Limited Angle Torque Motors Having High Torque Density, Used in Accurate Drive Systems

R. Obreja, I. R. Edu

Abstract

A torque motor is a special electric motor that is able to develop the highest possible torque in a certain volume. A torque motor usually has a pancake configuration, and is directly jointed to a drive system (without a gear box). A limited angle torque motor is a torque motor that has no rotary electromagnetic field — in certain papers it is referred to as a linear electromagnet. The main intention of the authors for this paper is to present a means for analyzing and designing a limited angle torque motor only through the finite element method. Users nowadays require very high-performance limited angle torque motors with high density torque. It is therefore necessary to develop the highest possible torque in a relatively small volume. A way to design such motors is by using numerical methods based on the finite element method.

Keywords: limited angle torque motor, finite element method, high performance, pancake, direct drive.

1 General considerations

Our purpose for this paper is to present some aspects of special torque motors with high torque density. More exactly, our attention will focus on limited angle torque motors used in very accurate drive systems.

A torque motor is a special electric motor that is usually direct jointed to a drive system (without a gear box). There is generally a pancake structure, which can easily be adapted to the system configuration.

A limited angle torque motor is a motor that does not have a rotary electromagnetic field. In certain papers it is referred to as a linear electromagnet.

Nowadays users require very special limited angle torque motors with high torque density versus the volume of the motor. The reason is that a performing drive system has to be as small as possible.

The authors of this paper have developed very special solutions for motors of this kind. Some aspects of these solutions will be presented here.

2 Limited angle torque motors with a small air-gap versus limited angle torque motors with a large air-gap

A limited torque motor is, usually, a toroidal motor relative to the winding solution. In this way, the total air-gap, relative to the magnet, also includes the winding. The dimension of the air-gap is, generally, more than 1.5 mm. Relative to the overall dimension of the motor, we can consider this to be a large air-gap. Depending on the size of the motor and the internal structure, the value of the air-gap can be several millimeters ($4 \div 5$ mm). For motors with the winding assembled in slots, the value of the air-gap may be 0.4 mm to 1.5 mm, depending on the size of the motor and the arrangements for total friction torque. This air-gap is small. We will now present some considerations on the small air-gap and large air-gap solutions.

2.1 A limited angle torque motor with a small air-gap

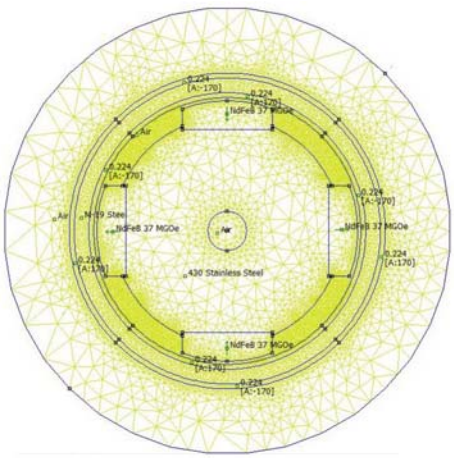

Fig. 1: An example of a limited angle torque motor with a small air-gap

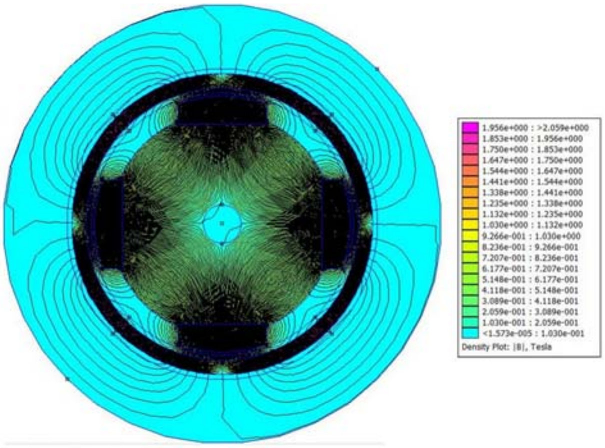

Fig. 2: Magnetic field distribution

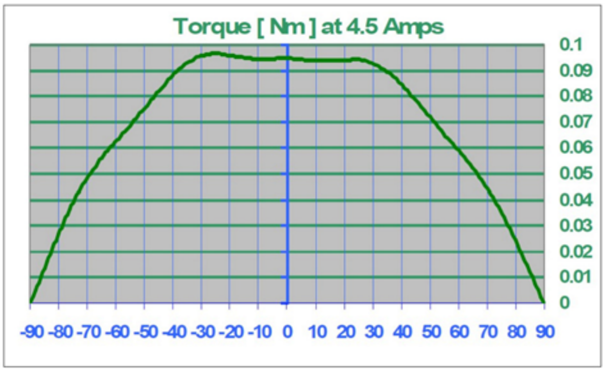

Fig. 3: Torque versus electric angle diagram

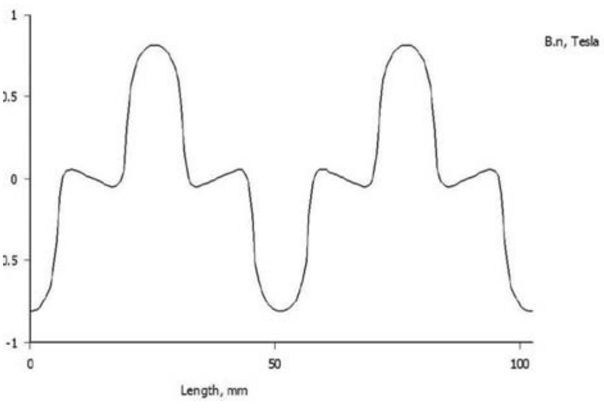

Fig. 4: Flux density diagram in the air-gap, in the proximity of the permanent magnet

Analyzing the figures above, it is found that the magnetic field generates 4 main poles, and also four other small poles in the neutral area, because the field lines may close in the neutral area of the poles directly between the magnets and the soft magnetic material of the rotor. A disadvantage is reflected in torque diagram form (the diagram is nonsymmetrical, as shown, as the current value is increasing).

