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Effect of Firing Sequence on Crankshaft Shaft Torsional Vibration of an 8-cylinder Diesel Engine

Li Yong

Department of Vehicle Engineering, Shandong Transport Vocational College, Weifang, Shandong, China

117830859@qq.com

Abstract

To study the ignition sequence on diesel engine crankshaft of diesel engine shafting torsional vibration, the influence of by the basis of the commonly used several kinds of 8 cylinder diesel engine ignition sequence, using AVL designer software to the existing 8 cylinder medium speed diesel engine crank shaft system under different firing order torsional vibration to the simulation analysis, focusing on different firing order effect on crankshaft torsional vibration in shaft system. The results show that the different firing sequence only affects the sub-harmonic amplitude and total amplitude of shafting, but has no effect on the natural frequency and primary harmonic amplitude of shafting. Based on the simulation results, the influence of ignition sequence on torsional vibration of diesel engine crankshaft system is described in detail, which provides a certain basis for determining ignition sequence and designing crankshaft system structure.

Keywords

Firing order; crankshaft shaft system; torsional vibration; AVLdesigner; diesel engine.

1. Introduction

As the most common fault problem of diesel engine crankshaft system, the main concern of most designers at the beginning of the design is how to optimise the crankshaft system structure to avoid the resonance point and finally to avoid torsional vibration amplitude and torsional vibration stress limit, very few designers can evaluate the torsional vibration situation from the perspective of firing sequence or conduct regular trial studies from the beginning of the design of the crankshaft to find out The effect of the change in firing sequence on the torsional vibration of the diesel engine.

The ignition sequence of an engine depends on factors such as engine construction, crankshaft design and crankshaft loading. For an inline 8-cylinder 4-stroke diesel engine, the crankshaft rotates twice in one working cycle, i.e. 720°. In order to maintain the work balance, each cylinder ignition interval angle is equal, 8-cylinder diesel engine ignition interval angle of 720/8 = 90°, in order to avoid the uneven crankshaft rotating mass generated by the centrifugal inertia force, so the crankshaft crank clutches to be as symmetrical and uniform as possible, continuous work of the two cylinders as far apart as possible, in addition to the need to focus on the crankshaft shaft system torsional vibration problem.

In the practice of diesel engine use, we will find that when the diesel engine runs to a certain speed, the mechanical noise increases, the diesel engine runs very unevenly, and the performance also decreases to a certain extent. When increase its speed or reduce the speed, the above phenomena obviously reduce or no longer occur. This phenomenon we usually call torsional vibration, a large number of theoretical and practical experience shows that the main reason for this phenomenon is the loss of balance between the active torque of the rotating crankshaft and the load reaction torque, resulting in a large periodic relative torsion, resulting in the direction of the synthetic torque changes back and forth, the longer the crankshaft, the more cylinders, the more serious this phenomenon. When reaching a certain speed, the shaft system combined torque and crankshaft itself vibration frequency between the "resonance", when the crankshaft torsional deformation intensified, that is, the diesel engine noise increased, the phenomenon of performance decline. Therefore, in the design of diesel engines, the torsional vibration of the shaft system must be calculated and analysed in advance to determine its critical speed, vibration type, amplitude, torsional stress and the need for vibration reduction measures, as shown in Fig. 1.

Fig.1 Crankshaft torsional fracture

There are many related studies on crankshaft shaft system torsional vibration at home and abroad, such as the optimized design of torsional vibration parameters of reciprocating compressor shaft system[1] , the effect of cylinder combustion on the torsional vibration of ship propulsion shaft system[2] , the study of the effect of high elastic rubber coupling on the torsional vibration characteristics of inverter fan shaft system[3] etc. This paper combines the crankshaft shaft system structure of 8-cylinder diesel engine, carries out the crankshaft shaft system torsional vibration simulation calculation, and through the analysis of simulation results, the main harmonic sub, sub-main harmonic sub, total harmonic sub amplitude, torsional vibration stress and other results analysis and research[4-5] , summarizes certain laws, to provide some theoretical basis for the determination of diesel engine firing order.

