Design and FEA of Pneumatic Shifting Mechanism of Tractor

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ABSTRACT

In order to solve the problem that it needs large shifting force when tractor transmission shifts, the structure of a tractor gearbox was transformed, and the electronic controlled pneumatic shifting mechanism was designed. Illustrated the working principle of the mechanism, analyzed stiffness, and strength and fatigue life of the key connectors, the results show that connectors meet the design requirements.

INTRODUCTION

For the tractor manual mechanical transmission, large shift control force can cause the drivers' fatigue when they drive for a long time. In recent years, the technology of automated mechanical transmission (AMT) is becoming more and more mature in the truck, it has important significance for reducing the labor intensity of the driver and improving the operating environment when AMT is applied in the tractor.

THE DESIGN OF PNEUMATIC SHIFTING MECHANISM

The structure analysis of cylinder.

Fig.1 illustrates the structure of shifting cylinder. The cylinder is in the neutral position in Fig.1, at this point, the hole A and C ventilate and hole B exhausts, air pressure in hole C is bigger than hole A. At this time piston 2 contacts with the locating ring and the piston 1 moves to the right until it is in contact with the piston 2 under the action of pressure. The neutral position is achieved.

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The working principle of the gas path.

Fig.2 illustrates the working principle of the gas path. The whole gas path is made up of double three-position five-way solenoid valves, three two-position three-way solenoid valves, two shift cylinders, a clutch-separated cylinder, a pressure regulating valve and an air compressor. Taking the 1-2 shift cylinder for example, when the neutral gear shifts into the first gear, the right coil of solenoid valve A1 is electrified, the left one and solenoid valve A2 has power outage, the shift cylinder’s hole B ventilate, the hole A and C exhaust. The piston 1 moves toward left to the first gear position. When the first gear shifts into the second gear, the left coil of solenoid valve A1 is electrified, the right one and solenoid valve A2 has power outage, the piston 1 moves toward right to the second gear position under the pressure. The other gears have the similar operation principle, as long as shifting into the neutral, solenoid valve A2 and B2 are electrified.

3D model of pneumatic gear shift mechanism.

Fig.3 illustrates 3D model of pneumatic gear shift mechanism, the shift cylinder is connected with the shift fork shaft by connectors, and drive the shifting fork shaft to realize the shift operation.

![Figure 1 The structure of shifting cylinder.](image)

![Figure 2. The working principle of the gas path.](image)
FINITE ELEMENT ANALYSIS OF CONNECTORS

The connectors are between the shift cylinder and the shifting fork shaft, as shown in Fig.3. The structure has special shape and large size, it is easy to produce deformation and fatigue fracture due to frequent work and high thrust of the cylinder. The deformation and fracture of the connectors can cause the transmission unable to shift gears. Therefore, it puts forward higher request to the safety of the connectors. The connectors must have sufficient strength and stiffness. The finite element analysis software ANSYS is used to analyze the strength, stiffness and fatigue life of the joints which can effectively predict the dangerous position and provide a reliable basis for the production and processing.

Material parameter setting.

The material of connectors is ZG310-570, and the yield limit of the material is 310MPa. The elastic modulus of the material E=2.1×10^11 Pa, Poisson's ratio L=0.3, and the density is 7850kg/m³.

Meshing of connectors.

In ANSYS, the finite element model are analyzed and calculated, not the geometric model. The ANSYS has a powerful function of meshing. The smaller the mesh is, the more accurate the analysis will be, but the speed of the computer will be slower. The shape of the connectors is complicated, and it requires the high accuracy, so the tetrahedral mesh is adopted. After the ANSYS divides mesh, the connector1 finite element model have 19078 nodes, 10931 units, connector 2 finite element model have 20577 nodes, 11848 units , the results shown in Fig.4.
Strength and stiffness analysis of connectors.

The force of connectors comes from the cylinder. The normal working pressure of the cylinder is 0.4 MPa, the cross-sectional area of the piston is known, and the shifting force can be obtained. The result is about 800 N. The force was applied to the finite element model of the connectors to analyze the strength and stiffness of the connectors and estimate the reliability of the connector.

Connectors’ strength and stiffness analysis are mainly analyze the connectors’ stress and deformation whether meet the requirements under the loading conditions and in order to find out the dangerous position and provide the basis for the fatigue analysis of the connector.

Strength analysis of connectors

Through the constraint analysis and load calculation of the connector 1 and 2, the stress clouds of the connectors were obtained by ANSYS. The results are shown in Fig.5. The maximum stress of connectors $\sigma_{1\text{max}}=89.95$ MPa, $\sigma_{2\text{max}}=127.99$ MPa. ZG310-570 yield limit $\sigma_s=310$ MPa. Considering the fatigue properties of the material, the working condition and importance of connectors, the factor of safety $[\eta]=1.2$, calculating connectors' the allowable stress: $[\sigma] = \frac{\sigma_s}{[\eta]} = 258$ MPa

The maximum stress of the connectors are less than the allowable stress, therefore connectors meet strength requirement under the static load.
Stiffness analysis of connectors

Due to connectors connect the cylinder with the shifting fork shaft, the stroke of the connectors are equal with the stroke of shift fork shaft, that is shift schedule of synchronizer. The large deformations of connectors will directly influence the shift quality. Therefore, it is necessary to carry out the stiffness analysis, the total deformations of connector 1 and 2 under shift force were obtained by ANSYS, the results are shown in Fig.6.

From Fig.6, the maximum deformation of the connector 1 is 0.42mm, the maximum deformation of the connector2 is 0.62mm, and the one-way trip of synchronizer is 11mm, the deformations of connectors are relatively small, the synchronization can successfully complete shift. The connectors meet the stiffness requirements.
Fatigue analysis of connectors.

During the shift of the transmission, the connectors are easy to cause fatigue and failure because of the action of variable load, so the fatigue life of the connectors must be analyzed.

Taking connector 1 as an example, the life, damage, safety factor and fatigue sensitivity clouds of connector 1 are obtained by ANSYS. The results are shown in Fig.7 and Fig.8.

The minimum life of the connector 1 are $2.1655 \times 10^5$ times which occurs in the point between connector 1 with the shifting fork shaft, according to the transmission gear shift number, it is known that no fatigue failure occurs. The maximum value of the connector 1 damage is 4.618, also occurs in the position between the connector with the shifting fork shaft connection, other areas will not be damaged.

Safety factor cloud indicates the ratio of material's failure force and the stress of design, the design life sets as $1 \times 10^5$, minimum safety coefficient is 1.2274, so design meet the requirements.

CONCLUSION

This paper illustrated the working principle of the mechanism, analyzed stiffness, and strength and fatigue life of the key connectors. Through the analysis of the strength, stiffness and fatigue life of the connectors, the design of the connectors meet the requirements.

REFERENCE

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