Optical Engineering

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Lecture – 22
Revisiting Ray intercept curves

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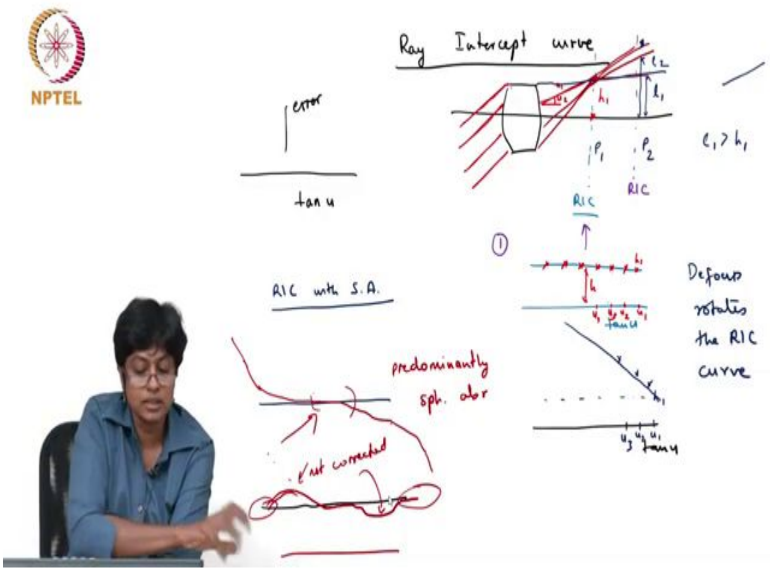

So, the other thing that I want to revisit, now that you have a better idea of aberrations in general is the Ray Intercept Curve. So, what will be plotting on this label less curve again; plotting tan u that is the tangent the ray made with respect to the optical axis versus the error, right. Now let us say I had some optical system that is the optical axis and I have a set of rays that are coming in and let us say, they actually the system has been optimized, so that they all focus at one point.

If and let me just draw this onward ok, it is a very bad drawing, this all focused at this point ok, that is a point. If my image plane were here and I was drawing the ray intercept curve for this claim, the rays at this plane; all the rays have come to focus at the same point. What would the curve look like? Straight line, but not a vertical straight line, a horizontal straight line, because the error is the same is zero in fact, in this case, right. So, it is a horizontal straight line, they all have the same value over here, right. So, it does not matter. So, if this is tan u, they all have the same height, it is constant, ok.

Now I do not change anything in my optical system, but I move the plane that I am looking at. So, looking at the plane where all these rays are focused, I move my plane to this position. What will change now? Take the tan u and for a particular and how do we? Again you do not even have to guess which ray to start with, you start always with the top most ray.

The top most ray is a height or deviation from focal position is plotted on the right most of the curve and then do it for the next ray and then do it for the next ray. What do you get? So, in this case, so for graph 1 which is here; this is the topmost ray, this is the topmost ray and it landed up here and let us say I am measuring heights from this point, so this height is h 1. So, it has this is the angle, it makes a very small angle with the optical axis. So, let us say maybe this is tan u for that, I will call this, so this is h_1, right.

So, this height is h_1 and this is tan let us call this u_1. So, this is utanu; then I would take the next ray that is this ray, now it lands up at the same height. So, its height is also going to be h_1 but it's angle is u_2 So, I have the tan u of this angle, but it has the same height, right. So, I will do that for every single ray and in this case, since they all come to focus at the same point, they all have the same height; but of course, the tanu is going to be different in each case.

So, I am just marking the angles here, but it is the tan of these angles; that is how I got this curve, this straight line. Now I am saying, plot the same thing, repeat this operation on the second plane. So, let us start again, ok. Now let us take the first ray. So, this is the first ray, oh I did not want to delete sorry, that is the first ray, so this is its height. Now this is slightly different from h 1 right; because it is at a further plane, travel through free space changes the optical parameters, there is no change in angle, but there is a change in height.

