

Design Optimization of a Valvetrain System under Engine Brake Switch Loading by means of Strain Measurement

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ABSTRACT

In this paper, a simultaneous design and development work for a diesel engine valvetrain system is presented. The rocker arm is one of the most important components of the valvetrain system which is transmitting the energy between the valves and the camshaft. Valvetrain system becomes even more complicated, when the extreme high speed of the system and nonlinear character of combustion is combined with the unpredictable behavior of the hydraulic lost motion mechanism during engine brake. As the complexity increases, it gets harder to predict valvetrain stress values especially while engine brake is in action. By taking all of these effects into account, that is reducing reliability of virtual analysis, requirement to conduct a strain measurement on valvetrain became inevitable. Therefore the challenge to make instrumentation on a complete fast moving, lubricated system which operates around 140°C and to select a proper location that can reflect the right stress values is solved by instrumenting one of the six rocker arms on the system. The engine is tested with a specific cycle, covering all critical operating regions including engine braking. As a result, during engine brake switch on and off maneuvers some unpredictable extreme stresses which can lead to mechanical failure are revealed. Upon completion of root cause identification of these extreme loadings, turbocharger control is manipulated at those critical switching regions in order to smoothen the transient response of the system, especially when engine brake is turned off. With all these optimization studies and verification processes, the risk of a possible catastrophic failure of the valvetrain system and relevant engine components is ruled out.

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INTRODUCTION

In this paper, a case study of a heavy duty engine valvetrain with a compression release engine brake system is investigated. To have a better understanding about the study, it may be better to give a brief description about the valvetrain & engine brake systems and challenges coming with engine brake implementation.

Valvetrain system consists of reciprocating and rotating elements which are responsible for opening and closing of exhaust and intake ports in synchronization with crankshaft of the engine. There are different types of valvetrain systems to serve the same objective with different principles. Said 6 cylinder, heavy duty truck engine is equipped with type 3 valvetrain mechanism. Main components under the assembly are camshaft, center pivot rocker arms, bridges, valves and springs.

Required valve motion profile is obtained with specific cam lobes on camshaft for each exhaust and intake valves. Roller side of the rocker is moved according to these cam lobes so that other end of the rocker

arm pushes corresponding valve up and down with the help of a preloaded spring. Since there are 4 valves per cylinder, valve bridge parts are also needed to be able to activate two valves at once.

When the engine is not fed with fuel, it is basically a compressor which is consuming power instead of producing it. This feature can be used for a good purpose in a heavy duty vehicle application. Maintaining a brake power from the engine, provides the option to use service brakes less, thus helps increasing service durations for brake pads and other consumables, not to mention the comfort of being able to use an automatic controlled brake feature which can keep the truck at constant speed when it is going downhill.

Consumed power can be dramatically increased by modifying valvetrain system in a way that engine will be charged with more air and just before piston reaches TDC, exhaust valves are opened to allow compressed gas release so that in the very next stroke, springing effect of the compressed air is removed. This valve motion deviation is obtained with the help of a solenoid valve which activates another valve lift profile on the same exhaust lobes using

lost motion-hydraulic lock mechanism integrated on exhaust bridges. With this solenoid controlled system, engine can operate in two different modes; one being normal run and the other engine brake.

In order to adjust the engine brake power upon request, amount of charged air into the cylinders can be altered by using variable geometry turbocharger vane control logic. Charged air is the major contributor to maximum cylinder pressures reached during engine brake. Limiting it also plays a crucial role to set a bearable physical loading on valvetrain components.

