Working With Meters

This is the first of a short series of articles discussing the practical application of meter movements. It covers the basic operation of the most common types of movements, and the methods which may be used to measure meter sensitivity and internal resistance. A following article will show how any particular movement may be arranged to perform a variety of measurement tasks.

by PHILIP PIK

Despite the dramatic growth of digital measuring techniques in recent years, there is still an important place in electronics for the familiar "analog" meter. In general this type of device is still to be preferred where a number of electrical quantities must be measured either simultaneously or at relatively low cost.

There is often a need, particularly in amateur and hobbyist situations, to arrange for a particular meter movement to measure a different quantity, or to display a different full-scale sensitivity, from that for which it was originally intended. For example it may be desired to use a basic micro- or milliammeter movement, obtained either new or from a disposals source, to measure the plate current of the PA or modulator valves in a high-power amateur transmitter, or perhaps to monitor the output voltage of a regulated power supply.

It is the aim of this article, and those which are planned to follow in later issues, to provide the basic information required for the practical application of meter movements. Described in this article will be the most common types of meter movement and their operation, and the methods which may be used to measure the basic sensitivity and internal resistance of a movement. Later articles will then describe the way in which this information is used to adapt a meter to perform a desired function, such as current, voltage or resistance measurement.

Meter movements are electromechanical devices which produce a mechanical change in position of an indicating pointer in response to an applied electrical signal. In general this change in position is produced as a result of the interaction of electric or magnetic fields, one of which is derived from the electrical energy supplied to the meter. The four most common types of meter movement are shown in figure 1.

Of the four, the electrostatic movement shown in (a) is the only type which employs interaction of electric ("electrostatic") fields. It is also the only type of movement which actually measures voltage, as opposed to current.

Basically, the electrostatic movement is a capacitor in which the electrostatic forces present between the plates are allowed to produce movement of one set of plates, this movement being opposed by a "restoring force" from spiral springs. The movement responds to AC as well as DC, the frequency response being limited only by the current carrying capacity of the meter and the capacitive loading effect on the circuit.

The response of an electrostatic movement is proportional to the square of the applied voltage, so that these meters give a true-RMS reading. However it is difficult to produce an electrostatic meter which is both sensitive and mechanically rugged, so that they are normally only used for measuring relatively high voltages.

Another, perhaps not so well-known movement, is the dynamometer variety, shown in figure 1(b). It consists of two coils; one fixed, the other movable. The measured current flows in both coils, the interaction of the magnetic fields producing the torque. As the same current flows in both coils, the torque is proportional to the square of the current making the dynamometer also a true RMS movement.

The absence of any magnetic materials with their associated non-linearity makes the dynamometer inherently the most accurate movement. Accuracies of 0.1% are not uncommon. Because the coils possess significant inductance, the frequency response of this instrument is limited to about 200Hz for high accuracy. Another limitation is the high power requirement, 1 to 3 watts being typical. Dynamometers are available as ammeters with a range from 1 to 50 amps and as voltmeters from 1 to 300 volts.

The moving iron movement, shown in figure 1(c), is closely related to the dynamometer type. Here the moving coil is replaced by a soft iron armature or vane, which is pivoted inside a fixed coil. A second soft iron vane is mounted inside the coil, but is fixed. When current flows through the coil, both the fixed and movable vanes become magnetised by induction, with the same polarity. The movable vane is thus repelled from the fixed vane, moving the pointer over the indicating scale.

The frequency response of these movements is limited to roughly 125Hz. The best obtainable accuracy is not as good as the dynamometer, being in the order of 0.5%. The general power requirement is somewhat lower at about 1 watt. Despite their greater inaccuracy the moving iron vane movements are more popular since they are less expensive. They are used mainly in automotive and other non-demanding applications.

