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# Non Sinusoidal Torque of Permanent Magnet Couplings

V. Lemarquand, J. F. Charpentier, G. Lemarquand

*Abstract*—This article presents new structures of permanent magnets couplings and their way of calculation. The analytical formulas of the force between two magnets are used to calculate the torque of the couplings. This allows to optimize the structures and to compare them easily for several criteria. The presented structures are fitted out with magnets on one rotor, which have not the same angular width, and magnets on the other rotor, which are not necessarily jointive nor have the same angular width. As a result, these structures appear to be very interesting in terms of maximal torque, of torque-to-weight ratio and of magnet volume. Such devices are particularly interesting for applications such as screwing devices.

*Keywords* - Magnetic coupling, Permanent magnet, Torque.

## I. INTRODUCTION

PERMANENT magnet couplings are devices whose utilization is now well-known in all the industrial fields where rotating parts have to be rotated without any contact with the driving part, either for speed reasons or for watertightness reasons. Classical devices have been largely described [?], [?] and calculation methods have been proposed [?]. This article proposes a new analysis of the calculation of the torque of PM couplings, based on the decomposition in elementary torques that are the result of the action of each type of magnets. It also presents new structures of couplings that are particularly efficient, for all kinds of applications and more especially for screwing devices applications.

Indeed, the torque of classical devices varies symmetrically with the angular shift of the rotors, and the curve is sinusoidal looking. The structure we propose has the peculiarity of a non symmetrical torque variation versus the rotors angular shift. This fact is very important. It is of great interest for applications to screwing devices. As a matter of fact, let us take the example of such a device in which the led rotor is used to screw something until a given value of torque. This special value has to be the maximal transmitted one for the coupling. The rotors rotate synchronously as long as the maximal value is not reached. After the pull-out, the led rotor goes on rotating, but its rotation is asynchronous with the leading rotor. The shifting angle between

the rotors increases, so the torque decreases and may become negative. The result is then an unscrewing. But if the negative torque has values far smaller than the positive ones, the unscrewing will be partial. There may be no unscrewing at all, if the absolute value of the negative torque remains smaller than the value of the dry friction torque. So, this property of dissymmetry is a really interesting one.[?]

## II. NON SINUSOIDAL TORQUE STRUCTURE

### A. Presentation of the geometry

We consider couplings with a cylindrical airgap. Such a permanent magnet coupling is fitted out with magnets stuck on the inner rotor and alternately magnetized and another set of magnets stuck on the outer rotor and also alternately magnetized. Both rotors are made out of a non magnetic material. The classical design of such devices leads to magnets that have all the same size on one rotor. They may be either jointive [?] [?] or parallelepipedic and apart from each other for a better use of the material [?] [?]. In the existing devices, all the magnets have the same angular size. The angular size of a north pole is equal to the angular size of a south pole and the dimension is the half of the pole pitch on both rotors.

The presented calculation method is very general, and has already been applicated to some studies [?] [?] but we want to illustrate it in the case of an original geometry, which is showed in Fig.??.

The magnets on the inner rotor are jointive but of different width. We call a north pole a magnet whose magnetization is oriented towards the airgap. We call  $\alpha$  the cyclic ratio of the pattern, which is the ratio of the width of an inner north pole over the width of two consecutive poles (the latter being the pole pitch  $\theta_p$ ).  $\alpha=0.5$  corresponds to the classical devices.

The magnets on the outer rotor are not jointive. The width of a south pole is equal to the width of a north pole,  $\sigma$  and the parameter  $\beta$  is defined as follows :

$$\beta = \frac{\sigma}{\theta_p/2} \quad (1)$$

### B. Calculation of the torque

In this section we consider a one meter long coupling with ten pairs of poles (P=10) and with following values of

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The authors are with the Laboratoire d'Electrotechnique et de Magnetisme de Brest, IUT-ENSIETA, rue de Kergoat, 29287 Brest, France.

