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Literature Review on Simulation and Analysis of Timing Chain of an Automotive Engine

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ABSTRACT
The current trend in automotive industry is to achieve compact, efficient, reliable systems. Engine timing drives used in engines are one of the most critical systems. 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. With the improvement of the speed and load of the automotive engine, and silent chain technology, as silent chain has a compact structure, high transmitting efficiency, high reliability and high wear resistance, its vibration and noise is low, and the silent chain have the advantage of life-long maintenance-free, it significant overcomes the gear drive and belt drive performance, therefore, the silent chain is increasingly widely used in automotive engine timing system. In this present review dynamic analysis as well as analysis of automotive engines timing silent chain system are studied.
Keywords: Chain drive, Cylindrical contact, Contact force, Tensioner, Chain stiffness.

I. INTRODUCTION

The auto industry is one of the important sector of the Indian economy. The industry is fulfilled of automobiles and auto components, spare parts sectors and in business of commercial vehicles, passenger cars, two wheelers and three wheelers. From past two decades optimum vehicle design is a prime concern in front of automobile industry. So now a day's creativity in this sector is increasing day by day. To accomplish this objective various techniques are developed to carry out design of engines, transmission system and entire vehicles. Modern computer based design and modelling, mathematical modelling and computerised FEA analysis is providing new approach in designing and manufacturing field of auto industry.

The timing drive system is one of the most critical system of an engine .The function of a timing drive 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. Timing drive consisting of timing belts, timing chains and timing gear drives.

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. Dynamics of the timing chain drive system becoming worse as the engine speed increases and causes serious durability issues for high speed diesel engines. The dynamic analysis of timing chain gives the idea of the behaviour of different components during motion & at specified conditions of working. Dynamic analysis includes computation of the forces coming on the chain, chain guides, sprockets, Plunger of tensioner.

Now a days, chain drives are most dominantly used over timing belts and timing gear drive systems. This is because of advantages of chain drives over other timing drive systems. Chains are more durable, compact and more efficient than other timing drive systems. At the same time, optimised chain layouting and dynamics is of prime importance. If dynamics consisting of contact stresses, contact forces between various chain drive components exceeding beyond acceptable limits, it leads to saviour vibrations, improper valve and fuel injection timings. Important customer demand of the diesel passenger cars is less Noise, Vibration and Harshness (NVH) and maximum comfort. As chain dynamics is the leading source of aggregating Noise, Vibration and Harshness (NVH) issues. If designed valve and injection timings are not achieved, it cause reduction in volumetric efficiency of the engine and affects overall vehicle performance and fuel economy. All together for better volumetric efficiency and vehicle performance, optimised chain system design and layouting is of prime importance. Optimised chain dynamics minimises Noise, Vibration and Harshness (NVH) issues of engine and hence vehicle.

II. CHAIN DRIVES

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.

1) Chain terminology

Pitch of chain: - It is the distance between the hinge centre of a link and the corresponding hinge centre of the adjacent link, as shown in Figure1 and Figure 2. It is usually denoted by 'p'.

Pitch circle diameter of chain sprocket: - It is the diameter of the circle on which the hinge centres of the chain lie, when the chain is wrapped round a sprocket as shown in Figure 1. The points A, B, C, and D are the hinge centres of the chain and the circle drawn through these centres is called pitch circle and its diameter (D) is known as pitch circle diameter.

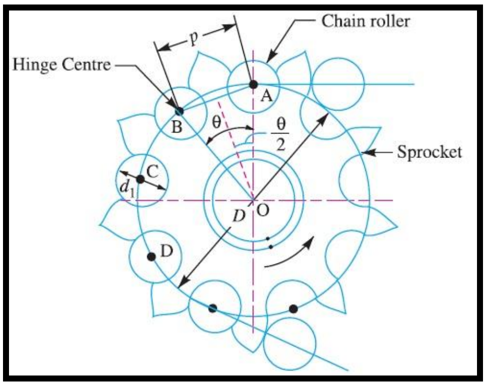

Fig. 1: Chain terminology

2) Length of Chain and Centre Distance

An open chain drive system connecting the two sprockets is shown in Figure 3.

Let,

T_1 = Number of teeth on the smaller sprocket,
T_2 = Number of teeth on the larger sprocket,
p = Pitch of the chain, and
x = Centre distance.

