CHECK ANALYSIS FOR AUTOMOBILE TRANSMISSION BEARING BASED ON THE SOFTWARE MASTA

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To ensure the reliable operation of automobile transmission, the life assessment of the bearing is particularly important for transmission performance. Aiming at the existing problems of the traditional checking method, this paper utilizes the latest professional transmission analysis software MASTA to analyze fatigue life of automobile transmission bearings. The results show that the software MASTA can more effectively perform the fatigue life analysis of the transmission bearings than traditional theoretical calculation method. So the software MASTA will further provide effective theoretical basis for overall optimization design and safety work of automobile transmission.

Keywords: Automobile transmission, Bearing, Check analysis, MASTA

1. Introduction

As the important power assembly of the automobile, the automobile transmission undertakes the heavy task in power transmission and speed change of the automobile. Generally speaking, the automobile transmission allows the driver to adjust the running speed of automobile through switching the automobile forward and backward, that is, the driver can choose the gear ratio of the transmission to change output torque of the engine so as to adjust the running speed of the automobile. Automobile transmission must meet a variety of requirements, such as smooth shifting, high power output, compact structure, lightweight design, low noise, and so on. Furthermore, with the development of automobile industry, people put forward increasingly higher requirements on the automobile transmission [1, 2]. Because the automobile has special running condition and operating environment, plus recurrent shifting, the gear, shaft and bearing installed in the transmission often go out of order. The statistical report indicates that 60 percent of the easy-damaged parts in the automobile transmission are connected with the gear, and the bearing also accounts for 19 percent [3]. The automobile transmission plays a vital role in the reliable operation of all transmitting gears, supporting and positioning of the drive shaft, as well as the

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basic guarantee of effective transfer of the engine power. In view of the fact of high working frequency and heavy loading, the transmission bearing is very easy to be damaged. So in order to ensure the reliable operation of the automobile transmission, the life assessment and reliability evaluation for the transmission bearing in the process of selection of bearing must be carried out [4].

The calculation method of traditional life assessment for the bearing attaches importance to determine the equivalent dynamic load applied to the bearing. The bearing dynamic load is affected not only by the torque on the gear shaft, but also by stress condition of the gear under different conditions. Because the undesirable changes of the torque on the gear shaft and changes of the stress on the bearing are brought out owing to the frequent shifting, it is very complicated to determine the actual dynamic load of the transmission bearing [5,6]. In addition, the life assessment for the bearing is associated with the position of supporting point, so the traditional life assessment for the bearing can be said to be a tedious process, which can be completed only after repeated calculations. Based on the above situation, this paper uses the transmission analysis software MASTA to complete the fatigue life analysis and calculation for the bearing of a certain automobile transmission. The software MASTA is characterized as its powerful parametric function, so the author uses it to model and analyze for all components of the transmission. The software MASTA may accurately obtain the damage rate, misalignment and fatigue life of the transmission bearing. What's more, the software MASTA can perform the checking analysis of the bearings, which mainly focuses on failure mode and improvement solution of the prone to fatigue-failure bearings used in the automobile transmission, such as the deep groove ball bearing on the input shaft, cylindrical roller bearing on the middle shaft and tapered roller bearing on the output shaft. Finally, the fatigue life of the bearing of the automobile transmission has been obtained, which verify the rationality of the theoretical analysis and calculation. In general, the results of CAE analysis will provide detailed theoretical basis for the whole structural design and safety work of the automobile transmission.

2. Failure mode analysis of the bearing

A. Fatigue pitting corrosion

Pitting corrosion is a localized form of corrosive attack on the metal surface. When the rolling bearing is in normal working conditions, such as lubrication, sealing and other load conditions, the cyclic contact stress acts on the inner ring, outer ring, rolling elements and cage of the bearing for a long time, so the metallic material in the contact surface will usually occur partial peeling, that is to say, fatigue pitting corrosion. When the fatigue pitting corrosion becomes worse enough, the vibration and noise of the transmission comes out, which will make working temperature higher and lastly cause the bearing to lose effectiveness.

B. Abrasion

If the improper seal and unpurified lubricating oil appear in the working conditions of the transmission bearing, the metal chips or dust will be mixed into the bearing, which will cause the gap between the rolling body of the bearing and the inner and outer rings to get bigger and bigger, and affect the rotating precision of the bearing and ultimately result in bearing failure.

