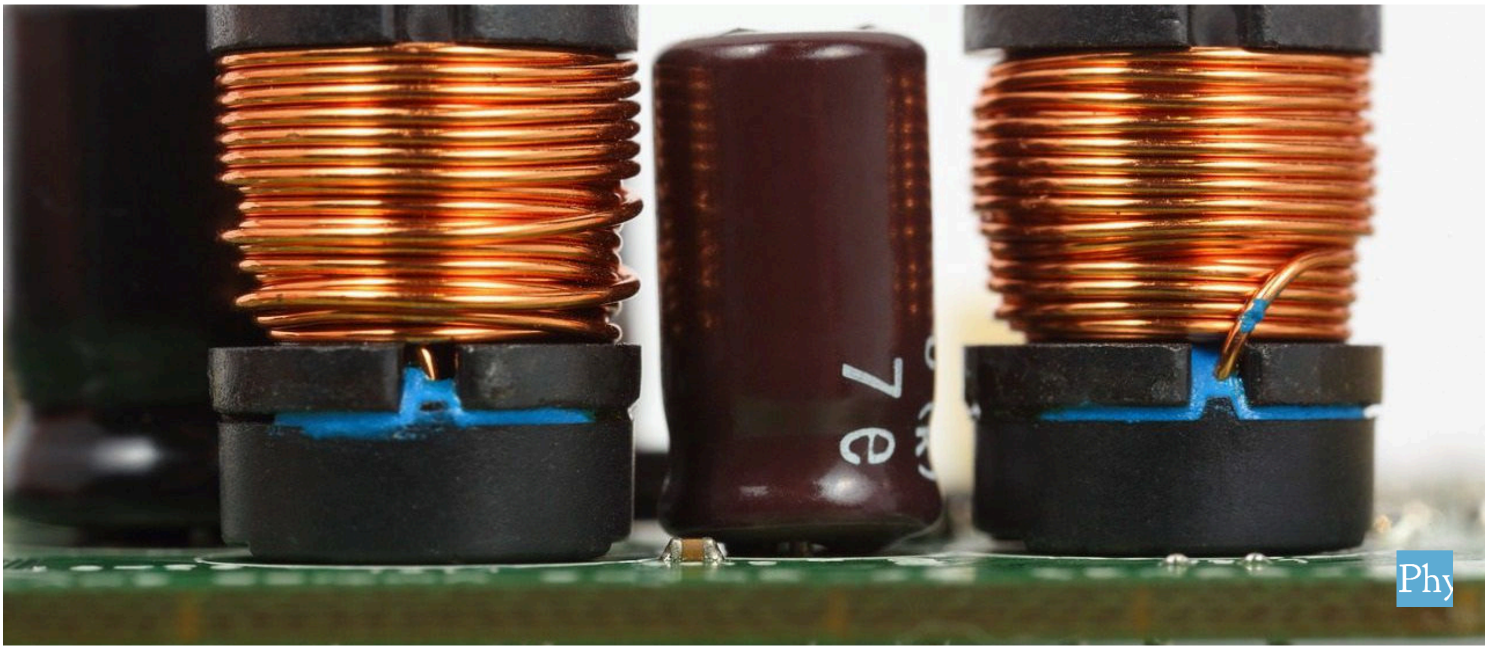
Coil in the AC circuit with Cobra4 Xpert-Link



Physics | Electricity & Magnetism | Electromagnetic oscillations & waves

Difficulty level	Group size	Preparation time	Execution time
hard	2	45+ minutes	45+ minutes

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General information

Application

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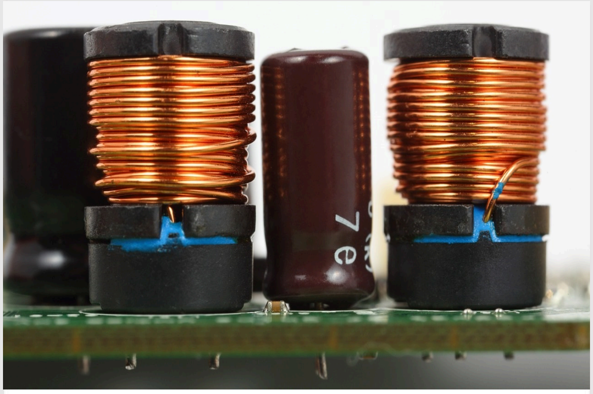

Electromagnetic coils on a board

Alternating current refers to electrical current that changes its direction (polarity) in regular repetition and in which positive and negative instantaneous values sum up, so that the net current is zero on average over time.

