3. Theory

1) Magnetoelectric DC galvanometer

(1) Structure of magnetoelectric DC galvanometer

The structure of the magnetoelectric DC galvanometer (also called pointer deflection DC galvanometer) is shown in Figure 2.

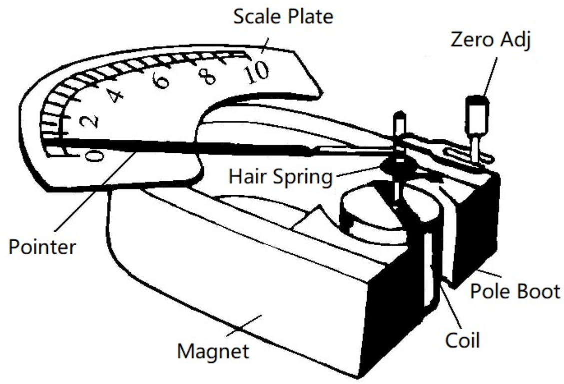

Figure 2 Structure schematic of galvanometer

The two poles of the permanent magnet are connected to the pole boot with a cylindrical cavity. A cylindrical soft iron core is installed between the two poles, and its function is to make the magnetic field in the gap between the poles and the iron core stronger, and make the magnetic field lines uniformly radiate around the central axis of the cylinder. A rectangular coil which can move in the gap between the iron core and the poles is supported on the cylindrical soft iron core, and a pointer is fixed on the coil.

When current flows through the coil, the coil will be deflected by the electromagnetic torque, until it balances with the reverse torsional torque of the hair spring and stays still. The deflection angle of the coil is proportional to the current passed. The deflection direction coincides with the direction of current.

(2) DC voltmeter and DC ammeter

The measurement range of the magnetoelectric DC galvanometer can be modified and expended to construct a DC voltmeter or a DC ammeter. After modification, it has the following characteristics:

a) Range: The range of the galvanometer after modification is changed. The scale of the original meter is still used but the scale value has changed.

b) Internal resistance: Internal resistance is the resistance at both ends of the meter. After modification, different measurement ranges will have different internal resistances.

c) Meter accuracy grade: The accuracy grade of the meter is expressed as a percentage of the basic error of the meter. For example, a voltmeter has a level of 0.5, indicating that the basic error of the voltmeter in use is $\pm 0.5\%$. If the accuracy grade α and the range X_m of the meter are known, the maximum allowable error e of the meter is expressed as:

$$e = \alpha \% X_m . \tag{1}$$

The basic error of all dividing lines on the scale of the meter does not exceed e.

(3) Use method and precautions of DC meters

a) Selection of measurement range

When using the meter, the maximum possible relative error of the measured value X can be estimated according to the accuracy grade of the meter:

$$\frac{e}{X} = \frac{\alpha\% X_m}{X}. \tag{2}$$

From formula (2), it can be seen that the closer the measured value X is to the range of the meter X_m, the closer the measurement error e is to the percentage of the meter's accuracy grade $\alpha\%$. When the measured value X is much smaller than the selected meter range X_m, the measurement error will be large. Therefore, the appropriate range should be selected according to the value of the current or voltage to be measured. If the range is too small, it will damage the meter; if the range is too large, it will increase the measurement error. Generally, the measured value X should be $2/3$ of the selected measurement range. At this time, the maximum relative error that the meter may occur is:

$$\alpha\% \frac{X_m}{2X_m/3} = 1.5\alpha\%. \tag{3}$$

That is, the measurement error will not exceed 1.5 times of the accuracy grade of the meter.

In practice, estimate the value to be measured in advance, select a slightly larger range, and then make adjustments after the first measurement. If do not know the value to be measured, the maximum range should be selected to start the measurement.

b) Electric meter connection

For a magnetoelectric-type meter, the positive and negative polarities of the electric meter must correctly match with the measured source. In addition, the connection method of the electric meter should not be mistaken. When using a voltmeter, it should be connected in parallel, and when using an ammeter, it should be connected in series.

c) Parallax

In order to reduce parallax, read the meter from the direction of perpendicular to the scale surface. For an electric meter with a mirror ruler, read meter when the pointer coincides with its image in the mirror.

d) Zero adjustment

There is a zero adjustment screw on the cover of the magnetoelectric meter. Check and adjust the pointer to zero before use.

e) Use conditions

There are usually various symbols indicating the basic structure, grade and use conditions of the meter on the left and right of the dial of the magnetoelectric meter. Before use, understand clearly these symbols to avoid additional errors.

