Coil in the AC circuit with Cobra4 Xpert-Link

(Item No.: P2440464)

Curricular Relevance

Area of Expertise:	Education Level:	Topic:	Subtopic:	Experiment:
Physics	University	Electricity and Magnetism	Inductance, Electromagnetic Oscillations, AC Circuits	Coil in the AC circuit with Cobra4 Xpert-Link

Difficulty	Preparation Time	Execution Time	Recommended Group Size
Difficult	1 Hour	2 Hours	2 Students

Additional Requirements:

Experiment Variations:

Keywords:

Inductance, Kirchhoffs's law, parallel connection, series connection, AC impedance, phase displacement, vector diagram

Overview

Short description

Related topics

Inductance, Kirchhoff’s laws, Maxwell’s equations, a.c. impedance, phase displacement.

Principle

The coil is connected in a circuit with a voltage source of variable frequency. The impedance and phase displacements are determined as functions of frequency. Parallel and series impedances are measured.

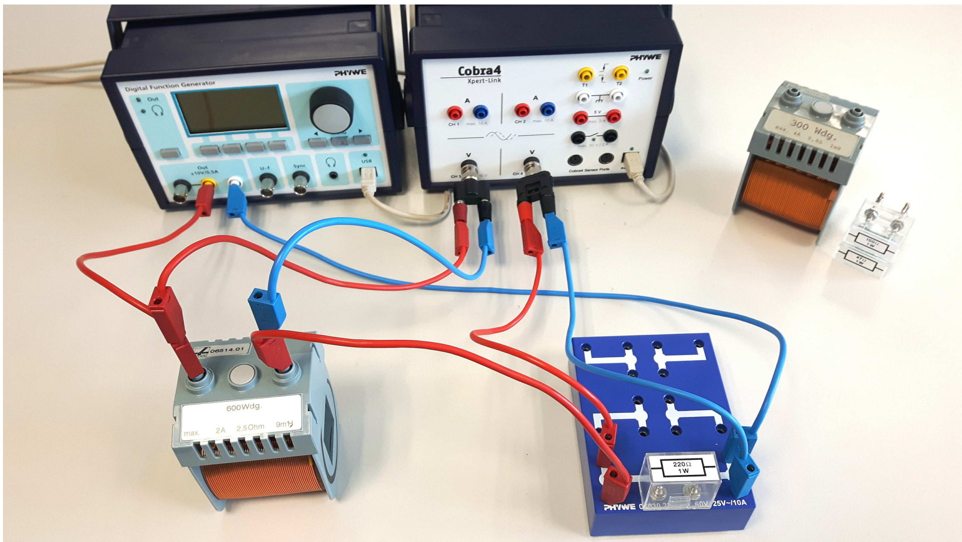

Fig. 1: Experimental setup for the measurement of the coil impedance.

Equipment

Position No.	Material	Order No.	Quantity
1	Coil, 600 turns	06514-01	1
2	Coil, 300 turns	06513-01	1
3	Connection box	06030-23	1
4	Resistor 47 Ohm, 1W, G1	39104-62	1
5	Resistor 100 Ohm, 1W, G1	39104-63	1
6	Resistor 220 Ohm, 1W, G1	39104-64	1
7	Connecting cord, 32 A, 250 mm, red	07360-01	4
8	Connecting cord, 32 A, 250 mm, blue	07360-04	4
9	Connecting cord, 32 A, 500 mm, red	07361-01	2
10	Connecting cord, 32 A, 500mm, blue	07360-04	2
11	PHYWE Digital Function Generator, USB, incl. Cobra4 software	13654-99	1
12	Adapter, BNC-plug/socket 4 mm	07542-26	2
13	Cobra4 Xpert-Link	12625-99	1
14	Software measureLAB	14580-61	

Additional equipment:
PC, Windows® 7 or higher

Tasks

Determination of the

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

Set-up and procedure

Setup

Task 1 and 2

- Build the electrical circuit according to figs. 1 and 2. Start with the smallest resistor (47 Ω) and the solenoid with 300 turns.

