Process Control and Instrumentation
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Lecture - 37
Instrumentation: General Principles of Measurement Systems (Contd.)

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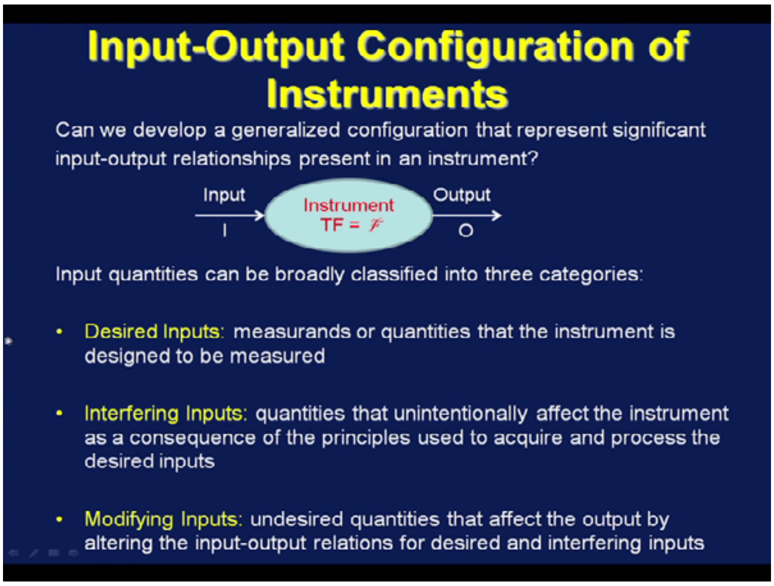

In your previous lecture, we studied our discussion on Input Output Configuration of Instruments. We were trying to develop a generalized configuration that represent, significant input output relationship that exist in an instrument. In this context we define three different types of inputs. We said that input quantities can be broadly classified into these categories. Desired Inputs we defined desired inputs as the quantities that the instrument is designed to be measured. So, the instrument has been design to be sensitive to desired inputs only. Interfering Inputs quantities that unintentionally affect the instrument as a consequence of the principles used acquire, and process the desired inputs. And, Modifying Inputs are undesired quantities that affect the output by altering the input output relations for desired and interfering inputs.

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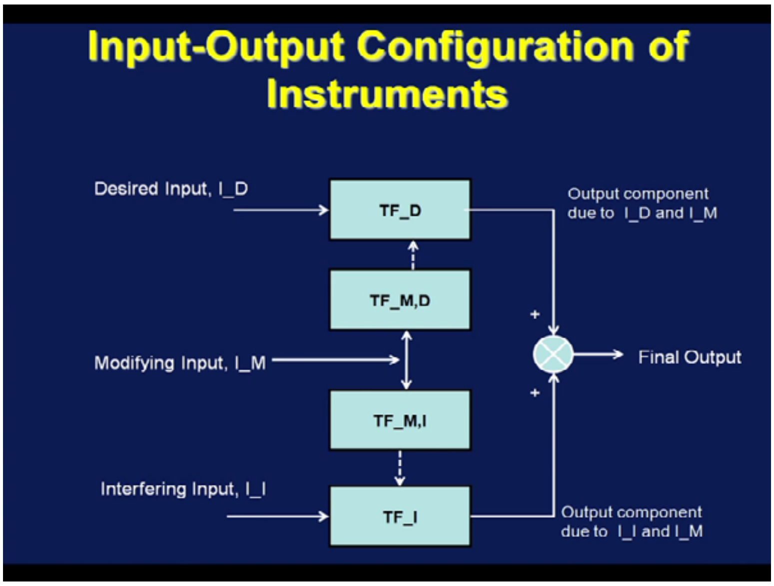

So, we presented this block diagram in previous class which represents a general Input Output Configuration of Instruments. You have Desired Input, Modifying input and Interfering Input. Let, us consider this as a Transfer Function which works on desired input this one or let, us 1st consider this the Transfer Function works on interfering input. And since modifying input alters the relationship that exist between desired input and output and interfering input and the output we have a transfer function TF M,D which alters, which represents interactions between these two and a transfer function which alters the which interacts with modifying input and interfering input.

So, you can consider that that this transfer function which works on the desired input signal gives us and signal which can be consider as component of the Final Output. And this, component is due to desired input as well as modifying input. Similarly, the component here is the result of interfering input as well as modifying input when these two components are summed up we get the Final Output.

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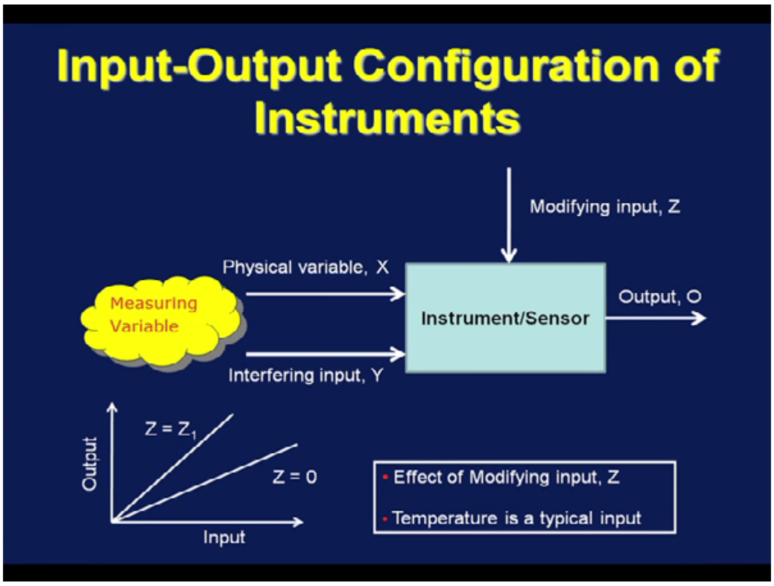

It can also be represented by mode gen by moves simple block diagram like this. Where, the instrument receives not only the signal corresponding to the Physical variable where interested in measuring but, also Interfering input as well as modifying input. So, the instrument receives all these different types of inputs and finally, responds with its output.

