Topic 2. What is measurement?

A. Introduction

Whenever it is necessary to decide about a process for quality control issues or for manipulating system parameters to change state of the system, an information about current state of the process or system is required (plant). The information concerned here contains the current state of the variables (both inputs (independent) and output (dependent) variables). The information of states are obtained through models (equations of variables) from the raw data and the data is acquired through a measurement system.

B. What is measurement?

Measurement is the process of empirical, objective assignment of numbers to the attributes of objects and events of the real world, in such a way as to describe them. According to this definition:

- Measurement is the process of obtaining the magnitude of a quantity relative to an agreed standard.
- Measurement of any quantity involves comparison with some precisely defined standard unit value of the quantity.

The experiment and observation require direct or indirect interaction with physical system or object.

Direct methods: In these methods, the unknown quantity (called) is directly compared against a standard.

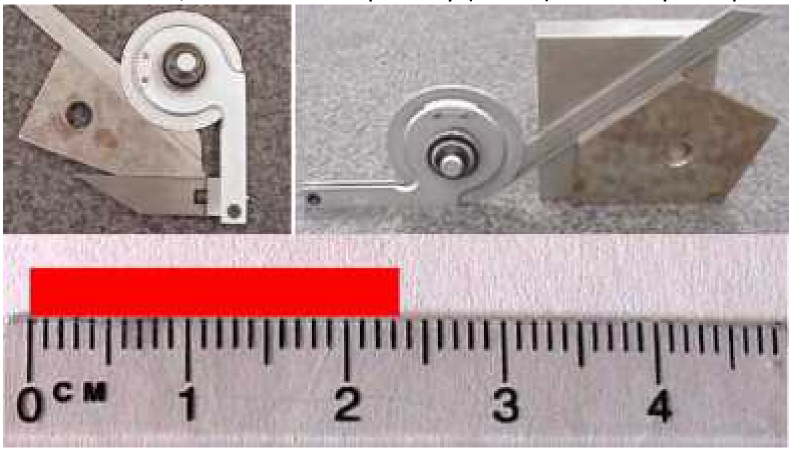

Figure 1. Direct Measurements (a)acute angle (b) Obtuse angle (c) Ruler

Indirect method: Measurements by direct methods are not always possible, feasible and practicable. In engineering applications measurement systems are used which require need of indirect method for measurement purposes.For example, measuring heat transfer is not possible because of the difficulty of creating some standard mechanism which can sense the heat without effecting the environment. Therefore, temperature measurements are used to monitor heat transfer and the measurement results are interpreted with system parameters to estimate the heat transfer.

Question: Is measuring speed with tachometer is direct or indirect measurement?

It is important to note that the measurement applies only to properties/characteristics/variables of an object or event, not the object or the event itself. Suppose that you are given a steel work piece and commanded to measure it. Only the command, “measure the work piece”, does not properly describe the process of measurement because it is not clear which property/characteristic should be described via measurement. On the other hand, if the command is like “measure the diameter/ temperature / weight of the work piece”, the measurement process becomes definite and clear.

Although the measurement is empirical, the observation must be objective, which means that it must be undistorted by emotion or personal bias. Hence, the experiment should be carried out with a universal (accepted by all) references. The term “universal reference” should be thought as a set of predefined rules, which are necessary for the results to be meaningful for the others. For example, if you use thickness of your thump as a reference when measuring height of the work piece, the qualitative result, such as 2, will be meaningless everywhere, where your thumb is not present.

For these two necessities, the measurements are executions of planned actions for a qualitative comparison of a measurement quantity with a unit.

B1. Standards

The need of a standard for any unit is clear for the exchange of information and materials, and for international agreements on matters concerning safety, reliability and environment. Therefore, the definitions and the physical basis of the units are described and kept in international institutions like International Bureau of Weights and Measurements (Sevres, France), Bureau Internationale de l'Hueure (BIH) in Paris. Turkish Standards Insititution (TSE) has the primary responsibility for maintaining these standards in Turkey.

B2. Units

A unit of measurement is a definite magnitude of a physical quantity, defined and adopted by convention or by law, that is used as a standard for measurement of the same physical quantity. Any other value of the physical quantity can be expressed as a simple multiple of the unit of measurement.

For example, length is a physical quantity. The metre is a unit of length that represents a definite predetermined length. When we say 10 metres (or 10 m), we actually mean 10 times the definite predetermined length called "metre".

