Acoustics • Shock • Vibration • Signal Processing **March 2005 Newsletter**

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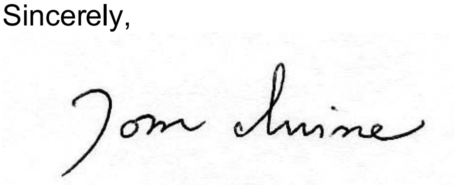
Magnetic fields from alternating current induce vibration in certain materials, such as iron, steel, and ferrite alloys. This effect is called magnetostriction.

Transformer hum is a common example of magnetostriction. This hum is a potential nuisance, and it is an energy loss mechanism. The first article in this newsletter discusses this effect and presents some measured field data.

Magnetostriction can serve useful purposes, however. Magnetostrictive actuators can be used for sonar transmitters, active vibration control devices, and hearing aids, for example. Sensor applications include magnetic and stress sensing devices.

The second article gives the results of some science experiments that demonstrate resonant excitation using this principle.

Sincerely,



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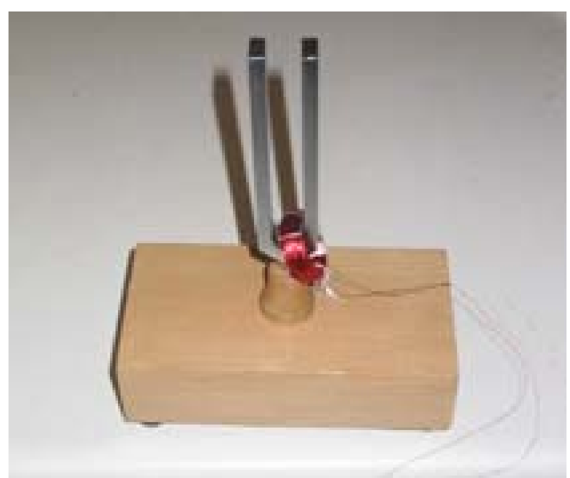
Feature Articles



Transformer Hum by Tom Irvine

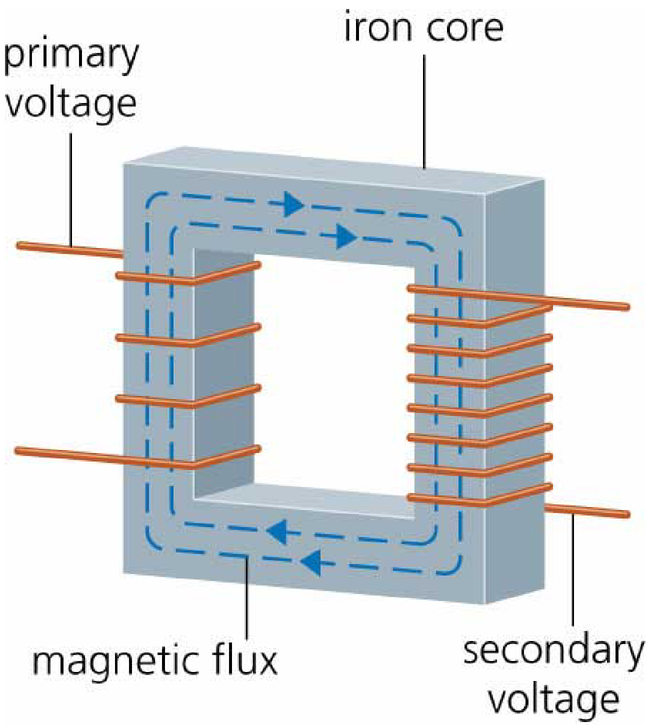


Figure 1. Step-up Transformer

AC power is applied to the primary coil. The secondary coil has more windings and thus higher resistance than the primary coil. The secondary coil produces a higher voltage but at a lower current relative to the primary coil.

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Introduction

There are numerous types of transformers.

Transformers may be used to step up or step down a voltage. The transformer is a passive device which does not add any energy. Thus the current must decrease if the voltage is increased so that the power remains the same. Note that power is equal to voltage times current.

