EXPERIMENT EM1: MAGNETIC INDUCTION AND FERROMAGNETIC HYSTERESIS

Related course: KIE2007 (Basic Electromagnetics)

OBJECTIVES:
Refer to every test

EQUIPMENT:
Ferromagnetic hysteresis, magnetic induction equipment

INSTRUCTIONS:

1. Record all your results and observations in a log book / on a piece of paper / pen drive
2. Follow the demonstrator's instructions throughout the experiment

REFERENCE(S):
Refer to the main references of KIE2007

TEST:
TEST 1: Ferromagnetic hysteresis
TEST 2: Magnetic Induction

INTRODUCTION:

When an external magnetic field is applied to a **ferromagnetic material**, the atomic dipoles align themselves with the external field. Even when the external field is removed, part of the alignment will be retained, where the material has become magnetized. The relationship between magnetic field strength *H* and magnetic flux density *B* is not linear in ferromagnetic materials (Figure 1). If *B* vs. *H* is plotted for increasing *H*, it will follow a curve up to a point where further increase in *H* will result in no further change in *B*. This condition is called **magnetic saturation**.

If the magnetic field is then reduced linearly, the plotted relationship will follow a different curve back towards zero field strength at which point, it will be offset from the original curve by an amount called the remanent flux density or **remanence**. If this relationship is plotted for all strengths of the applied magnetic field, the result is a sort of S-shaped loop (Figure 1). The 'thickness' of the middle of the S describes the amount of **hysteresis**, related to the **coercivity** of the material (Figure 2).

The curve for a particular material influences the design of a magnetic circuit. This is a very important effect in magnetic tape and other magnetic storage media like hard disks. In these materials, it is obvious to have one polarity represent a bit, say north for 1 and south for 0. However, to change the storage from one to the other, the hysteresis effect requires the knowledge of what was already there because the needed field will be different in each case. In order to avoid this problem, recording systems first overdrive the entire system into a known state using a process known as bias. Different materials require different biasing, which is why there is a selector switch for this on the front of most cassette recorders.

In order to minimize this effect and the energy losses associated with it, ferromagnetic substances with low coercivity and low hysteresis loss are used like permalloy. In many applications, small hysteresis loops are driven around points in the *B*-*H* plane. Loops near the origin have a higher permeability μ. The smaller loops, the more they have a soft magnetic (lengthy) shape. As a special case, a damped AC field demagnetizes any material.

Magnetic field hysteresis loss causes heating. This effect is used in induction cooking, where an alternating magnetic field causes a ferrite container to heat directly rather than being heated by an external heat-source.

