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To cite this article: Tianmin Guan *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **252** 022124

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Static Analysis and Structural Optimization of Traction Gearbox for Concentrated Load Locomotive

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Abstract. In order to reduce the volume and mass of the locomotive's traction gearbox, Firstly, the theoretical statics analysis of the traction gear box is carried out on the basis of establishing the gear box model. Then the box was statically analyzed in the ANSYS work bench software, it can be seen that which factors have a relatively large impact on stress and strain, and where the gearbox is most affected by stress and strain and deformation, and the best wall thickness is selected according to the parameters of the optimization of the box structure.

Key words: gear box, static ANSYS, structural optimization, wall thickness.

1. Introduction

The locomotive traction drive system [1] plays a very important role in regulating the running speed and load-carrying torque of the locomotive as a system-level core component for transmitting power and controlling the speed. Its characteristics are mainly reflected in the high power of the system and the situation is relatively harsh, and the system has high fatigue life requirements. The gearbox optimized in this paper is mainly applied to high-speed electric locomotive. This locomotive needs high running speed and starting acceleration, and can be used for long-distance operation, but the traction force does not have to be large. The gearbox optimized in this paper is a concentrated power load traction type [2]. This gear box has the weight of a part of the motor and the driven gear, and the gear oil is used to lubricate the gear. Therefore, the weight reduction problem of the gear box becomes the locomotive to the high speed. The constraints of the development of heavy-duty direction, this paper analyzes the problems of lightweight [3] of the gearbox, analyzes the main factors affecting stress and strain, and the maximum stress and strain, and according to the optimization of the box structure, Optimize the optimum wall thickness.

2. Theoretical static force analysis of locomotive traction gearbox

Figure 1 is a schematic diagram of the traction gearbox during operation[4]. As can be seen from Fig. 1, the motor 1 drives the driving gear 2 to rotate and the motor and the driving gear are coaxial. The driving gear drives the driven gear 3 through the transmission of the gear, and the axle and the driven gear rotate coaxially through the shaft to drive the wheel to rotate. According to Table 1, the transmission power of the main driven gear and the rotational speed can be known, thus the input torque, the tangential force, the radial force, and the axial force of the traction gear box can be known.
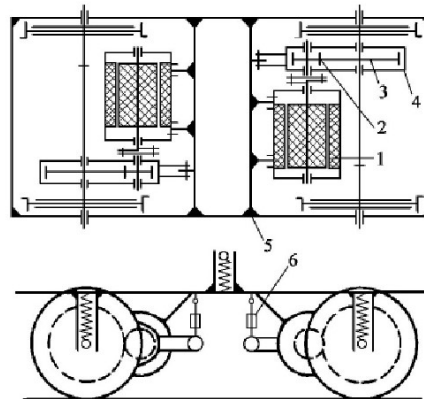
Figure 1. Schematic diagram of the traction gearbox during operation

Table 1. Basic calculation parameters

Parameter name	symbol	value
Gear modulus	M	8.75mm
Indexing circle pressure angle	α	20°
Indexing circle Helix angle	β	12°
Tip coefficient	ha*	1
Headspace coefficient	c*	0.35
Tooth width	B	137mm
Number of teeth	Z	104/21
Center distance	a	566.85mm
Modification coefficien	X1	0.452/0.477
Transfer power	P	435Kw
Rotation speed	N	602rpm

According to Table 1, the input torque and the tangential force radial force are as follows.

Input torque $M_d = 9550 * P / n = 6901 N \cdot m$

Tangential force $F_t = 2 * M_d / d1' = 72415.3 N$

Axial force $F_a = F_{t1} \tan 12° = -46046 N$

Radial force $F_r = F_{t1} \tan 20° / \cos 12° = 191981.89 N$

2.1. Force calculation of connecting boom

The system consisting of the box, the boom and the wheel is the research object. When the locomotive is running, the bogie will give the boom a force Fn. Ignoring the influence of the quality of the gearbox on the position of the center of mass, a schematic diagram of the force analysis of the gearbox case is shown in Fig. 2.

