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Torque Improvement in Brushed DC Motors by using Four Pole Permanent Magnet

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Abstract

Permanent magnet brushed DC motors are widely used in low power applications. Generally they use permanent magnet with two magnetic poles. This paper presents use of four pole permanent magnet to improve torque in these motors. Various constructional aspects have been explained so as to convey whole picture with such design. A theoretically calculated result has been put forward to differentiate motor performance parameters between 2 pole and 4 pole permanent magnet motors.
Keywords: 2-D FEMM, brush DC, four pole permanent magnet motor, electromagnetic torque, isotropic magnet

I. INTRODUCTION

Permanent magnet motors are finding their use in various applications. These include medical instruments, factory automation, beauty care products, healthcare products, aerospace, robotics, electric hand tools, electronic measuring equipment and many more. These applications predominantly work on low voltage-low power ranges [1] and have space constraints. Hence permanent magnet DC motors (here onwards referred as PMM) offer advantage over conventional field wound DC motors. Typical range of voltage for PMM is from 6V to 48V depending on application.

It is evident to mention that permanent magnets are used in both brushed DC as well as in brushless DC motors (commonly called as BLDC motors). However cost always plays an important role in selection of motor since many of the applications will go directly to consumers. This is where brushed PMM wins since it’s cheaper than BLDC. The future however may look bright for BLDC motors because of advancements in electronics in terms of technology and cost, brushed PMM motors still hold their ground on the basis of better performance to cost ratio.

According to a forecast [2], global permanent magnet motor market is expected to reach $45 billion by 2020. It is interesting that Asia Pacific region will be generating more revenue than Europe and North America. These figures highlight the increasing usage of PMM instead of equivalent field wound DC motors.

Advancements in permanent magnets have also contributed to great extent. Rare earth magnets like neodymium iron boron (NdFeB) and samarium cobalt (SmCo) are getting used in motors vastly because of their superior performance over traditionally used ferrite and AlNiCo magnets. The rare earth magnets still costlier than ferrite and AlNiCo but whenever high performance is required, they are the foremost choice.

II. TYPES OF PERMANENT MAGNET MOTORS

Permanent magnet motors can be broadly classified in two ways. One way as brushed DC and brushless DC. Other way as iron core and coreless. We are interested in employing 4 poles permanent magnet in brushed DC type of motors. These motors can be with iron core or with self-supporting iron core less type rotor. As shown in fig 1, Brushed PMM cross section with conventional field wound motors.

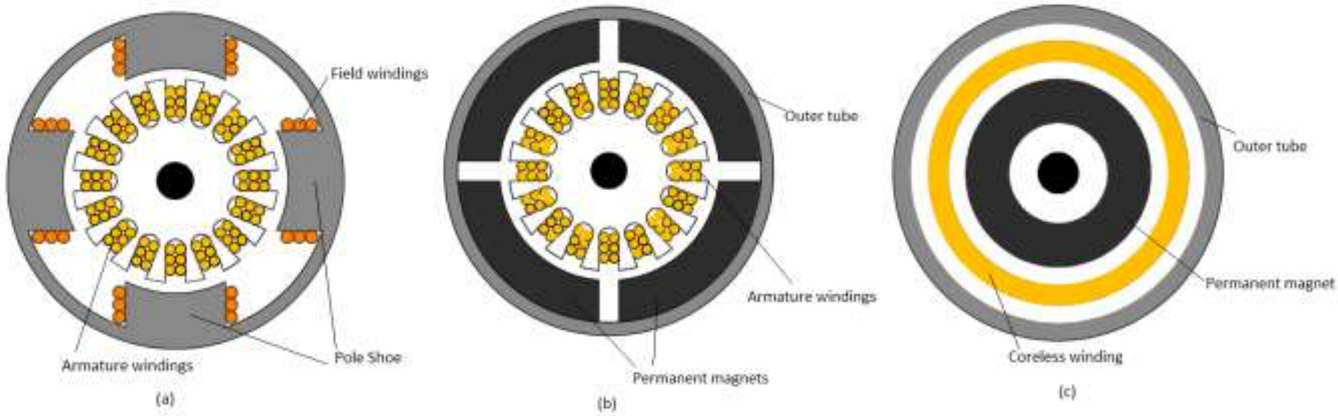

Fig. 1: (a) Conventional field wound motor, (b) Permanent magnet iron core motor, (c) Permanent magnet coreless motor

III. ELECTROMAGNETIC TORQUE

Many of the times an application requires high torque motor working at reduced speed. In such conditions one may reduce input voltage to obtain low speed without compromising the maximum continuous torque for it. But doing so reduces the stall torque i.e. torque at zero speed. Another way of meeting such condition is use of motor and gearbox together. Such combination would be costlier than a single motor which can deliver such requirement. Hence to obtain high torques at low speeds alternative design of motor is needed.