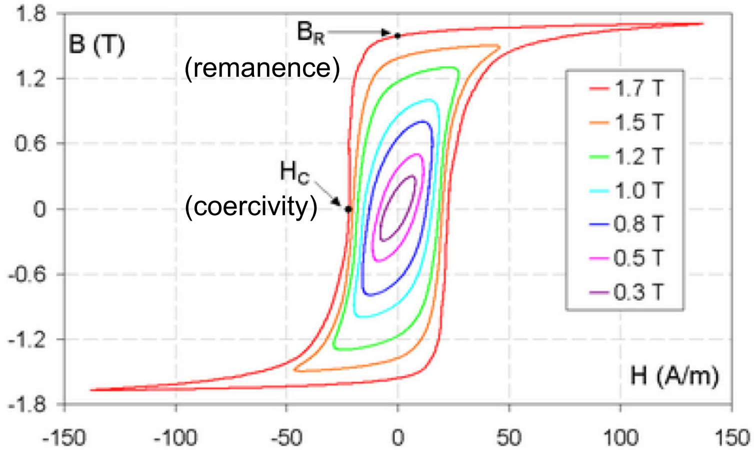


Figure 1: *B-H* loops for grain-oriented electrical steel

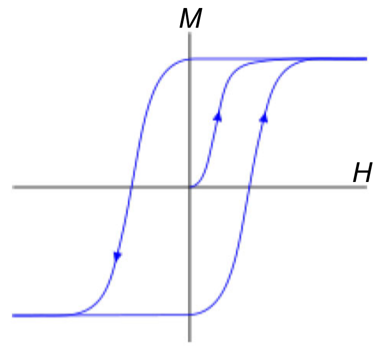


Figure 2: Hysteresis loop: magnetization *M* vs. magnetic field strength *H*

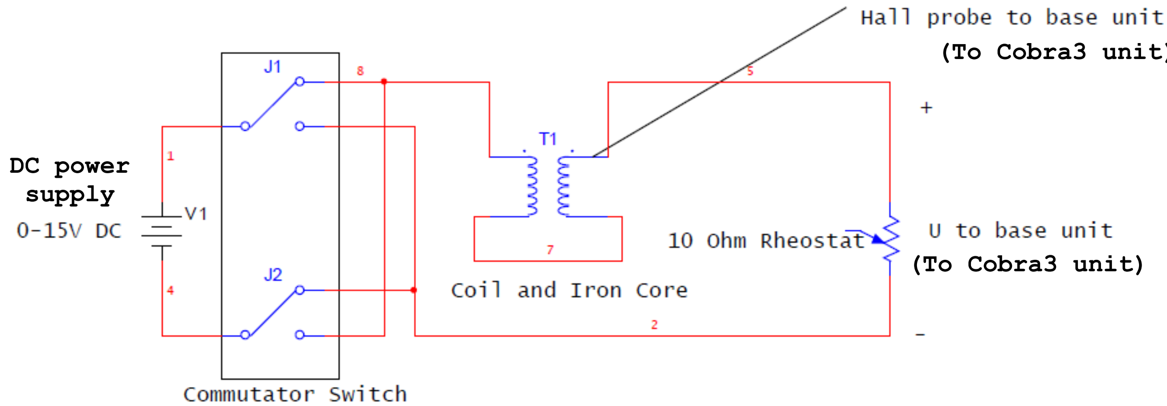
TEST 1: Ferromagnetic hysteresis

OBJECTIVES:

1. To generate a magnetic field in a ring-shaped iron core by a continuous adjustable direct current applied to two coils
2. To investigate magnetic flux density *B* vs. field strength *H*, remanence and coercive field strength for a massive iron core and a laminated iron core

PROCEDURES:

1. Connect the experimental set-up as shown in Figure 3.
2. Connect the variable transformator to an electric socket as far as possible from the one chosen for the interface and if possible, which uses another electrical phase.
3. Position the coil set-up far from the computer and from the Cobra3 unit to avoid errors during the transfer of data due to interference by the strong magnetic fields.
4. Put the Tesla measuring module on the module port of the Cobra3 unit and connect the voltage *U*, which is measured across the resistor, to the analogue input 2 of the Cobra3 unit.
5. Connect the cable of the Hall probe with the Tesla measuring module and attach the Hall probe under the yoke in such a manner that the sensor is located directly adjacent to the borehole for the positioning pin.
6. The magnetic field of the coils should be reversed with the commutator switch only at 0V. Otherwise, voltage spikes are generated, which can affect data transfer.
7. Record the flux density B_0 measured by the Hall probe and current I through the coils.
8. Set the measuring parameters in the software according to Figures 4 and 5.
9. Choose the icon **Continue** to enter the graphical illustration during the measurement. Here, the actual values of the flux density and the current are displayed.
10. Set the rheostat to 10 Ω.
11. If residual magnetism is present in the iron core, demagnetize the core as follows:
    a) Set the commutator switch in such a manner that an opposing field is generated.
    b) Slowly increase the voltage far enough for the flux density to assume a zero value; repeat a number of times.



