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Dynamic Analysis of Timing Chain Drive System of Diesel Engine of Passenger Car

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Abstract : The current trend in automotive industry is to achieve compact, efficient and reliable systems. Engine timing drives used in engines are one of the most critical systems. Timing drives include timing belts, timing gears and timing chains. Timing belts are subjected to excessive elongation and wear, while timing gears contribute excess mass and inertia in the system. Hence timing chains are preferred widely, in various high performance engines. Chain drives are easy to assemble and adjust, highly efficient, durable, reliable, compact and capable of attaining a wide range of power and speed capacities. In spite of these advantages their complex dynamic behaviour is not well researched. The scope of the work includes development of simulation model for two chain layout of timing chain system in suitable simulation software and its dynamic analysis.
Keywords : Chain drive, Cylindrical contact, Contact force, Tensioner, Chain stiffness.

I. INTRODUCTION

The timing chain system is one of the most critical systems of an engine .The function of a timing chain is to transfer the rotation of crankshaft to camshaft and Fuel Injection Pump (FIP) and other connected accessories so as to achieve proper timing at valves and the timing for fuel injection.

When the engine is in motion, the dynamic forces like normal reaction forces, frictional forces, Impact forces on the timing chain may cause considerable effect on the function of the camshaft and FIP shaft & hence on valve & Fuel injection timing. The effect is prominent when the engine is at high speed. It was noted from the literatures that, for diesel engines, speeds ranging from 0-1500 RPM are considered as low speeds, those between 1500-2500 RPM are medium speeds and those above 2500 RPM are considered as high speeds. The purpose of this project is to study the dynamic effects on the timing chain system at a high speed of 4000 rpm.

The dynamic analysis of timing chain gives us the idea of the behaviour of different components during motion & at specified conditions of working. It includes the forces coming on the chain, chain guides, sprockets, Plunger of tensioner. It also includes displacements of the guides, chain link, plunger& chamber of tensioner etc. The results then can be studied for the breaking loads of the chain link and maximum allowable stresses for guides, and sprockets.

II. CHAIN DRIVE

Chain drives are widely used in a variety of mechanical systems for transmission of power. Their popularity is rapidly expanding, especially in the automotive industries, because of their numerous advantages. The advantages of chain drive systems are as follows:

1. Negligible stretch, allowing chains to carry heavy loads.
2. Long operating life expectancy because flexure and friction contact occur between hardened bearing surfaces separated by an oil film.
3. Operates in hostile environments such as high temperatures, high moisture or oily areas, dusty, dirty, and corrosive atmospheres, etc., especially if high alloy metals and other special materials are used.
4. Long shelf life because metal chain ordinarily doesn't deteriorate with age and is unaffected by sun, reasonable ranges of heat, moisture, and oil.
5. Certain types can be replaced without disturbing other components mounted on the same shafts as sprockets.
6. No slippage between chain and sprocket teeth.

Drawbacks of the chain drive systems:

1. Noise is usually higher than with belts or gears, but silent chain drives are relatively quiet.
2. Chain drives can elongate due to wearing of link and sprocket teeth contact surfaces.
3. Chain flexibility is limited to a single plane whereas some belt drives are not.

4. Sprockets usually should be replaced because of wear when worn chain is replaced. Timing belts' sheaves exhibit very low wear.

With the requirement of lighter weight and higher speed chain drives within the automotive industry, the dynamic analysis of timing chain systems is becoming important. In order to further optimize their design, a more comprehensive knowledge of the system contact forces and impacts is desired.

A. Engine timing systems

An engine timing system transfers the motion from crankshaft to camshaft, Fuel injection Pump, balancer shaft etc. at proper velocity ratio so that the valve opening and closing as well as the fuel injection should occur correctly.

There are three types of engine timing systems.

1. Timing belt system
2. Timing gear system
3. Timing chain system

We have adopted Timing chain system for the following advantages.

