Elements of Electronic Instrumentation and Measurement

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PREFACE

Even the least observant among us has to notice that we live in a world of measurement; in fact, it has been said that you really cannot understand a physical phenomenon until you can measure, i.e. quantify, it. A physicist friend of the author is fond of saying that physics is the science that measures reality.

Just as measurements are a tool for our understanding, instruments are a tool for measurements. Electronic instruments have proliferated to the extent that it is not possible for a person to claim a technical or scientific education without having some exposure to electronic instruments. People who never in the past had any use for instruments now find themselves heavily involved with an array of electronic devices. We find traditional analog and digital instruments widespread. The advent of the microprocessor IC and the microcomputer adds near limitless capability; from small units inside of other instruments to larger number crunching systems.

In this book, you will study certain instrumentation techniques, both traditional and modern. You will be introduced to certain commercial products, and will come to understand *what* you are measuring. In certain cases, like the triggered sweep oscilloscope, skill in operating an instrument is so crucial to anyone in engineering, technology, or the sciences, that basic instructions are offered. You are, however, advised that it is best if you obtain as much practice as possible. If an electronics laboratory is available to you, then spend some time learning to operate all of the instruments . . . with special attention to the oscilloscope.

JOSEPH J. CARR

chapter 1

DC DEFLECTION INSTRUMENTS

1-1 OBJECTIVES

1. To learn the principles of operation of basic dc meter movements.
2. To learn methods for extending the current range of the basic dc meter.
3. To learn how to measure *voltage* by using a dc *current* meter.
4. To learn the operation of a volt-ohm-milliammeter.

1-2 SELF-EVALUATION

Before studying the material in this chapter, try answering the questions given below. These questions test your knowledge of the subject. If you cannot answer any particular question, then look for the answer as you read the text.

1. Describe in your own words the *D'Arsonval* meter movement.
2. What is the principal difference between the *D'Arsonval* and *taut-band* meter movements?
3. How may a dc current meter be used to measure an ac voltage?
4. A ____________ resistor is used to make a dc current meter into a dc voltmeter.
5. A ____________ resistor is used to increase the range of a dc current meter.

1-3 THE BASIC DC METER

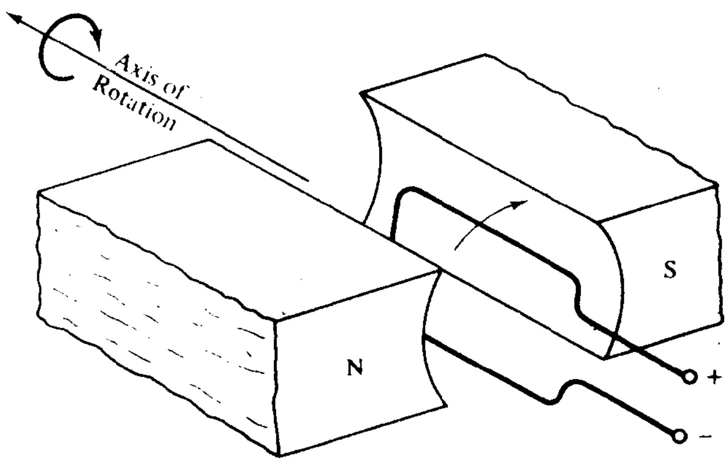
For many decades the basic dc meter movement has been used as the readout device in most electronic instruments, even in many instruments that measured ac. Digital readout devices were too expensive for general application until the early 1970s, so most instruments relied on analog meter movements to provide the readout function.

The two most common dc meter movement configurations are the *D'Arsonval* and *taut-band* designs. Both are examples of a *permanent magnet moving* *coil* (PMMC) galvanometer, and work on the same fundamental electrical principle as the dc motor.

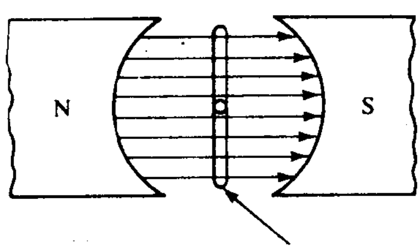
A simplified view of the PMMC galvanometer is shown in Figs. 1-1(a) and 1-1(b): a movable coil of wire is mounted in the magnetic field between the poles of a permanent magnet.

