Dynamic Analysis and Structure Improvement of Timing Chain of an Engine

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Abstract. Based on the dynamic theory, taking the timing chain system of an engine as the research object, the dynamic characteristics of the contact force between the chain and the components, the swing of the chain and the friction work at idle speed of the chain are analyzed respectively. And the influence of the structural design parameters on the abnormal noise of the engine is obtained. Thus, the optimization scheme of the timing chain system is proposed according to the analysis results.

1. Introduction
Timing system is an important subsystem of engine valve system, which transfers the high-speed crankshaft motion to camshaft according to strict phase relationship. Compared with gear and belt drive, timing chain drive has the advantages of high transmission power and compact structure. It can realize the whole life of engine and maintenance free. It has gradually become the mainstream solution of engine valve train transmission.

Aiming at the idling noise of an engine, the design of timing chain system is evaluated on the basis of establishing the dynamic analysis model of timing chain transmission. The contact force is analyzed between chain and components, the swing of chain, the friction between chain and guide plate and tension plate. The influence of structural design parameters on abnormal noise is obtained according to the analysis results. Combined with the analysis results of the basic scheme, the optimization scheme of the timing chain system is proposed.

2. Dynamic analysis of timing chain drive

2.1 Model assumptions
1) The movement reference point of the chain wheel is set as its centroid to define the concentrated mass and moment of inertia. The tension plate and guide plate are set as rigid bodies. And the deformation caused by contact with the chain is ignored. The tensioning plate and guide plate cannot rotate around its pivot in the process of chain operation[1-2].

2) The two-dimensional model of the chain in XY plane is established to simulate the movement of the chain, which is used to analyze the contact force and friction loss between the chain and the tensioning plate and the guide plate as well as the vibration of the chain itself.

3) The chain is represented by a series of mass points that can move in the XY plane. Each mass point is connected by a special stiffness element considering the force magnitude and direction. The stiffness is determined by the distance and direction of the two mass points connected with the mass point. At the same time, the rotation of the chain link is limited by the pin shaft connected to it.
4) The contact coefficients of the chain wheel, the contact plate and the contact plate of the chain wheel are described.

5) Based on the overall stiffness test results of the chain, the stiffness and damping of the chain link are calculated.

2.2 Analysis model
On the basis of the above model assumptions, the dynamic model of the timing chain system is established as shown in figure 1.

The stiffness, damping and friction coefficient are treated as follows.

1) According to the recommended value of the software, the contact stiffness is taken as 20000 N/mm between the chain and driven sprocket, driving sprocket, tensioning plate and guide plate, in which the critical damping is determined by the contact stiffness and chain link mass, and the contact damping is 25% of the critical damping, i.e. 89N.s/mm. The estimated friction coefficient is 0.05 between chain and sprocket, and that is 0.1 between chain and guide plate.

2) The chain link stiffness is calculated from the chain stiffness test results, and the chain link damping is calculated according to the system damping ratio and link mass. The stiffness of the link is 42945nN/mm and the damping of the link is 0.2577N.s/mm. The rotational friction coefficient between chain links is estimated to be 0.1.

2.3 Boundary conditions
The calculated working conditions are from 1500 rpm to 7500 rpm. There are 5 speed conditions every 1500 rpm. Applying the camshaft load at the calculated speed to the driven sprocket is shown in figure 2. Applying the speed fluctuation of crankshaft at the calculated speed on the driving sprocket is shown in figure 3. Camshaft load and crankshaft speed fluctuation are calculated by valve train dynamics calculation and crankshaft dynamics calculation respectively.
2.4 Evaluation content

2.4.1 Contact force between chain and component. It investigates the contact force of a chain link with guide plate and tension plate in a movement period. It can locate the position of the contact force in the chain with greater contact force, and then investigate the contact force at the chain and serve as the indicator to reflect the abnormal impact of contact impact[3-4].

2.4.2 Chain swing. It can reflect the lateral vibration of the chain.

2.4.3 Friction work between chain and guide plate and tension plate. Friction power consumption not only can reflect the transmission efficiency, but also can reflect high friction noise level with high friction power consumption.