- Longer life than Timing belts i.e. Durable(Over 150,000 miles life).
- Resistant to High Temperature and wear
- Not too light as belts and not unnecessarily heavy like gears.

B. Timing chain drive system

Figure 1 given below shows a timing chain system. In any internal combustion engine, fuel and oxygen are combined in a combustion process to produce the power to turn the crankshaft of the engine. To produce useful work, the combustion must take place at the end of the compression stroke of the engine cycle. Following the power stroke the exhaust valve must be opened to clear the cylinder of spent exhaust gases. The job of the timing system is to ensure the opening and closing of valves as well as the Fuel injection to occur in the correct sequence at the correct time.

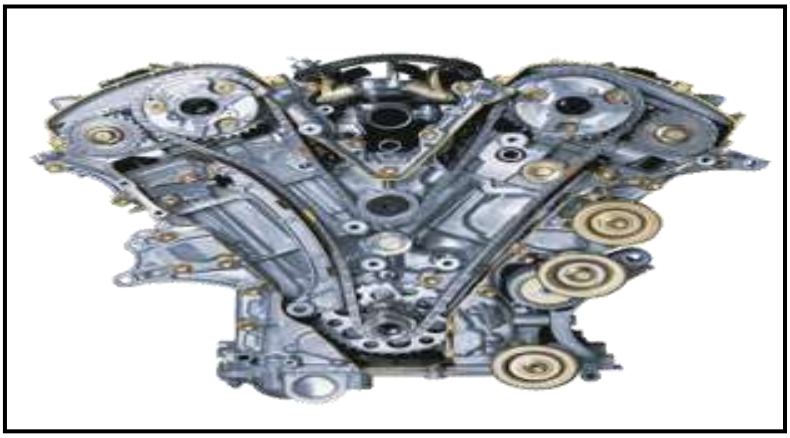


Fig.1: Timing chain system

The timing system consists of several mechanical components. The main drive sprocket is attached to the engine crankshaft outside the crankcase on the front of the engine. The chain runs around the driver sprocket and the driven sprockets. The arrangement is exactly like the chain on a bicycle, motorbike etc. from the pedals to the rear wheel. A tensioner is provided to keep the chain in tension.

III. METHODOLOGY

Figure 2 shows the CAD model of the timing chain test rig which is to be analysed for its dynamic behaviour. The layout is designed considering the space constraints in the actual engine. Input speed of 4200

RPM is given to the duplex sprocket. The speed ratio between the duplex sprocket and cam sprocket is 0.5 and that between duplex and FIP shaft is 0.75.

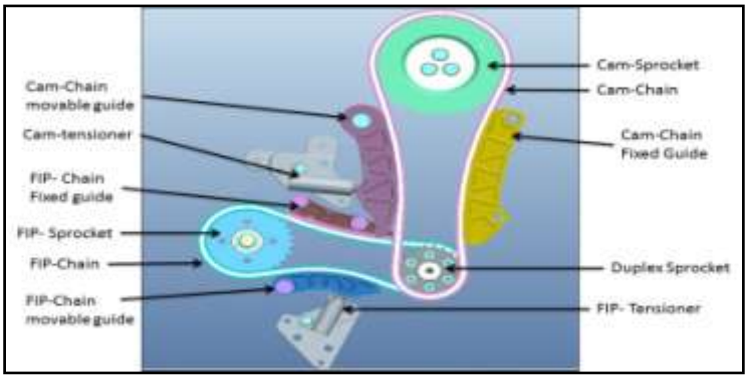


Fig. 2: Timing chain Layout

A simulation model of a three cylinder engine roller timing chain system has been developed as shown in figure 3(a). Figure 3(b) shows the 2D representation of the timing chain. The condition of external load (i.e. torque) is specified to the camshaft and FIP shaft. The external torque acting on camshaft is periodic and having maximum peak value as 16.5 Nm at 2100 RPM whereas the external torque acting on FIP shaft is constant at 28.8 at 3150 RPM. The input data required regarding the sprockets, guides, timing chain, tensioners etc, is specified according to the standard data available. Dedicated software was used to run the simulation and results obtained are specified.