But probably the most common type of meter movement used in electronics is the moving coil or d'Arsonval variety, shown in

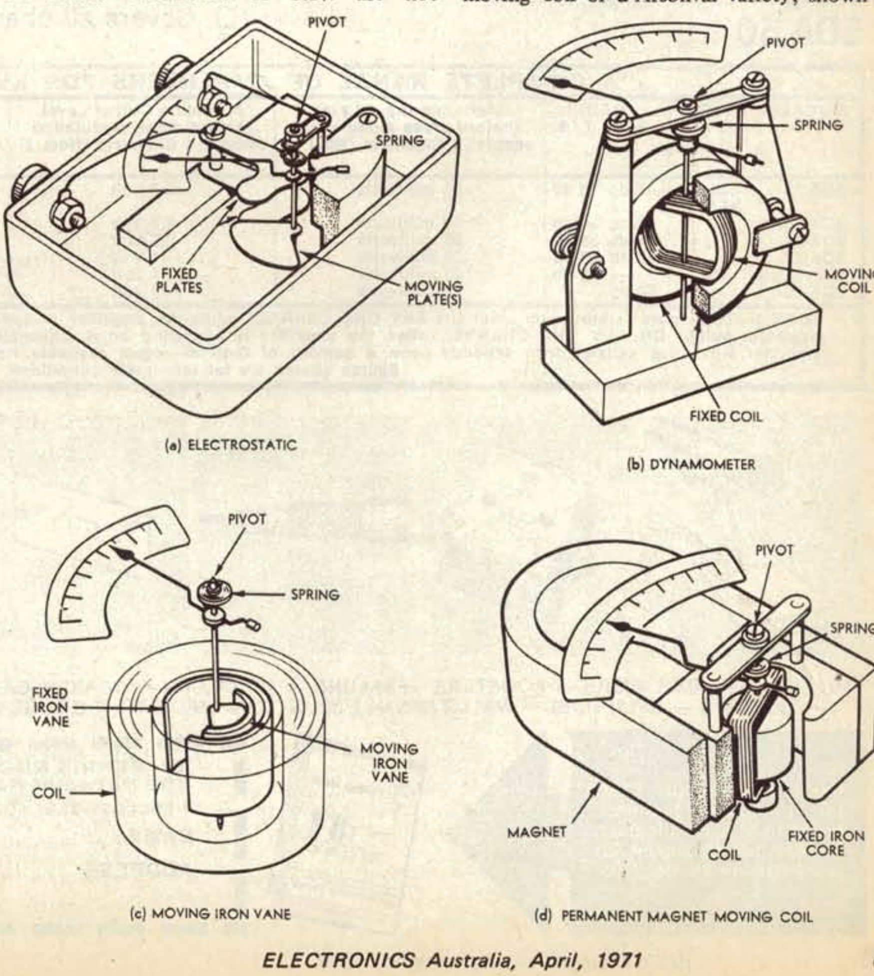


Figure 1. The four basic movements. The text describes the operating principles of each.

figure 1(d). This type of movement relies upon the fact that a current-carrying coil of wire suspended in a magnetic field experiences a "torque", or turning force.

In its usual form, the moving coil meter consists of a multi-turn coil of very fine copper wire, suspended between the poles of a permanent magnet in such a way that it is free to rotate about its own axis. Attached to the coil is a light pointer which moves over a calibrated scale when the coil rotates. The magnet system is arranged so that the coil moves in a "radial" field, that is one whose intensity is effectively constant and at right angles to the plane of.the coil.

When current is passed through the coil, a magnetic field is set up which reacts with the field due to the permanent magnet. The coil thus tends to rotate, rather like the armature of an electric motor. But opposing this rotation are two spiral springs, which tend to apply to the coil an opposing or "restoring" torque increasing in a manner directly proportional to the distance moved by the coil from its rest or "zero" position. The action of these springs is to bring the coil to

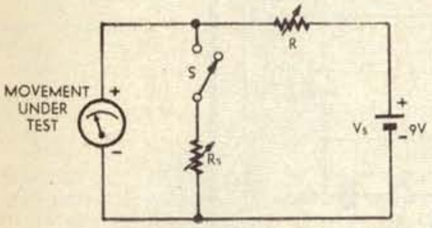


Figure 2. A simple circuit for measuring meter resistance.

rest in a new position whose difference from the zero position is directly proportional to the magnitude of the current flowing through the coil.

The movement is provided with damping to ensure that the coil and pointer come to rest quickly in the new position. The damping is provided by winding the coil on a copper or aluminium former, which acts as a "shorted turn" on the coil. When the coil and former move in the field, a current is induced in the former, and a reaction field set up in a direction which tends to oppose the motion.

