Series RLC circuit (remote experiment)

Tasks:
1. Familiarize yourself with the remote experiment Series RLC circuit.
   The remote experiment is available at http://ises2.prf.ujep.cz
2. Try measuring the Series RLC circuit with a Manual frequency of 1 Hz, 3 Hz, 5 Hz, 10 Hz and 20 Hz or with a frequency slider and automatic shift mode.
3. Measure the frequency dependence of the current I_0 , input voltage U, and voltages at the individual elements U_R, U_L and U_C. Measure the frequency point by point or use "Automatic shift". Construct graphs.
4. Experimentally find the resonant frequency f_0 for a series RLC circuit.
5. Measure the resonance curve of a series RLC circuit, e.g. graph I_0 at frequency.
6. Measure the phase shifts of the current and voltage on the resistor R, inductance L, and capacitor C. Show graphically e.g. only the phase shift of the voltage on the capacitor or on the inductor.
7. Verify that the phase shift is negative before resonance, positive after resonance, and zero at resonance.
8. Calculate the inductance of the coil L from Thomson's relation (at resonance).

Measurement principle

Elements R, L, and C are connected in series. They are connected to an AC voltage source U_0. The current is measured in series, and the individual voltages are measured at R, L and C. The circuit diagram is shown in Fig. 1. The voltage U_R in R has the same phase as the current, the voltage U_L on L precedes the current, and the voltage U_C on C lags behind the current.
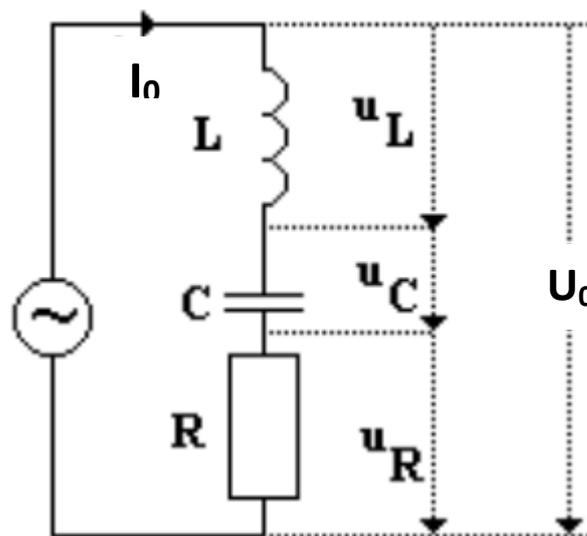

Fig. 1: Schematic of the RLC circuit

For the individual voltages:

$$U_0 = Z \cdot I_0$$
$$U_{R0} = R \cdot I_0$$
$$U_{L0} = X_L \cdot I_0 = \omega \cdot L \cdot I_0$$
$$U_{C0} = X_C \cdot I_0 = I_0 / \omega \cdot C$$

Total impedance in series connection:

$$Z = \sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}$$

Total current and phase shift in series connection:

$$I_0 = \frac{U_0}{Z} = \frac{U_0}{\sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}}$$

$$tg\varphi = \frac{\omega L - \frac{1}{\omega C}}{R}$$

The dependence of the amplitude of the current on the frequency of the AC source is called the **resonance curve** of the circuit. When the current in the circuit is maximum, we refer to this circuit state as the **resonance** of the AC series RLC circuit, and the corresponding frequency is the **resonant circular frequency**.

The circuit is in resonance, resonant circular frequency ω_0 (maximum current, minimum impedance):

$$\omega_0 L - \frac{1}{\omega_0 C} = 0$$

$$\omega_0 L = \frac{1}{\omega_0 C}$$

$$\omega_0 = \frac{1}{\sqrt{LC}}$$

Resonant frequency f_0 (Thompson relation):

$$f_0 = \frac{\omega_0}{2\pi} = \frac{1}{2\pi \sqrt{LC}}$$

In Fig. 2 a) is the so-called **reduced resonance curve** of the series resonant circuit, on the x-axis is the ratio ω/ω_0 and on the y-axis is the ratio $I_0/I_{0\text{max}}$.

In Fig. 2 b) is the so-called **reduced frequency dependence of the phase angle**, on the x-axis is ω/ω_0.