2.2 A limited angle torque motor with a large air-gap

In the situation of torque motors with a large air-gap, it is found that the magnetic field generates only the 4 main poles very accurately, because the field lines may not close in the neutral area of the poles directly between the magnets and the soft magnetic material of the rotor, due the dimensions of the air-gap. This advantage is reflected in torque diagram form, which is symmetrical.

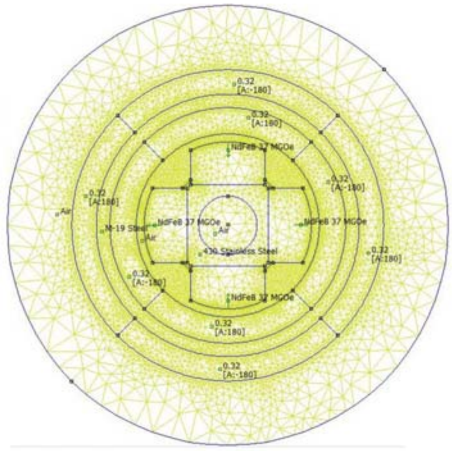

Fig. 5: An example of a limited angle torque motor with a large air-gap

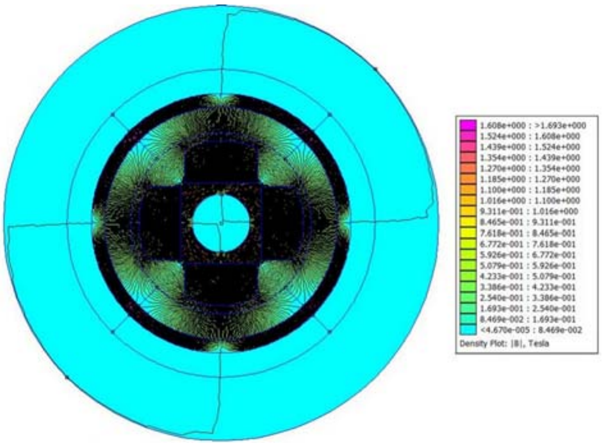

Fig. 6: Magnetic field distribution

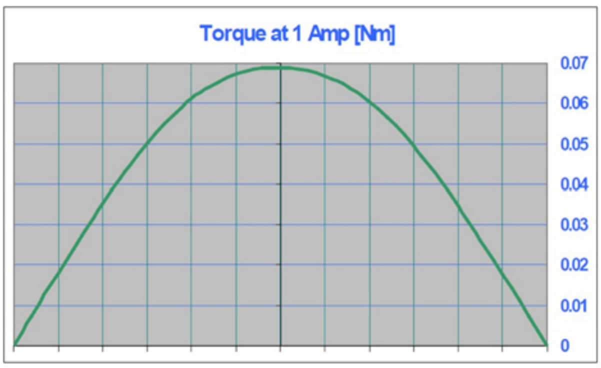

Fig. 7: Torque versus electric angle diagram

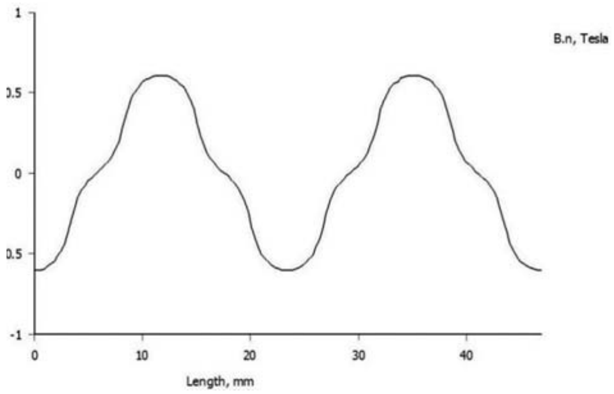

Fig. 8: Flux density diagram in the air-gap, in the proximity of the permanent magnet

3 Analysis of a limited angle torque motor with a large air-gap

Section 2 presented general aspects of the two types of motors. As the motor with a large air-gap is more usual, it will now be analyzed in greater detail.

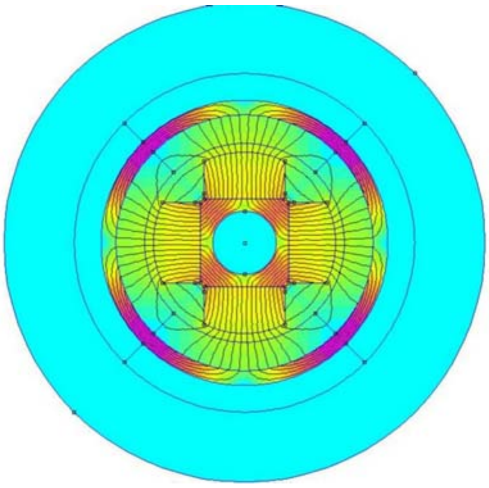

Fig. 9: Torque motor with a large air-gap in no load conditions — magnetic field distribution

