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Design research of chassis shaft for children's rotating coffee cup

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ABSTRACT

In this paper, the chassis shaft of the rotating coffee cup has been designed and checked. The strength of the shaft has been mainly calculated, mechanics model has been established, the shaft force and bearing reaction force have been calculated, the diagrams of torque and bending moment have been mapped, and the connection between thrust ball bearings and the key has been checked. The results of checking calculation provided a good theoretical basis to the structural design of rotating coffee cup.

KEYWORDS

Children; Rotating coffee cup; Bearing; mechanics.

INTRODUCTION

In today's era of rapid development of science and technology, the appearance, development and upgrading of products are very quickly. And before the advent of new products, each one has been carefully designed and tested to produce and market through each department. This is a very strict process. According to the survey, in every year there are a lot of amusement equipments on the market. Entertainment equipment what called children rotating coffee cup has a very good sale. No matter in domestic or international, it occupies a large market share, and has a larger development space. So, the vast numbers of entertainment equipment manufacturers are trying to intensify efforts to develop rotating coffee cup in the international market. Such cases, timely transformation of children's rotating coffee cup on the structure, function and appearance is the trend of The Times. It also provides design with a huge development space. At present, as A very popular and loved amusement equipment by the masses of tourists, it is the result of the development of the trend of The Times to important function and beautiful appearance. But the structural design is particularly important. In order to guarantee the normal operation of the machine and ensure the safety of the tourists, The reasonable structural design is the essence of the design. On the basis of structural design, it can extend function, appearance, shaping and etc of the design.

STRUCTURAL DESIGN OF THE CHASSIS SHAFT[1]

Structural design of the high-speed shaft

(1) Determination of the diameter of the each shaft end

d_{11} : Minimum diameter, installing coupling, $d_{11} = d_{1min} = 76mm$

d_{12} : Minimum diameter, installing the high speed gear, d_{12} =76mm

d_{21} : Minimum diameter, installing the low speed gear, d_{21} =165mm

(2) Determination of the length of the shaft

l_{11} :It was determined by the width of the coupling, choosing elastic component of flexible coupling HL2, Y type, length of the empty shaft was 52mm, d=76mm, l_{11} =60mm

Structural design of the low speed shaft

(1) Determination of the diameter of the each shaft

d_{22} : Minimum diameter, installing the bevel gear, d_{22} =170mm

d_{23} : Minimum diameter, installing thrust ball bearing, d_{23} =50mm

(2) Determination of the length of the shafts

d_{21} : Shaft sleeve d_{21} =165mm, L_{21} =30

d_{22} : Installing the bevel gear, d_{22} =170mm, L_{22} =100mm

d_{23} : Minimum diameter, installing thrust ball bearing, d_{23} =50mm, L_{23} =1000

CHECKING CALCULATION OF THE STRENGTH OF THESHAFT ROTATING OF CHILDREN "COFFEE CUP" (FOR EXAMPLE THE LOW SPEED GEAR SHAFT)

Establishment of the mechanics model

Mechanical model of the shaft was shown in Figure 1.

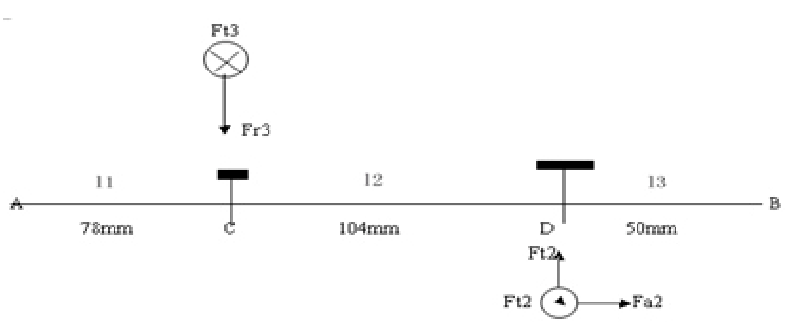

Figure 1 : Mechanical model of the shaft

Calculation of force on the shaft[2]

