Department of Physics
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Detection of Vibrations by Triangulation

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Abstract

In this lab we measured the amplitude and frequency characteristics of a tuning fork. We did this by using the laser triangulation technique with a *position sensitive detector* (PSD) that collects scattered light from the laser that hit the tuning fork. The measured frequency using this laser triangulation method was $253.68 Hz$ which deviates 0.9% from the value of $256 Hz$ specified by the manufacturer. We think that these results confirm that the laser triangulation technique using a PSD is good for measuring movements in the μm-range at frequencies of several hundred hertz.

Non-Invasive Measurement Techniques
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1 Introduction

One way to determine the small movements of objects, is to attach an accelerometer or similar electronics on the object. But the problem with this method is that the sensor itself will affect the object—it is an invasive method. Ideally we want to use a measuring technique that is *non-invasive.* One way to accomplish this is to use the laser triangulation technique.

The laser triangulation technique works by pointing a laser at the moving object and then collect the scattered light onto some detector. From this the position of the object can be determined at different times; the choice of detector depends on the application. But in general this technique can today offer resolution in distance of $\sim nm$ and measure frequencies of up to $\sim 100kHz$.

The laser triangulation technique has a wide area of application including a 3D-scanning device [1], biofilm thickness measurements [3] and fast optical hazard detection for planetary rovers [2]. The limitations of this technique mostly depends on what detectors you use but in general the system can be expensive with sensors and laser costing several $100 or $1000. The system might also be rather large and not suited for measurements outside the laboratory.

In this lab we applied this technique to measure a tuning fork to determine the following properties: main frequency, harmonic frequencies and amplitude. As a detector we used a *position sensitive detector* (PSD). The PSD outputs the position of the incident light on the PSD. The advantages of this sensor is that it can measure very high frequencies and very fast. The resolution of the sensor is $\sim 10\mu m$ and it's also very easy to use in electronics.The main disadvantage with this sensor is that the position is determined by some moving average of the intensity of light hitting it; so if the beam is not symmetric in two dimensions, but warped in some way; this can give erroneous results for the position.

2 Theory

2.1 Laser Triangulation

Triangulation describes a method of determining the location of a point C by measuring the angles α and β from two points A and B as well as their distance L, as can be seen in fig. 1. The distance d from the baseline between the points A and B is then given by

$$d = \frac{Lsin(\alpha)sin(\beta)}{sin(\alpha + \beta)}. \tag{1}$$

To measure the position of an object by means of laser triangulation, a laser beam is focused on the object. As can be seen in fig. 2, the reflected light is collected by a lens and focused onto a position sensitive device (PSD) or a charge-coupled device (CCD). A movement of the object then corresponds to a movement of the laser beam on the detector.

The measuring range depends on the size of the PSD as well as on the angle of the beam when being reflected by the object, which is determined by the relative position of PSD and laser. A smaller angle, i.e. a smaller distance between PSD and laser give a larger measuring range, whereas a bigger angle increases the resolution with which the position can be determined.

2.2 Position Sensitive Device

A PSD consists of a photodiode, that releases a current when an incident light beam strikes it. As shown in **??**, in the case of a one dimensional PSD there are two electrodes attached to each side of the diode. For a two dimensional PSD another two electrodes are attached on the backside of the diode, at 90 angle to the electrode pair on the front.[**?**][**?**]

The current caused by the incident photons is divided between the contacts on each side. As the active surface of the photodiode acts as a homogenous resistance, the currents generated depend linearly on the position of the incident light on the PSD.

The position y_2 as seen in 3can then be obtained by measuring both currents. The sum of the currents i_1 and i_2 is a constant dependent on the power of the incident light P_0 and the sensitivity of the detector η:

$$i_1 + i_2 = \eta \cdot P_0. \tag{2}$$

The location y_1 depends linearly on the difference of those currents,

$$y_1 = -\frac{L}{2}(\chi - 1), \tag{3}$$

where $\chi = \frac{i_1 - i_2}{i_1 + i_2}$ and L is the length of the sensor as illustrated in 3. The position on a two dimensional PSD is simply obtained by applying this to one pair of electrodes for each direction.