A small percentage of power may be lost to heat and vibration, however.

A basic transformer has two sets of windings, the primary and the secondary. Certain transformers may have secondary windings or taps. The primary connects to the power source. The secondary connects to the load usually at a lower voltage.

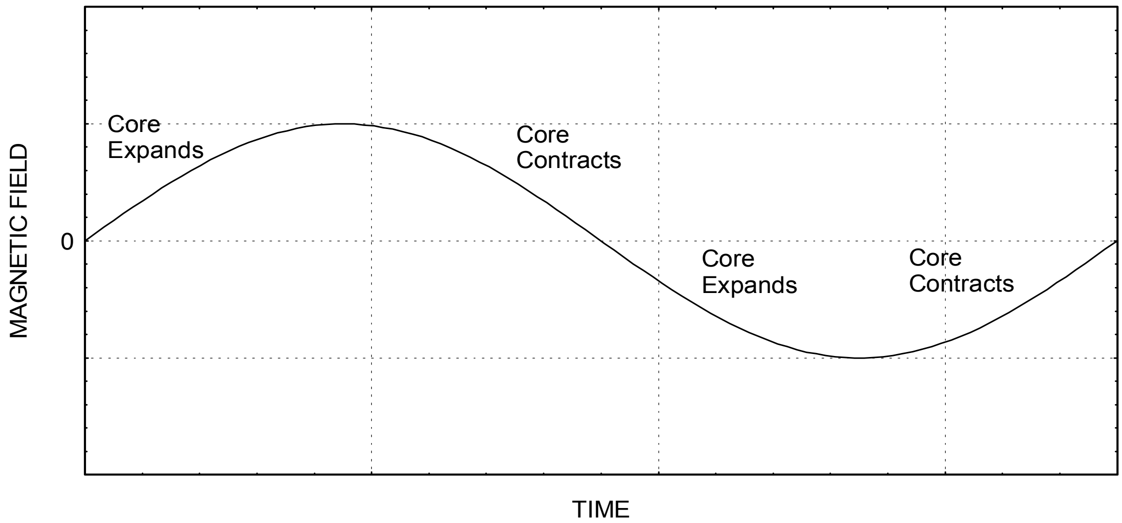

Figure 2.

Core Material

The windings are wrapped around a core. The core material may be iron or ferrite, depending on the design requirements.

An iron core may be laminated with layers of iron and non-conducting material stacked together.

A laminated iron core is used to reduce the creations of eddy currents in the iron core that would dissipate the energy being transferred from the primary coil to the secondary coil in the form of heat.

Furthermore, ferrite is used as the core material in some transformers. Ferrite is a ceramic material with useful electromagnetic properties It is a compound consisting primarily of Fe_2O_3 iron oxide.

Varying amounts of nickel, zinc and manganese are added to form different types of ferrite.

There are design trade-offs between the core materials. Ferrite cores require fewer turns, give more impedance per turn and couple better. Iron cores require more turns, give less impedance per turn, do not couple as well but tolerate more power and are more stable.

Operation

An alternating current is input to the primary winding. The current produces a magnetic flux, or magnetic lines of force in the core. The resulting magnetic field induces an alternating current in the secondary winding.

The number of turns on each winding determines the output voltage from the transformer. The output voltage from the secondary is proportional to the ratio of the turns on the windings.

Figure 3. Transformer, Mesa, Arizona

Magnetostriction

The magnetic field stresses the core material. The stress causes the core volume to expand regardless of the polarity. The core contracts to its equilibrium volume as the magnetic flux returns to zero. This property is called "magnetostriction."

The material expands and contracts twice per each magnetic cycle, as shown in Figure 2. The core thus vibrates at 120 Hz in response to the changing magnetic field from 60 Hz AC power.

The deformation amplitude may be so small that it is impercetible to the unaided human eye. Nevertheless, it may be large enough to generate a "hum." The hum frequency is 120 Hz, with integer harmonics.

Most of the magnetic field created by the current in the windings is contained in the core, but a portion extends outward.