C. Fracture

With a view to the bearing manufacturing defects or excessive loads on the bearing, the external load, if exceeding the material strength limit of the bearing, will cause bearing fracture, leading to failure. In addition, the bearing in work will be subjected to axial force as a result of inappropriate installation or removal mode of the bearing, which is the main reason of the bearing[7].

3. The traditional checking analysis method of transmission bearing

When the automobile transmission is in different gears, gear meshing among input shaft, middle shaft and output shaft will lie in different positions, which will make stress condition of the gear and the bearing different. Hence, it is very necessary to implement the stress analysis of all gears and gear shafts in different working conditions, to get the equivalent dynamic load of the transmission bearing, further to complete the life assessment of the selected bearings [8,9]. We apply a three-shaft transmission as an example to introduce the main procedures of traditional bearing checking analysis.

3.1 Force analysis of gears

When the transmission is in the first gear, the automobile is in the stage of the start-up and needs comparatively large torque to finish the start-up, which can be considered as the largest torque all the time in all working conditions. In order to ensure the accuracy and credibility of the bearing checking analysis, we will carry on the checking analysis under the most serious working condition, that is, the first gear.

Assuming the torque of input shaft is equal to the maximum torque of the engine, and then the torque subjected to the gears of output shaft in different gears can be obtained according to the following formula:

$$T_2 = T_1 \frac{Z_2}{Z_1} \eta \tag{1}$$

Wherein, Z_1 means the gears of input shaft in different gears; Z_2 means the gears of output shaft in different gears; η means the gear transmission efficiency in different gears.

When the gears in different gears are defined as the skew tooth cylindrical gears, circumferential force F_t, radial force F_r and axial force F_a from gear meshing can be obtained according to the following formula:

$$F_t = \frac{2M_{e\max} \cdot i}{d} \tag{2}$$

$$F_r = \frac{2M_{e\max} \cdot i \cdot \tan\alpha}{d \cdot \cos\beta} \tag{3}$$

$$F_a = \frac{2M_{e\max} \cdot i \cdot \tan\beta}{d} \tag{4}$$

Where in, i is the computational gear ratio; d is the pitch radius of computational gear; α is the pressure angle in the node; β is the spiral angle; $M_{e\max}$ is the maximum torque of the engine, that is, computational torque of input shaft, $N \cdot m$.

After implementing to the force analysis of supporting shaft, we can obtain the radial and axial supporting counterforce of each bearing in different working conditions by means of "Castigliano's theorem" or "Deformation comparison method".

3.2 Fatigue life analysis of the bearing

A. The expected life of the bearing

The maximum mileage of the vehicle near the overhaul period L (km) is generally looked as the design goal of the life expectancy of the transmission bearing. The total revolution of the transmission bearing can be obtained by the maximum mileage of the vehicle near the overhaul period L (km) and the vehicle wheel circumference C as shown in the following formula:

$$N_1 = \frac{L \times 10^3}{C} \tag{5}$$

In general, a transmission is a speed and power changing device installed at some point between the engine and driving wheels of the vehicle. It provides a means for changing the ratio between the engine speed and the driving wheel speed to best meet each particular driving situation. According to the engine speed at the maximum torque N, the gear ratio of the transmission i_{1x} and the gear ratio of the main reducing gear i_2, combined with time utilization rate of various gears q_x, the computational formula of average revolution of the vehicle's driving wheel N_m can be obtained from the following formula:

$$N_m = N\left[\frac{q_1}{i_{11}} + \frac{q_2}{i_{12}} + \cdots + \frac{q_x}{i_{1x}}\right] \tag{6}$$

So the ratio of two kinds of revolutions N_1 / N_m will be regarded as the expected life of each transmission bearing T_0 / h_0.

B. Select method of the bearing

According to the stress acting on the bearing in use and property characteristic of the bearing, the appropriate type of bearing is firstly determined, after combining with integral structural design requirement of the transmission, the specific model of bearing is selected, and then obtain the basic parameters of the bearing.

