Transducers For Instrumentation

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Lecture - 15

Optical Sensors: Interferometric based

Hello, ah welcome to the course Transducers for Instrumentation. Last lecture we discussed about the basics of optical sensors and some optical sources and optical detectors and how the wave actually travels in inside the optical fiber. Today we will discuss some real optical sensors which we use to to sense certain measurements. So we will basically discuss three types of sensors. One is the first one is the interferometric sensors. The second one is the distributed sensors and the third one is the Bragg grating based sensors.

So first we have interferometric sensor which is a point sensor. It means the the measurement which we are doing is is limited to a confined zone. We have a specially designed a measurement zone where the measurement is taking place with this sensor and the data comes back to transmitter of the receiver. The second sensor which we are going to discuss is distributed sensor. As we discussed earlier if we have a large structure and we want to monitor its performance or want to sense certain parameter along the entire length then we need to have a distributed sensor. It is not it cannot be done by using a point sensor or we cannot use multiple sensors to monitor the entire length of certain structures. In that case we need a distributed sensor. The third one is Bragg grating based sensor. This sensor which we can use for the distributed or for the point sensing as well. So these three sensors we are going to discuss. So the first one is interferometric sensor. These sensors provide a very good level of sensitivity. And some of the applications of these sensors are. Temperature sensor. Wind sensor. Pressure sensor. And we can measure even the refractive index of liquids as well. So these are some applications of interferometric sensors where we can apply these sensors to make the measurement. The good point about interferometric sensor is they have a very good level of sensitivity. These interferometric sensors are all again we have four kinds of sensors in these interferometric sensor which are. The first one is Fabry-Perot sensor. The second is McZandie sensor. Or we can call it MZ sensor. The first one we can call it FP sensor.

The third one is Michelson sensor. And the fourth one is Sagnac sensor. So these are the four optical sensors which we are going to cover in these interferometric sensors. So let's first discuss about the Fabry-Perot sensor. This is Fabry-Perot sensor. Or we can call in short FBI sensor. So this is generally composed of two parallel plate reflecting surfaces. Which are separated by a certain distance. And the interference occurs. Due to multiple super positions. Of both reflected and transmitted beams. So in this FBI sensor we have two interfaces. And the wave travels. Let's say wave is traveling in X direction. And then we have two interfaces. Or two discontinuity in the path of this optical wave. This wave is going to reflect at both of the interfaces. Some part will be reflected back at first interface. Some will be transmitted. And some part of this transmitted wave will again get reflected at the second interface. So when we look at the origin we get two waves. One is the reflected at interface one. And the second one is reflected at interface two. And there will be a time difference between these two waves. Because this second wave need to travel a extra distance of separation. What this the separation is between these two discontinuities. So accordingly there will be a phase difference between these two incoming between these two reflected waves. And based on that phase difference we can determine what is the time taken by the wave in between these interfaces. So let's say we have a optical fiber here. This is cladding and inside this we have core. And the wave is traveling in this optical fiber. Now we have first discontinuity here. Let's say this is my discontinuity here. And my second discontinuity is at this point. After this we have again this optical fiber. And the distance between these two interfaces is L which is a known number. Now my wave is coming in from the left inside this optical fiber. The first reflection will take place at this interface. Some of the wave will go back into the core which will be reflected back at interface one. This is interface one. This wave let's say we call it reflected one. Some part of this wave will be transmitted into this medium. And it will be reflected at interface two. This is interface two. And this wave will go back here.

And we receive another wave which is reflected at interface two. Let's say call it R2. So here we can see the wave R1 it traveled less distance compared to R2 because R2 has traveled twice the length L which is the separation between the interface one and interface two. So if we plot this R1 and R2 on the same scale this R2 will be time delayed compared to R1. This will give us the phase difference between these R1 and R2. Now this phase difference depends upon how much time the optical wave takes within this cavity which is of length L. Now this cavity it may be filled by air or it may be filled by some other liquid. We can pour some liquid into this cavity and because of that different refractive index of that chemical or whatever we pour it the velocity of wave will be different and accordingly the phase difference between R1 and R2 that will be different. So based on the how much the phase difference we get we can detect what material is poured into this empty cavity. So this is the working principle of this Fabry-Perot interferometer. This is the case where we have this is extrinsic type it means the fiber is cut in between and we have made a artificial cavity here and we can pour liquid here. We can pour chemicals here and based on the difference of refractive index we get different different phase difference between R1 and R2. This is the case of extrinsic type. We have cut the fiber here. The another case we can make intrinsic type where we are not cutting the fiber we have a single fiber only. So this is a single fiber and now within this fiber itself we make discontinuity at this point and at this point. This we can do by laser scribing and or many other methods. So this case is intrinsic type where we are not cutting the optical fiber and here when we are sending this optical wave here some of the part will be reflected at first interface and some part will be reflected at interface 2 and at the input side we get two waves one is R1 and R2. So this is how if FBI sensor look like we can have extrinsic type as well where we have a separate cavity where we can pour the liquid. So this can work as a refractive index meter we can detect the material based on the refractive index of that material.