(1) Gear 2 (the high-speed bevel big gear)

$$\delta_1 == 13°53`33`` \quad \delta_2 = 76°6`26``$$

$$F_{t2} = F_{t1} = 2T_1/d_1 = \frac{2\times 54.455}{66\times 10^{-3}} = 1650N$$

$$F_{a2} = F_{r1} = F_{t1}\cdot \tan\alpha \cdot \cos\delta_1$$
$$= 1650\times \tan 20°\times \cos 13°53`33`` = 585.16N$$

$$F_{r2} = F_t \cdot \tan\alpha \cdot \sin\delta_1$$
$$= 1650\times \tan 20°\times \sin 13°53`33`$$
$$= 135.1N$$

(2) Gear 3(the low speed small gear)

$$F_{t3} = \frac{2T_I}{d_3} = \frac{2\times 213}{93\times 10^{-3}} = 4580.65N$$

$$F_{r3} = F_{t3}\cdot \tan\alpha$$
$$= 4580.65\times \tan 20°$$
$$1667.2N$$

Calculation of the bearing reaction force on the shaft

(1)The vertical reaction force was shown in Figure 2.

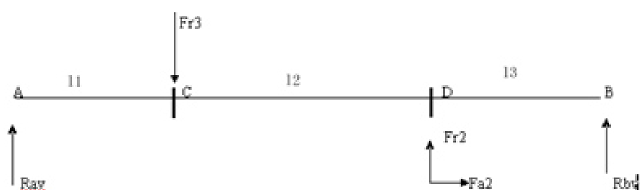

Figure 2 : The vertical reaction force

$$\sum M_{BV} = R_{AV}(l_1 + l_2 + l_3) - F_{r3}(l_2 + l_3) + F_{r2}\cdot l_3 - F_{a2}\times \frac{d}{2} = 0$$
$$\Rightarrow R_{AV} = 1331.678N$$
$$\sum M_{AV} = -F_{r3}\cdot l_1 + R_{BV}(l_1 + l_2 + l_3) + F_{r2}(l_1 + l_2) + F_{a2}\cdot \frac{d}{2} = 0$$
$$\Rightarrow R_{BV} = 137.2N$$

(2) The horizontal reaction force was shown in Figure 3.

Figure 3 : The horizontal reaction force

$$\sum M_{AH} = F_{t3} \cdot l_1 - F_{t2}(l_1 + l_2) + R_{BH}(l_1 + l_2 + l_3) = 0$$
$$\Rightarrow R_{BH} = -235.5N$$

$$\sum M_{BH} = -R_{AH}(l_1 + l_2 + l_3) - F_{t3}(l_2 + l_3) + F_{t2}l_3 = 0$$
$$\Rightarrow R_{AH} = -2574.05N$$

(3) The overall reaction force

$$F_{RA} = \sqrt{R_{AH}{}^2 + R_{AV}{}^2}$$
$$= \sqrt{2574.05^2 + 1331.67^2}$$
$$= 2898N$$

The overall reaction force at B

$$F_{RB} = \sqrt{R_{BH}{}^2 + R_{BV}{}^2}$$
$$= \sqrt{235.5^2 + 137.2^2}$$
$$= 272.56N$$

Drawing diagrams of torque and bending moment[3]

(1) Diagram of the vertical bending moment

Diagram of the vertical bending moment was shown in Figure 4.

The bending moment at C: $M_{CV} = R_{AV}l_1 = 1331.68 \times 78 = 103866.2N \cdot mm$

The bending moment at D:

$$M_{DV(left)} = R_{AV}(l_1 + l_2) - F_{r3}l_2$$
$$= 1331.68 \times 182 - 1667.2 \times 104$$
$$= 68976.96N \cdot mm$$

$$M_{DV(rght)} = -R_{BV}l_3 - F_{a2}\frac{d}{2}$$
$$= -137.2 \times 50 - 585.16 \times 123.5$$
$$= -79127.26N \cdot mm$$

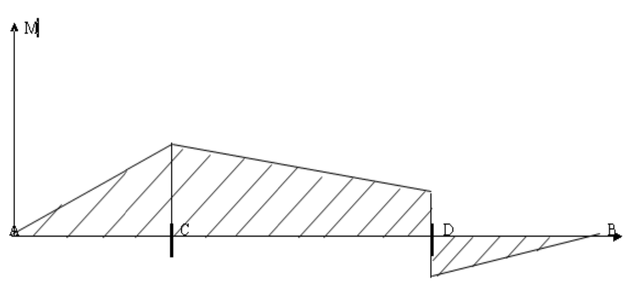

Figure 4 : Diagram of the vertical bending moment

(2) Diagram of the horizontal bending moment

Diagram of the horizontal bending moment was shown in Figure 5.

