Welcome to Vibrationdata.com

Acoustics • Shock • Vibration • Signal Processing

September 2002 Newsletter

Merhaba

A vibration is a motion that can't make up its mind which way it wants to go.

From a list of humorous quotes from fifth and sixth grade students.

A great deal of engineering effort is spent to reduce vibration in mechanical and structural systems.

As an example, vibration in machinery often represents lost kinetic energy. Vibration in aerospace vehicles can cause sensitive avionics components to fail. Furthermore, earthquake vibration can destroy bridges and buildings.

On the other hand, vibration can also serve useful purposes. Each of the articles in this newsletter shows an example.

I hope that you enjoy these articles.

Thank you for your support.

Sincerely,

Tom Irvine

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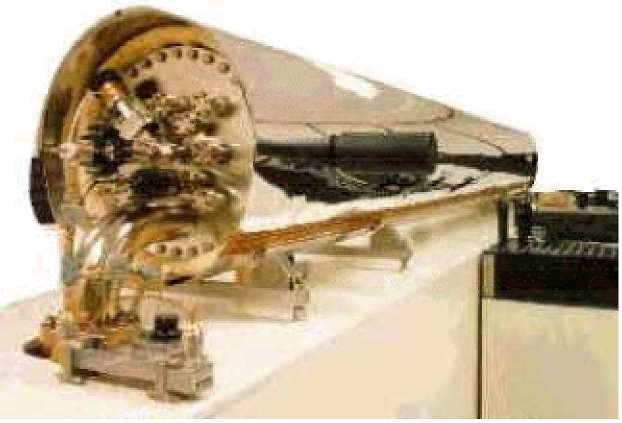
Feature Articles



Welcome to Vibrationdata Consulting Services

Vibrationdata specializes in acoustics, shock, vibration, signal processing, and modal testing. The following services are offered within these specialties:

1. Dynamic data acquisition
2. Data analysis and report writing
3. Custom software development and training
4. Test planning and support

Vibrationdata also performs finite element analysis.

Vibrationdata's Customers

Allied-Signal
Boshart Automotive

Delphi Automotive
Dynacs Engineering
Dynamic Labs

ECS Composites
Itron

Motorola Flat Panel Display

Motorola Government Electronics Group

Orbital Sciences Corporation
Prolink
Scientific Marine Services

Spectrum Astro

SpeedFam
Sumitomo Sitix

Three-Five Systems

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Atomic Clocks by Tom Irvine

Introduction

Extremely accurate time measurement is needed for the global positioning satellite (GPS) system, telecommunication networks, and space travel.

Official time in the United States is kept by National Institute of Science and Technology (NIST) in Boulder, Colorado; and by the United States Naval Observatory in Washington D.C. These organizations maintain a large number of atomic clocks, from which an average time value is taken.

In addition, the National Research Council (NCR) of Canada operates atomic clocks.

GPS Accuracy

Stephen Dick, the United States Naval Observatory's historian, reported that each nanosecond of error translates into a GPS error of one foot. A few nanoseconds of error, he points out, "may not seem like much, unless you are landing on an aircraft carrier, or targeting a missile."

Each GPS satellite thus contains an atomic clock in order to give the most accurate measure of time and distance possible.

Cesium Atom

These atomic clocks are based on the oscillations of cesium-133 atoms. A cesium-133 atom contains 55 protons and 78 neutrons in its nucleus. This is the only naturally occurring isotope of cesium.

Cesium is a non-radioactive metallic element. A gram of cesium could be found in about a cubic foot of ordinary granite. One second is defined as the period for 9,192,631,770 oscillations in a cesium-133 atom between its two “hyperfine” quantum states.

One second is formally defined as

> The duration of 9,192,631,770 cycles of microwave light absorbed or emitted by the hyperfine transition of cesium-133 atoms in their ground state undisturbed by external fields.

The 13th General Conference on Weights and Measures established this formal definition in 1967.

Note that atoms can have one of two hyperfine states: either the magnetic field of the outermost electron points in the same direction as the magnetic field of the nucleus, or it points opposite. The laws of quantum physics forbid other any other orientation.

An atomic clock employs an electromagnetic field that causes transitions between the two hyperfine quantum states of the cesium-133 atoms. The two states are called the F=3 and F=4 levels.

This oscillation within the atom can be modeled as a mechanical oscillation. In this sense, the oscillation frequency is determined by the mass of the nucleus and the gravity and electrostatic "spring" between the positive charge on the nucleus and the electron cloud surrounding it.

Accuracy

Today, cesium clocks measure frequency with an accuracy of 0.0002 Hz. This corresponds to a time measurement accuracy of 2 nanoseconds per day, or one second in 1,400,000 years.

Research is underway to develop atomic clocks with even greater accuracy.