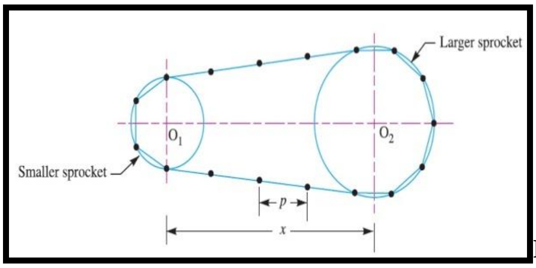

Fig. 2: Distance between sprocket and length of chain

The length of the chain (L) must be equal to the product of the number of chain links (K) and the pitch of the chain (p). Mathematically,

L = K * p

The number of chain links may be obtained from the following expression, i.e.

$$K = \frac{T_1 + T_2}{2} + \frac{2x}{p} + \left[\frac{T_2 - T_1}{2\pi}\right]^2 * \frac{p}{x}$$

The value of K as obtained from the above expression must be approximated to the nearest even number.
The centre distance is given by,

$$x = \frac{p}{4}\left[K - \frac{T_1 + T_2}{2} + \sqrt{\left(K - \frac{T_1 + T_2}{2}\right)^2 - 8\left(\frac{T_2 - T_1}{2\pi}\right)^2}\right]$$

3) 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.

4) Timing chain drive system

Figure 3given 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.

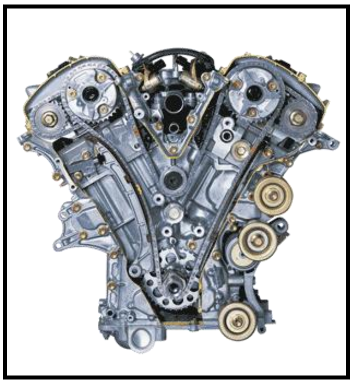

Fig. 3: Timing chain system

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. LITERATURE SURVEY FORM TECHNICAL RESEARCH PAPERS

Pavel NOVOTNÝ and Václav PÍŠT□K [1], they discussed about the dynamics of the chain driving system. The paper focuses on simulation of dynamics of the timing chain drive with the use of a multi-body system. A mass-produced four cylinder in-line engine with two camshafts and two valves per cylinder has been used as a computational model. Virtual prototypes of the timing chain drive are being created as higher-level computational models based on a multi-body system dynamics. These enable a detailed solution of the timing chain drive dynamics and can find weaknesses of the design before first prototypes are made. They will speed up the development of the timing chain drive with better technical and economic parameters. Dynamic analysis performed in proposed dissertation work will be compared with results available in this paper.

Pavel NOVOTNÝ and Václav PÍŠT□K [2], there is a clear trend to use chain or belt drives for the design of timing drives. Computational simulation of these drives has not been developing too long due to high demands on the computational technology. They focused on simulation of dynamics of the timing chain drive with the use of a multibody system. A mass-produced four cylinder in-line engine with two camshafts and two valves per cylinder has been used as a computational model. It will help in improving the design parameters from both technical and economic point of view.

Sine Leergaard Pedersen [3], in this work simulation and analysis of large roller chain drive systems, such as e.g. used in marine diesel engines is done. A novel formulation for the simulation of the dynamics of roller chain drives using a continuous contact force method is developed in their work. The model of the contact surface between the rollers and sprocket has shown to be an important issue regarding the numerical stability of the simulation program and a model with a real tooth profile proves superior to other applied models. With this model it is possible to perform a dynamic simulation of large marine engine chain drives. Through the application of this method, it is shown that the interrelated dynamics of the elements in the chain drive system is captured and the contact problem is characterized. The chain drive model is compared with simplified analytical results, while the necessary experimental validation is left for future studies.

James C. Conwell and G. E. Johnson [4], this work is related to the design and manufacturing of a new test machine configuration that will offer some advantages over thecurrently developed model. The new designed machine provides more realistic chain loading and allow link tension and roller-sprocket impact monitoring during normal operation. This new machine features offers new advantages and allow more data collection options.

C. Pereira *et al.* [5], in this work, a multibody methodology was used to address the kinematic and dynamic effects of roller chain drives was presented. The chain itself was modelled as a collection of rigid bodies, connected to each other by revolute clearance joints. Each clearance revolute joint, representing the connection between pair of links, was made up of the pin link/bushing link plus the bushing link/roller pairs, if the chain is a roller chain. Furthermore, the problem of contact initialization and its coordination with the numerical integration procedures is taken into account by controlling the time step size of the numerical integration algorithm in the vicinity of the impact. This methodology is demonstrated through its application to the study of a bicycle roller-chain drive being the methodological assumptions discussed in the process.