Some transformers have a metal housing. The magnetic field leaking out of the core may impose forces on the housing, causing it to vibrate at 60 Hz, thus generating another hum frequency.

Furthermore, the metal housing acts as a radiative surface for the various hum frequencies. Resonant amplification may occur if the housing has a natural frequency that coincides with any of the hum frequencies.

Damping

Some large transformers are cooled with oil. The oil is a viscous fluid which dampens the core vibration. In addition, a transformer may have a cooling fan and a radiator.

AC Motors

As an aside, electromagnetic motors may also have magnetostrictive vibrations.

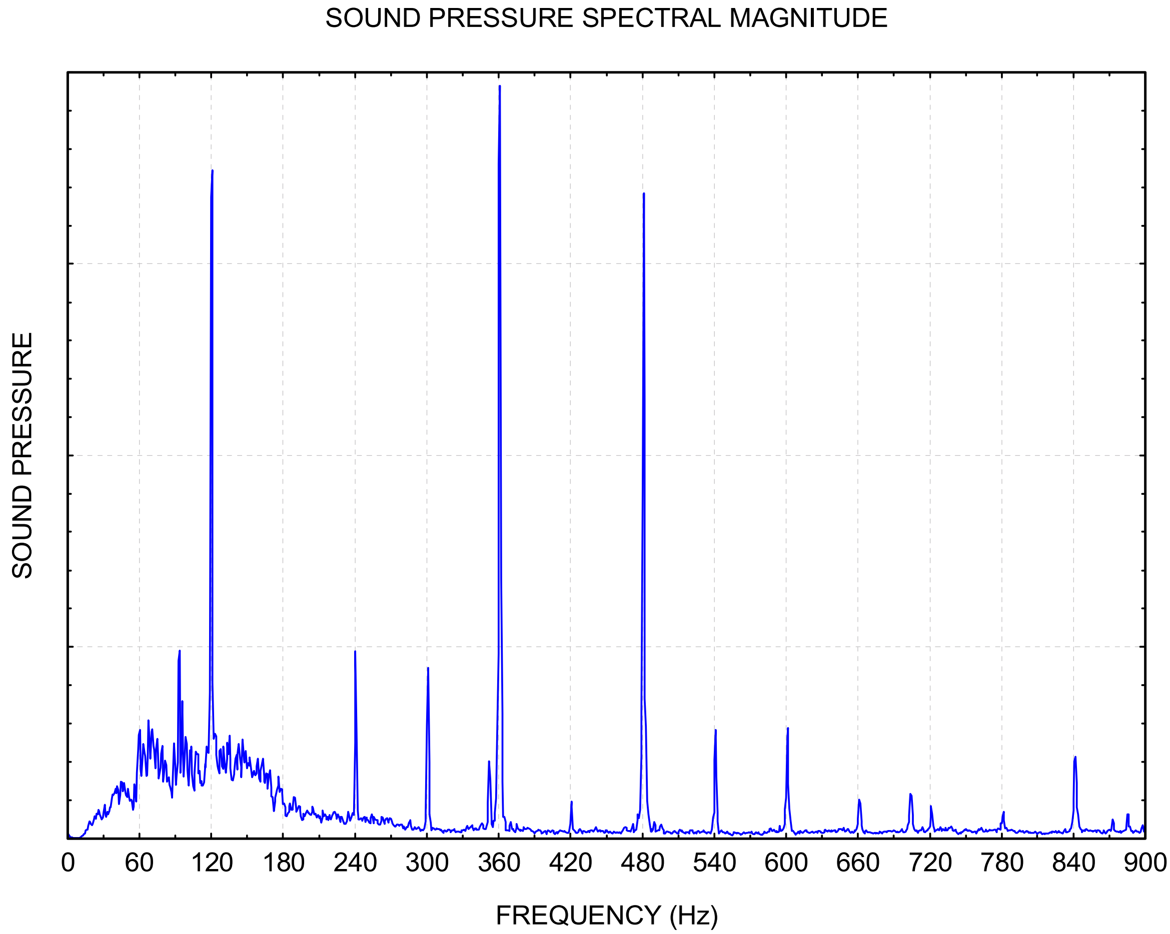

Figure 4. Transformer Hum

Measured Data

A sample transformer, located in the author's neighborhood, is shown in Figure 3. The transformer output a low level hum due to magnetostriction. The decibel level was not measured, but the hum was nearly inaudible about 20 feet away.