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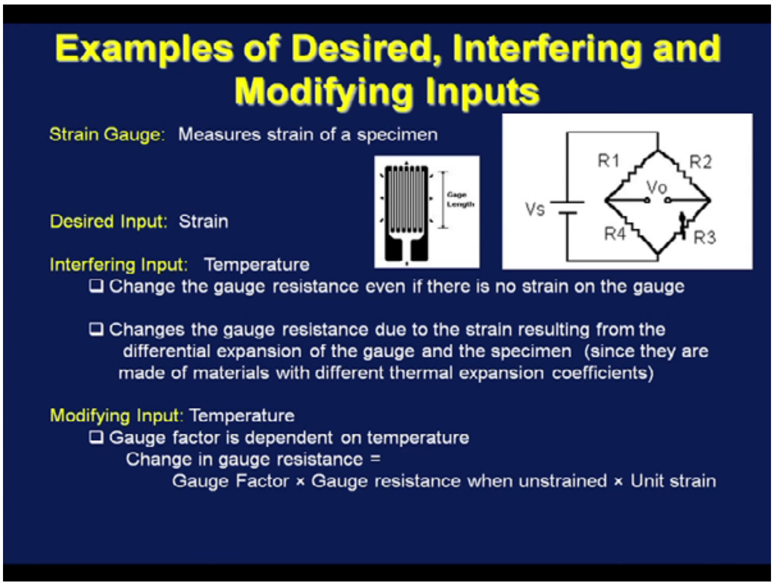

So, let us now take some Example of Desired input, Interfering input and Modifying Inputs.

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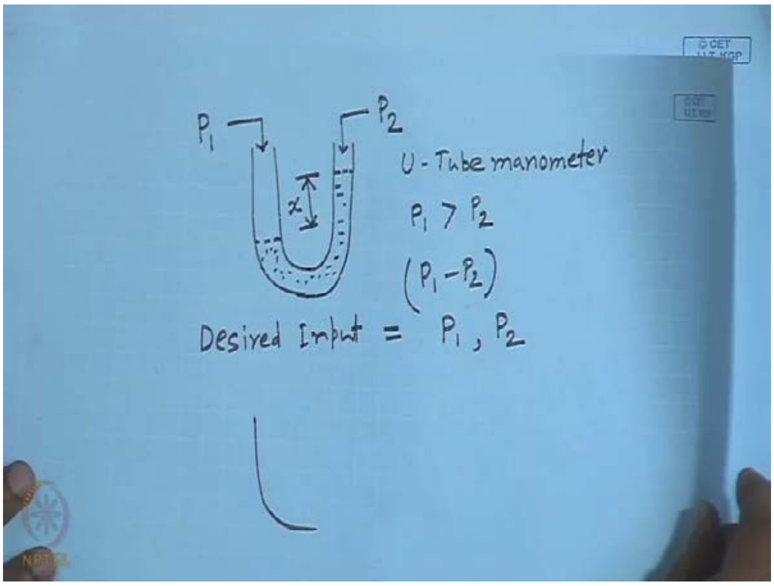

First let us consider, a manometer we are considering a U Tube manometer. You know U Tube manometer is used to measure different self ratio. Let us consider the two links of U tube manometer is connected to two different pressure sources. We consider P1 to be greater than P2 and there is manometer liquid. So, P1 is greater than P2 this, difference of liquid level between these two tubes to be called it x, x can be considered as a measure of P1 minus P2 the differential pressure. So, Desired Input here is P1, P2 for the differential pressure. Now, let us take the same U tube manometer and put it in a vehicle which is accelerating. So, we have the same U tube manometer.

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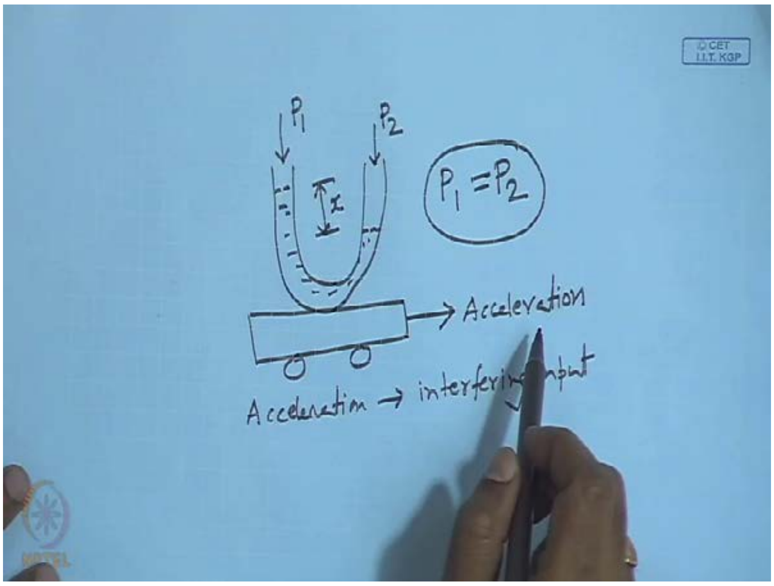

We put the U tube manometer on a vehicle that is Accelerating. Now, even if we apply same pressure to both the lames of the manometer will see a reading. We are considering here, P1 equal to P2. If, P1 is equal to P2 and if this is not mounted on a vehicle which is accelerating x would be equal to 0 but, if I mount the U tube manometer on a vehicle which is accelerating and even if the limes to both the limes of the U tube manometer is connected to same pressure source it will show a differential pressure gradient. So, Acceleration is working as an interfering input. The manometer has become unintentionally sensitive to acceleration. Similarly, if you tilt the manometer with an angle then, also you can see that even if both the limes of the manometer connected to the same pressure source the manometer show a non 0 really.