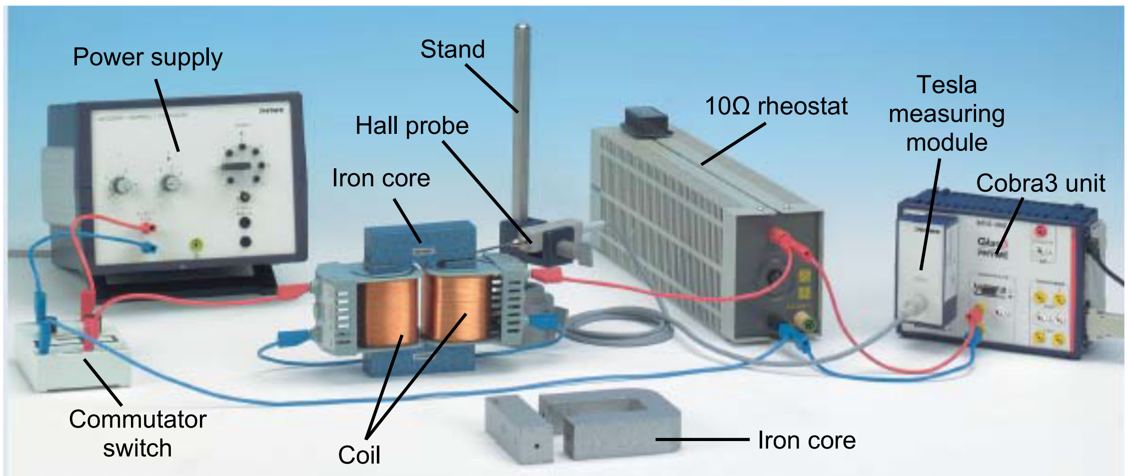


Figure 3: Experimental setup for the ferromagnetic hysteresis

12. After pressing the **Start measurement**, increase the voltage slowly and uniformly from zero upwards and decrease it to zero again. Simultaneously, record every value on key press, i.e. press **Enter** or **Space** after every change of the voltage.
13. Using the commutator switch, reverse the polarity of the voltage.
14. Again, increase and then decrease the voltage slowly and uniformly.
15. Once again, reverse the polarity of the voltage with the commutator switch and increase the voltage.
16. Stop the measurement and press the **Close** button.
17. Reset the voltage to 0 V.
18. The recorded values are represented graphically as flux density B_0 vs. field strength H for massive iron core and laminated iron core. The x-axis H can be set by inserting a function in **Channel Modification**.

    Notes: Field strength $H = I \cdot n/L$
    where n = number of turns in the coil (600 turns), L = average field line length in the core (solid core: L = 232 mm, laminated core: L = 244 mm)

QUESTIONS:

1. Explain the operation of the circuit in Figure 3 from TEST 1.
2. Explain all your findings in TEST 1.

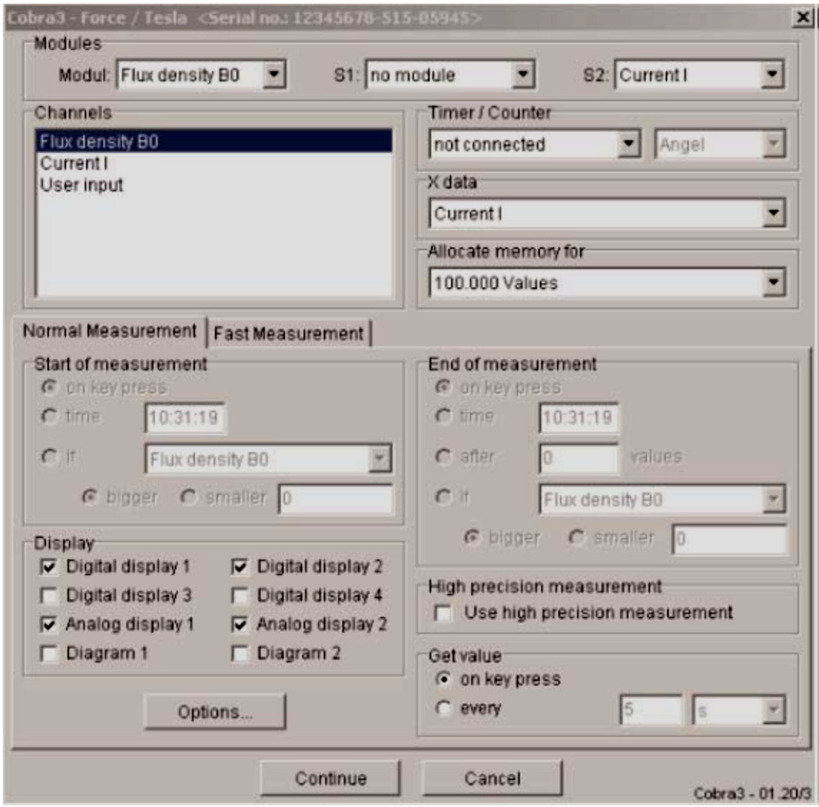


Figure 4: Measuring parameters for the ferromagnetic hysteresis

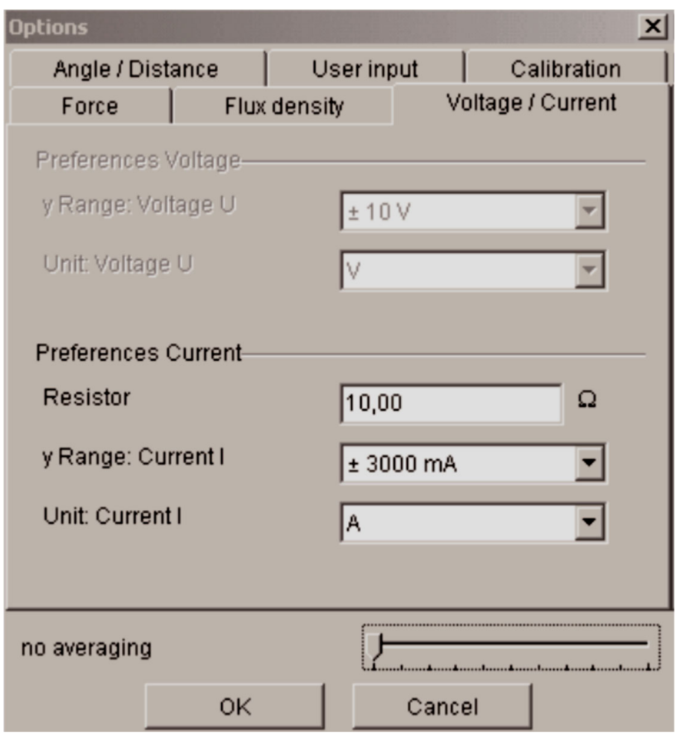


Figure 5: Measuring parameters for the ferromagnetic hysteresis

TEST 2: Magnetic Induction

OBJECTIVES:

1. To produce a magnetic field of variable frequency and varying strength in a long coil
2. To determine the voltages induced across thin coils that are pushed into the long coil as a function of frequency, number of turns, diameter and field strength

PROCEDURES:

1. Connect the experimental set-up as shown in Figure 6.
2. Connect the field coil to the function generator of Cobra3 unit.
3. Connect the induction coils to be put into the field coil to Analog In 2/S2, best to the two yellow sockets (+ and -) and not to ground.
4. Connect the Cobra3 Unit to the computer USB port and start the **Measure** program.
5. Select **Gauge** > **PowerGraph** and on the now visible **Setup** chart, click the function generator symbol. Use the function generator in the constant current mode. The produced field strength depending on the current strength is of interest and not the voltage that is needed to produce it. Set the parameter as in Figure 7.
6. Click the **Analog In 2/S2** symbol and set the module to **Burst measurement** as shown in Figure 8. The **Settings** and **Display** charts of PowerGraph should look like Figure 9 and 10.
7. Take measurement for every induction coil. Start measuring with **Continue** button.
8. Plot the graph of voltage response of the different coils vs. current in the field generating coil for fixed frequency of 800 Hz.
9. Use the function **Regression** of **Measure** to evaluate the slopes of the recorded measurement data, yielding the response voltage of the induction coils per current strength in the field coil in V/A.