The following section presents the overview of the software simulation and results to predict the dynamic behaviour of the timing chain at 4000 rpm. The two models when combined, gave us the simulation model for complete two chain layout. The procedure for the generation of duplex model is bit complicated and takes a longer time. The final simulation model of the three cylinder engine roller timing chain system is as shown in Figure 2(a). The condition of external load (i.e. torque) is specified to the camshaft and FIP shaft. The external torque acting on camshaft is periodic and having maximum peak value as 16.5 Nm at 2000 RPM whereas the external torque acting on FIP shaft is constant at 28.8 at 3000 RPM. The input data required regarding the sprockets, guides, timing chain, tensioners etc, is specified according to the standard data available. Dedicated software is used to run the simulation and results obtained are specified. The simulation model is run for 10 cycles of rotation with each cycle comprising of 720 degrees of duplex sprocket rotation. Figure 2(b) shows the 2D representation of the timing chain layout.

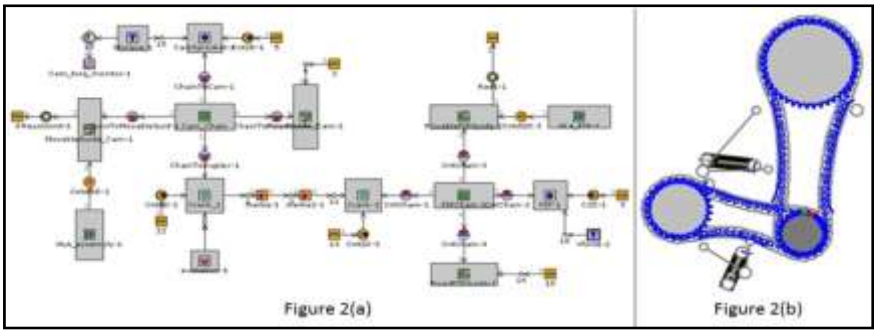


Fig. 3(a): Mathematical model of two chain layout **Fig. 3(b):** 2D layout of two chain layout

IV. RESULTS AND DISCUSSION

A. Chain tension

Figure 4 shows the Variation of tension force between the chain links w.r.t time in seconds.

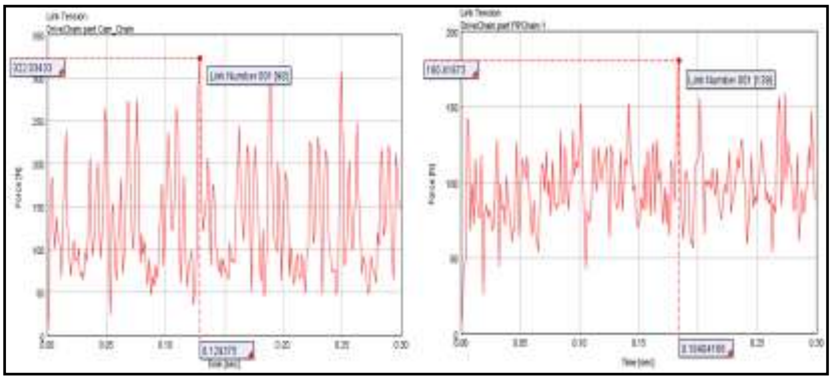


Fig. 4: Maximum chain tensions in Cam-chain and FIP Chain

It is noticed that the maximum chain tension in cam side chain is 322 N whereas the maximum chain tension in FIP side chain is 180 N. The data for four revolutions of the crank sprocket (duplex) is plotted. This chain tension value goes on increasing as the chain runs for a large number of cycles.

The breaking load of the chain is much higher and is 10500 N. The tension value obtained in both the chains is much below than this value. Hence, both the chains are safe and reliable from tensile failure point of view.