Unit systems were invented so that numbers could be assigned to the dimensions of physical quantities. There are three accepted unit systems:

- the International System of Units (SI units, from Le Systeme International d'Unites, more commonly simply called the metric system of units)
- the English Engineering System of Units (commonly called English system of units)
- the British Gravitational System of Units (BG)(no longer popular)

Even though the English system is much more difficult to use than the metric system, it is still widely in use in industry today. Therefore, we still have to learn both systems, and as engineers we must be comfortable using both systems. Therefore, it is necessary to know how to use the conversion factors, which are listed in handbooks to enable conversion from any of these units to any other.

A dimension is a physical variable used to specify the behavior or nature of a particular system. For example, the length of a rod is a dimension of the rod. In like manner, the temperature of a gas may be considered one of the thermodynamic dimensions of the gas.

All quantities that describe the properties or variables in all physical domains (mechanical, electrical, etc.) can be expressed with dimensions of seven primary physical quantities. They are named as primary dimensions:

Table 1. Primary Dimensions

Primary dimension	**Symbol**	**SI unit**
mass	m	kg (kilogram)
length	L	m (meter)
time	t	s (second)
thermodynamic temperature	T	K (kelvin)
current	I (or i)	A (ampere)
amount of light (luminous intensity)	C (or I)	cd (candela)
amount of matter	N	mol (mole)

Examples: How do the units change with time differentiation and integration?
Force is time rate change of momentum. Derive the unit.

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The dimension of any other physical quantity can be described with a combination of these dimensions and named as secondary units (table 2).

Table 2. Some Secondary Dimensions

Secondary dimension	**Symbol**	**SI unit**
force	F	N (newton = kg×m/s2)
acceleration	a	m/s2
pressure	P	Pa (pascal = N/m2)
energy	E	J (joule = N×m)
power	W	W (watt = J/s)

In most cases, the scale of measurand requires a prefix that determines a standard multiplier (Table 3).

Table 3. SI Prefixes for units

Factor	***Decimal Representation***	***Prefix***	***Symbol***	***Factor***	***Decimal Representation***	***Prefix***	***Symbol***
10^{18}	1,000,000,000,000,000,000	exa	E	10^{-1}	0.1	deci	d
10^{15}	1,000,000,000,000,000	peta	P	10^{-2}	0.01	centi	c
10^{12}	1,000,000,000,000	tera	T	10^{-3}	0.001	milli	m
10^{9}	1,000,000,000	giga	G	10^{-6}	0.000 001	micro	m
10^{6}	1,000,000	mega	M	10^{-9}	0.000 000 001	nano	n
10^{3}	1,000	kilo	k	10^{-12}	0.000 000 000 001	pico	p
10^{2}	100	hecto	h	10^{-15}	0.000 000 000 000 001	femto	f
10^{1}	10	deka	da	10^{-18}	0.000 000 000 000 000 001	atto	a
10^{0}	1						

Example: Calculate the pressure arising from a force of 10KN acting on a area of 10x20mm.

Volumetric flow rate is time rate of change of volume in a pipe? What is tis dimension? What is the conversion factor for it if volume is given in liters?(1litre=1 dm^3)

1 atm pressure is 1.0132×10^5 N/m^2 (Pa), which could be written 1 atm = 0.10132 MN/m^2 (MPa).

The Sun delivers 5.6 YJ (yottajoules) of energy to the Earth every year,

A proton is 1.6 fm (femtometres) in diameter.

C. Measurement Setup

A measurement system is a setup used for quantifying the measured variable. A measurement system contains two functional components: an instrument (or gauge) and an observer (which might be a human operator or a computer program) and it aims to acquire data about the value of a physical variable (or parameters). Any operator measuring value of a resistor via an ohmmeter is an example to human operator system and a smoke detector in a fire protection system is an example for the second. The purpose of using and instrument (or gauge) in measurement systems is to extend the abilities of the human senses.

A measuring instrument (or gauge) is a device for measuring a physical quantity. As it is previously mentioned established standard objects and events are used as units, and the process of measurement gives a number relating the item under study and the referenced unit of measurement.

Measuring instruments and formal test methods which define the instrument's use, are the means by which these relations of numbers are obtained. *But it must be kept in mind that all measuring instruments are subject to varying degrees of instrument error and measurement uncertainty.*

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A measurement system can be interpreted as a set up for transporting information from a measurement object to a target object. Three main functions can be distinguished: data acquisition, data processing and data distribution.