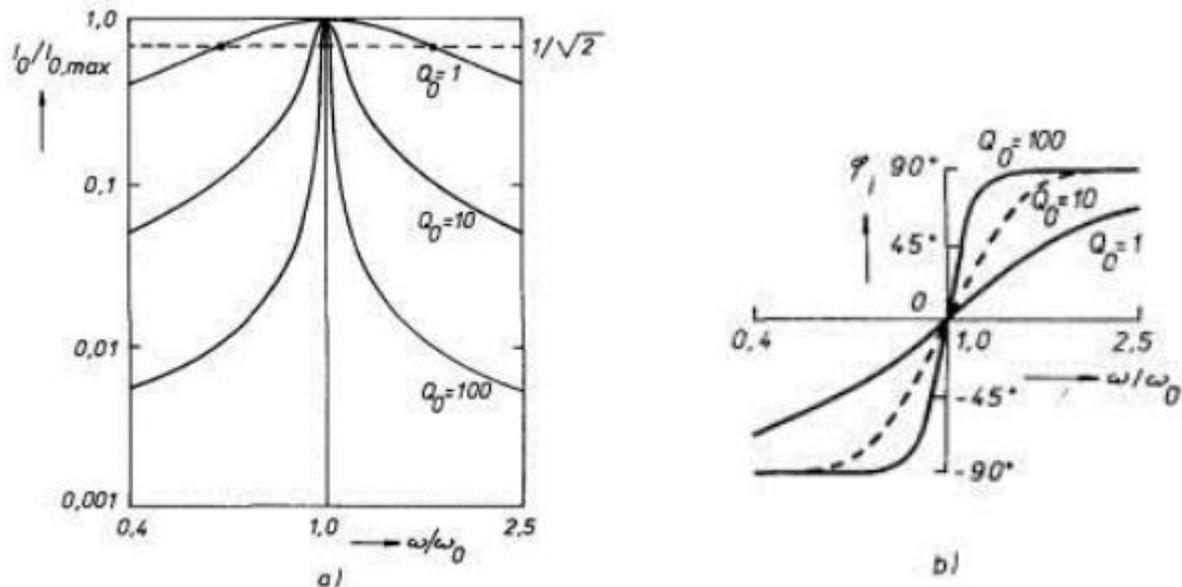**Fig. 2**: Reduced resonance curve and reduced frequency dependence of the phase angle of the series resonant RLC circuit.

Measurement procedure

Experiment

Note: If more visitors are connected to the measurement page, they are ordered in queue by time of visit. Every visitor has approximately 15 minutes to measure, then the measurement is provided to the next visitor in queue. This state can be read from status field (e.g. Connected, Remaining ... seconds, Max. ... of waiting). When the user is inactive for minutes or the page is closed, his measurement is stopped.

Instructions

1. Click on link Run Experiment

2. When the elements of the page are loaded, the camera and control elements are loaded.

3. First, familiarize yourself with the controls of the experiment and perform a test measurement to familiarize yourself with the functions of the buttons (Frequency, Automatic shift, etc.).

4. First, find the resonant frequency f_0 for the series RLC circuit. Click the "Automatic shift" button to automatically shift the frequency from 0 Hz to 20 Hz. All variables U, I, U_R, U_L, U_C are recorded. In the graph we can observe the measurement progress. We will also try manually adjusting the frequency 1 Hz, 3 Hz, 5 Hz, 7 Hz, 10 Hz, 20 Hz, or using the slider to set the desired frequency. The resonant frequency occurs at the maximum current I_0. In the graph on the top left, you can select all measured values U, I, U_R, U_L, U_C or only some of them, e.g. U, I, U_C, respectively U, I, U_L, etc. from the drop-down bar.

5. To start **Data recording** click **Start recording.** Measure desired data and then click on **Stop recording** to end data recording.

6. Then go to **Select recorded data**, where a new data set appears. To export them to computer, click **Export values** (Excel or HTML table, csv file decimal comma (CZ Windows) or csv file decimal dot (EN Windows)). Download the file (MS Excel option) or copy data from the table (HTML option) from new window by pressing Ctrl + A to select all, Ctrl + C to copy, and Ctrl + V to paste into your software (MS Excel option).

7. Continue to process all transferred data in MS Exel.

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Instructions for Processing Measurements

Prepare a measurement protocol that has the standard parts: introduction, theoretical part, work tasks, experimental part (measured data, graphs, calculations and tables), discussion, and conclusion.

Data

We export measured data and process it in suitable software, e.g. MS Excel. In the table, we find the maximum value of the current I_0.

The inductance value L is calculated from Thomson's relation for resonance.

Graphs

The resonance curve is constructed from the individual points of the measured frequency dependence. The amplitudes of the current I_0 , or the ratio of the amplitudes to the maximum amplitude $I_0/I_{0\max}$ are plotted in the graph in Fig. 2 a). Plot the ratio ω/ω_0 on the x-axis.

Determine the phase shift of voltage and current at R, L, and C as a function of frequency point by point for different frequencies. The period of the signal is 2π. The phase shift is read in the table as the part of the period by which the current or voltage is shifted (from the total period of 2π), e.g. when passing through zero. The subtracted and calculated phase shifts are shown in the graph in Fig. 2 b). We plot the ratio ω/ω_0 on the x-axis.