B. External forces on duplex sprocket

External forces acting on a sprocket include the forces acting on sprocket in X and Y direction due to chain pull. Figure 5 shows the external forces acting on the duplex sprocket plotted w.r.t time. The term crank-1 represents the portion of duplex sprocket connected to cam sprocket through chain whereas the term crank-2 represents the portion of duplex sprocket connected to FIP sprocket. The maximum external force on crank-1 in X direction is 519 N and 614 N in Y direction.

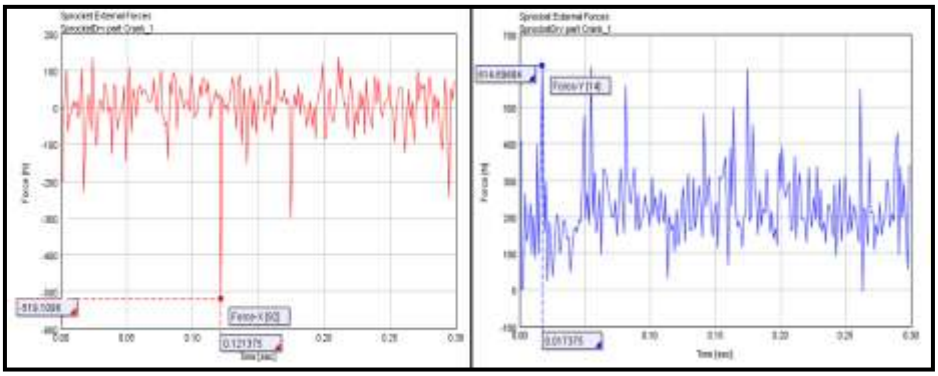


Fig.5: Maximum external forces(X-Direction and Y-Direction) on crank-1

Similarly the maximum external force on crank-2 in X direction is 441 N and 426 N in Y direction. The resultant of all these forces is calculated to be 979N. These values are very small as compared to the maximum permissible load that can be sustained by material of duplex sprocket. Hence the duplex sprocket is safer.

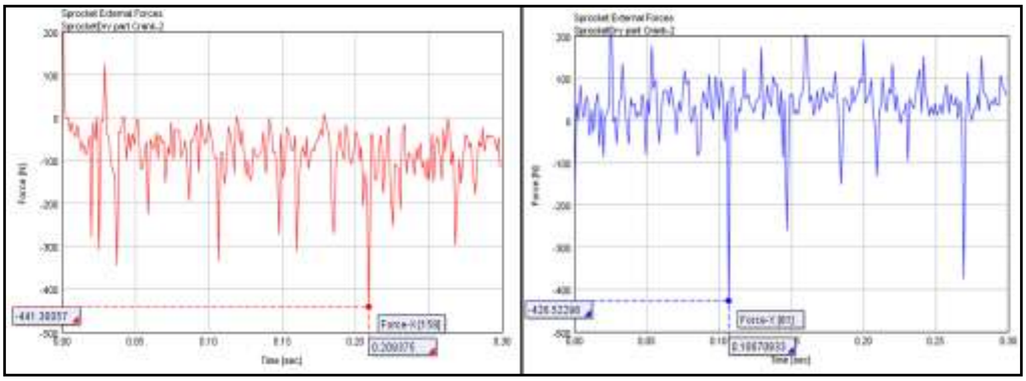


Fig. 6: Maximum external forces(X-Direction and Y-Direction) on crank-2

The value of maximum external force in X direction is negative whereas force in Y-Direction is positive. This is because the sprocket gets pulled from 2nd quadrant (Negative X and Positive Y).

C. Contact forces between Cam chain and other connected components

The contact forces between the chains and other connected components like guides and sprockets are major parts of investigation. Figure 7(A) shows the variation of contact force between cam-sprocket and Cam-chain w.r.t time in seconds. The maximum value of which is 446 N. Similarly Figure 7(B), 7(C), 7(D) shows contact force variation between cam-chain and Duplex sprocket and cam-chain movable guide, Cam-chain and fixed guide, respectively. The maximum values recorded for above parameters were 572 N, 356 N and 279 N respectively.

