Lightweight design of concentrated load traction locomotive gearbox

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Abstract: This paper proposes a method based on topology optimization to improve the overall performance of the concentrated load traction locomotive gearbox. The parameterized model of the gearbox was established in Creo3.0, and the parameters to be optimized were set. The seamless connection function between Creo3.0 and ANSYS was optimized in ANSYS, and the final model of the gearbox was obtained through superposition calculation. The optimized model was compared with that before optimization. The improved results show that the maximum stress after optimization is reduced by 53.217%, the maximum strain is reduced by 53.4836%, and the mass is reduced by 2.98%.

1. Foreword
As the main support and shock absorbing part of the traction locomotive [1], the gearbox is relatively shocked by the load and vibration, so the possibility of fault occurrence is relatively high. Statistics show that the failure rate of domestic gearboxes is as high as 40%-50% [2]. The gearbox has the functions of carrying part of the weight of the motor and the driven gear and lubricating the gear oil. It acts as a series of unsprung masses directly affecting the dynamic performance of the locomotive [3], so the weight of the gearbox [4] It has become an important influence and constraint factor for the development of locomotives in the direction of high speed and heavy load.

2. Establishment of finite element model of traction locomotive gearbox
The establishment of the finite element model of the traction locomotive gearbox is an important part of the finite element analysis. The establishment of the finite element model has a great impact on the final result. This paper introduces the seamless connection function of CREO and ANSYS into ANSYS for the creation of finite element model.

2.1. Parameter definition
In the creo3.0, the 3D model of the gearbox is established and the parameters to be optimized [5] are set. The set optimization parameters can be extracted by ANSYS and can be automatically changed within the set variation range. In the topology optimization design of the gearbox [6], the gearbox solid model in Creo3.0 will change with the change of the sample point parameters, and the optimal gearbox optimization model is obtained by superposition calculation [7].

2.2 Simplify the gearbox
Since the overall structure of the gearbox is complex and subject to large loads, topology optimization of the entire gearbox is impossible, so the gearbox needs to be simplified before topology
optimization.
The simplification of the gearbox should follow the following principles:
(1) Guarantee the integrity of the cabinet
Delete the small features such as chamfers and rounded corners in the model, but the rounded corners that have an effect on the last calculated result cannot be removed.
(2) Rationality of meshing
The smaller the meshing, the longer the computer will run, and the higher the performance requirements of the computer. At this time, the meshing is required to be qualified.

2.3 Definition of material properties and division of grids

2.3.1 Definition of material properties
The gearbox is made of aluminum alloy material AlSi7Mg [8]. The aluminum alloy has low density, but the strength is relatively high. It is close to or exceeds high-quality steel. It has good plasticity and can be processed into various profiles. The performance properties of aluminum alloy material AlSi7Mg are shown in Table 1.

| Material Grade | Elastic Modulus (pa) | Density (kg/m³) | Poisson’s Ratio Yield | Strength (Mpa) |
|----------------|----------------------|-----------------|-----------------------|---------------|
| AlSi7Mg        | 0.74E10              | 2650            | 0.33                  | 180           |

2.3.2 Meshing
The gearbox is meshed, and the result is divided into 53653 units and 101104 nodes, as shown in Figure 1.

![Figure 1. Division of the grid](image1)

2.4 Definition of boundary conditions
In this paper, the multi-objective design of the gearbox is lightweight.

2.4.1 Static analysis
Since the integrated box is connected to the motor by bolts, a fixed constraint is imposed on the joint, as shown in Figure 2.

![Figure 2. Gearbox boundary conditions](image2)

2.4.2 Modal analysis
(1) Apply a constraint at the hole of the boom
(2) Apply a fixed constraint to the front and back of the large bearing hole
(3) Apply a fixed constraint at the hole of the small cover
(4) Apply a fixed constraint at the bearing hole of the tank base
(5) Apply a fixed constraint at the rear (motor)
(6) Apply a fixed constraint at the large cover hole
Load and constraint application is shown in Figure 3.

