EXPERIMENT EM2: MAGNETIC FIELD OUTSIDE A CONDUCTOR & IN HELMHOLTZ ARRANGEMENT

Related course: KIE2007 (Basic Electromagnetics)

OBJECTIVES:

Refer to every test

EQUIPMENT:

Straight conductors, paired coils in Helmholtz arrangement

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: Magnetic field outside a straight conductor
TEST 2: Magnetic field of paired coils in Helmholtz arrangement

INTRODUCTION:

The magnetic field lines around a long wire, which carries an electric current, form concentric circles around the wire. The direction of the magnetic field is perpendicular to the wire and is in the direction the fingers of the right hand would curl if we wrapped them around the wire with our thumb in the direction of the current.

The magnetic field, *B* of an infinitely long straight wire *I* can be obtained by applying Ampere's law as follows, where μ_0 is the permeability of free space,

$$\sum B_{\|}\Delta l = \mu_0 I$$

For a circular path centered on the wire with *r* radius, the magnetic field is everywhere parallel to the path. Hence, the summation becomes

$$B = \mu_0 I/(2\pi r)$$

A Helmholtz coil is a device for producing a region of nearly uniform magnetic field. A Helmholtz pair consists of two identical circular magnetic coils (solenoids) that are placed symmetrically along a common axis, one on every side of the experimental area, and separated by a distance *h* equal to the radius *R* of the coil. Every coil carries an equal electric current in the same direction.

TEST 1: Magnetic field outside a straight conductor

OBJECTIVES:

To determine the magnetic field of:

a) a straight conductor as a function of the current and distance from the conductor
b) two parallel conductors, where the current is flowing in the same and opposite directions, as a function of the distance from one conductor on the line joining the two conductors

PROCEDURES:

1. Set the experimental circuit as shown in Figure 1.
2. Switch ON the AC power supply, Teslameter and multimeter.
3. Set the distance between the tip of the Teslameter probe and the straight conductor to 0 cm. Use the provided ruler to measure the distance.
4. Increase the voltage supply according to Table 1 and record the current (shown by the multimeter) and magnetic field (shown by Teslameter) in Table 1.
5. Set the voltage supply to 5V. Change the distance between the tip of the Teslameter probe and the straight conductor according to Table 2 and record the magnetic field. The distance can be measured radially from the tip of the Teslameter probe.
6. Change the straight conductor to parallel conductor with same current direction. Repeat step 5 and fill in Table 3. Negative means the distance is measured in the opposite direction.
7. Change the conductor to parallel conductor with opposite current direction. Repeat step 5 and fill in Table 4.

Table 1 (distance *d* = 0 cm)

Voltage *V* (V)	Current *I* (A)	Magnetic field *B* (mT)
2		
4		
6		
8		
10		
12		

Table 2 (Voltage *V* = 5V)

Distance *d* (cm)	Magnetic field *B* (mT)
0	
1	
2	
3	
4	
5	

Table 3 (parallel conductor with same current direction)

Distance *d* (cm)	Magnetic field *B* (mT)
3	
2	
1	
0	
-1	
-2	
-3	

Table 4 (parallel conductor with opposite current direction)

Distance *d* (cm)	Magnetic field *B* (mT)
3	
2	
1	
0	
-1	
-2	
-3	

Notes:

1. A phase displacement can occur between the “construction-kit” transformer and the magnetic field meter, giving the illusion of a “negative” magnetic field (minimum of the magnetic field indicator with increasing current). This can be eliminated by reversing the polarity of the primary of the transformer.
2. Higher short-time secondary currents can be achieved by connecting the constant and variable voltage in series on the power unit.
3. Attention should be paid to the correct phase angle.

QUESTIONS:

1. From Table 1, plot the magnetic field vs. current *I*. Comment about the graph.
2. From Table 2, 3 and 4, plot the magnetic field vs. distance *d* in separate graphs. Comment about every graph.