Taking the moment of the wheel center O1,after derivation $F_n = (1+i)M_d / L_2 = 33114 N$

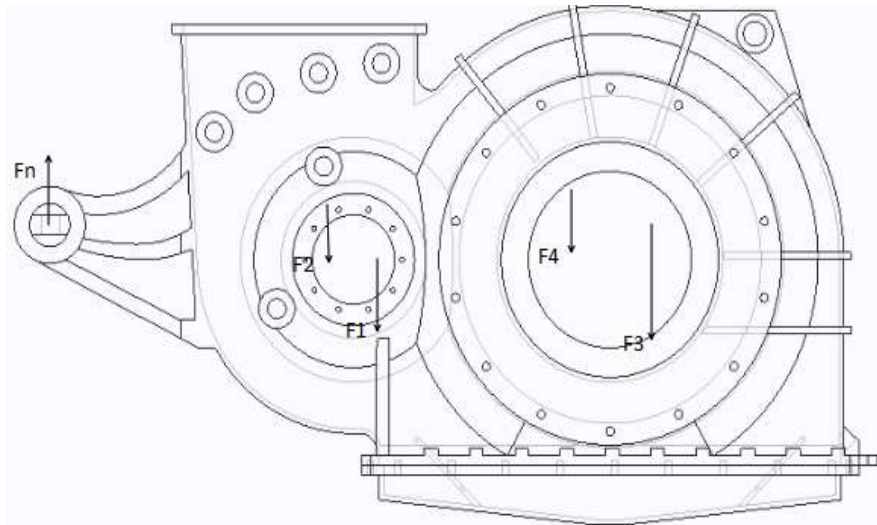Among them, Fn is the force that the bogie acts on the boom; Md is the torque.

Figure 2. Force analysis of the gearbox housing

2.2. Force wheel axle force analysis

For the force analysis of the driving axle, the force direction of the driving wheel circumferential force Ft is opposited to the rotating direction; the radial force Fr is directed by the force direction to the wheel center; the direction of the axial force Fa is left-handed, the left-handed is left-handed, and the four-finger is pointed in the direction of rotation, the direction in which the thumb points is the direction of the axial force. As shown in Fig. 3, F_1 and F_2 are the forces received at both ends of the driving axle. The distance between points 1 and 2 is L_1=250mm, and the pitch diameter of the driven gear is d_1=190.59mm. Substituting F_{t1}, F_{r1}, and F_{a1} into the formula to obtain the relevant parameter values is shown in Table 2.
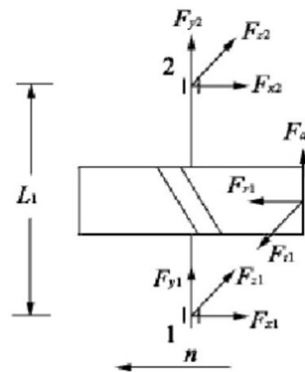

