ELECTRONIC MEASURING INSTRUMENTS

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PREFACE

A SURVEY of the field of electronic instruments published in *Electronic Engineering* for May 1950 led to the expansion into the present book, as there is considerable interest and activity in electronic measurements in industry.

For the purpose of this book the definition of 'electronic measuring instruments' is as follows: 'Instruments to measure either electrical or non-electrical quantities incorporating one or more electronic devices, used either with electrical measuring instruments presenting the reading on a scale or chart, or alternatively the electronic device may include its own means of indication, such as the trace on a cathode-ray tube. The readings are quantitative.' 'Quasi-electronic instruments are those which contain some of the elements of an electronic instrument, but which could also be classed by some alternative term in some cases, such as electromagnetic.'

The book is intended for the instrument engineer in general: the instrument user requiring to know more of the scope of electronic measurements: and the student with some knowledge of electronics, It is not an examination text-book.

The book cannot be complete, both on account of space and time. A more comprehensive book would result in such a high cost that use would be restricted, and if it were held up until considered complete then it would never be published.

The choice of what has been included and excluded is the author's, with the general aim of covering the main electronic devices used in measurement; the various classes of instrument using these devices and some typical examples of instruments, the selection of which will necessarily not satisfy all readers. In particular this applies to the quasi-electronic instruments such as the magnetic amplifier, which itself is perhaps no more electronic than is the transformer, but it is included owing to its comparable scope with electronic amplifiers in instruments and because it is not yet generally treated in other books on measuring instruments. Most radio test gear such as signal generators, oscillators, valve testers, etc, is excluded, other than valve voltmeters, which are included in the postulated definition. Present commercial radiation measuring instruments are not described individually as their number is legion and the technique is growing so rapidly that such descriptions would soon be out of date. One source of reference to these specific instruments is in the *Brochure of Instruments and Accessories for Radio-Isotope Applications*, published by the Scientific Instrument Manufacturer's Association.

Page references and chapter bibliographies are included, but are not intended to be exhaustive or they might well occupy half the book. In particular they are scarce for long-developed devices such as thermionic valves, and more complete for newer devices such as those used for radiation measurement. Bibliographical references are denoted [B] in the text.

The book endeavours to comply with British Standard terminology, symbols and spelling of technical terms, and quotes British Standards and Codes of Practice, where relevant. Due to alternative recommendations in some Standards it has not always been possible to adhere to uniform graphical symbols, however, drawings having been obtained from various sources.

Constructive suggestions will be welcomed and should another edition be called for they will be taken into consideration.

Possibly the science of electronics is not so young as we think. Were thermocouples and thermopiles used at Thermopylae? And are crystals descended from the Oracle of Delphi? Columns of ions may be akin to Ionic columns and the Odes of Horace have long developed beyond diodes and triodes.

The impact of electrical science on the measurement of many quantities is perhaps exemplified by the fact that any salesman's job is electrical—the conversion of a potential customer to a current customer.

This book was written during 1951 and early 1952, but some important amendments were made in the proof stage this year.

E. H. W. BANNER

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PART I

THE CHARACTERISTICS OF INDICATING INSTRUMENTS APPLICABLE TO ELECTRONIC DEVICES

CHAPTER 1

INDICATING INSTRUMENTS

INDICATING INSTRUMENTS reading volts and amperes, together with their multiples and sub-multiples, are normally two-terminal instruments requiring no auxiliary apparatus or source of supply. They are therefore simple to install and use, and where they can be read they are preferable to other instruments requiring auxiliary sources.

The fundamental law of most types of instrument, electromagnetic in particular, is

$$T \propto \frac{dS}{d\theta}$$

where $T =$ torque

and $\frac{dS}{d\theta} =$ change of 'system' with deflexion θ.

'System' is here used quite generally; it may be line-turns in the moving-coil instrument, inductance in the moving-iron, etc. A change of some electrical condition with deflexion is necessary for force to be produced, which combined with angular rotation becomes torque.

An indicating instrument may be considered to have three essential functional parts:

Torque-producing system
Controlling torque
Method of presentation.

In the electromagnetic class of instrument only the moving-coil type has much application to use with electronic devices. Such instruments read direct current only, and electronic devices are used with these instruments either to extend the minimum practicable range (or conversely to have a much higher resistance for a given range of voltmeter) or to use the instrument on other than direct current.

In many electronic circuits d.c. is present in the 'output' stage, such as the anode current of a valve, output of a photocell, etc, and the application of a moving-coil instrument is then simple and direct.

In other cases an instrument is required to serve a.c. of various frequencies and the need for an electronic device with a moving-coil instrument is seen.

Other electromagnetic instruments having some electronic application are the electrodynamic and moving-iron types. Both read d.c. and a.c. and their use is in connexion with electronic servo systems to increase the available torque. This subject is dealt with in Chapter 15.