The sound pressure was measured using a microphone. The resulting spectral magnitude is shown in Figure 4, with an unscaled amplitude. Spectral peaks occur at 120 Hz and integer multiples thereof.

Magnetostriction Experiments by Tom Irvine

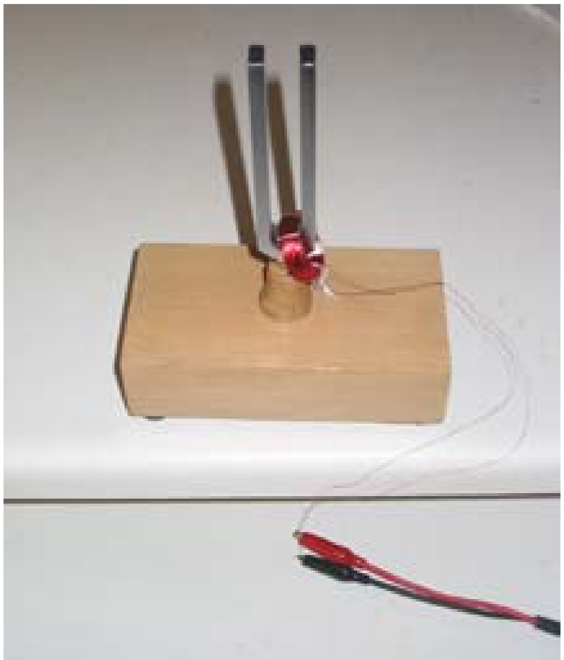

Figure 1.

Tuning Fork with Electromagnetic Coil

Introduction

Magnetostrictive materials have a coupling between their magnetic and mechanical states, as discussed in the previous article. Magnetic fields induce strain in certain materials. This strain takes the form of vibration if the magnetic field itself is oscillating.

Tuning fork Transient Test

A steel tuning fork is shown in Figure 1. The tuning fork is mounted on a wooden box. The walls of the box transform the vibration of the tuning fork into sound.

The first step was to identify the natural frequency of the tuning fork, as excited by the tap from a small rubber mallet. The coil was removed for this test.

The resulting sound was measured by a tape recorder microphone. The sound was then digitized using a Nicolet system.

The resulting sound pressure time history is shown in Figure 2.

A waterfall FFT is shown in Figure 2. The fundamental frequency is 442.4 Hz, as determined form the zoom FFT in Figure 3.

The RMS time history in Figure 4 shows that the tuning fork and box system does not have a consistent decay rate. The envelope decays approximately 30 dB over 19 seconds. The RT60 reverberation time is thus 38 seconds, which gives an amplification factor of Q = 7700, given that the frequency is 442.4 Hz. Note that the room acoustics may have affected the reverberation time.

The tuning fork is marked as 440 Hz, which is an A note. The experimental data thus agrees closely with the nominal frequency.