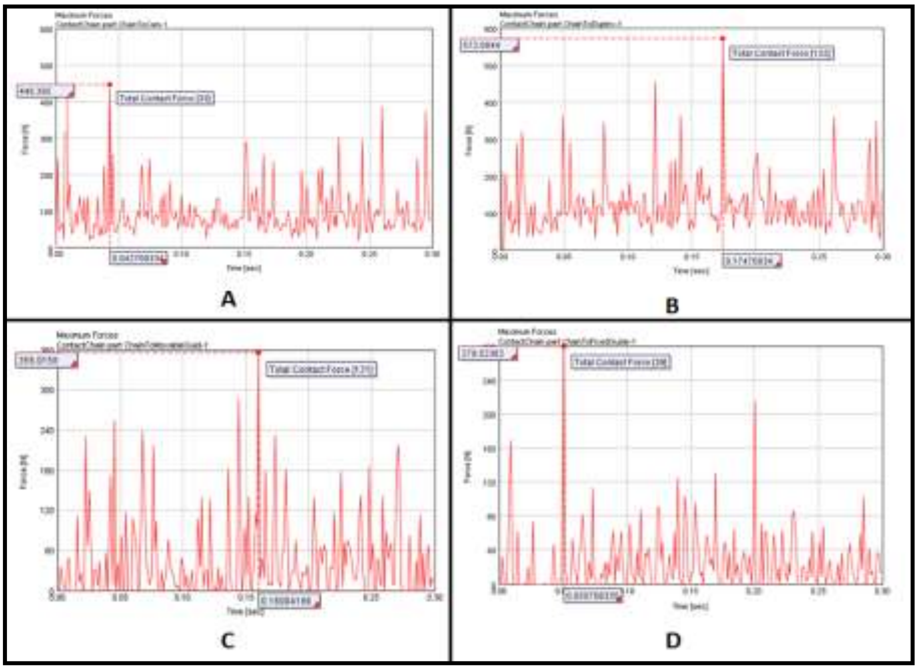
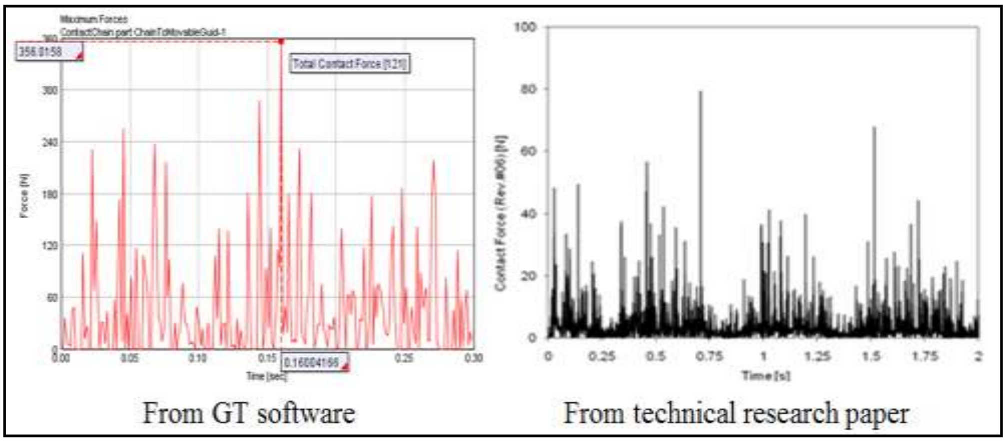


Fig. 7: Total Contact forces A: Between Cam chain and Cam Sprocket, B: Between Cam chain and crank-1 sprocket, C: Between Cam chain and Cam movable guide, D: Between Cam chain and Cam fixed guide

The profile of contact force obtained in the above figure closely matches with the profile of contact force from research work. Figure 8 shows the comparison of profiles of contact force obtained from software and that from technical research paper.



