Instrumentation and Control for the Process Industries

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Preface

The term 'process control' embraces a wide range of activities which include, but are not limited to, the measurement or automatic regulation of process variables. Control of any industrial process also includes the actions taken by the operators, and the setting and reviewing of objectives relating to energy balances, production rates, efficiency, etc. The ability to do any of these things, however, rests on the ability to measure the variables which describe these criteria, and for this reason any engineer who wishes to address himself to the science and art of control must first have a clear understanding of the principles and practice of measurement. More and more the design and synthesis of control systems is being recognised as the province of the systems engineer whilst the traditional instrument engineer's role is associated with the instruments used to measure and regulate variables, leaving the process engineer to decide how the process shall be controlled. The control engineer's function today in the process industries combines these two areas of technology. Clearly the control engineer must know as much as possible about process design and equipment design as well as measurement and systems engineering: in other words, a competent control engineer must have a very wide engineering knowledge indeed.

This book is an attempt to put into one volume the essential basic knowledge required by a control engineer in the process industries. Such a book cannot possibly be comprehensive and no pretence is made that this one is. The first half of the book describes the established measuring techniques and practices for the most fundamental measurements (which comprise 90% of all process measurement): the remainder of the book is devoted to the design of measuring systems, regulating systems and finally control systems. No attempt has been made to cover on-stream analysis, batch control, or the design of advanced control systems, but these may well form the subject matter for a second volume at a later date.

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Contents

CHAPTER 1

Principles of Industrial Measurement

1.1 GENERAL

In order to operate chemical plant processes, e.g. chemical reactions, petroleum distillation, etc., it is essential to know the values of physical states of the process fluids, such as pressure, temperature and density, as well as rates of flow and often analytical data. Industrial instruments have been developed to measure all these parameters and in turn the instruments themselves depend on physical laws. Before we can use any tool (and instruments are tools for measuring) we need to know its capability. It is necessary to define limits of performance for any measuring instrument or system, and before we can do this the terminology used needs to be defined.

1.2 INSTRUMENT PERFORMANCE

It is important to determine with what precision measurements can be made using the instrument or system, but this will depend on many factors. Because of slack in linkages, friction and many other imperfections, repeated measurements made with the same system will only give the same result within a certain *error band*. This limitation on performance of a measuring system is referred to as *repeatability*. No matter how repeatable the results there will be a limit on the *resolution* with which they can be indicated or recorded. The measuring system will have a range or *span* over which it can work, and ideally a graph of the relationship of measured variable to instrument indication (or recording) will be a straight line (Fig. 1.1). In fact this will never be the case, and *accuracy* will be defined as the limit of confidence which can be placed in a measurement, taking all the factors into account (Fig. 1.2).

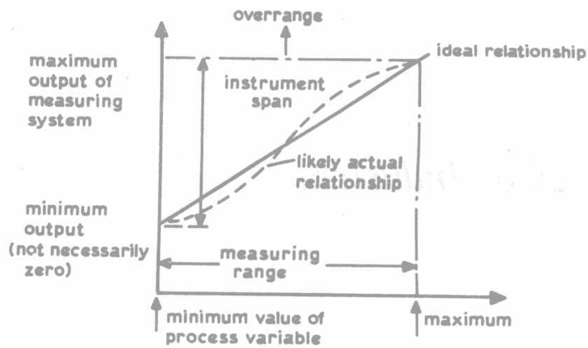

Fig. 1.1.

1.3 RANGEABILITY

Any industrial measurement system should give information of sufficient accuracy to facilitate control of the process operations over a *range* of operating conditions. It is often forgotten, however, that many of the causes of error are related to the maximum of the measuring range. Manufacturers usually quote errors in terms of FSD (full scale deflection). If a process variable is to be measured it is implied that it varies in the course of normal process operation; to allow for such variation the range of the measurement system will normally be selected so that the normal operating value of the variable represents about 70% of FSD. Thus, if, typically, a range of process variable of 3 to 1 is to be measured and the system accuracy is ±1% FSD then the errors to be expected at the lower end of the range will be

$$(1 \times \frac{1}{0{\cdot}70} \times \frac{1}{3}) = \pm 5\%$$

1.4 ASSESSMENT OF ERRORS

It is easier to say how the performance of a measurement system is determined, than to determine it in practice. Whilst the instrument technician at a refinery or chemical plant will rarely, if ever, be asked to carry out such an evaluation experimentally, it is, nevertheless, essential that he understand how this is done. Sometimes the errors caused in the different ways outlined above will cancel one another out; sometimes they will add up and so reinforce each other. Thus the actual error which occurs

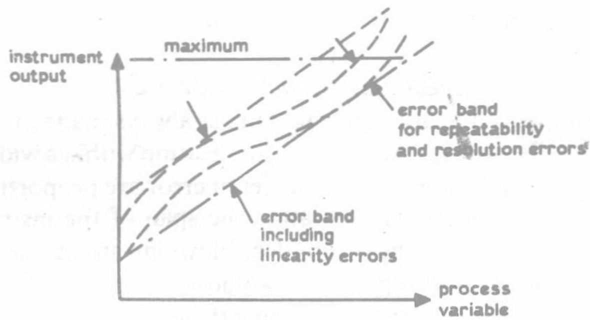

Fig. 1.2.

in any particular measurement is *randomly* determined; only the *probability* that the error will be greater or less than a certain size can be determined. Therefore the accuracy of a measurement system is always quoted in statistical terms, that is the size of error which has, say, a 90% probability of occurring; it cannot be quoted in any other way.