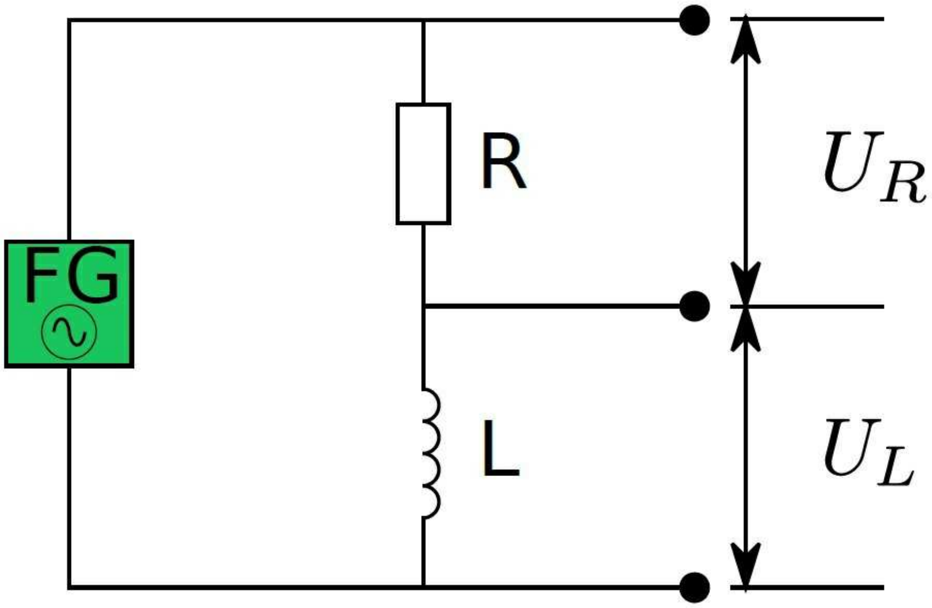

Fig. 2: Circuit for measurement of the coil impedance.

- Start the PC and connect the Xpert-Link device via USB.
- Start the measureLAB software package on the PC.
- Choose both of the voltage channels of the Xpert-Link device as your measuring channels.
- Load the experiment. All required settings for measuring are set automatically. Put the digital function generator to an amplitude of 20 V and the sinus wave signal with signal-type out.
- Continue reading the procedure part below for task 1 and 2.

Task 3

- Disconnect the energy supply and rebuild the circuit according to figure 3.

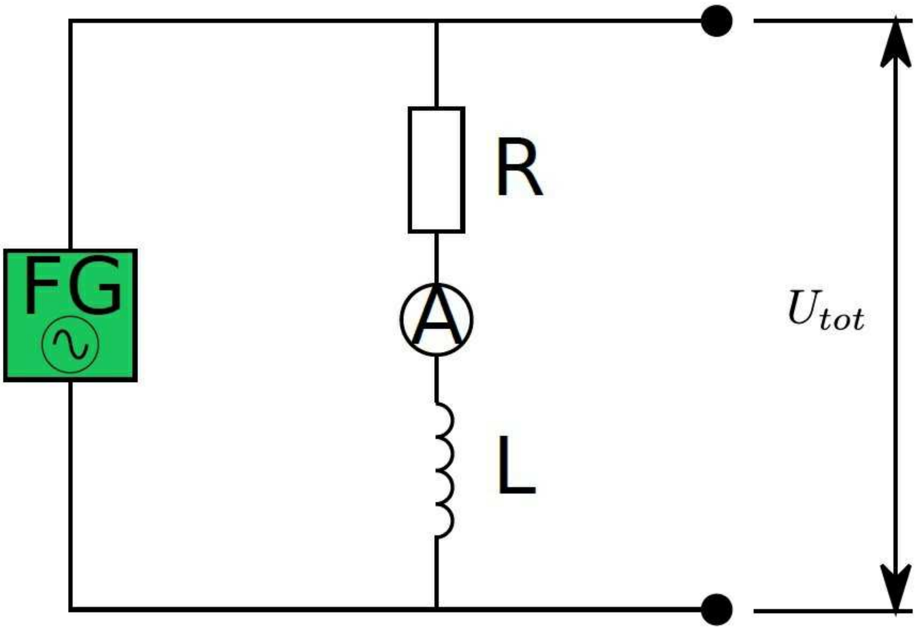

Fig. 3: Set-up for phase displacement measurement.