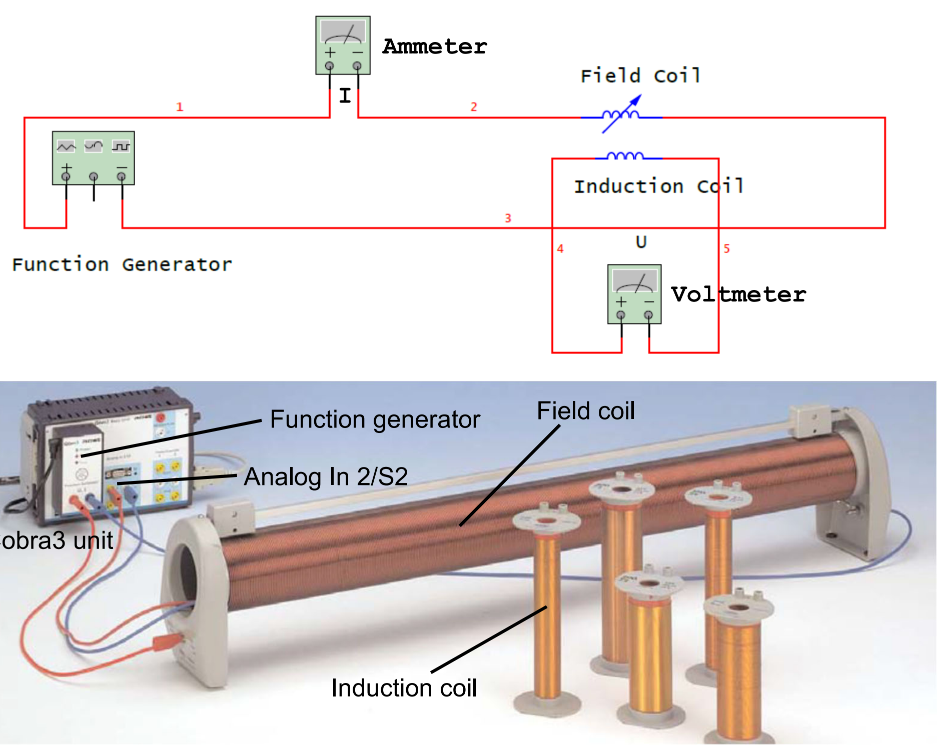


Figure 6: Experimental setup for the magnetic induction

10. Plot the response voltage per mA for induction coils vs. number of turns with constant cross-section area.
11. Plot the response voltage per mA for induction coils vs. the cross-section area with the same number of turns.
12. Then, set the function generator on the **Setup** chart of PowerGraph to tune the frequency from 100 to 1000 Hz with constant current strength as in Figure 11 and 12.
13. Take measurement for every induction coil. Start measuring with **Continue** button.
14. Plot the graph of voltage response of the different coils vs. frequency.