Alternating current always has a real and an imaginary component. There is single-phase or multi-phase alternating current, which can be differentiated depending on the phase shift φ. Since a coil's inductance is dependend on the current and since the inductance is subject to Lenz's rule, a change in voltage is retarded due to the inserted coil. This property makes a coil in a AC circuit a commonly used frequency filter component.

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Other information (1/2)

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Prior knowledge

Basic knowledge of physical quantities such as current, voltage and resistance should be available. Ideally, the process of electromagnetical induction should be known.

Scientific principle

The coil is connected in a circuit with a voltage source of variable frequency.
Due to the inductance of the coil, a phase shift of the current occurs. The impedance and phase displacements are determined as functions of frequency. Parallel and series impedances are measured in comparison.

Other information (2/2)

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Learning objective

After the successful completion of this experiment you will be able to theoretically describe the phenomenon of inductance with respect to alternating currents. You will also be able to experimentally determine the frequency dependend impedances and the caused phase shifts.

Tasks

Determination of the

1. impedance of a coil as a function of frequency and inductance of the coils.
2. phase displacement between the terminal voltage and total current as a function of circuit frequency.
3. total inductance of coils connected in parallel and in series.

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Safety instructions

The general instructions for safe experimentation in science lessons apply to this experiment.

Theory (1/3)

LC-circuit

If a coil of inductance L and a resistor of resistance R are connected in a circuit, the sum of the voltage drops on the individual elements is equal to the terminal voltage U:

$$U = IR + L \cdot \frac{\mathrm{d}I}{\mathrm{d}t} \qquad (1)$$

where I is the current. The resistor values are selected large enough in order to neglect the d. c. resistances of the coils (0.8Ω for the 300 turns, 2.5Ω for the 600 turns coil). If the alternating voltage U has the frequency $\omega = 2\pi f$ and the waveform $U = U_0 \cdot cos(\omega t)$ then the solution of eq. 1 for the current $I(t)$ with the resulting phase displacement φ and the amplitude I_0 is

$$I = I_o \cdot cos(\omega t - \varphi) \quad \Rightarrow \quad tan(\varphi) = \frac{\omega L}{R}, \;\; I_0 = \frac{U_0}{\sqrt{R^2 + (\omega L)^2}} \qquad (2)$$

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Theory (2/3)

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It is customary to treat resistances in alternating current circuits as complex impedances and therefore as operators $\hat{R}_i$:

Coils have an impedance of $\hat{R}_L = i\omega L$ while the ohmic resistance is $\hat{R} = R$. Accordingly, the real impedance of a circuit is the absolute value of $\hat{R}_{tot}$. The phase relationship, established in eq. 2, is the ratio of the imaginary part to the real part of R_{tot}.

Note: The relation between time shift $\mathrm{d}t$ and phase shift $\Delta\varphi$ with the given duration t of a full period is given by

$$\frac{\mathrm{d}t}{t} = \frac{\Delta\varphi}{360^\circ} \qquad (3)$$

Theory (3/3)

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Series and parallel circuit for inductances:

Connecting n inductances L_i in series yields a total inductances of

$$L_{tot} = \sum_{i=1}^{n} L_i \qquad (4)$$

However, when connected in parallel, they yield a total inductance of

$$\frac{1}{L_{tot}} = \sum_{i=1}^{n} \frac{1}{L_i} \qquad (5)$$

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Equipment

Position	Material	Item No.	Quantity
1	Cobra4 Xpert-Link	12625-99	1
2	Cobra4 Xpert-Link set of cables	12625-10	1
3	PHYWE Digital Function Generator, USB	13654-99	1
4	Connection box	06000-00	1
5	Coil, 300 turns	06513-01	1
6	Coil, 600 turns	06514-01	1
7	Resistor 47 Ohm, 1W, G1	39104-62	1
8	Resistor 100 Ohm, 1W, G1	39104-63	1
9	Resistor 220 Ohm, 1W, G1	39104-64	1