- Continue reading the procedure part below for task 3.

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

Task 4

- Disconnect the energy supply and rebuild the circuit according to figure 2. 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. After following the procedure part for task 4 come back and connect the two solenoids in parallel and one resistor in series.
- Adjust the measurement channels as described above for task 3. As in task 1 we are measuring two voltage signals.
- Continue reading the procedure part below for task 4.

Procedure

Task 1 and 2

- Start the measurement .
- The measurement stops automatically. 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.
- Replace the resistor with the 100 Ω 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.
- Repeat this step again for the 220 Ω resistor and note down the frequency.
- Change the solenoid for the 600 turns solenoid and repeat all of these steps again.

Task 3

- Choose a low frequency about 800 Hz and start the measurement .
- The two obtained signals for voltage and current show some phase displacement. You can measure the time difference of the phase displacment 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 up to 12 different frequencies and note the corresponding phase displacement. You can increase the frequency in a constant rate (e.g. multiples of 800 Hz).
- Transform the measured time displacement in phase displacement by using eq. 4. Add these values to your data table.

Robert-Bosch-Breite 10
D - 37079 Göttingen
Tel: +49 551 604 - 0
Fax: +49 551 604 - 107
info@phywe.de
www.phywe.com

Task 4

- This is the same procedure as for task 1. See description there.

Theory and evaluation

LC-circuit

If a coil of inductance L and a resistor of resistance R are connected in a circuit (fig. 2), the sum of the voltage drops on the individual elements is equal to the terminal voltage U:

$U = IR + L \cdot \frac{dI}{dt}$ (1)

where I is the current. The resistors are selected so that the d. c. resistances of the coils (0.8 Ω for the 300 turns, 2.5 Ω for the 600 turns coil) can be disregarded. If the alternating voltage U has the frequency $\omega = 2\pi f$ and the waveform

$U = U_0 \cos\omega t$

then the solution of eq. 1 is

$I = I_0 \cos(\omega t - \varphi)$

with the phase displacement φ given by

$\tan(\varphi) = \frac{\omega L}{R}$ (2)

and

$I_0 = \frac{U_0}{\sqrt{R^2 + (\omega L)^2}}$ (3).

It is customary to treat complex impedances as operators $\hat{R}_i$:

Coil $\hat{R}_L = i\omega L$, ohmic resistance $\hat{R} = R$.

The real impedance of a circuit is the absolute value of $\hat{R}_{tot}$. The phase relationship, established in equation 2, is the ratio of the imaginary part to the real part of R_{tot} .

Note: The relation between time shift and phase shift is given by

$\frac{\mathrm{dt}}{T} = \frac{\Delta\varphi}{360^\circ}$ (4).

Series and parallel circuit for inductances

Connecting n inductances L_i in series yields a total inductances of

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

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

$L_{tot}^{-1} = \sum_{i=1}^{n} \frac{1}{L_i}$ (6).

Robert-Bosch-Breite 10
D - 37079 Göttingen
Tel: +49 551 604 - 0
Fax: +49 551 604 - 107
info@phywe.de
www.phywe.com

Task 1

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 (fig.4). The resistance and impedance values are then equal:

$R = \omega L = 2\pi f L$ (6)

Fig. 4: Same voltage drop at resistor and inductance. The amplitudes are fairly equal.

The coils impedances for 300 and 600 turns coils as function of the circuit frequency are shown in fig. 7. The data points are marked with little red crosses. In between, the data have been fitted by a linear function. To do this, you can use any software you like.