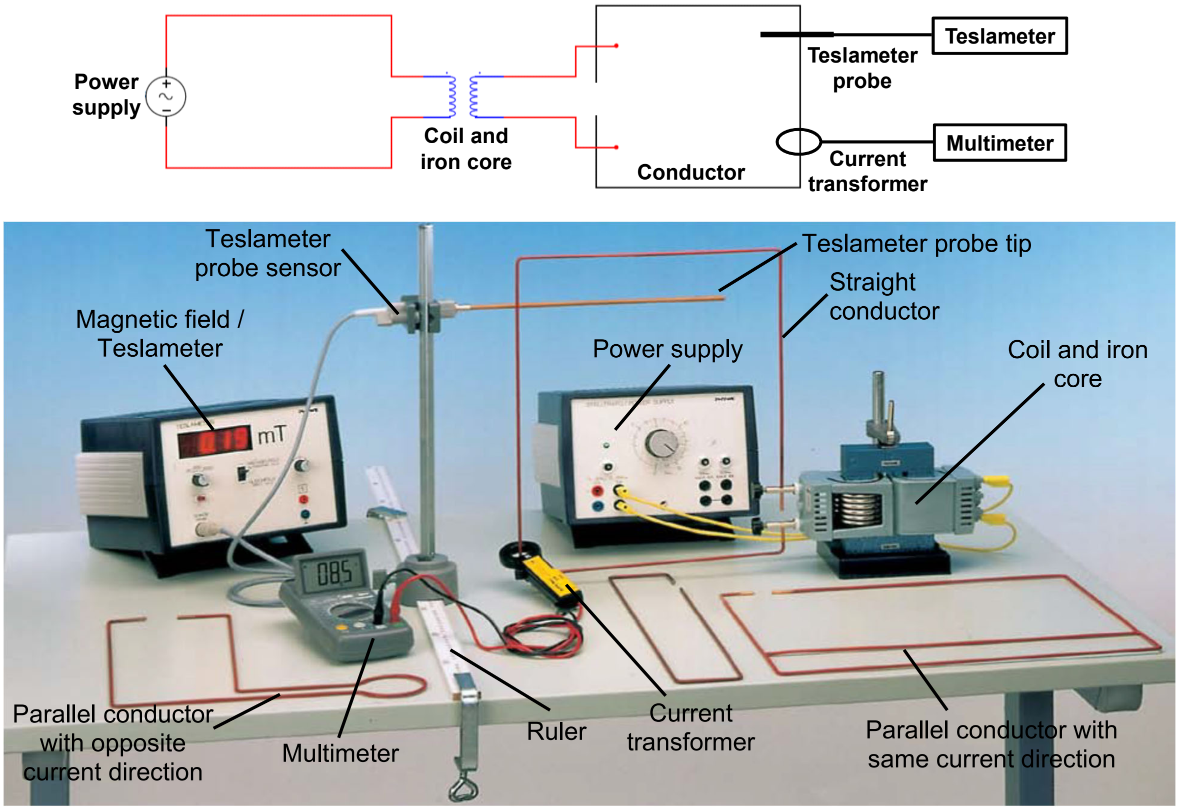


Figure 1: Experimental to determine the magnetic field outside straight conductors

TEST 2: Magnetic field of paired coils in Helmholtz arrangement

OBJECTIVES:

a) To measure the axial component of magnetic flux density along z-axis of flat ring coils
b) To measure the spatial distribution of the magnetic flux density B when the distance between coils $a = R$
c) To measure the radial components Br' and Br'' of two individual coils in the plane midway between them

Notes:

1. The Hall probe is at the tip of the plastic rod and measures the magnetic flux density's component parallel to the rod's axis, it is an axial Hall probe. The radius of the coils R is 200 mm.
2. The magnetic field of the coil arrangement is rotationally symmetrical about the axis of the coils, which is chosen as the z-axis of a system of cylindrical coordinates (z,r,Φ). The origin for measuring the magnetic field may be set to the centre of the system. The magnetic flux density does not depend on the angle, so only the components $Bz(z,r)$ and $Br(z,r)$ need to be measured.

