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Finite Element Analysis for Wave Spring of Multi-disc Wet Clutch Based on ANSYS

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Abstract. Wave spring is a key component of multi-disc wet clutch and the response speed and running quality of multi-disc wet clutch is affected by its characteristics. This paper analyses the theoretical calculation of load-deformation relationship of wave spring. The load-deformation relationship of wave spring is obtained by ANSYS10.0 software according to its structural characteristics and actual boundary condition and compared with the calculated results based on different methods and the measured value, and then study the effect of the wave number on the load- deformation relationship of wave spring. The results show that the calculated value of finite element analysis(FEM)is closer to the measured value and the FEM has more advantages on simulation of the working performance of wave spring.

Introduction

Multi-disc wet clutch is a shift element that has been used commonly in the automatic transmission. The Wave Spring that as a critical component is used to transmit power and achieve separation of the multi-disc wet clutch and its load-deformation performance affects the response speed, transmit smoothness and service life of clutch [1]. It can increase the jointing flexibility of master and slave of clutch and reduce the impact when the double clutch contact. The driving comfort is improved by make full use of its performance. In addition, hydraulic control system of multi-disc wet clutch could be optimized based on its performance, so as to realize that the joint moment of clutch is always at the optimal state. The wave spring has a special shape, geometry distorts significantly after loading and will cause boundary conditions change constantly at the same time. This complicated and changeable situation make it hard for analysis by strict theoretical. Currently, the analysis for load-deformation characteristics of wave spring is primarily that spreading out the wave spring into plane statically indeterminate straight beam, then calculate its deformation according to the straight beam formula. This calculation model ignores the influence of circumferential curvature and wave curvature, and the calculation method is too coarse to calculate load-deformation relationship of wave spring accurately. Correction coefficient is introduced according to the wave number based on the current calculation method and experience [2].These two kinds of calculation methods are worth studying, so that could find the theory design method of wave spring, but these two kinds of calculation methods consider the deformation of wave spring as linear.

The theoretical calculation methods of wave spring are analyzed in this paper and the load-deformation relationship of wave spring is analyzed by ANSYS10.0 software according to the multi-disc wet clutch wave spring's structure and actual stress situation. Comparison and analysis of load - deformation relationship obtained by different calculation methods have been given, and study the effect of wave number on load-deformation relationship of the wave spring.

Theoretical Calculation of the Load- Deformation Relationship of Wave Spring

Wave spring is formed by stamping sheet metal and has multiple peaks distributed evenly on the circumference. Structure of single chip wave spring is shown in Fig. 1.Where, ID and OD are the inner diameter and outer diameter of wave spring, respectively, b and t represent the width and thickness of wave spring, H and h denote free height and work height.

The wave spring could be represented by oval curve by unfolding the wave spring along the average diameter and converting to semi-elliptical spring that tangent to each other in the level of place. As shown in Fig. 2.Where, N_1 represents a wavelength, P_1 is the force applied on the single peak of wave, P_2 denotes reaction force applied on the single peak of wave.

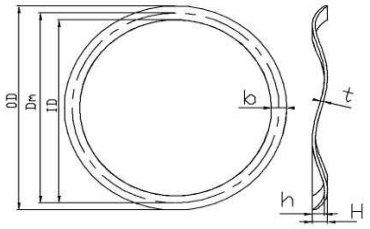

Fig. 1

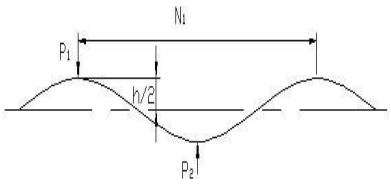

Fig. 2

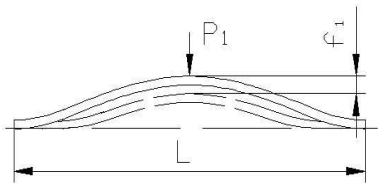

Fig. 3

A peak of wave has been taken as research object, as shown in Fig. 3. It is reasonable that assume it is a rectangular piece spring supported freely on both ends. When force P_1 applies on the peak of wave, according to material mechanics calculation method, the displacement of peak can be calculated as:

$$f_1 = \frac{P_1 L^3}{48EI} \tag{1}$$

Where, f_1 is the displacement of half of the amplitude under the force P_1, $f_1 = f/2$; f is the displacement of amplitude under the force P_1, I represents moment of inertia. Rectangular section's moment of inertia is described as:

$$I = \frac{bt^3}{12} \tag{2}$$

L denotes half wavelength.

$$L = \frac{\pi D_m}{2N} \tag{3}$$

N is the wave number of wave spring.
Eq.2 and Eq.3are plug in(1),as follow

$$f_1 = \frac{P_1 \pi^3 D_m^3}{32Ebt^3 N^3} \tag{4}$$

According to $f_1 = f / 2$, and the total load $P=N \cdot P_1$ that apply in wave spring, Eq.4 can be converted into

$$f = \frac{P\pi^3 D_m^3}{16Ebt^3 N^4} \tag{5}$$

Eq.5 is the load-deformation relationship formula of wave spring that unfolded into a horizontal plane statically indeterminate straight beam [2].