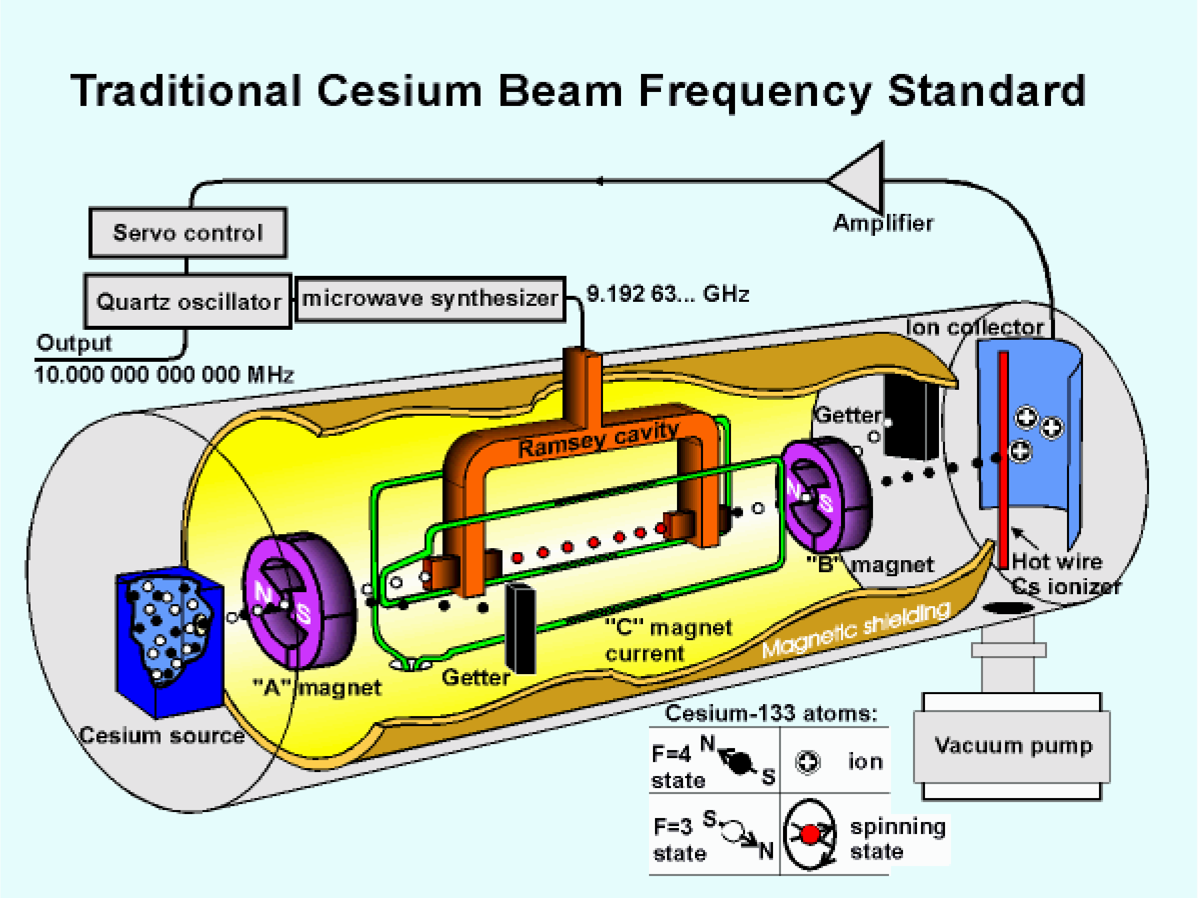

Figure 1-1. Cesium Atomic Clock Diagram

Image Courtesy of the Institute for National Measurement Standards, Canada

Atomic Clock Operation

A diagram of an atomic clock is shown in Figure 1-1.

First, liquid cesium is evaporated to a gaseous state at the source. The gas is formed into a beam of well-separated cesium atoms that travel without collisions at about 250 m/sec, through a vacuum, which is maintained by the vacuum pump.

The “A” magnet selects cesium atoms that are magnetized one way, those in the F=3 level of the ground state of the cesium-133 atom. The other atoms are absorbed by a carbon getter. The magnet thus serves as a filter.

Some magnetized atoms are set spinning by microwaves in the Ramsey cavity. The microwaves have a 3.26-cm wavelength, with a frequency of 9,192,631,770 Hz.

The microwaves excite the atoms in the cavity to spin at 9,192,631,770 rotations per second. Some of the spinning atoms respond by undergoing a hyperfine transition to the F=4 level.

This process occurs in a very uniform magnetic field, called the “C” field. This field is less than 1/10 the Earth's magnetic field.