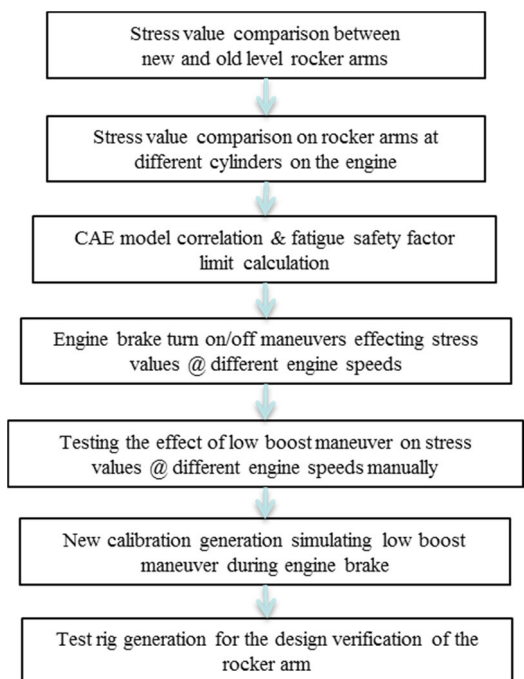
Adapting a compression release type engine brake on the engine comes with a drawback of increased valvetrain loads. As the piston approaches to TDC, cylinder pressure climbs. On normal run mode it is not a problem as all valves are seated at that instant, however when the engine brake is engaged, cylinder pressure causes a considerably high force on exhaust valves as exhaust valves are open due to compression release. At this moment, valves, bridges, rocker arms and camshaft are in solid contact. So these extreme force caused by cylinder pressure, acts on all these components. This situation brings the necessity of validation for valvetrain and engine brake components by means of durability and robustness. In other words, engine brake system and brake loading should be controlled wisely not to jeopardize valvetrain of the engine.

EXPERIMENT

Testing Methodology

For the simultaneous design & development and optimization study of the valve train system first of all a design of experiment (DoE) matrix is generated. The detailed steps of this matrix are listed at [Table 1](#).

Table 1. The Design of Experiment Matrix



The thread type of the rocker arm's elephant foot (e-foot) screw is changed from machined to rolled and corresponding groove at rocker arm side is removed to eliminate the risk of notch effect at the second phase of the design process. So according to this matrix first the stress value comparison between the new and old level rocker arms is measured. For this reason the rocker arms belonging to the new and old design, corresponding to the first and fourth cylinder of the engine are instrumented separately and strain measurement is taken at different engine speeds with an engine brake on-to-off and off-to-on maneuvers. With this study it has been proved that the strain values occurred on the rocker arm is directly proportional with the peak fire pressure values occurred in the combustion chamber and does not differs significantly from cylinder to cylinder. After this finding, the measurements are only taken from the fourth cylinder of the engine and the correlations are performed accordingly. Also it has been observed that the design change hasn't got an important impact on strain values, as expected. The objective of the thread type change and groove removal is to increase fatigue life of the part rather than reduce stresses acts on the part. Simultaneously the correlation for the CAE model is updated and the maximum allowable peak fire pressure value is determined for the fatigue safety factor limit to be greater than 1, including a safety margin specified by Ford Otosan.

From this point on, engine brake turn on/off maneuvers are performed to get strain values at high frequency between the boundary speed limits of the engine. It has been discovered that at higher speeds, the unpredictable behavior of the hydraulic lost motion mechanism during engine brake cause unstable strain values to occur on the rocker arm. More important than that, not during the engine brake is turned on but especially when it is turned off, remarkably high peaks of strain values can be observed on the rocker arm which may cause a possible catastrophic failure of the valvetrain system and relevant engine components. Another complexity of these peak strain values reaching up to 1.7 times than the regular run is they do occur only 30% of the measurements that is taken and they do not always cause the system to reach the same critical strain values.

Encountering with a peak is not 100% repeatable as it is a matter of engine brake turn off signal timing. This problem led the test engineer to repeat the measurements at least five times at every engine speed that is tested. In [Figure 1](#) one of the examples of these peak values is shown at 1600 rpm steady speed when engine brake is turned off.

At this stage of the DoE, instead of trying to eliminate this strain peaks completely, a low boost maneuver strategy is generated and in order to smoothen the transient response of the system especially when engine brake is turned off, a manual trial of manipulating the turbocharger control at those critical switching regions is applied. With this new strategy, a complete success is gained and it is clearly observed at every trial and every engine speed that (especially lower than 2000rpm), by only milliseconds, the decreasing boost values, disables those strain peaks to go over values measured in regular run.

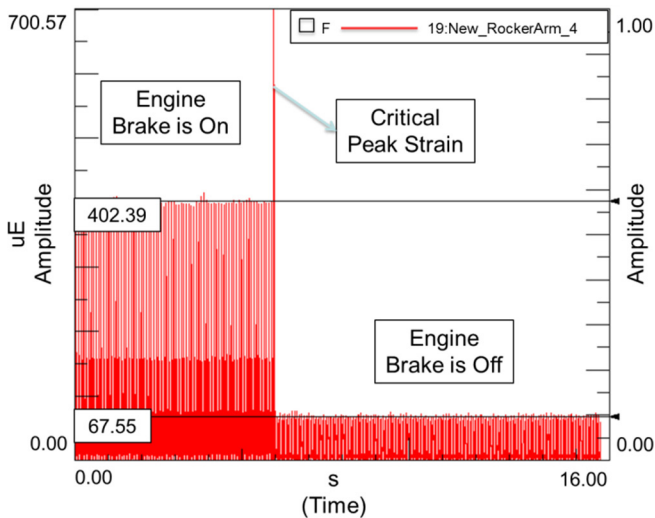


Figure 1. Critical peak strain occurred when the engine brake is turned off.