So, the tilt angle again works as an interfering input. So, what can be the modifying input here? We know the modifying input changes the relationship that exist between input and output or, in other words it affects the transfer function between the desired input and the output and also interfering input and the output. We know temperature affects the density of the manometer liquid. So, if temperature changes the change in temperature will affect the manometer really. Since, the density of the manometer liquid will play a role in the celebration of the manometer and the density changes with time density changes with temperature. So, the temperature can act as modifying input.

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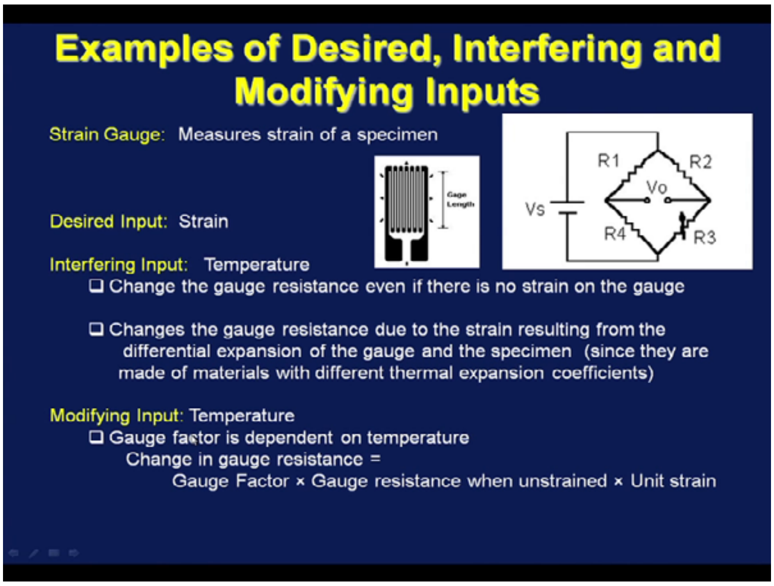

Let us take still another examples. Let us take an example of Strain Gauge. A strain gauge is a device which Measures the strain of a specimen. This is an example of a strain gauge will talk about strain gauge in more detail later for the time being let us consider this is a simple resistance wire. Now, this resistant wire is cemented on a specimen. Say if, the specimen is strain the resistance wire also gets strained.

Now, the resistance wire when strain it will change the resistance of the resistance wire. So, if I take help of an withsten barge, and put the strain gauge here and then, 1st maintain null point and then I strain there is specimen. So, the resistance wire gets strain which will cause a change in the resistance of the strain gauge. So, there will be an unbalance able circuit and the current can be taken as measure of the strain.

So, the Desired Input here is Strain. The strain gauge has been design to be sensitive to strain. So, the temperature can act as an interfering input because, temperature can change the gauge resistance even if there is no strain on the gauge. Because, the resistance of the wire is a function of temperature and if there is a change in temperature in the ambient the gauge resistance can change which can show an unbalance current in the circuit. So, temperature works as an Interfering Input. Temperature can also Change the gauge resistance due to the strain resulting from the differential expansion of the gauge and the specimen. Ordinarily the strain gauge on this specimen will be of materials with different thermal expansion coefficient. So, a change in temperature can calls differential expansion of the gauge on the specimen

So, this can calls a strain and again temperature this way also works as interfering input. Temperature also works as a Modifying Input here because, Gauge factor is dependent on temperature, we can define the gauge factor of this strain gauge as Change in resistance, Change in gauge resistance is equal to Gauge Factor multiplied by gauge resistance when unstrained multiplied by Unit strain. Since, Gauge Factor depends on Temperature. So, temperature will work as modifying input.

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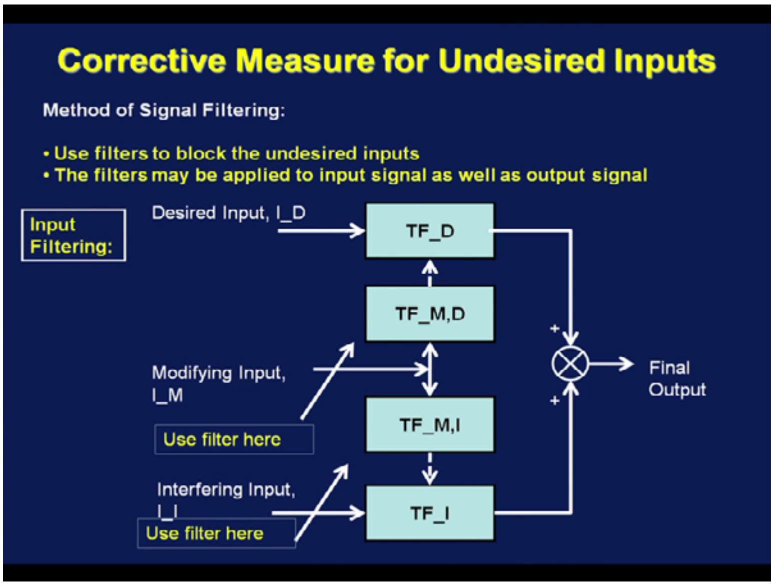

So, next let us talk about what we can do to make our instrument respond to only desired input. So, we want to filter out the effect of or the spurious effect of modifying input as well as interfering input. Now, method of Signal Filtering uses filters to block the undesired inputs. So, we can block the undesired inputs namely Modifying Input as well as Interfering Input by introducing suitable filters. The filters may be applied to input signal as well as output signal depending on whether we apply the filter to input signal or output signal we can have input filtering or output filtering.

So, this is a Corrective Measure for Undesired Inputs. In case of Input Filtering we want to apply the filter to input signal. So, that it blocks the undesired input. Again, let us consider the block diagram which represents the relationships between Desired Input, Modifying input, Interfering Input on one hand and the output on the other hand. I want this output to be sensitive to desired input only. But, the instrument also response in the process of being sensitive to desired input only to modifying input as well as interfering input.

So, if I can introduce a filter here, and if I can design a suitable filter it may block the modifying input. In other words you can consider that I want Transfer Function here which is actually 0. So, when I M the input modifying input is being worked upon by a transfer function which is equal to 0 will give a signal equal to 0.