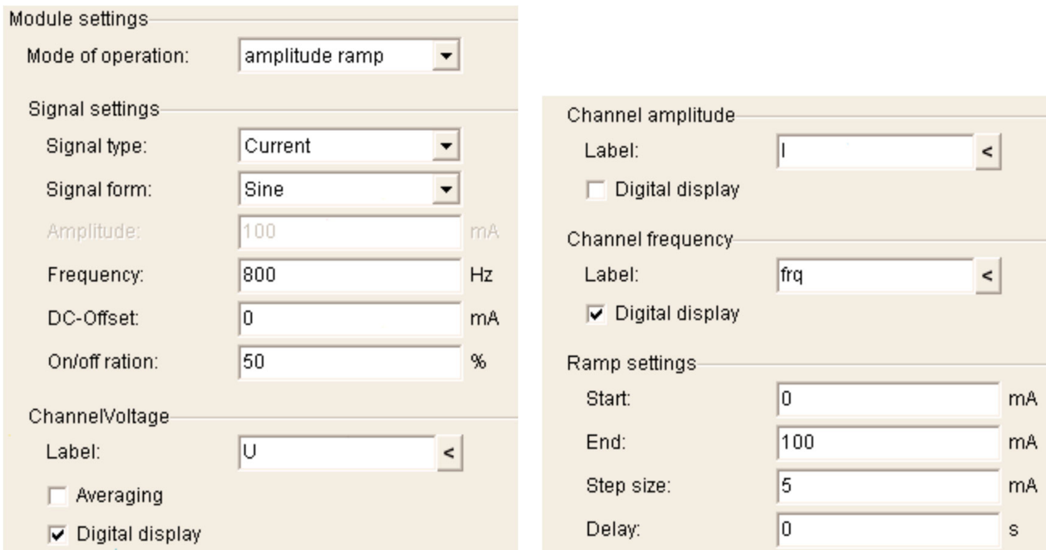


Figure 7: Function generator module settings for the amplitude ramp

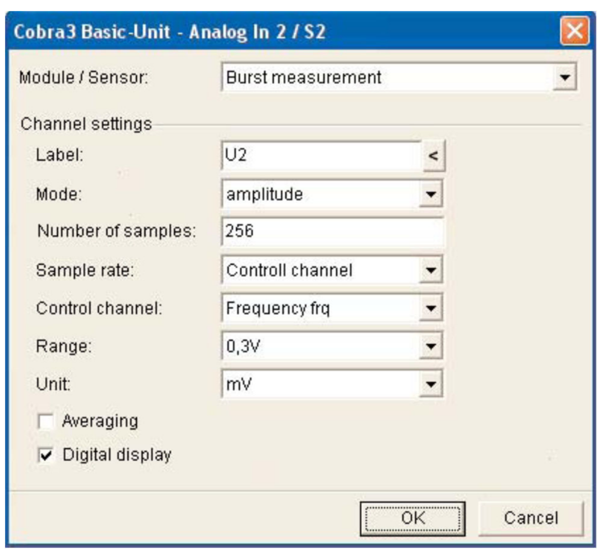


Figure 8: Setting for Analog in 2 /S2

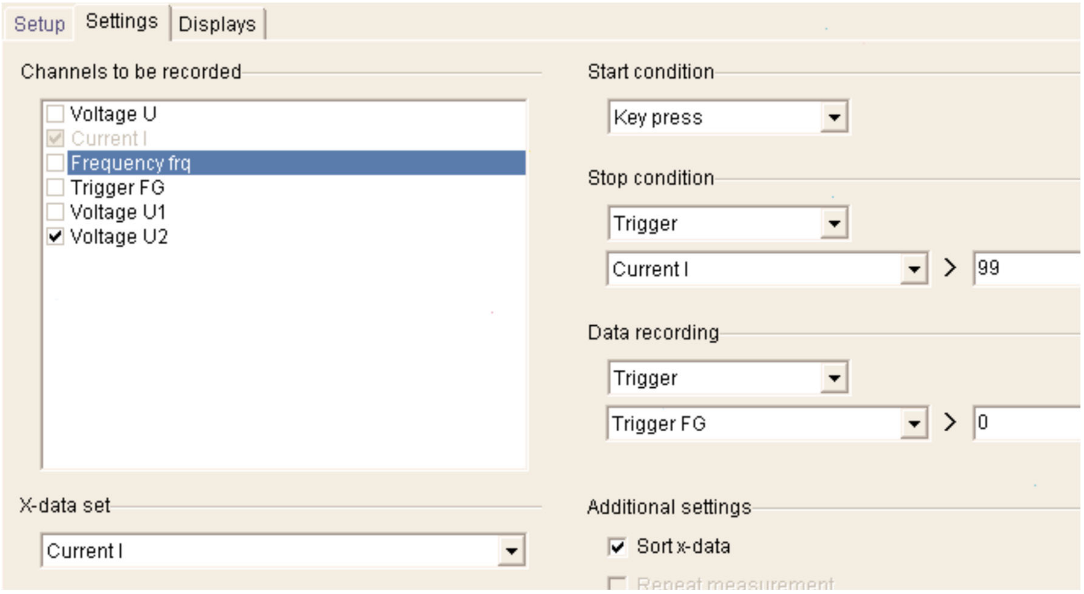


Figure 9: The **Settings** chart of PowerGraph for amplitude ramp

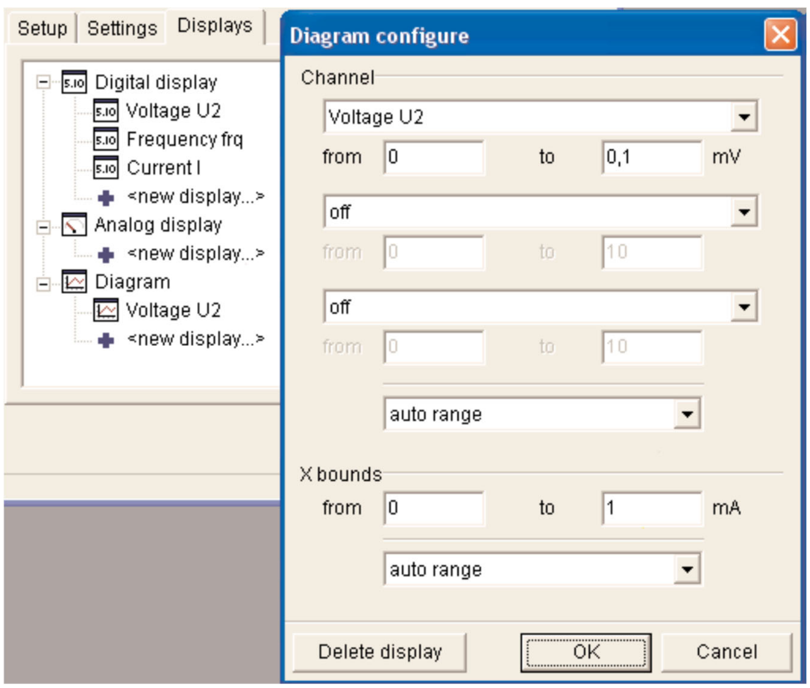


