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Incipient Fault Detection System Study
≫ Executive Summary ≪

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FINAL REPORT

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16. Abstract

This executive summary presents the results of the first phase of a project intended to detect incipient failure in bus components. This phase of the study has developed methods and instrumentation for measuring engine torque and torque non-uniformity. The next phase will involve collection of data from which a statistical model will be constructed. The statistical model will be used to estimate a time to failure for individual components, given the level of degraded performance.

This executive summary contains a summary of the theory and methods used to measure degraded performance and the results of a test of the instrumentation in diesel powered vehicles driven on a chassis dynamometer and on city streets. For details see: "Incipient Fault Detection System Study: Technical Report."

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CONTENTS

Introduction

This report is an executive summary for research which was intended to establish the feasibility of detecting incipient failure in bus engine/drivetrain components. A complete report on the research is available from the author. The goal of this project is to perform measurements during normal vehicle operation from which it is possible to determine the probability of failure of the bus engine/drivetrain in advance of the actual failure. This method, if successful, can have a significant impact on optimal maintenance scheduling strategy for transit authorities. Moreover, it should be possible to prevent bus breakdown in many cases by detecting the possibility of failure at sufficiently early stages.

The present project involves several phases, only the first of which has been completed. At the present time, the research concentrates on developing instrumentation for installation in buses which are to be used in normal fleet operation.

Concept for the method

In this research, the method of detecting incipient failure in engine/drivetrain components is based upon continuous, real-time measurements of engine performance. Any degradation in performance is an indicator of a potential future component failure.

Furthermore, the level of degradation serves as the basis for estimating the time to failure for the affected component. In the context of this project, "failure" of any component is defined as performance at or below the minimum level of acceptable performance with respect to normal vehicle in-service use. Obviously, this definition includes catastrophic failure.

The estimate of time to failure is to be obtained from a statistical data base which is derived from experimental studies on the actual degradation to failure for critical engine components in revenue service. A data base is to be obtained of the conditional probability of the time to defined failure level of performance given the present level of degradation.

The relevant data base will be obtained by continuously measuring engine/drivetrain performance. The measurements are to be made on a set of buses in actual transit operation. Performance data will be automatically collected and stored for a sufficiently long period to permit the computation of the required conditional probability. Preparation of the instrumentation for collecting the data is presently underway.

Accomplishments

During the initial phase of this project, there have been several significant achievements. Foremost among these has been the development of a method of measuring engine torque and horsepower. Torque (horsepower) can be measured continuously (in real-time) yielding a direct measurement of engine performance. Any degradation in torque output is instantly available for the instrumentation.

Another major accomplishment is the development of a method of measuring torque nonuniformity. This measurement, which is another direct performance measurement, can also be achieved continuously in real-time using the instrumentation which was developed on this project. This measurement of torque nonuniformity has sufficient information to quantitatively measure the combustion for each cylinder and to detect degraded performance for each individual cylinder.

The torque nonuniformity data is critical to the estimation of time to failure for engine components and to the identification, where appropriate, of the affected cylinder. Diagnosis of engine malfunction is greatly aided by the identification of the cylinder(s) which has(have) degraded performance.

One of the major accomplishments of the first phase of this project is the development of noncontacting instrumentation. This instrumentation incorporates an inductive sensor which couples magnetically to the starter ring gear and which can be installed with negligible engine modification. Relatively simple, inexpensive signal processing has been developed for the experimental measurements. This signal processing uses analog pre-processing and digital signal processing for the generation of the performance data.

Experimental results

The instrumentation has been experimentally tested on engines in test cells and in vehicles during actual road tests. These tests have clearly demonstrated the feasibility of the performance measurement method.

Experimental road tests were conducted in two vehicles:

1) a VW Passat having 1.6 L diesel engine and 5-speed manual transmission and

2) an Oldsmobile Vista Cruiser having 350 CID V8 gasoline fueled engine and 4-speed automatic transmission.

Torque non-uniformity is based upon a non-uniformity index which is obtained from measurements of crankshaft angular speed. The fluctuation in instantaneous torque associated with the firing of the individual cylinders results in a corresponding fluctuation in instantaneous crankshaft angular speed. In two crankshaft revolutions for an N cylinder, 4 stroke/cycle engine, there are N relative minima of crankshaft angular speed. These relative minima are measured and converted to a nonuniformity index n for each engine cycle:

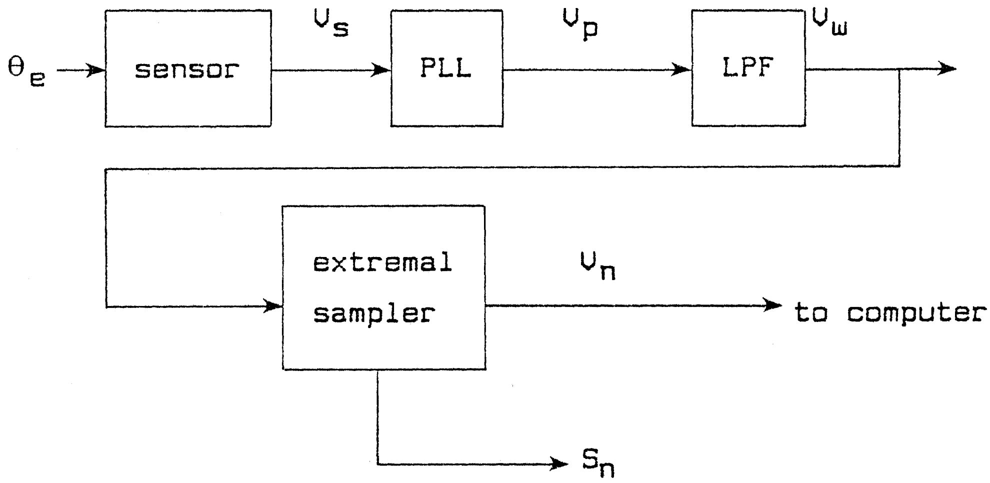
$$n = 1/N \sum_{k=1}^{N} (w_k - w)$$

$$w = 1/N \sum_{k=1}^{N} w_k$$

where w_k = kth relative minimum in crankshaft angular speed

The instrumentation for measurement of n uses a noncontacting sensor which couples magnetically to the starter ring gear. The instantaneous sensor output frequency is proportional to the instantaneous crankshaft angular speed.

