# INFRARED LASER SYSTEM TO PRODUCE AND DETECT WITH NO PHYSICAL CONTACT LOW AND VERY LOW FREQUENCY VIBRATIONS

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This work presents a device designed to measure resonance frequencies on different kind of materials, either in flexure or torsion modes, acting as a remote sensor for vibrations. This is an extension of earlier equipment by the same author. It is constructed as a single unit, including a *proximity exciter*, can be applied for both ferromagnetic and non ferromagnetic materials, and does not require neither emission of sound nor physical contact.

## I. INTRODUCTION

The need for measurement of material properties is always increasing, as new materials are appearing continuously and requirements on them are ever more strict. The device and system presented here offers a new alternative, the main advantage of which lays on the fact that no physical contact is required to excite vibrations on metallic materials and to receive them.

Firstly, all we need to do is to place *this special* exciter near the test piece, while the latter is submitted to a harmonic vibration (sinus wave). Secondly, a laser system is used: a laser beam, reflected from the sample; is collected by a lens and guided to a sensor, which converts on-line this kind of signal to an *amplitude-time* graph. Due to commercial availability, this system is limited in frequency to a maximum of about 10 kHz. However, this value is high enough and covers widely the low frequencies range.

## II. FEATURES OF THE SYSTEM

Device and system can produce and measure vibrations, only under conditions of mechanical resonance. Of course this device has all the features to produce vibrations on the surface of any metallic body and measure them. Figure 1 shows a general view where we can see: an oscilloscope, the vibrometer, a console to generate the vibrations and show the frequency values, and, near the surface under testing, the electromagnetic exciter. In this case, the vibrating surface is bell shaped.. In the picture the computer used to acquire the graphs and dynamic data is not shown. The computer is coupled to an HP 54603 B, 60 MHz digital oscilloscope, and data are fed through a transmission module into the RS-232 port.

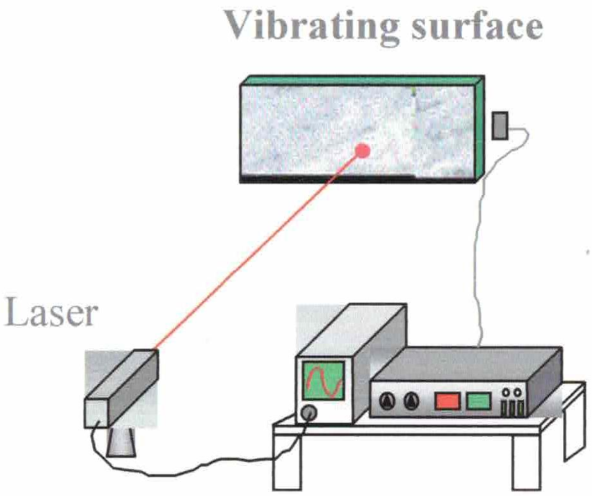


Figure 1. *Laser-Vibrometer, oscilloscope, exciter.*

"Bench-Link" software from Hewlett Packard was used to acquire and store the signals from the vibrometer; they are displayed on the oscilloscope and the computer, and stored in the latter. Data can be stored in dynamical form, and also recalled and analysed off-line. A digital HP 33120 A signal generator was used to produce the frequencies needed to scan the test pieces, to obtain the resonant frequencies with high accuracy. An external frequencemetre was used to measure the envelope frequency of the reflected laser beam. We must point out that the oscilloscope and the generator were designed to work together and to communicate between them.

## III. DESCRIPTION OF THE METOD

### Activation principia

When the generator performs a frequency scan looking for the resonant modes of the test piece, a high amplitude sine wave is displayed on the oscilloscope when a mode is encountered. The signal must then be "tuned" to reach its maximum value. In this moment the data are recorded in the oscilloscope memory and fed into the computer system. It is also possible to record data in the generator. How does the system work? There are two signals, which should not be confused. a) the signal emitted by the generator; which is amplified and guided to the transducer, near the body's surface. b) the actual signal from the laser beam, reflected by the sample, and which carries the information.

### The exciter system

Two different cases should be handled in different ways: a) the sample is ferromagnetic. b) the sample is non ferromagnetic.

a) Ferromagnetic samples.

Figure 2 shows a metallic bar located over two nodal supports. It is the typical scheme to obtain the Young's Module (E) in a dynamical way, under mechanic resonance condition.

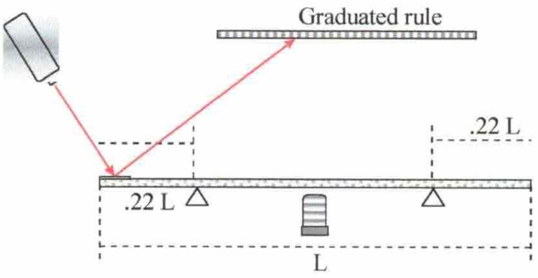


Figure 2.- *Ferromagnetic bar and coil.*

As shown in the picture, in the middle, below the bar, the exciter coil is placed. This case is simple. The exciter is a coil producing an alternate magnetic field: each hemicycle attracts the bar according with the expression:

$$\mathbf{F}\ \alpha\ \mathbf{I} . \sin(wt),$$

where F represents the force, and I sin (wt) stands for the time depending current.

