Transducers For Instrumentation

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Lecture - 13

Optical Sensors: Introduction and Classification

Hello, ah welcome to the course Transducers for Instrumentation. Today we will discuss about the optical sensors, these are the sensors where we use light as a sensing mechanism. There are multiple parameters associated with the light for example intensity, phase, polarization, and many other parameters. We can use any of these parameters and make a sensor which can measure our measurement for example velocity or ah refractive index or any multiple types of measurements we can measure using these optical sensors. These optical sensors primarily use light as a sensing mechanism. So if we see we have in optical sensors we have a optical source.

So today we are discussing optical sensors and in this optical sensors we first have an optical source. This is the source which generates this light or optical wave. So light actually originates from this optical source and then goes on something called fiber. We have a fiber here which is carrying this optical wave or light and after this we have a measurement zone.

This is the zone where measurement is taking place. We have certain operand which is applied here on this optical wave and the measurement is happening here. So this fiber we can call it the feed fiber which is going from optical source to measurement zone. After this measurement zone there is again one more fiber which goes from this measurement zone to the optical detector. This optical fiber we can call it the return fiber.

So in a optical sensor we have primarily these three zones. One is the optical source where the wave is actually originated and goes into the optical fiber. This optical fiber then goes to the measurement zone where we apply this measurement. It can be a pressure, it can be refractive index, it can be pressure, it can be any of the measurement and this is the zone where some of the property of this optical wave changes based on the measurement and after that we have a return fiber which carries this altered wave back to the optical detector. So this return fiber it can carry the wave back to the original destination itself where the optical source is sitting the same location or it can be a far end destination or far end location where our optical detector is sitting.

It may be the same place or it may be the other place but primarily we have these three units in a optical sensor optical source, the optical detector which detects this light and a measurement zone where the measurement is taking place. So now we have multiple parameters of a optical wave or light. Light is a kind of optical wave. We have multiple parameters which we can choose which we can alter based on the measurement. For example we have intensity, phase, polarization, etc.

So we have light may change in any of these optical parameters. Second is phase. Third is polarization. Fourth is wavelength. And five is the spectral distribution. So, we have these optical parameters for example intensity. So, when the light originates from a source It has a particular intensity, and then it goes into a measurement zone where the intensity of this light can be altered. For example we have certain different material in between. So based on the refractive index relative to the first one for example fiber based on these refractive index the intensity of light can be modulated and then the light at the far end it has different intensity than the first one. So difference between these intensities gives us the idea of which material was in between.

So in that way we can sense what that material is because all the materials have different refractive indices and based on that the intensity modulation will be different. So intensity can be one of the parameters. Second may be phase polarization how much polarized the light is wavelength or we can say the frequency. This can also be changed and can be used as a sensing element. The spectral distribution is also one important parameter.

So when we send a optical wave we do not actually send a particular frequency we actually send a band of frequencies. So that band propagates in an optical fiber and based on the media in between this optical distribution. Some of the frequency can get absorbed at that particular different materials. So based on the missing frequency at far end we can identify which material is there in between which can absorb that particular wavelength. So these are the few optical parameters which we can use to make a optical sensor.

So we can make multiple kind of optical sensors and some of the measurement for these optical sensors can be optical sensor measurements. That means we can make a optical sensor which we can measure temperature, pressure, we can measure flow of a liquid as well using optical sensors. The magnetic field can also be measured. In fact we can measure some other proper other measurement as well. For example the chemical species which is the chemical present in the measurement zone.

What sensor we can make using optical sensors? Radiation, pH, pH of a liquid, humidity, strain, velocity. Electric fields. In fact we can measure the caustic fields as well. So these are some of the measurements which you can measure using optical sensors. For example the temperature.

There is a parameter which in fact affects almost all the sensors. So let us say we have a optical sensor where we are using optical fiber of length let us say 1 kilometer because the optical fibers are very long in length and if the temperature changes the kind of length of this optical fiber also changes there is a expansion in the optical fiber because of the temperature. Because of the expansion of this optical fiber there is a change in the return path of light from source to the back to the source or to the destination that time actually changes because of the difference in the in the length of the fiber. So that we can detect as a phase difference between the input and output and by the phase difference we can measure how much is the length change in the optical fiber that change in the length is corresponding to the change in the temperature. So in that way there are many measurements which we can measure using optical sensors.

For example liquid levels, displacements, radiation, humidity, even electric fields. So these are some measurements. Let us talk about some classification of these optical sensors first. So the first classification can be based on the modulation and demodulation process. In this we use multiple parameters for example intensity can be modulated, the phase, the frequency, polarization etcetera.