The other is intrinsic type where we are not cutting the optical fiber and this can also be used as a temperature sensor for example because when the temperature increases this length which is a fixed number here we know because when we laser scribe it we know this number very precisely this L if the temperature changes this length of this optical fiber changes and based on this this change in the L R1 and R2 will get different phase differences because R2 is the one which has to travel this length two times however R1 is fixed in the in return path. So R2 always changes with change in the L which is a function of temperature. So this intrinsic type sense intrinsic type FBI sensor we can use as a temperature sensor. The phase difference of this FBI sensor is given by the delta FBI is equal to 2 pi by lambda into eta into 2 L. So this is the phase difference we get in case of FBI sensor where this lambda is the wavelength of incident light. This eta is the reflective index of cavity material and L is the distance the physical length of cavity. So this is the formula for getting how much phase shift we get we can see this depends on three parameters one is the lambda what frequency or what wavelength we choose for the optical optical wave light wave. So that is generally fixed by experiments we generally choose a single optical source and based on that our wavelength is fixed. So this is generally a fixed number the second parameter is the refractive index of cavity material. So what we put in this cavity the refractive index of this material changes the phase difference.

So according to this Ri of this cavity material we get the phase difference delta and the other property other parameter where this phase shift depends is the length which is the physical length of cavity which is generally fixed unless case of temperature sensor this length of the cavity is generally fixed and no number when we make this sensor we generally know how much is the length of this cavity. So this is again a constant number so our phase shift depends on how much is the Ri of cavity material and we can make some kind of chemical sensor using FBI sensor. To measure the refractive index of liquids because the measure end measure end is the chemical actually in this case so because the measure end can access the cavity very easily. So we have a cavity here in FBI sensor and we can pour our liquid in that and based on the refractive index of this material what we pour in we get different different phase shift. So if we plot the graph between the refractive index and phase difference it will look like something like this. First we plot the intensity normalized intensity on y axis and the round type on the round trip delay this is nothing but the phase difference. So we see based on the different materials we get different different peaks here. Let's say this is one peak we detect this is for let's say ethanol the other material can be like this where we have acetone. Some other case we can have like this where the liquid we pour in the cavity is water. So based on the different different liquids what we pour in the cavity we get different different peaks in this in this graph which is intensity versus the round trip delay and if we plot this measuring refractive index which is our actual measurement this is measured refractive index of liquid versus what we actually know that liquid let's say refractive index this kind of sensor performs pretty well and we can see kind of a very linear fit with the measured data. Let's say this is the measured data and this is the blue line is kind of the labeled RI so we get a very good fit between the measured and the labeled RI and this FBI sensor can be used as a refractive index meter of liquids. So this is FBI sensor. Next we discuss the max and the sensor or the MZ interferometer. We can call it MZ sensor or MZI sensor. These are commonly used in diverse sensing applications because of their flexible configuration.

These are commonly used in diverse sensing applications because of their flexible configuration. These MZI sensors have very flexible configuration and they have basically two arms. One arm is considered as a reference arm which we do not change and the other arm is called the sensing arm where we apply the measure end and the difference between the parameters of these two waves one is traveling in the reference arm one is traveling in the sensing arm. So based on the difference between these two waves we figure out what measure end is applied at MZI sensor. So this sensor this MZI sensor has two different arms. Which are the reference arms and the sensing arm. Here this reference arm is kept isolated. From external variation. And only sensing arm is exposed to this variation. So here we have one fiber which is coming in and we use some optical coupler to split the wave in two direction.

