Optical Engineering

Prof. Shanti Bhattacharya
Department of Electrical Engineering
Indian Institute of Technology, Madras

Lecture – 15
Tracing rays through optical pupils - Part 2

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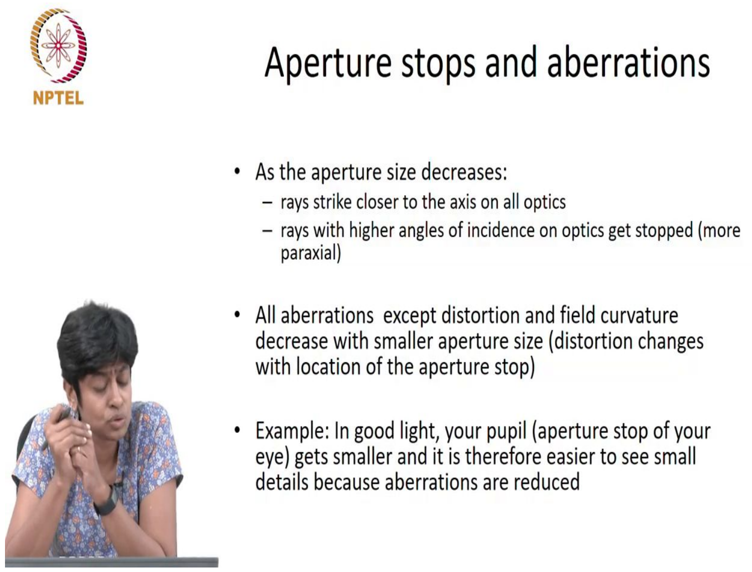

So, we saw that as the aperture size decreases what happens. You are capturing rays that are closer and closer to the optical axis. Your paraxial approximation is getting more accurate. And we discussed the pinhole camera yesterday where we said you really have only axial rays and have an infinite depth of field; however, it has very less light going through it and so there are all the implications that come with that.

We have not discussed aberrations in any detail, but as the name suggests the aberration means something is wrong and in optics and ray optics when you talk about aberrations, you are talking about the image quality getting deteriorated. There are many different types of aberrations, we split them up, we studied them separately because if you understand the cause of each one then fixing that particular one becomes easy. And because they each have a different cause the way you fix them is going to be different also.

But one common cause not for all the aberrations, but for some of the aberrations is to do with the cone of light coming into the system, thereby moving the aperture stopped, changing it is position or changing it is size will control which rays make it through the system and therefore, will control there it becomes a tool by which to control the aberrations of the system or design a system with better aberrations less aberrations I should say.

Our eyes are using an aperture stop all the time. So, one thing is very clear, when the lighting around us changes the amount of lighting around us changes the pupil of our eye automatically changes size, right. So, if in a very brightly lit situation, it will shrink down to a smaller size which is around 2 millimeters and in a very dark condition it will expand up to a larger size about 8 millimeters. Now the immediate benefit of that of course, is that we are able to see clearly despite the lighting condition, but you notice what happens when you move from a very bright to a very dark room or someone switches off the light.

Immediately what does the room feel like to you? So, you are in a black brightly lit room and someone switches off the light. The instant the light goes off what does it feel like to you? You feel like you are in a room where there is no light, it feels like this is really dark, but in a little while you find you can see things, it means; obviously, not as clearly as you saw them before, but you can see things. Why is that?

Student: The pupils are (Refer Time: 03:33).

Because your eye has a natural response time, the pupil takes time to change the size. So, it takes time to open up. When you are in a brightly lit room it is at its smallest size. So, the moment the light goes off it is still at that smaller size, there is not enough light reaching the eye, the retina the detector of your eye, but in a little while the pupil has expanded and then there is more light reaching your retina and therefore, you are able to see something right and similarly the reverse is also true right.