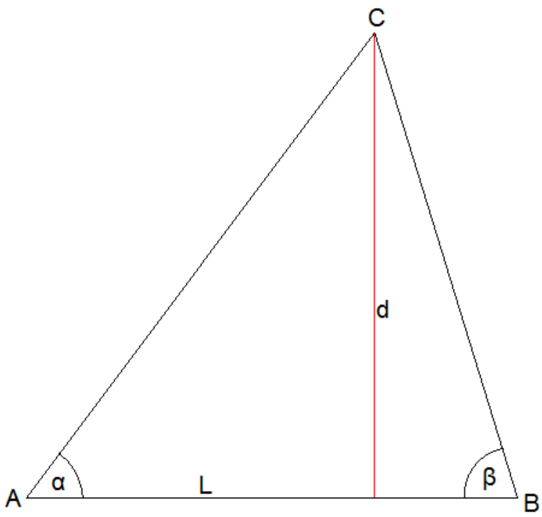

Figure 1: Illustration of the basic geometry of determining a distance d by means of triangulation.

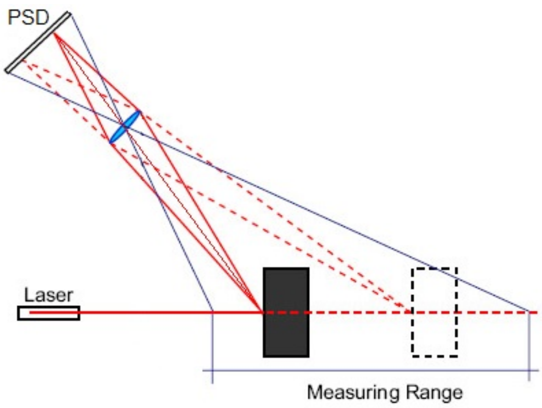

Figure 2: Functional principle of laser triangulation.

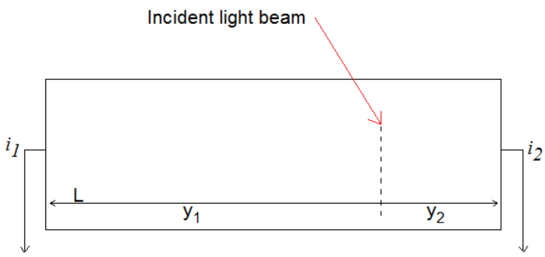

Figure 3: .

3 Experimental

The setup included a HeNe laser, tuning fork, lens, psd and some electronics. The laser were placed so that the laser beam hit the edge of the tuning fork. The tuning fork were placed in an holder that can adjust the position. Orthogonal to the tuning fork, a lens with focal length of 50mm focus the scattered light on a PSD, see fig. 4 and 5 for this setup. The output signals from the PSD were connected to some electronics that transfer the output signals to a computer, see fig. 6.

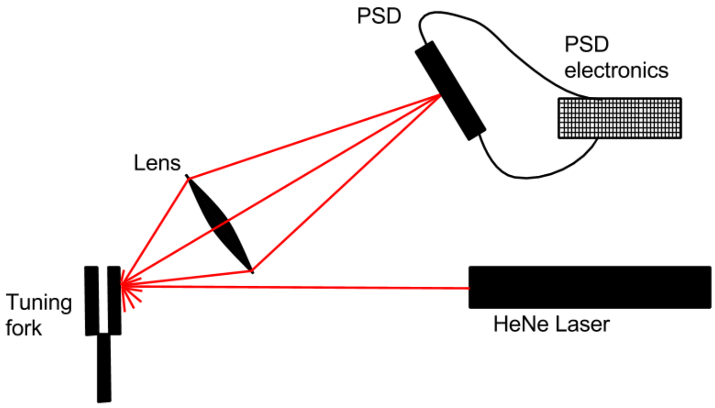

Figure 4: Diagram of the setup for measuring the movement of the tuning fork.