2.5 Analysis results

2.5.1 Dynamic calculation of engaging condition. The dynamic calculation of engaging is shown as figure 4. From the figure, it can be concluded that the guide plate is a straight plate, and there is a gap between the guide plate and the guide plate after the static tension of the chain. Due to the lateral shaking of the chain, the impact noise will be generated, especially in the case of high speed.

2.5.2 Internal force of chain. The chain link is the main component of the timing chain transmission system to transmit power. During the system operation, the change curve of the interaction force between the chain links can truly reflect the stress situation of the chain in the working process. The dynamic calculation monitoring points shown in figure 5 are analyzed below, and the internal forces of the chain under five engine speed conditions are shown from figures 6 to figures 10 respectively.
In figure 5, the dynamic calculation monitoring points of the driving sprocket are from 0 to from 90. The dynamic calculation monitoring points of the tensioning plate are from 110 to from 410. The dynamic calculation monitoring points of the driven sprocket are from 450 to from 650. The dynamic calculation monitoring points of the guide plate are from 670 to from 1020.

![Figure 6 1500r/min working condition](image6)

![Figure 7 3000r/min working condition](image7)

![Figure 8 4500r/min working condition](image8)

![Figure 9 6000r/min working condition](image9)

![Figure 10 7500r/min working condition](image10)

1-riving sprocket 2-tensioning wheel 3-driven sprocket 4-guide plate

The calculation results show that the average internal force of the chain is about 300N at different speeds. The minimum value of the internal force of the chain is close to or equal to zero, which means that the chain is sometimes too loose in operation and needs to be avoided in design. At high engine speed, the chain looseness is obvious, and the difference between the maximum and minimum internal forces is large, especially at the loose side of the chain. The design parameters of chain guide plate and tension plate need to be optimized.

2.5.3 contact force of chain tensioning plate. The power of timing chain transmission system is transmitted by the contact between chain wheel and chain plate. Therefore, studying the change curve of contact force between chain plate and chain wheel can better understand the operation of the whole system. The contact force of dynamic calculation monitoring point of tensioning plate is shown from figure 11 to figure 15 at five speed conditions of engine.[5-6]
The calculation results show that there is an obvious contact impact between the chain and the tensioning plate at the sprocket side of the crankshaft, which does not change with the speed change. This shows that the change of engine speed does not affect the overall contact condition of the chain tensioning plate. The contact force of the chain tensioning plate is zero, indicating that the contact between the tensioning plate and the chain is loose. The optimization work mainly focuses on reducing the average contact impact between the chain and the tensioning plate. And the tensioner is needed to dynamically adjust the contact between the tensioning plate and the tensioning plate in the design.

### 2.5.4 Side swing of chain guide plate.

In the process of operation, because the tight side chain is subject to large tension during transmission, the timing chain will vibrate due to the position change. And the chain has a certain side swing relative to the guide plate. The dynamic calculation of the side swing of the guide plate position monitoring point is shown from figures 16 to figures 20 under the five engine speed conditions.
The motion track of the chain on the guide plate side is a straight line. The calculation results show that the chain swings at the corresponding position of the guide plate at different speeds, and the swing amplitude is from 0.5mm to 1.5mm. By optimizing the guide plate profile, the lateral swing of the chain can be reduced.

3. CONCLUSION
From the above analysis results, it can be concluded that the original timing chain system has the following dynamic characteristics.
1) The abnormal characteristics of the chain work are not obvious with the speed change, so the idle speed is taken as a typical working condition for optimization analysis.
2) There is a gap between the chain and the guide plate, which makes the transverse vibration of the chain too large and the impact between the chain and the guide plate increases the risk of abnormal noise.
3) There is contact impact between the chain and the tensioning plate, and the friction function between the chain and the tensioning plate is too large, which increases the risk of abnormal friction noise. Therefore, the profile of the tensioning plate should be optimized.
4) The interference of the tensioners is investigated to reduce the contact impact and friction work between the chain and the tensioning plate.

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