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NON-INVASIVE SONIC SIGNATURE - A Novel Monitoring Technique

GEORGE SAWYER

VIBRO-METER LIMITED

Sonic Signature Analysis is the evaluation of acoustic signals emitted by a mechanical system in order to detect the presence of undesirable conditions such as the development of defects that are the first stages of serious failure. If a system is operating in a normal manner, the signal emitted is called the "sonic signature" of that system. Any change in this signature indicates incipient failure, long before any external signs become evident. The data collection is accomplished by externally mounted sensors that do not affect the operation of the engine.

Although sound is audible vibration, the two are commonly considered to be separate phenomena. Sound is heard, vibration is felt. For signature analysis, we define sonic signals as elastic wave motions in solids. When one object is struck by another which does not remain in contact with it, a sonic pulse is produced. The resulting elastic wave will contain a range of frequencies whose amplitudes will die away with time. These frequencies are the range of specimen resonant modal frequencies encompassed by the bandwidth of the impact stress pulse.

Fundamental mechanical events occurring in machinery, such as :

impact	scratching	hiss
sliding	rubbing	flow
rolling		

produce distinctive sonic signals. Basically, there are two kinds of event that are of concern - hammering impact and the hissing sound produced by streaming gas or liquid.

The main problem of diagnostics is to develop a selective technique for the extraction of discriminants which are correlated with the internal condition under study. In particular, cyclic machinery presents a high potential for sonic signature analysis. In these applications time domain analysis has proven as a powerful tool. Irregularities show up as changes in the various parts of the time signal rather than as a change in the frequency spectrum. The signature therefore consists of a series of sonic events occurring during the cycle. Any change in this characteristic signature, particularly a new event, will be a demonstration of impending malfunction. In a signature analysis both the appearance of new signals, and the disappearance of normal signals are criteria for the evaluation of engine malfunction.

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The Vibro-Meter System

The essential requirements for an industrial system to evaluate sonic events are :

a) The sensor should be external to the engine such that it in no case influences the engine.

b) The sensor must have high reliability and low temperature sensitivity.

c) The transmission of the signal from the sensor to the processing electronics has to be in such a form that it is immune to electrical interference.

In order to fulfill the requirement (a) the acoustic signal transmitted through the engine structure by an event is monitored. Therefore, there must be no possible loss of engine integrity due to the sensor. In order to gain maximum sensor reliability and insensitivity to temperature (b) a piezo-electric acceleration measuring principle was chosen. However, piezo-electric sensors have a sensitive point because their output is an electrical charge. Transmission of a charge signal over a long distance gives rise to problems. These were solved according to the requirement of (c) by having a charge to current converter built in near the sensor. The signal transmission from this converter is in terms of current and is simply done via a 2-wire system. In other words, this has converted the piezo-electric system into an industrially safe, resistive system.

The function of the equipment is as follows :

The elastic wave motion (sonic signal) is transformed within the piezo-electric sensor into an electrical charge signal. Then, in the conditioner this signal is converted into a current modulation with a transfer function of 1 mA/Volt. This modulation appears on the current drawn by the circuit from the power supply. The output signal can be carried over long distances (several hundred metres) and is reconstituted at the receiving end by reading the current variation i.e. measuring the voltage variation across a resistor in series with the positive power line.

The afore-mentioned described non-invasive sonic signature (NISS) detector forms the first section of a complete NISS evaluation equipment. But it forms the essential part, which serves in conjunction with oscilloscopes or tape recorders for the first tentative investigations in new applications. Therefore this part of the equipment is available as independant instrumentation!

The interpretation of the visual display information obtained from the NISS detector is the first step to a concept for an evaluation electronics. Because the sonic signal to this electronics evaluation unit is sequential in time, the time domain analysis offers the advantage of clear interpretation of mechanical phenomena and ease of signal treatment. Expensive and difficult frequency analysis of the signal is not necessary. The time domain is carried out in synchronism with the machinery under investigation.

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For the evaluation the following principles are possible :

- time gate technique
- time interval measuring technique
- digital integrator

The time gate technique is used, when a detection of the appearance of new sonic signals or the disappearance of normal sonic signals is necessary.
Scuffing warning on Diesel engines is a typical application for this technique.

The time interval measuring technique is used in applications where intervals in repetitive sonic signal sequences are an evaluation criterion. Examples for this method are injection monitoring on Diesel engines, monitoring of sequence phenomena in industrial machinery etc.

The digital integration method is used when an analysis of the mean value of several cycles is desirable. Examples of this method are knock or detonation monitoring on internal combustion engines. For scuffing warning the sensors are placed on the lower end of the cylinder liners. As scuffing condition causes the liners to ring at their resonance frequency, at defined moments typical sonic signals will appear. For injection monitoring the sensors are placed on the injectors. The signature gives information concerning the shock caused by the needle opening and closing. In this way both injection time and duration can be evaluated. For knock or detonation monitoring the sensors are placed on the cylinder heads. Abnormal combustion is characterised by both amplitude and time anomalies.

Typical applications for sonic signature evaluation are as follows :

1. <u>Internal Combustion Engines</u>

   (Diesel engines, dual-fuel engines, spark-ignition engines)
   Valves (timing, clearance)
   Valve-gear (cam, cam-follower, pushrod, rocker arm, tappet etc.)
   Injection pump (timing, check valve).
   Injection valve (timing, ignition lag, needle monitoring)
   Combustion (ignition timing, combustion quality, detonation, knock)
   Piston (piston slap, gudgeon pin and connecting rod rearings, piston ring interaction with inlet and exhaust ports, blowby)
   Scuffing

   The cause of scuffing is basically the high temperature produced at points of intimate contact as a result of high load and sliding speed. Since frictional heat cannot be dissipated rapidly, an unstable phenomenon develops that leads to localized welding of the opposing surfaces and their subsequent rupture. These critical events produce sonic signals which are used in time domain analysis for early warning of seizure.

   Sonic signature evaluation equipment on internal combustion engines is used as permanent installation on large low speed and medium speed engines, but also on test beds for adjustment purposes on small high speed engines.

2. Reciprocating Compressors (for industrial gases)

Valve function
Piston/cylinder liner clearance
Power train clearance

3. Hydraulics and Pneumatics

Pumps (valves, flow, cavitation)
Motors (valves, flow, cavitation)
Valves (switch pulse, flow)

4. Hydraulic or Pneumatic Sequential Controls

Automatic start sequence (turbines, gas generators)
Valve operating sequence (high vacuum equipment)
Automatic sequences (nuclear reactors, diesel engines, oil firing, hoisting machines, machine tool etc.)

5. General Industrial Applications

Automatic assembling machines
Automatic filling and packing machines
Printing machines
Textile machinery (weaving, knitting, spinning machines)
Die casting and injection moulding machines
Pile drivers and rams
Dosing pumps in chemical processing
Machine tool (point of contact indication on grinding and milling machines)
Bearings and bearing fixations
Pipelines and their fixations (chemical processing)
Gears
Wire drawing, extrusion, punching, cutting and other mechanical processing
Grinding mills (grading, filling factor)
High voltage breakers

6. Test Beds for

Automatic weapons
Explosive propulsion mechanisms (bolts, valves, ejector seats etc.)
Film cameras and projectors
Mechanical watches
Relay contact check etc.