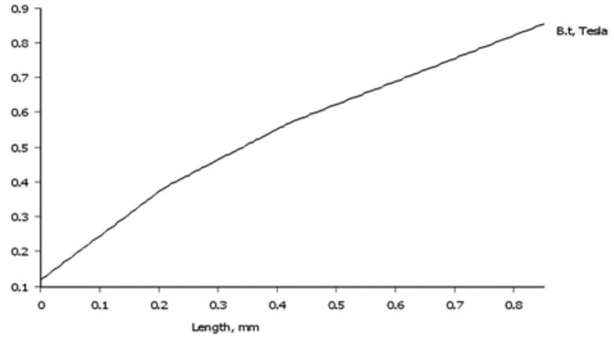

Fig. 10: Tangential flux density diagram in the rotor hub, through the magnet axis

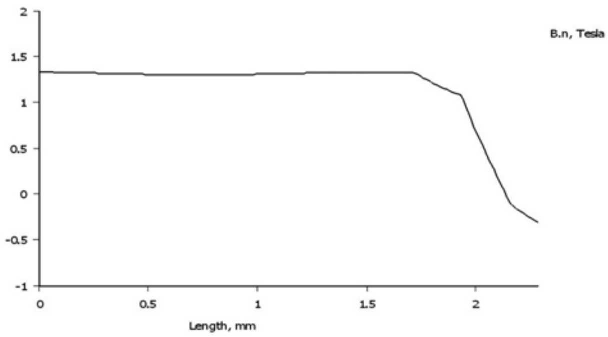

Fig. 11: Normal flux density diagram in the rotor hub, in the neutral area

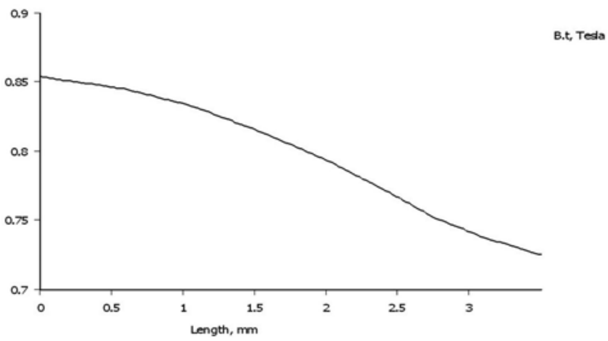

Fig. 12: Tangential flux density diagram, on the magnet, through the magnet axis

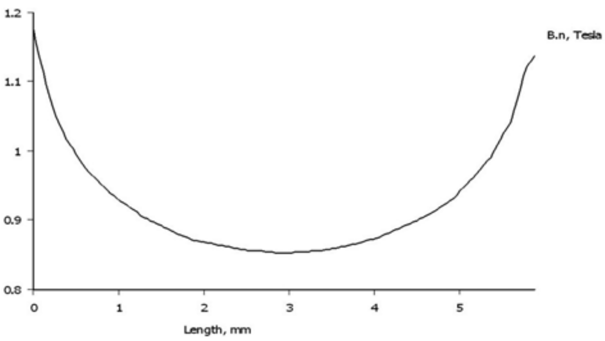

Fig. 13: Normal flux density diagram, transversal on the magnet, in the base of the magnet area

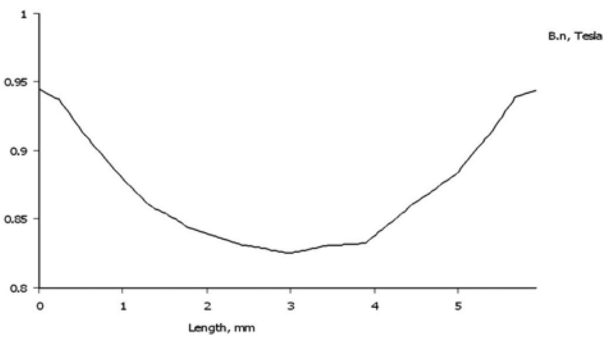

Fig. 14: Normal flux density diagram, transversal on the magnet, in the base of the middle area

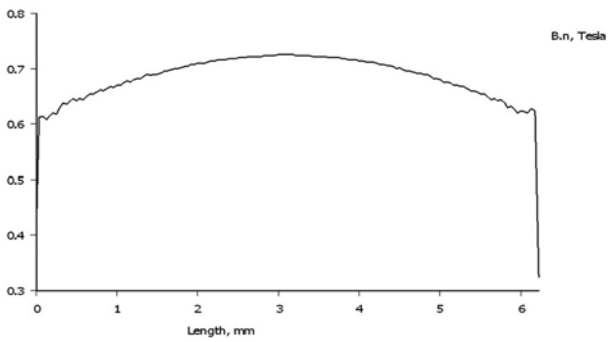

Fig. 15: Normal flux density diagram, transversal on the magnet, at the limit to the air-gap area

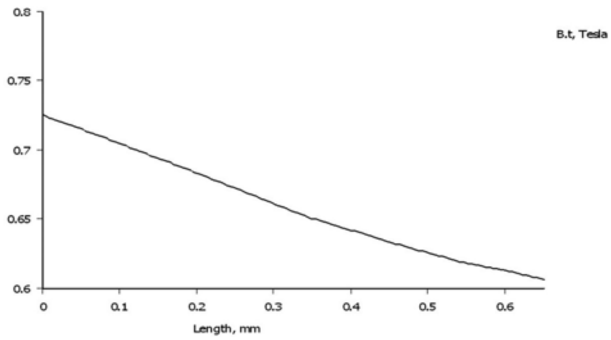

Fig. 16: Tangential flux density diagram in the air-gap area, through the magnet axis

