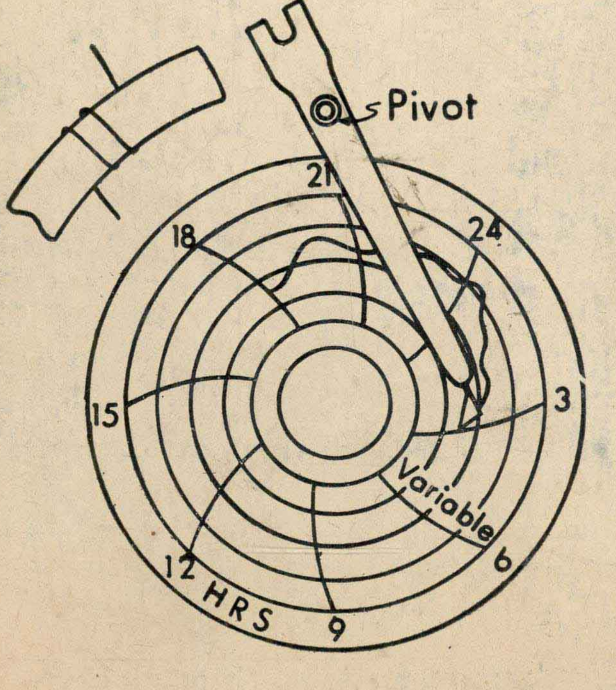
Principles of Industrial Instrumentation

D. PATRANABIS



PRINCIPLES OF INDUSTRIAL INSTRUMENTATION

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To Kakaji

Preface

Till recently, few technical institutes in India offered courses in industrial instrumentation, and these were taught in a piecemeal fashion to suit the varying demands of each curriculum. Things have now changed. The increasing demand for instrument engineers has led to the recognition of the importance of full-fledged courses at both undergraduate and postgraduate levels at several institutes in the country.

The desire to write this book arose when, in teaching the course at the undergraduate level, I became aware of the difficulties faced by my students through the lack of easily accessible reference and background material, and especially of the need for a handy single volume which would provide a basic text. This book attempts to fill the gap. I have tried here to combine a study of the practical aspects of this discipline with the theory underlying it. I hope that this will make the book of use to the practising engineer as well as to students. The text falls into three parts: Part I covers the topics of the general process and system variables measurement; important analysis instruments are dealt with in Part II, and in Part III I have taken up certain topics which are now recognized to have a bearing on the subject. There are three appendices, one of which contains useful tables for easy reference. The book is illustrated with line drawings, but I have not used any photographs as they do not, in my opinion, help in the understanding of the fundamental principles.

It is not possible to name all the many people to whom I am indebted for suggestions, comments, and help. The sections on Statistical Data and Error Analysis, Recorders, and Computer Control arose, in fact, as a result of suggestions. I am grateful to my students and in particular to my colleagues for their insistence on my writing this book, and to Messrs Tata McGraw-Hill Publishing Company for editorial assistance.

Calcutta D. Patranabis

Principles of Industrial Instrumentation

PART ONE

Process and System Variables Measurement

Contents

CHAPTER I

Characteristics of Measurement System

1. Introduction

THE basic purpose of instrumentation in a process is to obtain requisite information pertaining to the fruitful completion of the process. The object of fruitful completion, in industrial terminology, is obtained when process efficiency is maximum with minimum cost of production and a desired level of product quality.

The information that may be available, sometimes indicates the progress of the process in a very simple way involving, perhaps, a direct relation. Such direct measurements are generally accomplished by simple mechanical means. In the majority of the processes, however, a direct measurement is not always possible and an indirect measurement technique, involving a derived relationship between the measured quantity and the desired result is adopted. The modern trend, in the indirect methods of measurement, is to go for electrical methods which offer the possibility of high speed of operation and simpler processing of the measured value.

The types of information that are obtained may not always be in the form of a concrete value of a measured quantity, i.e. the instrument may or may not indicate or record the measured value as such. It might only transmit a variation of the value over a distance, or give a signal that a desired value has been reached, or indicate a specific value with an indicating hand over a suitable scale. It might also produce a written record of the variable against the time axis or even register the values in discontinuous steps by what is known as counting. A single instrument might be required to perform any one of the above operations individually or a number of them at a time.

2. Functional Units

Whatever operations an instrument may perform, it has to be composed of a number of building blocks. The appropriate combination of these blocks in a measurement system is necessary for the proper functions of converting a process condition into a suitable indication. These building blocks, also known as the elements, are only functional units. A generalized instrument system consists of three such functional units:

1. The primary element which converts a small part of the process energy into a suitable form to be operated on by the subsequent stages or elements. This conversion should contain the information regarding the magnitude or otherwise of the measured variable. This element is also known as the transducer.

2. The secondary element or the modifier converts the output of the primary elements into a condition useful to the appropriate function of the instrument. This element performs any correction necessary due to the preceding operations.

3. The final element, sometimes loosely spoken of as the display device, is the part of the instrument used for performing the operations previously described (such as indicating, recording, etc.).

