Finite Element Analysis and Vibration Control of Lorry's Shift Mechanism

Li Qiangwei

Engineering training center, Soochow University, Suzhou, China

Abstract. The transmission is one of the important parts of the automobile's transmission system, Shift mechanism's main function of transmission is to adjust the position of the shift fork, toggle the synchronizer's tooth ring, so that the gears are separated and combined to achieve the shift. Therefore, in order to ensure the reliability and stability of the shift process, the vibration characteristics of the shift mechanism cannot be ignored. The static analysis of the shift fork is carried out, and the stress distribution of the shift fork is obtained according to the operating characteristics of the shift mechanism of the lorry transmission in this paper. The modal analysis of the shift mechanism shows the low-order vibration frequencies and the corresponding modal vibration shapes, and the vibration control analysis is carried out according to the simulation results. The simulation results provide the theoretical basis for the reasonable optimization design of the shift mechanism of the lorry transmission.

1. Introduction
The transmission is a device that provides a gearshift operation for the vehicle, and the traditional mechanical manual transmission is still the most widely used in transmissions for light trucks. As an important mechanism in the transmission mechanism, Transmission shift mechanism's strength and dynamic characteristics influence the security and stability in the processing of gearshift. In recent years, the developed countries have adopted advanced virtual simulation system to simulate the reliability and rationality of mechanical structure, and provide a reference for the optimal design [1]. The Ford Motor Company carries out the static analysis by the method of finite element to the automobile transmission's structure in the study of its force situation, and then the stress distribution of the transmission is obtained. The Nissan Motor Company analyzes the structure and dynamic characteristics of transmission box, input shaft, output shaft and intermediate shaft with the computer simulation technology, and then optimizes the design of the transmission box, input shaft, output shaft and intermediate shaft [2]. The fatigue life analysis with the method of finite element of the transmission shift fork is carried out in reference [3], and the shift fork assemblies' fatigue lives are obtained. Based on the theory of finite element static and modal analysis, the finite element analysis and vibration control of lorry's shift mechanism are carried out in this paper, the stress distribution of the shift fork, the low-order vibration frequencies and modes of the shift mechanism are obtained, and then the results can provide a guidance for the later design and optimization. Figure 1 shows the structure of lorry's shift mechanism.
2. Method and Theory

The vibration characteristics of the mechanical structure mainly include the natural frequency and vibration mode. Through the static analysis of the lorry's forklift and the modal analysis of the gearshift mechanism, the stress distribution of the lorry's forklift and the shift mechanism's low-order vibration frequencies and vibration modes in the preload state can be obtained [4].

The vibration equation of the multi degree of freedom system is

\[ [M][\ddot{u}] + [C][\dot{u}] + [K][u] = \{F(t)\} \]  

where [M], [F] and [C] are the mass matrix, damping matrix and stiffness matrix, \{F (t)\} are the excitation vectors, \{\ddot{u}\}, \{\dot{u}\}, \{u\} are the acceleration vector, the velocity vector and the displacement vector in (1).

The natural frequency of the machine is the inherent characteristic of the mechanical system, which is not related to the application of the external load, and the influence of the small damping on the natural frequency and the mode of the structure is not significant [4]. Therefore, when the influence of the damping is neglected the free vibration equation with no damping multiple degrees of freedom is:

\[ [M]\ddot{\{u\}} + [K]\{u\} = 0 \]  

The corresponding eigenvalue equation is:

\[ ([K] - \omega^2[M])\{u\} = 0 \]  

\(\omega\) is the natural frequency, \{u\} is the corresponding vibration mode in (3).

3. Modeling and Pre-processing

Model of the lorry's shift mechanism is established in the professional three-dimensional modeling software, and then the three-dimensional model is imported into the finite element software by using the intermediate format between the 3D software and the finite element software for pre-processing. In the pre-processing process, the small fillets and thread feature are optimization by filling, parts which are easily lead to the calculation of divergent should be amended. The shift mechanism is assembled in the finite element software. The nonlinear part is linearized to reduce the computation time on the basis of ensuring the accuracy of the calculation. The finite element model of the shift fork is shown in figure 2a and the finite element model of the shift mechanism is shown in figure 2b.
Lorry's shift mechanism is mainly composed of 45 steel, so material properties for the simulation are steel, the elastic modulus of 200GPa, poisson's ratio of 0.3, and the density of 7850kg/m$^3$. Meshing is an important part of finite element calculation. The grid segmentation affects the calculation accuracy and calculation time [5]. Therefore, reasonable and effective meshing is very necessary. Static analysis and modal analysis of the grid division requirements are different in the finite element analysis, and static analysis requires high grid partitioning [6]. Therefore, the meshing of the shift fork is mainly based on the tetrahedron-based with free division, the precision level is Fine, and the grid correlation is 0. Holes and other parts are refined [7]. The number of nodes is 14816, and the number of elements is 7854. Meshing of shift fork as shown in figure 3a. As a result of that the static analysis requires a higher meshing precision, so the grid quality inspection of the shift fork is checked after dividing the grid, and the main part of the grid distortion below 0.88, therefore, the meshing of the shift fork is in accordance with the finite element calculation requirements. The shift mechanism is meshed in the condition of satisfying the calculation precision. The division method is the same as that of the shift fork. The number of nodes is 91150, and the number of elements is 48333. Meshing of shift mechanism as shown in figure 3b.
Under normal circumstances, the force of people to change shift under the sitting position is between 0N and 300N. The handle force takes 300N in the case of clutch failure shift. The force of shift fork is checked five times by the handle force, so the force is 1500N, acting on the contract between shift fork and synchronizer. The displacement constraint of the shift fork uses the constraint type of displacement to constrain the movement of the input shaft port in the Y and Z directions. The boundary constraint of the shift fork is shown in figure 4a. Since the shift mechanism is an assembly, so it is necessary to carry out the assembly restriction of the parts in the finite element software. Due to the large number of parts of the assembly, the contact type of the shift mechanism is assembled by bonded to improve the calculation efficiency. The fixed constraint type is used at the contact between the shift mechanism and the handle mechanism, and the displacement in the three directions of X, Y and Z is constrained. The boundary constraint of the shift mechanism is shown in figure 4b.