Similarly, to block the effect of interfering input I can introduce a suitable filter here. Again, mathematically speaking or in terms of our block diagram notation we should have a Transfer Function here, which is equal to 0. If, we can do that this component will be this signal will be essentially 0 and this signal will be void of effect of modifying input. So, this Final Output will be surely result of desired input. So, by introducing suitable filters to input signal it is possible theoretically to make my instrument sensitive to desired input only. Or to make my measurement to be sensitive to desired input only.

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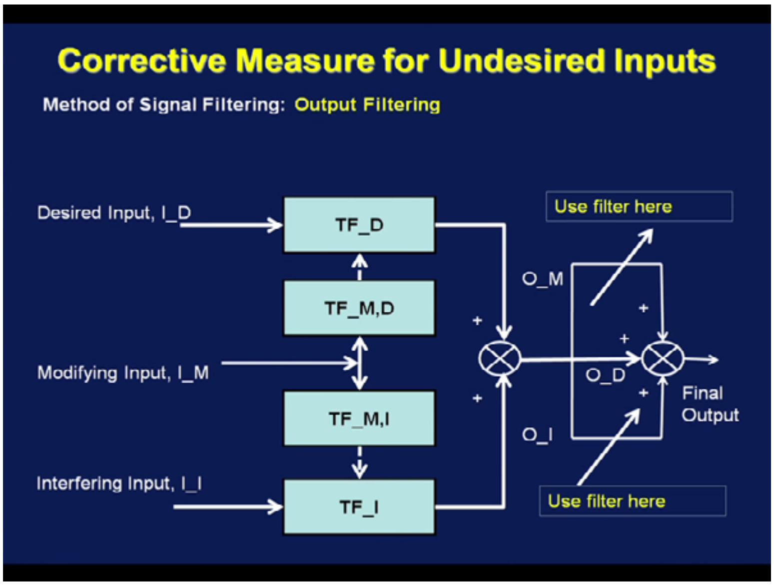

I can also introduce filters to the output signal again consider the same block diagram. In case of Input Filtering we put filters to the modifying input signal as well as to interfering input signal. In case of Output Filtering will introduce filters at output signal. So, if I can split this output here which is a result of desired input modifying input as well as interfering input if, I can split this output signal into components of output component coming from only desired input output component coming from only modifying input and output component coming from only interfering input. And then, introduce filters to the component that comes from modifying input to the component that comes from interfering input my Final Output will be sensitive only to desired input. So, the concepts are very much similar in case of input filtering will introduce filters to input signal in case of output filtering we introduce filters to the output.

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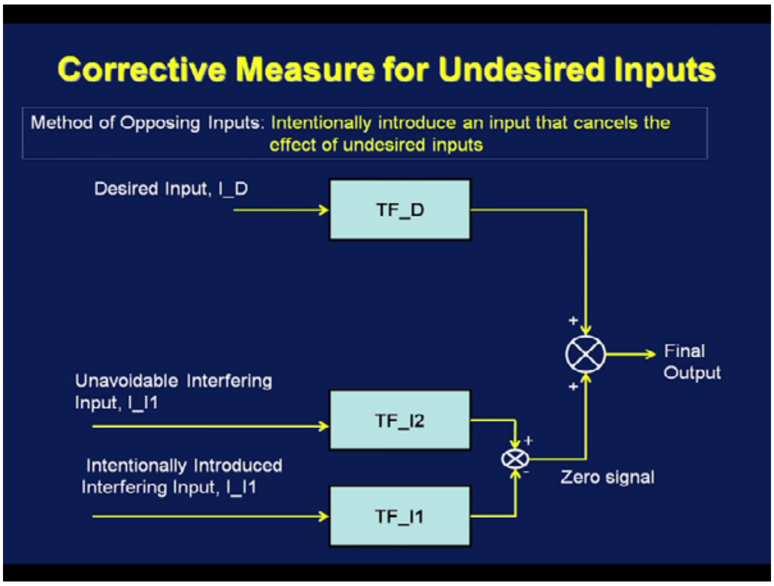

So, now let us take an example of input filtering.

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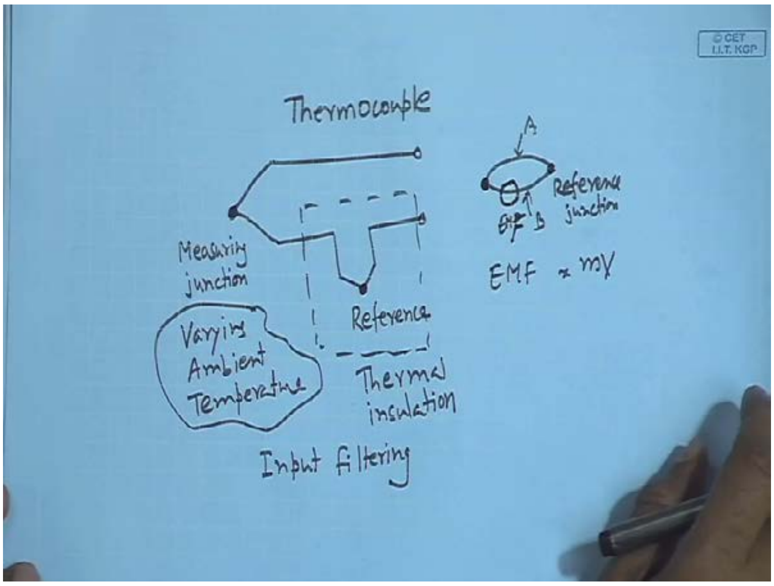

Let us consider a Thermocouple. Thermocouple is a temperature measuring instrument. It is made up two dissimilar metals we will talk about thermocouple in more detail later. Thermocouple is made of two dissimilar metals we make two junctions one we call Measuring junction another one is called Reference junction. So, if you take dissimilar metals let us say metal A and metal B and form two junctions if, you keep this two junctions at two different temperature them EMF is produced, and this EMF depends on the difference between this two junction temperature.