This splitting is done by 3 dB coupler. So here in this diagram we have a wave which is coming in from x direction and we use a 3 dB coupler which is which splits this wave this single incoming wave into two different path of course the intensity will be half because half of the wave come into the upper arm which is let us say called reference arm and the half of the wave will go into the lower arm which is sensing arm. Now the reference arm we do not expose it to the measure end only the sensing arm is the one where we apply the measure end for example temperature which is the sensing arm is exposed to and reference arm is kept isolated. So because this is the single wave which was split at the input the sensing arm the parameter of this optical wave will change based on the measure end and at the destination where we get both of these waves one wave will be different than the other and because we send the single wave at the input we know by the difference how much is the difference between the parameters based on that difference in the parameter we can detect what is the measure end which we have applied on the sensing arm. So we have here this is reference arm where which we kept which we keep isolated and this is the sensing arm and the wave is actually travelling here as well as here and here we apply the measure end. These waves one will be impacted by measure end and the other will be isolated when they reach here at this far end we again use a 3 dB coupler here and this 3 dB coupler is kind of reciprocal it can split as well and it can again combined also.

So this 3 dB coupler again combine both the waves back and here at the output we get a single wave. Now we have two waves in this one is let's say R1 which is from the reference arm and one is the R2 which is from the sensing arm. This R1 is from the reference and this R2 is from the sensing arm and based on the difference in these two waves we can detect what is the measure end is applied for example the temperature is applied then how much is the temperature is applied that we can measure using the phase difference between these two reference wave and the sensing wave. So this is how this MZI sensor works. Now there are many ways of creating the interference it in between the core and the cladding of this optical fiber there are multiple ways by which we can make the interference in the optical waves.

So we can discuss some of them for example we have one fiber inside this we have core and the cladding. So let's say this is core and this black is cladding. If we make certain discontinuities for example we put some grating here in the in the core so if in this fiber we have introduced certain discontinuities which is the fringes here whenever this optical wave sees a discontinuity it's tend it tends to this kind of refractive at that interface. So this wave let's say this optical wave which is traveling here this will be refracted into the cladding some part of this will be reflected into reflected into cladding and some part will be remain in core and they will travel separately in core and cladding. However this fringes they work in the reciprocal way when these waves reach here they can again be combined by these fringes for these discontinuities and we get a wave here at the output which is come which is a combination of the wave which is traveling in core.

Let's say this is our core plus our cladding. Some part of this optical wave was traveling in cladding so that will also be recombined back at interface two and interface one is splitting this wave into core and cladding. So this is one way of making interference the second can be we have optical fiber and some section of this optical fiber is misaligned with rest of it. Inside this we have this core. So we can see here some part of this optical fiber is misaligned and we have discontinuity and let's say this is discontinuity one and this is discontinuity two. These kind of discontinuity also act like a refraction at this point.

So some part will be traveling in the core and some part will be refracted into the cladding and again at the interface two this wave will be combined back here and we get this our core plus our cladding. So any discontinuity in the path of light it causes the optical wave to reflect to some other media. This is second case we can have multiple type of cases for example in case number three we use certain grating we can make certain grating inside this optical fibers. So here we change the material of this optical fiber here and here. So now if the wave is traveling this side this wave will be splitted here by this discontinuity some part will go into core and some will be in cladding and again by the second discontinuity which is here this will be combined back into the core and we get our core plus our cladding. So these are some of the waves by which we can create the interference in optical waves. Some of them are preferred because for example the grating which are easy to make using laser sources we can we can very precisely make these gratings into the optical fiber and we can create these interferences. So this is a good way of making these splitting these two waves from a single wave. So coming back to the MZI sensor we can see a particular case where this MZI sensor we can use for temperature measurement. So in this MZI sensor we take a optical fiber and we create multiple gratings at the input side and some at the output side with a known distance l in between.

This is d and this optical fiber we feed using a light source and on the other side we have a detector. Now this is the assembly of MZI sensor we have a fiber where we have precisely put this grating at the input side and at the output side with a distance which is known and which is fixed l. Now we expose this assembly to the temperature which we want to measure these gratings what we have put we have seen in last slide we these gratings can actually split the wave into core and the cladding. So the wave coming in at the left this actually gets split into core and cladding and again combined back at the output between the core and cladding is combined and goes to the optical detector. Now there is a difference between the temperature expansion of core and cladding material and that difference gives rise to the difference in the phase between these two waves which is one is travelling in the core one is travelling in the cladding and the interference fringes are formed to the core mode the interference fringes are formed. And the phase change is given by K into delta n effective and the l which is the distance between these two fringes. So this is the formula to calculate the phase difference and if we plot this transmission with respect to the wavelength on the y axis we have transmission on the x axis we have the wavelength this looks something like this let's say this is one wave if we change the temperature this transmission coefficient actually changes. So we have different, different these different, different minimas for different temperatures if we are changing the temperature here and if we plot this wavelength as a function of temperature which is our actual measurement on y axis we plot the wavelength and x axis we put the temperature we can see a fairly linear graph where this wavelength is linearly changing with rise in the temperature this graph is very linear. So this is a typical output for MZI sensor where we can see the output which is the function wavelength which is very much linear to the temperature change a linear change is always desirable in making the sensor. So this is MZI sensor which we have used as a temperature sensor here this length actually is changing with temperature there is a elongation in the or the expansion in the of this optical fiber length because of the temperature expansion and this length this change in the length on the expansion in the length is giving rise to the difference in the wavelength.