2. The Establishment of Simulation Model

In order to better simulate the simulation results, combined with the actual structure and characteristics of the crankshaft system of an 8-cylinder diesel engine itself, the crankshaft system and related accessories of an 8-cylinder diesel engine are used as the research object, based on the commonly used 8-cylinder diesel engine firing sequence, and the simulation calculation is carried out based on AVL_designer software[6-7] . The basic parameters of this diesel engine are shown in Table Ⅰ. In order to simulate the actual situation more accurately, the relevant module inertia is set up in the simulation model at[8] , taking into account the high elastic connection at the flywheel end and the influence of the dynamometer on the torsional vibration.

TABLE I. MAIN PARAMETERS OF MEDIUM SPEED DIESEL ENGINE

Type	Technical Route	Cylinder diameter *stroke /mm	Rated power/kW	Rated speed/(r·min-1)
in line, 8 cylinders	Supercharged intercooling, direct injection in cylinder	200×270	810	1000

Based on the above analysis, a 3D simulation model of the whole machine was built for the first model, as shown in Fig. 2.

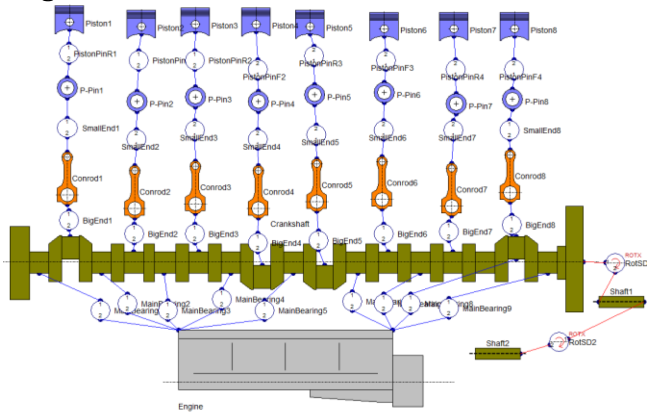


Fig.2 Machine simulation model

Based on the actual structure of the crankshaft, a lumped parameter model is established. The shafting model is shown in Fig. 3.

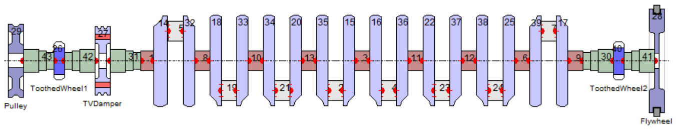


Fig.3 Shafting simulation model

The equivalence model[9-10] is based on the set parameter method, in which the following principles are followed: the crankshaft shaft system is discrete into individual components with concentrated rotational inertia, internal and external damping and elastic nodes without mass; the pulleys, dampers, flywheels and other components with large rotational inertia are concentrated on the crankshaft centre line; the rotational inertia of individual components such as pistons, connecting rods and crankshafts is concentrated on the cylinder centre line; the rotational inertia of each connected component The inertia of the shaft between the connected parts is proportionally loaded to the adjacent parts. The simplified shaft system equivalent model system is shown in Fig. 4.

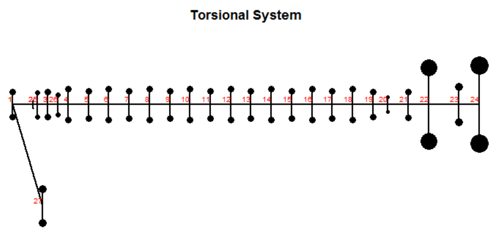


Fig.4 Shaft system equivalent model

3. Calculation scheme and loads

3.1. Calculation scheme

According to the firing order of common 8-cylinder diesel engines and with reference to related models at home and abroad, six 8-cylinder models were selected for firing order as a comparison. The schemes are listed in the Table Ⅱ below.