After the static analysis of the shift fork, the stress distribution of the shift fork is shown in figure 5.

It can be seen from figure 5 that the load of the shift fork is up to 166.9MPa under the effect of clutch failure, the yield strength of 45 steel with quenched is 840MPa, the maximum stress of shift fork stress is far less than the yield strength of the material, so the shift fork meets the job requirements.

The modal analysis of the shift mechanism is conducted after the pre-treatment and the low-order vibration frequencies and modes of the shift mechanism can be obtained. The low-order vibration frequencies of the shift mechanism is shown in table 1, and the corresponding modal vibration shapes of the shift mechanism are shown in figure 6.
Table 1. The low-order vibration frequencies of the shift mechanism.

| Mode | Frequency (Hz) |
|------|----------------|
| 1    | 172.7          |
| 2    | 178.6          |
| 3    | 185.1          |
| 4    | 191.2          |
| 5    | 263.3          |
| 6    | 268.3          |

Figure 6. The corresponding modal vibration shapes of the shift mechanism.

From the results of modal analysis, it can be seen that the vibration frequency of the shift mechanism is between 172.7Hz and 268.3Hz, the overall performance is the vibration of the shift fork:

(1) The first-order vibration frequency is 172.7Hz. The vibration performance is the shift forks of the first two gears rotate around left and right along the input shaft's axis. The maximum vibration appears in the contact front end between the shifts forks of the first two gears and the synchronizer, and the maximum displacement is 73.9mm;

(2) The second-order vibration frequency is 178.6Hz. The vibration performance is the shift fork of the fifth gear rotates around left and right along the input shaft's axis. The maximum vibration appears in the contact back end between the shift fork of the fifth gear and the synchronizer, and the maximum displacement is 84.5mm;

(3) The third-order vibration frequency is 185.1Hz. The vibration performance is the shift forks of the first two gear rotate around left and right along the input shaft's axis. The maximum vibration appears in the contact back end between the shift forks of the first two gear and the synchronizer, and the maximum displacement is 87.1mm;

(4) The fourth-order vibration frequency is 191.2Hz. The vibration performance is the shift fork of the fifth gear rotates around left and right along the input shaft's axis. The maximum vibration appears in the
contact front end between the shift fork of the fifth gear and the synchronizer, and the maximum displacement is 84.7mm;

(5) The fifth-order vibration frequency is 263.3Hz. The vibration performance is the shift forks of the third and fourth gear rotate around left and right along the input shaft's axis. The maximum vibration appears in the contact back end between the shifts forks of the third and fourth gear and the synchronizer, and the maximum displacement is 100.3mm;

(6) The sixth-order vibration frequency is 268.3Hz. The vibration performance is the shift forks of the third and fourth gear rotate around left and right along the input shaft's axis. The maximum vibration appears in the contact both ends between the shift forks of the third and fourth gear and the synchronizer, and the maximum displacement is 103.2mm.

4. Vibration Control
Through the finite element modal analysis of the shift mechanism, it can be concluded that the low-order vibration frequencies of the shift mechanism is within 172.7Hz ~ 268.3Hz, and mainly vibration performance is the torsional vibration of the shift fork. Therefore, the vibration characteristics and strengthen of shift fork should be focused in the latter part of the optimization process to prevent the vibration caused by the suspension in the course of driving.

5. Conclusions
The stress distribution of the shift fork and the low-order vibration frequencies and the corresponding modal vibration shapes of the shift mechanism are obtained through the finite element analysis of lorry's shift mechanism. The vibration control scheme is proposed according to the simulation results, and the results could provide the theoretical basis for the optimal design of lorry's shift mechanism.

References
[1] Qian Y D 2013 The Study on performance and test analysis of automobile mechanical transmission, Wuhan University of Technology.
[2] Xiao H Y 2015 Static and dynamic analysis and kinematics simulation of truck transmission, Shandong Jianzhu University.
[3] Jia Y, Luo D G, et al., 2014 Tianjin Auto (8) 48-50, 59.
[4] Dong X, Zheng Z C, et al., 2014 Appl. Mech. Mater. 685 265-70.
[5] Cheng L, Liu Y W, et al., 2012 Mach. Des. Manuf. 1 147-9.
[6] Wang J H, Wang Z C, Gao Y, et al., 2013 Int. Comb. Eng. Power Plant. 30(1) 29-34.
[7] Shu B, Yu D Y, Wang D and Zhang S Q, 2012 J. Mod. Manuf. Eng. 2 71-73, 121.