Quality Assurance in Measurement

Module 2 - The Vocabulary of Measurement

Contents

1.0 The Vocabulary of Measurement

1.1 Introduction

In all branches of technology it is important that the vocabulary used to describe procedures and processes have a common non-ambiguous meaning. Each term must have precisely the same meaning for all users. This is particularly true for Measurement where, because of its use in all branches of science and engineering, the terminology can become misused and eventually confused and misleading.

In an effort to resolve the problem of a common vocabulary for measurement at an international level the ISO (International Organisation for Standardisation) measurement group organised a joint working committee from;

- BIPM (International Bureau of Weights and Measures),
- IEC (International Electrotechnical Commission),
- OIML (International Organisation for Legal Metrology), and
- ISO to organise the preparation of the general terms used in metrology.

The outcome of this endeavour was the "International Vocabulary of Basic and General Terms in Metrology", PD 6461 part 1. This introductory note to the vocabulary of measurement is organised in the same order as PD 6461, as follows:

Quantities and units

Measurements

Measuring results

Measuring instruments

Characteristics of measuring instruments

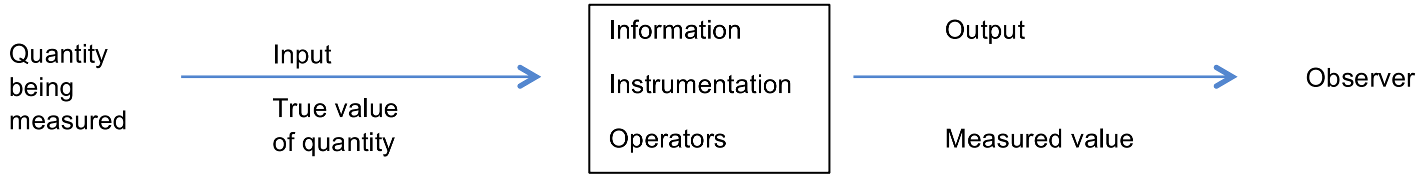
Measurement standards

This structure provides a logical framework for considering the different aspects of measurement. In reading this module, reference should be made to PD 6461, and through this activity a practice should be developed for referring to the standard to obtain the correct usage of unfamiliar terms.

Terms that are to be found in PD 6461 are shown in BOLD CAPITAL LETTERS and the definition of the term will be presented within the brackets []. Only a small number of the terms found in PD 6461 are covered in this introduction, they have been chosen to represent those terms most commonly encountered in the industrial environment when describing the measurements.

1.2 Quantities and Units

In general terms, the measurement process can be represented by the diagram below:



The purpose of a measurement (instrumentation) system is to determine as accurately as appropriate the **QUANTITY [an attribute of a phenomenon, body or substance which may be distinguished qualitatively and determined quantitatively]** of a given system or process. Typical quantities that may be measured in an industrial process are temperature, length, weight and volume. The quantity being measured is generally termed the **MEASURAND [a quantity subjected to measurement**].

The quantity measured will be in a **UNIT [a specified quantity, adopted by convention, used to express qualitatively quantities which have the same dimensions]** of measurement. The units of the quantities of temperature, length, weight and volume will be typically degrees centigrade, metres, kilogrammes and litres. Alternative units could be Kelvin, kilometres, tonnes and gallons.

The observer requires the **VALUE OF A QUANTITY [the expression of a quantity in terms of a number and an appropriate unit of measurement]**. For example, 1200 Kelvin is a value of quantity where 1200 is the **NUMERICAL VALUE (OF A QUANTITY) [the number in the value of a quantity]** and Kelvin is the unit.

All measurement processes have uncertainties associated with them. Quality in measurement is essentially concerned with limiting the uncertainties and understanding the nature of those that are left in the measurement process. Referring back to the diagram above, this can be summed up by stating that the output of the measurement system (that seen by the observer) will not be the same as the input to the system.

The input can be considered to be the **TRUE VALUE OF THE QUANTITY** to be measured **[the value that characterises that quantity perfectly defined, in conditions which exist when the quantity is considered]**. This is evidently an ideal concept and cannot be exactly known. To overcome this difficulty a **CONVENTIONAL TRUE VALUE [a value of a quantity which for a given purpose may be substituted for the true value]** is usually regarded as sufficiently close for most practical purposes.