So, now if I keep one junction temperature constant and call this as Reference junction and expose this junction which I call Measuring junction to the measuring medium whose temperature I want to measure then, this EMF produce can be taken as a direct measure of the temperature. The EMF produce depends on the difference between this junction temperature and this junction temperature but, by keeping one junction temperature constant I can measure the temperature directly by looking at the EMF value of course, after suitable calibration. So, now, let us come back to this. This is same as this. So, you have and EMF measuring instrument here a mille voltmeter the EMF is the order of mille volt.

Now, this reference junction has to be kept at some constant temperature. So, if there is Varying Ambient Temperature this can work as an interfering input to the thermocouple. So, one way to put a filter to block the effect of varying ambient temperature will be put a Thermal Insulation around the reference junction. So, by putting a Thermal Insulation around reference junction I can block the effect of varying ambient temperature. So, this is an example of Input Filtering. Again another example of blocking the effect of interfering input can be in strain gauge.

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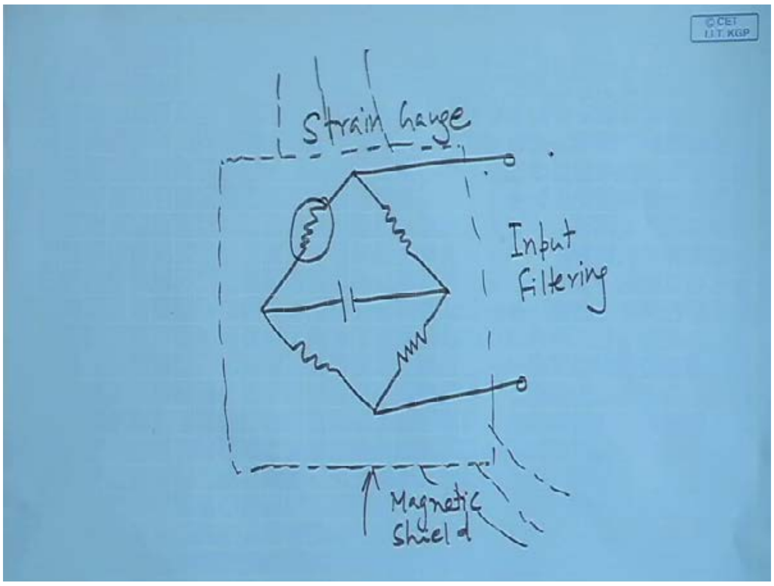

We just talked about Strain Gauge which measures strain in a specimen consider this to be the strain gauge put in one norm of the western bridge. We know the unbalance current is a measure of the strain in the specimen. Now, this strain gauge can become sensitive unintentionally to magnetic field. So, to block the effect of interfering magnetic field we can put a magnetic sealed around the circuit. So, we have a Magnetic Shield which blocks the effect of interfering magnetic field. So, again this is an example of Input Filtering. Another way of taking Corrective Measure for Undesired Inputs will be method of Opposing Inputs. Here, we intentionally introduce an input that cancels the effect of undesired inputs. So, we introduce intentionally an input to the instrument that tend to cancel the bad effect of modifying input and a interfering input.

Let us look at this block we have Desired Input corresponding Transfer Function. We have Interfering Input corresponding Transfer Function. We intentionally introduce this Interfering Input. We have this Unavoidable Interfering Input. So, we have a desired input signal we have an interfering input signal which is undesirable which is unavoidable but, we intentionally introduce another interfering input signal and we choose this signal such that, the effect of unavoidable interfering input signal and the intentionally introduced interfering input signal cancels each other out. So, this is essentially a Zero signal. So, the Final Output becomes this component alone or, in other words the Final Output becomes result of desired input alone. So let us now, take an example of method of opposing input.

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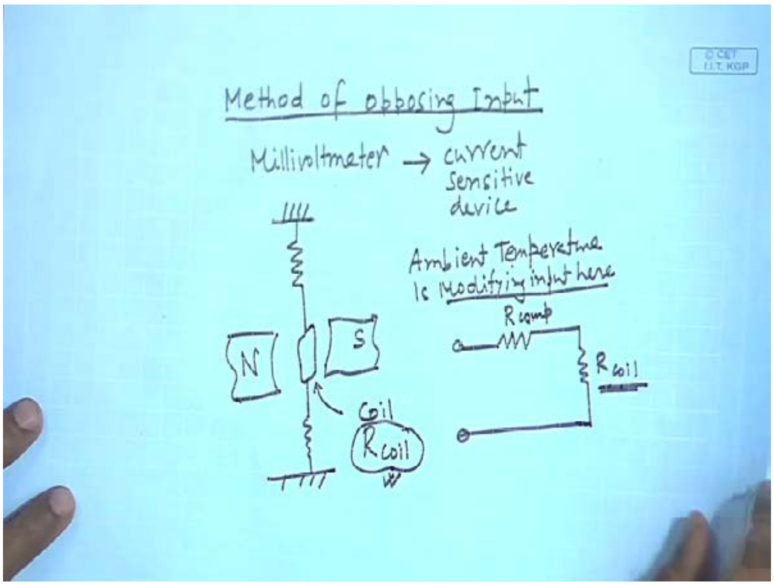

We know Milli voltmeter is essentially a current sensitive device. But, the scale of a milli voltmeter can also be calibrated in volts because volt and current are related let us consider this as schematic of milli voltmeter. So, you have the Coil Ambient Temperature works as Modifying input here because, the ambient temperature can cause a change in the Coil Resistance. So, how do I nullify the effect of ambient temperature? We can add another resistance into the circuit and it is materially such that it has a temperature coefficient of resistance opposite to that of coil ambient temperature can change the resistance of the coil. So, it can work as a modifying input. Now, if I add a compensatory resistance in the circuit and I choose the material such that it has a temperature coefficient of resistance opposite to that of coil I can cancel out the effect of ambient temperature. So, this is an example of Method of Opposing Input. I intentionally introduce a resistance to cancel out the effect of ambient temperature the changes in resistance of coil. Let us take another example of method of opposing input we are talked about Bourdon tube.