Figure 3. Force diagram of the drive axle

According to the principle of force balance, the column equation

X direction: $F_{X1} + F_{X2} - F_{r1} = 0$

Y direction: $Fy1 + Fy2 + Fa1 = 0$

Z direction: $Fz1 + Fz2 - Ft1 = 0$

Mx direction torque balance: $F_{z2}L_1 - F_{t1}L_1 / 2 = 0$

My direction torque balance: $F_{t1}d_1 / 2 = T$

Mz direction torque balance: $F_{r1}L_1 / 2 - F_{x1}L_1 - F_{a1}d_1 / 2 = 0$

Table 2. .The force of the drive axle

Fx1	113580.6N	Fx2	78401.4N
Fy1	0	Fy2	46046N
Fz1	36207.7N	Fz2	36207.7N

2.3. Force bearing bearing force analysis

The gear box case is used as the force analysis object, and the force analysis diagram is shown in Fig. 4. Force analysis is performed on the driven wheel bearing bore of the box. F'_{x1}, F'_{y1}, and F'_{z1} are the three component forces of F'_1 in the x, y, and z directions, respectively. The distance between the front and rear points of the driving gear bearing hole O_1 and O_2 is L_1=250mm, the distance between the front and rear points O_3 and O_4 of the driven gear bearing hole is l2=320mm, and the pitch diameter of the driven gear is d_2=943.42mm. Substituting F_{x1}, F_{y1}, F_{z1}, F_{x2}, F_{y2}, $F_{z2,}$ and Fn into the formula to obtain the relevant parameter values are shown in Table 3.
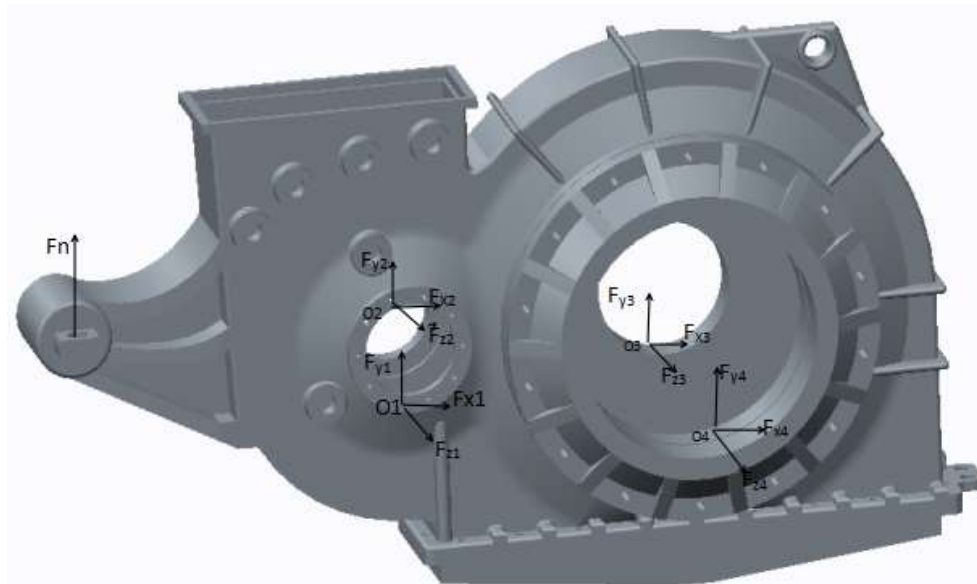

Figure 4. Force analysis of the gearbox

The column equation is:

X direction: $F'_{x1} + F'_{x2} + F'_{x3} + F'_{x4} = 0$

Y direction: $F'_{y1} + F'_{y2} + F'_{y3} + F'_{y4} = 0$

Z direction: $F'_{z1} + F'_{z2} + F'_{z3} + F'_{z4} + F'_n = 0$

Mx direction torque balance: $F_{z4}L_2/2 - F_{z3}L_2/2 + F_{z2}L_2/2 - F_{z1}L_1/2 = 0$

Mz direction torque balance: $F'_{x3}L_2/2 - F'_{x4}L_2/2 + F'_{x1}L_1/2 - F'_{x2}L_1/2 + F'_{y1}L_1 + F'_{y2}L_1 = 0$

Table 3. Forced axle force

Fx3	-46275.6N	Fx4	-145706.3N
Fy3	-46046N	Fy4	0
Fz3	-52764.65N	Fz4	-52764.65N

3. Static analysis of the traction gearbox housing

3.1. Establishment of 3D model of traction gearbox

The gear box is mainly composed of a boom, a large box cover, a gear box case, a fuel tank base and various sealing mechanisms. The gear box model established by the creo2.0 software is shown in Fig. 5.
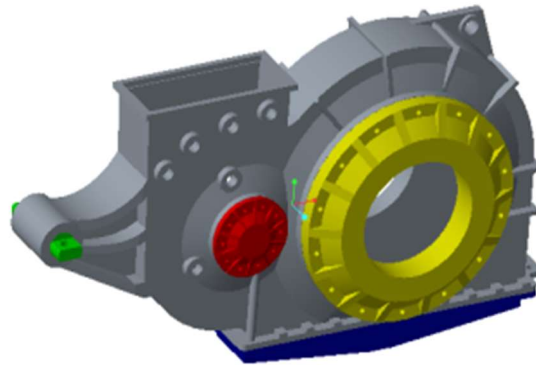