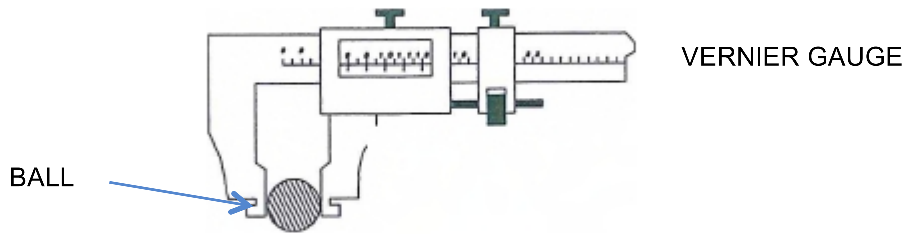
1.3 Measurements

When we wish to make a **MEASUREMENT [the set of procedures having the Object of determining the value of a quantity]** the **METHOD OF MEASUREMENT [the set of theoretical and practical operations, in general terms involved in the performance of measurements according to a given principle]** we adopt will be determined by the form of measurand and the methods of measurement available to us. A metre rule will be useful for measuring from a few millimetres to say ten metres, but it would be quite inappropriate for measuring long distances.

Consider the problem of counting a large quantity of small components. A widely used method of measuring such a quantity would be to weigh one of the components, and then determine what the weight of the number of components needed would be. Components are then added to those being weighed until the weight required is achieved, the required number of components has then been produced.

The measurement taken can be either static or dynamic. A **STATIC MEASUREMENT [the measurement of a quantity whose value can be considered constant for the duration of the measurement]** is in reality a misnomer since all quantities will have a degree of variability even if this is at a microscopic level. If we were producing metallic washers then the measurement of their outside diameter and the diameter of their central hole can be considered to be static measurements. The diameter of a squash ball will also be a static measurement.

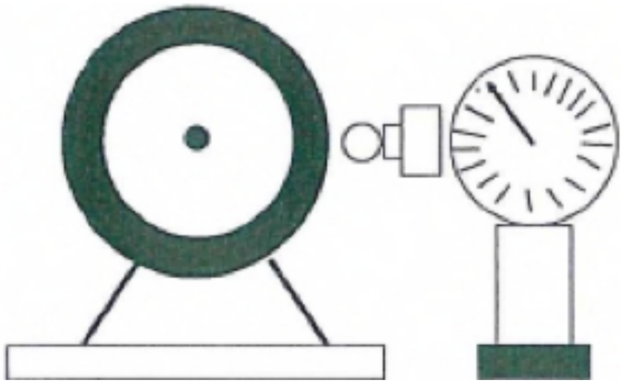
A Static Measurement



A **DYNAMIC MEASUREMENT [the determination of the instantaneous value of a quantity and where appropriate its variation with time]** is a more complex measure; its exact nature will depend on the variation of the quantity being measured. (The qualifier, dynamic, refers to the measurand and not to the method of measurement.)

Any continuous process, such as in the extrusion of plastic, will require dynamic measurement if the process is not to be interrupted. The thickness of the paper coming off the paper mill will vary with time. The variation will depend upon the process itself and the response of the measuring system. If the measuring system has a lower response time than the variation in the measurand then it will have the effect of rejecting (filtering) the higher frequency variations. Often an average (over a particular time span) Is chosen to be displayed. However it may be necessary to give an indication, in statistical terms, of the variation that is occurring.

