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HIGH LEVEL DIAGNOSTICS IN MACHINERY USING TRANSFER MOBILITIES

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INTRODUCTION

A high level diagnostic system is exemplified by the conductor of an orchestra. Using his eyes and ears he separates the sound of individual instruments, identifies them, and detects their contribution to the overall sound. If an individual instrument is not performing properly, the conductor exercises control and corrects the way in which that instrument is being played. This simile illustrates our concept of sensing machine operation by using multiple vibration sensors located at a distance from the sources of excitation. The processing of received signals needs to separate the sources, locate their position, recover their excitation signatures, and provide information needed to decide whether a defect is present or a change in operational setting is needed.

BASIC RESEARCH STUDIES

We have carried out a number of research studies, some concerned with the recovery of various sources of excitation, including combustion pressure [1,2,3], piston slap [4,5], and valve/valve seat impact [6]. Others are concerned with propagation through the structure [3,5,7]. Finally, other studies are concerned with the processing methods to be used in obtaining source signatures when multiple sources and multiple sensors are involved [8].

Combustion Pressure Recovery

A combustion pressure pulse produces a vibration pulse on the engine casing that results from the rapid pressure rise in this pressure pulse. While a direct visual inspection of the cylinder pressure can reveal a change in the cylinder combustion, the vibration pulse, which is more accessible, is not nearly so easy to interpret. If the transfer relation between the combustion pressure and vibration is linear, then the modification of the original waveform due to propagation can be undone by an inverse filter.

The ratio of casing acceleration to force at the cylinder transfer accelerance, expressed in terms of magnitude and phase, is

$$A(\omega) = |A(\omega)| e^{i\phi(\omega)}.$$

A filter which has a magnitude $|A|^{-1}$ and phase $-\phi(\omega)$ will change the received acceleration pulse into a delayed version of the source force waveform. Several studies have shown [2,9] that in recovering the waveform, it is very important that the details of the phase $\phi(\omega)$ be preserved in the inverse filter than that the magnitude $|A|$ be carefully reproduced. The quality of the recovered pressure waveform in this study was good enough to see the effect of a leak in the injector pump [2].

Piston Slap Signature

One can express the source signature itself in terms of its Fourier transform, and if the inverse of this function is included in the inverse filter, the recovered signature becomes an impulse. This process has particular relevance if the source signature is the result of a mechanical impact. We have examined the dynamics of the interaction of the piston and cylinder wall during piston slap [4]. This analysis leads to a model for the impact consisting of two masses and two springs. The masses have an initial velocity equal to the transverse velocity of the piston just before impact. The spectrum of the force exerted by the piston on the side wall is predicted. An analysis of the transmission path for piston slap shows two parallel paths for vibrations; through the cylinder wall into the block, and through the connecting rod and crankshaft [4].

Valve/Valve Seat Interaction

The collision between an engine inlet valve and its seat excites internal resonances of the valve and the relative strength of the modal responses is an indication of the nature of the impact. If the seat is in good condition and the valve is properly aligned, the valve hits square and longitudinal resonances tend to be emphasized. If the impact is not square, bending resonances are emphasized [6].

The transfer function relating valve seat force to block acceleration was measured. The inverse of the function will have sharp peaks whereever the transfer function has sharp minima. Since such peaks may tend to indicate false peaks in the spectrum of the impact force, they need to be removed by smoothing the magnitude of the transfer function. A comparison of the inferred excitation spectrum for a good and faulted valve impact shows a correspondence between major excitation peaks and the resonances of bending and longitudinal modes. The relative strength of the bending mode is greater for the faulted impact, as might be expected, since the impact force has a large component of moment if the valve does not hit squarely on its seat.

Propagation of Vibration Signals

Since the transfer function is so important we need to understand both its phase and magnitude. The magnitude may be estimated by the use of statistical energy analysis (SEA) [10,11]. Such an estimate of the magnitude is likely to be adequate in many cases, particularly when the waveform is to be recovered.

The phase of mechanical system transfer functions has had very little study. We have been studying ways of estimating phase using methods similar to those of SEA [7,10]. A comparison between the measured and predicted phase of a simple plate transfer function shows that the phase trend computed using is SEA is close to the measured value, but details of the phase curve are not predicted. More work on transfer function phase is needed.

Separation of Simultaneous Sources

Most machines, have several events that occur nearly simultaneously that one would like to detect separately for diagnostic or control purposes. Just as it is easier for us to separate sources using both our eyes and ears, it is easier to separate machine vibration sources if multiple sensors are used. A recent study has shown that simultaneous sources can be successfully separated by using multiple sensors and the signal processing method known as singular value decomposition [8].

In that study two sources with different temporal waveforms were used to excite a thin rectangular plate, and an array of four accelerometers was used to recover the transmitted signals. Force to acceleration transfer functions were measured and used to develop a best estimate for recovery of the excitation waveforms. Comparison of the inferred signatures with the directly measured source indicates a high quality of waveform reconstruction that is available with this method.

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REFERENCES

1. DeJong, R. G., "Vibrational Energy Transfer in a Diesel Engine", ScD Thesis, Dept. of Mech. Eng., MIT, August 1976.

2. Ordubadi, A., "Component and Fault Identification in a Machine Structure Using an Acoustic Signal", ScD Thesis, Dept. of Mech. Eng., MIT, May 1980.

3. DeJong, R. G., and Parsons, N.E., "High Frequency Vibration Transmission through the Moving Parts of an Engine", SAE Paper #800405.

4. Slack, J. W., "Piston Slap in Diesel Engines", PhD Thesis, Dept. of Ocean Eng., MIT, February 1982.

5. DeJong, R. G., and Parsons, N.E., "Piston Slap Noise Reduction in a Vee-Block Diesel Engine", SAE Paper #020240.

6. Bowen, D. L., "Recovery of the Valve Impact Force Signature in a Diesel Engine from Block Acceleration Data", MSc Thesis, Dept. of Mech. Eng., MIT, January 1983.

7. Lyon, R. H., "Progressive Phase trends in Multi-Degree-of-Freedom Systems", Submitted for publication to the *Journal of the Acoustical Society of America*, August, 1982.

8. Powell, R. E., "Multichannel Inverse Filtering of Machinery Vibration Signals", ScD Thesis, Dept. of Mech. Eng., MIT, January 1983.

9. Oppenheim, A. V. and Lin, J. S., "The Importance of Phase in Signals", *Proceedings of IEEE 69*, No. 5, May 1981, pp 529-541.

10. Lyon, R. H., *Statistical Energy Analysis of Dynamical Systems: Theory and Applications*, MIT Press, 1975.

11. Lyon, R. H., "Recent Developments in Statistical Energy Analysis", *Shock and Vibration Digest, V. 10*, No. 2, February 1978.