PROCEDURES:

1. Referring to Figure 2, connect the Tesla measuring module to the **Module** port of the Cobra3 unit and the Tesla probe module to the Tesla measuring module.
2. Connect the 6A current sensor to the **Analog In 2/S2** port of the Cobra3 unit.
3. Connect the **Movement recorder** to the Cobra3 unit according to Figure 3.

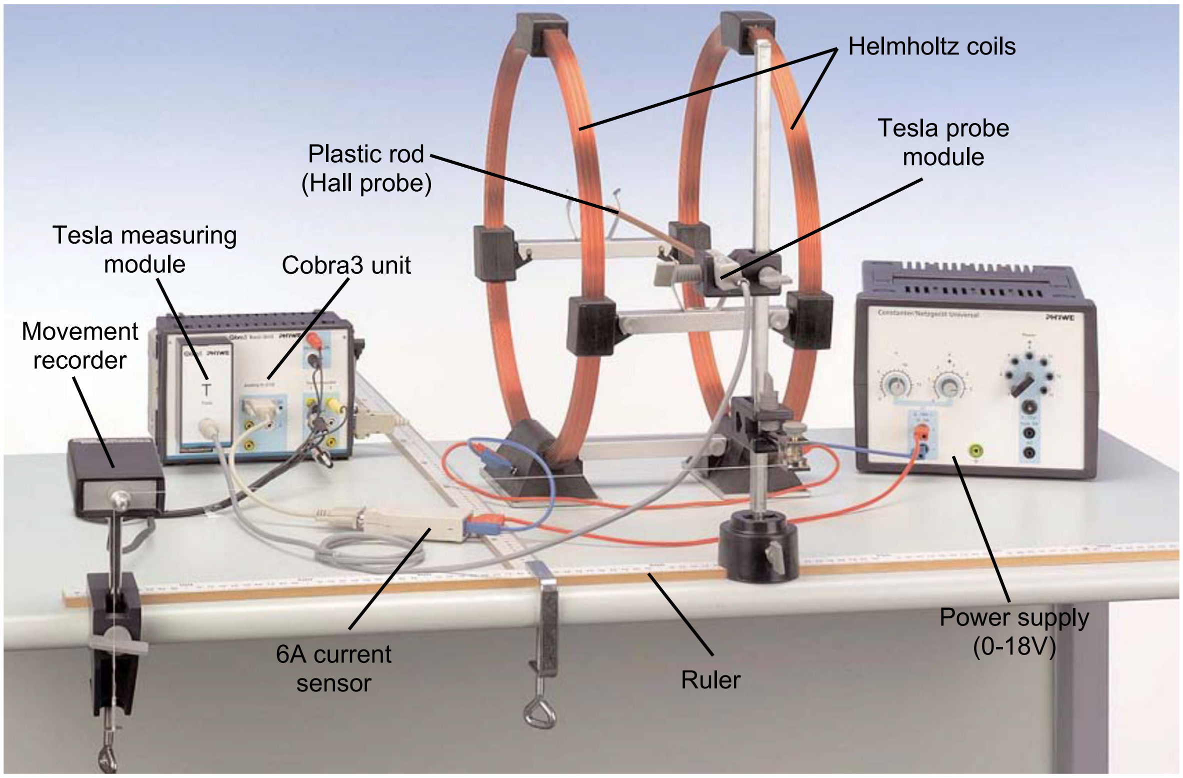


Figure 2: Experiment for magnetic field of paired coils in Helmholtz arrangement

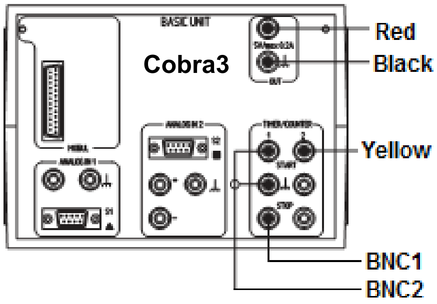


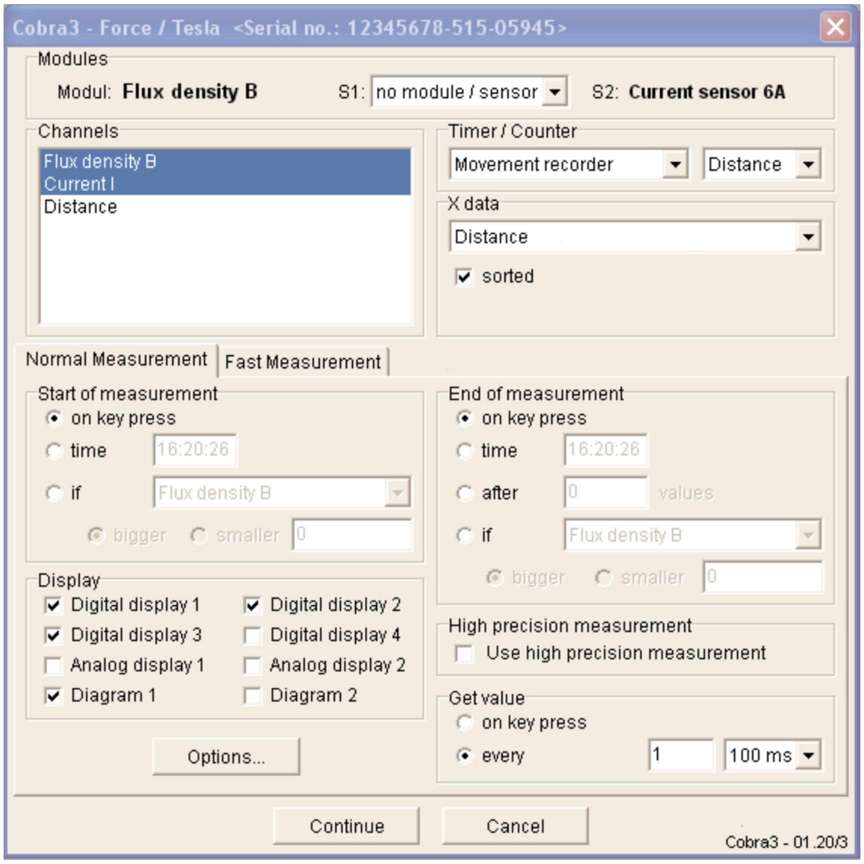
Figure 3: Connection of the movement recorder to the Cobra3 unit

4. Connect the Cobra3 unit to the PC USB port and start the **Measure** program. Select **Gauge** > **Cobra3 Force / Tesla** and set the parameters as shown in Figure 4.

5. When turning on the displays and diagrams, **Display options** charts appear. Click **OK** for the displays and set the parameters for the diagram as seen in Figure 5.

   After clicking the **Options…** button, the **Options** menu appears and the parameters in different charts can be set as shown in Figure 6 to 8. Execute the **Calibrate in the setup** function on the **Angle / Distance** chart (Figure 6). The thread may be wound one time around the bigger wheel of the movement sensor and it may be good to put some more weight on the thread's end to ensure that the wheel follows all the thread's movements properly. The silk thread is always to be parallel to the movement of the Hall probe along the meter scale and the wheel is to be well aligned with the thread.

6. Click the **Calibrate** button when the current of the coils is OFF and the Hall probe in the position where you want to take the measurement.