2) Measure the internal resistance of the galvanometer

There are two common methods for measuring the internal resistance of a micro-amp meter: the half-deflection method and the replacement method.

The circuit of the half-deflection method is shown in Figure 3. With the switch K_1 open, adjust the potentiometer R_1 to make the micro-amp galvanometer to the full scale (or a larger value); then close the switch to let the resistance box R_0 parallel to the micro-amp meter. Adjust the resistance box R_0 until the indication value of the micro-amp meter reaches one half of its previous value. If the resistances in the circuit satisfy $R_1+R_2 >> R_g$, it can be considered that the current at this time is approximately equal to that before the switch was closed. So, we have $R_0 = R_g$.

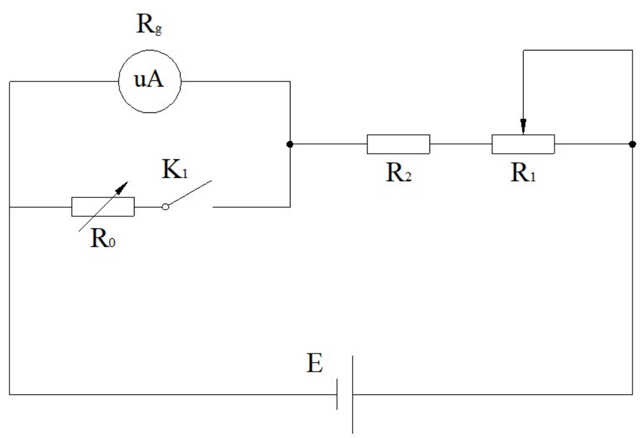

Figure 3 Circuit of half-deflection method

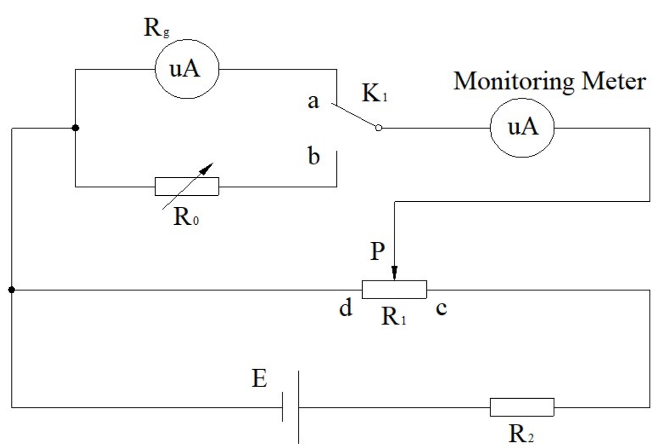

Figure 4 Circuit of substitution method

The circuit of the substitution method is shown in Figure 4. First connect the switch K_1 to point a, adjust the voltage divider R_1, and make the monitoring meter to a certain larger indication value I but the measured meter does not exceed the full range. Then keep voltage divider R_1 unchanged, connect the switch K_1 point b, and the resistance box R_0 is used to replace the measured meter. Adjust R_0 to let the monitoring meter achieve the same display value I. At this time, $R_0 = R_g$.

3) Modify the galvanometer to construct DC ammeter and voltmeter

A microampere galvanometer (i.e. to be modified meter) can only measure very small currents and voltages. If larger currents or voltages need to be measured, it must be modified to expand its range.

(1) Expand the range of a micro-amp galvanometer to construct a DC ammeter

The current I_g deflecting the pointer to full scale is called the range of the micro-amp meter. The smaller the full-scale current I_g is, the higher the sensitivity of the meter. The resistance of the meter coil is called the internal resistance R_g of the micro-amp meter. The current I_g is very small. To measure large currents, the range must be expanded. The method is to connect a shunt resistor R_p in parallel across the meter, as shown in Figure 5. In this way, the part of the current that the meter cannot withstand can flow through the shunt resistor R_p, and the meter current I_g is still within the original allowable range.

