Ultrasound Device 'Resonance-2' and its Applications

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Abstract

In this paper the authors, scientists from the CTRL Systems' Research and Development Department, describe a detector of solid surface's ultrasonic vibrations, called RESONANCE-2, and its applications for non-destructive test and diagnostics of different objects in industry and transportation.

The following are the two major phenomena upon which the RESONANCE-2 applications are based:

1. The correlation between ultrasound generated by an object and that object's condition;
2. The ability of ultrasonic waves to carry information about an object's internal processes and condition to the object's surface.

The prototype of this portable device features high frequency selectivity and a wide dynamic range. Its sensitivity at resonance frequency allows it to detect vibrations with sub-atomic amplitudes of displacement. There is no need for any preliminary preparation of the controlled object's surface.

Several of many possible practical applications of the device RESONANCE-2 are considered in this paper, including:

- The detection and location of internal subtle leakage in hydraulic systems' valves;
- The detection of malfunctions in fuel filters (clogging);
- The monitoring of the internal condition of roller and ball bearings, and;
- The detection of weak threading and riveting connections.

Introduction to Resonance-2

As it was originally designed to detect and locate internal leaks in aircraft hydraulic systems, the designers of the device were challenged to measure sub-atomic amplitudes of ultrasonic vibrations on the solid surface of a hydraulic unit, in the noisy environment of an airport. As a result of the research and design works the resonance type of receiver was chosen and a prototype named Resonance-2 has been created.

The detection of these vibrations on the hard surface of the object under test is achieved by dry point contact between that surface and the piezoelectric transducer of the device. That operation does not require any preliminary preparation of the surface.

The hold-down force applied by the tip of the sensor to the controlled surface is calibrated at 16 N by a stabilizer embedded into the transducer. The combination of the transducer's spherical tip and of a stable hold-down force ensures a good vibroacoustical contact with the surface of controlled objects of virtually any shapes and roughness.

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Resonance-2 operates in two frequency channels centered at 45 kHz and 105 kHz. Both analog and digital electronics technologies are used for signal processing. The instrument's meter is calibrated in Conventional Units (C.U.). One C.U. at 105 kHz resonance frequency corresponds approximately to the amplitude of a vibrational displacement of 10^{-14} m. A special electric-to-acoustic transducer has been built to accomplish this calibration.

Resonance-2 self-induced internal noise reading does not exceed 0.1 C.U., thereby allowing the detection of ultrasonic vibrations whose amplitudes of displacement are as small as $3x10^{-15}$ m.

Additionally, the instrument's characteristics, including its automatic selection of the measurement scale, allow the monitoring of ultrasonic signals within a dynamic range of 100 dB. The attenuation of the external noise within audible frequency range is more than 120 dB. Therefore, it can be used for field diagnostics of real objects in industry and transportation in noisy environments.

When it is necessary to receive ultrasound directly from the air, without contact, the probe is enhanced by one of several available acoustic horns with the appropriate reception pattern and frequency response.

Two additional features present in Resonance-2 include:

- A multi-channel signal output that can be connected to a computer for additional signal processing, and;
- An embedded self-control system that can perform an exhaustive checking of all functions and circuits of the instrument within a few seconds.

Resonance-2 is a portable device, whose mass is approximately 3 kg. It is powered by a 9 V battery, and can operate at ambient temperatures ranging from -45^{o}C to 55^{o}C.

The possibility of using the Resonance-2 for the diagnostics of many types of technical systems, machines and mechanisms during operation is predicated on the fact that changes in their mechanical condition are usually accompanied by changes in the processes causing the generation of ultrasonic noise. Among these processes are:

- Friction and impact of solid bodies;
- Deformation and destruction of the material;
- Turbulence of liquid or gas flow;
- Cavitation in a flowing liquid;
- Electrical discharge;
- Electrostriction, magnetostriction, etc …

In some other cases, as for example in diagnostics of bolt and rivet connections, the instrument is used in conjunction with an auxiliary ultrasound vibrator.

Resonance-2 applications and methods of use are numerous: from the simple location of a liquid or a gas leakage by finding the maximum level of the received ultrasonic signal, to the diagnostics of complex objects by elaborate methods that rely on advanced signal processing and analysis.

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Some Resonance-2 Applications:

1. The detection and location of internal subtle leakage in hydraulic systems' valves.

   The theory behind the use of RESONANCE-2 for the location of internal leakage through hydro-systems' closed valves is based upon the estimate of the intensity of ultrasonic vibrations on their outer surface. The location of valves with internal leakage in an airplane hydro-system consists in finding the units with the maximum level of ultrasonic noise on their surface.

