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Research Article

Camshaft Torque Analysis of Diesel Engine

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Abstract

Drive torque requirement for engine valve train system is the analysis of torque required to drive the valve train by the crankshaft. There are different types of valve trains used such as overhead camshaft, pushrod valvetrain and end pivot valvetrain system. There are different types of followers used for these valvetrain like flat face, roller or oscillating follower. The torque required for each of these valve train is different according to its application. Hence finding torque requirement for each valve train and the factors influencing it is the main aim of the project. The analytical torque values compared with the software simulations and also the actual testing of the test rig.

Keywords: *Engine valve train system etc.*

1. Introduction

Engine Valve train system is one of the most important system of an I.C Engine. The improper design would lead to the complete failure of engine and high power losses. Hence a correct operation and design is of utmost importance. Valve train consists of many parts like camshafts, valves, valve springs, HLA (Hydraulic Lash Adjuster), Pushrods, Rocker arms and Tappets or Followers. This adds to a large inertia of total components driven by the camshaft. Currently the valve train system must be optimized to improve its performance and reduce its weight.

Camshafts are an important part of a valve train system. These camshafts are driven by crankshaft and they run at about half the angular speed of crankshaft. In high speed engines the rotational speeds of camshaft can be very high leading to high torsional vibrations. These torsional vibrations give rise to high stresses in the valve train. Fatigue analysis of camshaft is very much important as it is expected to run for longer durations without affecting its strength.

The need of this project i.e.-Analysis of Drive Torque requirement for engine valve train system by using different types of followers is detailed in the following sections.

The valve train system is a significant part of the power train function & contributes to a power loss detrimental to fuel economy. Poor valve train dynamics characteristics & abnormal valve train vibrations significantly affect the performance, durability & noise of an engine. The challenges for valve train designer are that the system must operate robustly with changing with changing operating conditions

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2. Need of Work

- Power requirement for the engine to drive the valvetrain.
- Partial Engine optimization.
- Dynamic analysis.
- Camshaft Bearings and gear selection and optimization.
- Tribological significance.
- Tallying the analytical and the actual torque with the software simulated torque.

3. Literature survey

The torque variations of camshaft thus have a considerable effect on the working of crankshaft and engine flywheel. In this competitive automotive market engines with high power output consuming less fuel is very important. [Paper 1] Optimization of engine is thus important in every phase of engine development. Torque acting on the camshaft depends on the inertia forces of components, spring forces, vibratory forces and the frictional forces. Hence the torque analysis helps in optimizing the complete valve train inertia by choosing different materials etc. The largest source of vibration next to crankshaft is the valve train. The camshaft torque can give an indication of the possible inherent torsional vibrations. Camshaft torque analysis has a great influence on the valve train dynamics. It can be used to know the dynamic behavior of the flexible components such as valve springs. The difference between the calculated and the analytical torque can indicate the friction present in the valve train and hence we can reduce it. To enable optimization of the valve train system and component design it is necessary to be able to predict the various contributions to the valve train friction at the design stage itself. Hence the camshaft torque has a great influence on the tribological factors as well .By finding friction torque we can change the oils, oil film thickness, friction in bearings, effects of oil, additives etc. Thus the effect on valve train friction by many variations in valve train design (changes in the cam profile, spring design, surface finish, tappet coating etc.) can be evaluated. [Paper 3]

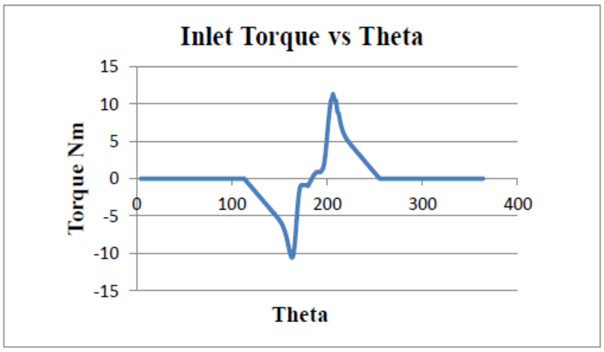
4.1 Inputs for pushrod mechanism by using flat face follower for 3 cylinders (inlet valve):