A current flowing in a wire generates a magnetic field. The *polarity* of the field is determined by the *direction* of the current flow, while the *strength* of the field is determined by the *magnitude* of the current.

The coil in a PMMC galvanometer is mounted so that it can rotate in the space between the magnet poles. A current in the coil creates a magnetic field



(a)



(b)

Figure 1-1. (a) Construction of a D'Arsonval meter movement. This meter uses a loop of wire rotating in a magnetic field, much like an electrical motor. (b) Side view of the D'Arsonval meter movement.

that either *aids* or *opposes* the field of the nearby poles. A current flow in one direction causes a clockwise rotation, whereas a current flow in the opposite direction causes a counterclockwise rotation. The amount of rotational position change is proportional to the magnitude of the current.

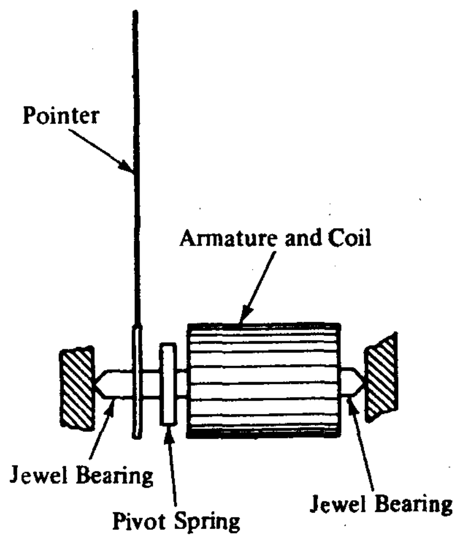
1-4 THE D'ARSONVAL MOVEMENT

The *D'Arsonval* meter movement is shown in Fig. 1-2. A side view of the meter, without the permanent magnet, is shown in Fig. 1-2(a), while a frontal view *with* the magnet is shown in Fig. 1-2(b).

The coil in Fig. 1-2(a) is shown wound on an *armature* or *bobbin*, which is mounted on a pair of jewel bearings to reduce friction. This assembly is shown frontally in Fig. 1-2(b).

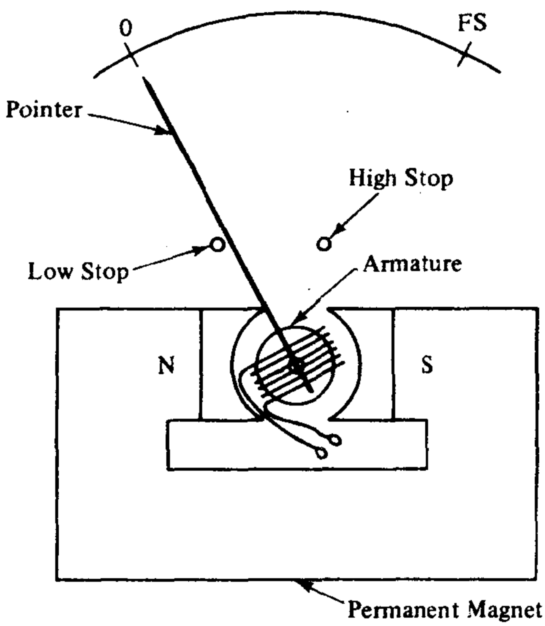
When a current flows in the coil, the armature assembly deflects *clockwise* [as viewed in Fig. 1-2(b)] an amount proportional to the strength of the current. The amount of deflection can be marked off in units of *current* on the dial scale. The coiled *pivot spring* serves to dampen the pointer movement, and to return the pointer to the zero position when the current flow in the coil ceases.

The travel of the pointer is limited by high and low end mechanical stops just beyond the *zero* and *full-scale* limits printed on the dial scale. The wires to the coil are given just enough slack that they will not be stretched anywhere in the pointer's normal range of travel.



