Automation in Manufacturing

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Week - 04
Sensors
Lecture – 04
Fluid flow, pressure, and temperature measurement

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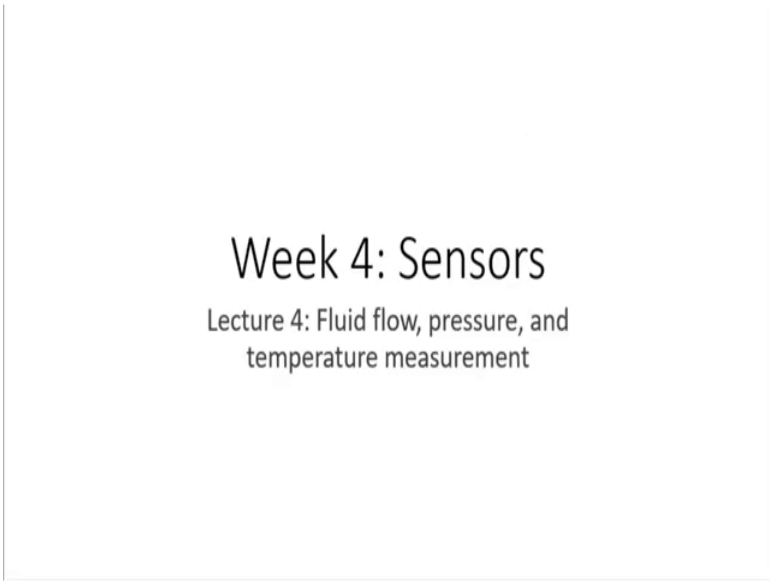

Hello friends, I welcome you to the lecture 4 of week 4. In this lecture, we will be studying various Sensors used for measurement of fluid flow and pressure. We will also study various temperature measurement sensors.

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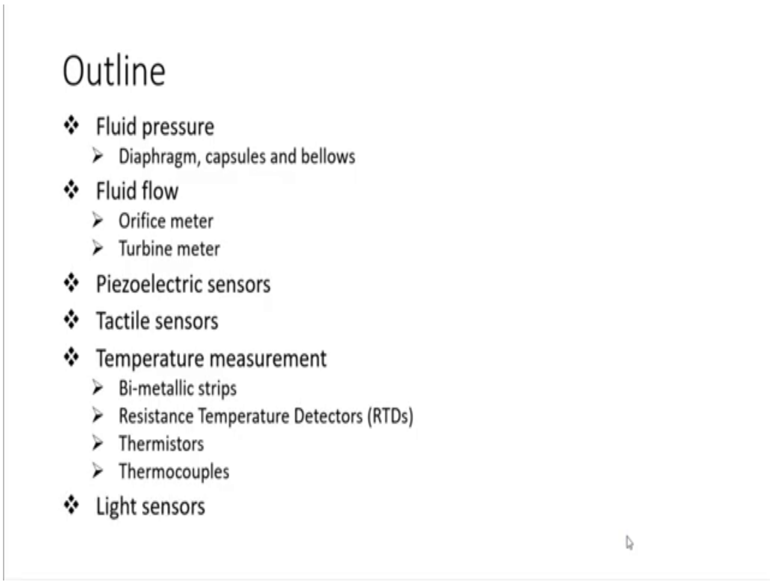

The outline of this lecture is as follows: at start we will study various sensors that are used for the measurement of fluid pressure; these are diaphragm, capsules and bellows.

The diaphragm with strain gauge base sensor will also be studied. We will also see how strain gauges are integrated with diaphragm and how they are useful to measure the fluid pressure. How LVDTs are integrated with bellows to measure the fluid pressure?

Then we will see how to measure the fluid flow. The sensors such as orifice meter and turbine meter will be studied. Then, we will study the piezoelectric sensors and tactile sensors. After that the important variable i.e. temperature, how to measure the temperature and its important sensors that will be studied. Some of the sensors such as bi-metallic strips, resistance temperature detectors, thermistors and thermocouples will be studied.

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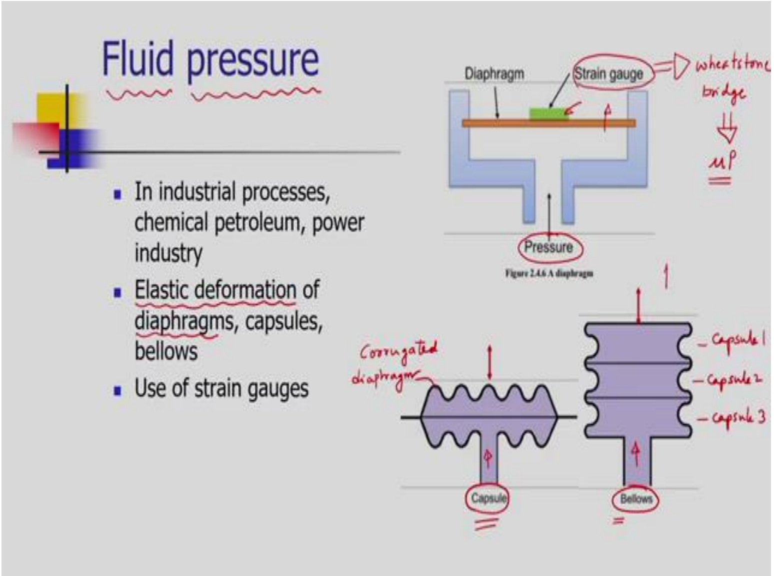

Finally, we will see how to detect the lights by using the photodiodes. Next application; where sensors are required is fluid pressure. In automation we are using variety of fluids; air, gas or it may be water or chemicals or many other liquids. We need to measure the pressure of this fluid for variety of application.

The most common sensor which is used for measurement of fluid is diaphragm. It works based on the elastic deformation principle. When we apply pressure on one side of the diaphragm, then there is elastic deformation of the diaphragm. This elastic deformation can be sensed with the use of strain gauge, which is mounted on its the other side of the surface. And then we can easily find out the pressure in terms of strain that is generated in the strain gauge.

As we have seen the strain gauges can be further connected with a Wheatstone bridge, which is generating the required signals. When we are using two different diaphragms of corrugated nature, we can consider this is a corrugated diaphragm.

When we attach two corrugated diaphragm together, we are generating a capsule. The fluid is passed through the capsule and then there is a deformation of the top corrugated diaphragm. The displacement of the top portion of the diaphragm is in proportion with the fluid pressure. When we are integrating or when we are using multiple number of capsules, then it comes the bellows.

We can see capsule 1, capsule 2, and capsule 3. Multiple number of capsules are integrated, they are stacked over each other and then we can have integrated construction; that is again utilized to sense the fluid pressure. The fluid is passage, as there is a increase in fluid pressure, the top portion of the below will displace, it will move in upward direction.