If you go from a very dark room to a brightly lit room or someone switches on the light and the change is abrupt you feel like it is too much light, you might close your eyes because you feel it is too strong because the pupil is open wide and suddenly there is too much light in and almost hurt you right. So, it is because of the response time of and that that is required for this optical system, our eyes to change it is pupil size ok.

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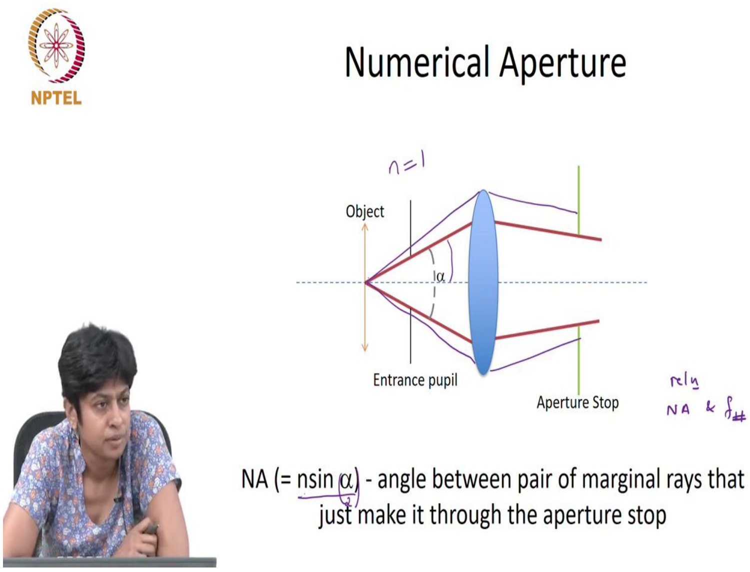

So, let us now look at a definition of a term called the numerical aperture. We talked about the aperture stop and I have been talking about the cone of light. So, if I want to formalize that cone of light definition, we do it through this term called the numerical aperture and if you work with any system in optics, you will often be given the numerical aperture of the system even what is a numerical aperture of this lens.

So, we understand now that the light gathering capacity of a lens or an optical system is not determined by the diameter of that system alone right. Even if I take a single lens, forget that I have a whole range of lenses, forget a system like that takes a single lens, the light gathering capability is not determined by the diameter of the lens alone, it is determined by both the diameter and the focal length. So, an aperture simple aperture with no power, it is light gathering capability is determined by its size.

But if the element has power I have to take the focal length into account because the way the light bends due to that element is going to determine it's light gathering capabilities ok. So, the numerical aperture is defined as n sin alpha, where actually I should have mentioned n is the refractive index of this medium ok. Clearly you want this to be a large number, let us say the medium around was air, so, this is equal to 1. What is the largest numerical aperture you could mathematically have? 1 because I am saying sin alpha and well actually it is in terms of this angle sin alpha. So, it should be alpha by 2 here, the way I have defined it right.

So, the largest angle that alpha by 2 could have is 90 degrees, but no optical system is going to capture a cone of light with 90 degrees right. So, you want the numerical aperture to be in 1 if the medium outside is air, but that does not happen and so, these people have defined or designed systems with as high a numerical aperture as possible in order to increase the amount of light that is collected. And as an exercise I ask you later to get the relationship between numerical aperture and f number ok, pretty simple.

Again, why does the diameter alone not control? Well in this system you can see these rays are captured by the lens they are bent by the lens and because they are bent they make it through this aperture stop here but if my rays traveled with this angle they would also be bent by this lens, but they would be blocked by the aperture stop right. So, clearly I have to take both focal length and diameter into account to find out exactly how much light is traveling through the system.