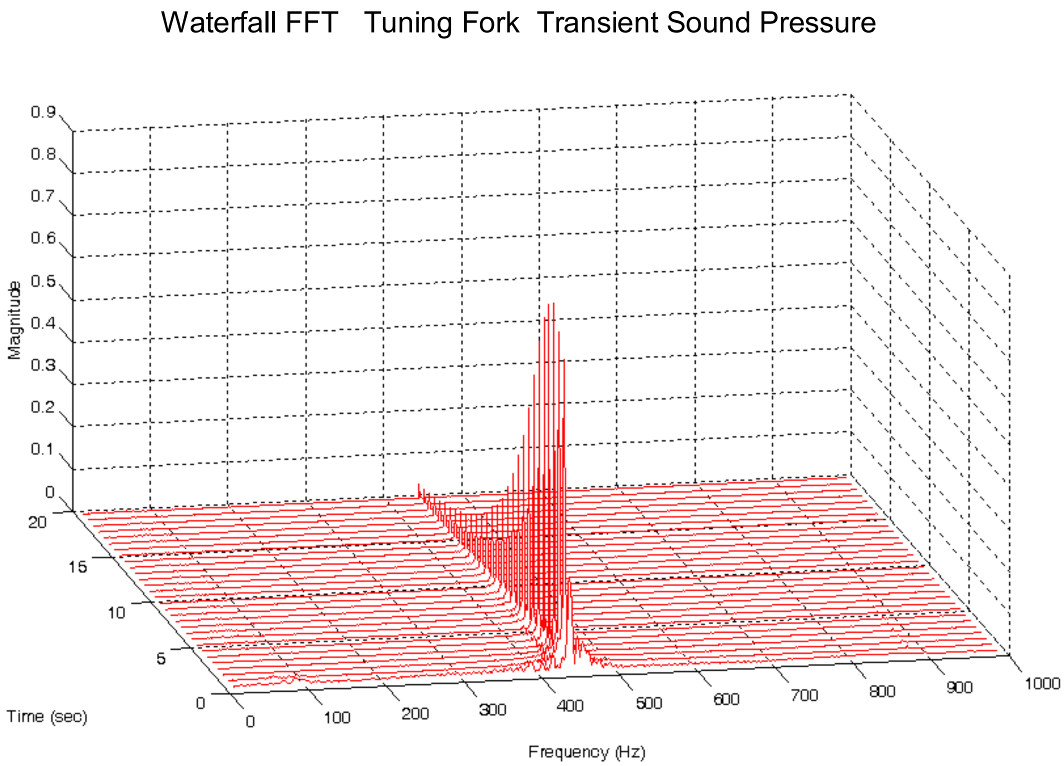

Figure 2.

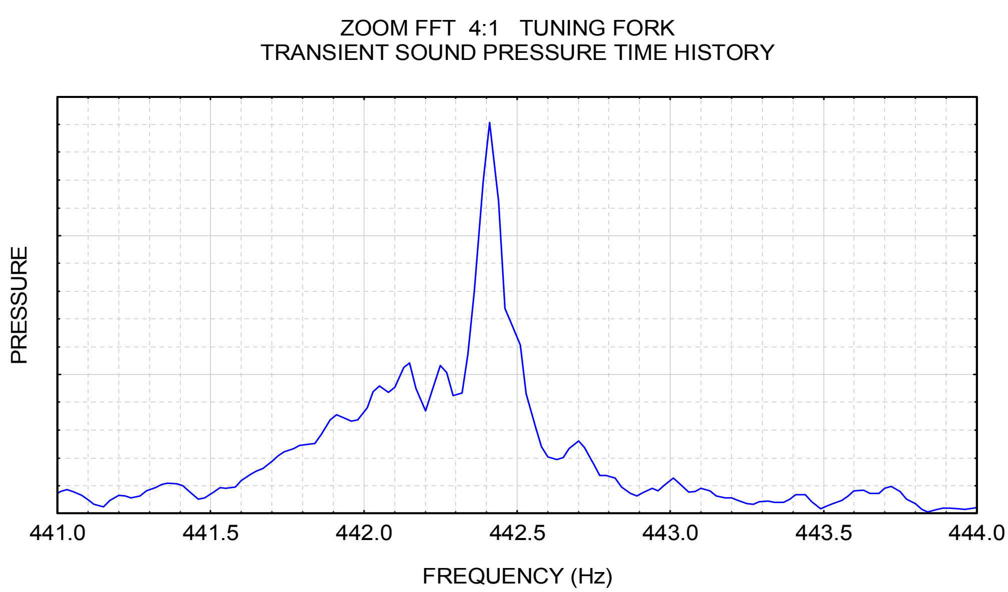

Figure 3.

