Numerical Simulation of a Certain Engineering Vehicle Gearbox under Low Temperature Conditions

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Abstract. The gearbox is an important part of the reducer. Its components must have high bearing capacity and reliability. Cracks often appear in the gearbox body in the actual work, so it is necessary to carry on the structure analysis to the gearbox body performance. In this paper, a 3-D model of an engineering vehicle gearbox is established by using Solidworks software. Based on the model, the stress State and maximum displacement of the gearbox under low temperature conditions are analyzed. According to the calculation, the structure of the gearbox meets the design requirements. The analysis results provide a theoretical basis for the structural optimization of the gearbox.

1. Introduction
Because of the bad working environment of engineering vehicle, its components must have high bearing capacity and reliability. Reducer is one of the important components of engineering vehicle. It is the decelerating transmission device between the original parts and the working machine [1]. It is mainly involved in the running of the vehicle and the operation system and is the key component to keep the stability of the whole vehicle. The gearbox is a very important component of the gearbox, and cracks often appear in the gearbox body in the actual work under low temperature conditions, so it is necessary to analyze the gearbox structure. In this paper, the model of reducer is established by solidworks, and the stress and strain analysis is carried out. The analysis results provide a theoretical basis for the structural optimization of the gearbox.

2. Simulation Analysis Theory [2-6]
The spatial domain is subdivided into elements, which are called finite element elements. In the finite element method, the spatial approximation is performed by linear combination of Ansatz functions with local support. For one-dimensional problems, each ansatz function is not zero in the interval [x_{i-1}, x_{i+1}]. There are several types of ansatz functions that are appropriate because the weak form contains only the space derivative up to one.

\[
N_i(x) = \begin{cases} 
0, & x \notin [x_{i-1}, x_{i+1}] \\
\frac{x - x_{i-1}}{h}, & x_{i-1} \leq x \leq x_i \\
\frac{x_{i+1} - x}{h}, & x_i \leq x \leq x_{i+1} \\
0, & x_{i+1} \leq x \leq x_M 
\end{cases}
\]

for \(i = 1, \ldots, M - 1\). Define the functions \(N_0(x)\) and \(N_M(x)\) at the boundary of the computational domain in a similar way.
Linear hat function satisfies the required characteristics \( N_i(x_j) = 1 \forall i = j \) and \( N_i(x_j) = 1 \forall i \neq j \). By these functions, the approximations \( u_x \) and \( \omega_x \) of \( u_x \) and \( w_x \) are given, respectively.

\[
\begin{align*}
    u(x) & \approx u(x) = \sum_{i=1}^{M-1} N_i(x)u_i + N_0(x)u_a + N_M(x)u_b \\
    \omega(x) & \approx w(x) = \sum_{i=1}^{M-1} N_i(x)w_i
\end{align*}
\]

where, \( u_i = u(x_i) \) and \( w_i = w(x_i) \) represent the approximation at the node \( x_i \). Note that the approximations of \( u(x) \) and \( \omega(x) \) between two adjacent nodes depend on the selected ansatz function. In the special case, the intermediate value is calculated according to the linear equation. However, because we can apply higher order ansatz functions, we can make more precise approximations.

The weak form of the partial differential equation is

\[
\int_a^b \left[ \frac{\partial \omega(x)}{\partial x} \frac{\partial u(x)}{\partial x} + c \omega(x) \frac{\partial^2 u(x,t)}{\partial t^2} \right] \, dx = \int_a^b \omega(x) f(x) \, dx \quad \text{(4)}
\]

Insert equation (2-3) in equation (4) to get

\[
\begin{align*}
    \int_a^b \frac{\partial \omega}{\partial x} \frac{\partial u}{\partial x} \, dx &= \int_a^b \frac{\partial}{\partial x} \left[ \sum_{i=1}^{M-1} N_i w_i \right] \frac{\partial}{\partial x} \left[ \sum_{j=1}^{M-1} N_j u_j + N_0 u_a + N_M u_b \right] \, dx \\
    &= \sum_{i=1}^{M-1} w_i \left[ \sum_{j=1}^{M-1} N_j \frac{\partial^2 u_j}{\partial x^2} \right] \, dx = \sum_{i=1}^{M-1} w_i \left[ \sum_{j=1}^{M-1} \frac{\partial^2 u_j}{\partial x^2} \right] \, dx
\end{align*}
\]

\[
\int_a^b \omega(x) \frac{\partial^2 u}{\partial t^2} \, dx = \int_a^b c \left[ \sum_{i=1}^{M-1} N_i w_i \right] \left[ \sum_{j=1}^{M-1} N_j \frac{\partial^2 u_j}{\partial t^2} \right] \, dx = \sum_{i=1}^{M-1} w_i \left[ \sum_{j=1}^{M-1} \frac{\partial^2 u_j}{\partial t^2} \right] \, dx \quad \text{(5)}
\]