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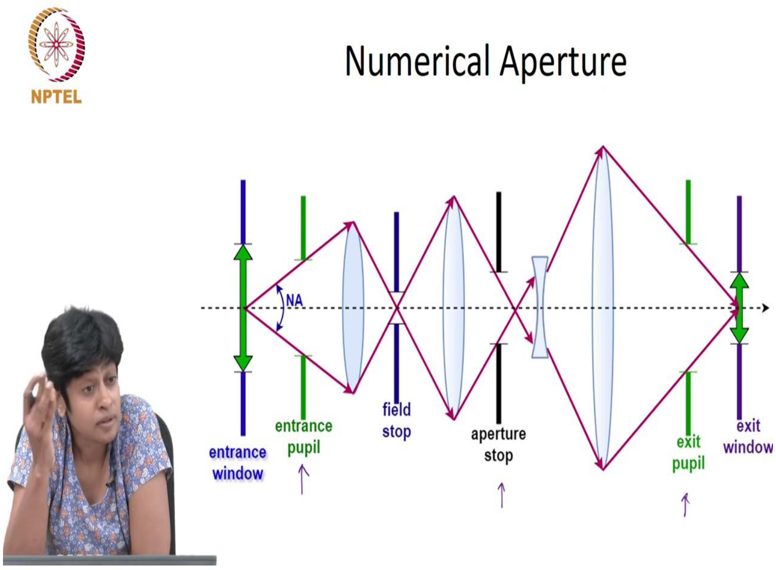

Just to give an overview now of everything that we have done in the last two classes. So, you have a system here, it has a number of lenses and there are few more terms that have been thrown in here that are not so important for us in this class. So, I have not spent time defining them, but I want you to just be familiar with these terms because if you are going through any optical book you may see these names. So, what we have spent two classes looking at is of course, the aperture stop and then the image of the aperture stop has been seen by all the proceeding elements that was the entrance pupil. The image of the aperture stops as seen by all the elements after it that was the exit pupil.

But there are some more terms over here they include the field stop and the entrance window and the exit window and they have exactly the same definition except now you are not talking about the rays coming from the object point on axis, but the rays coming from the extreme points. We talked about the field stop earlier. Do you remember what we define the field stop as? It was we drew the plane at where the image was formed and we said if that clay you know that screen or the detector, the device that is capturing the image is smaller than the image it may be a perfectly focused image, but if that device is smaller than the image then you only capture what falls on the detector.

The extremities that fall outside are not captured and therefore, the size of that detector becomes your field. That element that is your field stops it is limiting the field right. So, that field stop could actually occur anywhere in your system it says, what are the rays that make it through to form the edges of my object or my image rather. And exactly as we defined the aperture stop right, the aperture stop had a physical element in my system, but in order to understand the aperture stop what you use the aperture stop I then defined entrance and exit pupils right.

The field stop has exactly the same definition: you take the image of the field stop with the preceding elements and that is nothing, but your object that is your entrance window and the image of the field stop with all the elements after it and that gives you your exit window. So, your detector must be the size of the exit window if it is smaller than that you are going to lose the extreme points of that ok. So, you can think of the aperture stop in the fields are very similar and the definitions of exit and entrance pupil similar for as exit and entrance window, one set is for the field stop, one set is for the aperture stop. So, you may see these terms which is why I wanted you to be familiar with them.

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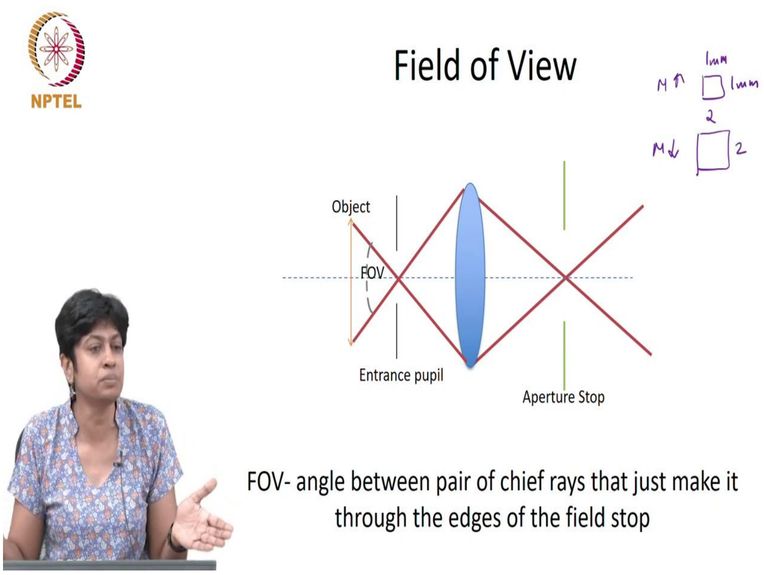