(a)

Figure 1-2. (a) Construction of the coil and pointer assembly in a D'Arsonval meter movement.



(b)

Figure 1-2. ***(cont.)*** (b) Usual configuration for a D'Arsonval meter movement.

1-5 THE TAUT-BAND MOVEMENT

The taut-band meter movement is essentially the same as the D'Arsonval, except for the manner in which the armature coil is mounted (see Fig. 1-3). In the taut-band movement the armature is *suspended* from fixed supports on a stretched, i.e., taut, rubber band. The band is twisted as the armature rotates, so no restoring force from a pivot spring is needed.

There are two principal advantages to the taut-band meter movement over the older D'Arsonval design: greater *sensitivity* and more *durability*.

Older D'Arsonval movements are rarely found with full-scale sensitivities of less than 50 microamperes; whereas there are taut-band models available that boast full-scale sensitivity of only 2 microamperes.

D'Arsonval movements are more easily damaged than taut-band types because of their jewel bearing construction. Even a short fall to the floor or a table top is sufficient in many cases to break the bearings. The rubber band in a taut-band meter can snap, but this occurs far less frequently than does bearing damage.

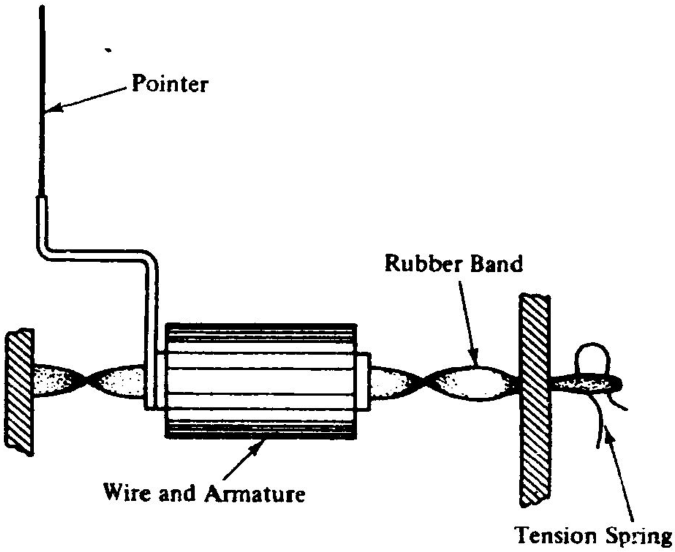


Figure 1-3. Construction of taut-band meter movement.

1-6 TYPES OF METERS

The two basic meter movements are available in an almost endless variety of sizes and shapes, but we can classify meter types by the form of scale that is used. Figure 1-4 shows three different configurations.