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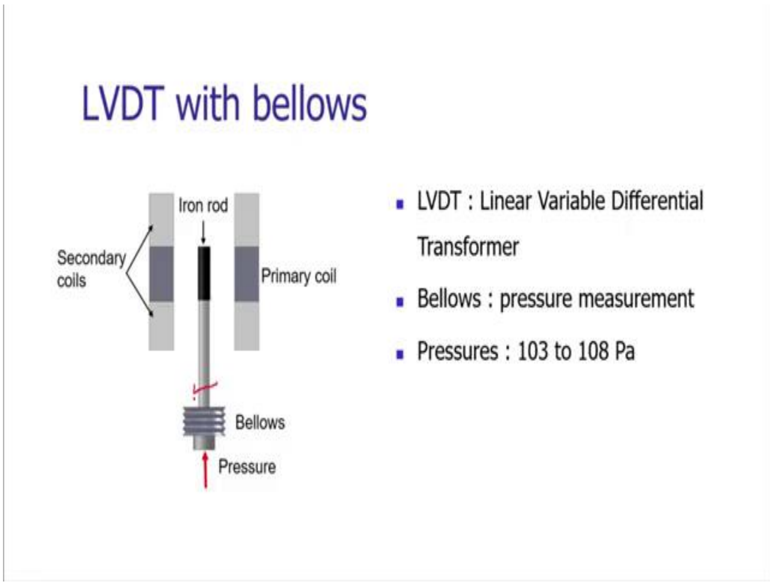

More precise measurement of pressure can be done with bellows when we add the LVDT sensor. On our slide we can see, the LVDT sensor integrated with the bellows. LVDT as we know, it is Linear Variable Differential Transformer. When there is increase in the pressure, the bellows will expand, and as the bellows are expanding the iron rod inside the LVDT sensor will move, it will displace.

As the iron rod is displacing, there is generation of EMF across the secondary coils and that EMF generated across the secondary coil is proportional to the displacement of the rod and displacement of the rod is proportional to the pressure.

In this way we can easily measure the pressure using the LVDT attached with the bellows. These type of arrangement can be utilized to measure pressures about 103 to 108 Pa.

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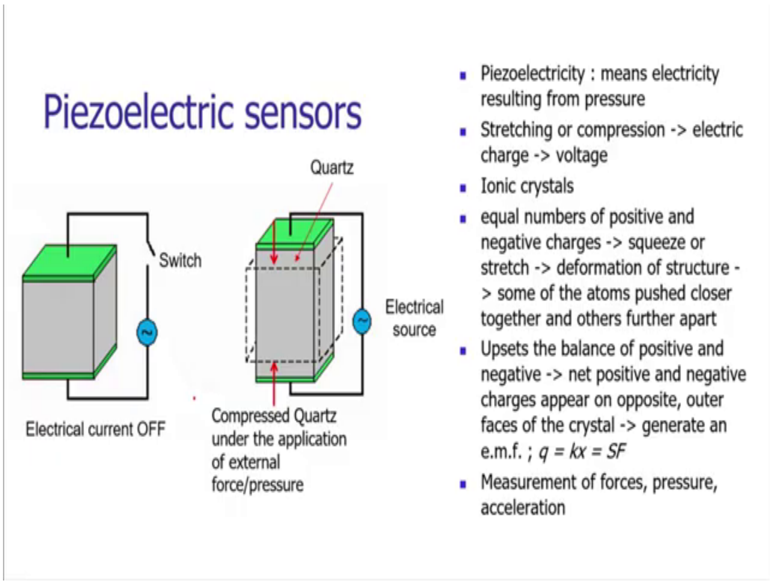

The next type of sensor is piezoelectric sensor. These are very useful and widely used in the industry. What is the meaning of piezoelectricity?

Piezoelectricity means, the electricity resulting from the pressure. There are certain materials, where on the application of a compression force on these materials or when we stretch these materials, the electric charge will be developed and that electric charge will generate the voltage.

Voltage generation is proportional to the force or the pressure which is being applied. These materials are having the ionic crystals. What happens when we apply the compressive force on these materials? At the natural stage and the normal stage, there are equal number of positive and negative charges on its surfaces, but when we squeeze them or when we when we apply pressure or force over these materials, there is deformation of the structure.

During this deformation of the structure, some of the atoms will be pushed closer together and some of the atoms will be moved apart. These lead to upsetting the balance of positive and negative charges over its surfaces and this will generate an EMF. In general, the EMF is directly proportional to the application of the force and the application of the force is nothing but by what amount we are squeezing, or by what amount we are stretching the material.

Mathematically,

EMF, $q = kx = SF$

where k is the proportionality constant. Piezoelectric sensors are widely used to measure the forces, pressure and the acceleration.

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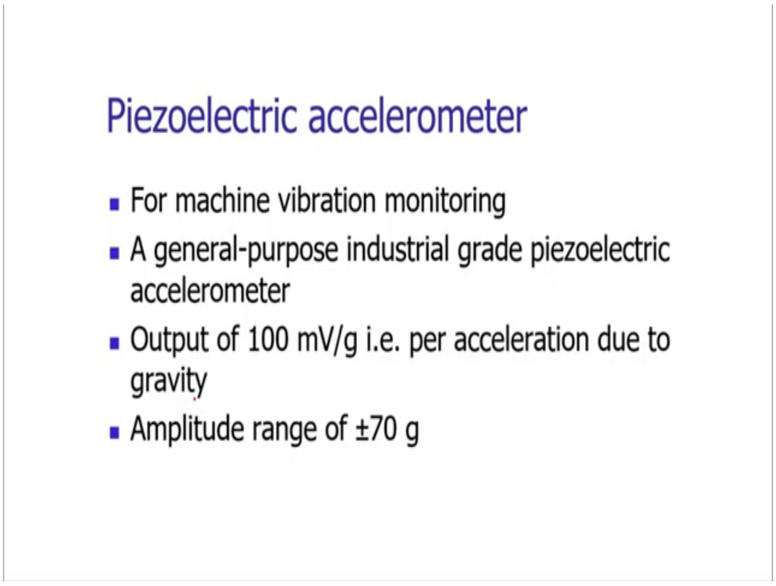

They are popular in monitoring the machine vibrations. In general, a typical industrial grade piezoelectric accelerometer is giving output of 100 mV/g per acceleration due to gravity. Its amplitude range is about ± 70 g.

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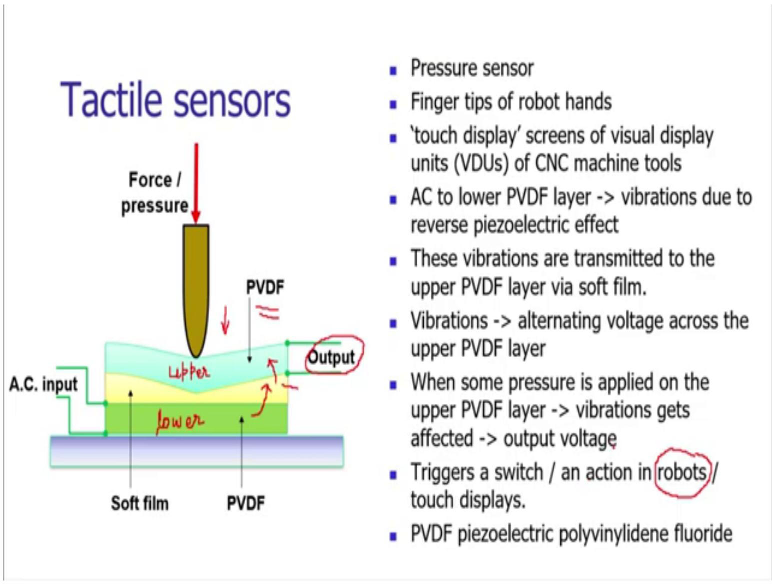

The next interesting sensor is the tactile sensor. It is used to measure the force or pressure. These type of sensors are widely used in the automation purpose and robotics.