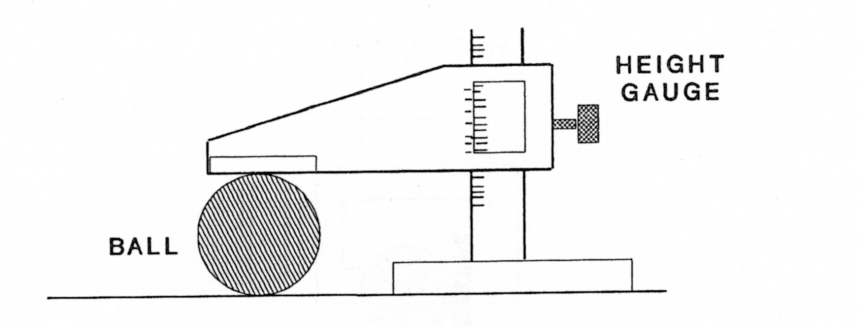
A Dynamic Measurement



Tyre Radius
Measurement

Measurements can generally be grouped into two distinct categories, direct and indirect measurement. **DIRECT MEASUREMENT [a method of measurement in which the value of the measurand is obtained directly, rather than by measurement of other quantities functionally related to the measurand]** is concerned with a single measurand. Measurements of length using a tape measure, the measure of the diameter of round object using a micrometer or measurement of mass using an equal arm balance are examples of this.

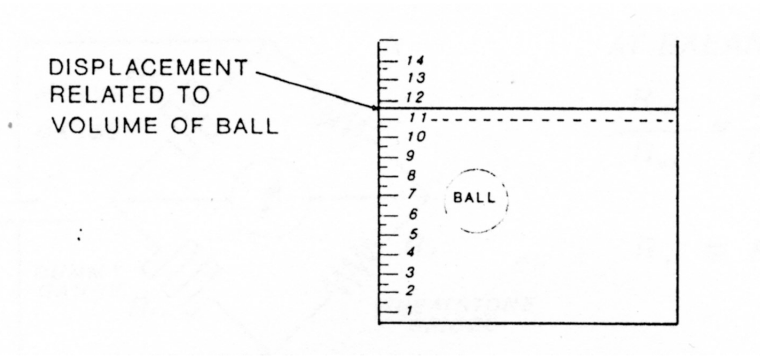
Direct Measurement



The majority of industrial measurement processes use **INDIRECT METHODS OF MEASUREMENTS [a method of measurement in which the value of the measurand is obtained by measurement of other quantities functionally related to the measurand].** The level of water in a washing machine can be gauged by the pressure of the water at the bottom of the tub. Temperature can be measured by determining the resistance of a metallic element exposed to that temperature.

An indirect method of measuring the diameter of a squash ball would be to measure its volume by submerging it in water and measuring the volume of the water displaced. The diameter can then be calculated from the volume.

An Indirect Measurement

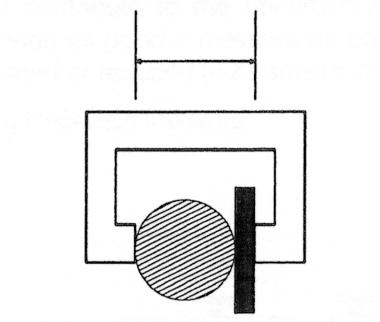


There are three basic methods, in addition to those above, that are in common use in metrology.

The **SUBSTITUTION METHOD OF MEASUREMENT [a method of measurement in which the measurand is replaced by a quantity of the same kind, of a known value, and chosen so that the effects on the indicating equipment are the same]** can be illustrated by considering the batch weighing of a powder required in a manufacturing process. A standard weight equal to the weight of the powder required is first put on the weighing scale pan. The position of the pointer is marked on the weighing scale dial. The standard weight is then removed and powder added until the pointer reaches the mark. The powder therefore has the same weight as the standard. The advantage of this method is that any uncertainty of measurement due to friction and other faults in the weighing scales is effectively avoided.

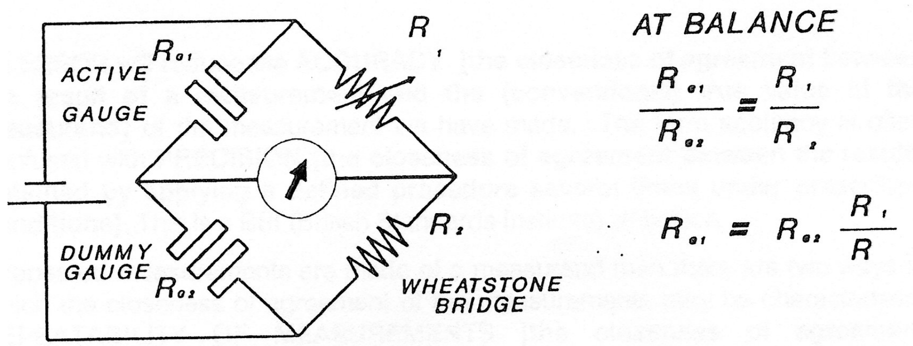
The **DIFFERENTIAL METHOD OF MEASUREMENT [a method of measurement in which the measurand is compared with a quantity of the same kind, of a known value only slightly different from the value of the measurand, and in which the difference between the two values is measured]** can best be illustrated by using a standard gauge, of known dimensions, and feeler gauges to measure the diameter of a shaft.