Figure 5. Model diagram of the traction gearbox

3.2. Establishment of finite element model of traction gearbox

1. The simplified principle of the gearbox housing[5]

The simplification of the gearbox housing should follow the following principles:

(1) Guarantee the accuracy of the cabinet

After building the gearbox model in the creo software, you should check the structure of the model to ensure that there are no structural errors and other problems with the gearbox model when importing the ANSYS software.

(2) To ensure the integrity of the cabinet

Delete the small features such as chamfers, rounded corners, and small holes in the model, but the rounded corners that have an effect on the final calculated result cannot be removed.

(3) Rationality of meshing

The level of detailing of the meshing will affect the pre-processing run and the time of analysis, while the performance requirements for the computer will be higher.

2. Box material properties and meshing

(1) Box material properties

The gearbox housing is made of aluminum alloy material AlSi7Mg[6], AlSi7Mg material properties; density: 2700 kg / m3; Poisson's ratio: 0.34; Young's modulus 7.4E + 10pa.

(2) Division of the box grid

After defining the properties of the box material, the box grid is divided. The number of units in the finite element model is 411642; the number of nodes in the finite element model is 593010.

3. Set the boundary conditions

According to the static theory analysis of the box according to the first chapter, it can be known;

(1) Add a fixed constraint on the base of the fuel tank

(2) Applying a direction upward force Fn at the boom

(3) Add F1 F2 force at the front end of the small bearing hole

(4) Add F3 F4 force at the front end of the large bearing hole

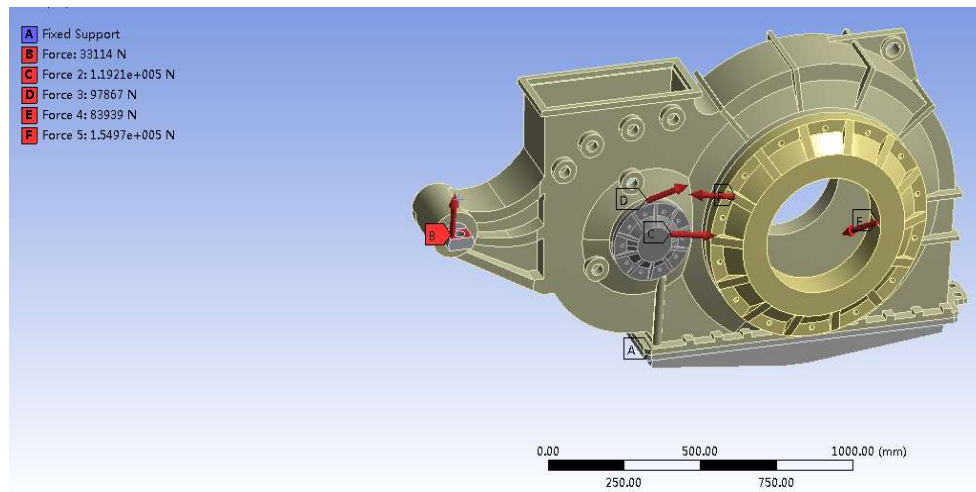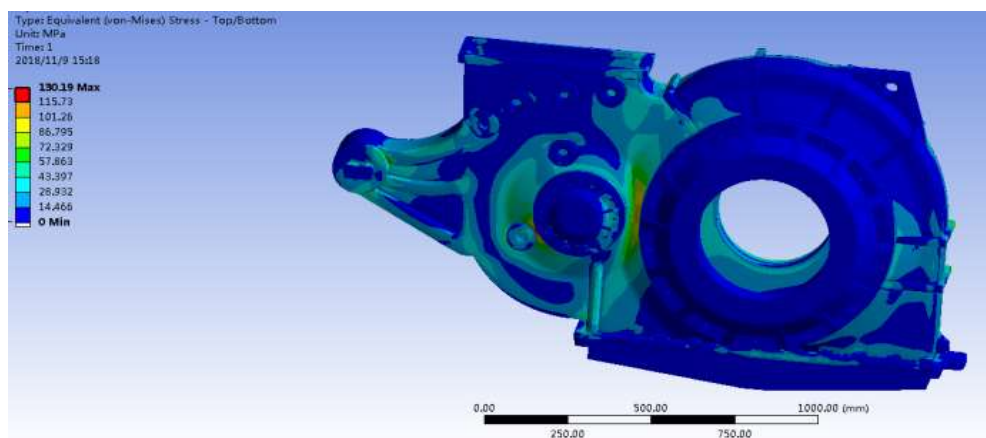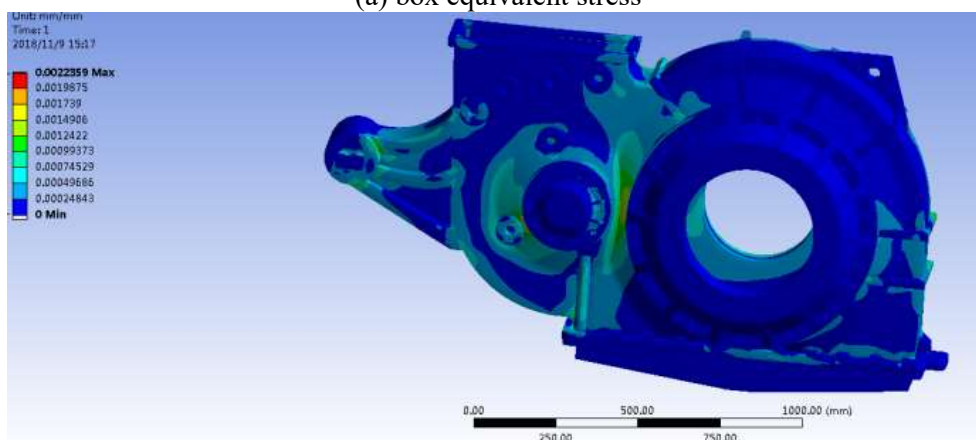The overall boundary conditions of the gearbox housing are shown in Figure 6.

Figure 6. Box boundary conditions

3.3. Analysis of results

After the solution is completed, the result file generated by the ANSYS software can be used for post processing.

(a) box equivalent stress

(b) box equivalent strain

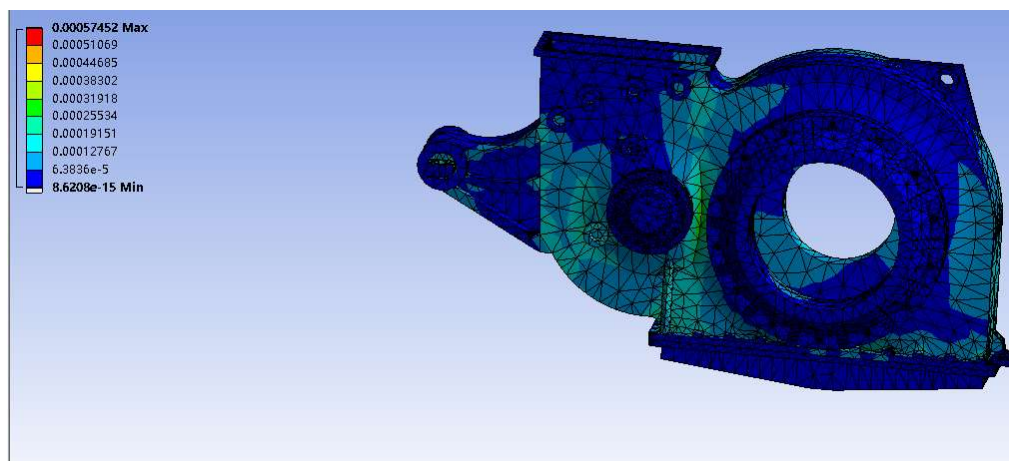**Figure 7.** equivalent stress strain of the box