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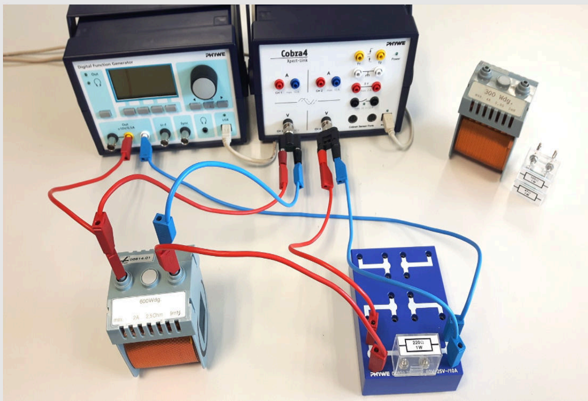
Setup and procedure

Setup (1/2)



Experimental setup

Task 1:

- Build the electrical circuit according to the shown figure with a resistor and a coil connected in series. Start with the smallest resistor (47Ω) and the coil with 300 turns.
- Start the PC and connect the Xpert-Link device as well as the digital function generator via USB.
- Start the measureLAB software on the computer.
- Choose both of the voltage channels of the Xpert-Link device as your measuring channels.

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Setup (2/2)

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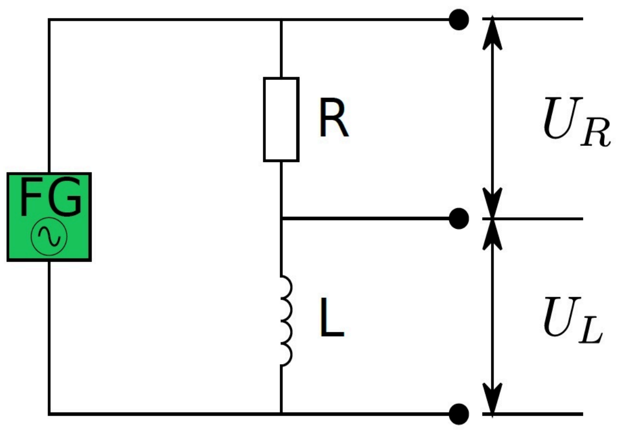

Circuit for measurement of the coil impedance

Task 1:

- Load the experiment. All required settings for measuring are set automatically. Put the digital function generator to an amplitude of $20V$ and the sinus wave signal as the signal-type output.

Procedure (1/4)

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Task 1:

- Start the measurement. The measurement stops automatically and the result will be displayed.
- Compare the amplitudes of the two voltage signals. They need to have the same value. If they don't, set another frequency on the digital function generator and repeat the measurement until the amplitude looks fairly equal. Note down the corresponding frequency in the evaluation section.
- Replace the resistor with the 100Ω resistor. Repeat the mentioned steps until you find the right frequency, where the the two voltage signals have the same amplitude. Note down the frequency for that resistor as well.
- Repeat this step again for the 220Ω resistor and note down the frequency.
- Change the solenoid for the 600 turns solenoid and repeat all of these steps again. Note down all resulting frequency values in the evaluation section.

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Procedure (2/4)

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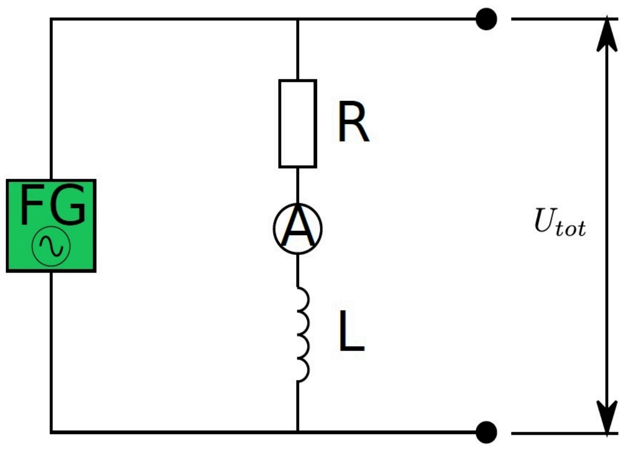

set-up for phase displacement measurement

Task 2:

- Disconnect the energy supply and rebuild the circuit according to shown figure. Reconnect the digital function generator to the circuit.