This is first classification. Second classification can be based on their application. For example we want to measure some physical quantity for example pressure. So this can be one of the measurement or some chemical composition we want to measure using optical sensor and maybe some biomedical applications. The third classification can be based on the type of sensing.

So there can be two types of sensing. First is the extrinsic and the second is intrinsic type. So we can classify optical sensors basically based on three types. One is the modulation and demodulation. We are modulating some of the parameters for example intensity or phase.

Second classification can be based on the application. Let us say we want to measure the pressure. So we can say it is a pressure sensor which is using optical means. And the third classification can be based on the intrinsic and extrinsic type which will come to this point later. So the first one is based upon the modulation and demodulation.

So in this type of classification let us say we have an optical wave which we can represent by simple equation E cos omega t plus phi. So we have let us say a equation E which is the amplitude and this is a function of time let us say cos omega t plus theta which is again a function of time. This E can also be a function of time. So this is a simple equation of a optical wave and we can change any of this parameter. For example intensity based sensor is the one Where we change the amplitude of this wave.

So intensity based sensor we change the amplitude E. So for example if we plot this optical wave in three dimension let us say this is one direction, the other direction let us take different color this is another direction let us say. So we have a optical wave which is nothing but a electromagnetic wave propagating in this direction. So we have electric and magnetic field vectors.

This is electric field vector. And then we can plot the magnetic field vector along this. So that magnetic field vector is perpendicular to electric field vector. It will look something like this. So these electric field and magnetic field vectors they are perpendicular to each other and both are perpendicular to the direction of propagation of this wave. So this wave is propagating in this along this black arrow which is let us say in the x direction then in the y direction we have electric field vector and in the z direction we have magnetic field vector.

So this wave has all these parameters for example it has the amplitude, it has a time varying cos factor, this electric field is changing based on the time how when the time progresses it is just like a wave. So we can change any of these parameters for example intensity sensor uses the amplitude variation. We can choose another parameter for example frequency based sensor. So we can choose omega which is a function of time. This omega is the angular frequency which can be changed.

The third is the phase modulating sensing. This is theta and we can have a polarization modulation. So we can choose any of these parameters for example the amplitude, the frequency, the phase or even the polarization because we know that light is actually polarized in certain direction. This polarization we can change and make use of the properties of polarization to make a optical sensor. So this is the classification based on the modulation and demodulation techniques.

This classification is based on the application. So here we can have multiple types of application for example the chemical sensor, the temperature sensor or the strain sensor, biomedical sensors, electrical and magnetic sensors, and the magnetic sensors. Others can be rotation sensor for example, pressure sensor and displacement or position sensor. So this is the classification based on the application. What application we want to serve to use this sensor? For example chemical sensor is the sensor where we want to investigate which chemical is there in certain cavity that we can measure using optical sensor.

We will see in some other in some next lectures we can make this optical sensor which can detect which material it is. So for example, in sensor or temperature sensor we want to measure the strain or the temperature. So based on these applications we can also classify these type of optical sensors. The third one is based on intrinsic and extrinsic one. The third classification is based on the intrinsic and extrinsic type.

So in this type of classification we have two types of sensor. First is we have a light source which is generating the light or optical wave. This optical wave goes into optical fiber and in the measurement zone or in between we have this measurement zone. For example, we want to make a pressure sensor here and measurement zone looks something like this. It has two bodies one on the top one on the bottom and this has these kind of structures and pressure is applied in this Y direction and on the far end we have this light detector.

So in this type of assembly we see light source is at one end and light detector is at other end. In between there is a there is running a optical fiber which is carrying this optical wave. In the measurement zone we have a this kind of assembly on top and bottom both from both the sides we apply this pressure. When we apply this pressure these both bodies will come into close to each other and they will start bending this optical fiber. So if when we apply this pressure on this a assembly our optical fiber will be bend it will come something like this.

This optical fiber will bend zigzag and based on this bending of optical fiber the intensity or multiple parameters of optical wave will change. So this is called intrinsic type because the optical wave does not leave its media which is this optical fiber from the source to the destination. It is a single optical fiber it is not cut in between or there is no material in between inserted in this optical fiber. So it is called intrinsic type and this optical fiber remains uncut from the source to the destination. So this is called intrinsic type where this light travels inside the optical fiber.