The finger tips of the robot hands are equipped with the tactile sensor. Various touch displays or the screens are used in an automated industry or in a typical factory. Even on the CNC machine tools we are having the touch screens.

How this touch screens do work? A typical construction of the tactile sensor is shown on the slide. It has basically two layers of piezoelectric material and that piezoelectric material is PVDF. The PVDF material is polyvinylidene fluoride; a soft film or a soft foam is sandwiched in between these two PVDF layers.

We apply AC input to the lower PVDF layer. As the material is piezoelectric, due to the application of alternating current, there will be generation of vibrations; due to the reveres piezoelectric effect. We have seen in the previous slide, as we apply the pressure, there is a change in voltage across the surface of the material.

The reverse is also true, if we apply electrical potential, if we give electrical potential to piezoelectric material, there would be expansion of the material. As we give AC input to this lower PVDF material, there will be generation of vibrations.

These vibrations will be transferred to the upper PVDF layer. The upper layer is also piezoelectric material layer. Due to the vibrations inside this upper layer, there would be generation of electrical potential. With uniform supply of the AC input, we are getting uniform output across the upper PVDF layer.

Or let us consider, we are applying force or pressure on the top layer. When a pressure or a force is applied, that force or pressure will disturb the vibrations of the top layer. As the vibrations are getting disturb, there is change in output. The change in output with respect to the application of force or pressure is calibrated in the laboratory. Information will further be utilized to take the necessary decision or the action.

As we are touching on the screen at certain point, there is some function associated with the location of this. There are certain functions associated with location of the screen, wherever we are touching. As we touch at that particular location, microprocessor knows the location. As the force is getting applied at that location, that will be sensed; that will be measured; that will be detected and accordingly the microprocessor is taking the action.

For example, open and close. If two buttons are there on the screen; i.e. open and close. As you are touching the location of the close at the screen, that action will be carried out by the microprocessor. In robots, when these PVDF top layer will be in contact with the objects, that signal will be given to the microprocessor.

Microprocessor understands, like the object is there. It will detect the object and accordingly it will actuate its actuators. For gripping purpose, we are using the pneumatic power. The microprocessor will give the instructions to the pneumatic system and that pneumatic system will provide the compressed air for the gripping purpose.

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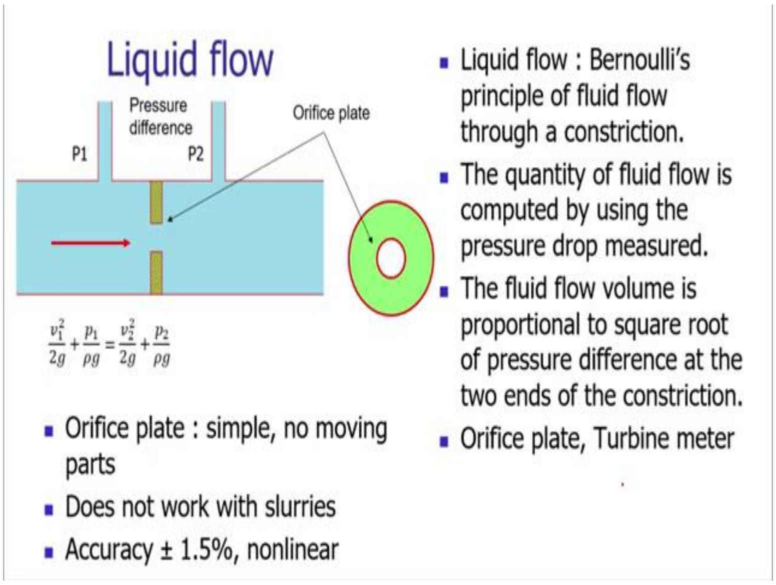

In the industry, we need to measure the flow of various liquids. The liquid may be water; that liquid may be the petroleum products; or chemicals or the liquid may be having certain solid elements that we call the slurries as well.

To measure the flow of the liquid, the very simple and basic sensor is the orifice sensor. Orifice sensor is working on the principle of Bernoulli's. As per the Bernoulli's principle of fluid flow, we can measure the quantity of fluid flow by computing the pressure drop across the constriction in the fluid flow.

The fluid flow volume is proportional to the square root of the pressure difference at the two ends of the constriction. Consider a high pressure fluid is flowing through the pipe; as the high pressure fluid comes in contact with the constriction i.e. the orifice plate, there is obstruction to the fluid flow.

However, it has an opening. When the fluid is moving through this opening, pressure will drop but the velocity will increase. So by measuring the drop in pressure, we can easily find out the liquid flow.

Orifice plate is very simple and it does not have any moving parts. But, the sensor is non-linear and the accuracy is about ± 1.5. Important limitation of the orifice plate is that; it does not work with slurries. If the liquid is having solid particles, the solid particles will get obstructed and they will settle in this region, and due to this there may be clogging of the fluid passage.

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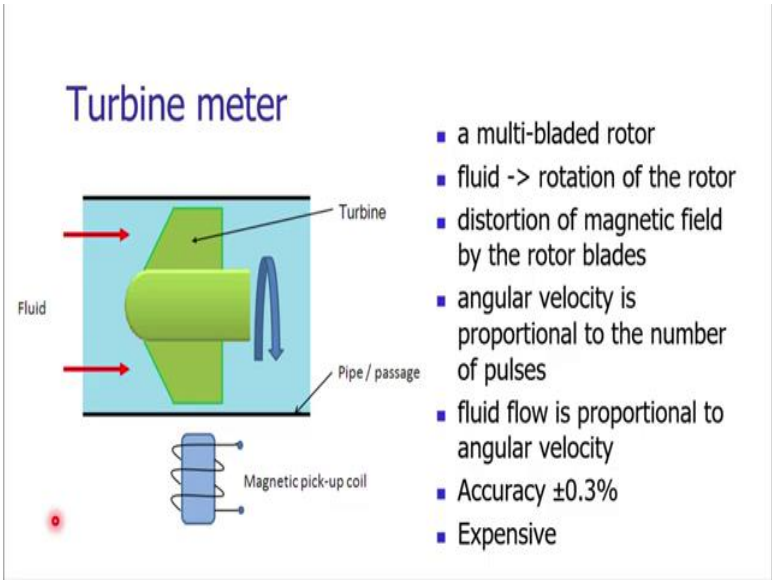

One more popular fluid flow measurement device is turbine meter. The arrangement is very simple. We are having multi bladed rotor. As the fluid is passing over the multi bladed rotor, the rotor will rotate. In the turbine meter, we are having a magnetic pickup coil.