In terms of mechanics model for the wave spring calculation and the perspective of the practical engineering requirements, the mechanical model that using horizontal plane straight beam has cross section and be fixed on both ends can be used as the basis of analyzing load - deformation relationship of wave spring. But in terms of the geometric shape of the wave spring, there are two aspects difference between the mechanics model of Eq.3 and the actual wave spring. On the one hand, the structure of wave spring is circular and the above mechanics model does not consider the effect of circumferential curvature. On the other hand, wave spring is carried with waveform and the above model is also not considering the influence of the waveform.

In order to the calculate load - deformation relationship of wave spring more accurately, we can obtain the correction calculation formula of load-deformation relationship of wave spring based on the measured results according to different type of wave spring and correction coefficient of wave spring deformation calculation according to the wave number of wave spring.

$$f = \frac{PKD_m^3}{Ebt^3 N^4} * \frac{ID}{OD} \tag{6}$$

Where, K is the correction coefficient of multiple waves. The details are illustrated in the following Table 1.

Table 1.The table of correction coefficient of multiple waves

Correction coefficient of multiple waves(K)				
N	2.0-4.0	4.5-6.5	7.0-9.5	10.0 and above
K	3.88	2.90	2.30	2.31

Finite Element Analysis of Wave Spring

Wave spring belongs to nonlinear large deformation elastic element. Calculation method of theoretical analysis usually considers the wave spring as a linear deformation and it can't reflect the real deformation of wave spring accurately. Requirements that needing to know load - deformation relationship of wave spring accurately cannot be meet. In this paper, multi-disc wet clutch wave spring installed in the automatic transmission is taken as research object. The wave spring is analyzed by ANSYS10.0 software that can simulate nonlinear large deformation more accurately and the load-deformation relationship of wave spring is obtained. It lays a solid foundation for later experiment study and provides reference for the design of hydraulic system of the multi-disc wet clutch. The multi-disc wet clutch wave spring's material is 65Mn, inner diameter ID = 137 mm, the outer diameter OD = 146 mm, width b = 4.5 mm, thickness t = 1.2 mm, free height H = 4 mm, wave

number N = 5.The maximum working pressure is 200N. For the convenience of research, some basic assumptions for wave spring as following.

(1) Internal stress of wave spring generated in the manufacturing process is not considered.

(2) Ignoring the influence of friction.

(3) Other factors are not considered.

Wave spring model is imported into ANSYS10.0 after establishing in CATIA V5. 8 -node Solid45 unit is selected to mesh the model because it has some characteristics such as creep properties, plasticity, expansibility, large deformation and large strain [3-5]. Setting the material properties of wave spring, the elastic modulus of material is197GPa, Poisson's ratio is 0.282; material density is $7.82\times103Kg/m^3$ [1]. The trough positions of the wave spring are applied by Z direction constraints and peak positions are applied by displacement loads because the wave spring mainly bears the normal hydraulic force in the multi-disc wet clutch. Wave spring belongs to the geometric nonlinearity, so we can use the method of static large deformation and Full Newton--Raphson to solve. When the wave spring is under the maximum working pressure of 200N, the strain and stress contours are shown in Fig. 4 and Fig. 5, respectively.

Different load are applied on the peak of wave, we can get the overall reaction force by using time history processor to read reaction force of all nodes in the five peaks, and then accumulate. That is the total load. The deformation of wave spring is obtained by using the time course processor to read the displacement of peak [6].