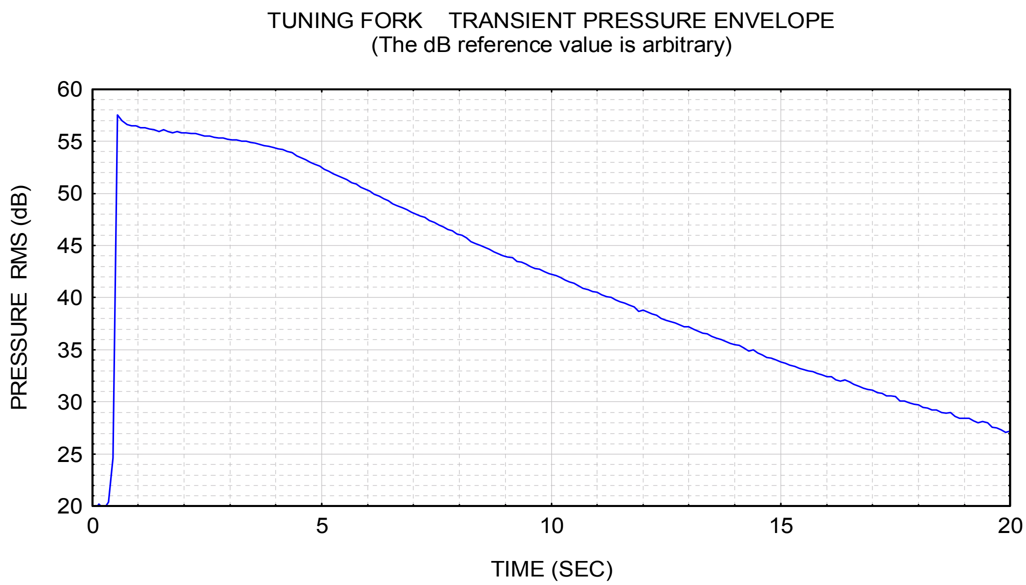

Figure 4.

Tuning Fork Steady-State Test

The tuning fork's resonant frequency was excited by the coil as shown in Figure 1, using the principle of magnetostriction. The tuning fork produced a loud hum at this frequency.

Again, the tuning fork's fundamental frequency is 442.4 Hz. The current applied to the coil had a frequency of one-half this value. The excitation frequency required some precise adjustment because the tuning has such a high Q value. The resulting time history is shown in Figure 5.

TUNING FORK DRIVEN BY COIL

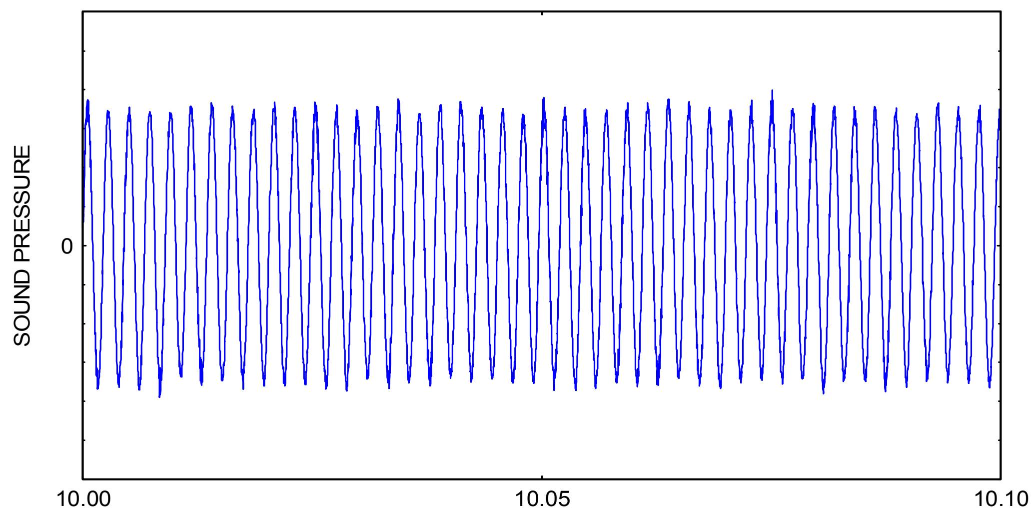

Figure 5.