To establish this statistical data, experiments must be made repeatedly with the measuring system under test, so that the error is found on a sufficient number of occasions to allow the data to be reliably grouped; the probability of the occurrence of errors of different sizes can then be evaluated. This is obviously a very time-consuming method.

1.5 CALIBRATION

Industrial measuring devices and systems must be robust and easily maintainable, and to some extent accuracy is sacrificed to these ends. Any experiment to assess the error of measurement requires that there exists some other means of establishing the true value of the process variable being measured. Since such experiments are carried out under laboratory conditions, a more accurate instrument is often available so that the measurements can be made simultaneously on this and the industrial instrument under test. Such high accuracy instruments are known as ***substandard***, and are usually at least one order of magnitude better in terms of accuracy (that is ten times more accurate). If such substandard instruments are not available, some fixed physical phenomenon, such as the boiling point of a liquid, must be used to evaluate the accuracy, at least at certain fixed points on the instrument range.

1.6 ZERO AND SPAN

As the range of the process variable will be different for each individual application, industrial instruments are almost always made in such a way that the *span* can be adjusted to suit each application within a wide range, so that sensitivity, accuracy and other sources of error are proportional to the span. In the course of normal operation the span of the instrument can change owing to vibration, heat, physical blows or any number of other causes, as can the zero setting. These two adjustments must therefore be checked (and if necessary corrected) frequently, often whilst the instrument remains in its installed position on the plant. Obviously it is not possible in most cases to use substandard instruments or other laboratory techniques, and such 'on plant' checks are usually made by 'injecting' known test inputs using special test equipment.

1.7 DRIFT

A very important aspect of the performance of industrial measuring systems is their propensity to 'drift'. Either span or zero may change gradually because of the ageing of components (this is very important in the case of electronic equipment) or other forms of slow deterioration. Such drifting is common in new equipment and for this reason span/zero checking should be carried out more frequently immediately after installation. However, if an instrument should be found to drift continuously, long after its installation, it should be returned to the manufacturer as unsatisfactory. Unfortunately this type of failure often goes undetected and manufacturers rarely provide data on drift as part of performance specifications.

1.8 RESOLUTION

This term applies to the precision with which the measurement can be displayed, recorded, or logged. If the measuring system presents the results of the measuring process to the operator in the form of an indicated figure then the size and length of the indicator scale will inevitably limit the size of the smallest unit which the human eye can 'discriminate'; however, there would be little point in supplying a larger indicator if the size of unit which could then be read is smaller than the limit of accuracy of the measuring system itself. Thus, the indicator or recorder should have a scale size which is consistent with the limits of accuracy of the measuring system.

A different situation arises in the case of digital displays which are becoming very popular; discrimination depends on the number of digits used to represent the measured value, regardless of the size of the display, and the precision of the electronic circuitry which converts the measurement into the digital quantity displayed (or recorded).

1.9 HYSTERESIS

A common cause of error in many measurement systems is hysteresis, caused by friction or by any one of a multitude of directional effects in mechanical, pneumatic, hydraulic or electrical mechanisms. These result in a different measurement being obtained if the process variable has increased to the measured value from some previous lower value, or alternatively has decreased from some previously higher value.

1.10 DIRECT/INDIRECT MEASUREMENT

For the most part the techniques used in industrial measurement are inferential or indirect. For instance, in order to measure the temperature of a process fluid, the pressure of a liquid or gas sealed into a metal container may be measured, and the temperature 'inferred' from the pressure according to certain known relationships. Some techniques, however, are 'direct', e.g. the measurement of flow rate of a fluid by the positive displacement technique, in which the meter actually transfers a 'package' of process fluid from one place to another, depending on mechanical seals to prevent any of it returning. Such techniques are usually more accurate though much more expensive than inferential techniques.

1.11 SAMPLING

It is necessary to ensure that the measurement made, though it may be perfectly accurate, is representative of the measurement required. For instance, the flow rate or temperature of a fluid may vary across the diameter of the pipe if the flow is not sufficiently turbulent to ensure good mixing. Again, even if flow is sufficiently turbulent, the flow rate or temperature may vary with the passage of time. Temperature or pressure may vary at different places in a large tank either in a regular manner, and therefore predictably, or in a random manner, and therefore unpredictably. In such cases it may be necessary to make more than one measurement in order to determine the mean value of the variable. If the 'distribution' of the variable in time or position is predictable (as, for instance, the distribution of fluid flow across a pipe) this may not be difficult: if however the distribution is random it will only be possible to make a number of measurements (as many as is practicable) and hope that their average is a close approximation of the true mean value of the variable. The probability that this is the case increases with the number of such measurements made and decreases with the differences in the measurements across the distribution in time or position. The calculation of a suitable tolerance is statistically based and will depend upon the degree of certainty which is considered adequate (there can never be absolute certainty in such cases); for instance, there may be a 90 % certainty that the average of the measurements is within ±1 % of the true mean value.