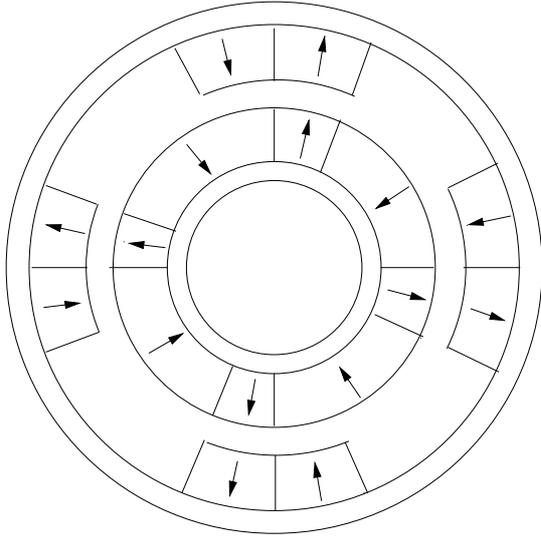


Fig. 1. Original geometry of a coupling

the defined parameters :

$$\alpha = 0.25 \quad (2)$$

$$\beta = 0.5 \quad (3)$$

This means that for our example we have following values :

$$\begin{aligned} \theta_p &= 36^\circ \\ \text{Inner south width} &= 27^\circ \\ \text{Inner north width} &= 9^\circ \\ \text{Outer south width} &= 9^\circ \\ \text{Outer north width} &= 9^\circ \end{aligned} \quad (4)$$

The inner south poles are three times wider than the inner north poles. The outer south poles have the same width as the outer north poles. They are jointive on one edge, but each pair of poles is separated from its neighbour by air (Fig.??). The half of the space along the periphery of the outer rotor is occupied by air.

The length of the mechanical airgap is 2mm, the height of the magnets is 10 mm and the radius of the device in the middle of the airgap is 100 mm.

The torque of the device is analytically calculated by the use of the formulas of the force between two parallelepipedic magnets.

The total torque can be seen as the result of the action of all the magnets of the inner rotor on all the magnets of the outer rotor. The torque is of course deduced from the force by its multiplication by the radius of the device. We will describe the torque as the sum of several contributions.

Figure ?? shows the torque exerted between two magnets radially magnetized [?], for example one north pole of

the inner rotor on one south pole of the outer rotor. This curve is of course symmetrical : the positive maximum has the same absolute value as the negative maximum. The angular origin is taken for the position of the rotors where the torque is zero.

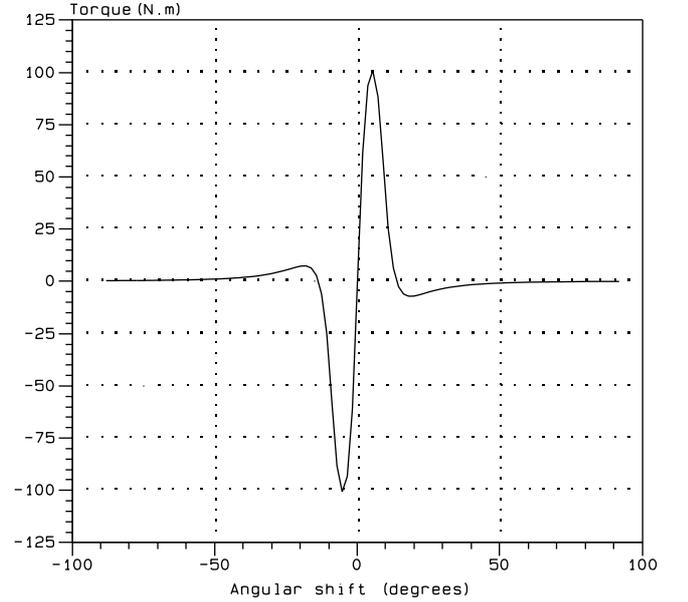


Fig. 2. Torque created by one inner north pole on one outer south pole.

The angular variation of the torque resulting from the action of one magnet (north pole) of the inner rotor on all the south poles of the outer rotor can be constructed as the superposition of previous curve with the same curve angularly shifted of an angle corresponding to the spatial periodicity of the south poles of the outer rotor, that is the pole pitch  $\theta_p$  ( $36^\circ$ ). If there are P pairs of poles ( $P=10$ ), there will be P curves, each shifted of  $k\theta_p$ , with k varying from 0 to (P-1). The obtained pattern is of course periodical, the angular period is the pole pitch  $\theta_p$  (Fig. ??). The symmetry of the maximal values is maintained.

The action of the P north poles of the inner rotor on the P south poles of the outer rotor is deduced from the preceding curve by a simple multiplication of the values by P. Indeed, a north pole of the inner rotor has the same contribution as its "neighbouring" north pole, but shifted of  $\theta_p$ . As this is the period of the curve, the two curves are strictly identical, and the superposition of the P curves results in a multiplication of the values by the number of north poles considered (Fig. ??).