When a rotor blade will come in close proximity of the magnetic pickup coil, there is distortion of the magnetic field of the magnetic pickup coil. Due to the distortion, a signal will be generated across the magnetic pickup coil. As the number of times these vibrations will be disturbed, we are getting the pulses.

The frequency of pulses is proportional to the rotation of the turbine; the frequency of pulses is proportional to the angular velocity of the turbine; and the angular velocity of the turbine is proportional to the fluid flow rate. The turbine meter accuracy is better than the orifice plate; however, the cost associated with the turbine meter is high.

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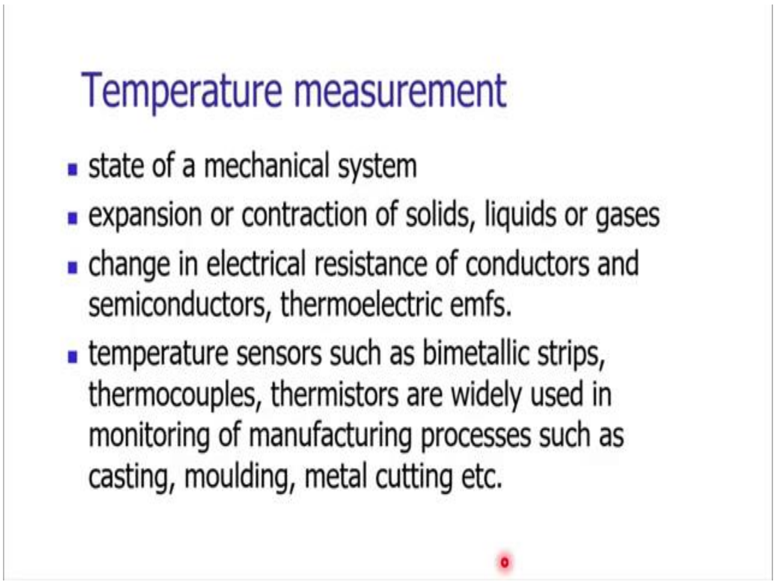

The next set of sensors are the temperature measurement sensors. Temperature is very critical and important field variable or parameter in the manufacturing industry.

The temperature is giving us the state of the mechanical system. As we know that the increase in temperature is affecting the state of the materials. If the temperature of the material is increased, it will expand and as the temperature is reduced, the materials will contract. Temperatures are not only affecting the dimensions of the materials; the temperatures are also affecting on its electrical resistance as well.

In general, various sensors such as bi-metallic strips for alarms, thermocouples to measure the temperature of various components of machine tool, thermistors are used. Various operations which we have seen in our previous lecture such as casting, moulding, and metal cutting, in all these applications we need the measurement of temperature. Now, let us look at the construction working of some of the important temperature measurement sensor.

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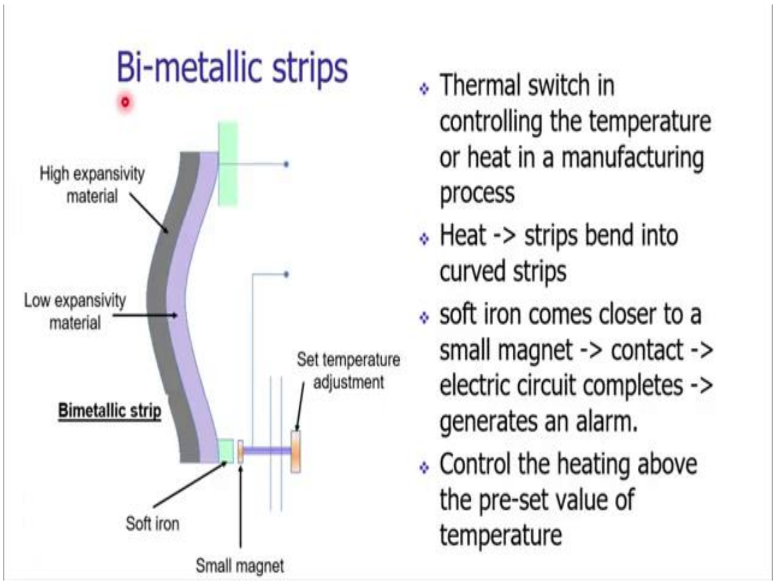

The first sensor is the bi-metallic strips. It is working as a thermal switch to control the temperature or the heat in a manufacturing process. Let us consider an example of a furnace; furnace are used to heat up iron, raw metals and then we are changing its state from solid to liquid. The liquefied metal will be utilized for the casting operation, but the controlled heating of these material is required.

The excessive heating may burn the material or may be hazardous to the entire system. To control the heating, we need to cut off the electric supply to the furnace. For that purpose the bi-metallic strips would be useful.

The construction of a typical bi-metallic strip can be seen on the slide. It has two strip and these two strips are bonded together. We can call it as a composite strip. The top layer of the composite strip is having the material with high coefficient of expansion.

At the inside we are having a material with low coefficient of expansion. One end of bi-metallic strip is fixed; the other end is free. At the other end we are having a soft iron; the soft iron is in proximity with a magnet. There is a knob which will set the distance between the small magnet and soft iron. If we heat up this composite layer, if we increase the temperature of this composite layer, top layer of the composite strip will expand. It’s coefficient of expansion is high.

It will try to expand, but the inner layer whose coefficient of expansion is less will restrict the movement of the top layer. Due to this, the entire composite layer will be converted into a curved shape and as the shape is getting changed, the soft iron will come closer to the small magnet. As the soft iron will come closer to the small magnet, there would be a contact, and as there is a contact between the soft iron and the small magnet, the electric circuit will be completed.

When the electric circuit will be completed, it will generate an alarm or it will generate a signal. That signal would be that signal which will be given to the microprocessor; the microprocessor will take the decision to cut off or to stop the flow of electric current inside the system. In this way we can control the heating of the system above the pre-set value of the temperature.

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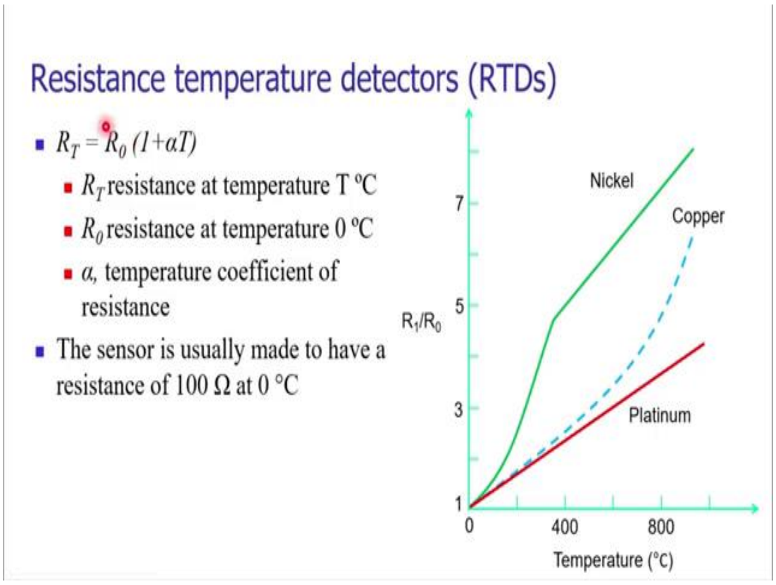

The next temperature measurement sensor is Resistance Temperature Detector. It is very popular and is called as RTDs. The principle is very simple; there are certain materials whose resistance will increase with the application of heat energy. In the slide, we can see the plot of the increase of the temperature with resistance of certain materials such as nickel, copper and platinum. And they do generally follow the equation of increase in resistance as you can see on the screen.