Electromagnetic torque is given as [3]:

$$T = z*p*\varphi*Ia / 2*\pi*a$$

Where,

Z = total number of armature conductors
P = number of poles
Φ = flux per pole
Ia = armature current
A = number of parallel paths

From this equation it can be observed that torque will increase with increase in total number of armature conductors, flux per pole and number of poles. We may not able to increase number of conductors to great extent owing to constraints of space. We can try to increase grade of the magnet in order to increase flux value but this depends on thickness of magnetic return path provided. High grade magnet will need thicker magnetic return path which will increase motor dimensions and will not lead to significant torque improvement. The most promising design change to obtain high torque at reduced speed will be increase in number of poles.

Generally PMM incorporate single pole pair i.e. 2 pole magnets. The proposed design considers use of 4 pole magnet. Depending upon type of motor, one has to choose the magnet type.

IV. CONSTRUCTION OF 4 POLE PMM

A. Air Gap Flux:

Quantities flux density in air gap and flux per pole are related as:

$$Bg = \varphi /[(\pi D/p) L]$$

Where,

Bg = air gap flux density
D = rotor diameter
L = length of magnet or rotor whichever is shorter
Φ = flux per pole

When a 2 pole magnet is replaced by 4 pole magnet considering same geometrical parameters, we get reduced Bg value since flux is divided among 4 poles instead of 2 poles (See Figs.). But this provides us other advantages. First being that the back iron or magnetic return path is not saturated which is the case with 2 pole motor. This allows us to use thinner return path which reduces weight of motor. Another optimization can be done with this thinner path is make use of extra space available in the motor to incorporate more windings thereby again increasing the torque value. One can also keep existing back iron geometry constant and go for higher grade magnet to saturate the return path.

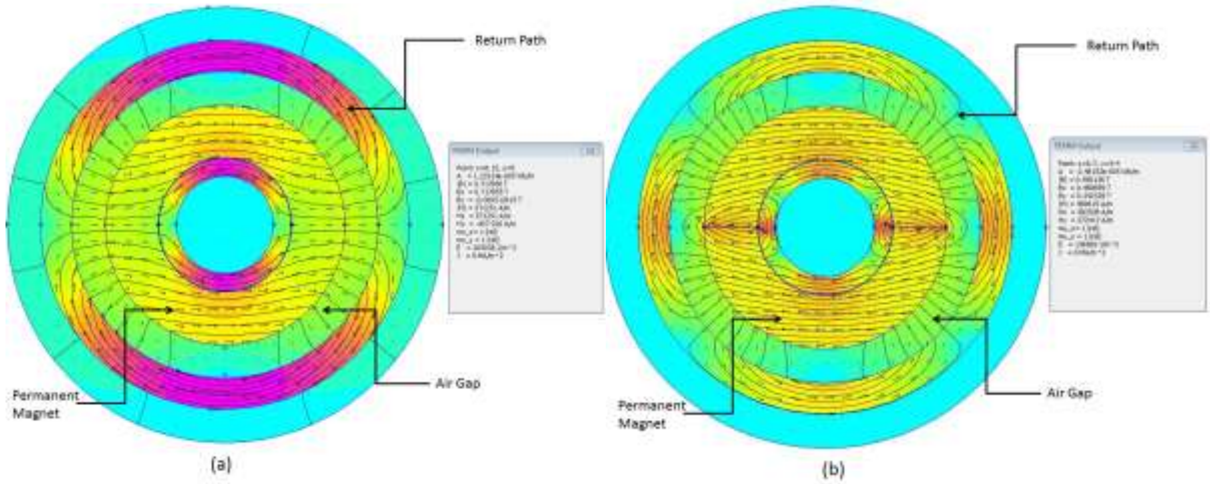

Fig. 2: (a) Two pole PMM 2-D FEMM, (b) four pole PMM 2-D FEMM

As it can be seen from fig. 2 a 2-D FEMM (Finite element method magnetics) analysis for PMM where coil (winding) would rotate in air gap that for two pole motor we get maximum Bg of 0.717 Tesla and for four pole motor we get maximum Bg of 0.59 Tesla. Thus for this construction maximum Bg value is reduced by appx 18%. But as mentioned in earlier, electromagnetic torque depends directly on number of pole; the net result will be increment in torque.