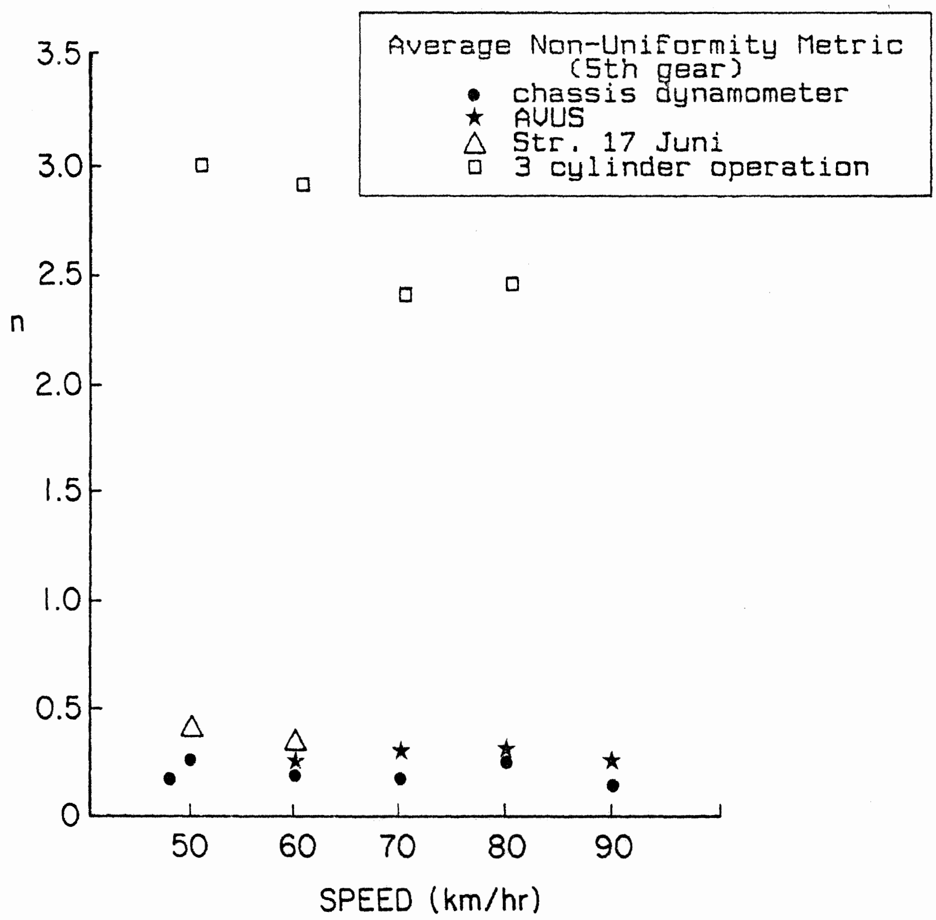
The block diagram for this instrumentation is shown on the next page.



The extremal sampler obtains the required samples of the relative minima of crankshaft angular speed. A digital computer which is not shown calculates the non-uniformity index <u>n</u> for each engine cycle.

One measure of the utility of this non-uniformity index is the relationship between the average value $< n >$ for normal and abnormal engine operation. Experimental measurements were obtained for $< n >$ for a 4-cylinder diesel engine in a VW Passat (equipped with a 4-speed manual transmission). Abnormal operation was achieved by disabling one cylinder.

The non-uniformity index was obtained for the experimental configuration while operating the car on a variety of roads. The figure on the following page shows the results of these experiments:



Note that the non-uniformity is significantly higher for 3-cylinder operation than for normal operation on any of the roads for which tests were performed. For more detailed discussion and further results the reader should consult the main report available from Dr. William Ribbens, Department of Electrical Engineering and Computer Science, the University of Michigan, Ann Arbor, MI 48104. In addition, the main report explains measurement of average torque delivered by the engine and presents experimental results.

This experiment conclusively establishes the feasibility of measuring the torque non-uniformity in actual vehicle operation. Both torque and torque non-uniformity are primary engine performance variables.

Any measured degradation in either variable can be used to anticipate potential component failure.

Second-Phase Studies

During the second phase of this study, measurements will be made from which the necessary statistics will be obtained. In obtaining these data, portable instrumentation is being designed and constructed. This instrumentation includes a duplicate of the analog instrumentation which was used during the first phase study. In addition, a special-purpose portable digital system is under development which will permit automatic data collection of the performance variables. This instrumentation will be installed on approximately ten buses which will be operated in normal transit use. Periodically, the memory of this special-purpose digital system will be read into a master file which will become the data base for the statistical studies.

Summary and conclusions

The present research project is intended to develop a method for detecting incipient failures in engine/drivetrain components for buses. This method is based upon continuous engine performance measurements and upon a data base from which time to failure can be estimated for a given level of performance degradation.

The performance-measuring instrumentation and methods have been developed and tested experimentally. The data base which is required for the statistical model involved in time-to-failure estimation is being obtained as part of the second phase of this project.