The other type of sensor is extrinsic type where we cut this optical fiber and insert a special measurement zone and that measurement zone actually modulate the property of light. So in extrinsic type we have this light source. This generates the optical wave then this goes on a optical fiber let's say I am showing the optical fiber with certain width. This optical fiber is now cut here at this point and we insert a special measurement zone here. So we have let's say a special measurement zone we will talk about this zone later.

This measurement zone let's say has a length L and this is a different media which is coupled to this optical fiber and after this measurement zone we have another optical fiber which is coupled at the output of this media and goes to the light detector. So in this extrinsic type of sensor we have two wires two fibers one is which is connected from source to the measurement zone which carries the input light and after that measurement zone we have a different fiber which is coupled between the measurement zone and the light detector. This carries the return wave or return optical wave based on the difference between the input in at the input and at the output there are certain parameters are changed based on the difference in these parameters at input and output we can detect what is actually changed because of this measurement zone and based on the property or shift in that particular parameter we can detect what that stimulus is or what that measurement is. So we have here this measurement zone which is actually inserted in between these two fibers.

And a separate zone is inserted in between. So, we can see there is a clear discrimination between the intrinsic type of optical sensor and extrinsic type of optical sensor. If the wire is not cut from the transmitter to the receiver then it is intrinsic type and if the wire is cut in between and inserted certain different measurement zone then it is a extrinsic type of optical sensor. So, there are certain advantage and disadvantage of these intrinsic and extrinsic type. For example, we have the extrinsic one here and this side we have intrinsic type. So, if we talk about the extrinsic type these are easy to multiplex.

However, the intrinsic type these are tougher to multiplex. So, what do we mean by multiplexing? We have one fiber coming in and we want to send this optical wave to three or four different type of different receivers. So, we need to multiplex or we need to join all these three four wires to the single transmitter fiber. This is difficult in intrinsic type because we are not cutting this optical fiber. So, there is no way we can attach multiple units to this optic this intrinsic type optical sensor.

However, in extrinsic type we are cutting this optical fiber. So, now we can put some multiplexers optical multiplexers after this fiber and we can connect multiple units of receivers at this point. So, this is easy to multiplex in case of extrinsic type intrinsic type is difficult to multiplex. The next one is the connection problem because we are cutting this optical fiber. So, we have we may have multiple connection problems in connecting different receivers.

However, in intrinsic type we have a very reliable connection because we are not cutting the optical fiber. This is easier to use this is more elaborate kind of signal mode demodulation. Some of the applications of these extrinsic type is the temperature, pressure, liquid level and flow. These are some applications for extrinsic type intrinsic type optical sensor. We have typical applications like rotation, acceleration, strain, acoustic pressure, and vibration is also one of the measuring where we apply these intrinsic type sensor.

So, these optical sensors though we use it in many applications they have certain advantages compared to other sensors. For example, some optical sensors has these particular advantages and the very first one is the electrical isolation. So, when we talk about optical sensors or optical devices the very good advantage of these optical devices is electrical isolation. When we make electrical devices when we have certain electric circuit on one end and another electric circuit which is very close by connected to each other. The one state change of the first electric circuit actually has some interference with the second circuit as well.

There is a change in the one so it affects the output of the second as well. So, there is a electrical interference because of the parasitic coupling between the first and the second. Another example is for example we have two wires running in parallel. So, one state change in first of the wire it actually couples to the second wire as well because there is a certain parasitic capacitance in between these two wires. So, this electrical interference is a big problem at very high speed circuits where we use a very small signal to send from transmitter to receiver.

If there is a electrical interference with this wire from any other place or any other wire running around then this signal is impacted by that interference this is a big problem in electrical circuits. Optical circuits however they are not as sensitive as electrical circuit because the parasitic capacitance or inductance they do not cause any coupling or optical coupling between these two wires. So, they are used for electrical isolation very one very good example of this is let us say we have small signal circuit and one end and on the other side we have a very heavy load for example a big motor is running on the other end a small microcontroller is controlling this motor. Now if this electrical motor need to shut off we suddenly turn it off then because of the parasitic inductance there is a very high voltage build up at this the input of the second stage the motor and this high voltage can impact this microcontroller which is running at very low voltages for example pi volt or so. This motor however is running at 250 volt or even beyond and this there is a spike of voltage at the out at because of this sudden shutdown of motor it can go up to 1000 of volts.