Valve Mass	166gm
Mass of Retainer	31gm
Mass of Valve Spring	65gm
Rocker arm	63.1gm
Cam width	24mm
Follower Radius	10.5mm
Follower Width	9mm
Stiffness of Spring	23N/mm
Valve lift	12mm
Cam lift	4.702mm
Rocker ratio	1.5
Total weight at cam	319.4gm
Total weight at valve	87.6gm
Wire diameter	3mm
Spring free length	54.7mm
Density of steel	7850kg/m3
Moment of inertia	4.95×10-4kg/m2
mass of guide	36gm
mass of follower	188gm
mass of cam	75gm
Mass at Valve Side(i.e Mass of Valve, Spring, Retainer, Guide)	304gm
Mass at Cam Side(i.e Mass of Follower, Cam)	258gm

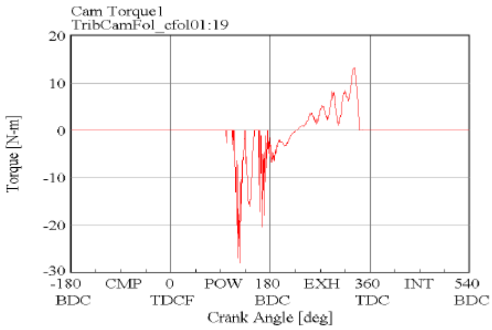
Comparison of Analytical and Software:

(a)Camshaft Torque for flat face pushrod mechanism of 3 cylinder inlet valve engine

Analytical Graph



Software Graph



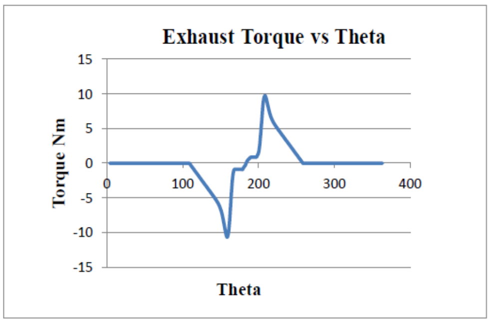
4.2 Inputs for pushrod mechanism by using flat face follower for 3 cylinders (exhaust valve):

Valve Mass	163gm
Mass of Retainer	31gm
Mass of Valve Spring	65gm
Rocker arm	63.1gm
Cam width	24mm
Follower Radius	10.5mm
Follower Width	9mm
Stiffness of Spring	23N/mm
Valve lift	12mm
Cam lift	4.702mm
Rocker ratio	1.5
Total weight at cam	319.4gm
Total weight at valve	87.6gm
Wire diameter	3mm
Spring free length	54.7mm
Density of steel	7850kg/m3
Moment of inertia	4.95×10-4kg/m2
mass of guide	36gm
mass of follower	188gm
mass of cam	75gm
Mass at Valve Side(i.e Mass of Valve, Spring, Retainer, Guide)	304gm
Mass at Cam Side(i.e Mass of Follower, Cam)	258gm

Comparison of Analytical and Software:

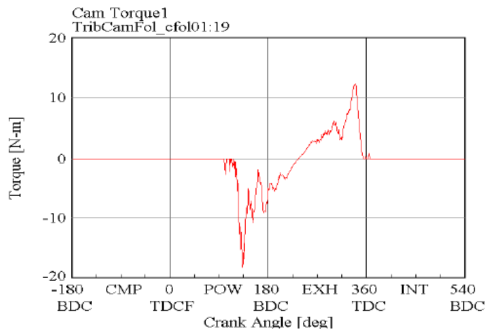
(a)Camshaft Torque for flat face pushrod mechanism of 3 cylinder inlet valve engine:

Analytical Graph



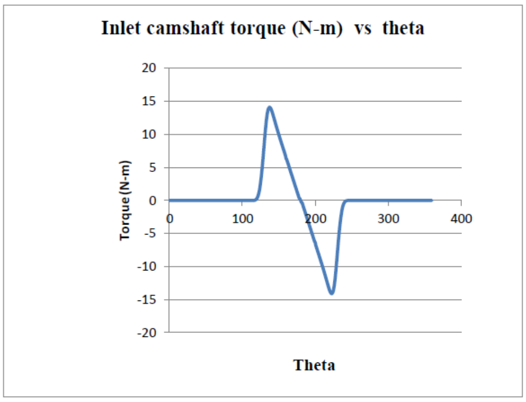
Graph 6.22 b (i)

Software Graph



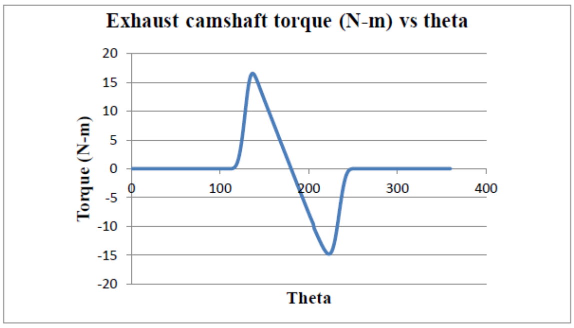
4.3 Inputs required for type 2 (input)

Valve Mass	48gm
Mass of Retainer	7gm
Mass of Valve Spring	23.69gm
Rocker arm	63.1gm
Cam width	12mm
Follower Radius	10.5mm
Follower Width	9mm
Stiffness of Spring	27.82N/mm
Valve lift	7.6mm
Cam lift	4.02mm
Rocker ratio	1.8901
Total weight at cam	335.49gm
Total weight at valve	92.5gm
Wire diameter	3mm
Spring free length	54.7mm
Density of steel	7850kg/m3
Moment of inertia	4.95×10-4kg/m2
Spring Force	882.6N
mass of guide	55
mass of follower	51
mass of cam	75
Mass at Valve Side(i.e Mass of Valve, Spring, Retainer, Guide)	133.69gm
Mass at Cam Side(i.e Mass of Follower, Cam)	Dddd1 126gm



4.4 Inputs required for type2 (exhaust)

Valve Mass	42.1gm
Mass of Retainer	7.5gm
Mass of Valve Spring	23.69gm
Rocker arm	63.1gm
Cam width	12mm
Follower Radius	10.5mm
Follower Width	9mm
Stiffness of Spring	27.82N/mm
Valve lift	8.9mm
Cam lift	4.702mm
Rocker ratio	1.8925
Total weight at cam	319.4gm
Total weight at valve	87.6gm
Wire diameter	3mm
Spring free length	54.7mm
Density of steel	7850kg/m3
Moment of inertia	4.95×10-4kg/m2
Spring Force	955.2N
mass of guide	36gm
mass of follower	50gm
mass of cam	75gm
Mass at Valve Side(i.e Mass of Valve, Spring, Retainer, Guide)	109.29gm
Mass at Cam Side(i.e Mass of Follower, Cam)	125gm



4.5 Remark

From the above graphs it can be concluded that the torque required for exhaust valve is greater than that of inlet.
Reasons:
1. The cam lift of exhaust valve is more
2. The weight of the exhaust valve is more hence more drive torque is required to operate it

5. Experimental Analysis

Development of test rig

Component Required

Camshafts, springs, Exhaust Valve, Inlet Valve, Hydraulic Lash Adjusters, Flanges, Hydraulic Motor, Drive Motor, Engine Head, Hydraulic Valves, Pressure Gauge, Sump, Ball Valves, Pipes and Tubes, Nipples, Bolts and Nuts, Pressure Reducing Valve and Flow Control Valve, Plugs, keys, VFD Connection.

Development Process:

1) Design of test setup.

2) Collection of parts like springs, valves, HLAs, Nuts and Bolts for engine Assembly.

3) Tapping of camshaft.

4) Assembly of engine head.