In a different category is the electrostatic voltmeter and this is dealt with on page 10.

The controlling torque is almost always by means of springs; but gravity may be used, as in the bifilar suspended form of galvanometer and in some types of switchboard moving-iron instruments. An auxiliary control by a second current-carrying coil, or by a permanent magnet is sometimes used.

The method of presentation is normally a pointer on a scale, but variations are found such as a light beam, giving an effective scale multiplication factor, and a fixed pointer and moving scale. For graphic recorders some form of pen on a moving chart is required, generally with friction and requiring higher torque. A class of self-balancing recorders is available in which additional torque is provided from the mains and places no restraint on the movement. These are described in Chapter 15.

For optimum performance accuracy and sensitivity should be related and as a summary the practical limits may be taken as about 0·1% for portable instruments and 0·01% for long-scale laboratory deflecting instruments.

The subject of the presentation of instrument readings is well covered in a paper by Golds[B].

A short survey of types of instrument and their applications, including the measurement of non-electrical quantities, is given in a paper by the author[B].

UNITS

'Absolute' units are now standard in the United Kingdom from 1 January 1948, replacing the former 'International' units.

The numerical difference is within 0·05%, and so for most practical and commercial purposes it is of little account, but for standardization and measurements at the maximum order of accuracy the new values are of importance.

The relations are as follows:

1 International Ohm	=	1·000 49	Absolute Ohms
Volt		1·000 34	Volts
Ampere		0·999 85	Ampere
Watt		1·000 19	Watts
Henry		1·000 49	Henrys
Farad		0·999 51	Farad.

SCALE SHAPES

A moving-coil instrument, due to its permanent magnet, has a linear law when the airgap flux is spatially constant, resulting in a linear scale. Wattmeters, reading the product of $V I \cos \phi$ also have a linear scale, again provided that the flux due to the fixed system is uniform in space over the travel of the moving system, with but air-cored electrodynamic wattmeters some distortion may be present due to the finite swing of the moving coil, resulting in a slightly cramped scale at the ends. Voltmeters and ammeters other than moving-coil obey a square law, in that their forces are proportional to the square of the voltage or current being measured, but this does not necessarily result in a square-law scale. For the moving-iron instrument, as an example, suppose the movement to be held at a given position and the force due to a given current be measured; this would be found to follow a square law. But in practice the moving iron necessarily moves in relation to the fixed iron system so that the scale does not follow a true square law, the continually opening scale divisions of the true square-law scale being modified. This also holds for most electrostatic voltmeters.

Normally a linear scale is preferred and in design the system is deliberately modified to produce a good scale shape, and in the best examples of moving-iron instruments the scale is practically linear from about the first 10% upwards.

For mains voltmeters the true square-law scale is of advantage, as a small departure from nominal voltage results in about twice the change of deflexion of that of a linear-scaled instrument. For some purposes there is some advantage in a scale closing up rapidly at the top so that overloads can be seen on the scale, still retaining a good open scale for normal or full load. This type of scale also can be achieved in the moving-iron instrument by suitable design, The scale shape of a moving-coil instrument may be made non-linear, if required, by shaping the pole-pieces and/or the iron core so that the magnet flux in the airgap is spatially non-uniform. A nearly logarithmic scale can be made in this way, and it may be either direct or reversed as required. Such a logarithmic scale has not only the obvious advantage of constant percentage accuracy all over the scale, but it can be used in some circuits to provide a linear calibration of some quantity which is already logarithmic. Two examples are decibel meters and photographic exposure meters. Moving-coil instruments with non-linear resistors such as metal rectifier elements, in parallel with the movement, have been produced. An approach to a logarithmic scale can be made, by suitable choice of resistances, but the calibration is not good and this method is best for the final advantage, that of protection against overloads. As current is increased, more and more is shunted through the non-linear resistor. This is an example of an electronic device applied to an indicating instrument.

For null detectors an enhanced sensitivity over a small arc may be made by suitably reducing the pole-face area.

A true square-law scale is found in the thermo-couple instrument, where the thermo-couple obeys a square law and applies its voltage to a linear moving-coil indicator.

MOVING-COIL TYPE

The moving-coil instrument comprises a movable coil carrying current proportional either to circuit voltage or current, as required. In normal designs the magnet poles embrace the coil, with a central core to reduce the airgap, but in Lipman's design the high magnetic energy of modern magnet steels is used by inserting a very small magnet inside the coil with only a small iron ring outside the coil to complete the magnetic circuit. This latter construction results in a small and compact instrument.

Some figures for current range and resistance for moving-coil instruments are given on p. 7. These are typical of modern good practice, but they are not necessarily universal. They are not covered by any British Standard.

Although only current ranges are given, the figures can also apply to voltage ranges by the use of a suitable current range and series resistance, adding a proportion of not less than three times the coil resistance