In this case the figure shows an arrangement prepared to obtain the resonant values, for the "free-free" hanging mode. This behaves as a variable electromagnet.

b) Non ferromagnetic samples

Figure 3 describes the basic principles. The big piece, in grey, is a magnet. The small piece is a coil to produce the variable field. The test sample is above the pieces.

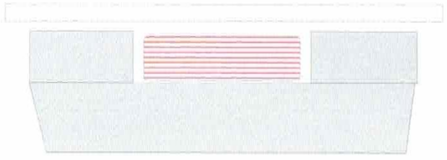


Figure 3.- *Magnet, coil, and sample above.*

Both magnetic fields **must be mutually perpendicular**: the continuous field (magnet) and the variable field (coil). The generator feeds the coil. The cross product between these fields results in a Lorentz force on the material.

$$[\mathbf{F}]\ \alpha\ \mathbf{B} \times \mathbf{Li} . \sin(wt) . \sin\theta$$

A different arrangement is shown in Figure 4.:

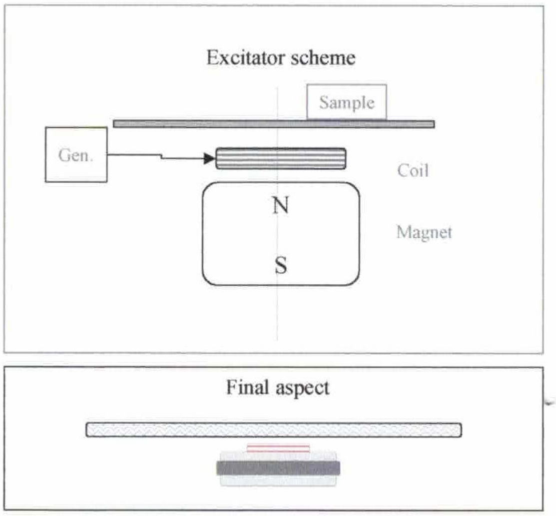


Figure 4.- *Working principles and final arrangement aspect.*

In case **a**, the bar is attracted by the coil once per hemicycle; i.e. twice in a cycle: if a frequency of 100 Hz is supplied by the exciter, the frequency of the reflected signal will be 200 Hz. In case **b**, the sample is *attracted* and *rejected* once per cycle. Then, both response and excitation frequencies are equal. In consequence: *if we know* *the excitation frequency we know the resonant frequency*. However the physical phenomenon is the same: a Lorentz force. The expression is the same, but the physical difference must be found just on the surface of the non magnetic material, on the point where the flux lines make an inflexion.

## IV. DESCRIPTION OF THE DETECTOR

The detection method has two different parts. First, a laser beam impinges on a target on the sample and is reflected from it. The reflected beam is then focused into a photo sensor, which a photo transistor prepared to convert the signal into an amplitude-time graph as mentioned above. Details of the electronics are not the object of the present work, but we will try to explain it through the scheme in figure 5.

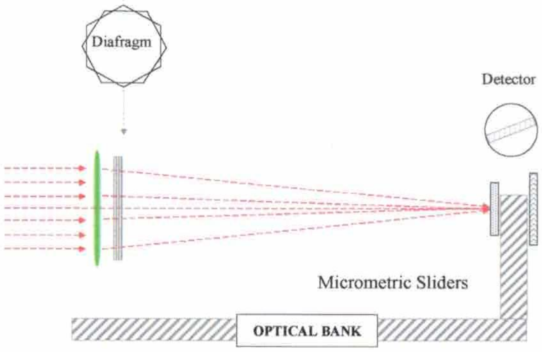


Figure 5.- *Optical bank, lens, sensor, laser beam.*

We consider practical to show a view of the vibrating surface reflecting the beam. Figure 6 can give us an idea about the problem of the reflected laser light capture.

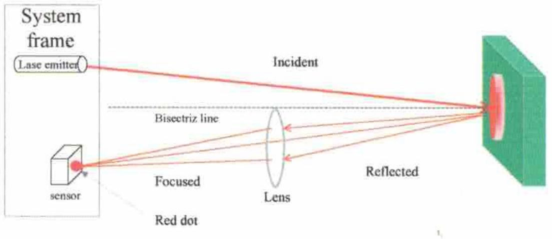


Figure 6.- *Target, beams, lens, in a general scheme.*

## V. MEASUREMENTS & CARACTRISTICS

The first frequency value, which corresponds to the fundamental mode, is determined as described above. Figure 7 is not just a drawing, but an actual graph, as provided by the oscilloscope after pass trough the laser-system.