5) Manufacturing of flanges and plates.

6) Mounting of engine head on plates.

7) Manufacturing of sump.

8) Connection of drive motor with engine head.

9) Lubrication system.

10) Connection of hydraulic motor through pipes & tubes with engine head and Sump.

11) Pressure gauge and connection of different types of valves like ball valve, Pressure reducing valve etc.

12) Completion of the assembly.

13) VFD connection to run the setup.

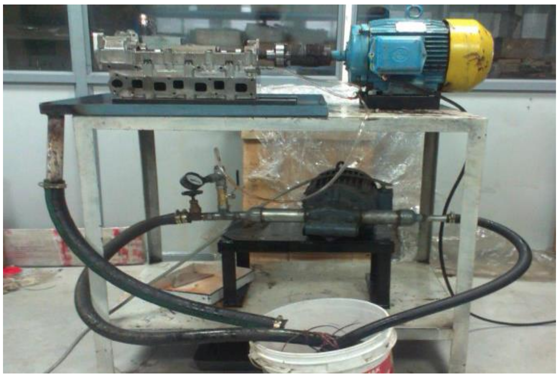
Experimental methods for camshaft torque measurement

1 Torque measurement by electric drive motor:

The intake camshaft can be driven by an electric motor connected to the end of the camshaft..The camshaft operates 12 intake valves via hydraulic tappets. The drive torque is measured by the electric motor. Voltage and current measurement gives the camshaft torque.

2 Torque measurement by strain gauging:

Transducers require some electrical input power or excitation. The raw output signal of the actual sensing device also generally requires conditioning into a level and format appropriate for display on a digital or analog meter or to meet the input requirements of data acquisition equipment. Excitation and signal conditioning are supplied by electronic circuits designed to match the characteristics of the specific sensing technology. For example, strain gage bridges are typically powered with 10 V to 20 V (dc or ac) and have outputs in the range of 1.5 mV to 3.0 mV per volt of excitation at the rated load. Raising these millivolt signals to more usable levels requires amplifiers having gains of 100 or more. With ac excitation, oscillators, demodulators (or rectifiers) are also needed. Circuit elements of these types are normal when inductive elements are used either as a necessary part of the sensor or simply to implement noncontact constructions. Strain gages, differential transformers, and related sensing technologies require that electrical components be mounted on the torque member. Bringing electrical power to and output signals from these components on rotating shafts require special methods. The most direct and common approach is to use conductive means wherein brushes (typically of silver graphite) bear against (silver) slip rings. Useful life is extended by providing means to lift the brushes off the rotating rings when measurements are not being made. Several noncontacting methods are also used. For example, power can be supplied via inductive coupling between stationary and rotating transformer windings, by the illumination of shaft mounted photovoltaic cells or even by batteries strapped to the shaft (limited by centrifugal force to relatively low speeds). Output signals are coupled off the shaft through rotary transformers, by frequency-modulated (infrared) LEDs or by radio-frequency (FM) telemetry. Where shaft rotation is limited to no more than a few full rotations, as in steering gear, valve actuators or oscillating mechanisms, hard wiring both power and signal circuits is often suitable. Flexible cabling minimizes incidental torques and makes for a long and reliable service life. All such wiring considerations are avoided when noncontact technologies or constructions are used.



6 Actual procedure to measure torque by strain gauging

1) The actual testing for torque analysis was performed in ARAI developed on 3 cylinder high performance CRDI diesel engine.
2) CRDI diesel engine specifications-
TYPE-4 valve, water cooled, CRDI
Bore/Stroke Ratio: 0.87
Number of cylinders :3 inline
Displacement: 1.5 Litre
Rated Power: 113KW@4200rpm
Specific Power: 75 KW/lit
Max. Torque: 308 Nm@2000 rpm
bmep: 21.5 bar
3) Strain gauges are of bounded coil types were attached on the valve springs, one on the inlet and one on the exhaust.
4) The camshaft was driven by a VFD (Variable Frequency Drive) connection which was connected to the electric motor for changing the speed.
5) 2100 rpm speed was maintained to measure cam lift.