Since \( u_j \) and \( w_i \) are constants, integrals and sums were interchanged. Since \( \omega(x) \) can be chosen almost arbitrarily, and since these and are the same on all terms, we can also ignore the sum of approximate trial functions. Therefore, the expression in Parenthesis \{•\} is retained only in equation (5-6). By introducing matrix and vector components

\[
\begin{align*}
    M_{ij} &= \int_a^b c N_i(x)N_j(x) \, dx \\
    K_{ij} &= \int_a^b \frac{\partial N_i(x)}{\partial x} \frac{\partial N_j(x)}{\partial x} \, dx \\
    f_i &= \int_a^b N_i(x) f(x) \, dx - \int_a^b \frac{\partial N_i(x)}{\partial x} \left[ \frac{\partial N_0(x)}{\partial x} u_a + \frac{\partial N_M(x)}{\partial x} u_b \right] \, dx
\end{align*}
\]

We can write the resulting algebraic equations in matrix form

\[
\mathbf{M}\ddot{\mathbf{u}} + \mathbf{K}\mathbf{u} = \mathbf{f} \quad \text{(10)}
\]

where, \( \mathbf{M} \) and \( \mathbf{K} \) are mass matrix and stiffness matrix respectively.

3. Establishment of Geometric Model [7-10]
Firstly, according to the size of gearbox, the geometric model is generated in solidworks 3D modeling software. In the modeling process, the small structure, such as chamfering structure, was removed. The weld in the model is treated as normal structure. The resulting geometric model is shown in figure 1.
ANSYS software includes line element, beam element, bar element, Shell Element, volume element and elastic element. Because the gearbox is a solid structure, taking into account both calculation accuracy and calculation time, the SOLID92 unit type is selected, the unit type is solid unit, it is a tetrahedron unit with 10 nodes, so it is not easy to be deformed when dividing the grid, at the same time, each node has 3 degrees of freedom. When the finite element method is used to analyze the stress and strain of the structure, the result has higher precision.

The material of this part is aluminum alloy. The material constant can be found in table 1.

| The Actual Material | Finite Element Type | Elastic Modulus E (GPa) | Poisson’s Ratio μ | Density ρ (Kg m³) |
|---------------------|---------------------|-------------------------|-------------------|-------------------|
| Cast aluminum       | Solid92             | 71                      | 0.33              | 2700              |

After the solid structure model of gearbox is established, the next work is to grid the MODEL. Grid Division needs to pay attention to density degree, thickness uniformity. The grids need to be finer for the parts with larger loads. In the part where the precision is not very high, the density of the grid is reduced properly, which provides the guarantee of the precision and time for the boundary condition and the load in the post-processing. The element on the model is close to the regular hexahedron as far as possible, and can be tetrahedron in the irregular structure, so the calculated result is very reliable. The finite element model divided according to this principle is shown in figure 2.

4. The Analysis and Calculation of the Typical Work Conditions

4.1. Load and Constraint
Apply loads of 30254 N, 30254 N and 54073 N at B, C, D respectively, and apply the load at the red part that is the contact point, as shown in figure 3.
4.2. The Result of Calculations

4.2.1. The Whole Stress Distribution. The temperature of the oil changed from 22 ℃ to -30 ℃. Under this condition, the overall stress distribution of the gearbox is shown in figure 4.

![Figure 4. The whole stress distribution displacement.](image)

We can get from figure 4, in this work condition, the maximum stress value is 956.59 MPa, which doesn’t get the yield limit of cast aluminum. In this work condition, the structure is safe.

4.2.2. The Whole Displacement Distribution. The whole displacement distribution is showed in figure 5.

![Figure 5. The distribution of the overall.](image)

We can get from figure 5, the whole maximum displacement is 0.025 mm. From the point of displacement, in this work condition, the displacement of this component is smaller.

5. Conclusion
The structure design of the reducer is very good, safety coefficient is very high, in the case of vehicle running is absolutely safe.
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