B. Winding Arrangement:

Arrangement of winding pattern is important as number of poles is four. Traditionally for core DC motors coil is wound in two ways, one in lap pattern and other in wave pattern. In lap pattern, two ends of coil are terminated to adjacent segments. This pattern would require use of 4 numbers of brushes when used for 4 pole design. In case of wave pattern, coils do not terminate to adjacent segments due to which it is possible to use only 2 brushes for 4 pole motor also. However wave pattern is more suitable for low currents and lap pattern is suitable for high currents.

In case of coreless PMM, it is very challenging to incorporate number of poles more than two since most commonly used winding patterns which are skewed and rhombic are designed for two poles PMM. These winding patterns would fail as current and in turn torque generating areas can make use of only two poles. Being coreless, this winding does offer some considerable advantages such as elimination of core loss, cogging torque, light weight design, and lower mechanical time constant. It is difficult to use 4 poles in already existing winding patterns. For any coreless winding pattern, torque generating area is dependent on direction of flow of current through winding and placement of magnetic poles with respect to it. Number of poles is equal to number of torque generating areas. Hence a coil pattern very different than traditional ones should be designed to take advantage of 4 poles if permanent magnet.

C. Commutation Design:

Commutation includes rotating commutators connected to winding and stationary brushes making contact with commutators. Commutation design is solely based on type of winding considered. As mentioned earlier lap winding would need number of brushes equal to number of poles while for wave pattern two brushes are sufficient irrespective of number of poles.

In case of 2 pole coreless PMM, general practice adopted is use of odd number of commutators and couple of brushes. Use of odd number of commutators facilitates generation of smoother torque ripple since with odd number of commutators and 2 brushes we get more pairs of commutators in contact with brushes. For example, with 6 commutators (1, 2, 3, 4, 5, and 6) we get commutation between 1-4, 2-5, and 3-6. But with 7 commutators (1, 2, 3, 4, 5, 6 and 7) we get commutation between 1-4, 1-5, 2-5, 2-6, 3-6, 3-7 and 4-7. Thus smoother torque generation is achieved. While incorporating 4 poles in coreless PMM, odd number of commutator arrangement may not be possible since 4 brushes would need. Since to have better torque ripple, current entering from brush 1 will have to commute oddly and leave through brushes 2 & 3, similarly current entering from brush 4 will have to commute oddly and leave through brushes 2 & 3. Hence total number of commutators would be even.

D. Four Pole Permanent Magnet:

Magnets used in PMMs are ferrite, AlNiCo, SmCo & NdFeB. Rare earth magnets i.e. SmCo (samarium cobalt) and NdFeB (Neodymium iron boron) are high performance magnets. Use of these has increased rapidly in recent past. A magnet can be sourced in two ways, one being in magnetized condition and other being unmagnetized condition where it can be magnetized with use of magnetizers on site. With 2 pole magnets which are most commonly used, anisotropic magnets are preferred since they can be magnetized in one direction i.e. north & south along one axis. As magnetic moment is aligned in one direction during production, we get spontaneous or easy magnetization.