C. Calculation of equivalent dynamic loading of the bearing

In the course of the bearing's life calculation, it is very key to ascertain the equivalent dynamic loading p_m, first of all, the equivalent dynamic loading in each gear can be obtained according to the following formula:

$$p_x = f_p\left(XF_x + YF_a\right) \tag{7}$$

Wherein, X is coefficient of radial dynamic loading; Y is coefficient of axial dynamic loading; f_p is coefficient of shock load, $f_p = 0.5 \sim 1.8$.

$$p_m = \left(q_1 p_1^{\varepsilon} + q_2 p_2^{\varepsilon} + \cdots + q_x p_x^{\varepsilon}\right)^{\varepsilon} \tag{8}$$

Wherein, $p_1 \cdots p_x$ means the equivalent dynamic loading of bearing in each gear; $q_1 \cdots q_x$ means the time coefficient of utilization of bearing in each gear; ε means the life index (ball bearing, $\varepsilon = 3$; roller bearing, $\varepsilon = 10/3$);

The judging coefficient E can be ascertained by the ratio of F_a and the rated dynamic loading of bearing to look up the reference table, and then comparing F_a / F_r with E to get the values of X and Y, but the procedure is too complicated.

D. Life calculation of the bearing

Because each supporting shaft exists various working conditions, resulting in unstable load acting on the bearing and continuously changeable revolution, the life calculation of the bearing can generally be obtained with the unstable loading formula, that is,

$$T_{10h} = \frac{10^6}{60n_m}\left[\frac{p_r}{p_m}\right]^{\varepsilon} \tag{9}$$

Wherein, p_r means the basic rated dynamic load of the bearing; n_m means the average revolution.

$$n_m = n_1 q_1 + n_2 q_2 + \cdots + n_x q_x \tag{10}$$

When the bearing life calculated by using the above formula T_{10h} is greater than the life expectancy T_0, it indicates that the selected bearing can meet the working demand, otherwise it is necessary to reselect other types of bearing with larger load capacity.

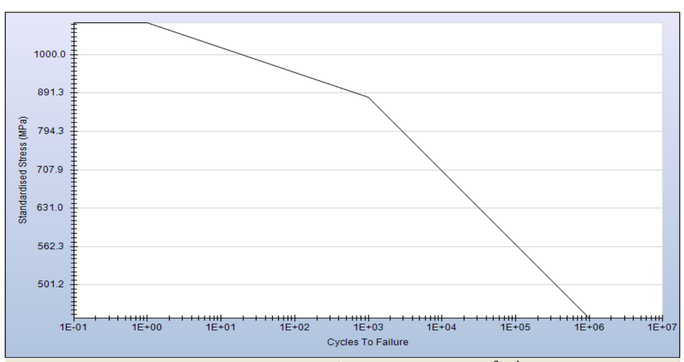
Meanwhile, if the calculated life of the bearing T_{10h} is too greater, after overall consideration of other influencing factor, we can replace with lesser bearing in order to diminish the whole dimension of the transmission.

4. MASTA modeling of transmission system

According to 2D drawing and 3D models of a certain transmission as the research object, provided by the technical departments, the project has established a complete detailed MASTA model [10]. The model includes gears, gear shafts, cylindrical roller bearings, tapered roller bearings, needle roller bearings, clutches, synchronizers and shell. We will put the whole transmission system as a whole to undertake systems analysis, to get system global stiffness, and then to obtain the bearing misalignment and service life, etc.

A. Establishment of gear shaft

According to the design drawings, 20CrMnTi was selected as the material of gear shaft of automobile transmission because it possesses better mechanical properties. The elastic modulus of the material is 207GPa, material density is 7800 kg/m3, Poisson's ratio is 0.3, tensile strength is 1100MPa, yield strength is 850MPa, fatigue strength limit is 525MPa. The gear shaft is mainly under self-weight and is used to transmit power. SN curve of the gear shaft studied in this paper is shown in the following figure.



Cycles to Failure (*10e6)	Standardised Stress (MPa)
1E-06	1100
0.001	880
1	453.82659708

Fig.1. SN curve of gear shaft

In the software MASTA, the structure of gear shaft is divided into two types: one is that the structure characteristics of gear shaft is symmetric, called the standard shaft; another is that the structure characteristics of gear shaft is asymmetric, called the special-shaped shaft, commonly including planet carrier, irregular wheel spoke, etc. Standard shaft can be established in the design module of the software MASTA, and special-shaped shaft must be completed with the aid of the flexible structure module of the software MASTA.