The strain indicating system is a specific example. It is an electrical type instrument. The primary element is the strain gauge, the secondary element consists of a bridge circuit and an amplifier, and the final element consists of an electrical output meter (a voltmeter).

3. Classification

An instrument, however, is classified from a number of viewpoints. From an industrial engineering viewpoint, the distinction between an automatic type and a manual type is quite important. The manual type requires the services of an operator while the automatic type does not. From the viewpoint of system design, a distinction between the self-operated type and a power operated type is more important, as the provision for the power-line layout should be incorporated in the design.

4. Performance Characteristics

All instrumentation systems are characterized by what is known as the system characteristics. If the system is considered as a black box with an input side and output side, three different types of characteristics are to be considered, viz. 1. input characteristics; 2. transfer characteristics; 3. output characteristics. If the system consists only of a basic functional unit, all these three characteristics are of considerable importance, as then the impedance levels, the ranges, etc. will affect the preceding, or subsequent stages after interconnection. In the present sequel, a generalized concept of these characteristics, considering the measurement system as a single entity, will be presented. The performance characteristics of the instrument will then be studied with respect to the input conditions. If the instrument is required to measure a condition not varying with time, the characteristics are static while for a time-varying process-variable measurement the dynamic characteristics are more important. These characteristics, in general, determine how far the measurements made are valid.

4.1 Static Characteristics

The qualities of measurement of an unvarying process-condition are stated in terms of accuracy, repeatability or precision and sensitivity. There are a number of related definitions such as linearity, resolution, etc. After the more important and independent ones are discussed adequate attention can be given to the rest.

In connection with accuracy, one should also mention the importance of calibration. This generally means a quantitative comparison of the instrument under test with a standard. Only proper calibration can establish the accuracy of the instrument. Manufacturers specify the accuracy of an instrument in terms of what is known as span. If the lowest and highest points of calibration are A and B respectively of the instrument, then the instrument range is from A to B, and the span (S_I) is

$$S_I = \text{B}-\text{A}$$

Any statement regarding accuracy such as accurate to within $\alpha\%$, in general, means $\pm\alpha\%$ of the span (B$-$A). Of course, it must be remembered that accuracy may be specified in terms of the range or units of indication.

The counter-term of accuracy is static error. In general, the instrument will not measure the true value of the process condition. This is symbolically written as

$$V_i - V_t = E_s \tag{1.1}$$

where V_i = instrument reading, V_t = true value of the variable, and

E_s = static error.

From the experimentalist's viewpoint, static correction (C_s) is more important than static error. The two quantities are related as

$$C_s = -E_s \tag{1.2}$$

If the instrument consists of n number of functional units each having the accuracy limits to within $\pm\alpha_1$, $\pm\alpha_2$ and so on, the overall accuracy may be stated in two different modes. The least accuracy(L.A.) is a pessimistic mode, for it keeps the provision that all units of the system may have the largest static error at the same time and is given by

$$\text{L.A.} \leqslant \pm(\alpha_1 + \alpha_2 + \ldots + \alpha_n) \tag{1.3}$$

A more reasonable definition is the root square accuracy (R.S.A.) and is given by

$$\text{R.S.A.} \leqslant \sqrt{\alpha_1^2 + \alpha_2^2 + \ldots + \alpha_n^2} \tag{1.4}$$

Repeatability, reproducibility or precision is a measure of the closeness with which a given input may be measured over and over again. Sometimes a distinction is made between repeatability and reproducibility in so far as the reproducibility is specified in terms of scale-reading over a given period of time while the repeatability is defined as the variation of the scale reading and is random in nature. Figure 1.1 shows this repeatability. The counter term of

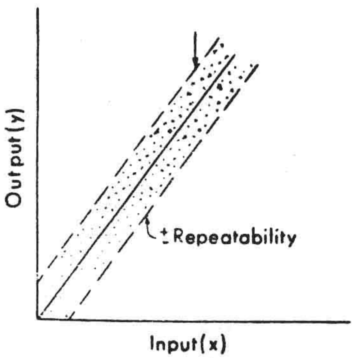

Fig. 1.1 Input-output curve with ± repeatability

precision is drift. Three different types of drifts are known: 1. zero drift or calibration drift; 2. span drift; 3. zone drift.

If the whole calibration gradually shifts due to slippage, permanent set, or lack of warming-up time in the case of electronic instruments, zero drift is said to occur. This is avoided by zero-correcting or zero-setting. If there is a proportional change in the indication along the upward scale, span drift is said to set in. If the drift occurs only at a certain zone of the span, zonal drift is said to occur. Drift is the real problem in industrial instruments. Wear and tear, high stress developing at some parts, and contamination of primary sensors, are reasons for drift. Regular calibration at standard conditions is a check to rectify this defect.

Sensitivity may be defined as the ratio of the deflection of the pointer to a given change in the measured quantity. This also means the slope of the input-output calibration curve. This definition clearly points out that the sensitivity can be increased by increasing the slope but, unfortunately, this might adversely affect precision. Consider the case of the analytical balance. Its sensitivity may be increased by raising the centre of gravity by moving the sensitivity ball. If this operation is carried too far, the balance is likely to lose its repro-