Note: Depending on which resistor you are using for this part, you might have to adjust the measuring range for the current measurement.

Procedure (3/4)

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Task 2:

- Choose a low frequency of $800 Hz$ and start the measurement.
- The two obtained signals for voltage and current show some phase displacement. Measure this temporal difference by using the measure function. Note down the result for that frequency.
- Increase the frequency to about $1.6 kHz$ and start a new measurement. Again, measure the time displacement and note it down together with the frequency.
- Repeat this step for a series of in total 10 different frequencies and note the corresponding phase displacement. Thereby increase the frequency in a constant rate to multiples of $800 Hz$).
- Note all resulting values in the table of task 2 in the evaluation section.

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Procedure (4/4)

Task 3:

- Disconnect the energy supply and rebuild the circuit according to the circuit of task 1. Instead of just one solenoid you will have to use both of them. First, connect them in series so that you will get a series circuit of two solenoids and one resistor.
- The procedure is the same as for task 1: The frequency is varied until there is the same voltage drop across the two coils (first in series, then in parallel) as across the resistor. The resistance and impedance values are then equal. Repeat this for the two other resistors. Note the resulting frequencies in the evaluation section.
- Afterwards connect the two solenoids in parallel and one resistor in series. Repeat the measurement for all three resistors.

Note: When coils are connected in parallel or in series, care should be taken to ensure that they are sufficiently far apart, since their magnetic fields influence one another.

Evaluation (1/9)

Task 1

	$N = 300\,\text{turns}$	$N = 600\,\text{turns}$
$R\,[\Omega]$	$f\,[kHz]$	$f\,[kHz]$
47		
100		
220		

To determine the impedance of a coil as a function of the frequency, the coil is connected in series with resistors of known value.

The frequency is varied until there is the same voltage drop across the coil as across the resistor. The resistance and impedance values are then equal:

$$R = \omega L = 2\pi f L \quad \Rightarrow \quad R = 2\pi L \cdot f$$

Note down all resulting frequencies found that full-fill this relation for both coils.

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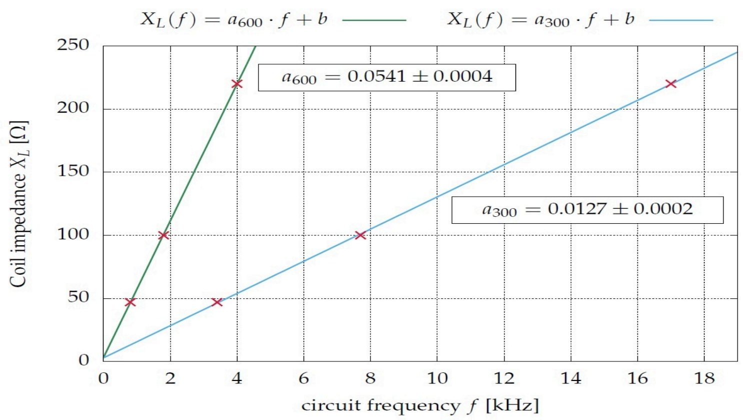
Evaluation (2/9)



coil impedance as function of circuit frequency for two different coils

Plot the resistance values against the found frequencies and create a linear fit of each data set.

The coils impedances for 300 and 600 turns coils as function of the circuit frequency are exemplary shown in the figure. The data points are marked with little red crosses. In between, the data have been fitted by a linear function.