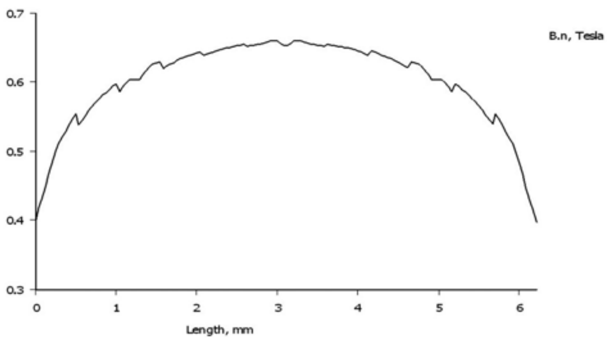

Fig. 17: Normal flux density diagram in the air-gap area, on polar pitch

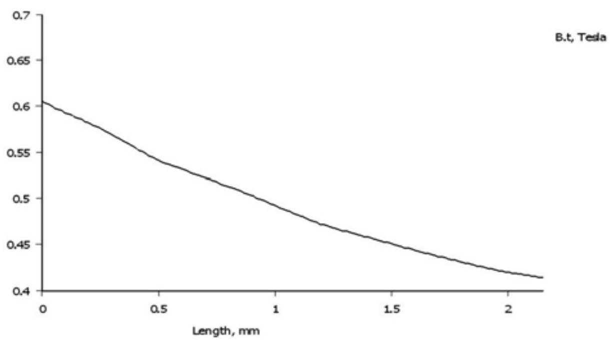

Fig. 18: Tangential flux density diagram in winding area, through the magnet axis

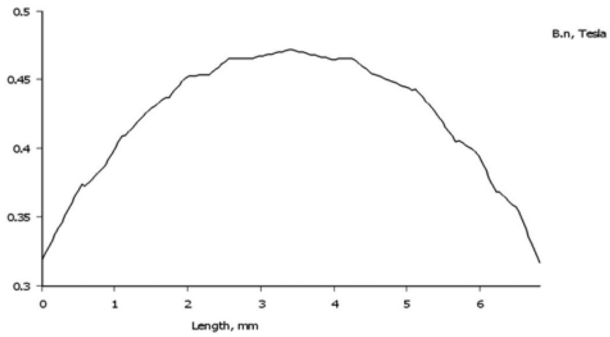

Fig. 19: Normal flux density diagram in the winding area, on polar pitch

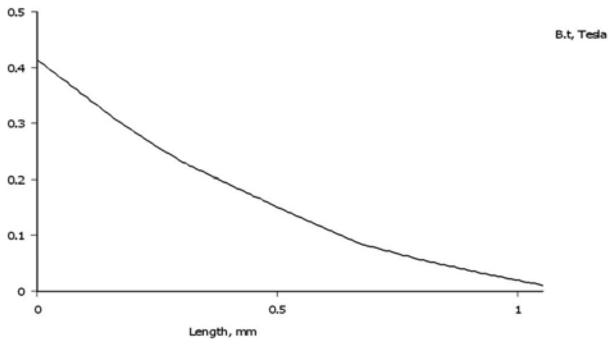

Fig. 20: Tangential flux density diagram in the stator core area, through the magnet axis

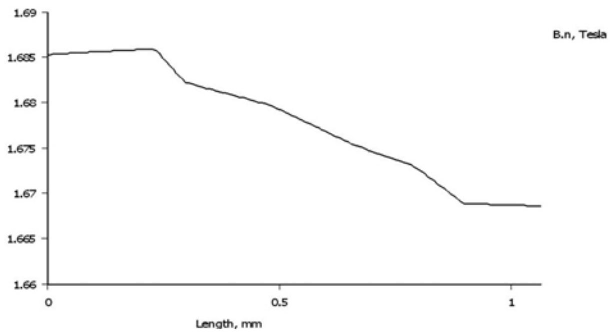

Fig. 21: Normal flux density diagram in the stator core area

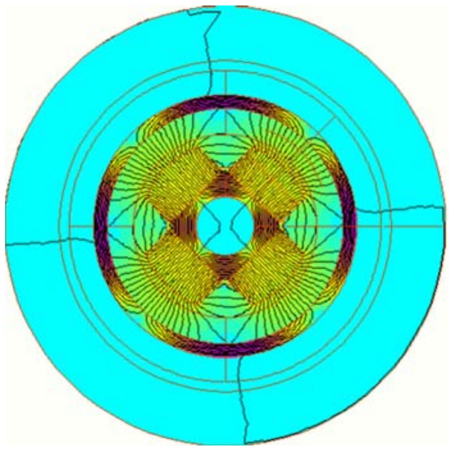

Fig. 22: Torque motor with a large air-gap in load conditions at 1A – magnetic field distribution

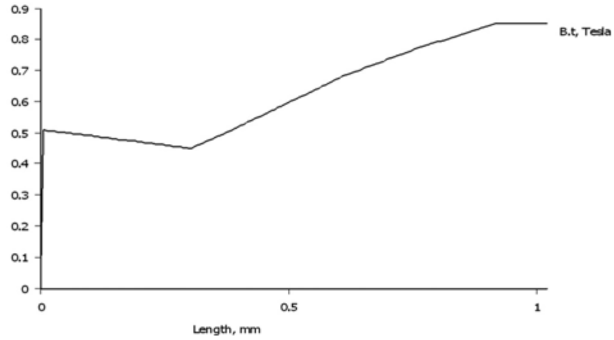

Fig. 23: Tangential flux density diagram in the rotor hub, through the magnet axis