$R_T = R_O (1 + \alpha T)$

where, R_T is the resistance at temperature T°C. This T temperature is the temperature that we want to measure. R_O is the temperature at 0°C, α is the temperature coefficient of resistance. So, the ratio R_T/R_O is plotted here.

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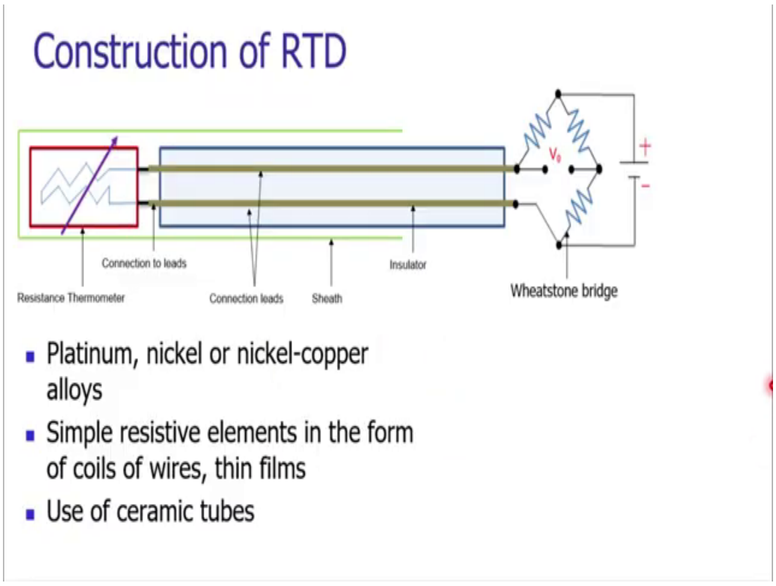

These sensors must be utilized along with a signal processing device. The sensor must be used along with the Wheatstone bridge because the RTDs are providing the change in resistance, but the microprocessor knows the language of voltage. To convert the information from the RTDs that is ΔR that will be converted into the ΔV by using the Wheatstone bridge.

The typical construction of RTDs can be seen on the slide. We can see,the resistive element which is made up of the nickel, platinum or copper. This resistive element is connected to the leads; the connecting leads are properly insulated. And through the leads, we are getting the signal in terms of change in resistance. This entire construction is properly protected with the sheet, because we are using these materials in hazardous or harsh working conditions.

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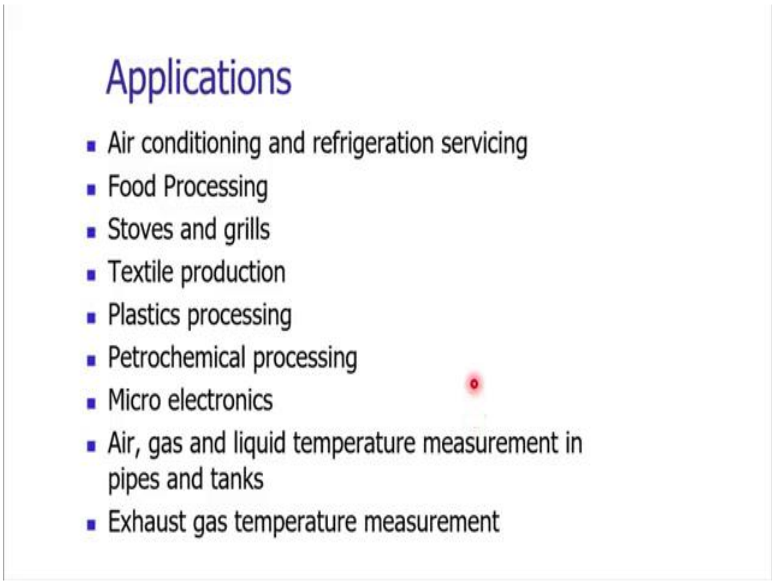

Now friends, let us see what are the various its applications. RTDs are used in air conditioning, refrigeration, they are also used in food processing to control the temperatures of stoves and grills; in textile production, textile to process the fibres.

In plastics processing, plastic we are using in the injection moulding machines; and in the injection moulding machine, we should have the controlled liquefaction of the plastic material or the polymers. Petrochemical processing in micro electronics.

The accuracy of RTDs is quite high. We are also using these RTDs to measure the temperatures of air, gas and liquid. The RTDs are also used in automobile applications and energy applications, where we need to measure temperature of the exhaust gas.

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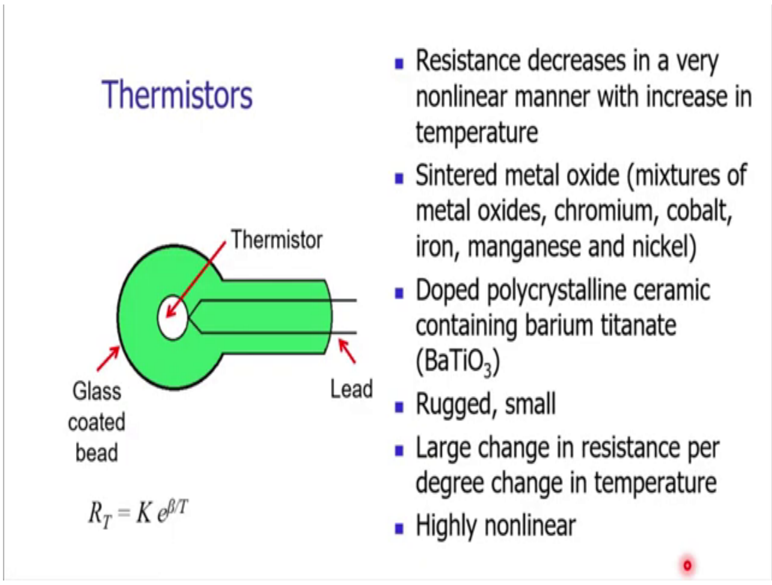

The next temperature measurement sensor is thermistor. In RTDs we have seen, the resistance of the material is increasing with the temperature. In thermistors, the resistance is decreasing in non-linear fashion with the increase in temperature.

Some materials such as sintered metal oxide, which is mixture of the metal oxide, chromium, cobalt, iron, manganese and nickel are the semiconductors and they exhibit the property that, when the temperature is increasing there is reduction in the resistance.