GAUGE WIDTH



Shaft diameter = gauge width - feeler gauge thickness

The **NULL METHOD OF MEASUREMENT [a method of measurement in which the value of the measurand is determined by balancing, adjusting one or more quantities, of known values, to which the measurand has a known relationship at balance]** is well illustrated in the Wheatstone bridge for measuring the value of an unknown resistance. The resistance whose value is required could be a strain gauge, the resistance being an indication of the strain experienced by the gauge.

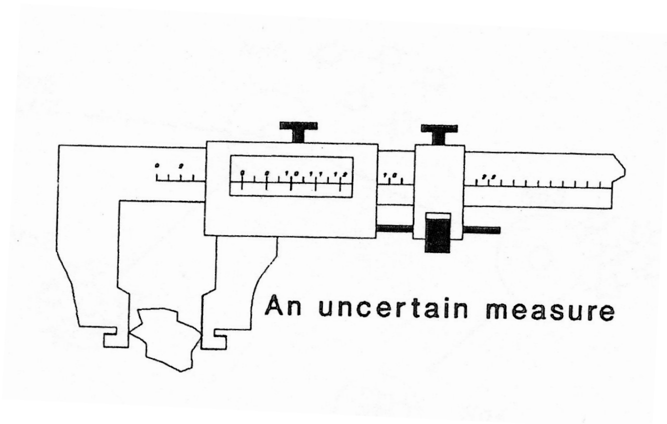


1.4 Measurement Results

The **RESULT OF A MEASUREMENT [the value of a measurand obtained by measurement]** is the culmination of the measurement process. There is an **UNCERTAINTY OF MEASUREMENT [an estimate characterising the range of values within which the true value of a measurement lies]** in the measurement result. The magnitude of this UNCERTAINTY will be determined by elementary **ERRORS [contributions to the difference between the measured value and the conventional true value of the measurand]** including;

- Poor definition of the quantity to be measured.
- The measurement method.
- The operators.
- Intrinsic errors in the instrument
- Usage over time
- The conditions of utilisation
- The site of operation

All these factors will contribute to the uncertainty of the measurement. It is fundamental to achieving as good a measure as possible that these sources of error are either eliminated or reduced to as small a magnitude as possible.



An ERROR will reduce the **ACCURACY [the closeness of agreement between the result of a measurement and the (conventional) true value of the measurand]** of the measurement we have made. The term accuracy is often confused with **PRECISION [the closeness of agreement between the results obtained by applying a defined procedure several times under prescribed conditions].** This is a BSI (British Standards Institute) definition.

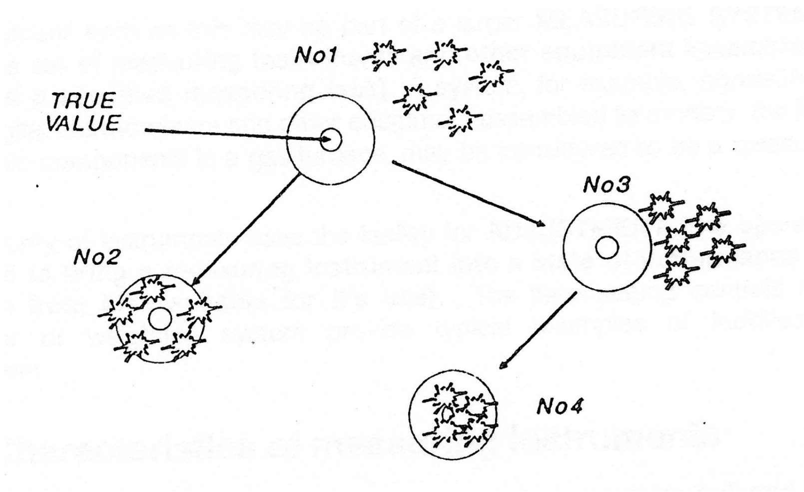
If repeated measurements are made of a measurand then there are two ways in which the closeness of agreement of the measurements may be characterised. **REPEATABILITY OF MEASUREMENTS [the closeness of agreement between the results of successive measurements of the same measurand carried out subject to all the following conditions; the same method of measurement, the same observer, the same measuring instrument, the same location, the same condition of use, repetition over a short period of time]** will be quantified by the statistical nature of the results.