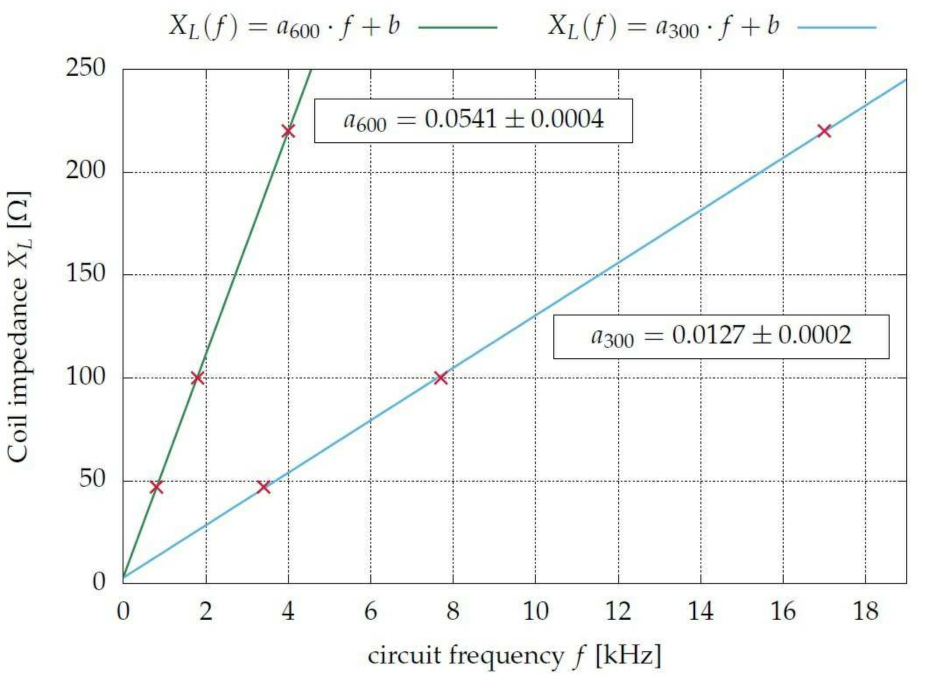

Fig. 7: Coil impedance as function of circuit frequency for two different coils.

Task 2

To determine the inductances of the coils, equation 6 has to be used. It states, that the coil impedance is a linear function of frequency. The slope a of that function can be read off from the 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 is $a_{300} = 0.0127 \pm 0.0002$. For the 600 turns coil, the slope is $a_{600} = 0.0541 \pm 0.0004$. For the inductances, you will get

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

Both values are very close to theoretical values of the used inductances $L_{300} = 2\mathrm{mH},\ L_{600} = 9\mathrm{mH}$.

Task 3

The phase displacement between the total voltage and the total current can be measured using a circuit shown in fig. 3. Use the "Survey Function" of measureLAB as it is shown in fig. 8 for the measurement of time displacements.

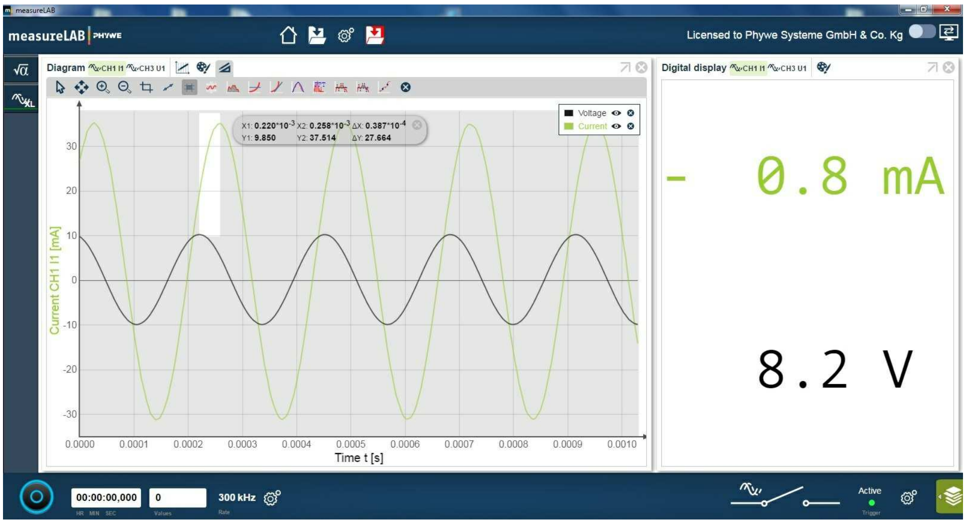

Fig. 8: Measuring the time displacement between total voltage and current.