CHAPTER 2

Measurement of Process Pressure

2.1·DIRECT PRESSURE MEASUREMENT

Deadweight testers are the most accurate calibration instruments in use for pressures above those which can reasonably be measured using a manometer. Pressure is provided by weights acting on a piston which fits very closely into a cylinder containing oil (Fig. 2.1(a)); the pressure developed in the oil is equal to the weight divided by the cross-sectional area of the piston, and this pressure is applied to the inferential instrument under calibration:

$$p = \frac{W}{A}$$

Friction between the piston and the cylinder is the only source of error and in a well-made instrument this is negligible.

To obtain very high pressures the piston is stepped as shown in Fig. 2.1(b) and a second gland added. This has the effect that the area over which the weight is distributed is the difference of the cross-sectional areas of the two sections of the piston, and thus the pressure generated by even quite a small weight can be very high indeed:

$$p = \frac{W}{(A_1 - A_2)}$$

The ring balance manometer comprises a tube bent into a circle and supported on a knife-edge pivot so that it can rotate (Fig. 2.2). Pressures p_1 and p_2 are isolated from each other by a partition on the one hand and liquid fill on the other. Because of the difference in pressure across the partition (which is fixed to the tube) a turning moment is applied to the tube; this is balanced by a turning moment produced by a counterweight and the angle of rotation is a measure of the pressure applied. For very low

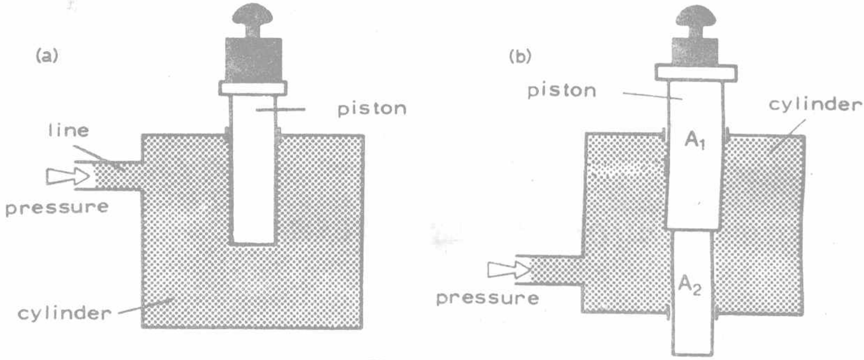

Fig. 2.1.

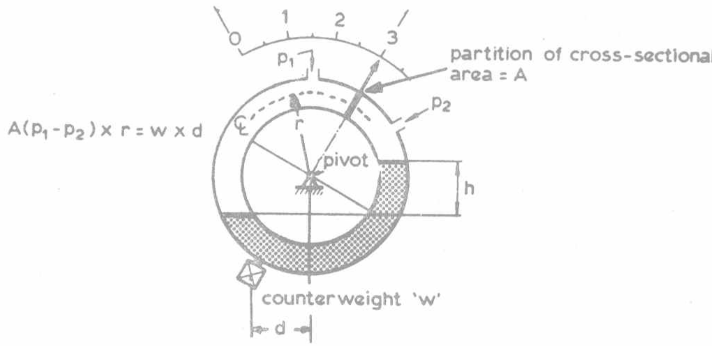

Fig. 2.2. Ring balance gauge.

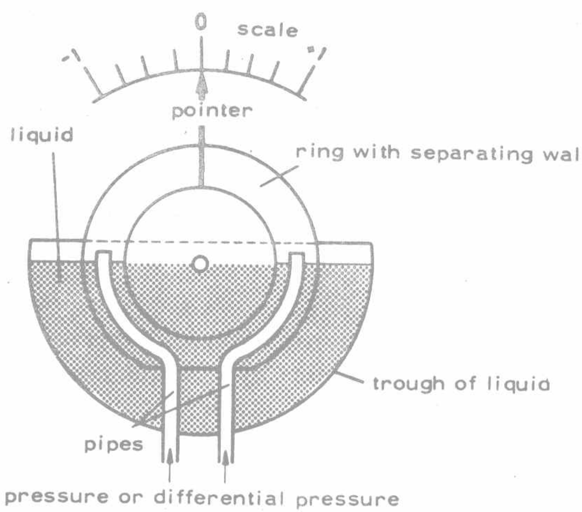

Fig. 2.3. 'Bell' ring balance gauge.