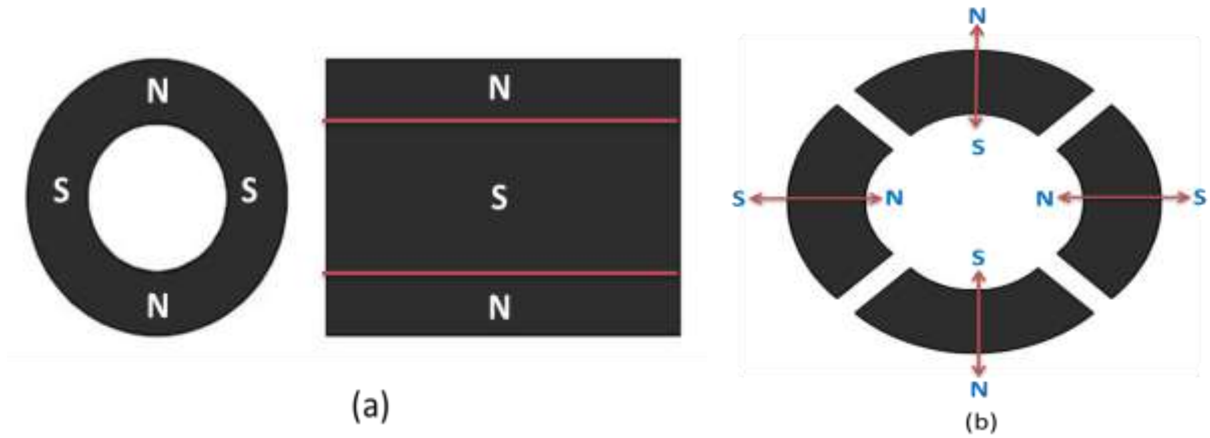

Fig. 3: (a) Isotropic magnet, (b) magnet tiles

However while incorporating four poles in PMM; anisotropic nature of magnetic moment is not useful as north- south pair in direction perpendicular to anisotropic direction will be weaker in field. Hence an isotropic magnet would be useful for obtaining multiple poles on magnet. Another way of obtaining 4 poles is use of anisotropic magnet tiles in semi cylindrical or quarter cylindrical shape. Depending on type of PMM, these tiles can be glued to tube or together to form complete 4 pole magnet in cylindrical shape.

V. Theoretical Calculation

Upon using 4 pole permanent magnets instead of 2 poles we get following results in coreless type of motors. It is required to mention that these theoretical calculations have been done for same motor size by using 2 pole magnet and 4 pole magnet. Results are put side by side in graphical format to get understanding of the comparison.

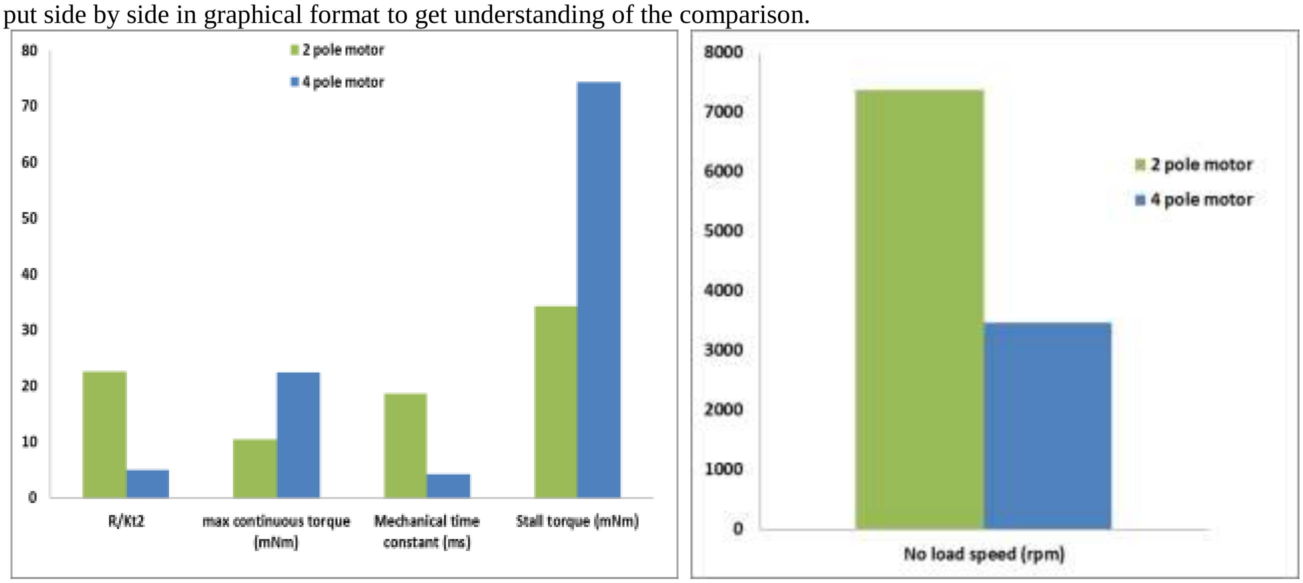

Fig. 4: Two pole vs four pole motor performance difference

Following can be deducted:
1) R/K^2 i.e. slope of speed torque curve is improved. Smaller the value powerful is the motor.
2) Maximum continuous torque has doubled.
3) Mechanical time constant for 4 pole PMM is lower than for 2 pole PMM, indicating that motor will attain 63% of its no load speed quicker.
4) Stall torque i.e. torque at zero speed has doubled.
5) No load speed of 4 poles PMM is halved compared to 2 pole PMM which is expected. However speed can be improved by increasing the voltage.

VI. CONCLUSION

Improved torque is always desired for any motor in same space constraints. Use of 4 pole permanent magnet in PMM meets this desire. Brushed DC PMMs are used as cost effective option to BLDC motors which is why they will continue to dominate in near future. Theoretical calculations in this study prove that PMMs can be made powerful through use of 4 pole magnet. Research has gone further in [4] where number of poles can be varied in same PMM in order to meet different torque requirements during its application. This again highlights results of this study of increment in torque through use of 4 poles in PMM

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