It may be appreciated from the foregoing that the moving coil meter can only be used to measure direct currents which are either steady or changing only very slowly. It cannot in general be used to measure directly alternating currents, except perhaps those having an extremely low frequency. The inertia of the movement is such that the coil and pointer tend to remain stationary at the "zero" setting, being unable to follow the rapid reversals of torque.

In order to calculate the series and shunt resistances required to modify the range and function of a basic meter movement, we need to know two quantities: the internal resistance of the meter, and its sensitivity.

With a meter purchased new, it is likely that the internal resistance will be already known. However this is less likely with a disposals meter, and very unlikely with a meter salvaged from old equipment. In these cases the resistance will have to be measured.

Except for large low-sensitivity moving iron meters, it is generally not possible to measure the resistance of a meter movement using a standard ohmmeter or a resistance measuring bridge. The reason for this is that these instruments tend to drive excessive current through the movement, and may well cause permanent damage.

Luckily, the resistance of a meter may be measured quite easily using a simple circuit, consisting of nothing more than a battery and two variable resistors. No additional meter is required, because the meter being tested can itself be used to monitor the adjustments.

The idea is that the meter movement to be measured is connected to an effectively constant current source, which is adjusted for an indication at or near FSD of the meter. A resistance is then connected in parallel with the meter, and adjusted until the meter indication falls to half its initial value. The shunt resistance must then be equal in value to the internal meter resistance.

It should perhaps be noted that before attempting to measure either the internal resistance or the current sensitivity of a movement, a check should be made to ensure that the meter does not contain internal shunts, series multipliers, thermocouples, or other complicating devices. This involves opening the meter casing, an operation which calls for considerable care if damage is to be avoided.

Some movements may appear to contain either a low-value series resistor or a high-value shunt, which is usually in the form of a coil of wire rather than a moulded "resistor". This is not a shunt or multiplier in the normal sense of these terms, but a trimming resistor used to compensate for manufacturing tolerances and adjust the movement for the desired nominal sensitivity. As such, it should strictly be left connected to the meter.

However if the trimming resistor is inadvertently removed, no great harm is done. The only result will be that the shunts or multiplier resistors required for adapting the movement to the desired task may tend to have "awkward" values, corresponding to the untrimmed sensitivity of the actual movement.

Figure 2 shows the practical circuit used to measure meter resistance. The resistor R in series with the battery is arranged to have a sufficiently high value to ensure that the meter is fed from an effectively constant current source. This implies that the resistor should have a value higher than 100 times that of the highest resistance meter likely to be tested.

Most moving coil movements with current sensitivity figures below about 5mA FSD have a voltage sensitivity of approximately 100 millivolts. This is because the main factor controlling current sensitivity is the number of turns on the moving coil; sensitive movements thus tend to have a great many turns on the coil, while relatively insensitive movements have relatively few. The effect is to cause the voltage required for FSD to remain substantially constant.

The highest resistance likely to be encountered in disposals moving coil meters will thus generally be 2,000 ohms, corresponding to a 50uA movement. This suggests that the resistor R in figure 2 should have a maximum value of at least 200K.

For testing the majority of moving coil meters, a 9V battery and a 250K variable resistor form an entirely adequate constant current source. These values have therefore been shown on the circuit; however they may not be adequate for moving iron instruments, as some of these have an internal resistance as high as 5K. To check such meters, a resistance of 500K or more will be required, together with a correspondingly larger supply voltage.

The operating procedure is as follows. With the switch S open, the series resistor R is adjusted until the meter reads a convenient value, preferably a value near FSD to ensure maximum reading accuracy. Next the switch S is closed, and the shunt resistor Rs adjusted until the meter reading is as close as possible to half its first value. The value of Rs is then equal to the resistance of the meter, and after opening S it may be measured using an ohmmeter or resistance bridge.

The current sensitivity of a meter movement is the second important quantity to be determined for the purpose of calculating shunts and series resistors.

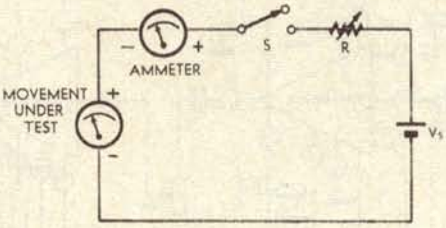
The "sensitivity" of a meter movement is basically the measure of the power requried to produce full scale deflection (FSD). It is thus a function of the voltage and current requirements of the movement, which will be related by the internal resistance.