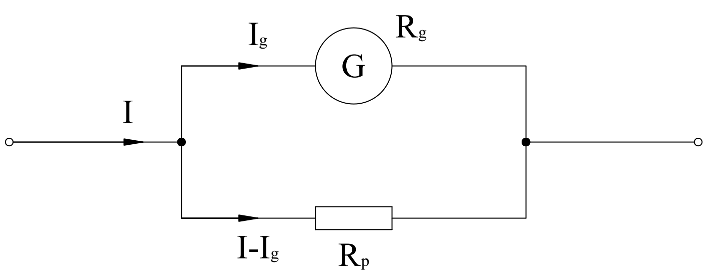

Figure 5 Circuit of the modified DC ammeter

Assume the range of the constructed ammeter is I, by Ohm's law, we have

$$(I - I_g)R_p = I_g R_g . \tag{4}$$

That is:

$$R_p = \frac{I_g R_g}{I - I_g} = \frac{R_g}{\frac{I}{I_g} - 1} . \tag{5}$$

(2) Expand the range of a micro-amp galvanometer to construct a DC voltmeter

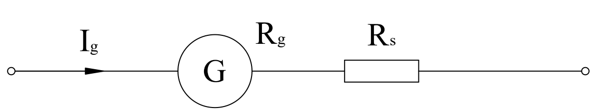

Figure 6 Circuit of the modified DC voltmeter

The voltage the galvanometer itself can measure is very low. In order to be able to measure higher voltages, a resistor R_s can be connected in series with the micro-ampere meter, as shown in Figure 6. At this time, the part of the voltage that the micro-ampere meter cannot bear will fall on the resistance R_s, and the voltage value U_g will still drop on the micro-ampere meter.

Suppose the range of the microammeter is I_g, the internal resistance is, R_g and the range of the constructed DC voltmeter is U, then by Ohm's law, we have

$$I_g(R_g + R_s) = U . \quad (6)$$

That is:

$$R_s = \frac{U}{I_g} - R_g = (\frac{U}{U_g} - 1)R_g . \quad (7)$$

(3) Calibration of electric meters

After the meter is constructed with expended range, it must be calibrated before it can be used. The method is to compare the constructed meter with a standard meter. When the meter passes the same current (or voltage), if the reading of the meter to be calibrated is I_x and the reading of the standard meter is I_0, the correction value of the scale is:

$$\Delta I_x = I_0 - I_x . \quad (8)$$

Calibrate all the scales in this range once, and we can get a set of I_x and ΔI_x (or U_x and ΔU_x) values. Plotting $\Delta I_x - I_x$ (or $\Delta U_x - U_x$) graph by connecting two adjacent points with a straight line, we get the a calibration curve, as shown in Figure 7. When this meter is used in the future, each reading can be calibrated according to the calibration curve, thereby obtaining higher accuracy.

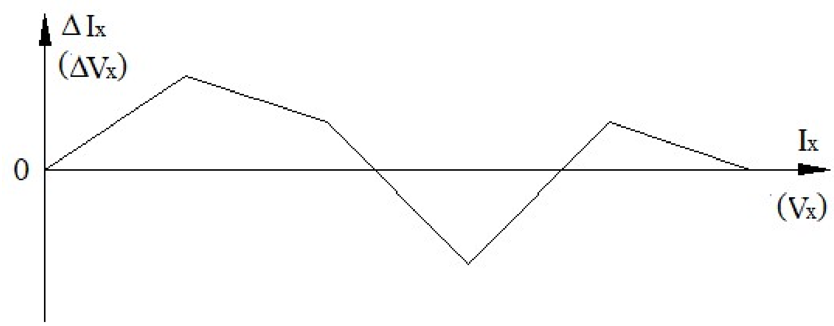

Figure 7 Calibration curve

The maximum relative error of the constructed meter can be calculated as follows:

Maximum relative error = (Maximum absolute error/Range)× 100% ≤ α%. (9)

where α is the grade of the meter. $\alpha = \pm 0.1, \pm 0.2, \pm 0.5, \pm 1.0, \pm 1.5, \pm 2.5, \pm 5.0$.

Therefore, according to the value of the maximum relative error, the grade of the meter can be determined.

For example, to calibrate a voltmeter of range $0 \sim 30V$, if the largest error of the meter is $0.12V$ at scale point $12V$, then the maximum relative error of the meter is $\frac{0.12}{30} \times 100\% = 0.4\% < 0.5\%$.

Because of $0.2 < 0.4 < 0.5$, the grade of the meter is determined as 0.5.