These oxides can be converted into small beads or disc and they can be utilized for the measurement of temperature. These sensors are highly non-linear. There may be sudden decrease in the resistance of the sensors with the increase in temperature.

The resistance of this oxide materials is reducing exponentially with the temperature. We can say R_T is the resistance of the oxide material, T is the temperature and K and β are the material constant. These thermistors are small, they are rugged and they are very useful for the harsh environments. But the problem with these type of sensors is that they are highly non-linear in behaviour, highly non-linear in response.

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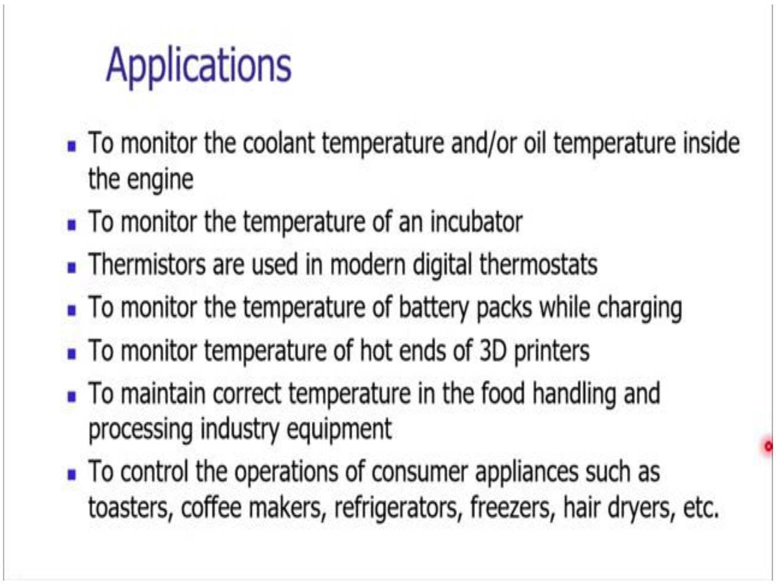

Therefore, such sensors can be utilized when we do not want to have high precision in the measurement or when we want to have the gross idea about the status of the system. In general, the thermistors are used to monitor the coolant temperature or the oil temperature inside the engines. They are also used to monitor the temperature of incubators in the poultry industry.

The thermistors can be utilized as thermostats. Then we can utilize the thermistors for temperature of battery packs and to monitor the temperature of hot ends of the 3 D printers, the nozzles of the 3 D printers. Thermistors are also utilized for applications such as food handling and processing industry. Moreover, we can utilize the thermistors for the domestic consumer appliances such as toasters, coffee makers, refrigerators, freezers, hair dryers.

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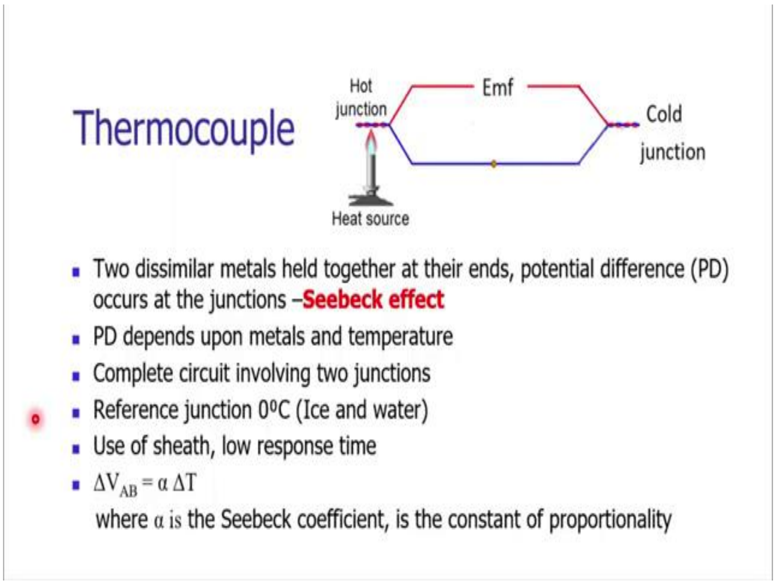

One more important temperature may measurement sensor is thermocouple. It is very much used in the process monitoring and control of manufacturing operations, such as welding. The thermocouple is working based upon the Seebeck effect. What is this Seebeck effect?

The Seebeck states that when two dissimilar materials held together at their ends, then there will be a potential difference occurs at the junction. And this potential difference is proportional to the temperature at these junctions. Let us consider two dissimilar materials are connected at their ends; one end is getting heated up; however, the other end is cold 0° . To have the junction at 0°C, we are using ice and water.

When we apply the external heat source at the other junction, there is increase in temperature of this junction. Due to this increase in temperature on the application of heat energy, the electrons will be excited and they will start moving from the hot junction to the cold junction. And there is formation of electric current.

Or due to the movement of the electrons there will be creation of valency at the hot junction. To balance it out the electrons from cold junction will be moving towards the hot junction.

However, the energy at cold junction is comparatively less. Therefore; the speed of electrons would be less. In this way as the number of electrons are moving from the hot junction to the cold junction, the negatively charged particles would be more at the colder junction and the positively charged particles would be more at the hot junction. Due to this, there would be generation of potential difference and that potential difference will create the electro motive force.

The magnitude of the EMF will be in proportion to the difference of temperature at hot junction and the cold junction. We know the temperature of the cold junction, and as such we can easily compute the temperature of the hot junction.

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Thermocouple materials

Materials	Range (°C)	(μV/°C)
Platinum 30% rhodium/platinum 6% rhodium	0 to 1800	3
Chromel/constantan	-200 to 1000	63
Iron/constantan	-200 to 900	53
Chromel/alumel	-200 to 1300	41
Nirosil/nisil	-200 to 1300	28
Platinum/platinum 13% rhodium	0 to 1400	6
Platinum/platinum 10% rhodium	0 to 1400	6
Copper/constantan	-200 to 400	43

A variety of materials are used in the measurement of the temperature based upon the Seebeck effect. These materials can be seen on the slide. The first type of thermocouple material combination is platinum and rhodium with 30%. This is one wire or one material; it is connected with the other material that is platinum with 6% of the rhodium.

Then we can have a combination of chromel and constantan, iron and constantan, chromel and alumel, nirosil and nisil and platinum and platinum in 13% of rhodium, platinum and platinum with 10% of rhodium.

And we can have the copper and constantan. In this way a variety of combinations are available in the market and we need to choose a proper combination based upon its application. To choose the thermocouple material we have to look at the range of the temperature for our application. In the slide, we can see the respective ranges of temperature measurement.

In addition to these, the sensitivity values are also provided. This sensitivity values will help you to choose the proper thermocouple material.