Cobra3 - Force / Tesla <Serial no.: 12345678-515-05945>

Modules

Modul: **Flux density B** S1: no module / sensor S2: **Current sensor 6A**

Channels

Flux density B
Current I
Distance

Timer / Counter: Movement recorder | Distance

X data: Distance

☑ sorted

Normal Measurement | Fast Measurement

Start of measurement
● on key press
○ time 16:20:26
○ if Flux density B
● bigger ○ smaller 0

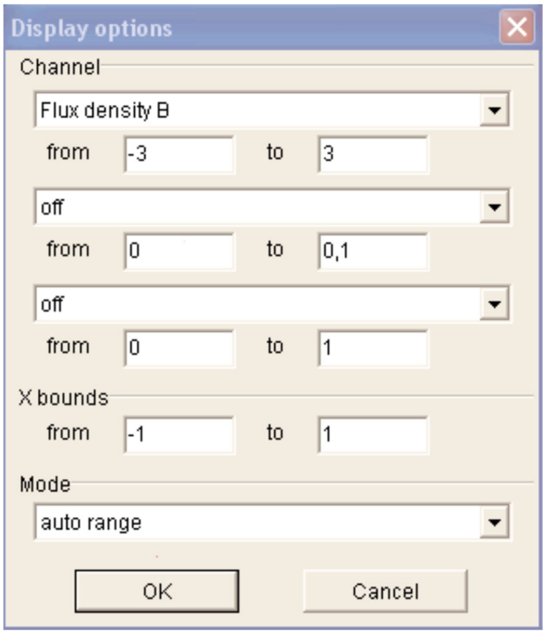
End of measurement
● on key press
○ time 16:20:26
○ after 0 values
○ if Flux density B
● bigger ○ smaller 0

Display
☑ Digital display 1 ☑ Digital display 2
☑ Digital display 3 ☐ Digital display 4
☐ Analog display 1 ☐ Analog display 2
☑ Diagram 1 ☐ Diagram 2

High precision measurement
☐ Use high precision measurement

Get value
○ on key press
● every 1 100 ms

Figure 4: Force / Tesla settings



Display options

Channel

Flux density B from -3 to 3

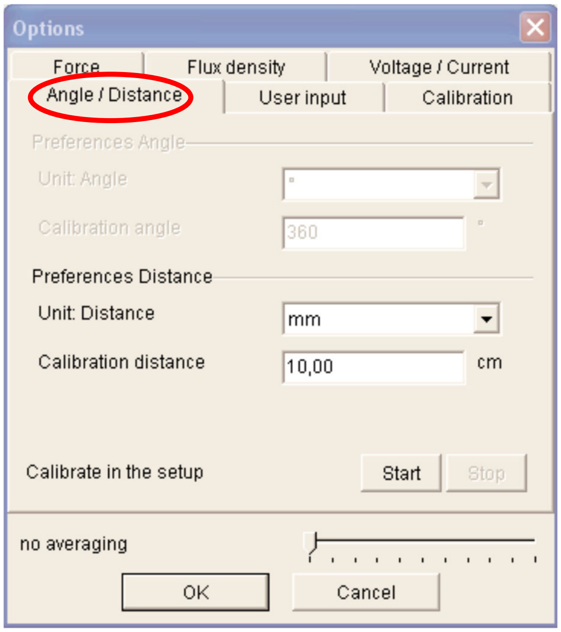
off from 0 to 0,1

off from 0 to 1

X bounds from -1 to 1

Mode: auto range

Figure 5: Diagram settings



Options

Force | Flux density | Voltage / Current
Angle / Distance | User input | Calibration

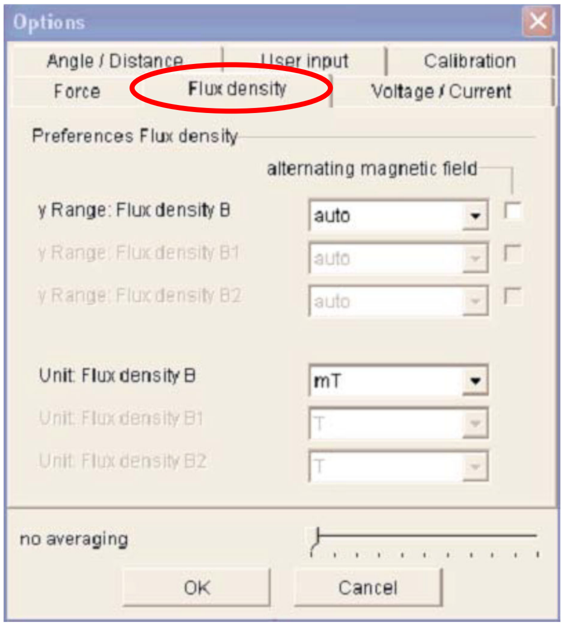
Preferences Angle
Unit: Angle °
Calibration angle 360 °