REPRODUCIBILITY OF MEASUREMENTS [the closeness of the agreement of the results of measurements of the same measurand where the individual measurements are carried out under changing conditions such as; method of measurement, observer, measuring instrument, location, condition of use, time] will similarly be quantified by a statistical measure but to be valid a precise definition of the conditions under which the measurement was made will be required.

Errors can be conveniently divided into two types. **A SYSTEMATIC ERROR [a component of the error of measurement which in the course of a number of measurements of the same measurand remains constant or varies in a predictable way]** or a **RANDOM ERROR [a component of the error of measurement which in the course of a number of measurements of the same measurand varies in an unpredictable way].**

An electrical meter may have good repeatability but if the needle is slightly bent it will give inaccurate readings. Random errors will be present in addition to systematic errors and will be characterised by a spread in the results of a measurement. A statistical measure is usually used to describe such errors.

A useful analogy to illustrate the definitions above is the likening of the measurement process to firing a gun at a target. Each measurement can be thought of as a bullet hitting the target. The aim is for every measurement to be exact, represented by hitting the bull's eye, the true value of the measurand.



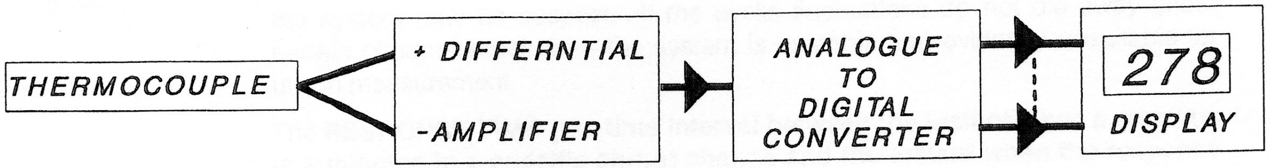
Following the targets in order, no 1, the loose clustering of the values shows poor repeatability, the cluster appearing off target showing poor accuracy. This is a systematic error called a **BIAS ERROR [the systematic component of the error of a measuring instrument].** The electrical meter with the bent pointer will have a bias error.

Number 2 shows a system with fair accuracy, but poor repeatability. Starting from number 1, if we improve the system of measurement or the instrument then number 3 could result. This shows poor accuracy but good repeatability. However, there is still a bias error. Adjustment of the system can remove the bias error giving number 4, showing good accuracy and good repeatability.

1.5 Measuring Instruments

A **MEASURING INSTRUMENT [a device intended to make a measurement, alone or in conjunction with other equipment]** usually consists of many elements known as a **MEASURING CHAIN [a series of elements of a measuring instrument or system which constitutes the path of the measurement signal from the input to the output**].

A typical measuring instrument, such as a digital thermometer, can be represented by the block diagram shown.



This has a measuring chain consisting of a thermocouple, differential amplifier, an analogue-to-digital converter and a display.

An instrument such as this may be part of a larger **MEASURING SYSTEM [a complete set of measuring instruments and other equipment assembled to carry out a specified measuring task].** A system, for example, consisting of many digital thermometers and other equipment assembled to monitor the firing of ceramic components in a gas furnace, may be considered to be a measuring system.

The majority of instruments have the facility for **ADJUSTMENT [the operation intended to bring a measuring instrument into a state of performance and freedom from bias suitable for it's use]**. The zero setting controls on a voltmeter or weighting system provide typical examples of facilities for adjustment.