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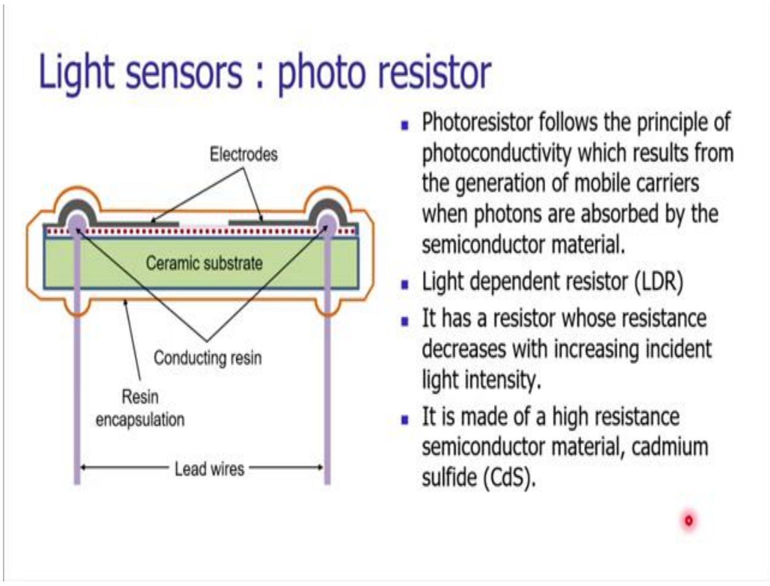

We also require to sense the light in automation. For that purpose, we are using photo resistor. The photo resistor follows the principle of photo conductivity. In photo conductivity, there is generation of mobile carriers when photons are absorbed by semiconductor material. When the light energy will be incident on semiconductor materials, these materials we absorb the photons.

And due to the absorption of the photons, there is a generation of mobile carriers. And in this way, these mobile carriers will generate signal that can be utilized to measure the light or to sense the light. The photo resistors are also called as the light dependent resistors, LDR’s. These LDR’s do have a resistors whose resistance is decreasing with increasing incident of light intensity.

These materials are cadmium sulfide, this is the semiconductor material and their resistance is very high and that will be utilized to detect the light.

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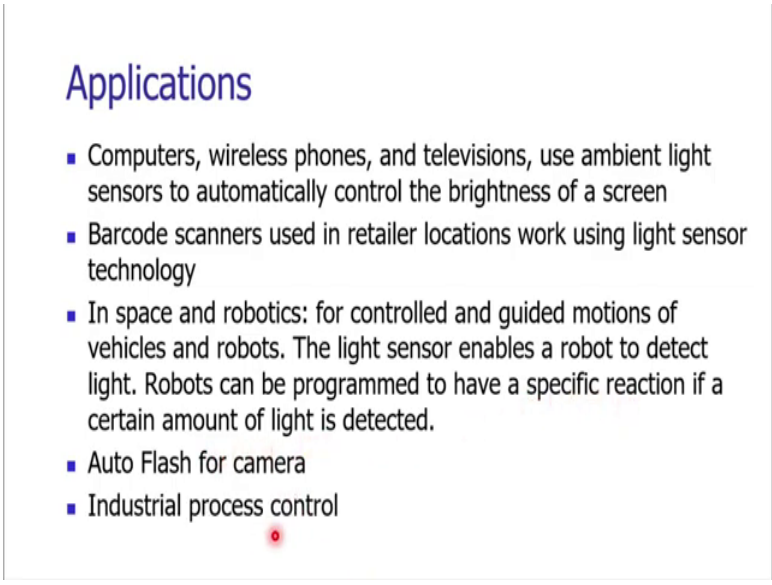

These sensors are used in computers, wireless phones and televisions. When more ambient light is incident upon these sensors they will automatically control the brightness of a screen.

The LDR's are also used in barcode scanners, which you might have seen at various retailers at retail stores. In space and robotics, we need to have a very controlled and guided motion of various vehicles and robots in automated industry. These LDR's are enabling the robots to detect the light; and accordingly, the robots are choosing the path of movement. The robots can be programmed to have a specific reaction if a certain amount of light is detected.

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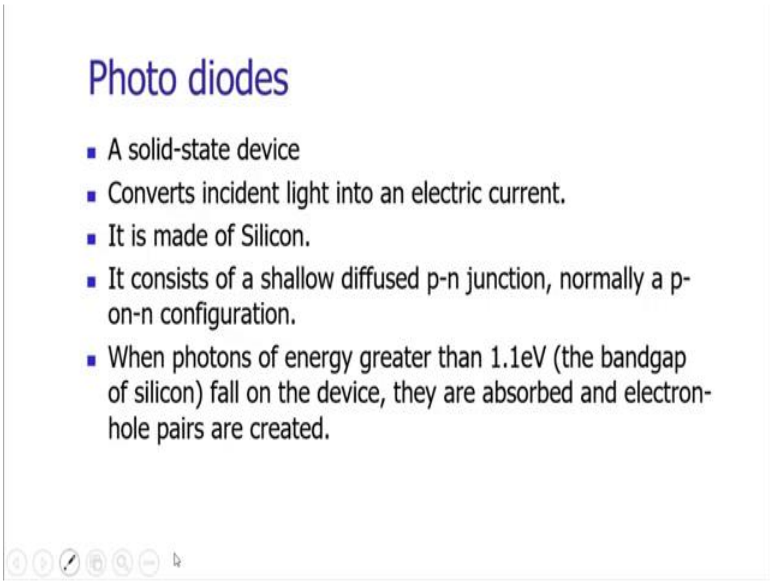

Moreover, these are used in auto flash for camera and the industrial process control. The next sensor is photodiode, it is a solid state device and it converts the incident light into an electric current. Photodiodes are made up of silicon and they do consist of shallow diffused p-n junction, normally, a p-on-n configuration. When photons of energy more than 1.1 eV fall on the device, it will be absorbed and electron hole pairs will be created.

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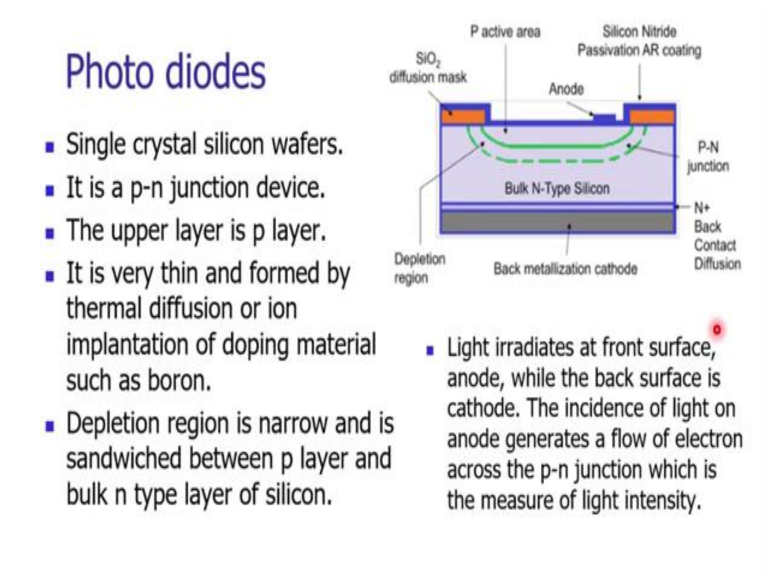

Now, let us study the construction of the photo diode. It is constructed on single crystal silicon wafer. The constructional details are shown in the slide. The photo diodes are also called as p-n junction devices.