- Data Acquisition is to obtain information about the measurement object and convert it into a signal carrying the measured value (data). The signal can be any physical domain that can be processed. The change (or the absolute value) in the measurand causes an equivalent change in the sensor property. The change in the sensor property is converted into a more usable form, e.g., temperature change results in the change in generated voltage by a thermocouple.
- Data Processing is to apply necessary manipulations to the signal to convert data to information.
- Data distribution is to supply processed data to the target object via human instrument interface (eg. LCD Screen)

Figure 2. Measurement Process

Example: Distance between two cities
Suppose that you are trying to determine a distance between two cities on a map. The data acquisition is to place ruler parallel to line that connects two cities and to count the number of ticks from one city to the other. The data processing is the multiplication of scale of map with measured distance. Writing it to a paper or to save it to anywhere is the data distribution.

Example: Measuring current flowing through a circuit
The task of measuring current on an electric circuit may be accomplished with various sensing elements but the simplest one is to place a known low valued resistance on current path and measure the voltage drop on the resistor. The most of multimeters acquire data by this method. But the voltage value does not directly corresponds to measured value because of the measured value is the resistance times current so, voltage must be divided to find the current value. An opamp circuit is implemented for this modification. The opamp circuit does the job of data processing. The data distribution is obviously through LCD screen.

D. Measurement System Analysis

Although nature is prefect and exact, no observation of its properties is perfect. The limits of our instruments and implementation errors cause a deviation of measured value from its true value.

In order to provide reliable information, the measurement setups should be analyzed systematically. The process of measurement system analysis characterizes the instruments performance in following manners:

- The measurement system should measure what is aimed to be measured.
- The measurement results should have an average close to the true value
- Every measurement system has unpredictable deviation due to the nature of the system but I must still be self-consistent
- Measurement setup must be still functional independent of observer
- The performance of a measurement setup should not vary as time goes.

The purpose of Measurement System Analysis is to qualify a measurement system from these points of view and provide results as a below set of attributes:

Accuracy of an instrument indicates the deviation of the reading from a known input
Precision of an instrument describes the spread of these measurements when repeated under same conditions.
Tolerance is a term that is closely related to accuracy and defines the maximum error that is to be expected in some value.

The idea is that firing an arrow at a target is like making a measurement.

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Accuracy is a qualitative measure of how close a measurement is to the centre of the target – the 'true answer'. Precision is represented by a cluster of consistent measurements, but there is no guarantee that these are accurate.To comment about accuracy, the true value must be known.

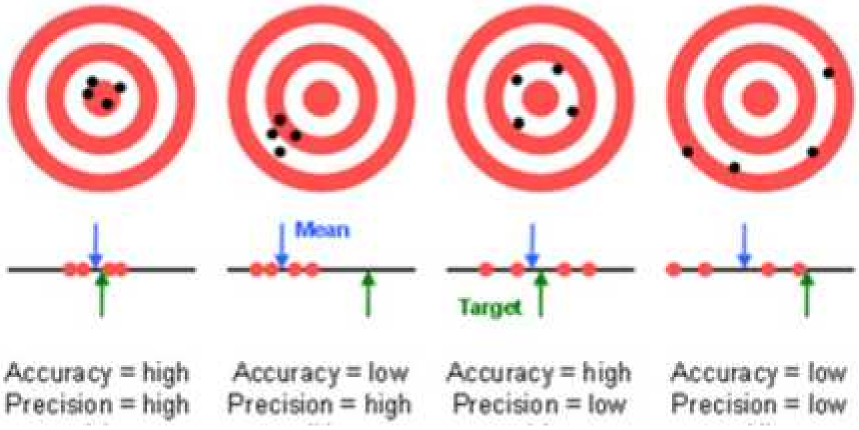

Figure 3. Representation of accuracy and precision

Precision is often, though incorrectly, confused with accuracy. High precision does not imply anything about measurement accuracy. An instrument can be precise but inaccurate and, likewise, it is possible to have an accurate but imprecise instrument

To comment about precision, a set of measured values must be known. The terms repeatability and reproducibility mean approximately the same as precision but are applied in different contexts as given below.

Repeatability assesses whether the same observer can measure the same part/sample multiple times with the same measurement device and get the same value.
Reproducibility assesses whether different observers can measure the same part/sample with the same measurement device and get the same value

The measurement analysis also presents instrument characteristics and limits.

Range (or Span): The total range of values an instrument is capable of measuring. For a standard thermometer this is 0 to 100°C. This is the same as the full scale.
Resolution is the smallest change in input signal needed to produce a change in the output signal.

Offset of an instrument is a specified as its error when measuring zero magnitude input.

A measurement must be made with respect to a known datum or base line. It is very common and convenient to adjust the output of the instrument to zero at the datum. For example, a thermometer is set up to display zero at the freezing point of water. A pressure gauge is adjusted to read zero when open to atmosphere.

