METHODS FOR CALCULATING THE TRANSMISSION TORQUE OF MAGNETIC TRANSMISSION MECHANISMS

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Abstract: The methods of analyzing and calculating the magnetic field and the main problems of designing magnetic mechanisms are reviewed and discussed. The comparatively precise engineering methods for calculating the transmission torque of the plane axial and coaxial radial magnetic transmission mechanisms based on the magnetic theory are introduced, which can be used for optimization of designing the magnetic transmission mechanism. Two application instances of magnetic transmission mechanisms used in the Three-For-One and Two-For-One textile twisting machine are introduced, and the transmission torque of the mechanisms are measured by experiment and calculated by means of the engineering methods.

Key words: Magnetic mechanism, Torque, Calculation, Design.

1. INTRODUCTION

The magnetic coupling transmission mechanism is one of the main application of magnetics. The main task for designing the magnetic coupling transmission mechanism is determination of the reasonable mechanical electromagnetism structural style and the parameters, so as to realize the transformation of magnetic energy into mechanical energy, accomplish a certain movement and drive requirement. Simplifying and transforming the problem of magnetic field as the problem of magnetic circuit is a general design method used at present[1, 2, 3]. Generally, the following factors must be considered: (1) the transmission torque ought to be able to meet the operation needs; (2) the structure size ought to be as far as possible compact, the magnetic material used ought to be as far as possible little; (3) the dynamic performance of the mechanism(vibration, noise and so on) ought to

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be satisfy the requirements. At present, there is still no more complete satisfactory method for calculating the transmission torque of the magnetic mechanism, it is still relied on the empirical data and the empirical formulas.

2. THE METHODS OF ANALYSIS AND DESIGN OF MAGNETIC MECHANISMS

The method for analyzing and calculating the magnetic field and the transmission torque of magnetic mechanism is the key problem of designing magnetic mechanism, which is attracted great attention in the academic and engineering circles. So far, some methods for calculating the magnetic field and the transmission torque have been given as follows[1, 2, 3, 4, 5].

(1) The test-calculation method together with experience or experiment based on the magnetic circuit concept. The main limitation of this method is that the calculating formula is generally made very great simplification, and the values of some parameters of the formula have to be given based on experience. Thus, the calculated results by using this method have low precision, on the other hand the calculation and design are blindness in some degree, and the operation load is great.

(2) The Finite Element Method (FEM). The method FEM used in the electromagnetic field analysis is generally based on the Maxwell equation. For analyzing the permanent magnetic field with the FEM method, the permanent magnet is processed as boundary electric current model, this brings on massive mathematic analysis and calculation. Until now the effective mathematic analysis model for the permanent magnetic field hasn't been established.

(3) Analytic and approximate analytic methods. In the process of these methods, the processes of variable separation, effective equipotential surface, and even magnetization are always used. Among them, the variable separation is the basic analysis method for the problem with boundary value. For the effective equipotential surface method the ferromagnetic surface is modified as equipotential surface. For even magnetization method it is assumed that the magnetic material is magnetized evenly under the action of external field, then analyze and calculate the interelectrode field distribution.

In recent years the domestic scholars attempt to develop the equivalent magnetic charge method[6]. It is considered that the equivalent magnetic charge of permanent magnet is distributed on the two surfaces which are vertical to the direction of magnetization, and then the Coulomb force of the equivalent magnetic charge acted on the two surfaces, the torque between the two magnetic charge, the torque of magnetic field can be calculated.

3. ENGINEERING METHODS FOR CALCULATING THE TRANSMISSION TORQUE

There is much progress in the above-mentioned researches about the analysis and calculation of magnetic transmission torque, however, at present the research results are still immature and too complex, and almost impossible to instruct the engineering design. For instance, the paper [6] obtained the four multiple integrals expressions of calculating the magnetic torque for the plane axial magnetic transmission mechanism. But according this method and its expression the values of some parameters must be measured in advance, and this is almost impossible for the first development and design of a magnetic mechanism. Thus, here we attempt to give effective engineering methods.

Figure 1 shows the schematic drawings of the plane axial (a) and coaxial radial (b) magnetic transmission mechanisms. The transmission torque can be described as follows[4, 7]:

$$M = \frac{1}{2}\frac{V_m B_r^2}{\mu_0}\frac{r}{L_g}\frac{L_m}{L_g}\frac{K_f}{K_r}\frac{\sin\phi\cos^2\phi}{[1+(K_f/K_r)\bullet(L_m/L_g)\cos\phi]^2} \quad (1)$$

Where V_m---the sum of magnets volume in the drive rotor and driven rotor of magnetic mechanism, m3 ; $V_m = 2A_mL_m$; L_m---the average axial length of permanent magnets , m; A_m---the axial cross-sectional area of the permanent magnet, m^2 ; L_g---the axial space between the drive and the driven rotors, namely the air gap length, m; r---the mean radius of the permanent magnets distribution, m ; μ_0---magnetism constant, $\mu_0 = 4\pi \times 10^{-7}$, H/m; B_r---the remanence of the permanent magnet, T; K_f , K_r---the coefficients of the magnetism leakage and magnetism resistance respectively while the drive and driven rotors are rotating; $tg\ \Phi = r\theta / L_g$, θ—relative rotation angle between the drive and driven rotors, rad.

The equation (1) indicates that the transmission torque M is the function of angle ϕ, the relative rotation angle between the drive and driven rotors, while the other parameters are determined. For getting the limited value of the transmission torque from the equation (1), let $\partial M / \partial\phi = 0$, we have:

$$P\cos^3\phi + 3\cos^2\phi - 2 = 0 \quad (2)$$

where $P = (K_f / K_r)/(L_m / L_g)$.