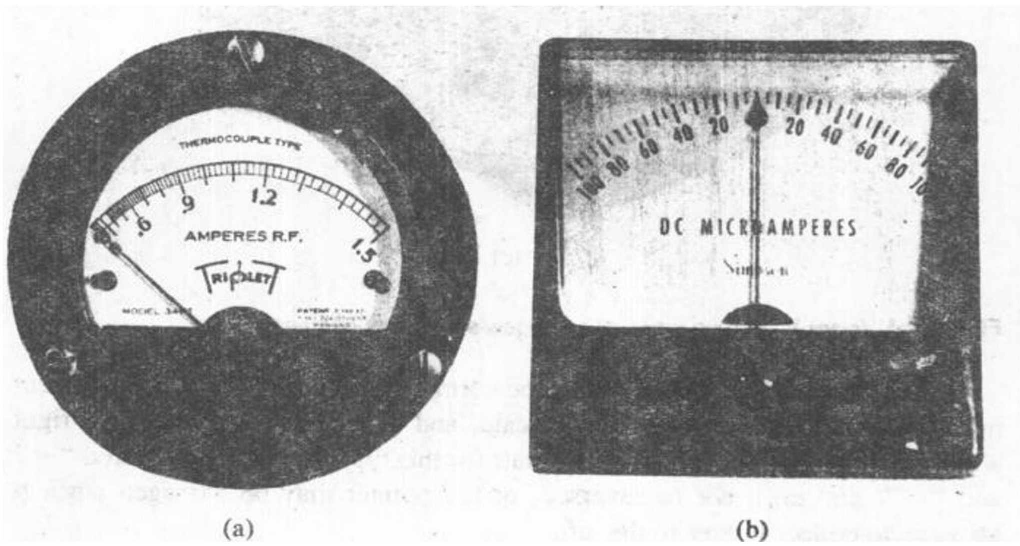
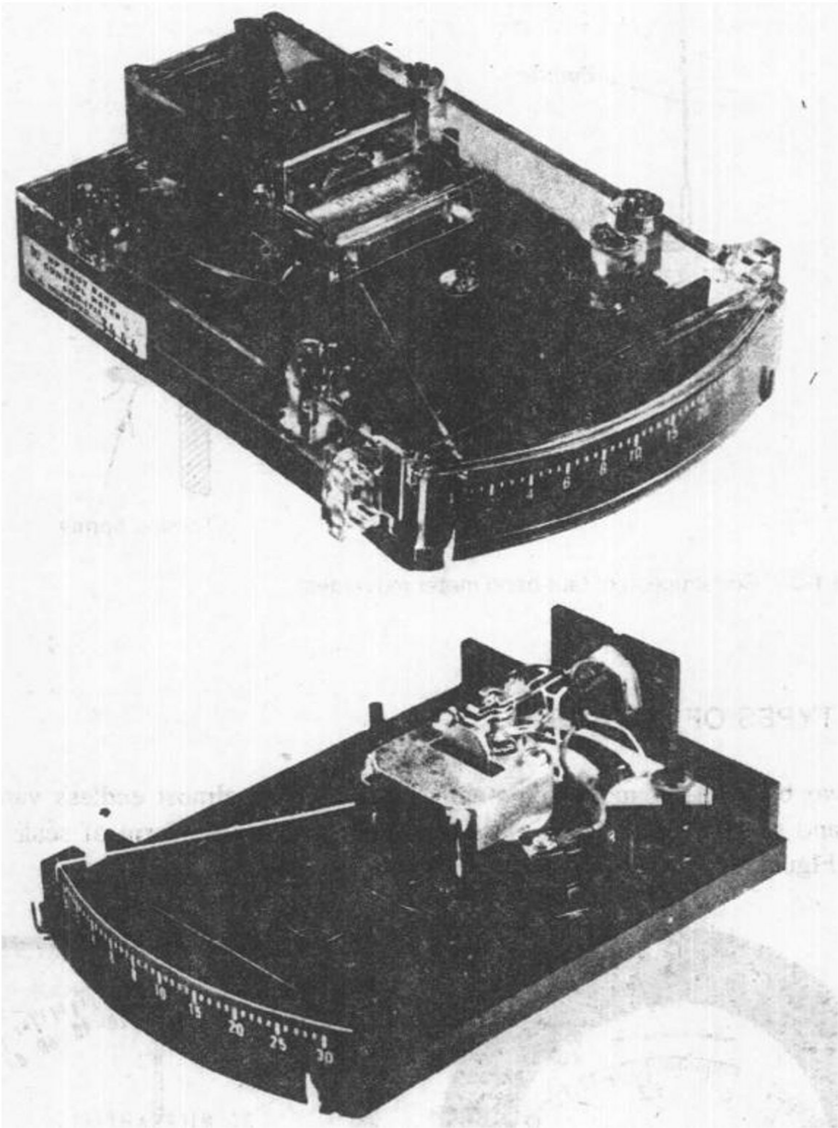


Figure 1-4. (a) Thermocouple RF ammeter. (b) Zero-center dc microammeter.



(c)

Figure 1-4. ***(cont.)*** (c) Two views of an edgewise meter movement.

The meter in Fig. 1-4(a) is the type normally encountered. The zero-current mark is on the left-hand side of the scale, and the pointer deflects to the right when a current flows. The input terminals for this type of meter are marked "+" and "−", and must not be reversed, or the pointer may be damaged when it attempts to deflect further to the left.

