ME 482 – Rapid Product Development and Manufacturing

Chapter 5

Measurement Techniques (Part I)

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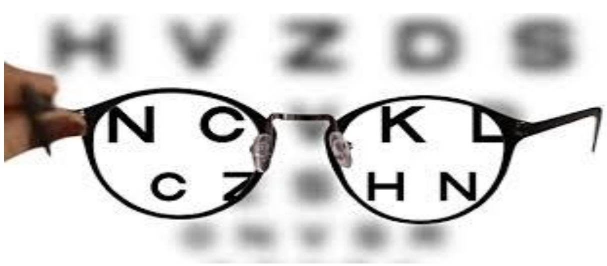
- **Measurement** is the process of associating numbers with physical quantities and phenomena. Measurement is fundamental to the sciences; to engineering, construction, and other technical fields; and to almost all everyday activities.
- **Metrology** is the science of measurement, embracing both experimental and theoretical determinations at any level of uncertainty in any field of science and technology.
- Measurement techniques have been of immense importance ever since the start of human civilization, when measurements were first needed to regulate the transfer of goods in barter trade in order to ensure that exchanges were fair.
- The industrial revolution brought about a rapid development of new instruments and measurement techniques to satisfy the needs of industrialized production techniques.

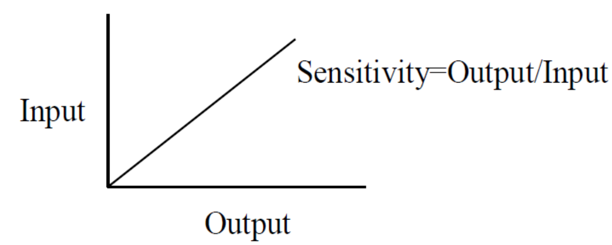
Measurement for RPD

- As modern production techniques dictate working to ever tighter accuracy limits, and as economic forces to reduce production costs and time become more severe, so the requirement for instruments to be both accurate and cheap becomes mandatory.
- Life in the 21st century relies heavily on precision measurement.
  - Navigation systems depend on ultra-stable clocks, as any small error in timing can throw navigation a long way off course.
  - Nuts ordered from one supplier will fit together and work with bolts ordered from another.
  - Food producers know the optimal temperature for preparing food products perfectly, so that they do not waste any unnecessary energy.
- Precision measurement is at the heart of each of these experiences, and many more that we often take for granted.

- For example, aero engines are built to a very high accuracy and require about 200.000 separate measurements during production. Some measurements are simple, and others more complicated. Some are made on a factory floor, others in specialist measurement laboratories. But by having confidence in each individual measurement, manufacturers save time and money, and improve the quality of their products.
- All engineers measure things, but try asking yourself the following questions:
  - Are the measurement results accurate enough?
  - Is the measurement device working correctly?
  - How critical is this measurement? If it is wrong, could someone lose their life? Or Will someone lose money?

- **Readability:** (of a instrument) indicates the closeness with which the scale of the instrument may be read. Readability is dependent on scale length, spacing of graduations and size of pointer. *(An instrument with a 12-in scale would have a higher readability than an instrument with a 6-in scale and the same range)*.
- **Sensitivity:** (of an instrument) is the ratio of the linear movement of the pointer on an analog instrument to the change in the measured variable causing this motion. *(a 1-mV recorder might have a 25-cm scale length. Its sensitivity would be 25 cm/mV)*





General Terms

- **Accuracy:** (of an instrument) indicates the deviation of the reading from a known input. Accuracy is frequently expressed as a percentage of full-scale reading. *(100 kPa pressure gage having an accuracy of 1 percent would be accurate within ±1 kPa over the entire range of the gage)*
- **Precision:** (of an instrument) indicates its ability to reproduce a certain reading with a given accuracy.

  Accuracy can be improved up to but not beyond the precision of the instrument by calibration. The precision of an instrument is usually subject to many complicated factors and requires special techniques, such as **uncertainity analysis**.