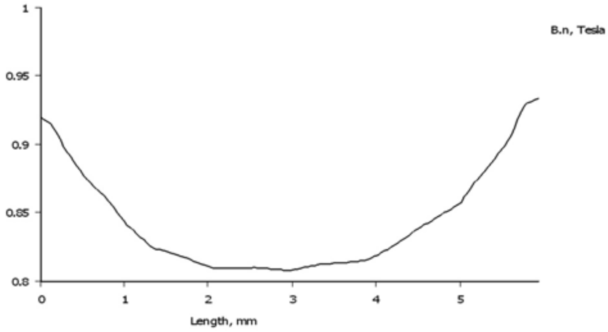

Fig. 27: Normal flux density diagram, transversal on the magnet, in the middle area

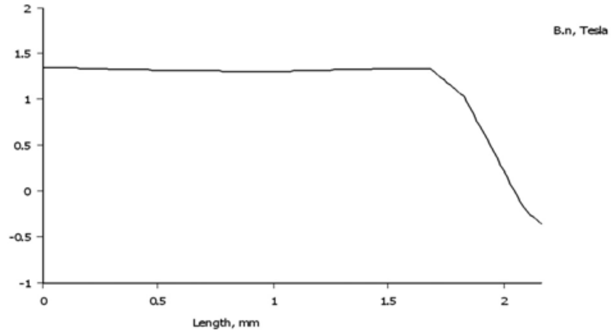

Fig. 24: Normal flux density diagram in the rotor hub, in the neutral area

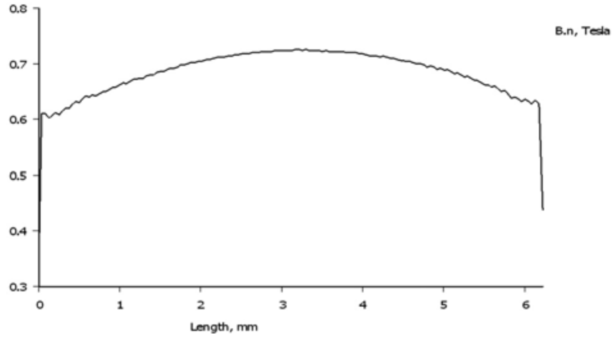

Fig. 28: Normal flux density diagram, transversal on the magnet, at the limit to the air-gap area

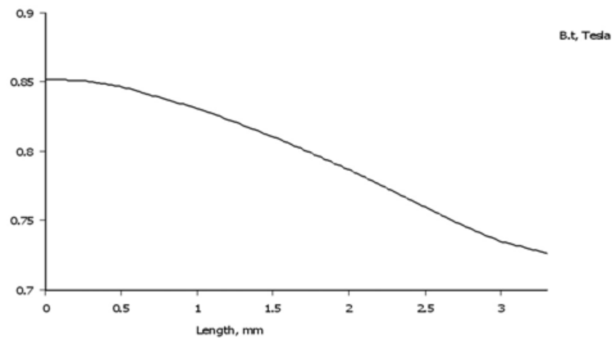

Fig. 25: Tangential flux density diagram, on the magnet, through the magnet axis

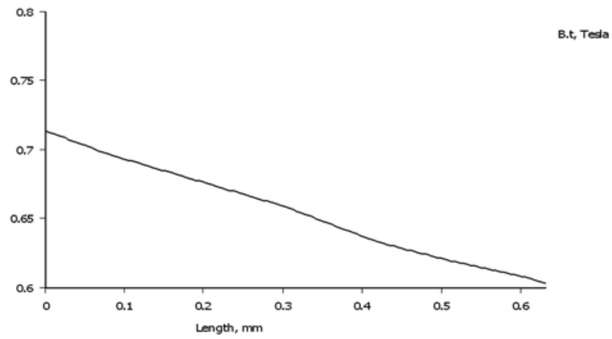

Fig. 29: Tangential flux density diagram in the air-gap area, through the magnet axis

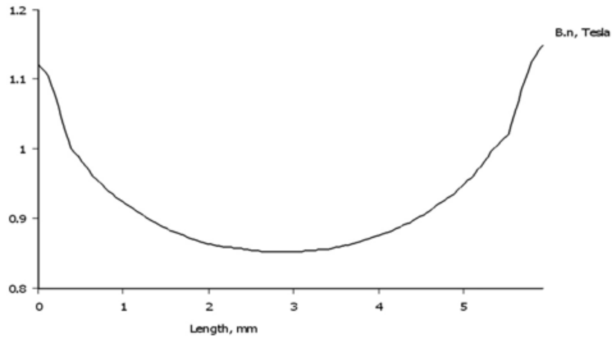

Fig. 26: Normal flux density diagram, transversal on the magnet, in the base of the magnet area

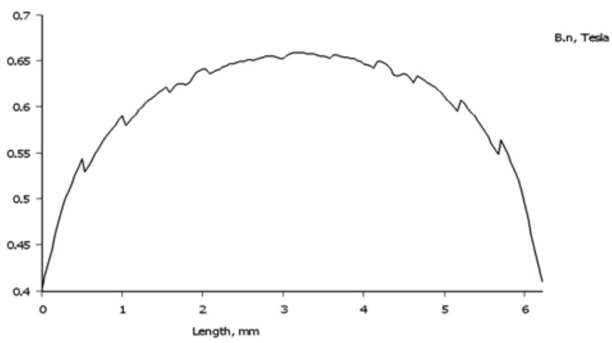

Fig. 30: Normal flux density diagram in the air-gap area, on polar pitch

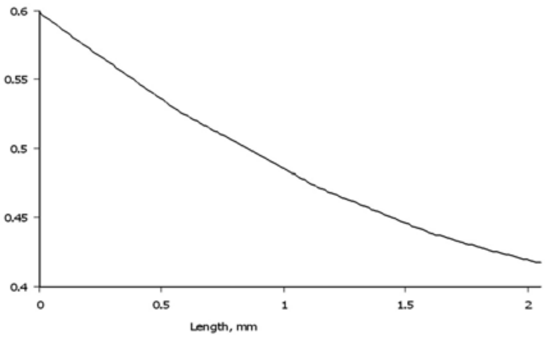

Fig. 31: Tangential flux density diagram in the winding area, through the magnet axis