Figure 10: **Displays** chart of PowerGraph

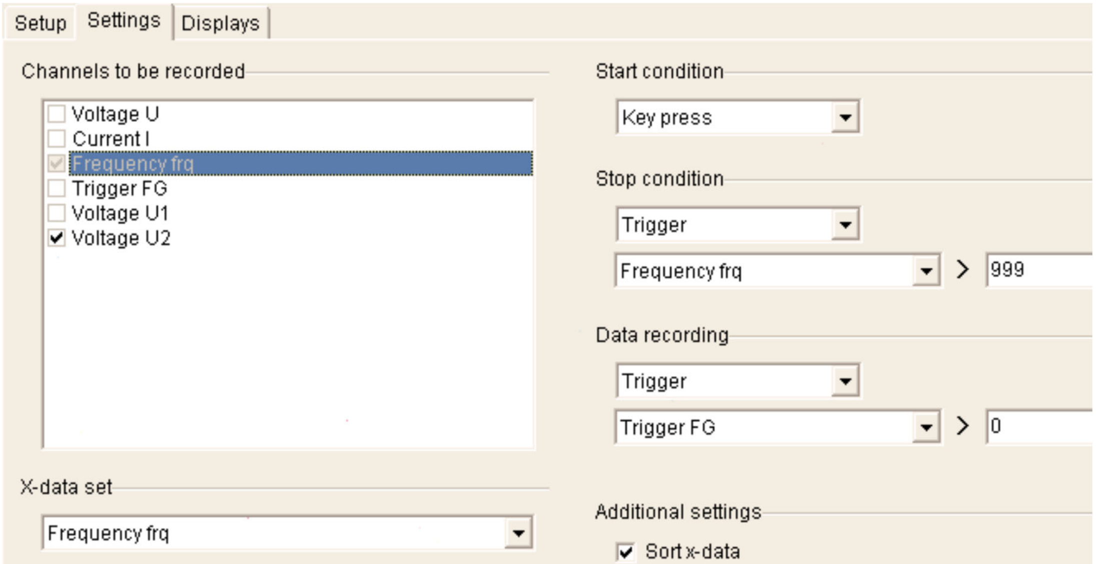


Figure 11: **Settings** chart for frequency ramp

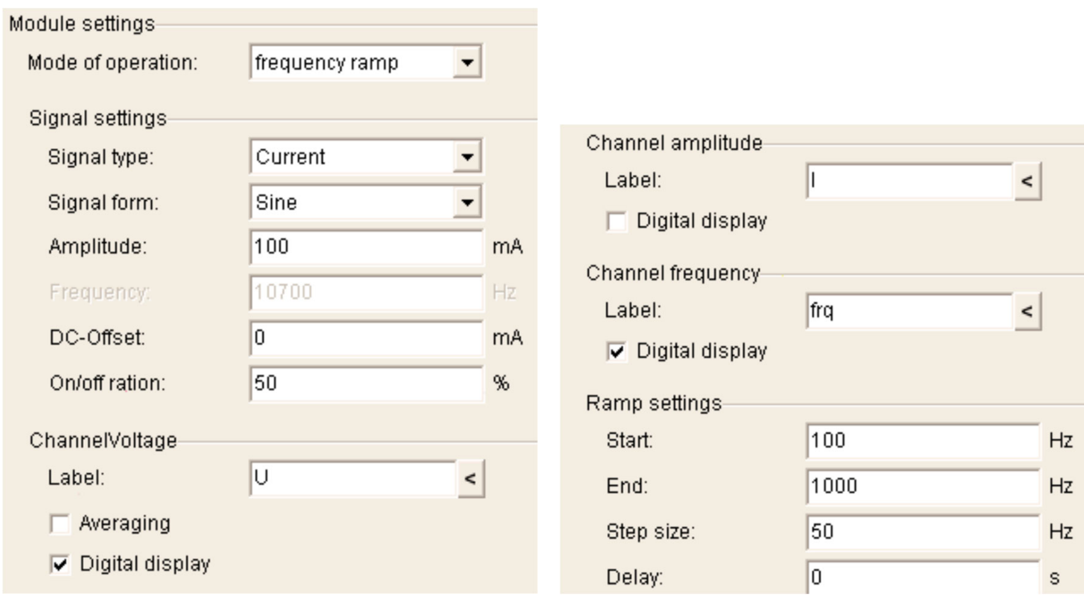


Figure 12: **Module settings** for frequency ramp

QUESTIONS:

1. Explain the operation of the circuit in Figure 6 from TEST 2.
2. Explain all your findings in TEST 2.

END OF EXPERIMENT