Name:
Study group No.: 8
Date: April 17, 2017
Experiment No.: 5
Title of the experiment:

LaTeX

DOPPLER EFFECT

Table of Contents

1 Purpose of the experiment

- To measure frequency shift of an ultrasound wave if the observer represented by stationary microphone and the source represented by a model train with speaker are in mutual motion.
- To plot a graph of frequency depending on the train velocity. Compare curves for theoretical and measured values in the graph.

2 List of Apparatus

Name of apparatus	Limit of error
Ultrasound unit	2 Hz
Thermometer	0.2°C
Computer with Measure programme	0.02 m/s
Voltage source	
Train	
Optical barrier	

3 Data

3.1 Temperature

The only measured temperature was **23.6°C**

3.2 Standing train

The only measured frequency for standing train was **39 022 Hz** because this frequency is the same for all voltages

3.3 Velocity

Voltage[V] \ No.	Velocity to left [m/s] | Velocity to right [m/s]									
	1		2		3		4		5	
6	0.239	0.182	0.246	0.199	0.247	0.205	0.245	0.193	0.249	0.213
7.5	0.263	0.323	0.269	0.314	0.274	0.327	0.285	0.336	0.288	0.334
9	0.374	0.396	0.378	0.416	0.376	0.422	0.380	0.423	0.380	0.418
10.5	0.452	0.462	0.447	0.480	0.448	0.496	0.445	0.488	0.448	0.488
12	0.525	0.587	0.498	0.597	0.529	0.594	0.540	0.612	0.541	0.596

Tabulka 1: Measured velocities

3.4 Frequency

Voltage[V] \ No.	Frequency to left[Hz] | Frequency to right[HZ]									
	1		2		3		4		5	
6	39048	38995	39047	38994	39045	38994	39045	38994	39047	38995
7.5	39056	38984	39055	38983	39057	38984	39058	38984	39058	38983
9	39067	38975	39068	38974	39067	38974	39067	38975	39064	38975
10.5	39076	38965	39075	38967	39074	38966	39075	38965	39075	38960
12	39087	38954	39088	38954	39089	38954	39084	38954	39087	38954

Tabulka 2: Measured frequencies

4 Computations outline

4.1 Average

Average of the measured values can be calculated by this formula:
$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$
where x_i are all measured values.
Average velocity for 6V to left: $\bar{v} = \frac{1}{5}\sum_{i=1}^{5} v_i = \frac{1.23}{5} = 0.25\ m/s$
Average frequency for 6V to left: $\bar{f} = \frac{1}{5}\sum_{i=1}^{5} f_i = \frac{195232}{5} = 39046.4\ Hz$
Averages for all measured values:

Voltage[V]	Velocity to left[m/s]	Velocity to right[m/s]	Frequency to left[Hz]	Frequency to right[Hz]
6	0.25	0.2	39046.4	38994.4
7.5	0.28	0.33	39056.8	38983.6
9	0.38	0.42	39066.6	38974.6
10.5	0.45	0.48	39075	38964.6
12	0.53	0.6	39087	38954

Tabulka 3: Average velocities and frequencies

4.2 Uncertainties

4.2.1 Standard A type

Standard A type uncertainty can be calculated by: $u_A(\bar{x}) = \sqrt{\frac{1}{n(n-1)}\sum_{i=1}^{n}(x_i - \bar{x})^2}$
where n is the number of measurements, x_i are all measured values and $\bar{x}$ is an average of these values.
Velocity for 6V to left uncertainty: $u_A(\bar{v}) = \sqrt{\frac{1}{5(5-1)}\sum_{i=1}^{5}(v_i - \bar{v})^2} = \sqrt{0.0000028} = 0.0017\ m/s$
Frequency for 6V to left uncertainty: $u_A(\bar{f}) = \sqrt{\frac{1}{5(5-1)}\sum_{i=1}^{5}(f_i - \bar{f})^2} = \sqrt{0.36} = 0.6\ Hz$
Type A uncertainty for all measured values:

Voltage[V]	Velocity to left[m/s]	Velocity to right[m/s]	Frequency to left[Hz]	Frequency to right[Hz]
6	0.002	0.005	0.6	0.245
7.5	0.005	0.004	0.583	0.245
9	0.066	0.005	0.6	0.245
10.5	0.101	0.005	0.6	0.245
12	0.008	0.004	0.837	0

Tabulka 4: Type A uncertainties

4.2.2 Standard B type

Standard B type uncertainty can be calculated by: $u_B = \frac{\Delta}{\sqrt{12}}$
where Δ is the least division on the scale of the measuring device.
Ultrasound unit uncertainty: $u_B = \frac{2}{\sqrt{12}} = 0.58\ Hz$

Measure programme uncertainty: $u_B = \frac{0.02}{\sqrt{12}} = 0.0058\ m/s$

Thermometer uncertainty: $u_B = \frac{0.2}{\sqrt{12}} = 0.14°C$

4.2.3 Combined uncertainty

Combined uncertainty can be calculated by: $\sqrt{u_A^2(x) + u_B^2}$
$u_A(x)$ stands for standard type A uncerainty of sample amd u_B stands for standard type B uncertainty of used device
Combined uncertainty of average velocity for 6V to left: $\sqrt{0.0000028 + 0.000033} = 0.006\ m/s$
Combined uncertainty of average frequency for 6V to left: $\sqrt{0.36 + 0.33} = 0.833\ Hz$
Combined uncertainties for all measured values:

Voltage[V]	Velocity to left[m/s]	Velocity to right[m/s]	Frequency to left[Hz]	Frequency to right[Hz]
6	0.006	0.008	0.833	0.627
7.5	0.007	0.007	0.821	0.627
9	0.006	0.008	0.891	0.627
10.5	0.006	0.008	0.658	1.339
12	0.010	0.007	1.017	0.577

Tabulka 5: Combined uncertainties

4.3 Speed of sound

Speed of sound can be calculated using formula: $c = 331.06 + 0.61 \cdot t$
where t is temperature in °C
$c = 331.06 + 0.61 \cdot 23.6 \doteq 345.46\ m/s$

4.4 Frequency

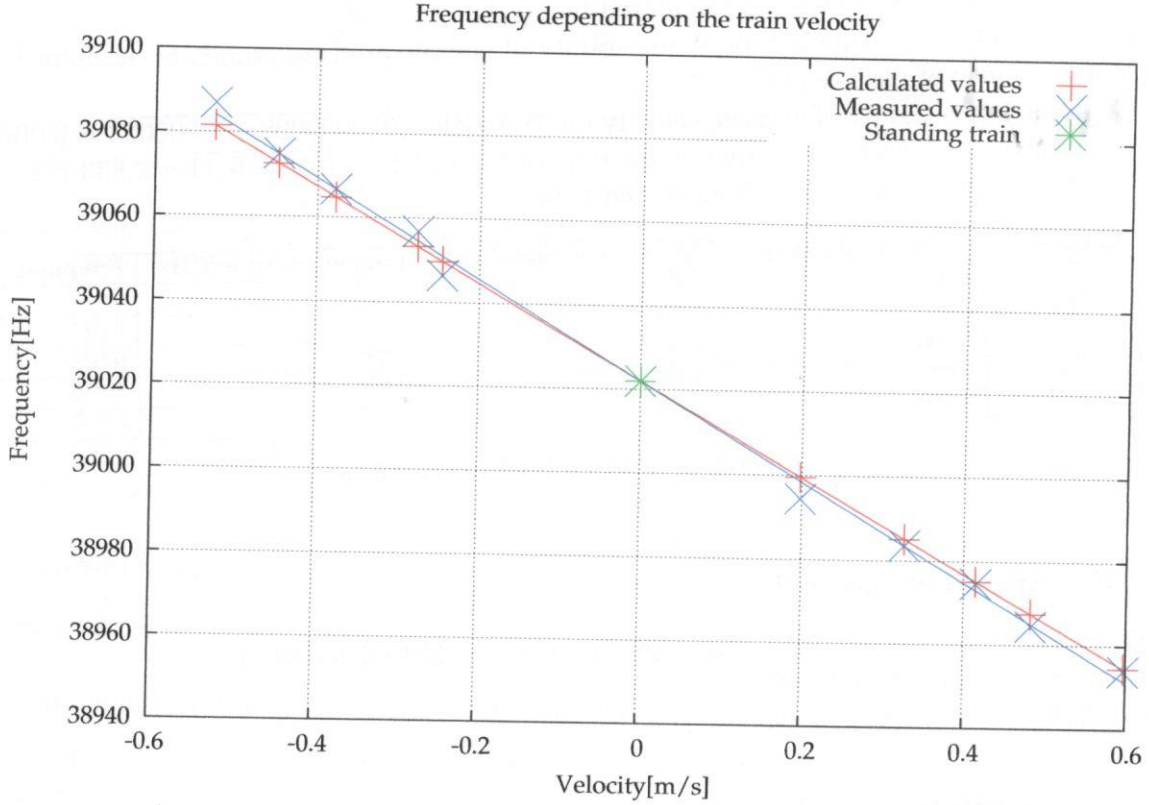
Theoretical frequency can be calculated using formula: $f' = \frac{c}{c + v_z} \cdot f$
where f is frequency measured when the train was not moving, c is speed of sound and v_z is velocity of source moving from the observer
Direction to right is in our case moving away from the observer and direction to left is movement towrds the observer. v_z in our case is when the train moves to the right. When the train moves to the left it's the opposite direction so velocity in that case will be negative.
Theoretical frquency for voltage 6V and direction to left:
$f' = \frac{345.46}{345.46 - 0.25} \cdot 39022 \doteq 1 \cdot 39022 \doteq 39049.72\ Hz$
Theoretical frequency for all voltages:

Voltage[V]	Frequency to left[Hz]	Frequency to right[Hz]
6	39049.72	38999.60
7.5	39053.18	38985.12
9	39064.70	38975.18
10.5	39072.67	38967.54
12	39081.57	38954.66

Tabulka 6: Theoretical frequencies

5 Graphs

5.1 Frequency depending on the train velocity



6 Results and conclusions

Results are visualized at graphs shown above.
Frequency for standing train was **39 022 Hz**

	Direction to left		**Direction to right**	
Voltage	**Calculated frequency**		**Measured frequency**	
6 V	39050 Hz	39000 Hz	39046 Hz	38994 Hz
7.5 V	39053 Hz	38985 Hz	39057 Hz	38984 Hz
9 V	39065 Hz	38975 Hz	39067 Hz	38975 Hz
10.5V	39073 Hz	38968 Hz	39075 Hz	38965 Hz
12 V	39082 Hz	38955 Hz	39087 Hz	38954 Hz

According to our result and graphs we think that our measurements are fairly accurate. We enjoyed measuring during this task. We hope we will get to measure with train more time are at least with some equaly interisting vehicle.