Preferences Distance
Unit: Distance mm
Calibration distance 10,00 cm

Calibrate in the setup

no averaging

Figure 6



Preferences Flux density

alternating magnetic field

y Range: Flux density B: auto ☐

y Range: Flux density B1: auto ☐

y Range: Flux density B2: auto ☐

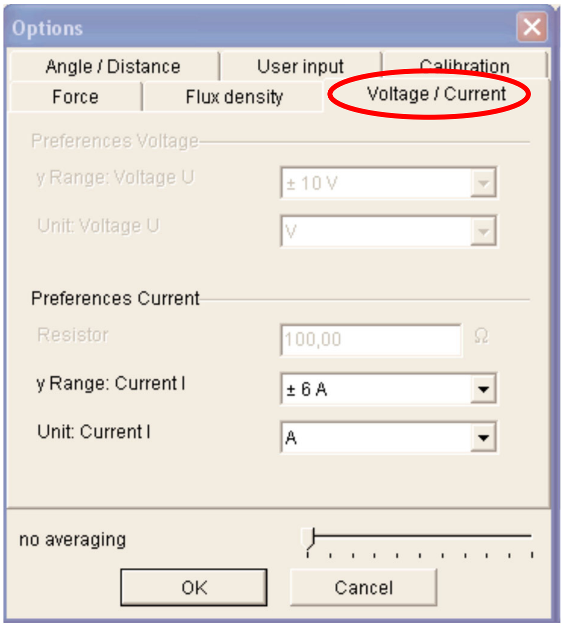
Unit: Flux density B: mT

Unit: Flux density B1: T

Unit: Flux density B2: T

no averaging

Figure 7



Preferences Voltage

y Range: Voltage U: ± 10 V

Unit: Voltage U: V

Preferences Current

Resistor: 100,00 Ω

y Range: Current I: ± 6 A

Unit: Current I: A

no averaging

Figure 8

7. Set the coils and Hall probe according to Figure 9. After the calibration, record the curves for *Bz* (*z*, *r* = 0) for different coil distances *a* with the **Continue** button and then appearing **Start Measurement** button. Make sure that the current stays constant for all measurements. The **Measure** program sets the distance to zero at the beginning of data recording, so note down the place of the Hall probe when beginning the measurement. You may alter the zero position in your data with the **Analysis** > **Channel modification…** function by selecting **Distance** as source channel, adding some value to the distance *s* and overwriting the old set of distance as seen in Figure 11. You can change the name of the coordinates with **Measurement** > **Information…**.