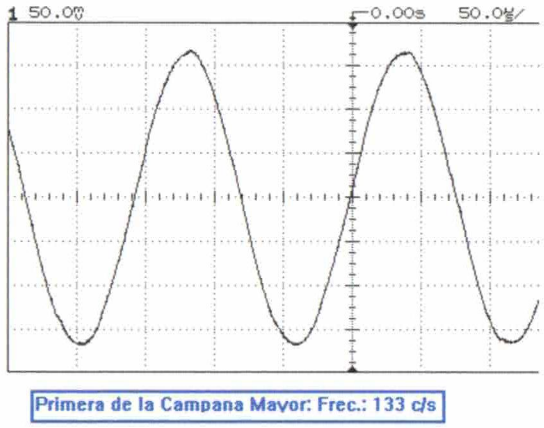
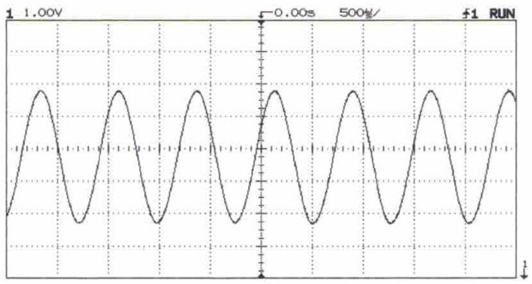
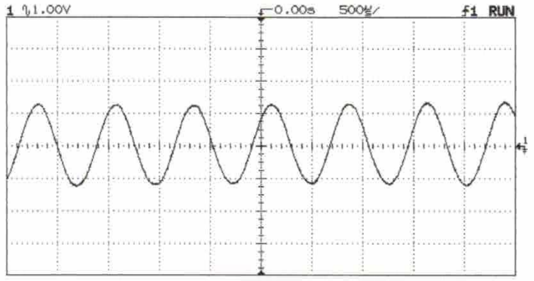


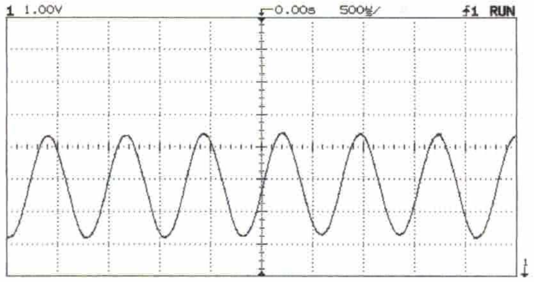
Figure 7.- *First graph, signal, and Amplitude-Time scales.*

In the same way, the other resonant frequencies were determined, one at time. More than ten values were found, but only one more will be shown. Figure 8 shows the amplitude vs time display for resonant frequency 1305.6 hertz. Figures 9 and 10 show the same type of graph for a slightly higher and lower frequency, 1305.8 and 1305.4 Hz respectively.: the amplitudes differ in about 15% while the frequency varies only 0.2 Hz in 1305 Hz. We want to point out an interesting feature of this system: the high mechanical "Q" of several materials when excited near resonance.

Figures N° 8, N° 9, and N° 10 (graphos)







The graphs corresponds to frequencies 1305.6 Hz; 1305.4 Hz; and 1305.4 Hz respectively.

## VI. PRECISION AND ACCURACY

Because this system is a-periodical, it has no frequency response of its own. Both accuracy and precision are depending on the features of instruments connected to it. In our case the precision of the generator is 1/100.000, but we appreciate only .01 Hz in any scale.

## VII. APLICATIONS

The system is suitable to be applied in general cases. The minimum requirement for the test piece is that it should have at least a small surface to which the exciter may be coupled and some other place where the laser should impinge. Figure 11 illustrates the general case. The body looks like a turbine's wing or a general curved shape.

## FINAL ASPECT & GENERAL CASE

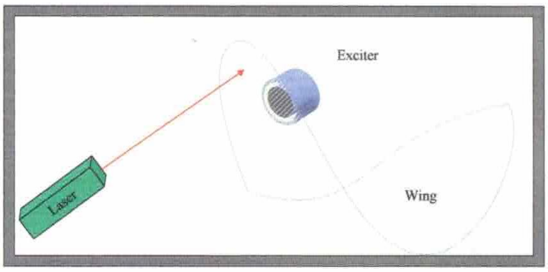


Figure 11.- *Body, Laser & exciter.*

## VIII. CONCLUSIONS

The described system is not calibrated yet to measure amplitudes into the standard rules, but can perform comparative determinations. It was specially constructed to detect and measure resonance frequencies, under unusual conditions. It is possible to work in the extreme rang: 0 to 10 KHz.

## ACKNOWLEDGMENTS

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