It can be seen from Fig. a that the maximum equivalent stress of the gearbox case is 130.19Mpa when the locomotive is started, the stress value is less than the yield strength of the aluminum alloy of 180Mpa, and the yield safety factor is about 1.4, which satisfies the static strength requirement under continuous working conditions. The maximum equivalent stress occurs in the lower side of the joint between the box and the boom. The connection between the box and the boom is also the most vulnerable part of the entire box. As can be seen from Figure b, the maximum equivalent effect of the gearbox housing at the start of the locomotive becomes 0.0022359.

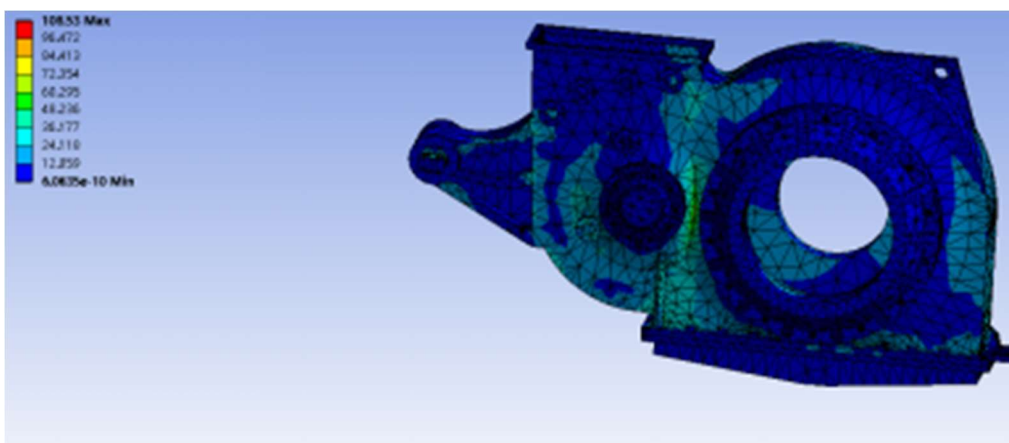## 4. Factor affecting the stress and strain of the box
When performing static analysis in ANSYSworkbench, it was found that the ribs on the gearbox had a great influence on the final result. In order to verify the accuracy of the influencing factors, the verification was performed in the ANSYS software.

  1.Reinforcement
  (1) Equivalent strain stress
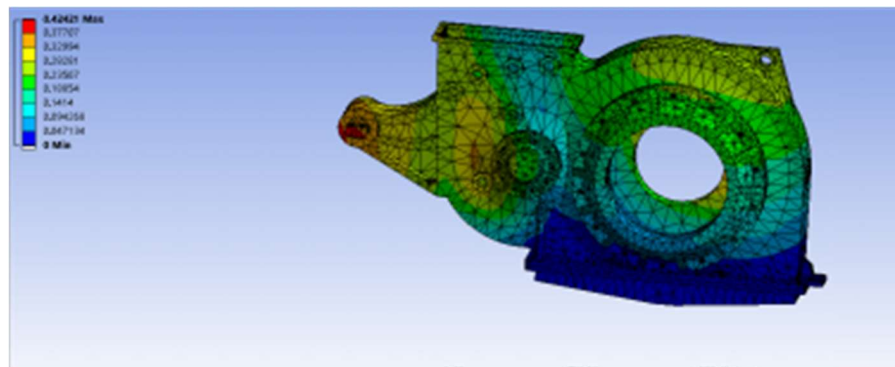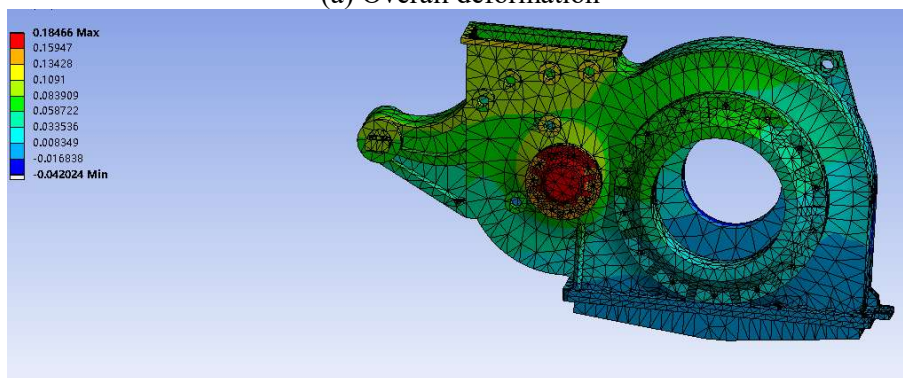