2.5 Finite element results
(1) Static analysis results
(2) Modal analysis results

| Modal order | natural frequency |
|-------------|------------------|
| 1392.83     | 1392.83          |
| 2474.04     | 2474.04          |
| 3484.51     | 3484.51          |
| 4748.49     | 4748.49          |
| 5749.44     | 5749.44          |
| 6760.62     | 6760.62          |

3. Optimization design of structural parameters of traction locomotive gearbox

The fundamental purpose of topology optimization of the gearbox is to rationally arrange the model material for the purpose of reducing the quality of the gearbox and improving the structural performance according to the loading conditions of the gearbox.

(1) Optimization design parameter selection

The design variable [9] is selected as the size of the box boom, the thickness of the box ribs, the port size on the box, the thickness of the box connected to the motor ribs, the thickness of the box ribs, the total height of the sump Height length.

(2) Selection of target variables

In this paper, the maximum stress and strain values, the maximum deformation and the first and second natural frequencies are selected as the target variables, as shown in Table 3.

| Design variable | Target variable |
|-----------------|-----------------|
| box boom size   | gearbox maximum stress value |
| Number of box ribs | Gearbox maximum strain value |
| Port size on the cabinet | Gearbox overall deformation |
| Number of motor ribs connected to the cabinet | First. second order natural frequency |
| Number of boxes and ribs |                |
| Oil sump height total height length |                |

4. Optimization results analysis

In order to reduce the calculation time, this paper selected 40 design samples. Based on 40 design samples, three optimization results were optimized by multi-objective genetic algorithm [10] under optimization, as shown in Figure 7.
By analyzing the optimization results of the three candidate points, it is found that the result of the candidate point 2 is more satisfactory. Based on the above three sets of results, the optimized variable values are rounded, and then the model is re-established, and the results are checked to obtain the best optimization plan. The results before and after optimization are shown in Table 4.

Table 4. Comparison of gearbox optimization results

| Item                      | Maximum strain | Maximum stress |
|---------------------------|----------------|----------------|
| Before optimization       | 0.00057397     | 42.197         |
| Optimized                 | 0.00026699     | 19.741         |

| Item                      | Maximum deformation amount | First order frequency |
|---------------------------|-----------------------------|-----------------------|
| Before optimization       | 0.40391                     | 392.83                |
| Optimized                 | 0.20562                     | 244.2                 |

| Item                      | Second order frequency | third order frequency |
|---------------------------|------------------------|-----------------------|
| Before optimization       | 471.04                 | 484.51                |
| Optimized                 | 281.43                 | 295.62                |

| Item                      | fourth order frequency | quality               |
|---------------------------|------------------------|-----------------------|
| Before optimization       | 748.49                 | 259.69                |
| Optimized                 | 313.12                 | 252.18                |

Through optimization before and after comparison, it can be seen that the maximum stress after optimization is reduced by 53.217%, the strain is reduced by 53.4836%, the mass is reduced by 2.98%, and the purpose of weight reduction is achieved. The optimized working frequency has a certain safety distance from its natural frequency. Avoid resonance and avoid stress concentration [11], which can extend the life of the gearbox.
5. Conclusion
In this paper, through the lightweight design of the concentrated load locomotive gearbox, the following conclusions are drawn:

1. When the concentrated load gear box is lightened, the stress concentration can be reduced.
2. The first natural frequency of the optimized gearbox case is far away from the natural frequency of the gearbox, avoiding the resonance phenomenon and improving the service life of the gearbox case.
3. After the weight reduction, the manufacturing cost can be reduced, the fuel consumption can be reduced, and the exhaust pollution can be reduced.
4. The research shows that it is feasible to use the topology optimization method of this paper to design the gearbox lightweight, which has guiding significance for the optimization of gearbox housing. However, the application of topology optimization method in mechanical engineering needs further research.

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