The Development of a Cost Effective Engine Dynamic Signal Monitoring and Diagnostic System

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ABSTRACT

This paper describes the development of a cost effective engine dynamic signal monitoring and diagnostic system for use in a high volume engine manufacturing plant as well as in a research environment for development of new engine components.

Modal analysis was performed to determine the optimum locations of vibration transducers. The techniques of decomposition of raw signals obtained from an engine are described.

The engine dynamic signal monitoring and diagnostic system has been successfully implemented in on-line assembly of engine. In all cases, the system is capable of detecting and isolating manufacturing and assembly defects.

INTRODUCTION

Today, one of the key goals of an engine manufacturer is to achieve higher quality and productivity at competitive cost. This coupled with higher standard of customer satisfaction, requires not only innovative concepts in engine design, manufacturing and assembly processes, but also the integration of on-line engine monitoring and diagnostics system which is capable of detecting manufacturing and assembly defects.

This paper describes the development of a viable and cost effective engine dynamic signal monitoring and diagnostic system for detecting and locating manufacturing and assembly defects by means of time domain noise and vibration signature analysis.

TIME DOMAIN AVERAGING

The time domain signal processing techniques are extremely useful for engine diagnosis because of their abilities to correlate the amplitude of the signals at corresponding angular positions of the crankshaft.

Time domain averaging (TDA) is a powerful technique for extracting periodic components from a complex dynamic engine signal. It is accomplished by simply averaging several time traces, data point by data point, producing an average time trace. It is useful for detection of faults which occur consistently at a certain locations in a cycle.

VARIANCE ANALYSIS

In the last section time domain averaging was described, which allows the extraction of periodic components which are always present in the signal. The other components which are not always present but occur at specific location in a cycle are termed as semi-periodic can be extracted by variance analysis of the signals.

The mathematical descriptions of the TDA, including its properties as a filter in eliminating non-cycle linked signals, and variance are provided in reference (1).

MEASUREMENT SYSTEMS

Two systems, time locked and position locked, are used to accomplish time domain averaging and variance analysis. The time locked system is consisted of a digital storage oscilloscope interfaced and controlled by computer that is triggered by TTL (Transistor-Transistor Logic) signals which are generated by an inductive voltage at #1 spark plug firing.

In the position locked system, exact measure of angular position can be achieved by sampling the data at a rate dictated by a 512 pulse per revolution encoder, installed in-line with the drive train. This encoder generates external sampling clock. Thus, a sampling resolution of up to 0.6 degrees of crank rotation can be achieved. The custom designed engine signal monitoring and diagnostic system was used coupled with specially build encoder system. This system uses the PIP (Profile Ignition Pickup) and CID (Cylinder Identification) signals from the engine electronic control for triggering the start of the event and hence enable to reference the zero crank angle to piston # 1 on the firing stroke.

Figures 1 and 2 show the waterfall plots of vibration variance of a defective engine at varying speed with time lock and position lock data acquisition system, respectively. With position lock system the angular location of the peaks indicating defect are consistenly at 390 degree. While the time lock system the locations of the peaks were scattered.

EXPERIMENTAL RESULTS

The experimental results are divided into two sections: (a) Dynamometer test and (b) cold test.

DYNAMOMETER TEST

Warranty field return engine with noise complaint was analyzed to determine the root cause. Vibration measurements were made with accelerometers mounted on the cylinder block wall. Figure 2 illustrates the waterfall plot of vibration variance with respect to crank angle. The plot indicates that the distinct amplitudes are occuring at about 390 degrees crank angle which coincide with the peak pressure of cylinder #5. Upon engine teardown and measurements, it was revealed that the concentricity of the piston ringland with respect to skirt was excessive in the thrust direction. When piston number 5 was replaced with concentric ringland with respect to skirt piston, the vibration was drastically reduced as clearly illustrated in Figure 3.

COLD TEST

With the successes of using the custom designed engine dynamic signal monitoring and diagnostics system for evaluating piston design as well as diagnosing warranty field return engines, the next step is to apply the same system in cold test for on-line detection of manufacturing and assembly defects.

Modal analysis was performed in a partially assembled engine (as shown in Figure 4) and the results were reviewed for all modes of vibration up to 3200 Hertz. The optimum locations of accelerometers were selected for two reasons: (a) exhibiting the maximum response and (b) accessible for accelerometers carried by hydraulic actuated arm to reach.

Figure 5 illustrates the waterfall plot of vibration variance which is generated by partially assembled engine with connecting rod bearing missing. Distinct amplitudes appear coresponding to the side force reversals in the piston.

The experiments were repeated and the results indicate the feasibility of using the system for consistent on-line detection of missing rod bearing, missing cap bearing and loose connecting rod nuts.