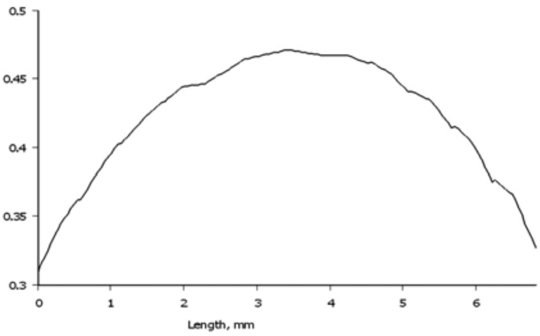

Fig. 32: Normal flux density diagram in the winding area, on polar pitch

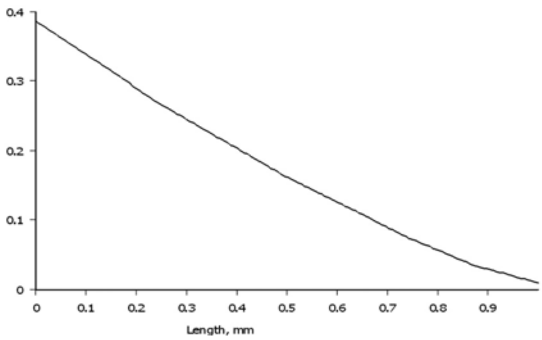

Fig. 33: Tangential flux density diagram in the stator core area, through the magnet axis

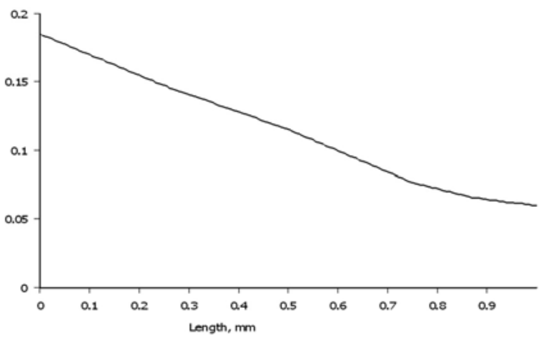

Fig. 34: Normal flux density diagram in the stator core area, through the magnet axis

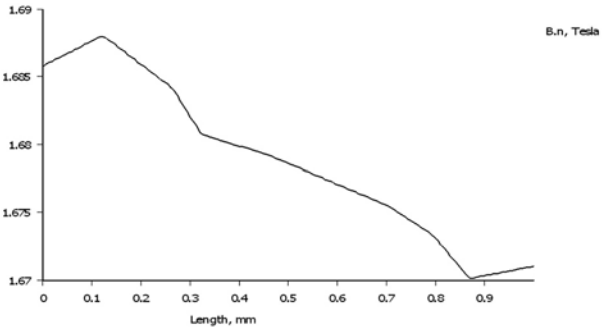

Fig. 35: Normal flux density diagram in the stator core area

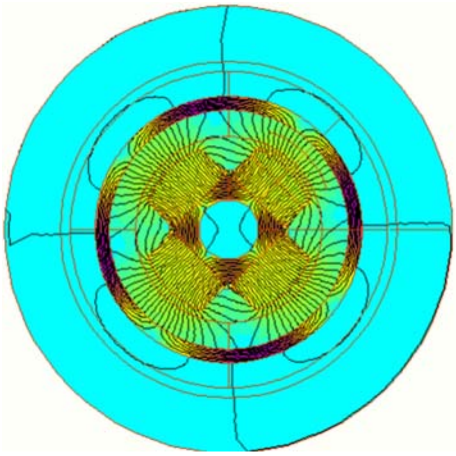

Fig. 36: Torque motor with a large air-gap in load conditions at 5A — distribution of the magnetic field