Figure ?? (continue) shows now the torque resulting from the interaction of the inner north poles on the outer north poles. When compared to the preceding one, the

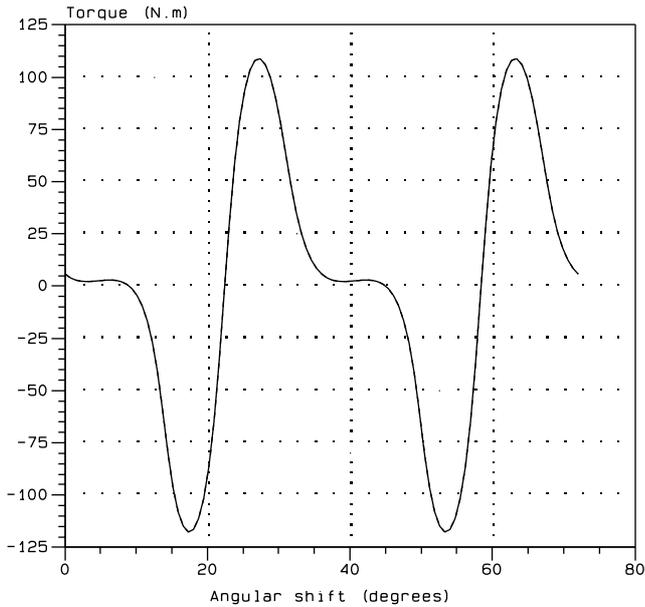


Fig. 3. Torque created by one inner north pole on all the outer south poles versus the angular shifting of the rotors.

change of nature of the poles of the outer rotor has as consequence a change of sign and an angular shifting. This shifting corresponds here to the width of one outer pole,  $\sigma$ , ( $9^\circ$  as said in (??)). One can notice that in our example the maximum of each curve corresponds to the same position of the rotors (shifting angle= $27^\circ$ ). This is due to the fact that the outer north and south poles have the same size.

Figure ?? shows two curves : one represents the torque variations resulting of the action of the inner north poles on the outer north poles, the other gives the torque produced by the inner south poles on the outer north poles. Both curves have the same general shape because, though the tangential forces between the different sets of magnets are respectively repulsion and attraction, they contribute to the same sense of torque.

As the inner south poles are wider than the north poles (inner and outer), the peaks of the corresponding curve become wider, and the maximum position is shifted. This position corresponds to a shifting angle for which the radial edges of the inner magnets are facing the middle of the outer magnets. The part of the curve where the torque varies rapidly always corresponds to this kind of magnets configuration.

Figure. ??(dashed) (respectively, Fig. ??(dashed)) shows the torque due to the action of the inner south poles on the outer north poles (respectively, the outer south poles). Again, one curve can be deduced from the other. Firstly, by changing the sign of the torque value. And sec-

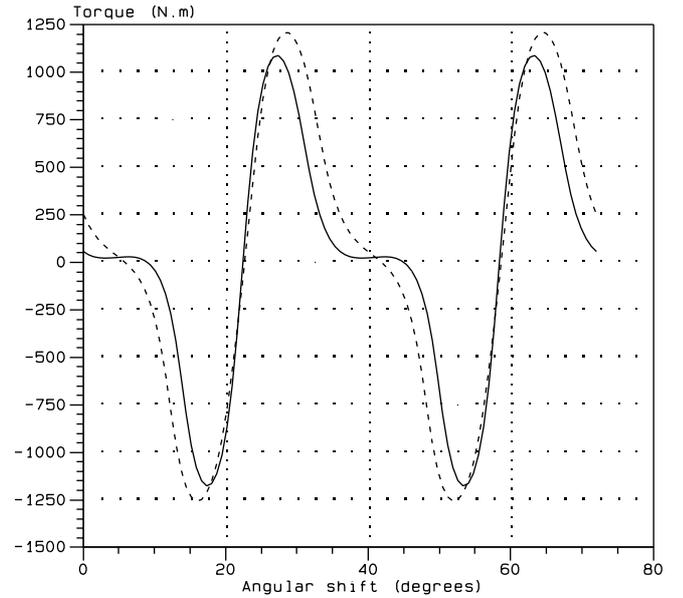


Fig. 4. Torque created by all the inner north poles on all the outer south poles (continue) and by all the inner south poles on all the outer south poles (dashed) versus the angular shift of the rotors.

only by shifting the thus obtained curve of the same angle as previously described in the case of the inner north poles (width of one outer pole,  $\sigma$ , ( $9^\circ$  as said in (??)).