The bending moment at C: $M_{CH} = -R_{AH}l_1 = -2574 \times 78 = -200772N \cdot \mathrm{mm}$

The bending moment at D: $M_{DH} = R_{BH}l_3 = 235.5 \times 50 = 11775N \cdot mm$

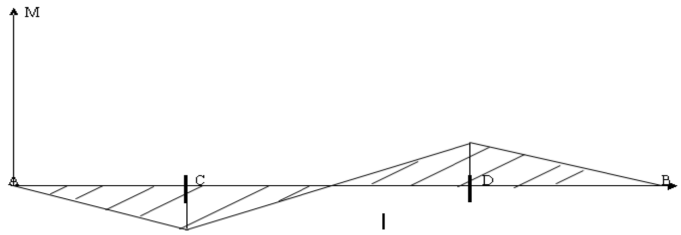

Figure 5 : Diagram of the horizontal bending moment

(3) Synthesis diagram of the bending moments

Synthesis of the bending moments at C:

$$M_{C(left)} = \sqrt{M_{CV}{}^2 + M_{CH}{}^2}$$
$$= \sqrt{103866.2^2 + 200772^2}$$
$$= 26049.5 N \cdot mm$$

Synthesis of the bending moments at D:

$$M_{D(left)} = \sqrt{68976.96^2 + 11775^2} = 69978.7 N \cdot \mathrm{mm}$$

$$M_{D(right)} = \sqrt{79127^2 + 11775^2} = 80003.4 N \cdot \mathrm{mm}$$

Selection and calculation of the thrust ball bearing

Bearing checking methods are consistent. In this design, the intermediate shaft was the most dangerous. So it was a the case to check.

Selection of the bearing

Type of bearing: Thrust ball bearing
Code of the bearing: 51214
Parameters of the bearing: $d \times D \times B = 35 \times 72 \times 17$
The rated dynamic load: 54.2kN
Rated static load: 63.5kN
Limited speed: 5300r/min
Lubrication mode: Grease lubrication

Design and checking

Look-up table to the equivalent dynamic load of the bearing:
When A/R$\leq$e, P=R
When A/R>e, $P = 0.4R + YF\mathrm{a}$
The derived axial force was: $F_d = \dfrac{F_r}{2Y}$
For this bearing, e=0.37, Y=1.6
Bearing for positive installation, schematic diagram was shown in Figure 6:

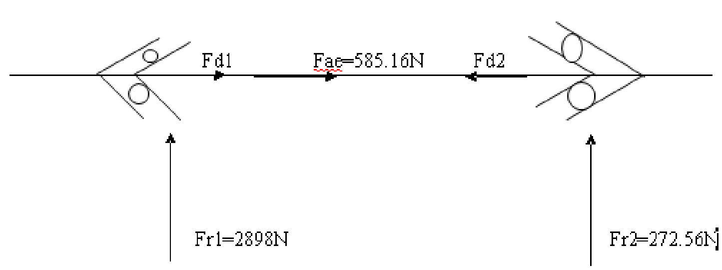

Figure 6 : The stress analysis diagram of the bearing

$$F_{d1} = \frac{F_{r1}}{2Y} = 905.625N$$

$$F_{d2} = \frac{F_{r2}}{2Y} = 85.175N$$

$\because F_{d1} + F_{ae} > F_{d2}$ $\therefore$ Bearing 2 was compacted, and created an additional axial force $F`_{d2}$.

According $F_{d1} + F_{ae} = F_{d2} + F`_{d2}$, so $F`_{d2}$ =1405.6N

The two bearing were checked respectively.

