors as HB, RM, PM type have introduced and their advantages have argued. As the result, HB type is rather suitable for low speed high torque application, RM type is suitable for smooth rotation and high speed application like more than 1000rpm. PM type is low cost actuator and 3 phase PM type is better performance in vibration at low speed and high torque at high speed range than 2 phase type.

#### 6. Reference

- 1) Masafumi Sakamoto. [Development of High resolution 3-phase HB type stepping motor]. PCIM 1997 Proceeding, in Nurnberg.