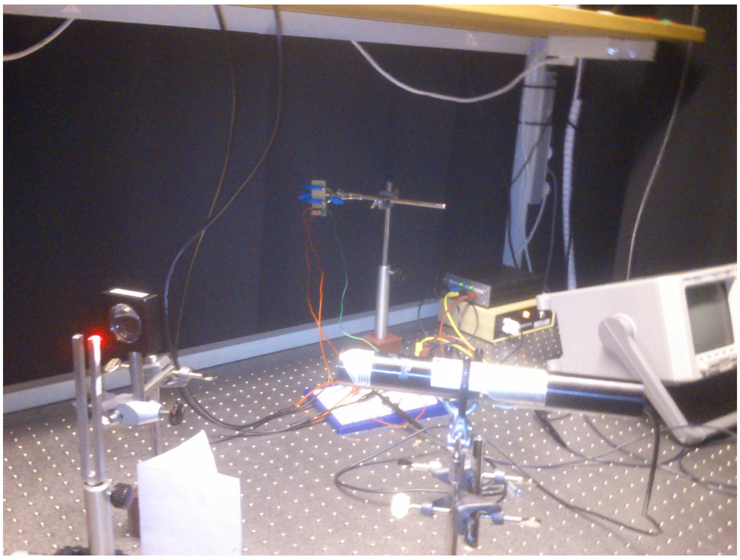

Figure 5: The setup with the laser pointed at the tuning fork and a lens that collects the scattered light onto the PSD

In order to be calibrate the output signal an accurate slide is used to see what signal correspond to what signal on the output, see fig 7.

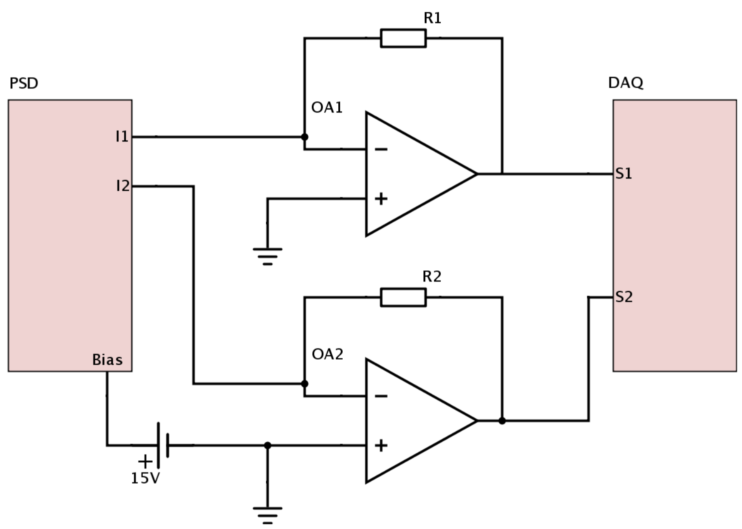

Figure 6: The circuit design to transform and amplifies the current signal from the PSD to a voltage signal for the DAQ that sends it on to the computer.

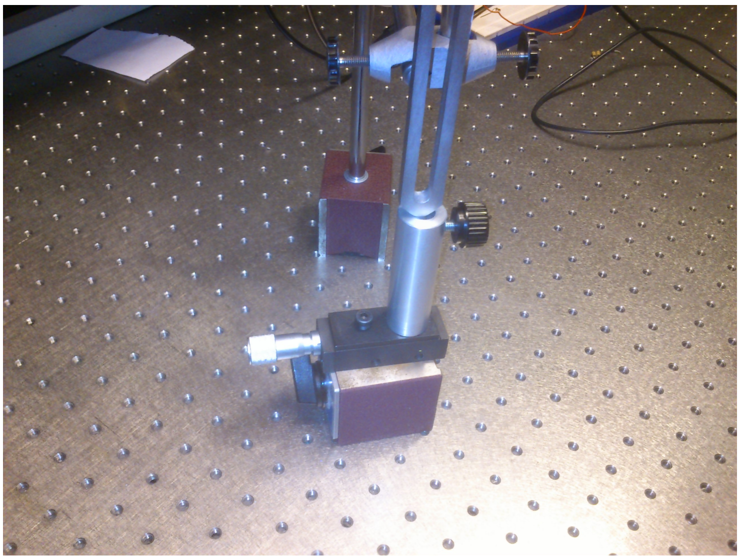

Figure 7: The position of the tuning fork can be adjusted using this slide. This is used to calibrate what movement on the PSD corresponds to what movement on the tuning fork.

4 Results

4.1 Oscillation of the tuning fork

A tuning fork is an acoustic resonator in the shape of a fork with two prongs, forming a U. it is usually made of elastic metal, as f.i. Steel. Apart from the fundamental mode, as illustrated in 8, the tuning fork can also oscillate in higher overtones. Due to the fact, that these higher modes are damped more strongly by the base, they die out faster and leave a a typical pure musical tone. This also causes the short clang, that appears when tipping the fork. The pitch of a particular tuning fork depends on the length as well as on the mass of the prongs.