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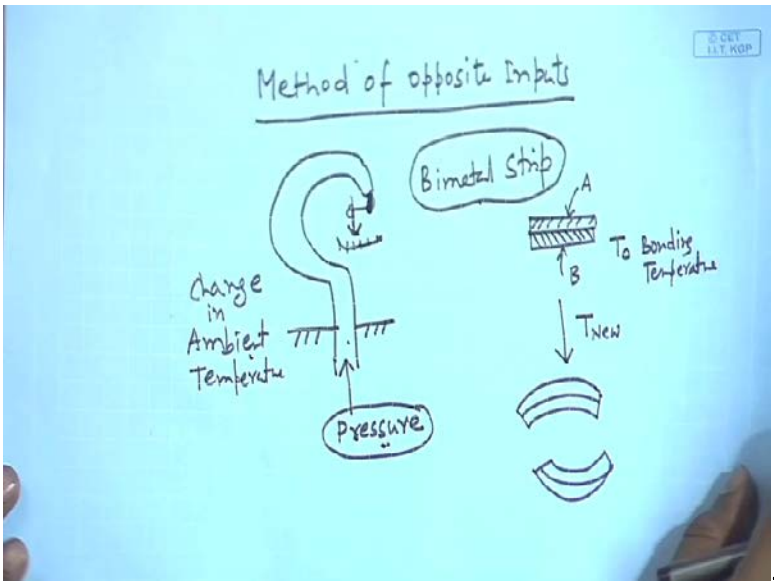

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Let us consider a schematic diagram of Bourdon tube. We know the deflection of the T is the measure of the pressure being apply inside the bourdon tube. Now, the tip deflection depends on various factors but, for given bourdon tube other things being un change this tip deflection can be consider as a function of Pressure alone. Among the various factors on which the tip deflection will depend the elasticity of the material is 1. So, modules of elasticity can change with temperature.

Now, if it changes sufficiently the tip deflection can no longer be considered as a function of Pressure alone. So, in sit we can get additional deflection for changes in temperature. One solution can be we put a Bimetal Strip here. Suppose, we are talking about a situation where the tip of the bourdon tubes is deflecting mode then it should correspond to the given pressure being applied and that additional deflection is the result of change in Ambient Temperature.

Now, if I can design a Bimetal Strip which, deflects when subjected to a temperature let me explain what a bimetal strip is? You take two different metallic strip they are different thermal expansion coefficient they are bounded rigidly at some temperature called T0 Bonding Temperature. Now, if I subject this bimetal strip to a different temperature say New temperature the bimetal strip since they have different thermal expansion coefficient can reflect like this or can reflect like this.

So, now come back to the bourdon tubes example. If, I can suitably design a bimetal strip such that the extra reflection that is caused in the bourdon tubes by the change in Ambient Temperature and the deflection of the bimetal strip due to change in ambient temperature is same in magnitude but, opposite in direction then this deflection of the point are against this scale will be surely a function of this Pressure. So, by putting a suitably design bimetal strip I can cancel out the extra deflection that has cause due to Change in Ambient Temperature. So, this is again an example of Method of Opposite Inputs.

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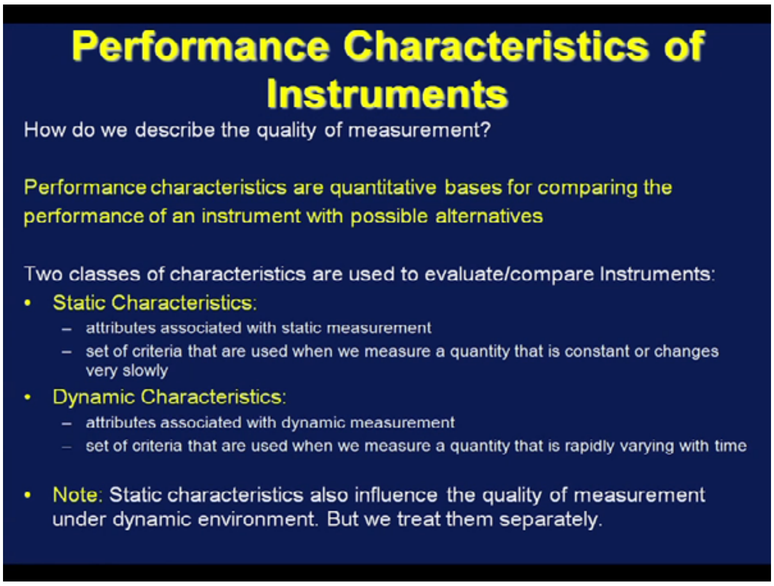

Now, let us talk about Performance Characteristics of Instruments. The question you ask here is. How do you describe the quality of measurement? Or, How do I evaluate the performance of an instrument? They are various instruments available if, I want to compare an instrument with other possible alternatives I must have some quantitative basis for comparison. So, Performance Characteristics of Instruments are those quantitative bases for comparing the performance of instrument with possible alternatives.

Two classes of characteristics are used to evaluate or compare instruments namely Static Characteristics and Dynamic Characteristics. Static Characteristics are associated with static measurement these are set of criteria that are used when you measure a quantity or a condition that is either constant changes very slowly with time. So, Static Characteristics are those characteristics which we must consider any one to analyze the performance of an instrument that is measuring a medium which is constant or varying very slowly with time.

So, you are essentially talking about static medium or steady states situations. On the other hand Dynamic Characteristics are associated with dynamic measurements. So, these are set of criteria that are used when we measure a quantity that is rapidly varying with time. So, Dynamic Characteristics are those characteristics which we must consider if inputs are varying with time while, static characteristics are those characteristics which we must consider when you measure a quantity that is not varying with time. We would like to emphasize here, that Static Characteristics also influence the quality of measurement under dynamic environment.