Rod Experiment

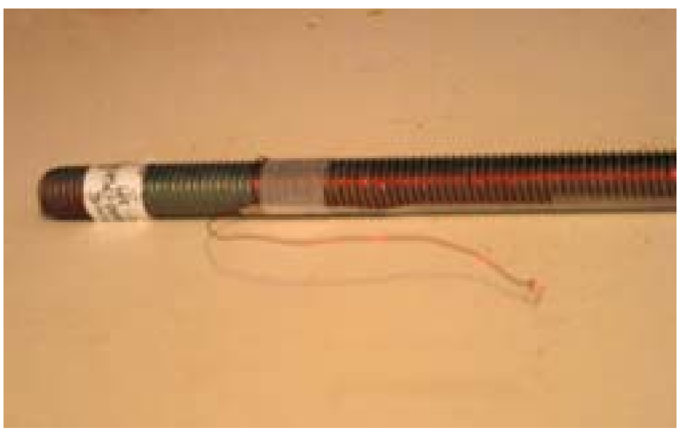

Figure 6. Rod with Magnetic Wire

The steel rod is 36 inches long. Magnetic wire was wrapped in the rod's thread grooves, along most of the length.

The rod was configured so that it had free-free boundary conditions.

The longitudinal natural frequencies are given in Table 1.

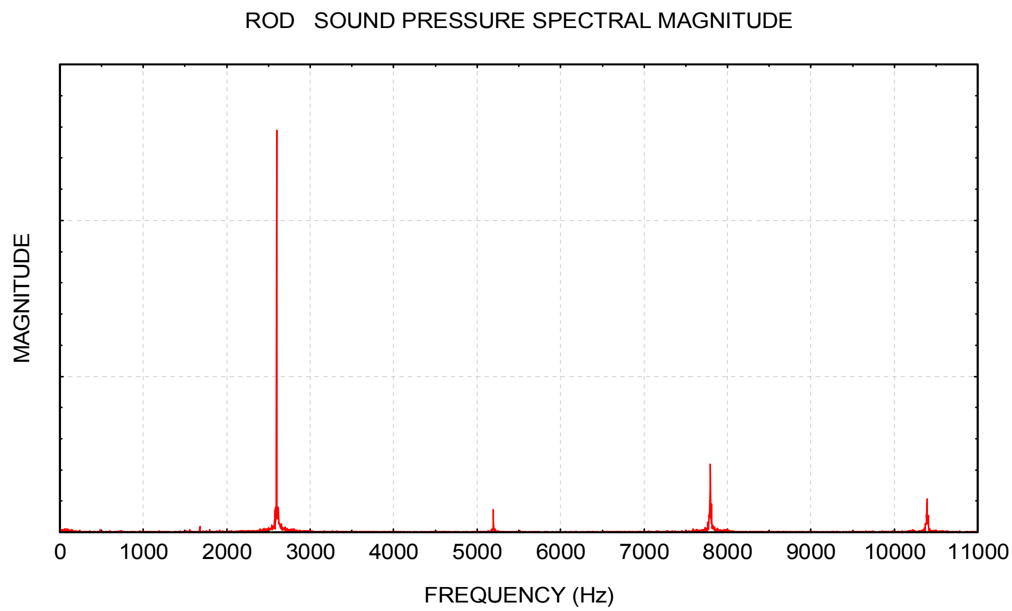

Figure 7.

Table 1. Rod Longitudinal Frequencies		
Mode	Measured (Hz)	Calculated (Hz)
1	2600	2825
2	5200	5650
3	7790	8475
4	10,390	11,300

Each measured frequency is about 8% lower than the calculated value.

The rod generated the tones in Figure 7 when the current in the coil was set directly at the rod's fundamental frequency. This result needs further consideration. A tentative conclusion is that magnetostriction may yield one mechanical cycle per electromagnetic cycle under certain conditions, in addition to harmonics.

Furthermore, the rod also produced the tones when the coil current frequency was at one-half the rod's fundamental frequency, as expected per the magnetostriction principle. The sound volume was somewhat softer in this case, however.