Because of the way in which the voltage and current requirements of the meter movement are determined by the internal resistance, it is common to relate the sensitivity of a movement to the current required for FSD. Knowing this current sensitivity and the internal resistance, it is an easy matter to calculate the power or voltage sensitivity of the movement.

A term sometimes used to indicate the current sensitivity of a meter movement is its "ohms per volt" figure. This gives the total resistance of the meter and its appropriate series multiplier when arranged to measure voltage, and is expressed per unit volt. Thus a movement described as having a sensitivity of 20,000 ohms per volt will involve a total resistance of 20 Kilohms when used as a voltmeter reading 0-1V. By Ohm's law, the current sensitivity of such a meter is the inverse of the ohms per volt figure, or in this case 50 microamps FSD.

In the case of a meter movement purchased new, the current sensitivity will again normally be known. This may also be the case with a meter from a disposals source. However with a meter salvaged from a piece of equipment, it may be necessary either to measure the current sensitivity, with no idea of its approximate value, or to make a measurement in order to check one's suspicions.

Figure 3 shows the basic circuit for measuring current sensitivity. The ammeter A may be nothing more than a standard multimeter with suitable direct current ranges. To make the measurement, the



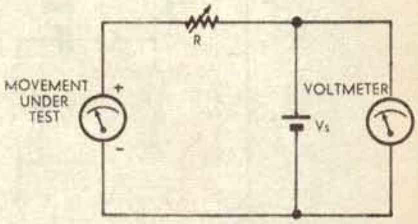


Figure 3, at left shows how an ammeter is used to measure current sensitivity, whilst figure 4. at right, shows the voltmeter method.

multimeter range switch should first be set to the highest current range, and the variable resistor R adjusted to maximum resistance Switch S should then be closed, and R adjusted until the meter indicates FSD. The multimeter may than be switched to lower current ranges, to read the current flowing. It may be necessary to re-adjust R when this is done, to compensate for the changes in multimeter resistance. The final reading of the multimeter will correspond to the FSD current sensitivity of the meter movement being tested.

If neither an ammeter nor a multimeter with suitable current ranges is available, the alternative arrangement of figure 4 may be used. This uses a voltmeter, and relies upon being able to determine accurately the value of the adjustable resistor R. When R is adjusted for FSD on the meter movement, the current sensitivity is then found by dividing the supply voltage indicated on the voltmeter by the total circuit resistance.

If for the FSD situation the adjustable resistor R has a value which is more than 100 times the internal resistance of the meter movement, the current flowing will be for practical purposes equal to the supply voltage divided by R. In other words, the meter resistance becomes negligible and may be ignored. However if the available supply voltage is not great enough to allow R to be made more than 100 times the meter resistance, then the later will play a significant part in determining the circuit current, and should thus be taken into account.

Although the basic testing circuits of figures 2, 3 and 4 will generally be all that is required for checking individual surplus meters for internal resistance and current sensitivity there may be some readers who have a need to check many meters rapidly. Such readers may find figure 5 of interest, as it shows the circuit for a general-purpose meter checking unit.

The procedure for measuring internal resistance using the unit is as follows. Set switch S3 to position 2, and switch S1 to position 1. Then turn the potentiometer R1 fully anticlockwise, corresponding to maximum resistance in circuit. With S2 in position 1, the meter should now be showing some deflection, although it may only be very small.

The value of R1 should now be reduced, in an effort to produce an FSD reading on the meter. If this cannot be achieved, switch S1 should be turned to position 2, or if necessary position 3. Alternatively a decade box may be used for R1, with S1 turned to position 4. But for meter resistance measurement the decade box is not really necessary.

Once the movement is reading FSD, switch S2 may be moved to position 2. Potentiometer R2 is then adjusted until the pointer of the movement reads half of the FSD value of the scale indications. Note that this may not correspond to the physical midpoint of the meter scale, particularly in the case of a moving iron movement, due to non-linearity.

If it is found that the adjustment of R2 with the switch S2 in position 2 is difficult to carry out because the adjustment falls at the extreme end of the pot, position 3 should be selected. Position 4 allows a decade box or external resistor(s) to be connected into the circuit.