(a) equivalent strain

(b) equivalent stress

Figure 8. equivalent stress strain

It can be seen from Figure a that the maximum equivalent effect of the gearbox housing becomes 0.00057452 .when the locomotive is started. It can be seen from Fig. b that the maximum equivalent stress of the gearbox case is 108.56Mpa when the locomotive is started, and the stress value is less than the yield strength of the aluminum alloy of 180Mpa, which satisfies the static strength requirement.
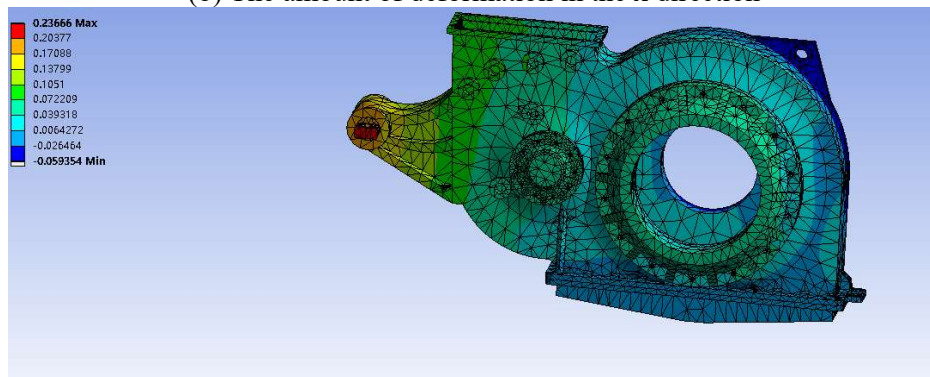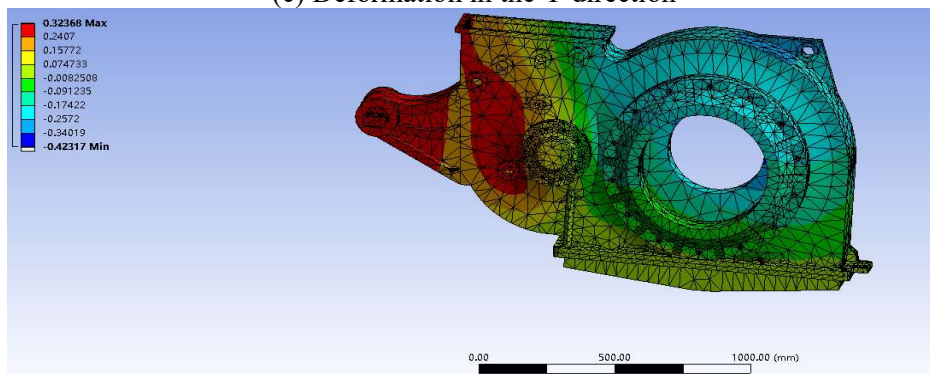
Overall deformation:

(a) Overall deformation

(b) The amount of deformation in the x direction

(c) Deformation in the Y direction

(d) The amount of deformation in the Z direction

Figure 9 Deformation of the box

It can be seen from Figure a that the overall deformation of the box under the guiding condition of the gearbox is 0.42421mm when the locomotive is started. It can be seen from Figure b, Figure c and Figure d that the box is in the X, Y and Z directions. The deformation amounts were 0.18466 mm, 0.23666 mm, and 0.32368 mm, respectively.

5. Box structure optimization
1. Establishment of parameterized box model

After the static analysis of the box is completed, the parameters of the optimization design[7] are set to provide analysis data for the next optimization design. In this paper, the wall thickness of the box is selected as the input parameter for the optimization of the box structure, and the parameters are set as the objective function of the box stress and strain.

2. Setting of input and output variables

For the optimized wall thickness parameters of the gearbox, the optimal model can be obtained by changing the size of the box, on the premise that the shape and structure of the box remain unchanged. In this paper, the size of the box body is continuously changed within the range of 10% of the original size. The initial wall thickness is 11mm and the minimum is 10mm.

3. optimization calculation

According to the range of wall thickness parameters set in this paper, 10 points are set for iterative calculation, and 10 points are shown in Table 4.

Table 4. Variable design

Design point	1	2	3	4	5
wall thickness	10	10.1	10.2	10.3	10.4
Design point	6	7	8	9	10
wall thickness	10.5	10.6	10.7	10.8	10.9

The equivalent strain and stress of the box corresponding to each design point are obtained by iteration calculation of 10 design points as shown in Table 5.

Table 5. Calculation results

wall thickness D(mm)	Equivalent stress (Mpa)	Equivalent strain (mm)
10	151.35	0.002578
10.1	149	0.0025404
10.2	146.71	0.0025035
10.3	144.47	0.0024674
10.4	142.28	0.0024321
10.5	140.15	0.0023976
10.6	138.06	0.0023638
10.7	136.03	0.0023308
10.8	134.04	0.0022985
10.9	132.09	0.00262688

4. select the best solution.

In this paper, three indexes are used to select the optimal solution, one is the mass and volume of the box, the other is the stress formula, the stress value is equal to the yield strength divided by the safety factor, and the third is the total deformation of the box. After calculation and analysis, three optimal numerical groups are obtained, as shown in Table 6.

Table 6. Optimal solution

Optimal value	Equivalent stress (Mpa)	Equivalent strain(mm)
10	151.35	0.002578
10.1	149	0.0025404

In this paper, AlSi7Mg is used. The material number of Germany corresponds to ZAlSi7Mn of China. It is a cast aluminium alloy. Its yield strength is 180 Mpa. When the wall thickness is 10 mm and 10.1 mm, the yield strength of the gearbox body is less than 180 Mpa. Therefore, the wall thickness of 10 mm and 10.1 mm meets the static strength requirements. Aluminum alloy sheet specifications are mainly 9mm 10mm 11mm, so an optimal solution should be selected according to the actual needs of the factory, so this paper should select 10mm.

6. Conclusion
In this paper, through static analysis of gearbox and structural optimization of gearbox, the following conclusions are obtained:

(1) The location where the maximum equivalent stress and strain occur is the connection between the box and the suspender, which can be reduced by adding reinforcement.

(2) Reasonable arrangement of the thickness and location of reinforcing bars has an important impact on improving the stiffness and strength of the box.

(3) In order to lighten the gearbox, the main way is to change the structure of the gearbox, in which changing the wall thickness is an important way, and on the premise of getting the theoretical wall thickness, we need to consider the actual factory existing plate to choose the best wall thickness.

(4) Comparing the results of finite element simulation and theoretical calculation, the data show that the design results are within the desirable range, the design theory is feasible, and it has guiding significance for the following design of traction gear box.

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