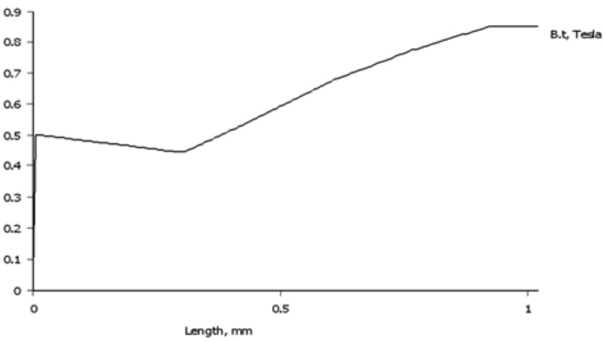

Fig. 37: Tangential flux density diagram in a rotor hub, through the magnet axis

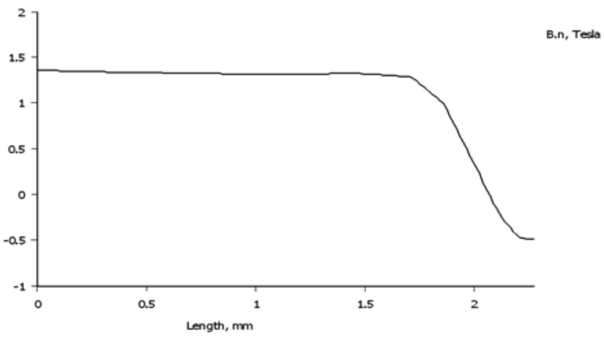

Fig. 38: Normal flux density diagram in the rotor hub, in the neutral area

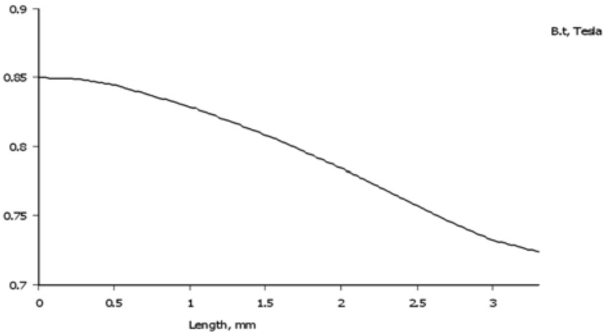

Fig. 39: Tangential flux density diagram, on the magnet, through the magnet axis

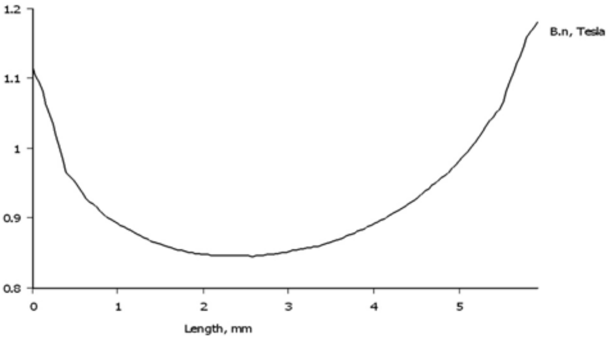

Fig. 40: Normal flux density diagram, transversal on the magnet, in the base of the magnet area

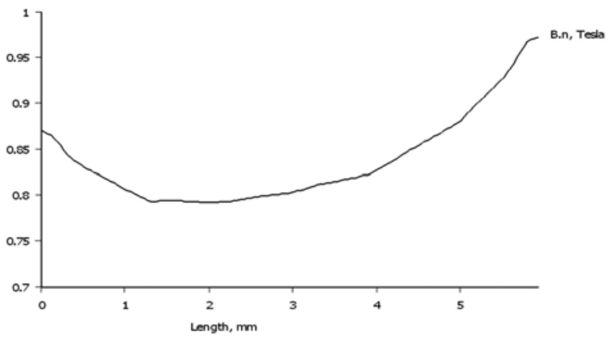

Fig. 41: Normal flux density diagram, transversal on the magnet, in the middle area

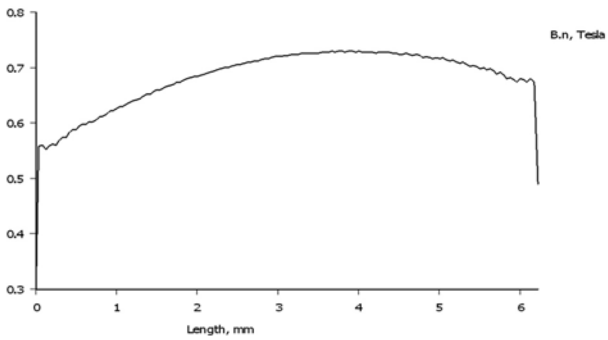

Fig. 42: Normal flux density diagram, transversal on the magnet, at the limit to the air-gap area

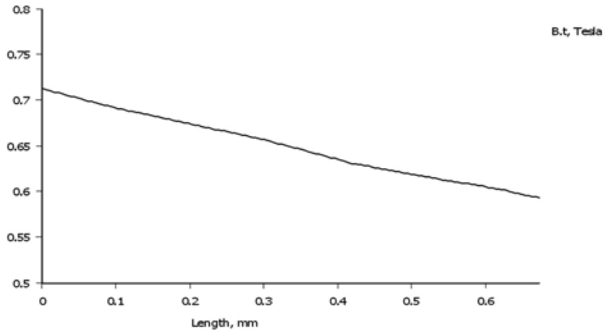

Fig. 43: Tangential flux density diagram in the air-gap area, through the magnet axis

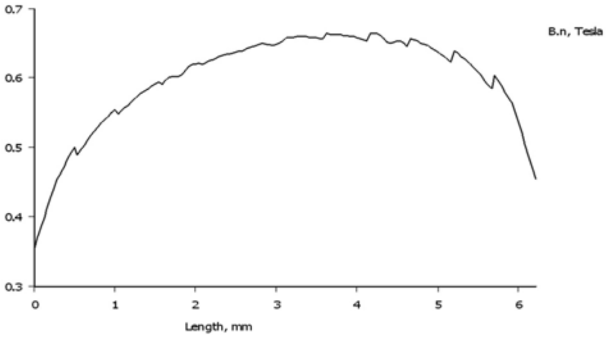

Fig. 44: Normal flux density diagram in the air-gap area, on polar pitch

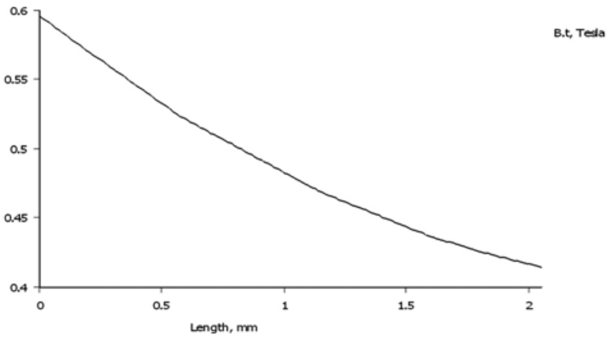

Fig. 45: Tangential flux density diagram in the winding area, through the magnet axis