The microwaves at the other end of the Ramsey cavity stop the spinning of the cesium atoms. At this point, some of the atoms are in the F=4 state, while others remain at the F=3 state.

The “B” magnet collects the cesium atoms in the F=4 state. These are the atoms that stayed in step with the microwaves, their respective outer electrons having undergone the magnetic shift.

The cesium-133 atoms in the F=4 level are thus collected. They are not recirculated, however.

The “B” magnet deflects the in-step atoms towards a detector, the hot wire cesium ionizer and ion collector. A second carbon getter absorbs the other atoms.

The control mechanism uses data from the detector to maintain the microwave frequency that produces the most changed atoms. This frequency, the atoms' natural hyperfine transition frequency, is counted to determine the length of a second.

In some sense, the purpose of the control loop is to excite the “resonant frequency” of the cesium atoms.

The servo control keeps a quartz oscillator locked at a frequency of 10 MHz. The oscillator outputs this signal, along with a one-pulse-per-second signal. These signals are the actual output of the clock.

Note that the entire apparatus is shielded from external magnetic fields.

The Use of Tuning Forks in Medical Exams by Tom Irvine

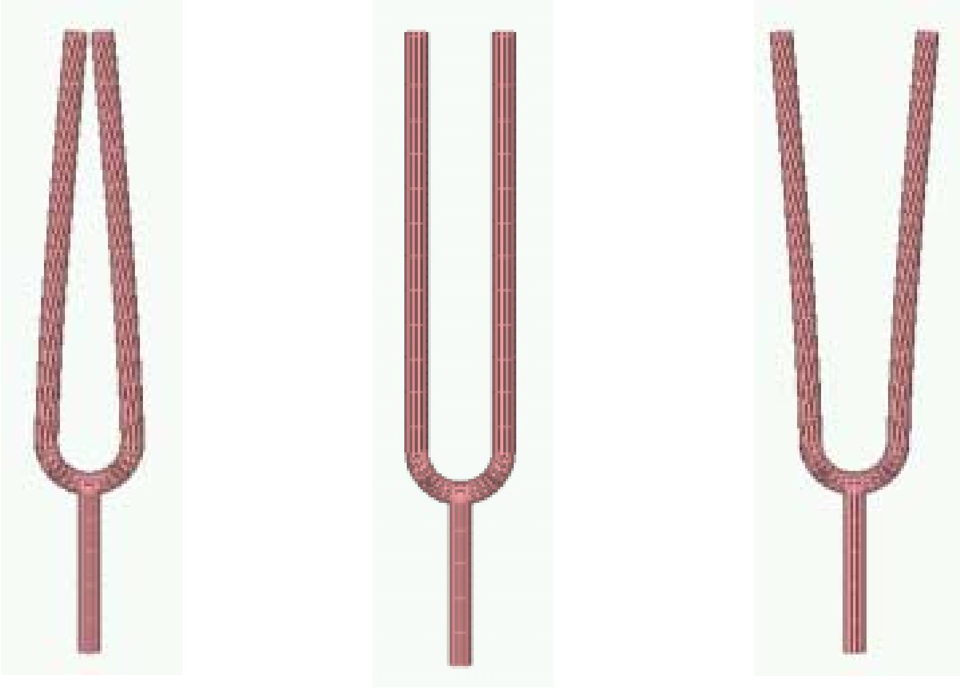

Figure 2-1. Fundamental Mode of a Tuning Fork

Introduction

Tuning forks are used for tuning musical instruments and for science demonstrations. Tuning forks are also used for hearing tests and neurological exams. This report focuses on these medical tests.

Modes

The fundamental vibration mode of a tuning fork is shown in Figure 2-1. The mode shape is an in-plane bending mode. Each fork vibrates 180 degrees out-of-phase from the other.

Human Vibration Sensory Threshold

Studies of vibration sensitivity in the hand have consistently shown average thresholds at 100-125 Hz of 0.2-0.4 µm in 20-40 year old healthy subjects, according to Reference 2-1. Similar values are obtained for the fingertips, the palm, and the back of the hand. Repeat tests at intervals of one day to several weeks usually show good repeatability, within ± 20%.

Neurological Exams

Neurological exams are used to test patients for diabetic foot disease, multiple sclerosis, carpal tunnel syndrome, and other conditions. Vibratory sense tests are one of several examination procedures.

A tuning fork with a frequency of 128 Hz or 256 Hz is typically used for this test. An example is shown in Figure 2-2.

The doctor begins by striking the tines against the heel of his or her other hand so that the tuning fork vibrates. The stem of the tuning fork is then placed on the bony prominence of the patient's ankle, foot, shin, wrist, elbow, shoulder or sternum. The patient is then told to respond to the vibration, rather than to the sound or pressure of the tuning fork.