As the resistance of R2 at the half current deflection point is equal to that of the movement it is beneficial here to use a decade box, as then the meter resistance can be read straight from the box. Provision has also been made to switch an external resistance measuring instrument such as an ohmmeter across R2, by placing S3 in position 1. This also automatically disconnects the movement from the circuit, preventing any possible damage.

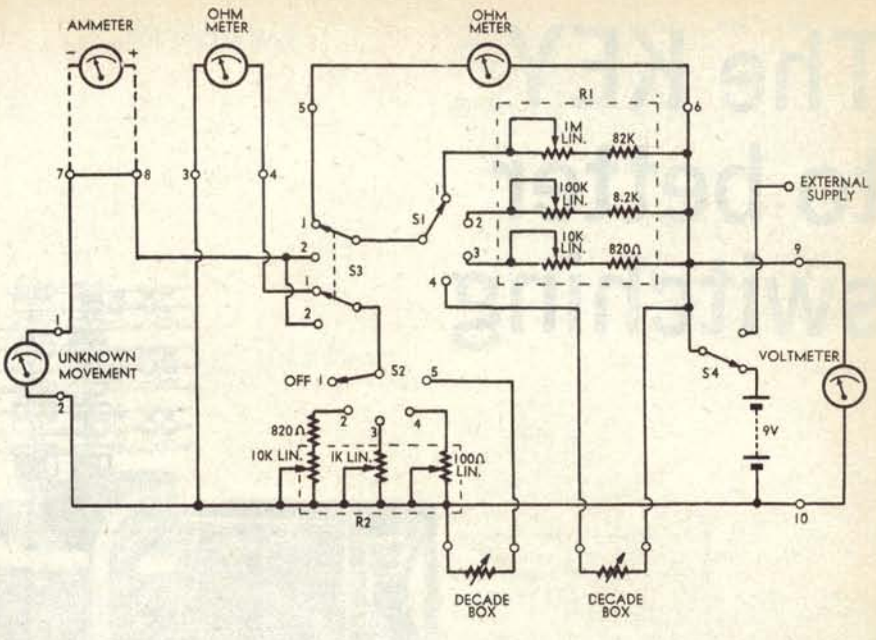


Figure 5. A flexible all-purpose circuit which measures the resistance and current sensitivity of almost any type of movement.

Moving iron movements are measured using an identical procedure. However, it may be necessary in some cases to use a higher supply voltage. For this reason, a switch S4 has been included in the circuit. Normally DC can be used for both moving coil and moving iron movements. If, however, a moving iron instrument contains shunt or series resistances in the form of chokes and it is desired to keep these in circuit, it is preferable to use an AC supply of the frequency at which the movement is to be used.

The reason for this is that some of these chokes have magnetic cores and thus their impedance (reactance) is highly frequency dependant. Hence meters using this type of choke must be used at the designated frequency (usually marked on the scale), as inaccuracies otherwise result. Remember though that most basic moving iron movements can be operated over at least a limited range of frequencies from DC to about 200Hz or higher, depending on the type and make. Other than these precautions, the procedure for all the measurements is exactly as for a moving coil movement.

To use the unit of figure 5 to measure current sensitivity using the method of figure 3, an ammeter or multimeter with direct current ranges should be connected between terminals 7 and 8 in place of the link. Switch S2 should be placed in the "off" position, and S1 in one of the four positions depending upon the known or estimated resistance of the movement. R1 is then adjusted to give an FSD reading on the meter under test, as outlined in the procedure for figure 3.

The voltmeter method as described for figure 4 can also be used with the multi-purpose unit. In this case the link is used between terminals 7 and 8, and R1 used for FSD movement indication, after S1 has been positioned according to the meter resistance. To measure R1, S3 is then turned to position 1 and an ohmmeter or resistance bridge connected to terminals 5 and 6. The alternative is to use a decade box for R1, in which case the box itself will indicate the resistance value in circuit.

Once the two basic quantities of current sensitivity and internal resistance of a meter movement are determined, it is possible to calculate readily the shunts and series multipliers required to adapt it for use as a voltmeter, ammeter or ohmmeter. In the next article we hope to explain the procedure involved in this further step. ■