The total torque (Fig.??) is effectively the addition of the four previous elementary torques. One has to note that as the maximum value of the four interactions occur approximately for the same position of the rotors, the total maximum torque is the sum of the four maximum values. In fact, the positive maximum occurs naturally for a position of the rotors that is intermediate between the positions of the maxima for inner south poles and inner north poles. On the contrary, the minimal values occur for the same position for only two types of interactions (Fig. ??, Fig. ??). The total minimal torque is therefore the addition of two minimal values only. Thus the positive maximal torque is nearly the double of the negative maximal torque.

When applied to a classical device, where all the magnets have the same size and are at the same distance from their "neighbours", this method gives the well-known result of a sinusoidal total torque, resulting from the superposition of four sinusoidal elementary torques. But this new structure allows to see more easily how each type of magnet contributes to the total torque.

### III. STUDY OF THE NEW STRUCTURE

As a result of our example, we note that the curve representing the total torque is no longer symmetrical and we

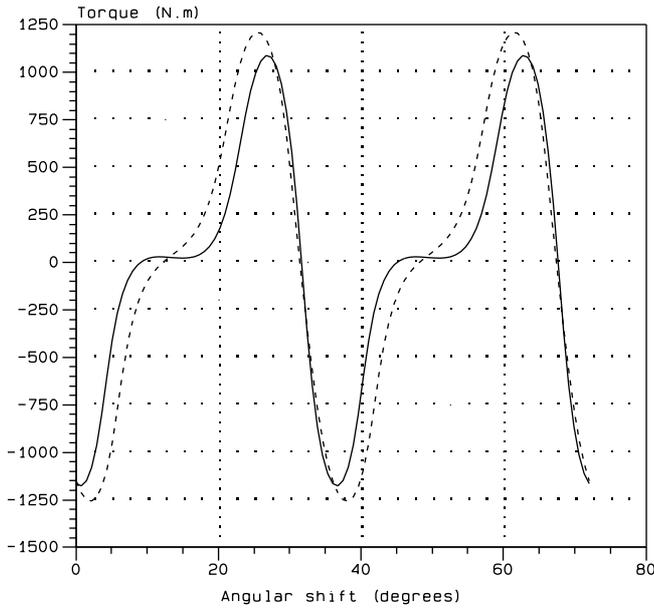


Fig. 5. Torques created by all the inner north poles on all the outer north poles (continue) and by all the inner south poles on all the outer north poles (dashed) versus the angular shifting of the rotors. The south poles are wider than the north poles.

want to discuss this now, as well as the influence of the several geometrical parameters. The parameters whose influence is studied are the number of pole pairs,  $P$ , and the widths of the magnets (described by  $\alpha$  and  $\beta$ ). We first want to present the influence of  $\alpha$  and then, the influence of  $P$ .

#### A. Influence of $\alpha$

We consider the structure that has already been presented. We still assume that the poles on the outer rotor have the same angular size and we first consider a geometry with ten pairs of poles.

For this set of values ( $\alpha=0.25$ ), we previously explained that the four maxima were added and so were two minima, and there was a great undulation as there were two positions of maximal negative values between two consecutive maximal positive values. The torque went back to zero between the two maximal negative values.

When  $\alpha$  is varied, the shape of the total torque is modified.

When  $\alpha$  increases ( $\alpha=0.30, 0.33, 0.35, 0.5$ ) (Fig. ??), the maximal values -both positive and negative- increase but the undulation decreases. The torque does not vary as much between the two maximal negative values. There exists a value of  $\alpha$  for which the torque remains at its maximal negative value over an angular range that corresponds to the distance between the previous maximal negative values.