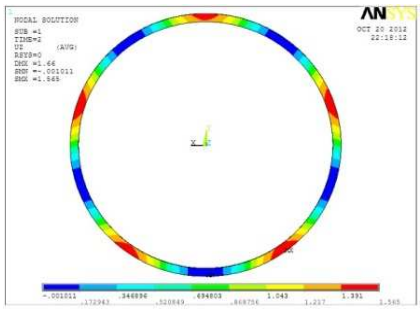

Fig. 4 Strain contours of wave spring when the total load is 200 N

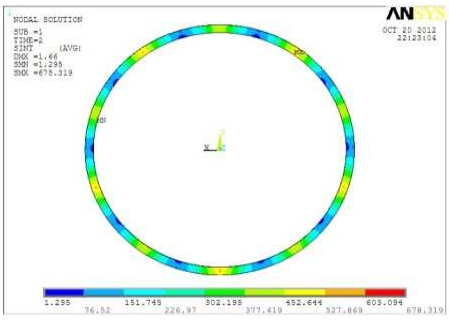

Fig. 5 Stress contours of wave spring when the total load is 200 N

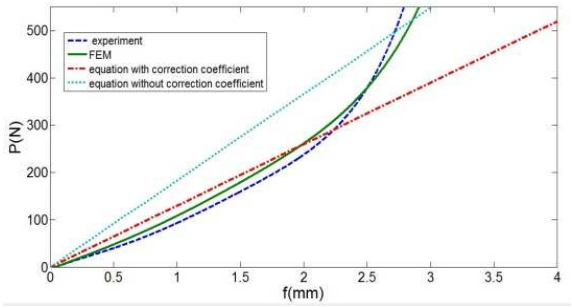

Fig. 6 Comparison of load- deflection relation of wave spring obtained by theoretical calculation without correction coefficient, theoretical calculation with correction coefficient, FEM, experiment

In order to verify the exactness of calculation method of load–deformation relationship of wave spring, the experiment of the wave spring was carried out. The measured data is compared with the data obtained by theoretical calculations and finite element calculation. As shown in Fig.6.

As can be seen from the Fig.6, the flexibility of wave spring is large at the early stages, small at the later. Its excellent features make wave spring play an important role of buffer and vibration. The deformation of wave spring obtained by theoretical calculation with correction coefficient is closer

to the true value than the theoretical calculation without correction coefficient. The deformation of wave spring obtained by FEM is smaller than the theoretical calculation with correction coefficient and theoretical calculation without correction coefficient under the same loading and it is close to the true value. The load - deformation relationship changes linearly within 80% effective deflection. The calculation results of the theoretical calculation with correction coefficient and FEM is smaller. They can calculate deformation of wave spring accurately at this phase. The deformation obtained by theoretical formula deviates from the true value when deformation exceeds 80% effective deflection. The measured value is much higher than the value of theoretical calculation, while FEM can simulate the deformation of wave spring better at this phase.

The parameters of wave spring in the multi-disc wet clutch are affected by the structure of the clutch size and the outer diameter, inner diameter, thickness. While the height of wave spring is restricted, and material elastic modulus is also basically remain unchanged. At this moment, the most important factor that impacts load-deformation relationship of wave spring is the wave number of wave spring. Selecting properly wave number of wave spring is not only save materials and adapt to the development of automobile lightweight, but also can make full use of the characteristics of wave spring to realize accurate control of clutch, make the joint moment at the optimal state constantly.

Effect of Wave Number on the Load- Deformation Relationship of Wave Spring

The wave number of wave spring is changed while other parameters remain unchanged. Fig. 7 is finite element mesh of wave springs of different wave number. Fig. 7 (a) is the finite element mesh of four wave number and Fig. 7 (b) is the finite element mesh of five wave number, and Fig. 7 (c) is the finite element mesh of six wave number.

(a) Model A

(b) Model B

(c) Model C

Fig.7 Finite element mesh of wave springs of different wave number

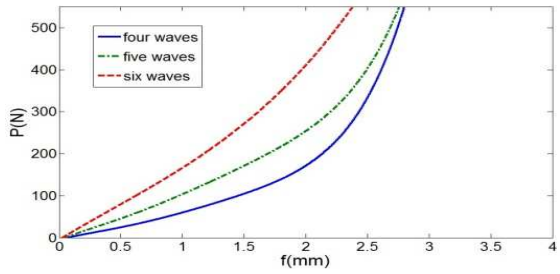

Fig.8 Load-deformation relationship of wave spring of different wave number

The load-deformation relationship of wave springs of different wave number is obtained by applying constraints on the model, loading and solving. As shown in Fig.8.

We can see that the wave number is less, while the flexibility and deformation is larger under the same load, and the working pressure that wave spring could bear is smaller. Wave number has a

great influence on load- deformation relationship of wave spring. The wave number of wave spring that has a function of restoration is less, the response speed of the clutch is faster, but the impact is greater. The wave springs of different wave number should be selected appropriately according to different requirements when we design and choose wave spring.

Conclusion

(1)The value of load-deformation relationship of wave spring calculated by FEM is close to the measured value and FEM can calculate the load-deformation relationship of wave spring accurately.

(2) The wave number has a great influence on the load-deformation relationship of wave spring. The load-deformation relationship calculated by FEM has a certain engineering application value on the selection of wave spring.

(3) The FEM can not only simulate real deformation situation of wave spring better, but also can calculate the three dimensional deformation and internal stress of wave spring. FEM has more advantages than theoretical formula calculation in designing and manufacturing of nonlinear large deformation elastic component.

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