TABLE II. CALCULATION OPTIONS

Programmed serial number	Firing sequence
1 (original machine)	(1-3-5-7-8-6-4-2)
2	(1-3-2-5-8-6-7-4)

3	(1-3-7-4-8-6-2-5)
4	(1-6-2-4-8-3-7-5)
5	(1-5-7-3-8-4-2-6)
6	(1-4-7-6-8-5-2-3)

3.2. LOADS

The engine speed range is: 600r/min-1000r/min. The external load input is the cylinder pressure curve, which is taken from the test results of the measured cylinder pressure data. This is shown in Fig. 5.

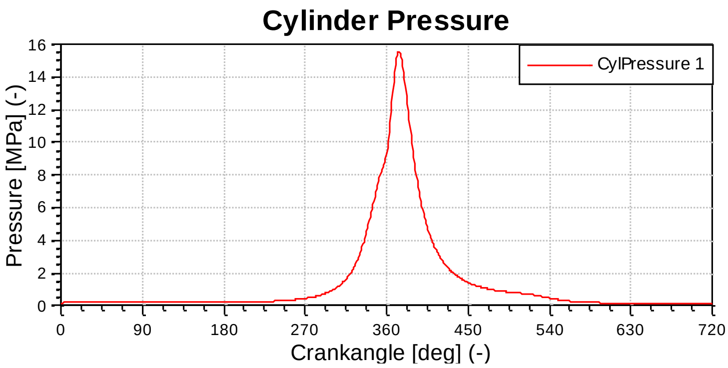
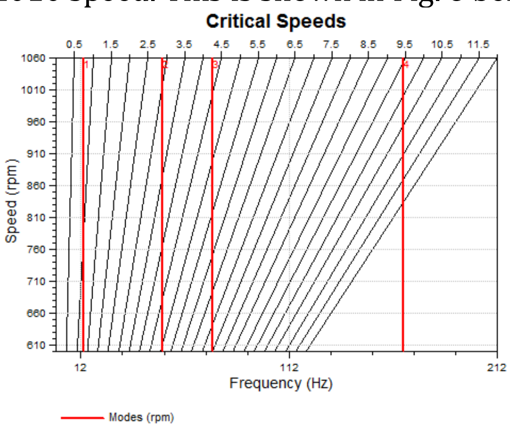


Fig.5 Cylinder pressure test data

4. Simulation results and comparative analysis

Extracting the critical speed spectrum of the system under free vibration, it can be seen that the first order intrinsic frequency of the shaft system is 13.3Hz, at this frequency there is an intersection with 760 speed, at this speed there will be a resonance point, but not necessarily torsional vibration

The amplitude exceeds the limit. Again, there is a resonance point between the 2nd order intrinsic frequency and the 1010 speed. This is shown in Fig. 6 below.



mode [-]	frequency [Hz]
1	13.3
2	51.3
3	75.4
4	167.0

Fig.6 Critical speed spectrum of the system

Extracting the torsional amplitude values of the damper under forced vibration, it can be seen that the highest single harmonic amplitude is as the 4th harmonic of the main harmonic, with a peak range at 800-850 rpm, close to the limit of 0.25. The total harmonic amplitude does not exceed the limit of 0.65deg. The total harmonic amplitude does not exceed the limit value of 0.65deg. as shown in Fig. 7.

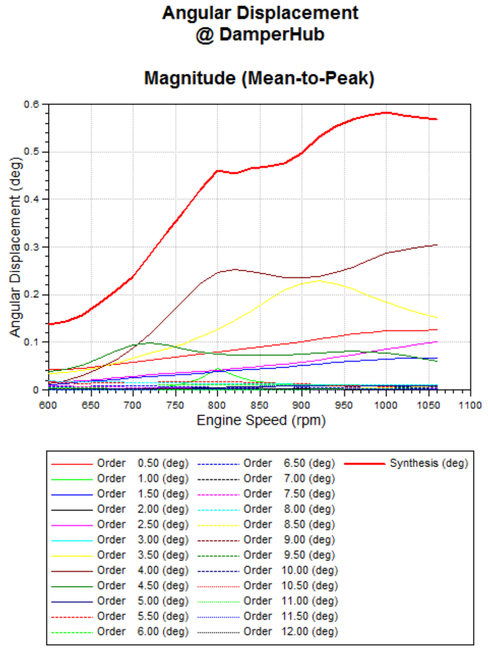


Fig.7 Amplitude results

Finally the torsional vibration (shear) stress results were extracted for each crank arm, with the total torsional vibration stress not exceeding the limit of 60 MPa. The Fig. 8 below shows the torsional vibration stress diagram for the 15th crank arm.