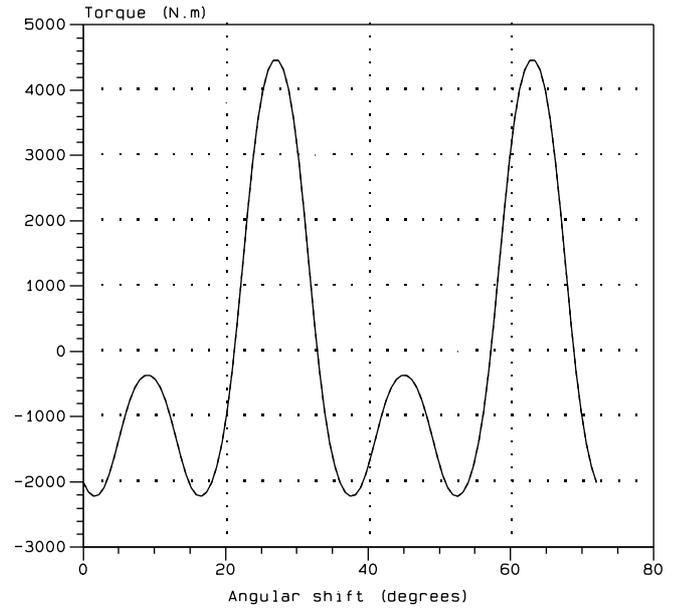


Fig. 6. Total torque versus the angular shift of the rotors.

This can be explained by the fact that when  $\alpha$  increases, the peaks of the curves of the elementary torques become wider and the positions for the maxima move apart. Thus, when superposed, the positive maxima still occur approximately for the same position, but the negative ones come closer one to the other and the torque decreases less and less towards zero between two negative maxima. For a given value ( $\alpha = 0.33$ ) it does not decrease any more and for even greater values the torque increases negatively between these two positions. Of course, the shape tends towards the sinusoidal curve of the classical device ( $\alpha=0.5$ ).

When  $\alpha$  decreases ( $\alpha=0.2, 0.15$ ), the maximal positive value decreases and so do the maximal negative values. This is normal, as the magnets volume decreases. The torque remains zero over a larger angular range between the minima, because the couples of outer magnets are separated by a larger portion of air. The curves of the elementary torques have "thin" peaks, and the angular portions where the torque is zero get superposed.

#### B. Influence of the number of pole pairs, $P$ .

For classical devices, the value of the maximum torque depends on the number of pole pairs and there exists an optimum of this number to reach a given torque value. In the new structure also, the maximal value of the torque depends on the number of the pole pairs. Moreover the influence of the parameter  $\alpha$  is more or less important and depends on the number of pole pairs too. This can be seen on Fig.( ??, ??, ??) and it is more easily analyzed on Fig.?? that rep-

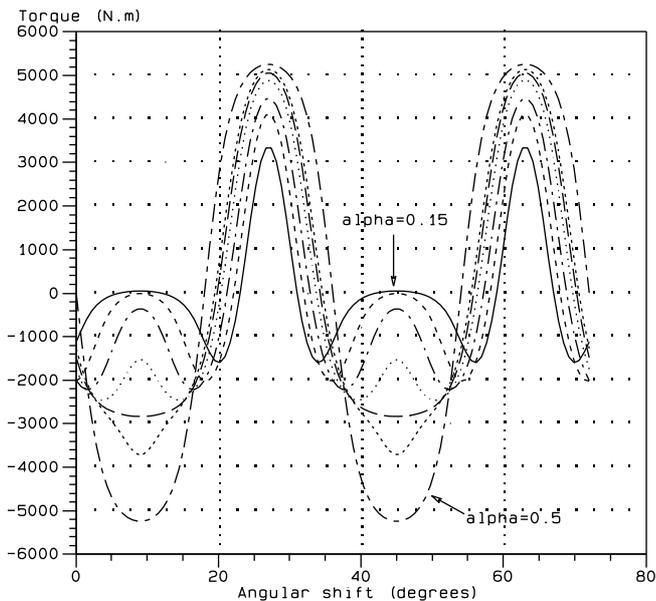


Fig. 7. Total torque variation versus angular shift of the rotors. ( $P = 10$ ). From bottom to top in the negative values,  $\alpha = 0.5, 0.35, 0.33, 0.30, 0.25, 0.2, 0.15$ . Note that  $\alpha = 0.5$  is the classical device.

resents the ratio of the maximal torque for a value of the  $\alpha$  parameter over the maximal torque for  $\alpha = 0.5$  - the classical device is taken here as reference-, and this, for several values of the number of pole pairs. The new structures are thus compared with the classical device that has the same number of pole pairs. This choice can be explained by the fact that all the structures have then the same number of magnet pieces and so, approximately the same mounting price.