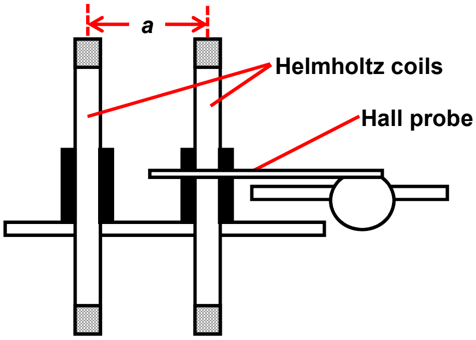


Figure 9: Measuring *Bz* (*z*, *r* = 0) for different coil distance *a*

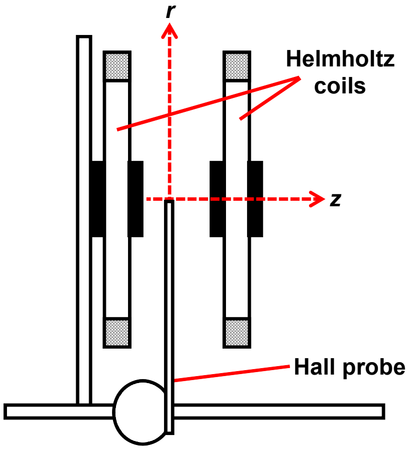
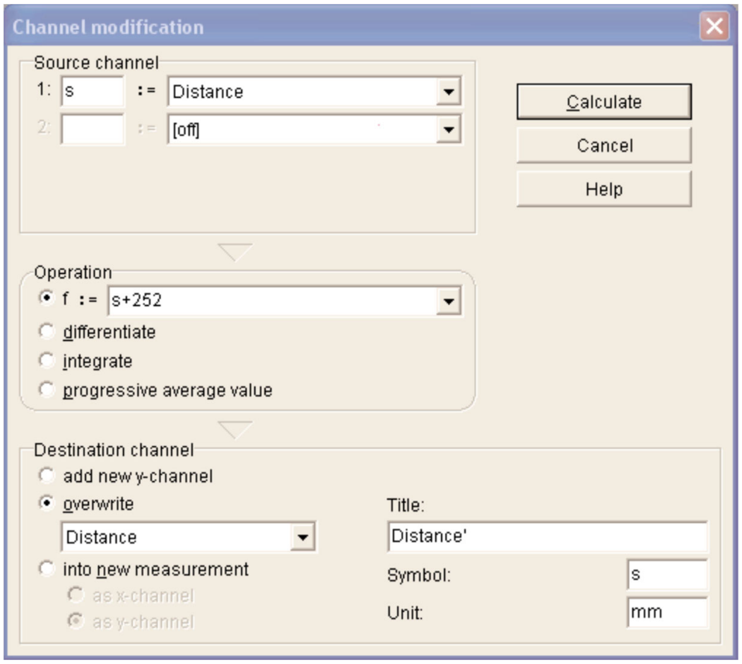


Figure 10: Measuring *Br*(*z*) for different *r*

8. Put the curves of *Bz* (*z*, *r* = 0) for at least 3 different values of *a* into one diagram with the **Measurement** > **Adopt channel…** function and scale them with the **Scale curves** button and selection **Fit collectively**. Comment about the *Bz* curve for different coil distance *a* at fixed *r*.

9. Connect both coils with the spacers so that they have fixed distance *a* = *R* = 200 mm to form the Helmholtz assembly.



Channel modification

Source channel
1: s := Distance
2: := [off]

Operation
● f := s+252
○ differentiate
○ integrate
○ progressive average value

Destination channel
○ add new y-channel
● overwrite
Distance
○ into new measurement
○ as x-channel
● as y-channel
Title: Distance'
Symbol: s
Unit: mm

Figure 11: Altering the zero position

10. Displace the coils in the *r*-direction from the centre of the coils, i.e. perpendicular to the axis of the coils or to the scale the Hall probe slides along. The Hall probe moves along the meter scale parallel to the axis of the coils but in some distance *r* from it. Record curves *Bz*(*z*) for different values of *r* but with fixed *a* (Figure 9). If several curves are combined with **Measurement** > **Adopt channel…** and scale them to the same value, you can see that the field is almost uniform in the space between z=-100 mm and z=100 mm and r<100 mm. Also, record curves for r=R=200 mm to see the flux density outside the coil arrangement. Comment about the curves obtained.
11. Set up the coils and Hall probe according to Figure 10 and record curves of *Br* in dependence of *z* for different values of *r*. Combine all curves obtained. You may also record curves of *Br* in dependence of *r* for different values of *z* using the setup of Figure 10 but with the coils rotated about 90° in order to measure the field outside the coils. Comment about the curves obtained.
12. To measure the radial component of one coil alone, short circuit the other. Make sure the current source is in the constant current mode. Always turn the current OFF before unplugging a cable leading to a coil. Record the radial component curves along the axis of the coils for:
    a) Left coil on
    b) Right coil on
    c) Both coils on
    Comment about every curve.

END OF EXPERIMENT