So, the second graph that I plot actually I am going to plot for exactly the same u_1, u_2, u_3, because I am taking the same rays, their angles have not changed, but what has changed is their height at this plane. So, let us consider this first ray, this is height h_1 and let us call this l 1 to show we are at a different plane. So, l 1 which is slightly bigger than h_1 ; because a ray is traveled like this, so if this was h_1 position l_1 is going to be over here.

Then I take the second ray, this is the second ray, this is its height, this is l_2 Now you see a big difference between, you just shifted the plane that you are looking at; at this plane it did not matter which ray you took, all the rays had the same height. But when you move the plane, the rays no longer have the same height, so you know that you will not have a horizontal line, right.

So, you do not have a horizontal line. So, this is l_2 which is slightly larger, so it is over here. If I take the next ray, this is its height; so I am going to have this. And so it turns out, you will get a straight line, it is not a curve, it is not a there is no reason for it to bend again; the rays just go on increasing in height, right. Meniscus or something that would mean, there was again a reduction in height, there is nothing here to cause a reduction in height.

So, I do again get a straight line, but the straight line will now be rotated. So, defocused, what have you done by moving your image plane from this plane p_1 to this plane p_2 ? What have you done? You have defocused, p_1 was the plane where the best focus happened; but instead of looking at p_1 , you have looked at a different plane. And what did I do to the RIC curve? It just rotated the RIC curve. So, defocus rotates the RIC curve.

So, if you understand the RIC curves really well, if you are given a set of RIC curves for an optical system; you do not know anything about the optical system, but you are given these curves, you will be able to look at this and get a sense of what this system is doing, where you are looking at the system, has there been some correction in the system. So, for example, what did the RIC curve look like for a system with predominantly a spherical aberration present?

It was something like this right; I mean not drawn it very well, but something with an anti symmetry do it, right. So, if you had a system like this, you would say this predominantly spherical aberration present. Now if I gave you, I said I am going to change something in the system and the changed one looks like this. What do you think has happened to this system? What would you say is the aberration of this system?

It has anti symmetry. So, what is the predominant aberration? Anti-symmetry, it is still spherical aberration; but it does not look like a typical spherical aberration. What happened in spherical aberration or what is spherical aberration? The further you go away from the optical axis, the worse the aberration gets; and that is why this goes on increasing like this and this goes on increasing like this.

If I increase the aperture of my system, I would go on having this get larger and larger; because the further we went away, but what is the graph below showing you? The further you go away it is getting worse and then what happens?

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So, what does that give you an idea of? So, this is a system with spherical aberration corrected, it should have been going like this; but something has been done to the system that pulls it back down, not all. If there was no aberration, if I had got all of the spherical aberration, my RIC curve would be a nice flat horizontal line. But I said and I said it repeatedly, you never correct for all zones of the lens.

So, this shows you some zones are corrected for and why this is still better than this case; because here the central part is fairly corrected and as you go for then further away, it gets worse and at least that region gets corrected, the place where it would have got worse is corrected. So, even though it is not corrected here, that is not the zone where it is the worst and that is why sometimes this is an adequate enough correction; because it does not allow the aberration to increase too much. It pulls it back down when it is getting too large, right.

I am just giving you here some examples of what an aberration curve looks like for some of the monochromatic and earlier we have looked at some of the chromatic aberrations. So, understand the curves we plot, these are transverse curves; we plot transverse curves, we plot longitudinal curves, we plot longitudinal curves which are focal distance versus height, we plot longitudinal curves which are focal distance versus wavelength, we plot transverse curves which are tan u versus error transverse error.

So, you have to understand what is being plotted in each of these curves, what the curve looks like when there is one aberration predominant in the system, how correcting that aberration will change that curve, ok. And finally, in a real system, you will have all the mono chromatic aberrations as well as chromatic aberration present simultaneously. So, the curve is the combined effect of all of those and of course, that makes them harder to analyze. But if you do not understand them when aberrations are present independently, there is no way you are going to be able to analyze the curve when the aberrations are present together.