Finally instead of a manual control, a fine tuning and an optimization study for determining the duration to decrease boost just before turning off the engine brake is performed. Trials conducted at 200, 350, 800ms delay periods and the calibration is updated according to the best option that is chosen. As the last step of the determined DoE, to get rid of the long hours of high cost engine testing, a rig test is generated for the Design Verification process of this complex, forged, valvetrain part. Therefore the risk of a possible catastrophic failure of the valvetrain system and relevant engine components, originated from the rocker arm is ruled out.

Instrumentation Type & Locations

Experiments were performed on the rocker arm of a heavy duty diesel engine. In [Figure 2](#) a similar rocker arm design is shown.



Figure 2. Similar rocker arm design. [7]

The challenge to make instrumentation on a fast moving, lubricated part operating around 140°C, led the test engineer to use high temperature resistant (up to 250°C), foil type, uniaxial strain gages. To eliminate the environmental effect on the sensor, the gage is covered with a high temperature resistant coating. In [Figure 3](#) the strain gage instrumentation and coating on the front end of the rocker arm can be observed.

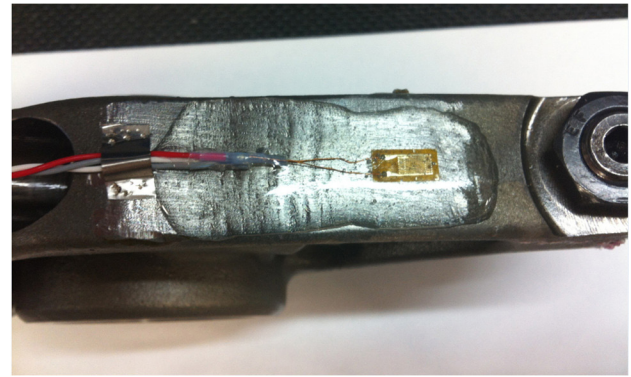


Figure 3. Strain gage instrumentation & coating.

The instrumentation is performed near to the critical stress locations on the front end of the rocker arm where the effect of the peak fire pressure coming from the combustion chamber is transferred to the rocker arm via exhaust valve directly. Therefore detecting a simple stress source on the part and of course creating a better CAE model correlation afterwards is aimed. Also, special care is applied for the sensors and the cable connections not to be damaged during measurement. The holes created on the valve cover are cautiously insulated so that either the cables are not damaged due to the rapid movement of the system or a possible oil leakage is prevented. After all the instrumentation and isolation operations, nulling is applied to the sensors so only the amount of stress during engine operation is gained.

Due to the design properties of the valve train system and also to be able to compare and correlate the stress values obtained from different cylinders, the rocker arms corresponding to the first and fourth cylinder is instrumented. In [Figure 4](#) the instrumentation on the engine can be observed.

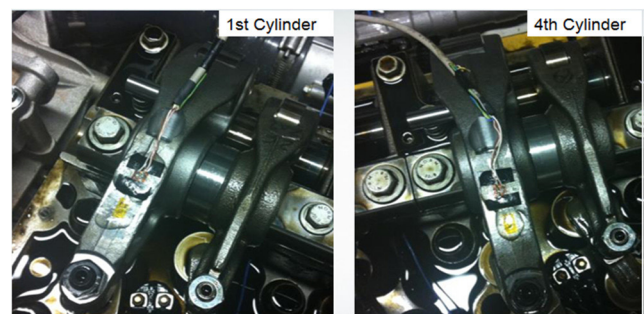


Figure 4. Strain gage locations on the first and fourth cylinder respectively.

EXPERIMENTAL RESULTS

At the beginning of the DoE the strain data from the two rocker arms corresponding to the first and fourth cylinder of the engine are taken with 25600Hz sampling rate. This measurement is repeated for the new design rocker arm which has a modification on its e-foot screw groove. Totally below listed five different configurations are taken and every configuration is repeated three times for repeatability approval;