TP n° 7

Ultrasound

The goal of this practical is to study some properties of ultrasonic waves.

1. Preparation

1.1. Piezoelectric effect

1.2. Wavelength measurement

1.3. Sound velocity measurement

1.4. Doppler effect

2. Experimental part

2.1. Piezoelectric effect

2.2. Wavelength measurement

2.3. Sound velocity measurement

2.4. Doppler effect

1. Preparation

1.1. Piezoelectric effect

Piezoelectricity is the ability of some materials (notably crystals such as quartz crystals) to generate an electric potential in response to applied mechanical stress (such as pressure variation). This may take the form of a separation of electric charges across the crystal lattice. If the material is not short-circuited, the mechanical stress induces a measurable voltage across the material. This effect is reversible and we note the production of stress and/or strain (inducing a vibration of the whole crystal) when a electric field is applied to the material. In this practical, this effect will be used to detect and to produce ultrasound (the same device can be used as ultrasound sensor or ultrasound generator, we call it a piezoelectric transducer). In the first case, ultrasonic waves induce pressure variation (and mechanical stress) on the crystal which is directly transformed into electric voltage. In the second case, a sinusoidal voltage is converted into sinusoidal oscillations of the crystal and creates ultrasonic waves. In practice, the vibration is largest when electric field stimulates a natural frequency of the crystal. This is an example of mechanical resonance phenomena. In this practical, it is close to 40 kHz.

1.2. Wavelength measurement

- Give a method to determine the wavelength λ of a progressive ultrasonic wave using the piezoelectric transducers (ultrasound generator and sensor) and the oscilloscope.
- Give the relation between the wavelength λ, the frequency f and the sound velocity c_{son}.

1.3. Sound velocity measurement

- Indicate a method to measure the sound velocity using ultrasonic pulses and an oscilloscope.

1.4. Doppler effect

The Doppler effect is the change observed in the wavelength of sound waves due to the relative motion between a wave source and a wave receiver. This effect is highly dependent on the speed of motion, the frequency of the waves emitted by the source, and the angle between the wave direction and the motion direction (in the following, we will make the approximation that this angle is very close to zero). Imagine that a receiver (detector) moves away from the source. The source is emitting signals with a period T_{em}, v is the velocity of the receiver and c_{sound} is the velocity of the ultrasound. At t=0 the receiver get a signal. Since the detector is moving away, the separating distance between the source and the receiver will increase. The next signal on the receiver will arrive at a time larger than T_{em}. This characteristic time will be called T_{re} and corresponds to the time between two signals has received by the detector.

- Show that in this case : $c_{sound}\, T_{re} = c_{sound}\, T_{em} + v\, T_{re}$
- Deduce the relation : $f_{re} = \left(\dfrac{c_{sound} - v}{c_{sound}} \right) * f_{em}$

For a moving receiver approaching the source, the above equations are the same except that a plus sign appears in place of the minus.

- Give examples of Doppler effect that can be found in everyday life.
- Demonstrate that in the case of a source moving away a fixed receiver, we get the relation :

  $c_{sound}\, T_{re} = c_{sound}\, T_{em} + v\, T_{em}$, and thus, $f_{re} = \dfrac{c_{sound}}{c_{sound} + v} * f_{em}$

In this practical, the source and the receiver are fixed, and we use a moving reflector.

- Try to use the above equations to determine the Doppler shift between source frequency and the receiver frequency on the detector $\left(f_{em} - f_{re} \right)$.
- Show that if the refector moves away from the source : $f_{em} - f_{re} = \dfrac{f_{em} * 2\, v}{\left(c_{sound} + v \right)}$

  Or, if $v << c_{sound}$: $f_{em} - f_{re} = \dfrac{f_{em} * 2\, v}{\left(c_{sound} \right)}$

2. Experimental part

2.1. Wavelegth measurement

- Install the piezoelectric transducers (the source and the detector) on the mechanical stand.
- Connect the source to the signal generator (sinusoidal signal) and both transducers to the oscilloscope.
- Change the source frequency f_{em} in order to maximize the signal on the detector.
- Measure this frequency f_{em} on the oscilloscope and give the uncertainty Δf_{em} .
- Determine the wavelength λ of the progressive ultrasounds waves (carefully describe the operating procedure).

- Give the uncertainty $\Delta\lambda$.
- Calculate the sound velocity c_{sound} and give Δc_{sound}

2.2. Sound velocity measurement

The sound velocity can also be measrured with ultrasonic pulses. Ask to the teacher how to use the signal generator.

- Describe carefully the experimental procedure.
- Determine c_{sound} and give Δc_{sound} .
- Compare the results with the previous method.

The ultrasonic pulses can also be interesting for distance measurement.

- Replace the detector by a reflector.
- Put the detector just near the source turned toward the reflector.
- Give a method to determine the distance between the source and the reflector.
- Measure this distance with a rule.
- Determine this distance with the ultrasounds.
- Compare the results.

2.3. Doppler effect

We propose to measure the speed of a reflector using the Doppler effect.

- Estimate $\left(f_{em} - f_{re}\right)$ if the speed of the reflector is 1 cm/s.
- Do you think it is possible to study Doppler shift for slow displacements only by measuring frequencies of the source and of the receiver ?

In case of slow displacement, the Doppler shift is very difficult to evidence. It can however be studied with the help of an electronic multiplier. Let's consider two oscillating signals $s_1 = a \cos\left(2\pi f_1 t\right)$ and $s_2 = a \cos\left(2\pi f_2 t\right)$.

- Show that the product of these two signals is a combination of two oscillating signals : a slow component with a frequency $\left(f_1 - f_2\right)$ and a fast component with a frequency $\left(f_1 + f_2\right)$

If we use an electronic filter to reject the fast component, the frequency of the resulting signal is $\left(f_1 - f_2\right)$ which directly corresponds to Doppler shift.

- Install the ultrasonic generator and receiver in front of the reflector.
- Connect the receiver and the generator on the multiplier (the receiver will be first connected to an electronic amplifier).
- Switch on the reflector motor, and describe the signal with and without any electronic filter.
- Measure the speed of the reflector v with a chronometer (estimate also Δv).
- Determine v and Δv from Doppler measurements (carefully describe the experimental procedure).
- Compare these two experimental values.
- Is it possible to know from Doppler measurement if the reflector is approaching or moving away from the ultrasound source ?