Figure 1-4(b) shows an example of the *zero-center galvanometer;* the zero-current mark on this type of meter is in the exact center of the scale. Current flowing in one direction will deflect the pointer to the left, while current flowing in the opposite direction will deflect the pointer to the right. When the polarity markings on the input terminals are observed, a positive current deflects the pointer to the right and a negative current deflects it to the left.

The type of meter movement shown in Fig. 1-4(c) is an *edgewise* panel meter. Its design allows conservation of *area* on the front panels of equipment in which the movement is used. Of course, this saving is at the expense of increased depth. The high and low limits are sensed by external circuitry and are set by the tabs on the meter face. Edgewise meters are available in both left-zero and center-zero models.

1-7 USING BASIC DC METERS

There are three basic rules for using dc *current* meters:

1. Connect the meter in *series* with the load or circuit in which the current is being measured.
2. Use the meter with a full-scale rating greater than the maximum expected current.
3. Use a meter that has an internal resistance that is *low* compared with the resistance of the circuit in which it is being used.

A current meter is *always* connected in *series* with the load. There are never any exceptions. *Failure to observe this rule may result in permanent damage to the instrument.* In cases where the meter is used to measure current in a branch of a larger circuit, then the meter is to be connected in series with that branch.

Figure 1-5 shows the correct connection for the 0 to 1 mA dc current meter. It is necessary to break the circuit, i.e., the wire to resistor $R1$, and connect the meter in series.

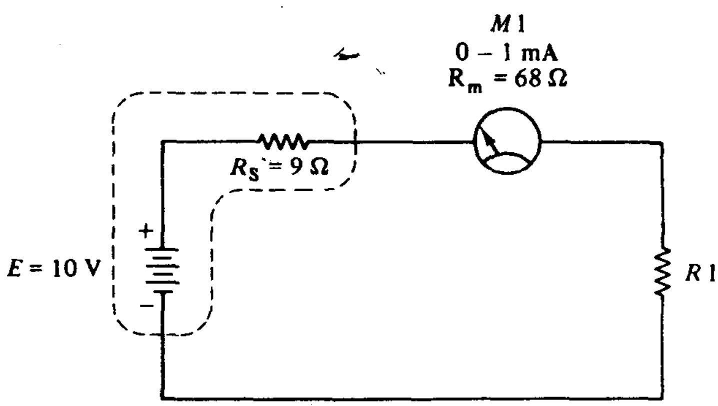


Figure 1-5. Circuit with 0–1 mA milliammeter.

The current flowing in meter $M1$ is given by

$$I_{m1} = \frac{E}{R_s + R_m + R1} \qquad (1\text{-}1)$$

where I_m = the meter current in amperes (A)
E = the open-circuit voltage (V)
R_s = the power supply *source resistance* in ohms (Ω)
R_m = the internal resistance of the meter in ohms (Ω)
$R1$ = the load resistance in ohms (Ω)

In most cases R_s and R_m are very small with respect to $R1$, so are considered negligible. If that is true, then Eq. (1-1) reduces to Ohm's law

$$I_{m1} = \frac{E}{R1} \qquad (1\text{-}2)$$

Example 1-1

Find the current flowing in $M1$ if $R1$ is 15 kΩ.

SOLUTION

[Since $R1$ is very much greater than R_s or R_m, use Eq. (1-2).]

$$I_{m1} = E/R1 \qquad (1\text{-}2)$$
$$I_{m1} = (10\ \text{V})/(1.5 \times 10^{4}\ \Omega)$$
$$I_{m1} = 6.7 \times 10^{-4}\ \text{A} = \mathbf{0.67\ mA}$$

The current in Example 1-1 is less than the full-scale rating of the meter—i.e., 1 mA—so our circuit obeys rule 2.

Example 1-2

Find the current flowing in $M1$ if it were *incorrectly* connected in parallel with $R1$ instead of in series as is proper.

SOLUTION

[Use Eq. (1-1) because $R1$ is very much greater than R_s and R_m so its parallel effect is negligible; delete $R1$ from the equation.]