Calculate the phase displacement according to equation 4. Plot the phase displacement (fig. 9) and the tangent of the phase displacement (fig. 10) as function of frequency.

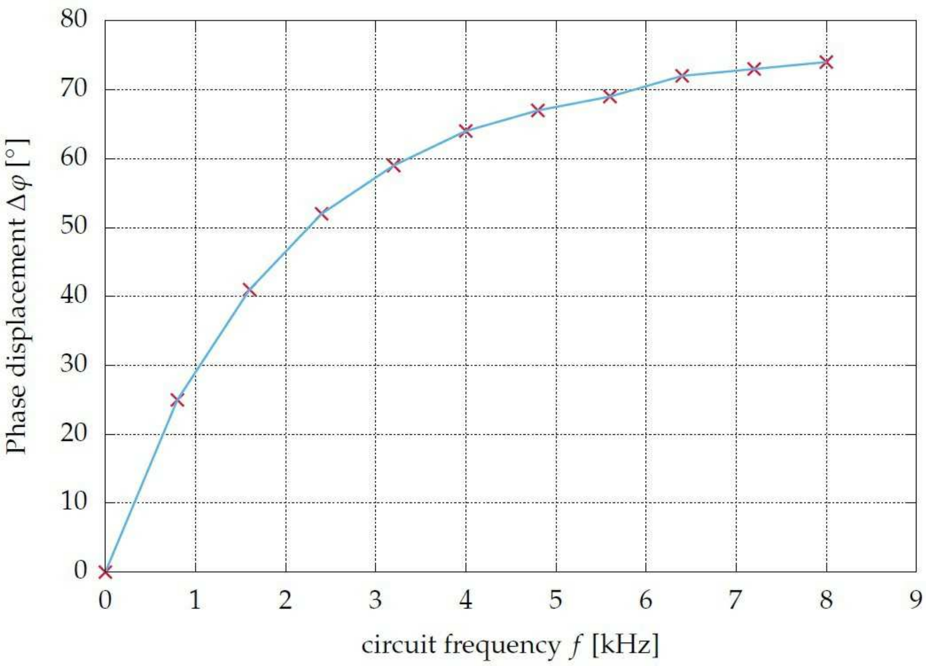

Fig. 9: Phase displacement between voltage and current signal as function of frequency.

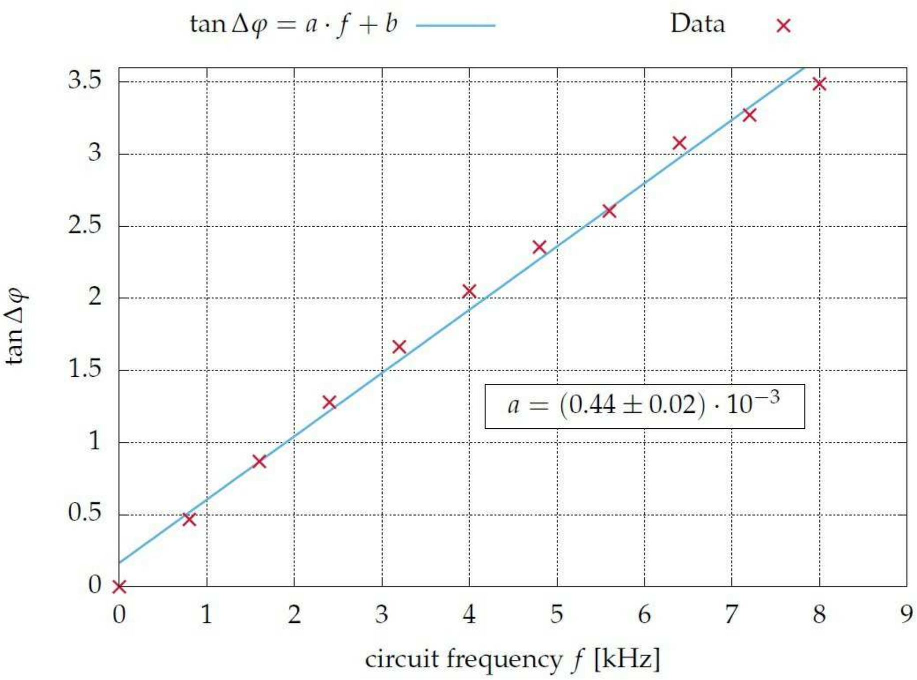

Fig. 10: Tangent of phase displacement between voltage and current signal as function of frequency.