However, the output signal may be offset from zero by some amount. It is often possible to adjust the instrument to remove this offset. For example, a bathroom weighing scales can be adjusted to display zero when no one is standing on it.

Sensitivity of an instrument is the ratio of the readout form the instrument to the change in the measured variable causing this. Sensitivity is also defined as the output over the input and therefore it is named as the gain of the instrument.

For example, a temperature measuring system that uses a platinum resistance temperature device (RTD) produces a change in resistance as the temperature changes. The input is temperature and the output is resistance. The output over the input is therefore, (Sensitivity = dR/dT Units = Ω/°C)

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Linearity of an instrument actually refers to nonlinearity of it. It represents validity of linear model of the input output relationship of measurement system.

It is the difference between actual and ideal straight line behaviour. One way to define non linearity is to divide the maximum non linearity value by the full scale deflection.

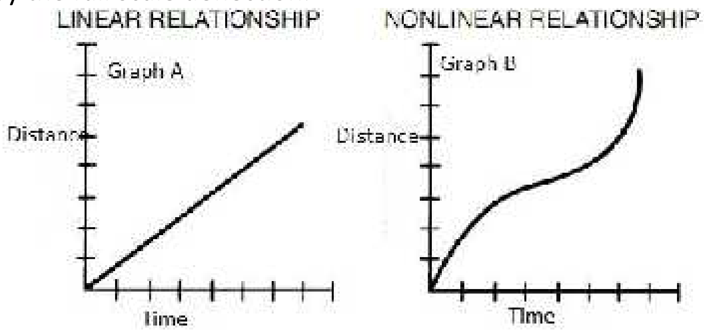

Figure 4. Linear and nonlinear relationships

The offset and the sensitivity of an instrument defines the linear input/output relationship of measurement system.

Calibration

As there are predefined standards and units, the measurement devices/instruments are the devices that are the stereotypes of their standards. This means that they have the representative physical quantitative scales that correspond to "exact" physical characteristics of standard unit definitions. Hence, the reliability of each measurement device/instrument must be determined with respect to these standards. This experimental process that defines/arranges the reliability is named as calibration.

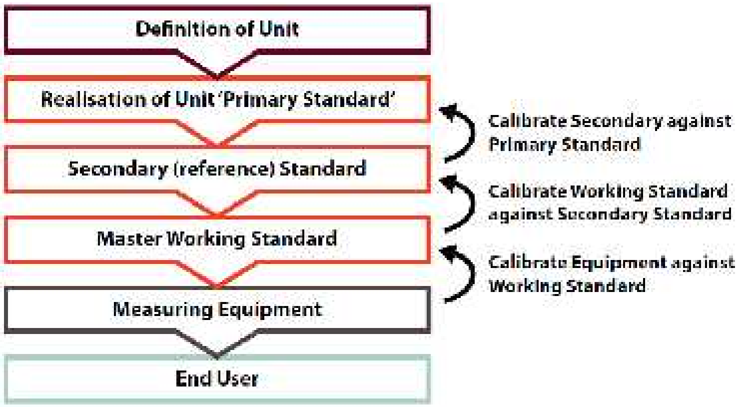

Figure 5. Hierarchy of Calibration Process

In a calibration process, a known input value is applied to a measurement device/instrument for the purpose of observing the system output value. It establishes the relationship between the input and output values. The known value used for the calibration is what is defined in the standard.

Calibration can be classified in to two categories according to characteristic of measured variable: Dynamic and static calibration.

When the variables of interest are time (or space) dependent then varying information is needed. In a broad sense, dynamic variables are time (or space) dependent in both their magnitude and frequency content. A dynamic calibration determines the relationship between an input of known dynamic behavior and the measurement system output. The dynamic calibration results are more deliberate and determine the dynamical properties like rate or frequency range (Bandwidth) of the instrument.

In static calibration, a known value is input to the system under calibration and the system output is recorded. The term ''static'' implies that the values of the variables involved remain constant; that is, they do not vary with time or space. In static calibrations, only the magnitudes of the known input and the measured output are important. In a calibration the input value is usually a controlled independent variable, while the measured output value is the dependent variable of the calibration.

By applying a range of known input values and by observing the system output values, a direct calibration curve can be developed for the measurement system. On such a curve the input, x, is plotted on the abscissa against the measured output, y, on the ordinate. In an equation that describes the calibration, the input value is usually a controlled independent variable, while the measured output value is the dependent variable of the calibration.