So this is MZI sensor. Or MI sensor. In MI sensor this is very much similar to the previous sensor in previous sensor we have two arms one is the reference arm one is the sensing arm and of this reference arm is kept constant and sensing arm is exposed to measurement at the output we again combine these sensing and reference arm to get a common output if we see closely this structure is very symmetrical from the input we split up and again we combine to get the output if we cut this structure in between and put a mirror is a physical mirror then this wave will be again reflected back to the origin and because these waves can travel in both the directions there will be no kind of problem in cutting this structure into half. So this MI sensor or Michelson interferometer is very similar to this MZI sensor. The basic concept is same. Which is interference between the beams in two arms.

But each beam is reflected at the end of each arm. So, in the last in the MZI sensor we have this optical fiber and we use a 3 dB coupler to split the wave into two and one we call the reference arm the second is the sensing arm this is 3 dB coupler this wave comes from the left now instead of completing these arms we put some sort of mirror here this is actual mirror where we are reflecting the light this light goes here and again reflects back from here the same thing in the sensing arm it goes and reflect back here and 3 dB coupler is also reciprocal so it can again combine these reflected waves and send it back to the origin where we can detect it using optical detector. So now we see we need not to complete this whole assembly and we can we need not to use another 3 dB coupler at the output we just kind of reflect all the waves back one is the reference arm which we again keep isolated so this is isolated and this is the sensing arm which where we apply measurement and except this change in the structure all the phenomena of this MI sensor is very close to the MZI sensor we can use this sensor in a similar way as MZI sensor. The fourth sensor is the Segnik sensor or Segnik interferometer. So, these Segnik sensors these are very much of interest nowadays because of their robust configuration easy fabrication and we can use in multiple environments so these Segnik interferometer sensors are of very much interest nowadays. The basic structure of these SI sensor is something like we have a optical fiber which is coming in here and then we have a 3 dB coupler which splits this wave which is coming from this fiber into two part and this fiber both the end are connected to a single fiber in this way this is a circular loop of the fiber and again we have a fiber going out this is our input and this is our output this is 3 dB coupler.

Now from the input let us say one wave is coming here this is splitted by this 3 dB coupler half of the wave will go in this direction half of the wave will go in this direction. So, we can see in this assembly half this wave is split by this 3 dB coupler half wave will go in this direction it means it is moving clockwise and the other wave is moving anticlockwise so both these both of these waves they are originated from same wave, but now they are traveling in opposite direction one in clockwise and one in anticlockwise. So, right now the path difference in both the waves is same so there will be no phase difference at the output now what we do we take this assembly and rotate it this whole assembly is now being rotated let us say this is the rotation of this whole assembly. Now what will happen the wave number one for example, this is the wave number one when the rotation is in opposite direction this wave will take less time in reaching from one end of this fiber to the other end because by the time it reaches the other end the assembly moves in this the opposite direction so the end point actually comes nearer. However, this wave number two it takes longer time in reaching from start to end because by the time this wave reaches at the far end this assembly rotates in the same direction it means the end point shifts further away from this wave and it takes more time compared to the wave one which is taking less time.

So because of this difference in the in reaching the end point there is a phase difference in between these two waves wave number one and wave number two so these are originated from the same wave so we can compare the phase difference of wave one and wave two and see how much is the speed of rotation of the assembly. So this the faster we rotate the more will be the phase difference between wave one and wave two. Due to simple structure and robustness. And send into opposite direction one return on return to the point of entry the two light waves allowed to exit this ring and they undergo interference. And the phase difference delta pi is approximated as eight pi upon lambda into omega. A to A where this A is the area and omega is the frequency of rotation. So A is the area of this loop and omega is the frequency of rotation. This phase difference here delta pi is a function of this omega or how fast the assembly is being rotated and if we plot this phase shift with angular velocity. On the y axis we have phase shift and x axis we have angular velocity. The graph looks something like this which is the phase shift with angular velocity and we can see that phase shift is actually increasing with angular velocity because this delta pi is proportional to w the or the omega the angular velocity. So today we discussed interferometric sensors which are basically four types and we discussed each four of them here.

So this is all for today.

Thank you.