The automobile manual transmission studied in this paper belongs to the rear drive transmission, which itself has no differential part, so the three shafts are standard parallel shaft, can be directly established in the design module of the software MASTA. First of all, a principal shaft needs to be created, and then add the exterior features on the shaft in order, including the shaft diameter, inner hole, the stepped surface and the inclined surface on each of the shaft section; secondly, defining the shaft surface roughness, grooves, radial holes, the stress concentration factor and other detail features. Meanwhile, the left end of input shaft is acted as a reference to determine the space position of the output shaft, the middle shaft and reverse gear idler shaft.

B. Gear modeling

In the software MASTA, transmission gear is completely defined through its parameters, so as to generate automatically the two-dimensional and three-dimensional models of gear. Gear parameters consist of tooth number, modulus, tooth width, displacement coefficient, helix angle and pressure angle and other basic parameters as well as the pitch circle diameter, base circle diameter, tooth root transitional circular arc fillet radius, addendum chamfer and other external dimensions.

When the gear is mounted on the shaft, as long as the gear position on the shaft is defined, we can choose a different location reference to conveniently position the gear on the shaft.

C. Bearing modeling

Because the bearing belongs to standard part, the bearing database in the software MASTA has already covered most of products series provided by the bearing manufacturers. In the ordinary course of events, we can select the corresponding bearing from the bearing database. If necessary, we can also add new bearings to the database through setting the bearing's basic parameters such as bearing width, inner & outer diameter, parameters and shapes of raceways and rollers of bearings.

For example, rolling bearing is used as the front bearing of the middle shaft of the manual transmission as shown in Figure 2. Other bearings, including needle roller bearing, are selected through the corresponding parameters and models found in the bearing database.

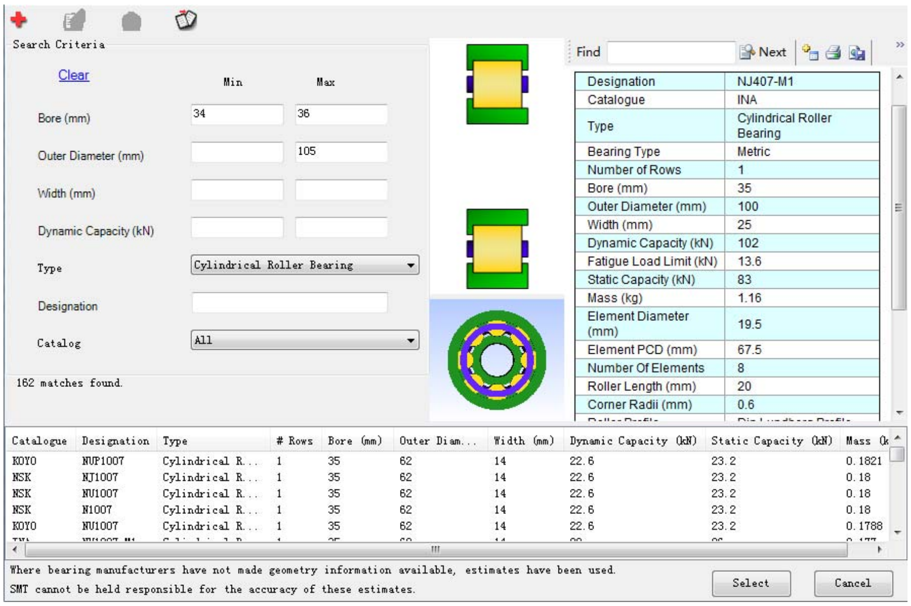


Fig.2. Select of bearing

D. Synchronizer modeling

After the basic parameters of synchronizer are input to the corresponding synchronizer module of the software MASTA, the simple model of the corresponding synchronizer will be generated in the software. So it can be assembled to the corresponding gear shaft and then will be connected to the corresponding gear together.