Evaluation (3/9)

To determine the inductances of the coils, the slope a of the resulting fit can be read off from the respective equation as $a = 2\pi L$. Therefore, the inductances of the two coils can be calculated by using the slopes of the fitted graphs and divide its value by 2π:

$$L = a/2\pi$$

For the 300 turns coil, the slope of the exemplary data is $a_{300} = (0.0127 \pm 0.0002)\,\Omega s$ For the 600 turns coil the slope results in $a_{600} = (0.0541 \pm 0.0004)\,\Omega s$ For the inductances, this leads to

- $L_{300} = (2.0 \pm 0.1)\,mH$
- $L_{600} = (8.6 \pm 0.1)\,mH$

Both values are very close to theoretical values $L_{300} = 2.0\,mH, L_{600} = 9.0\,mH.$

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Evaluation (4/9)

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Task 2 Fill the table with the measured temporal displacements $\mathrm{d}t$ and calculate the resulting phase displacements $\Delta\varphi$ and their tangent.

$f\,[kHz]$	$\mathrm{d}t\,[\mu s]$	$\Delta\varphi\,[°]$	$\tan\Delta\varphi\,[1]$
0.8			
1.6			
2.4			
3.2			
4.0			

$f\,[kHz]$	$\mathrm{d}t\,[\mu s]$	$\Delta\varphi\,[°]$	$\tan\Delta\varphi\,[1]$
4.8			
5.6			
6.4			
7.2			
8.0			

Evaluation (5/9)

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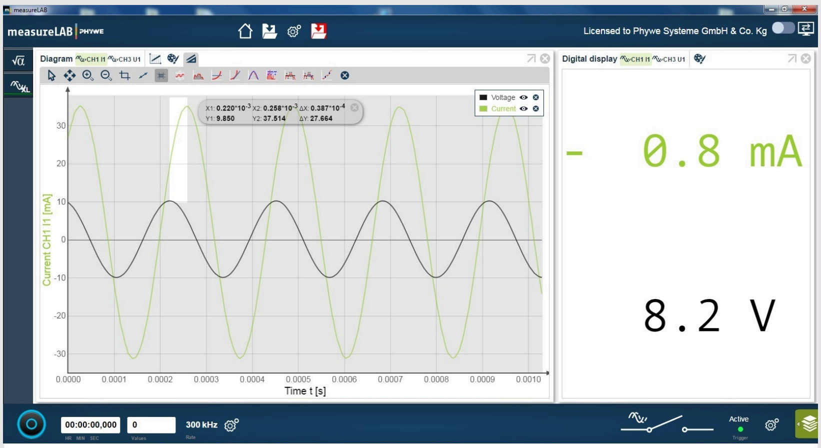

measuring the time displacement between total voltage and current

The phase displacement between the total voltage and the total current is measured. The "Survey Function" of measureLAB as it is shown in the figure on the left is used for the measurement of time displacements, from which the phase displacement ist calculated.

Plot the phase displacement and the tangent of the phase displacement each as function of frequency as exemplary shown on the following pages.

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Evaluation (6/9)

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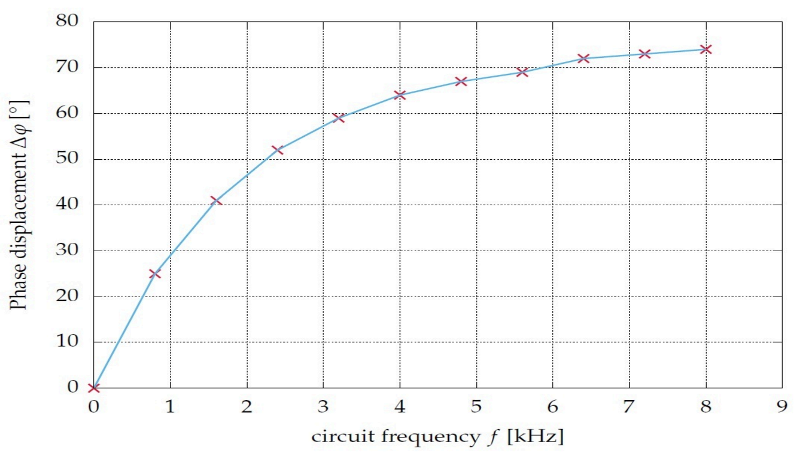

phase displacement between voltage and current signal as function of frequency

Plot the values of the phase displacement against the respective frequency.