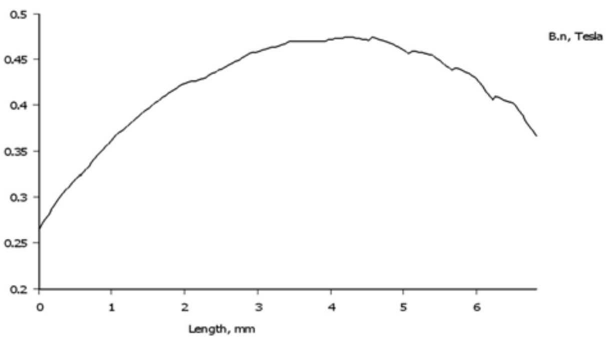

Fig. 46: Normal flux density diagram in the winding area, on polar pitch

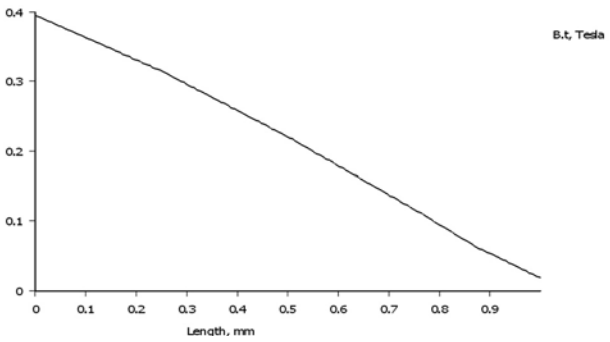

Fig. 47: Tangential flux density diagram in the stator core area, through the magnet axis

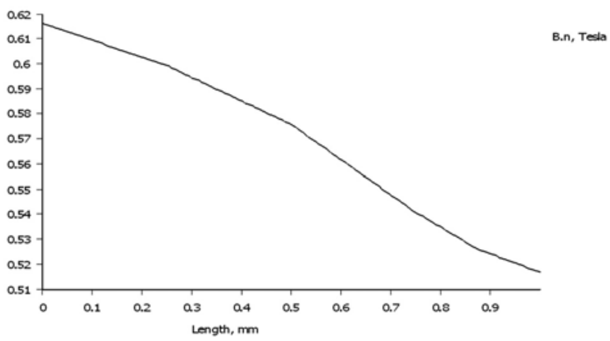

Fig. 48: Normal flux density diagram in the stator core area, through the magnet axis

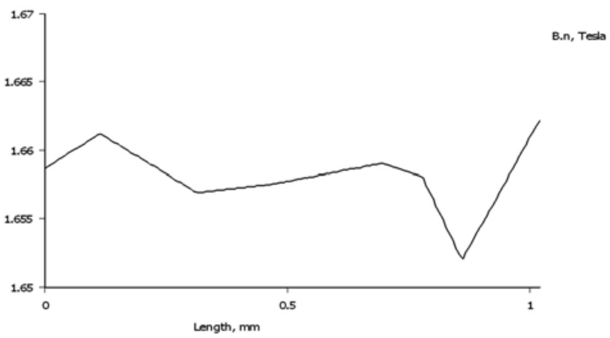

Fig. 49: Normal flux density diagram in the stator core area

The diagrams above present three different situations of a torque motor, limited angle, that can be met in applications: no-load conditions, or a very low load, below 1A, which is the most usual situation, and below a 5A load, which is considered to be a peak torque situation.

It is extremely important to consider the magnetic field in any of the above situations, because the goal of the motor design is to put maximum power into a certain volume (maximum torque), while assuring that the motor operates properly in any working regime of interest.

There are many areas where a designer controls the evolution of the magnetic field in various working regimes, but those mentioned above are the most important: to control the status of the dispersion field between the magnets; to control the level of the field and the influence of the winding field in the permanent magnet area; to control the level of saturation in the rotor hub area, as well as in the stator core area; to control the level and distribution of the field in the winding area.

4 Conclusion

Limited angle torque motors are important components used in various applications: control systems, automatic systems, drive systems, etc.

Most limited angle torque motors have a pancake configuration, which means two separate parts: a rotor and a stator. In this way, such motors can easily be adapted and assembled in the above systems.

Present day applications require limited angle torque motors with: the smallest possible relative size and dimensions; the highest possible torque density, which means the highest possible torque constant relative to a certain volume; a high insulation class, which means having the ability to work in harsh ambient conditions, at high current density.

General classical formulas can be used to design a limited angle torque motor, but it is difficult to achieve the best results in this way. It is only by using numerical methods, based on finite element analysis, that the magnetic field can be controlled in any area of interest ensuring that: any area is properly dimensioned; the total volume is used optimally; and the maximum torque constant is obtained.

This way was used to analyze, design and produce many types of very well performing limited angle torque motors, with different sizes and electric parameters, with outer diameters from 15 mm to 300 mm, and also with a torque constant from 5 mNm/A to 5 Nm/A.

One of the most special limited angle torque motors has two poles and an angular excursion of ± 40 degrees. When there was an outer diameter of 40 mm and a length of 9 mm, it was necessary to have 20 mNm/A as the torque constant, but 75 mNm at 4.5 A. Earlier motors had worked properly only up to 2.5 A. At a higher current, saturation caused faster degradation of the torque constant. Only using numerical methods was it possible to design a magnetic circuit and a winding distribution that would meet the application requirements.

Acknowledgement

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