E. General model of the whole transmission

Aimed at a certain automobile transmission, this paper mainly completes the entire transmission system modeling in design module of the software MASTA. The sequence of the entire modeling process in order is to establish the model of all gear shafts, and then to determine the space position of these shafts, followed by assembling other parts of gear shaft, such as gears, bearings, synchronizers, etc. According to the detailed parameters of the gear, shaft and bearing and other parts, the transmission simulation model is established in the software MASTA as shown in Figure 3 and in Figure 4.

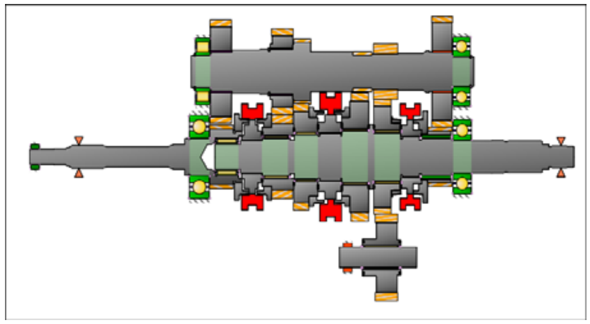


Fig.3. 2D model view of the transmission

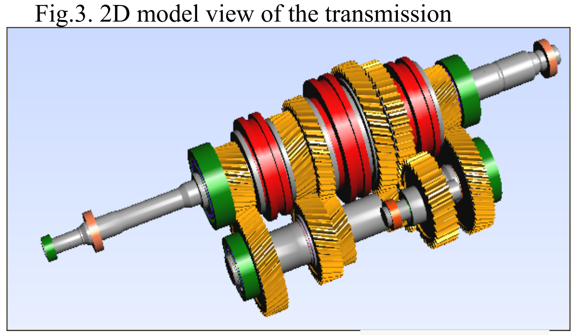


Fig.4. 3D model view of the transmission (Excluding housing)

F. The load case on the transmission simulation model

When the transmission is in the actual working condition, the loading born by the transmission is changing, embodying that both the torque and the speed are changing, in addition, the usage frequent rate of the different stop positions, that is, the acting time of each stop positions, is not same also. The corresponding relationship among three variables is called the load cases. After clarifying the load cases of the transmission in actual working conditions, we can get the actual stress condition of every component in the whole transmission system under the load cases, so as to obtain the accurate calculation result.

Load cases are mainly used to define the input conditions of the proposed model, which can be load cases under actual working conditions or load cases of bench test. In the software MASTA, the working condition usually refers to torque, rotating speed and acting time under the action of a certain power flow, while the load cases are the combinations of different working conditions. Therefore, before the definition of load cases, we need to define the input and output power flows for the proposed model.

The automobile manual transmission has five forward gears and one reverse gear, considering that each gear corresponds to a working condition, it is necessary to define six working conditions. Only when we specify the name, acting time or cycle number, rotating speed, torque or power for each working condition, can the definition of the whole working condition be considered to be complete. The load cases used by the article are consistent with the ones in the fatigue life test of the gear assembly, as shown in Table 1.

Table 1

Load cases of the transmission

Design State	Load Case	Duration (hr)	Power Load	Speed (rev/min)	Torque(Nm)	Power (kW)
3rd Design State	New State Load 100%	70.25	Input Power Load	[√] 2000	[√] 280	[ ] 58.6431
			Output Power Load	[ ] 1186.5079	[ ] -471.9732	[ ] -58.6431
4th Design State	New State Load 100%	0	Input Power Load	[√] 2000	[√] 280	[ ] 58.6431
			Output Power Load	[ ] 2000	[ ] -280	[ ] -58.6431
5th Design State	New State Load 100%	63.58	Input Power Load	[√] 2000	[√] 280	[ ] 58.6431
			Output Power Load	[ ] 2622.807	[ ] -213.5117	[ ] -58.6431
R Design State	New State Load 100%	2	Input Power Load	[√] 2000	[√] 280	[ ] 58.6431
			Output Power Load	[ ] -437.1345	[ ] 1281.0702	[ ] -58.6431
1st Design State	New State Load 100%	16.86	Input Power Load	[√] 2000	[√] 280	[ ] 58.6431
			Output Power Load	[ ] 395.5026	[ ] -1415.9198	[ ] -58.6431
2nd Design State	New State Load 100%	36.04	Input Power Load	[√] 2000	[√] 280	[ ] 58.6431
			Output Power Load	[ ] 693.6508	[ ] -807.3227	[ ] -58.6431