So, to understand why diffractive optics has a different dispersion, you have to understand how diffractive optics works. Refractive optics is not part of this course, but since you have asked.

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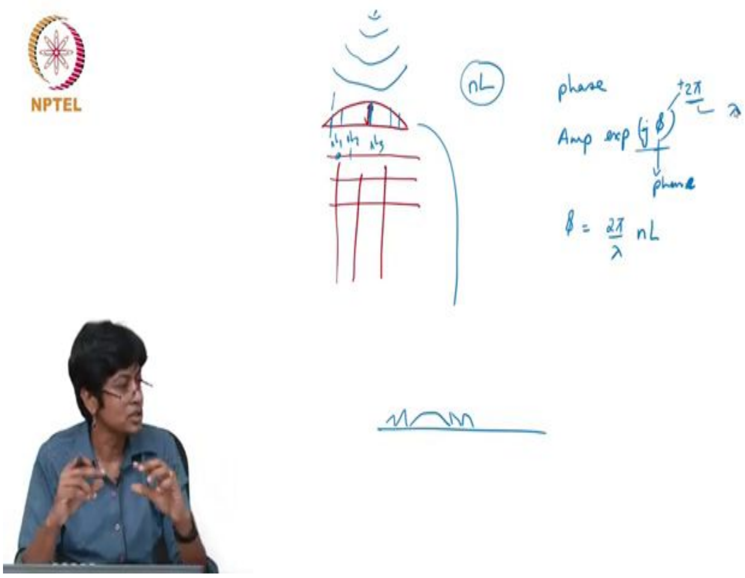

Let us take a lens ok, this is your standard Plano convex lens. Now in the ray optics picture, we do not really worry about what is happening to the wave; but if you really want to understand why, why does this focus? If I look at the wave that is incident on this lens, the wave front of this wave is say coming in like this.

Now, what does the wave the ray that goes through this travels through the longest path. So, it is slowed down the most, this ray that goes through this region is already in the air while this is still traveling over here. So, it is in air, it is in air and it is traveling faster; this is traveling through glass and it is traveling slower. So, the wave is going to sorry, the wave is going to actually do my god, the wave is not doing anything of the kind of kit as a nice spherical shape and it is going to go on reducing till it goes to the origin of the wave, ok.

Now, why has this happened, because the wave travels through this region, so everywhere there is a different thickness; but now you know it is not just the thickness that matters, it is n into L that matters. So, everywhere this part of the wave has travelled through some nL_1, this part has traveled through nL_2, this has travelled through nL_3 and so on and that is what changes the shape of the wave. This actually relates to phase right, you need to go back to. So, if you really want to understand; in geometric optics, we do not try to understand why things happen the way they do.

It is an empirical, it is based on, I have seen this happens, it works, right. But if I really want to understand, I have to go back to wave optics. And in wave optics you know that, the moment you write down the equation of a wave, you are going to write out in terms of an amplitude and exponential J phi phase. And this phase is nothing by 2 nothing, but $2\pi/\lambda$ into the optical path length. So, if this is a phase, if I said let me add $+2\pi$ everywhere, does not make any difference.

So, I can convert this lens into a lens which just has these variations, I have removed all the excess $+2\pi$ s; but that in doing that when I say $+2\pi$, $+2\pi$ relates to a distance of lambda, this becomes an extremely dispersive element. Diffractive optics is horribly dispersive, because I design it for one wavelength alone and it is dispersive nature is opposite to that off, because the way it is working is quite different. So, combination, so you can have these telephoto lenses from Zeiss, you know the kind that you see photographers use well for sports photography and so you, the zoom lens is so long.

So, there are so many refractive elements in there, you can add up the chromatic aberration, it can be really; I mean it would not be useful unless you did some serious correction. So, you can have a range of refractive elements and one diffractive element to correct for that; and you know and the diffractive is thin and slim, so it is a very lightweight element that can do the correction.