1.6 Characteristics of measuring instruments

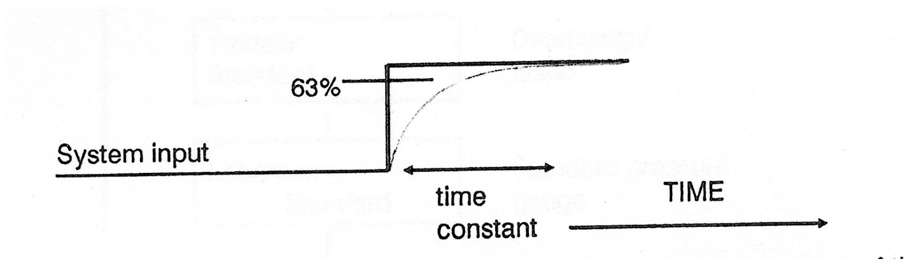
Ideally a measuring instrument, transducer or measuring system (referred from here as a system) should be chosen to respond to the range of input quantities that it is required to monitor. This is referred to as the **SPECIFIED WORKING RANGE [the set of values of a measurand for which the error of a measuring instrument is intended to lie within specified limits]** of the system. It is usually very difficult to design a single system to respond to a wide range of inputs. A pressure transducer that is required to monitor very high pressures will of necessity have a heavy construction and will not necessarily have the **SENSITIVITY [the change in response of a measuring instrument divided by the corresponding change in the stimulus]** that may be required for measurement of lower pressure levels.

All systems have a finite **DISCRIMINATION [the ability of an instrument to respond to small changes in the value of the stimulus]** level that will result in a **DEAD BAND [the range through which the stimulus can be varied without producing a change in response of the measuring instrument]** in the response. A dead band is sometimes deliberately designed into the system performance to increase the system **STABILITY [the ability of a measuring instrument to maintain constant it's metrological characteristics].**

The **RESOLUTION [a quantitative expression of the ability of an indicating device to distinguish meaningfully between closely adjacent values of a quantity indicated]** of a measuring system is a quantitative indication of a system's discrimination.

Instability is often produced by environmental changes. Changes in temperature can cause **DRIFT [the slow variation with time of a metrological characteristic of a measuring instrument]**. Another form of instability will be characterised by cyclic fluctuations, particularly after a sharp change in the input. Such fluctuations should die down quickly, but if they do not the design of the system may be suspect. If the cyclic fluctuations do not die away under certain circumstances then the system is unstable and evidently unsuitable for use in measurement

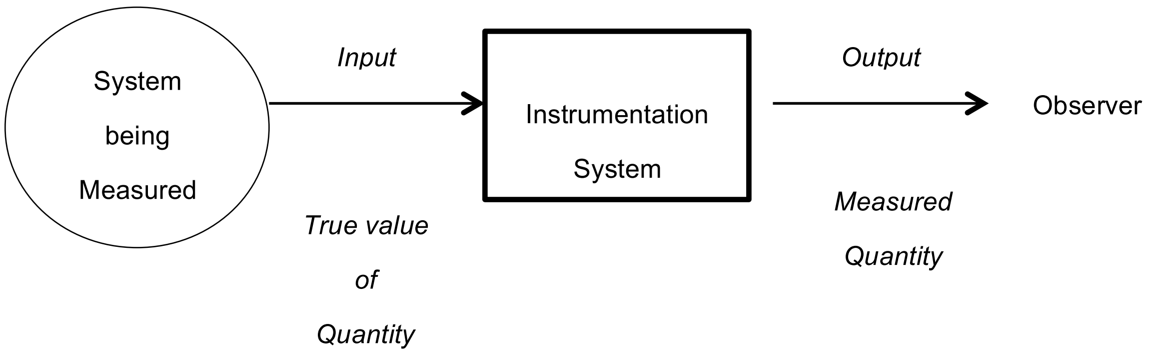
The **RESPONSE TIME [the time interval between the instant when a stimulus is subjected to a specific abrupt change and the instant when the response reaches and remains within specified limits of it's final steady value]** of a system must be appropriate for its expected use. It is particularly important for dynamic signals that the system follows changes of the input quantity as closely as possible. The most usual way to test for the response time is to apply a step input to the system and monitor its output.



The time taken to achieve 63% of the input is known as the time constant of the system. It can be seen that if the time constant is too long in relation to a changing input then the output will not faithfully follow that input. The output of a system will only reach 99% of a step Input change In five times the time constant.