It clearly appears that for great numbers of pole pairs, ( $P \geq 10$ ), the variations of  $\alpha$  (and the corresponding enhancement of the dissymmetry) lead to lower torques for the new devices. But there is a peculiar number of pole pairs for which the torque is the same for both types of structures. Moreover, the torque is greater in the new device for small numbers of pole pairs ( $P < 10$ ) (Fig. ??, ??).

If we characterize the dissymmetry of the torque variations by the ratio of the maximal positive torque value,  $T_{\max}$ , over the absolute value of the maximal negative one,  $T_{\min}$ , the dissymmetry is higher for great numbers of pole pairs and small values of  $\alpha$  (Fig.?? ). It seems possible to find a compromise to have a high dissymmetry and to keep good performances of the device. A number of pole pairs around 10 is quite a good compromise for our example. This compromise depends of course on the choice of the dimensions (radius and airgap) of the device. The corresponding dissymmetry is characterized by a positive torque two times

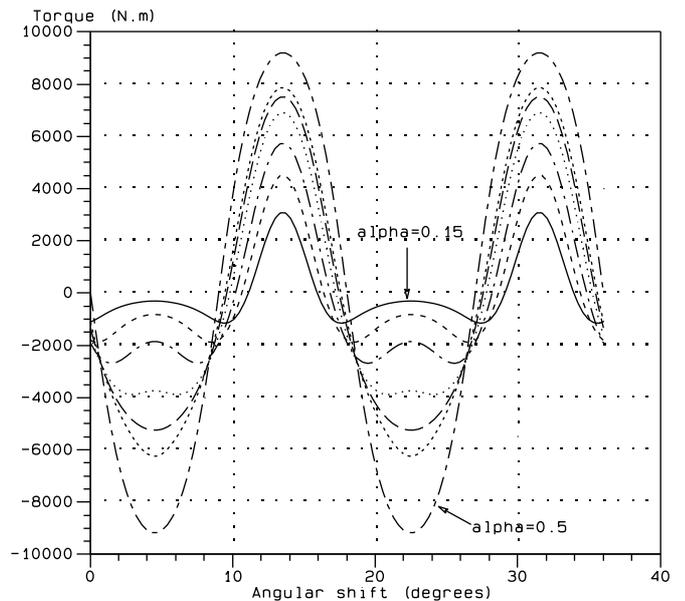


Fig. 8. Total torque variation versus angular shift of the rotors. ( $P = 20$ ). From bottom to top in the negative values,  $\alpha = 0.5, 0.35, 0.33, 0.30, 0.25, 0.2, 0.15$ . Note that  $\alpha = 0.5$  is the classical device.

higher than the absolute value of the negative one.

This result has to be emphasized, as this means that the new devices can have the same torque performances as the classical ones (in fact they can be even better) for the same number of pole pairs. But they have in addition the advantage of a dissymmetrical torque behavior, which is to be appreciated in screwing devices. Moreover, as the magnets of one rotor are not jointive and are twice as small as in the classical device, the corresponding rotor carries a weight of magnets that is the half of the weight in a classical device. If this rotor is the led one, this means that its inertia is proportionally reduced and this is also of great importance in the applications.

#### IV. CONCLUSION

This study explains how the different magnets of a magnetic coupling participate to the global torque. This allows naturally to understand why the torque of a classical device is symmetrical when the angular shift between the rotors varies. But, in the new presented structure, the magnets have different dimensions and the consequence is a dissymmetry of the part they play. This results in a torque behavior that is dissymmetrical. The study of the influence of the relevant parameters of this geometry shows that there exist solutions that present a high dissymmetry of the torque as well as a maximum torque value unchanged with regard to the corresponding classical device (with the same number of