Fig, 8: Contact force profile comparison between results of software and technical research paper

D. Contact forces between FIP chain and other connected components

Figure 9 shows contact force variation for FIP-chain. The maximum contact force between FIP- chain and FIP sprocket is 472 N whereas that between FIP-Chain and duplex sprocket is 433 N.

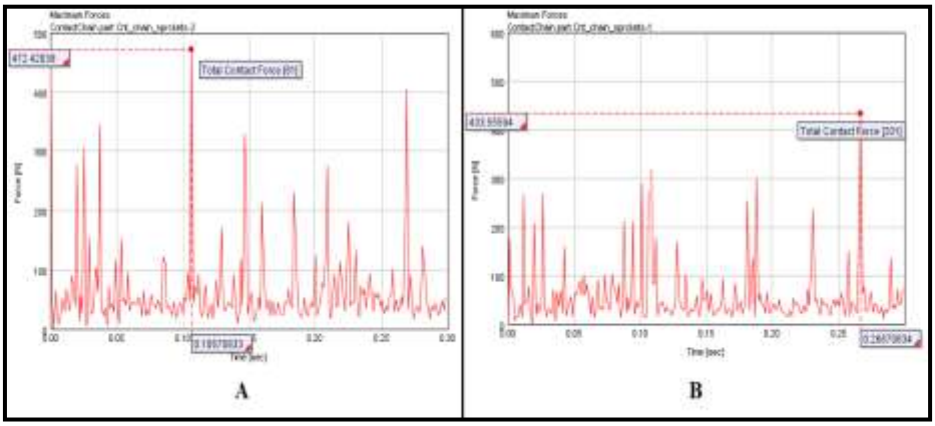


Fig.9: Total Contact forces A: Between FIP chain and FIP Sprocket, B: Between FIP chain and crank-2 sprocket

The contact force between FIP-Chain and movable guide is noticed to be 264 N. The maximum contact force between the FIP chain and fixed guide is 142 N. The graphs for the same are shown in figure 10.

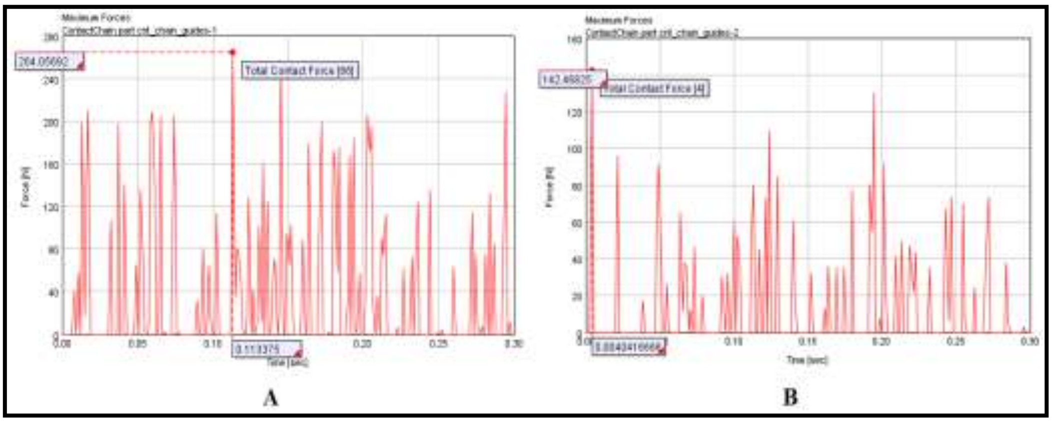


Fig10: Total Contact forces A: Between FIP chain and FIP movable guide, B: Between FIP chain and FIP fixed guide

V. CONCLUSION

The work done presented in current research work confirms that the methodology adopted for design and manufacturing, assembly of the timing chain test rig, development of the test setup using the CAD model is correct and reliable.

The results obtained from dynamic analysis, carried out in the software work, have a close match with the results from literatures, technical research papers and the experimental results. The results presented shows that the external forces and loads can be easily sustained by the timing chain components. The obtained values for the contact forces, tensions etc. were much below the maximum permissible values.

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