Low accuracy, but high precision

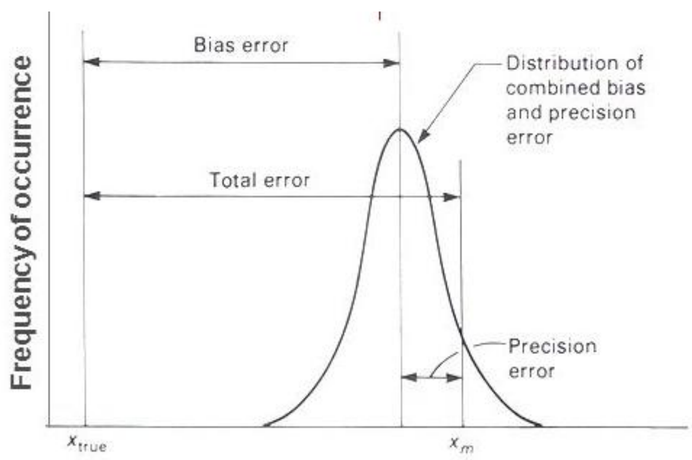
Higher accuracy, but low precision

High accuracy and high precision

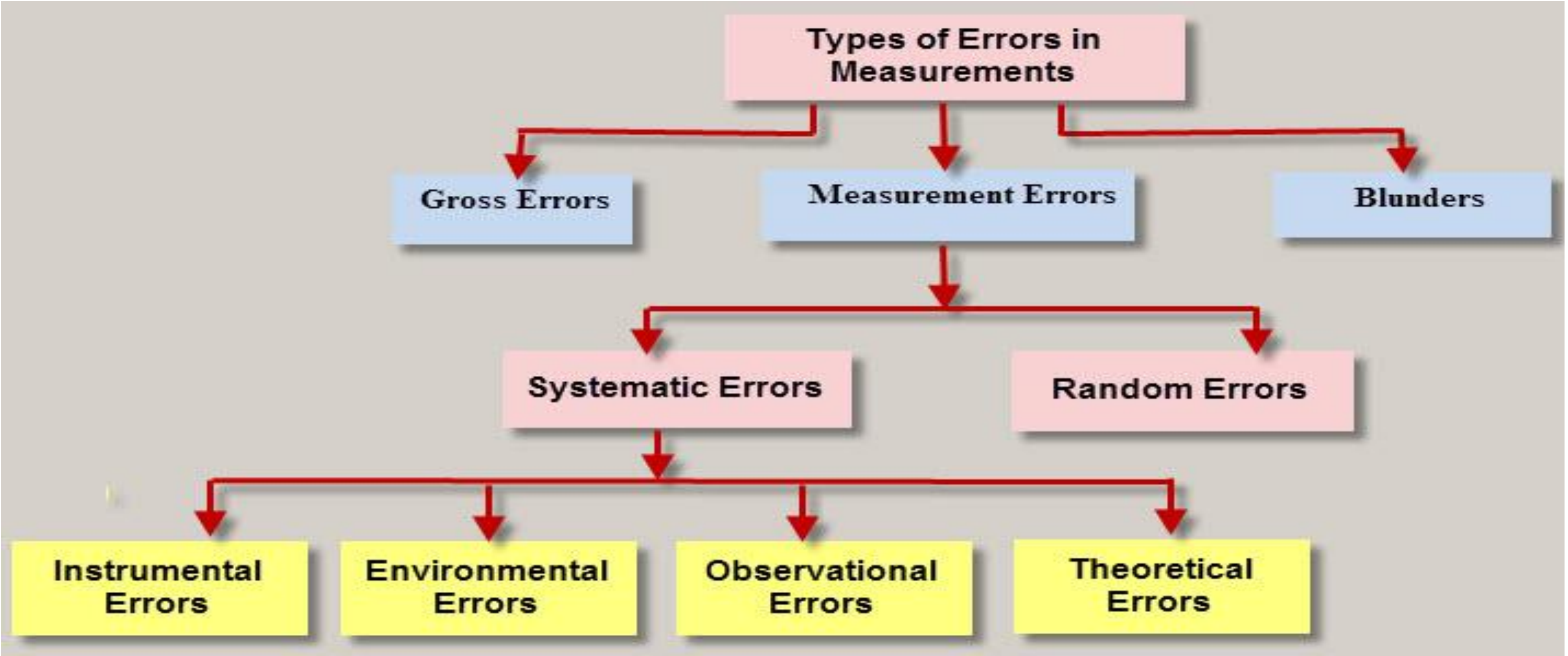
Types of Errors

There are some types of errors that may cause **uncertainty** in a measurement.