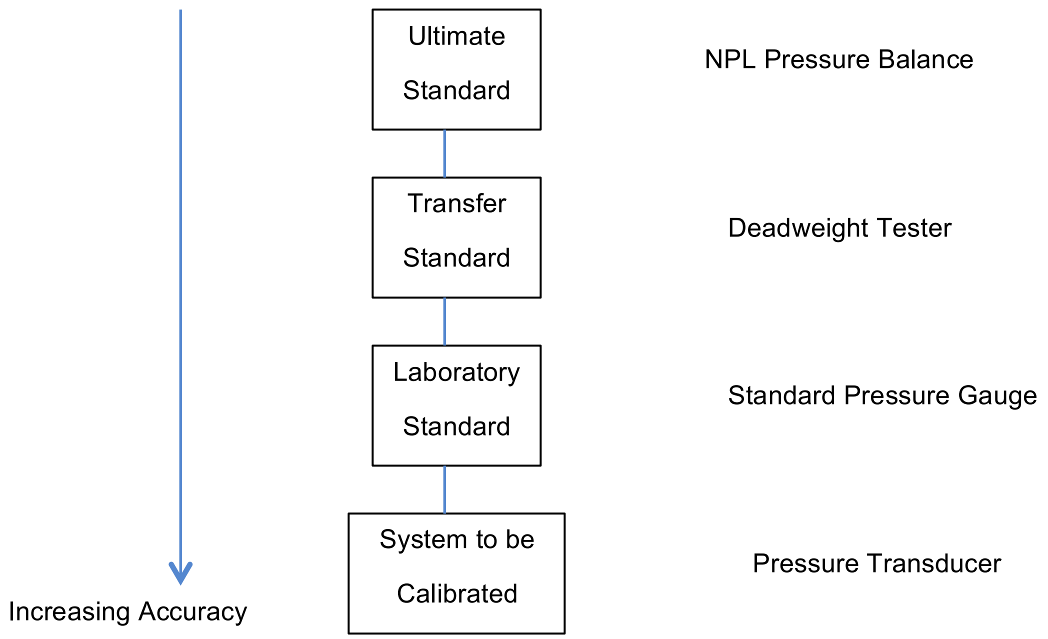
1.7 Measurement Standards

The purpose of a measurement (instrumentation) system is to produce, for an observer, a numerical value corresponding to a quantity being measured. This can be summarised by the block diagram below.



To have confidence in the results obtained from the use of a measuring instrument it is important to perform Instrument **CALIBRATION [the set of operations which establish, under specified conditions, the relationship between values indicated by a measuring instrument or measuring system, or values represented by a material measure, and the corresponding known values of a measurand].** Calibration has meaning only if the input and output quantity is referred to a **MEASUREMENT STANDARD (ETALON) [a material measure, measuring instrument or system intended to define, realize, conserve or reproduce a unit of one or more known values of a quantity in order to transmit them to other measuring instruments by comparison]** that precisely defines the quantity being measured. A gauge block is measurement standard. It must be noted that the environment in which the instrument makes its measure can also vary (e.g. temperature, pressure, humidity, etc.) and this can alter the relationship between input and output. A measure of the environmental conditions must therefore be made, and usually controlled, to define the performance of the instrumentation system.

The true value of a variable is obtained using a **PRIMARY STANDARD [a standard which has the highest metrological qualities in a specified field]** of ultimate accuracy. This standard will not normally be available to the engineer, but standards derived from this, called **SECONDARY STANDARDS [a standard whose value is fixed by comparison with a primary standard]** will be available. These standards should be related to that standard and others by means of a **TRACEABILITY [the property of a result of a measurement whereby it can be related to appropriate standards, generally international or national standards, through an unbroken chain of standards]** ladder. A simplified example of a traceability ladder is shown below:



In Great Britain the National Physical Laboratory (NPL) is responsible for the physical realisation of base units and is the custodian of the primary standards in this country. The International Bureau of Weights and Measures (BIPM) in France is the custodian of the International Kilogram.

Secondary standards are kept in British Calibration Service centres (BCS) throughout the country. Certain industrial organisations also have this designation and keep secondary standards. Measurement instruments in industry can, for a fee, be calibrated against these standards and therefore, through a traceability ladder, their error with respect to the ultimate base standard can be determined.

A traceability ladder for the measurement of length