Now this high voltage has some parasitic capacitance connected to the input side and this high voltage will easily influence the output of this microcontroller. So, this is always there this parasitic capacitance or parasitic inductance these are always there in electrical circuits. If we want to get rid of this application we can use some optical devices optical devices like we have a microcontroller now the signal of this microcontroller goes to the motor as a optical signal not as a electrical signal. So, there is a transmitter like for example LED, LED is there which sends the signal and this optical signal goes to this motor which is running at 1000 volt this has a optical receiver now this optical signal goes from LED to receiver. Now there is no way coming back a optical light which can be generated by electrical receiver cannot generate this light.

So, there is a optical isolation there is a electrical isolation between the input side and the output side. So, these optical sensors these are very much used as a electrical isolation. The other advantage is compact and light though these are subjective for example a optical sensor can also be having a significant weight and size. The third is amenable to multiplexing. So, as we discussed in intrinsic and extrinsic type we can multiplex the output of these sensors to multiple receivers.

For example a sensor is sending its data in terms of optical wave which is generated by this LED and this LED can now be coupled to many of the receivers which can simultaneously receive this data. So, multiplexing of these optical sensors is very easy compared to other type of sensors. The other is extremely high bandwidth capability. This is also very important parameter about the optical waves the bandwidth available to us in terms of optical wave is very high compared to the electrical bandwidth of signals.

The bandwidth is directly proportional to how much past we can send our data and how much more data we can send.

So, that depends on the bandwidth available to us. In optical waves we have enormous amount of bandwidth available to us which we can use to transmit our signal. So, compared to the electrical signals we can send more amount of data at much faster speed if we use optical sensors or the optical wave as a transmitting media. The other is high sensitivity and high dynamic range. So, these optical sensors are very highly sensitive because the quality factor of these sensors is very high we can very easily detect the peak or the crest in these type of sensor. These are very highly sensitive and the dynamic range of these sensors is also very high.

The other advantage of these optical sensors is the remote sensing. This is also a very good advantage of these optical devices the remote sensing. For example, in optical sensors we use optical fibers which are very thin in dimension and they run for very long distances. For example, from one country to another we have optical fiber network this optical fiber can carry the optical wave from one country to other country. In fact, very long distances thousands of kilometers without degrading in the intensity. If in on the other hand if we use electrical signals these electrical signals degrades with distance because the electrical resistance of these wires when we run them for very long distances the electrical resistance is very high.

Then the electrical signal we send this degrades or this dissipates in just like a power dissipation and the signal actually degrades with the distance. However, in case of optical sensors we can send these optical waves through these optical fibers to a very very long distances thousands of kilometers without even using a repeater or without even losing the signal intensity. So, remote sensing is very good application of these optical devices where we can send these signal or this data from one end to the other end at very far distances. The other advantage is the ability to embed in unfriendly environment or the harsh environments.

So, here with harsh environment we mean. The environment which is full of noise and interference though the optical fibers they run the optical wave actually is transmitted through these optical fibers by in total internal reflection and they do not lose out to the environment. So, whatever is the environment it is noisy or it has interference it does not affect the quality of optical wave which is actually being transmitted inside this optical fiber. So, we can employ this optical devices in harsh environments as well. The next advantage is distributed and array sensors.

Covering extensive structures. And geographical locations. So here what we mean by the distributed and array sensors, we can do a sensing in distributed nature for a particular very long or very big structure. For example, we have a water dam which is very big in structure. It's a 1 kilometer long kind of structure and with very massive amount of concrete it is built on. And we need to be aware that how much is the strength of this dam and whether there is a degradation in the strength of this dam. One way of doing it to put multiple sensors, in fact thousands of sensors along the length of this dam.

Even then if we have let us say one sensor every 1 meter apart, there may be a crack or damage in between these sensors. For example, there are two sensors 2 meter 1 meter apart, there is a crack in between. So, this will not be detected by any of this sensor. So, this is the problem of how many sensors we can put to monitor the strength of this dam. We can do this by these optical sensors very easily which by because they can use for distributed kind of sensing.

Distributed sensing is when we have a optical fiber which is running along the full length of dam. So, this there is a optical fiber which is running from one end to other end without any break. So, if there is any crack happening in between of the dam wherever it is, this will be always detected by this optical fiber because this is a continuous fiber from start to end. There is no 1 meter gap in between two positions. So, wherever there will be a gap, there is a if there is a weakening of structure that can be easily detected by these optical devices.

So, this is called distributed sensing where we are sensing not at a particular point, but along a complete length or complete area we are sensing. So, today we discussed the optical sensors, t heir classification, what are the different type of measurements. We saw some advantage and disadvantage of sensors of these optical sensors. Some of them is electrical isolation, high sensitivity, remote sensing and distributed sensing.

So, this is all for today.

Thank you.