So, static characteristics not only influence the quality of measurements under static environment it can also influence the quality of measurement under dynamic environment. But, usually we treat them separately the reason is as follows will see later that the dynamic characteristics can be describe usually in terms of differential equations. Now, if I one to incorporate that if static characteristics on to this dynamic characteristics the resulting differential equations will become extremely difficult to handle. So, a general procedure is stood state static characteristics and the dynamic characteristics separately. And we can always have a qualitative super in position of both the characteristics to make a final choice about, the instrument or to have a final say on the performance of the instruments or quality of measurements.

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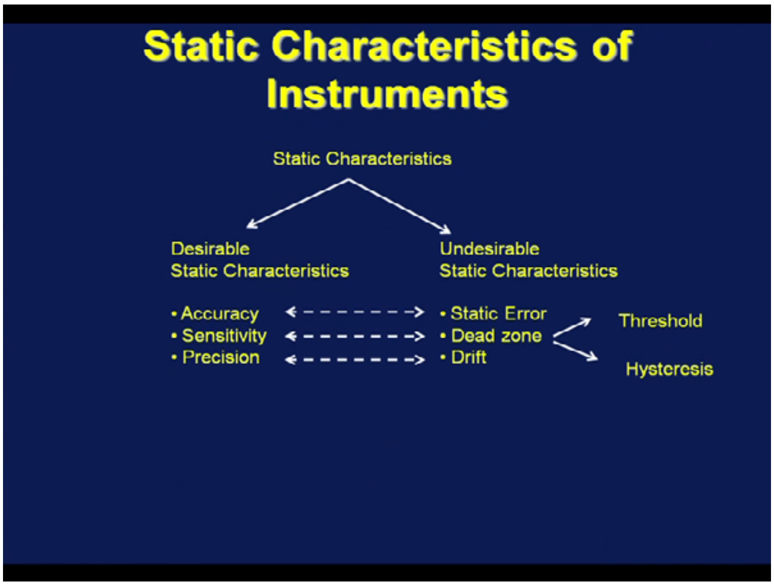

These are the set of Static Characteristics we should be familiar with as we define these are the characteristics which we must consider when the measuring medium is not changing with time or changing very slowly with time. The Static Characteristics can be classified into two categories Desirable Static Characteristics and Undesirable Static Characteristics. Under Desirable Static Characteristics we have Accuracy, Sensitivity and Precision as various characteristics.

Similarly under Undesirable Static Characteristics we have Static Error, Dead zone and Drift. Dead zone can be result of Threshold or Hysteresis. It can also be noted here, that accuracy and static error are related in the same stat if your instrument is accurate enough or if the desirable static characteristic accuracy is high the undesirable static characteristic static error will be low. So, corresponding to accuracy which is desirable static characteristic we have static error which is undesirable static characteristics. So, corresponding to sensitive which is desirable we have dead zone which is undesirable corresponding to precision which is desirable we have drift which is undesirable.

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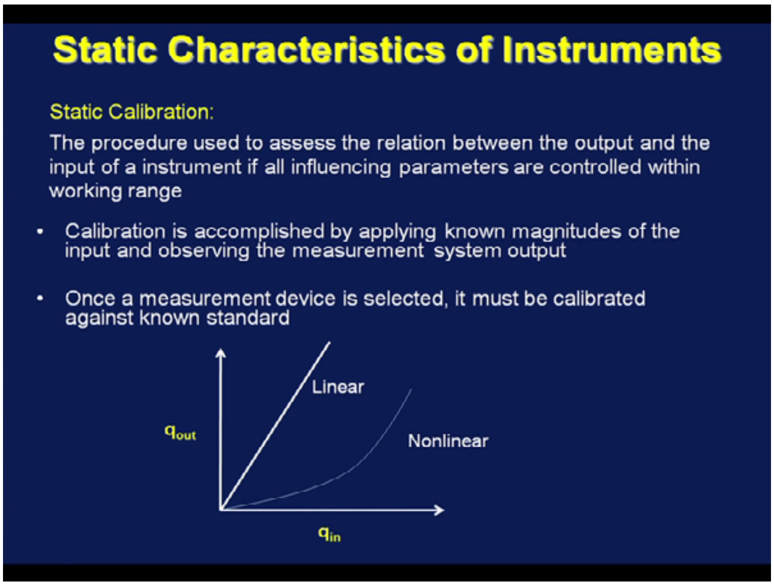

So, let us start our discussion on Static Characteristics of Instruments with a term called Static Calibration. This is a procedure use to assess the relation between the output and the input of a instrument if all influencing parameters are controlled within working range. So, calibration is the act or result of quantitative comparison between the known standard and the output of the measuring system measuring the same quantity. Calibration is accomplished by applying known magnitudes of the input and observing the measurement system output.

So, what do you do is as follows. All inputs desired interfering or modifying inputs except one are kept at some constant values, then the one input under steady is varied over some range of constant values which, causes the outputs to vary over some range of constant values the input output relations developed in this way comprise a static calibration valid under the stated conditions of all the other inputs. So, all inputs except one are kept some constant values then one input under steady is vary over some range of constant values which, causes the outputs to vary over some range of constant values. The input output relations developed in this way comprise Static Calibration which is valid under the static condition static constant conditions of all the other inputs.

So, essentially it is determining a relationship between input and output. So, we keep all the influencing parameters or all input except one constant and vary this constant over some range each time we know the instruments output and can generate the relationships that exist between this set of inputs and outputs. Depending on whether the instrument is Liner or Nonlinear I can have a Linear relationship that exist between input and output represented by a straight line or, a Nonlinear curve that represents the relationships that exist between input and output. Once an instrument is selected it must be calibrated against known standard.