Bearing 1: $F_{a1} = F_{d1} = 905.6N$, $F_{r1} = 2898N$

$$\frac{F_{a1}}{F_{r1}} = \frac{905.6}{2898} = 0.312 < e$$

So, P= $F_{r1} = 2898N$

Bearing 2: $F_{a2} = F_{d2} + F`_{d2} = 1490.8N$, $F_{r2} = 272.56N$

$$\frac{F_{a2}}{F_{r2}} = \frac{272.56}{1490.8} = 0.18 < e$$

So, P= $F_{r2} = 272.56N$

So, the equivalent dynamic load what the bearing 2 bear was bigger, so the bearing 2 was the object checked.

Life expectancy: $L`_h = 8 \times 300 \times 16 = 38400h$

Real life: $L_h = \frac{10^6}{60 \times n_1}(\frac{C}{P})^{\varepsilon}$

Look-up table, when A/R$\leq$e, X=1, Y=0

Look-up table $f_p = 1.2$

Equivalent dynamic load: $P_1 = f_p(X_1 F_{r1} + Y_1 F_{a1}) = 3477.6N$

$$L_h = \frac{10^6}{60 \times n_1}(\frac{C}{P})^{\varepsilon} = \frac{10^6}{60 \times 23.8}(\frac{63000}{3477.6})^3 = 416346.1h > L`h$$

So the intermediate shaft met the design requirements.

SELECTION AND CHECKING CALCULATION OF THE KEY LINKS[4]

Design of the key connecting the high-speed shaft and coupling shaft section

$\because d_{11} = 25mm, L_{11} = 50mm$ So, chose ordinary flat key type A $b \times h = 8 \times 7$, L=40mm,

$l = L - b = 32mm$, K=0.5h=3.5mm

Look-up table to $[\sigma_P] = 100 \sim 120MP = 110MP$

$$\sigma_P = \frac{2T \times 10^3}{kld} = 38MP < [\sigma_P]$$

So, the strength was qualified.

Design of the key connecting the high speed shaft and high speed level tapered pinion shaft section

$\because d_{11} = 25mm, L_{11} = 60mm$ So, chose ordinary flat key type A $\mathrm{b} \times h = 8 \times 7$,

L=48mm, $l = L - b = 40mm$, K=0.5h=3.5mm

$$\sigma_P = \frac{2T \times 10^3}{\mathrm{k}ld} = 31MP < [\sigma_P]$$

So,the strength was qualified.

Design of the key of the conical gear on the intermediate shaft

$\because d_{22} = 25mm, L = 60mm$. So, chose ordinary flat key type A $\mathrm{b} \times h = 14 \times 9$,

L=30mm, $l = L - b = 16mm$, K=0.5h=4.5mm

$$\sigma_P = \frac{2T \times 10^3}{\mathrm{k}ld} = 131MP > [\sigma_P]$$

The two keys were adopted into 180 ° to decorate, 131/1.5=87.6
So the strength was qualified.

Design of the key of the cylindrical gear on the Intermediate shaft

$\because d_{24} = 40mm, L_{24} = 96mm$.So, chose ordinary flat key type A $\mathrm{b} \times h = 12 \times 8$, L=80mm,

$l = L - b = 68mm$, K=4mm

$$\sigma_P = \frac{2T \times 10^3}{\mathrm{k}ld} = 39MP > [\sigma_P]$$

So, the strength was qualified.

CONCLUSIONS

In the design, the main parts of the rotating coffee cup have been carried on the detailed calculation and checking. Although this was more cumbersome, but accurate calculation could provide good theoretical basis for structural design, could choose the more precise the needed parts, and guarantee the machine running in good condition, avoid because some of the problems caused by the wear and tear, or even damaged, more could prolong the life of the machine, to better protect the safety of tourists. Calculate and check the parts including the strength of the shaft, thrust ball bearing and key links to calculate, and establish the mechanics model, calculation of shaft force, bearing reaction force, mapped the torque, bending moment diagram. The result of checking calculation for the structure design of rotating coffee cup had the very good design theory basis.

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