   Experiments on internal valve leakage detection were performed on the hydraulic systems of wide-body aircraft under 16 – 24 MPa pressure from its hydraulic accumulator. Subsequently these experiments were repeated on laboratory test bench. As a result of multiple laboratory and field experiments the following facts were established:

   a. Resonance-2 readings in the 105 kHz frequency channel on non-leaking valves were from 0.1 to 0.3 Conventional Units (C.U.). The readings were not dependent upon the type of valve.
   b. Resonance-2 readings on different types of valves with 7 to 9 drops per minute leakage were from 0.5 to 1.2 C.U.
   c. Resonance-2 readings on different types of valves with 40 to 55 cm^3 per minute leakage were from 45 to 110 C.U.
   d. When using Resonance-2 45 kHz frequency channel, the instrument sensitivity to leakage is approximately three times higher than its sensitivity in the 105 kHz frequency channel. However, the use of the high frequency channel allows a more accurate location of the source of ultrasonic noise, and ultimately the detection of the defective element.

   Laboratory experiments showed that leaks of less than 5 drops per minute usually stop by themselves gradually due to gap obliteration. Such leakages do not create turbulence and do not generate ultrasonic noise. Therefore, Resonance-2 cannot detect them. Also, it was established that Resonance-2 readings of a given leakage depend upon the type and shape of the unit, its temperature, and the kind of hydraulic fluid in use. However, Resonance-2's readings rise approximately 100 times when the leakage changes from a minimum drop rate to a small flow, which allows Resonance-2 to locate leaking valves with a high degree of accuracy. Complete testing of a wide-body aircraft hydro-system by one operator takes 15 – 20 minutes.

2. The detection of clogging in fuel filters

   Clogging usually cause changes in flow turbulence inside fuel filters. Those changes lead to subsequent variations of the level of ultrasonic vibrations on the filter's body. Experiments on the estimation of ultrasonic vibration levels on fuel filter bodies in gas turbine engines confirmed Resonance-2 capability to detect obstructions.

   As a result of a series of experiments with filters of the same type in aircraft gas turbine engines under small gas regime, we found statistically stable differences higher than 40% between Resonance-2 readings on obstructed and clean filters.

   Analysis of a filter's condition by this method conducted by a single operator did not exceed 6 minutes.

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3. The monitoring of the internal condition of roller and ball bearings

   Industry generally acknowledges that functioning bearings generate a wide range of vibrations, and that the parameters of these vibrations depend upon the bearings’ mechanical condition, their working regime, their lubrication, and upon other factors. For the purposes of bearing diagnosis and of the diagnosis of elements inside the working mechanism, the use of the high frequency portion of the vibrations spectrum is preferable, a fact that is supported by numerous research articles.

   The unique characteristics of the dual channels in RESONANCE-2 and the possibility to estimate spectral, correlation, cepstral, and other characteristics of the received signal by computer signal processing allows the user to implement not only well known methods of bearing diagnostics, but also innovative methods developed by CTRL Systems, Inc.

4. The detection of weak threading and riveting connections

   In this specific application, Resonance-2 is used in combination with an auxiliary ultrasonic vibrator.

   The principle behind the use of RESONANCE-2 for the identification of weak riveted or bolted connections is based upon the attenuation rate of the induced ultrasonic vibration intensity in the connection area between the fastener and the main structure. The detection of the weak fastener is carried out by comparison of the vibrations intensity on the fastener’s head and on the adjacent connection surfaces. An auxiliary wide frequency band electric-to-acoustical transducer supplied by the low power noise generator injects ultrasonic vibrations in the controlled structure.

   The validation of Resonance-2 capability to detect weak rivet connections was performed on an aircraft scheduled for overhaul. Tests established that readings by Resonance-2 on the head of weak rivets differ by a factor greater than 10 times from readings on an adjacent surface. Corresponding differences between readings on properly clenched rivets did not exceed 25%.
   The validation of Resonance-2 capability to detect weak bolt connections was conducted in CTRL’s laboratory by using two aluminum plates with through bolt connections. Tightening torques were applied by a calibrated torque wrench. Changes in the bolt connection’s tightening torque from 2.8 N*m to 14 N*m caused changes in the instrument’s readings by a factor of approximately 6 times.

   In these tests, the power supplied from an electric noise generator to the auxiliary electric-to-acoustical transducer was less than 1mW.

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