You will find a non-linear behaviour as exemplary shown in the figure to the left.

From eq. 2 it is know, that $tan(\varphi)$ follows a linear relation as function of circuit frequency. Therefore the tangent is also plotted against the frequency and a linear fit is applied.

Evaluation (7/9)

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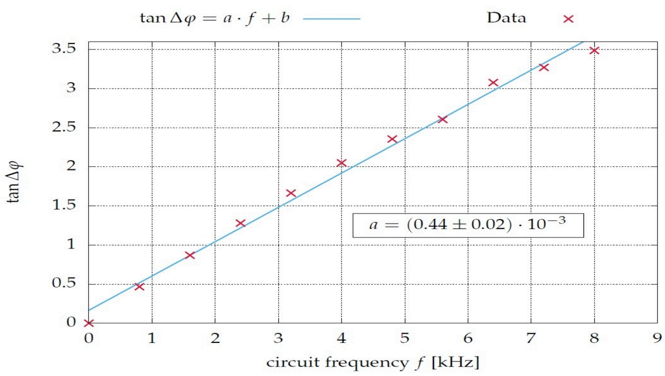

tangent of phase displacement between voltage and current signal as function of frequency

According to eq. 2 the slope a of the regression of the exemplary data is

$$a = \frac{2\pi L}{R} = (0.44 \pm 0.02) \cdot 10^{-3} s$$

Resolving to the induction of the used coil, leads to:

$$L = a \cdot R/2\pi \quad \Rightarrow \quad L_{600} = (7 \pm 2) mH$$

with used resistance R and the slope a.

This value is a good approximation for the given value of $9mH$.

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Evaluation (8/9)

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Task 3

$R\,[\Omega]$	series circuit $f\,[kHz]$	parallel circuit $f\,[kHz]$
47		
100		
220		

To determine the impedance of the coils as a function of the frequency, the coils are connected in series with resistors of known values.

The frequency is varied until there is the same voltage drop across the coil as across the resistor. The resistance and impedance values are then equal:

$$R = \omega L = 2\pi f L \quad \Rightarrow \quad R = 2\pi L \cdot f$$

Note down all resulting frequencies found that full-fill this relation for both coils connected in series and in parallel. Plot the data as in task 1 and perform linear regressions.

Evaluation (9/9)

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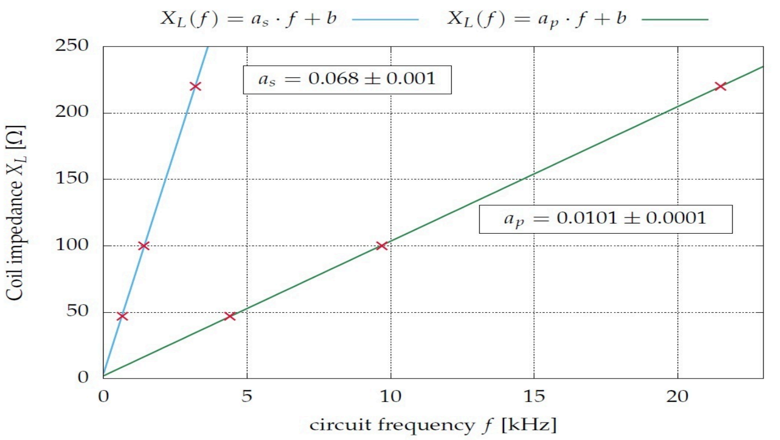

Coils impedances as a function of circuit frequency. Parallel and series circuit.

The slopes $a_s = (0.068 \pm 0.001)\,\Omega s$and $a_p = (0.0101 \pm 0.001)\,\Omega s$for the two coils connected in series and parallel for the exemplary data, the total inductances of the circuits result in

- $L_s = (10.8 \pm 0.2)\,mH$
- $L_p = (1.61 \pm 0.02)\,mH$

which is in optimal agreement to the theoretical values of $L_s = 11\,mH$ and $L_p = 1.63\,mH$ that can be obtained from equations 4 and 5.

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