- **Systematic error (bias error):** It is the fixed or constant component of the total error and sometimes referred to simply the bias. *(errors due to method, instrument, calibration, human, arithmetic, dynamic response)*
- **Random error:** It is the random component of the total error. It may be caused by *personal fluctuations, random electronic fluctuations in the apparatus or instruments, various influences of friction, and so forth*. These random errors usually follow a certain statistical distribution, but not always.



Types of Errors



It is somewhat more explicit to speak of measurement uncertainty than measurement error.

- Suppose that we have some measurements to combine and calculate a particular result due to the uncertainties in the primary measurements.
- Let us consider the calculation of electric power from

P=EI

where **E=100±2V** and **I=10±0.2A**

- The nominal value of power **=100x10=1000 W**

Possible variations in voltage and current;

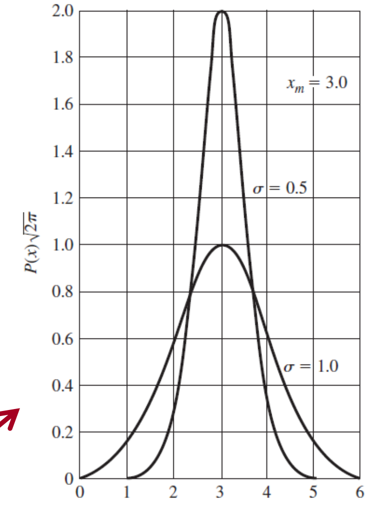
Pmax=(100+2)(10+0.2)=1040.4 W

Pmin=(100-2)(10-0.2)=960.4 W

The uncertainty in the power +4.04%, -3.96%

Statistical Analysis

- Aritmetic mean
- Standart deviation
- Geometric mean
- Pictorial Methods
- Binomial distribution (success-failure, good-bad type of observation)
- Poisson distribution
- The Gaussian or Normal error distribution
- Confidence interval
- Chauvenet's Criterion
- Standard Deviation of the Mean
- The Chi-Square Test
- Method of Least Squares
- Student t-distribution



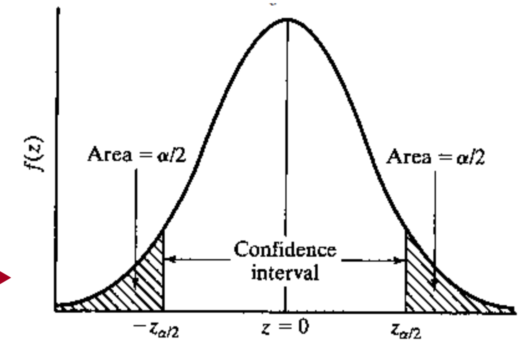


Table 3.5 Chauvenet's criterion for rejecting a reading

Number of Readings, n	Ratio of Maximum Acceptable Deviation to Standard Deviation, d_{max}/σ
3	1.38
4	1.54
5	1.65
6	1.73
7	1.80
10	1.96
15	2.13
25	2.33
50	2.57
100	2.81
300	3.14
500	3.29
1000	3.48

Distribution	Application
Binomial	Used for quality control (rejection of defective products), failure–success, good–bad type of observation. This is a discrete distribution.
Poisson	Used to predict the probability of occurrence of a specific number of events in a space or time interval if the mean number of occurrences is known.
Normal (Gaussian)	Continuous, symmetrical, and most widely used distribution in experimental analysis in physical science. Used for explanation of random variables in engineering experiments, such as gas molecule velocities, electrical power consumption of households, etc.
Student's *t*	Continuous, symmetrical, used for analysis of the variation of sample mean value for experimental data with sample size less than 30. For sample sizes greater than 30, Student's *t* approaches normal distribution.
χ^2	Continuous, nonsymmetrical, used for analysis of variance of samples in a population. For example, consistency of chemical reaction time is of prime importance in some industrial processes and χ^2 distribution is used for its analysis. This distribution is also used to determine goodness of fit of a distribution for a particular application.
Weibull	Continuous, nonsymmetrical, used for describing the life phenomena of parts and components of machines.
Exponential	Continuous, nonsymmetrical, used for analysis of failure and reliability of components, systems and assemblies.
Lognormal	Continuous, nonsymmetrical, used for life and durability studies of parts and components.
Uniform	Continuous, symmetrical, used for estimating the probabilities of random values generated by computer simulation.