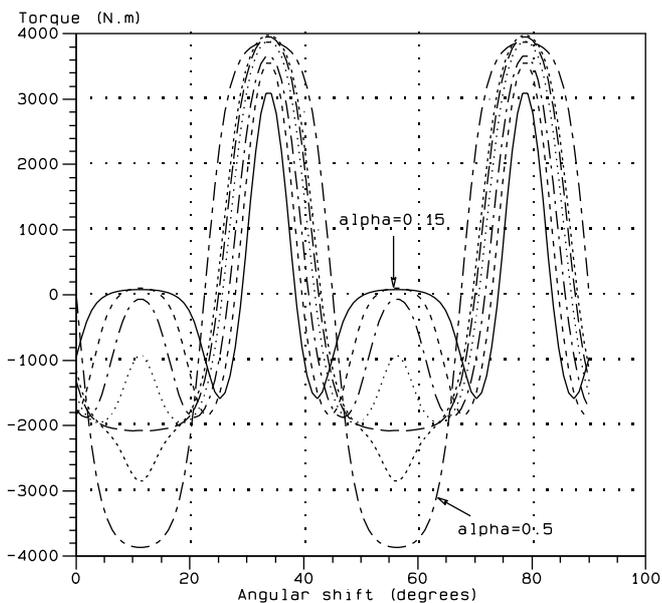


Fig. 9. Total torque variation versus angular shift of the rotors. ( $P = 8$ ). From bottom to top in the negative values,  $\alpha = 0.5, 0.35, 0.33, 0.30, 0.25, 0.2, 0.15$ . Note that  $\alpha = 0.5$  is the classical device.

pole pairs). The torque can even be greater and the device is lighter. In summary, this new structure seems promising, because it has all the advantages of the classical one and even more : it can have at the same time a smaller weight and a higher torque than a classical device and a dissymmetrical torque behavior. Such devices can be very interesting for industrial applications such as screwing devices.

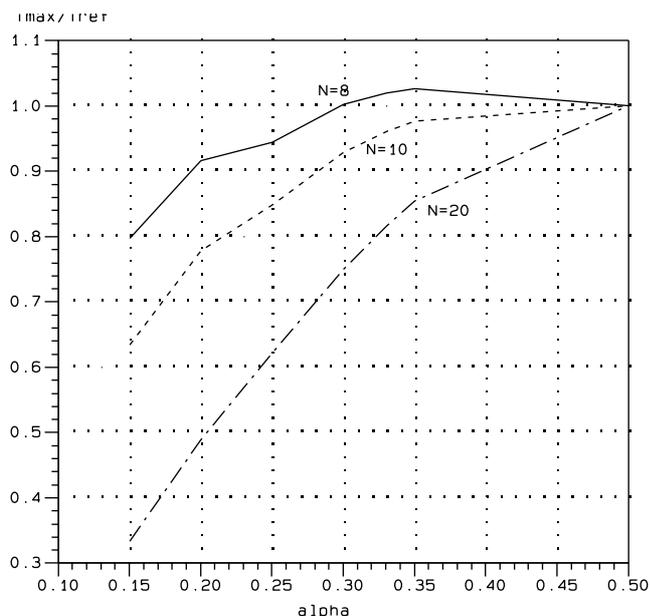


Fig. 10. Ratio of the maximum torque over the reference torque (classical device torque) versus  $\alpha$  for several numbers of pole pairs.

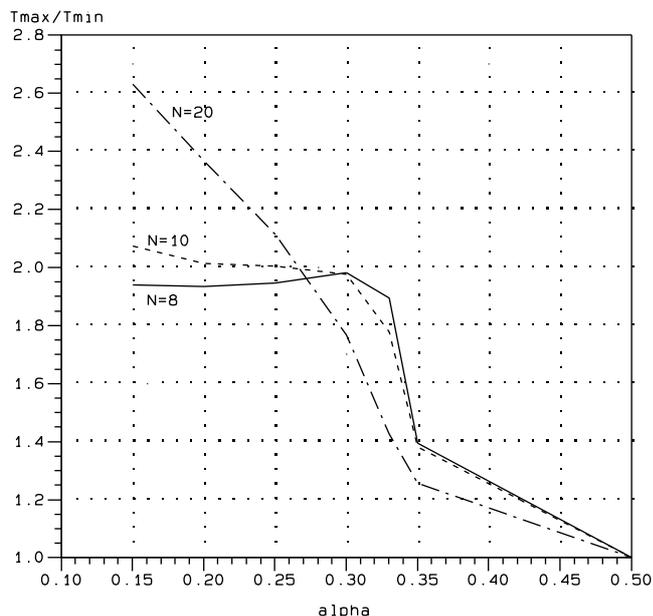


Fig. 11. Characterization of the dissymmetry by the ratio of the maximum torque over the absolute value of the minimum torque versus  $\alpha$ , for several numbers of pole pairs.