Apart from the modes in which the two prongs oscillate in antiphase, of which the two first are shown in 8, more unbalanced modes exist that transfer onto the base. As the base is in general fixed by holding the tuning fork in the hand or having it fixed by other means, these modes generally don't appear significantly. The main interest was to measure amplitude and frequency of the vibrations of the tuning fork. To do so, the difference and the sum of the two currents as given out by the electric circuit explained in 4.1 were processed with labview. To calibrate the PSD, the micrometer screw attached to the slide of the tuning fork was used.

In 9 the vibration of the tuning fork after 3 seconds of damping is illustrated. The difference of the two currents, that the PSD feeds the electric circuit with, is depicted as a function of the time. As can be seen the tuning fork is harmonically oscillating at a steady frequency.

This frequency was determined by averaging the periodic time T over 229 periods. Doing this, a frequency of

$$f = 253,68Hz \tag{4}$$

was found. This gives a relative deviation of $0,9\%$ from the 256 Hz specified by the manufacturer of the tuning fork. Due to the high number of samples a statistic deviation of this magnitude is unlikely.

In 10 the amplitude of the vibration is shown over time. The amplitude was directly calculated from the signal from labview. It can be well seen how after a short phase of transient oscillation withing the first 5 seconds the amplitude decreases very steadily.

Measuring this repeatedly shows that the maximal amplitude highly depends on how hard the tuning fork is stroke, while never exceeding about 0.3 mm and always decreasing in the same way that can me seen in 10.

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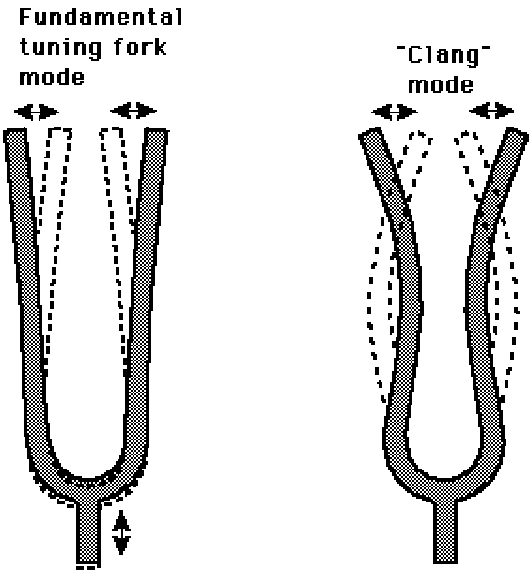

Figure 8: First two balanced modes of a tuning fork.

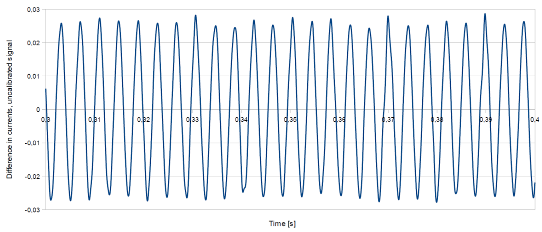

Figure 9: Uncalibrated difference in currents given out by the PSD.

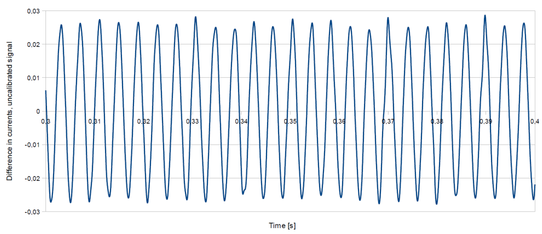

Figure 10: Calibrated amplitude of the oscillations.

5 Discussion

The PSD does not output the position of the maximum intensity; but a rather a moving average of the intensity on the entire PSD. So that if any external light hit the PSD; the position output may be erroneous if it is not evenly distributed over PSD—this can be avoided by removing external light sources.

Since we wanted as large magnification as possible, the PSD were placed close to 90° to the movement of the tuning fork. This made the the scattered beam from the tuning fork around the maximum intensity asymmetric. This implies that the PSD will return a position that is shifted. A way to handle this problem could have been to use an aperture stop. Because of the calibration. This problem did not significantly disturb our measurement.

References

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[3] Okkerse W.J.H., Ottengraf S.P.P., Osinga-Kuipers B., 2000, Biofilm thickness variability investigated with a laser triangulation sensor, *Biotechnology and Bioengineering* v.70 p.619-629.