In p-n junction device the upper layer is the p layer. It is thin and it is generally formed by using either thermal diffusion technique or by ion implantation technique. The boron is doped inside P material.

The bottom layer that is the N layer is bulkier one and the junction of P and N layers is called as the p-n junction. They also called as the depletion region. The depletion region is narrow and it is get sandwiched between the p layer and the n layer. The principle of operation of photodiode is very simple, when the light is incident on the anode surface, there is a generation of electric current. The photons which are incident on the anode will get absorbed in the p-n junction layer.

And the photons which are incident on the anode will get absorbed and then there is a flow of electrons across the p-n junction. Due to this flow of electrons, there is a generation of electric current and that is the measure of the incident light energy.

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Photodiodes have variety of applications; they are primarily used in cameras for the measurement of light, to control the shutters, to carry out the autofocusing operation on the objects and to have the flash control. In addition to this, the photo diodes have applications in medical industry.

In medical industry we require many scanners, X ray detection units, measurement of oxygen levels and analysis of blood particles. In all these applications, the photodiodes are extensively used.

Moreover, in the automation industry, the photo diodes are used for scanning purpose to control the brightness; for encoding purpose to measure the position. They are also used in surveying instruments, copiers to measure the density of toner. One important application of photodiode is in safety equipment.

Like detection of smoke, monitoring of flames. These diodes are also used for security inspection equipment such as X ray scanning instrument, the system which is providing intruder alert alarm system, so on and so forth.

Well, my friends there are a variety of sensors being used in automation industry. In the present course we have seen a limited variety of sensors; you can explore the advance sensors available in the market study them carefully and can utilize in your projects.

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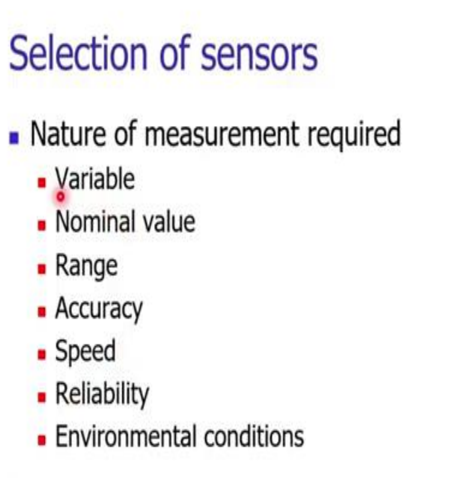

When we choose a sensor for typical application, we need to first look at what kind of major and for which we are selecting the sensor, what is the variable, whether it is for measurement of temperature or force or pressure, what is the nominal value that we are anticipating for the measurement, what is the value that we are expecting to be measured. Then what could be the range, then how accurate the results are expected, and what speed we want the signals from a sensor. And how much the reliability of the sensor would be.

For safety applications, the sensors should be reliable in addition to these parameters the environmental condition in which the sensors will be employed. If the environmental conditions are harsh, such as it may have a lot of dirt or a temperature or humidity. Under these all environmental conditions, whether the chosen sensor will work properly or not. These things are very important when we choose a particular sensor for our application.

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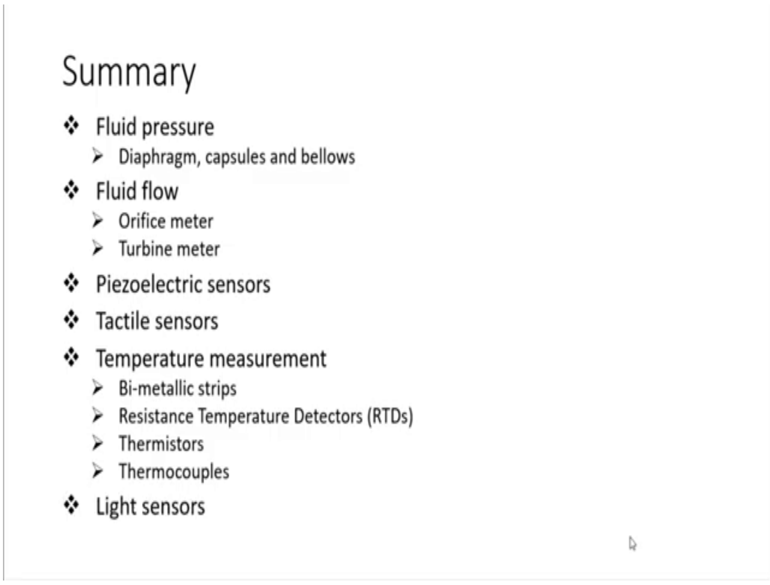

Well let us summarize the lecture 4 of week 4. In this lecture we have seen various sensors, that are used to measure the fluid pressure and these were diaphragm, capsules and bellows. We saw how fluid flow can be measured by using orifice meter and turbine meter.

After that, important sensors such as piezoelectric sensor and tactile sensors we have seen. Then we learned various sensors which are used to measure the temperature. These are RTDs i.e. resistance temperature detectors, thermistors and thermocouples. At the end we learnt about the light sensors.

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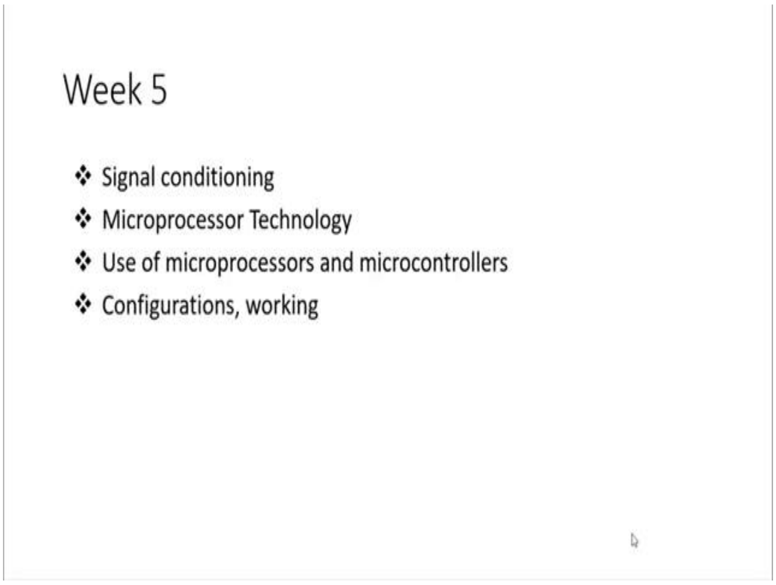

In the next week, we will see how the raw signals which are coming from the sensors can be made useful to process in the microprocessors. We will see in detail the technology associated with microprocessor. The difference between micro controllers and microprocessor and what are the various applications of both these technologies in the automation industry. Various configurations and working of the microprocessors.

Thank you; see you in the next week.