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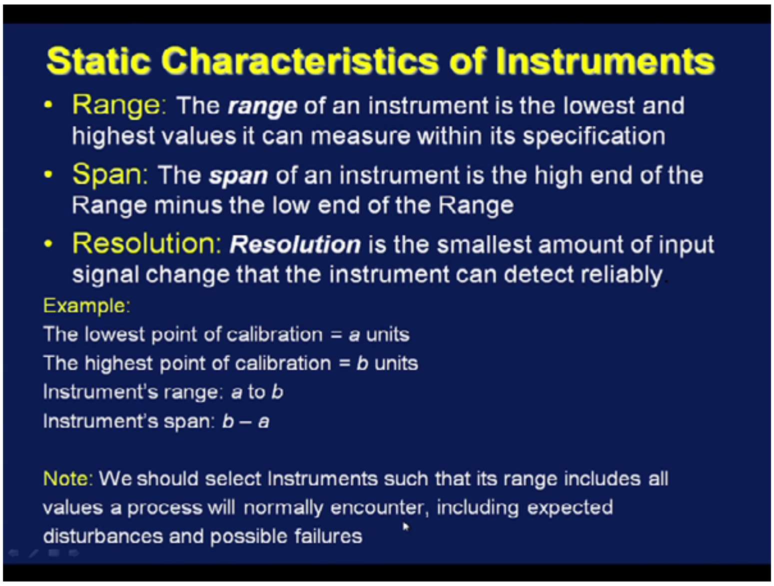

Let us now, define the Static Characteristics of Instruments. Range the range of an instrument is the lowest and highest values it can measure within its specifications. Span the span of an instrument is the high end of the range minus the low end of the range. So, if I have an instrument where the lowest point of calibration is a units and the highest point of calibration is b units then the instruments range is a to b the lowest point of calibration to the highest point of calibration and the instruments span is b minus a, so highest point of calibration minus lowest point of calibration. Resolution is the smallest amount of input signal change that the instrument can detect reliably. It should be noted that we should select instrument such that its range includes all values a process will normally encounter, including expected disturbances and possible failures.

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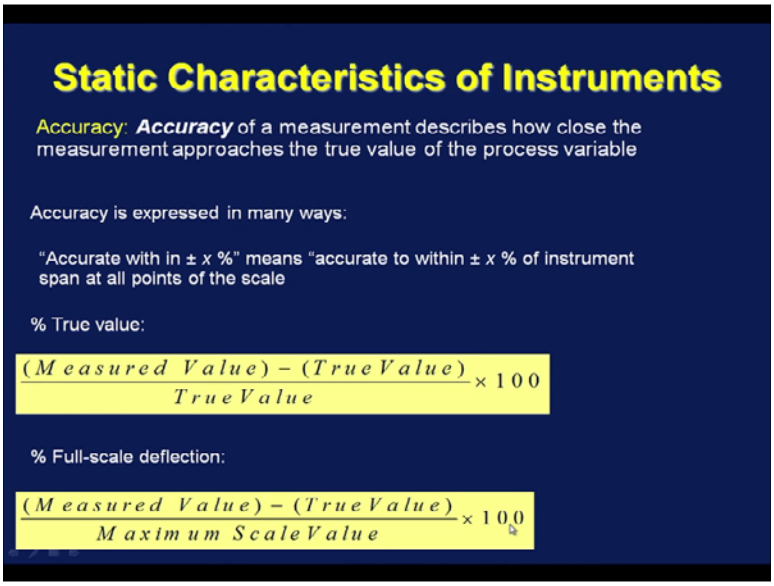

Accuracy of a measurement describes how close the measurement approaches the true value of the process variable. So, it is a measure of how close the measured value is to the true value. Accuracy can be expressed in many ways accurate within plus minus x percent means accurate to within plus minus x percent of instrument span at all points of the scale. Accuracy can also be expressed in terms of percentage True Value which can be expressed as Measured Value minus True Value divided by True value multiplied by 100. Similarly, accuracy can also be expressed in terms of percentage Full scale deflection and this can be represented as Measured Value minus True Value divided by Maximum Scale Value multiplied by 100.

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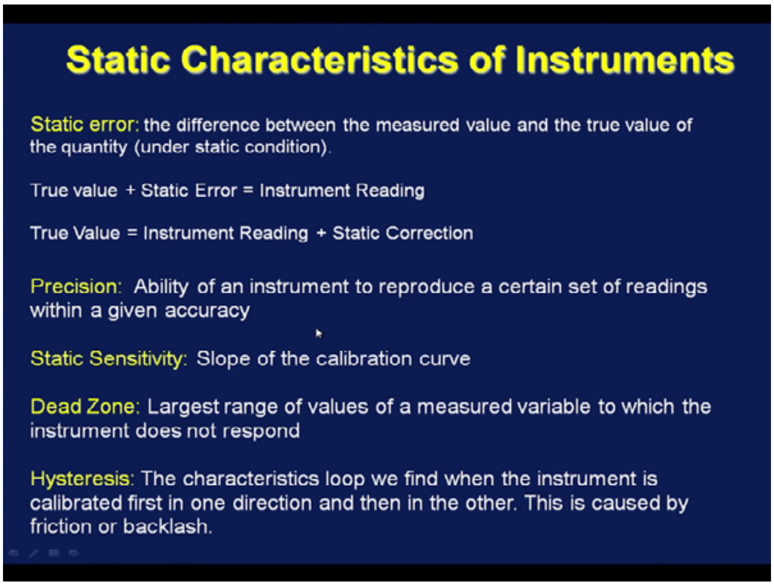

If, accuracy is measure of how close the measured value is to the true value static error must be the difference between the measured value and the true value of the quantity and of course, we are talking about Static Characteristics, so, under static condition. So, Static error is the difference between the measured value and the true value of the quantity. So, True Value plus Static Error is actually what instrument gives us as its reading. So, True Value is Instrument Reading plus some correction factor which we called Static Correction.

Precision is the Ability of an instrument to reproduce a certain set of readings with a given accuracy. So, precision is an ability of an instrument to reproduce a certain set of reading with a given accuracy. This instrument can have precision low accuracy, it can have poor precision poor accuracy and so on and so forth. In our next class will see mode of static characteristics and also talk about dynamic characteristics.