Equation 2 tells, that $\tan\varphi$ follows a linear relation as function of circuit frequency. The slope a of that line can be read off from equation 2. You find, that $a = \frac{2\pi L}{R}$.The fitted line in figure 10 has a slope of

$a = (0.44 \pm 0.02) \cdot 10^{-3}$.

To get the induction of the used coil, we get the formula

$L \;=\; a \cdot R/2\pi$.

Plugging in the values for the used resistance R and the slope a, the inductance takes a value of

$L_{600} = (7 \pm 2)\mathrm{mH}$.

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

Task 4

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.

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 (fig. 6). The resistance and impedance values are then equal.

The coils impedances for 300 and 600 turns coils as function of the circuit frequency are shown in fig. 11. The data points are marked with little red crosses. In between, the data have been fitted by a linear function. To do this, you can use any software you like.

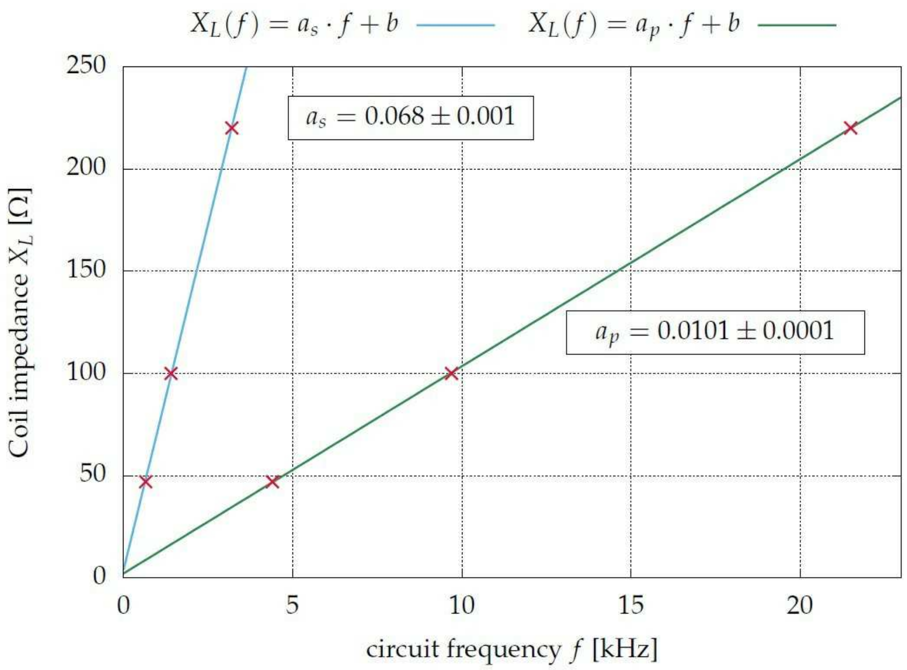

Fig. 11: Coils impedances as a function of circuit frequency. Parallel and series circuit.

The slope a_s for the case, where the two coils are connected in series is $a_s = 0.068 \pm 0.001$. The slope a_p for the case, where the two coils are connected in parallel is $a_p = 0.0101 \pm 0.001$. From these slopes, the total inductances of the circuits come out to be

- $L_{\text{series}} = (10.8 \pm 0.2)$ mH
- $L_{\text{parallel}} = (1.61 \pm 0.02)$ mH

which is in optimal agreement to the theoretical values of $L_{\text{series}} = 11$mH and $L_{\text{parallel}} = 1.63$mH that can be obtained from equations 5 and 6.