Another very important parameter is the field of view, now when you have been doing these few lab classes you have to enter the field of view as one of the parameters to start with, what is the field of view. So, the field of view if I take the object and I trace the rays from the extremities of the object this is a field of view and the name should be fairly obvious. We are saying if I say these two chief rays make it through the system, in other words they define the field of view of the object that I can see. This is very important in a microscope I want I want to in a microscope. The purpose of a microscope is to magnify.

So, I want to take some part of a sample, magnify it and look at it with very high resolution. Now can I look at an area of 10 millimeter by 10 millimeter at a very high resolution. It turns out you cannot in a regular microscope. So, what is the field of view? Maybe you are looking at 1 millimeter by 1 millimeter, that is the field of view for a certain setting of the microscope, for another setting of the microscope maybe we are looking at 2 millimeter by 2 millimeter.

So, I am changing some settings of the microscope so that I change the field of view and I am able to view it with a certain magnification. Clearly the magnification here will be greater and the magnification here will be less. It is one of the problems of a micro regular optical microscope, I can either have a very small field of view and a very high magnification or a very large field of view and a very low magnification. And what people want, biologists and doctors want, they want a large field of view with a very large magnification and with the conventional optical microscope that is not possible to achieve.

So, the field of view is basically the angle between the two extreme chief rays that make it through the system, that tells you what is the area over the object that I am able to image ok.

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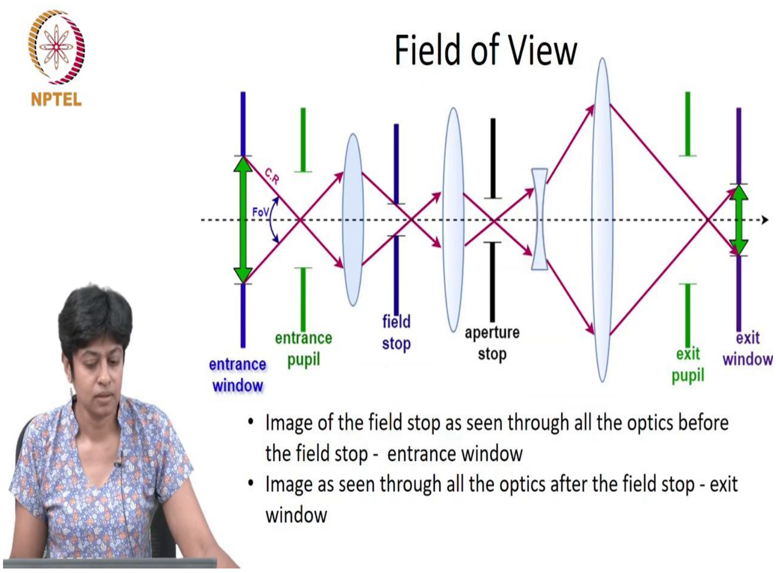

And this then just traces it out through a system with more than one lens again I am just redefining what the entrance and exit pupils are just so that you are sorry entrance and exit windows are just so that you are familiar with those terms ok. So, we will stop the class at this point and we will be starting with matrix optics in the next class, would suggest you take the exercise we did and go over it again, because if you are able to do that exercise then you have got your definitions of aperture stop, axial ray, chief ray, you know got them down fact you have understood them.