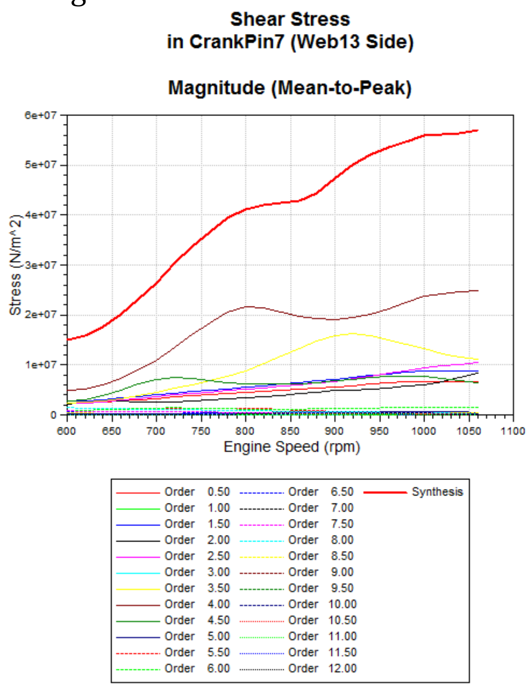


Fig.8 Torsional vibration stress results

A comparative analysis of the simulation results under different firing sequences is shown in Table III.

TABLE III. SIMULATION RESULTS FOR DIFFERENT FIRING SEQUENCES

Projects	First order torsional frequency/Hz	Second order torsional vibration Frequency/Hz	Front end torsional vibration amplitude (deg)			Maximum torsional vibration stress amplitude (MPa)
			Synthesis	4 harmonious times	3.5 harmonic times	
Option 1	13.3	51.3	0.592/1000	0.292/1000	0.252/920	52.36
Option 2			0.590/1000	0.292/1000	0.230/920	56.07
Option 3			0.539/1000	0.292/1000	0.168/920	52.32
Option 4			0.582/1000	0.292/1000	0.105/920	56.01
Option 5			0.554/1000	0.292/1000	0.105/920	54.51
Option 6			0.577/1000	0.292/1000	0.230/920	53.41
Reference limits	-------	-------	< 0.65	< 0.25	< 0.25	

A comparative analysis of the simulation results reveals that

1) Inherent frequency: Different firing sequences have no effect on the inherent frequency of the crankshaft system.

2) Torsional amplitude: different firing sequences have no effect on the amplitude of the main harmonic torsional amplitude (4th harmonic), and have some effect on the submain harmonic (3.5 harmonic) and total harmonic amplitude.

3) torsional stress: different firing order has a certain influence on torsional stress, the trend is that the corresponding torsional stress is also larger for large torsional amplitude.

5. Conclusions

The AVL simulation software designer was used to simulate and model the whole engine and shaft system of an 8-cylinder marine diesel engine[11-13] and to study the effect of different firing sequences on the torsional vibration of the crankshaft shaft system. By simulating and analyzing the 8-cylinder model under several different firing sequences, the inherent frequency, torsional vibration amplitude and torsional vibration stress of the shaft system[14-15] were analyzed and the following conclusions were finally drawn.

1) By building a simulation model of the complete machine and the shaft system, and adding flywheel end height spring and dynamometer inertia modules according to the actual situation of the bench, a more accurate simulation can be ensured.

2) Simulation using the AVL software's built-in aggregate parameter method can greatly simplify simulation time and produce the desired conclusions quickly and efficiently.

3) The analysis of the simulation results shows that the different firing sequences only affect the subdominant harmonic sub-amplitude and the total amplitude of the shaft system, and have no effect on the intrinsic frequency and the main harmonic sub-amplitude of the shaft system.

Acknowledgments

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