6) After taking the readings calibrated data in terms of spring displacement in mm.

7) The spring displacement causes strain in the spring stiffness and change in the electrical resistance and data is calibrated with the help of data acquisition system.

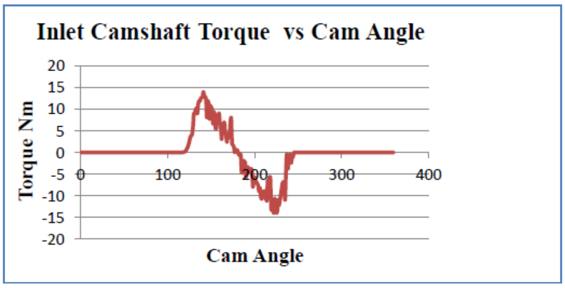
8) The spring displacement were taken in the excel sheet.

9) With the help of spring displacement cam lift was calculated.

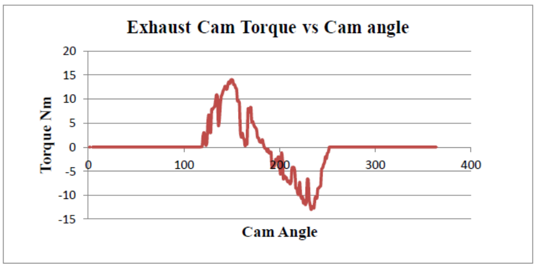
10) Actual camshaft torque was calculated by using cam lift.

Experimental graphs:

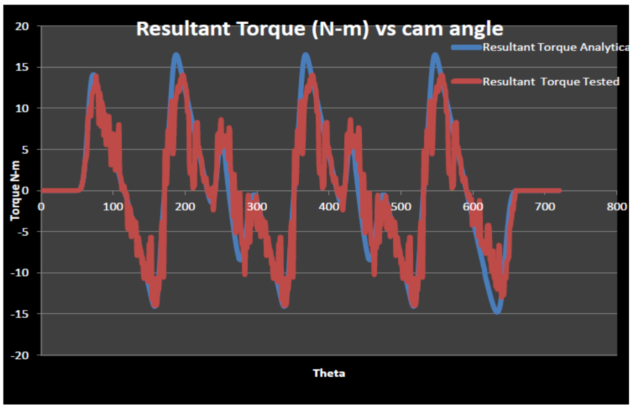
1. Inlet camshaft torque graph



2 Exhaust camshaft torque graph



Resultant Graph of Experimental Torque Vs Analytical Torque



Output

Inlet torque		Exhaust torque	
Max value error in %	Min value error in %	Max value error in %	Min value error in %
14.81%	8.92%	12.59%	6.49%

Inlet torque		Exhaust torque	
Max value error in %	Min value error in %	Max value error in %	Min value error in %
1.2%	1.11%	14.47%	11.74%

Conclusion

It is observed that the torque required for roller follower is more than that of flat face follower. In the flat face follower the pressure angle forces is zero or negligible, but in the roller follower the pressure angle forces are considered. Hence, the torque required for the roller follower is more than that of flat face follower

The analytical torque values were compared with the GT simulation software values for the flat face pushrod type. In the analytical calculations the vibratory and the friction forces are not accounted, but in the simulated torque values the effect due to friction and vibration are considered. Hence the torque curve is not smooth but deviates from the sinusoidal curve. Following table gives the present error for torque between the analytical calculated torque and the Software simulated graph.

The analytical torque values were compared with the actual torque testing for type-2 valvetrain system (i.e. End- pivot valvetrain with HLA (hydraulic lash adjuster). It is observed that there is lot of friction involved in the actual setup. Also the hydraulic pressure maintained by the hydraulic motor keeps on fluctuating. This also has an effect on the torque values. As the speed vs. torque characteristics are not linear for the electric motor that also influences the torque curve. Hence the torque curve for the test-rig is not smooth but is fluctuating from the sinusoidal curve.

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