MotoyasuSakaguchi*et al.* [6], in this work a method for reducing friction loss in the engine timing chain was investigated using multi-body dynamics simulation. The method known as the link-by-link model was employed in the simulation to enable representation of the behaviour of each single link of the chain and its friction due to contact. In order to predict the friction under actual engine operating conditions, a model that takes camshaft torque fluctuation and crankshaft rotational speed fluctuation into account was created. This simulation was used to verify the detailed distribution of friction in each part of the chain system as well as the changes of friction in the time domain. Simulation was used to verify the predicted effects of these measures, with the result that reducing the moment of inertia of the camshaft and reducing the initial load on the chain tensioner were confirmed to reduce friction loss.

R. S. Dwyer-Joyce *et al.* [7], a photoelastic stress analysis technique has been used to determine the contact stresses in an automotive chain drive tensioner. The tensioner in normal operation is subject to high magnitude, short duration impact stresses. These stresses are known to cause surface damage, wear, and surface pitting. In order to adequately design the drive system layout, a means for stress quantification is needed. A replica tensioner was made from epoxy resin and tested in a variety of configurations. A simple model has been created to relate the chain link load to the resulting tensioner subsurface stress field. This model has been used to correlate the observed and predicted location of isochromatic fringes, and hence to evaluate the chain link load from the photoelastic fringe pattern. Once the load was determined the contact model was used to determine the magnitude and location of the resultant peak stresses. Measured impact stresses were found to be several times higher than those which would have been calculated from a static analysis

C. Weber *et al.* [8], in this work the new test method developed to facilitates the direct measurement of the real timing chain load under all engine conditions. The measuring principle is based on a strain gauged chain link in combination with a telemetric transducer system. It guarantees the continuous observation of the link force during the complete chain revolution in order to identify significant dynamic effects, which are responsible for noise, wear and incorrect valve timing. In this paper, an experimental investigation of the dynamic behaviour of an engine timing chain drive system has been performed.

Kevin Maile*et al.* [9], in this work a design for reliability methodology based on the Design for Six Sigma(DfSS) Define – Characterize – Optimize - Verify (DCOV) process, applied to the development of a cost effective timing chain drive for a four cylinder diesel engine. CAE model for the timing chain drive was used to study the distribution of the chain loads, which provided an essential input both for the concept selection stage and for the development of a reliability model for the timing chain. Design of Experiment (DoE) study on the CAE model aimed at investigating the significant factors for chain load variability lead to a reliability improvement achieved by reducing the variability in the chain load through revising the tolerances for the sprocket tooth profile. This work demonstrates the efficiency of the process and the usefulness of computer simulation in achieving reliability and robustness enhancement while reducing design and development time and costs. In this paper, CAE tools and FEA techniques are used for computing chain loads. The study of the manufacturing process showed that this variability could be considerable reduced by tightening the tolerances.

Hiroshi Takagishi and Atsushi Nagakubo [10], in this work, on the longitudinal model the load prediction accuracy was inadequate. Accordingly, a link-by-link model was created, allowing transversal vibration to be taken into account. As a result, the features of a chain system using a blade tensioner were clarified, thus enabling the chain load and behaviour to be predicted with a higher degree of accuracy than before. The results shows that it was possible to predict the behaviour of the chain and the chain load more realistically and with higher accuracy, clarifying the features and limitation of a chain system that uses a blade tensioner

IV. CONCLUSION

Study of layouting and dynamics behaviour of timing drive system is having prime importance during design of IC engine. Failure of the timing drive system or non-tolerable dynamics of the timing drive system finally leads to failure of IC engine. It causes improper valve timings, fuel injection timings and non-acceptable level of vibrations in engine. Detailed solution of the timing chain drive dynamics before first prototypes of engines and vehicles is required for avoiding durability issues in engines. Literature survey shows study of dynamics and performance of the timing chain drive system is performed in commercially available software's. Timing drive test rigs are designed and manufactured for testing the performance of the chain drive systems before actually assembled in engine and before engine getting productionized. This helps in optimizing and finalising chain system design. FEA models of the timing chain drive system is compared with dynamic results of the system measured from actual experimentation.

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