5. The life analysis of the transmission bearing

For the traditional checking method on the bearing, the calculation is too complex and be inaccurate. But the use of MASTA can conveniently analyze the damage rate of the transmission bearing under the action of load cases and carry on fatigue life analysis of the transmission bearing. In the software MASTA, the bearing is regarded as elastic body, not simplified as infinite rigidity like before. After running the whole transmission system under the load cases, we can get the damage rate of the transmission bearing in each gear, so as to obtain the total damage rate of the transmission bearing under overall consideration of all gears being in motion as shown in Figure 5. The damage rate of the transmission bearing means the ratio of calculating life of the bearing to actual life of the bearing. In general, the recommend value of the damage rate of the bearing in the automobile industry should be less than 80 percent. According to the above figure, the damage rate of every bearing of the transmission is less than 80 percent and then meets the working requirements.

When the transmission bearing is under the combined action of the axial force and radial force, the misalignment will emerge between the roller of the bearing and inner and outer ring of the bearing. The misalignment of the bearing reflects the expanding angle between inner and outer ring of the bearing, which should not generally exceed 1.6mRad at the most. However, the misalignments of a few bearings, obtained by numerical simulation analysis in the software MASTA, seemed to be somewhat larger as shown in Figure 5, the larger misalignments will result in the non-uniform stress and large deformation at the end face of the roller, and thereby reduces the bearing life of the automobile transmission. Meanwhile, too large misalignment could reduce the static carrying capacity of the bearing and then bring about the friction power consumption. Because the transmission bearing is directly installed on the housing of the automobile transmission, the deformation of the bearing will affect the deformation of the housing and then give rise to more large vibration and noise. For this reason, the following guidelines should be observed to minimize the misalignments of the transmission bearing. So, under meeting the working conditions, in order to enhance the rated dynamic load and the rated static load of the bearing, we may try to apply some ways such as replacing the bearing type or the bearing material, using different heat treatment methods, performing the modification of the rollers and rollaway nests of the bearing and so on. That is to say, we may improve the stiffness of the bearing to solve the problem of excessive misalignment of the bearing.

Bearing Summary Table

Name	Designation	ISO 281 Damage (%)	ISO 281 Life (hr)	ISO DIN A4 Damage (%)	ISO DIN A4 Life Time (hr)	Worst Misalignment (mRad)
IS Assembly\IB Bearing	6308-RS1	10.08	3275.5111	10.52	3138.3437	2.4155
IS Assembly\IF Bearing	6203	8.63	3825.0983	5.69	5800.2858	1.6168
MS Assembly\MF Bearing	6207-RS1	4.51	7325.2249	4.77	6916.2834	2.4283
MS Assembly\MB Bearing	63/32	46.26	713.9415	50.75	650.7134	2.9212
OS Assembly\OF Bearing	Self-Definition	1.75	18915.5744	23.39	1411.6846	1.6945
OS Assembly\OB Bearing	6307	7.37	4479.9285	7.98	4136.5958	1.1663

Fig.5. Check analysis of the transmission bearing

6. Conclusions

In this article, some correction measurements are advanced in order to decrease the fatigue failure and improve the service life of the bearings. The appropriate automotive transmission bearing is beneficial to good mesh between driving gear and driven gear, which will reduce the wear of gear parts and improving the service life of the gear. This paper firstly introduces the powerful simulation analysis functions of the professional transmission system software MASTA. As for the automobile transmission bearing in this paper, the check process of life assessment is especially complex and the accurate law of fatigue life is very difficult to grasp when we utilize the conventional method. In view of the above situation, this paper applies the software MASTA to implement the overall modeling and simulation analysis of the existing automobile transmission. Combined with the actual load condition in the course of fatigue test of the transmission, the checking system of the automotive transmission has been studied and developed for the fatigue life analysis of the bearing, which makes the checking process of the bearing more efficient and simpler. The analytical data under load cases indicates that the damage rate of every bearing of the transmission is less than the recommend value in the automobile industry and then meets the working requirements. However, the misalignments of some transmission bearings obtained by simulation analysis are too large and will seriously affect the service life of the bearing, which needs to be adjusted and improved.

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