Figure 2-2. Vibratory Sense Test

Human Hearing

The audible frequency range for the average human extends from about 20 Hz to about 16,000 Hz. In general, people are less sensitive to low-frequency noise, below 100 Hz, than they are to high-frequency noise, above 2000 Hz.

Note that the human hearing threshold is zero dB at 1000 Hz. The decibel scale is thus defined with respect to this threshold.

Hearing Tests

Audiologists and medical doctors perform hearing tests on patients to determine whether a patient has suffered hearing loss due to aging, prolonged noise exposure, or due to some illness.

The Weber test and the Rinne test are part of the examination. These tests are used to evaluate hearing by bone conduction. The Rinne test also tests hearing by air conduction.

Both the Weber and Rinne tests are performed using a tuning fork.

Weber Test

The purpose of the Weber test is to check for asymmetrical hearing loss.

The recommended frequency for the Weber test is 512 Hz to 1024 Hz. The test can be repeated using tuning forks with various frequencies in order to perform a thorough test. Note that the amount of hearing loss may vary with frequency.

The vibrating tuning fork is place at the midline of the patient’s forehead, as shown in Figure 2-3. The examiner then asks the patient "Where do you hear this loudest: left, right, or in the middle?"

Figure 2-3. Weber Test

A reply that the sound is louder in one ear than in the other is an indication of a hearing disorder.

Rinne Test

The Rinne test has two parts. Its purpose is to compares air conduction to bone conduction.

The recommended frequency for the Rinne test is 256 Hz to 1024 Hz. The test can be repeated using tuning forks with various frequencies in order to perform a thorough test.

Figure 2-3. Rinne Test, Part 1

Figure 2-4. Rinne Test, Part 2

First, the vibrating tuning fork is held against the patient's mastoid as shown in Figure 2-3. The patient is told to say "now" when he or she can no longer hear the sound.

Next, the still vibrating tuning fork is moved over the ear canal, with the U-section nearest to ear as shown in Figure 2-4. The patient again signals when he can no longer hear the sound.

Parts 1 and 2 are then repeated for the other ear.

A healthy patient will have greater air conduction than bone conduction and therefore hear the vibration longer with the fork in the air.

Images 2-3 through 2-4 are courtesy of the New York University School of Medicine.

Quartz Tuning Fork By Tom Irvine

Figure 3-1. A Quartz Tuning Fork Covered with a Thin-film Metal Layer

Image Courtesy of Physicist Erhard Schreck.

Introduction

Quartz is composed of silicon and oxygen, in the form of silicon dioxide. Ordinary sand is also composed of silicon dioxide. There is a fundamental difference between quartz and sand, however. Quartz is a crystal in which the atoms are arranged in an orderly pattern. In contrast, atoms in sand are arranged in more random pattern, and sand contains many impurities.

Quartz is a piezoelectric material. It surface will carry a voltage when it is under pressure. On the other hand, the crystal will be slightly deformed if a voltage is applied to its surface. Furthermore, the quartz material will vibrate when it is subjected to an alternating current. This vibration is very stable and is nearly independent of temperature.

Manufacture

A quartz watch has a tuning fork made of quartz. The quartz may be natural or synthetic. Natural quartz is mined from the earth. Cultured quartz is grown artificially in high pressure autoclaves.

Thin sheets of quartz are cut from the raw crystal stock. The quartz tuning forks are cut from the sheets. Grinding, and polishing are used to obtain a precise fork shape.

A piezoelectric effect occurs within the crystal during the grinding and polishing processes. The emitted electrical signal is monitored to determine the resulting quartz natural frequency.

The quartz tuning forks are then plated like an integrated circuit. An example is shown in Figure 3-1. The penny in this figure used for a size comparison.

The fork is connected to a test oscillator during the plating process. The resonant frequency is monitored with a frequency counter. Plating stops the instant the correct frequency is reached. Accuracy is critical. The standard is 32,768 Hz.

Operation

An oscillating electrical signal from a battery is applied to the thin-film metal layer deposited on both sides of the crystal quartz tuning fork. This causes the fork to undergo resonant vibration due to the piezoelectric effect. Again, the typical vibration frequency is 32,768 Hz.

The quartz crystal itself is a capacitive component of the oscillator circuit. The oscillating voltage of this circuit is detected. A microprocessor then divides the signal down electronically to become a 1 Hz signal, which is used to drive a stepper motor. The stepper motor consists of a magnet and a coil. The stepper motor drives the gear train that controls the hand movement.

The second hand on an analog quartz watch skips from second to second. In contrast, the second hand of a mechanical watch moves continuously. Note that a mechanical watch uses the energy of a spring to drive its hands.

Digital watches also make use of quartz tuning forks. The operation is similar to that in an analog watch except that the microprocessor divides the signal into pulses.