For the magnetic mechanism with determined structure parameters, the value K_f/K_r can be determined by means of magnetic circle analysis[5], then the value of P is determined, and the value of ϕ can be obtained by solving the equation (2), and then solving the equation (1) the value of maxim transmission torque M is determined. Thus in the process of designing magnetic mechanism, we can in advance suitably give the value of parameters L_m, L_g, r, V_m according the structure and dimension limit, calculate the value of maxim transmission torque M until it is equal or close to the required design value by means of above mentioned method.

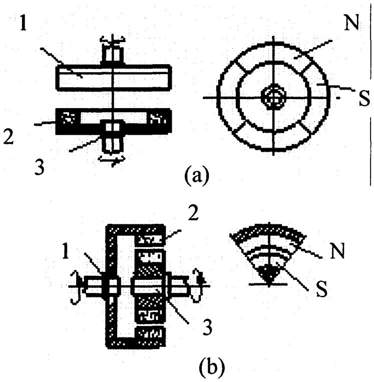

Figure 1 Schematic drawings of magnetic mechanism
1: drive rotor, 2:magnet, 3:driven rotor.

At present, for the coaxial radial magnetic mechanism there is also no really effective method for calculating the transmission torque, which is researched not adequately. For the purpose of engineering design the transmission torque M can be determined by following equation[4, 8]:

$$M = n \bullet B^2 \bullet S \bullet R / (2\mu_0) \tag{3}$$

where n—the number of magnets; B—the magnetic induction intensity, T; S—the area of the air gap in the direction of transmission, mm^2; R—the mean radius of the air gap, m.

4. APPLICATION OF MAGNETIC MECHANISMS IN TEXTILE MACHINERY

Nowadays along with the progress of the technology of textile machinery and magnetic material production, the magnetic transmission mechanism is gotten wider and wider application. In the Three-For–One and Four-For-One twisting machine the plane axial magnetic transmission mechanism is used for driving spindle, in the Two-For-One twisting machine the coaxial radial magnetic transmission mechanism is used for fixing the yarn package and balloon limitor.

For instance, in the Three-For-One twisting spindle developed by us (Figure 2) the parameters of the magnetic transmission mechanism are as follows: r=0.037m, L_g=0.012m, B_r=4000Gs=0.4T, the drive and driven rotors are installed with 16 magnets, the total volume of which V_m =1.584 × 10-6 × 32=5.07 × $10^{-5}m^3$. The measured maxim transmission torque by experiment is 1.17Nm. On the other hand, by means of magnetic circle analysis, we can get the coefficients of the magnetism leakage and magnetism resistance: K_f =2.14, K_r =1.25; solving the equations (2), (1) in terms of above mentioned method we get the maxim transmission torque with the value of 1.2274Nm. Meanwhile, if the influence of magnetism leakage is neglected, i.e. $K_f / K_r = 1$, the maxim transmission torque is solved from the equation (1) with the value of 1.2333Nm. Obviously, the two calculated results are close. In fact, in the case of little air gap with the little value of L_m / L_g(but it must be $L_m / L_g > 1$) for the plane axial magnetic transmission mechanism, it will have no serious influence on the calculated result that the magnetism leakage is neglected, but the analyzing and calculating process will be simplified to a great extent. The experiment shows that the magnetic transmission mechanism in the spindle runs well. In the Two-For-One spindle manufactured by Zhejiang Xinya textile machinery Co. (Figure 3) the relative parameters of the coaxial radial magnetic transmission mechanism are as follows: material of magnet is ferrite, B_r=0.4T(4.0kGs), H_{cb}=175kA/m(2.2kOe), number of magnets n =12, L_m=0. 017m, L_g=0.013m, R =0.0745m, S =1.3 × $10\text{-}4m^2$. By means of magnetic circuit analysis we have B=0.0886T(886Gs), substituting it in the equation (3) we obtain the maxim transmission torque M=0.358Nm. In the experiment we measured the maxim transmission torque M with the value of 0.333Nm, which is comparatively close to the calculated result, the difference between them is 6.5%, and the magnetic mechanism fulfill its own task well.

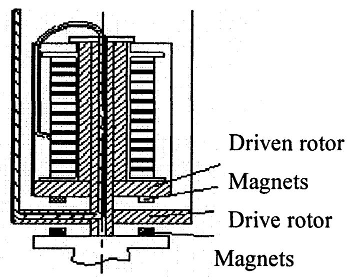

Figure2. Three-For-One spindle.

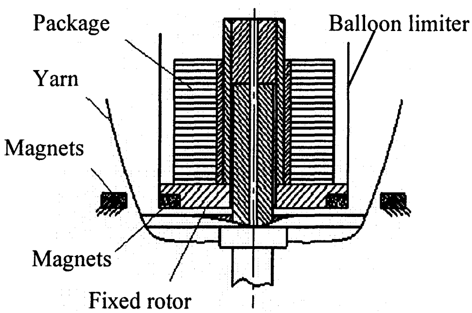

Figure 3. Two-For-One spindle.

5. CONCLUSIONS

Analysis and calculation of transmission torque is the key problem for designing magnetic transmission mechanism. The magnetic circle method and analytical method can describe directly and approximately the relationship between the transmission torque and parameters of the magnetic mechanism, but can not obtain precise solution. The numerical method such as Finite Element Method (FEM) has advantage of precisely including the influence of magnetism leakage and bow wave on the solution, but the analysis model and process are rather complex, and difficult to be applied in engineering design. In this paper an improved method of calculating magnetic transmission torque based on the theory of magnetic filed is provided, which has comparatively precise solution and is convenient for engineering design. It is clear that establishing effective analysis model and method for designing magnetic transmission mechanism is a important direction in this filed.

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