Introduction to Biomedical Imaging Systems
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Lecture - 47
MRI_Instru_S1_S16

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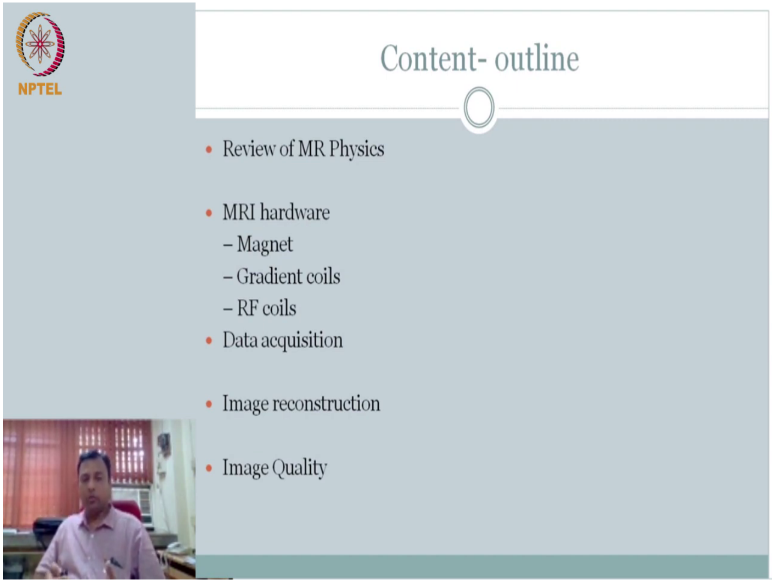

Ok, welcome back to the next session here we want to know we completed the MRI physics module and as per our template of coverage after physics we will do the data acquisition or the instrumentation and then move on to the image reconstruction and image quality. That is how we have been covering each of the modules at imaging modalities as well.

So, after completing the MR physics in the last module, we now proceed to the remaining part which is going to be starting with the hardware part and then focusing on data acquisition, reconstruction and image quality. In fact, the object for this particular session of the video would be mostly on just the MR hardware and magnet perspective ok.

So, we will start I do not I am not going to do a review of MR physics as I have it here because usually when I do in class it is after a week and. So, I have to refresh you know. But now that you have the video maybe you should finish viewing the previous video again and then start with the new one. So, that will save some time ok. So, how does it go to the next slide ok?

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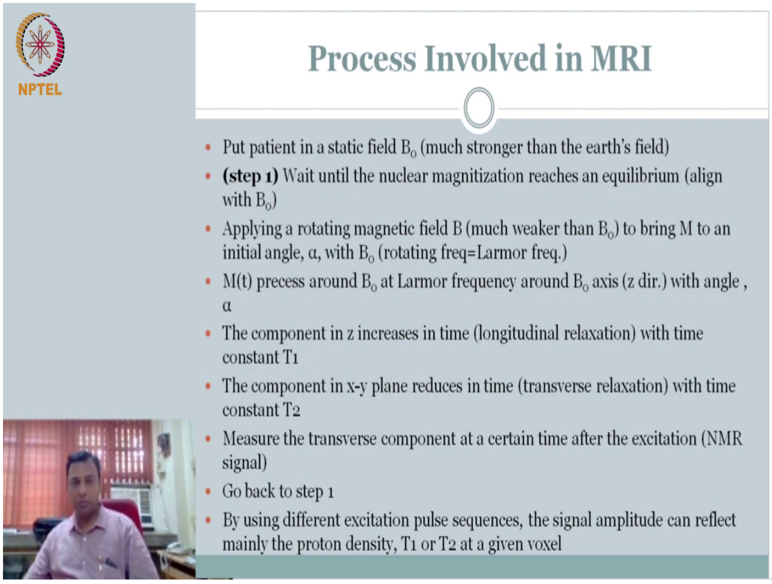

So, let us skip the process involved in MRI because this is supposed to be review we have gone over this several times as to how we go about this. So, you can refresh yourself before start of this in a material what we were doing until now ok. So, where we will jump this again despite me showing it here and asking you to preview previously.

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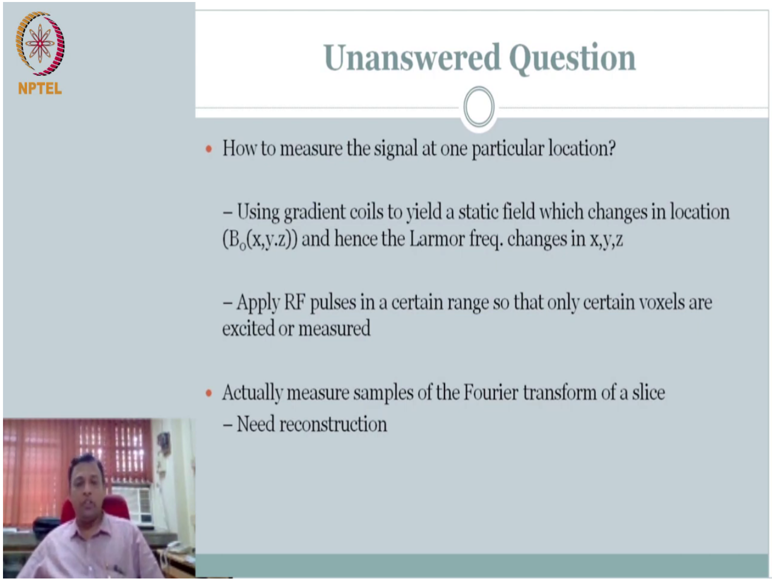

You start answering this question ok we have already covered all the physics ok, what is it missing? How do we do this jump from we are interested in MRI we covered the physics part of it, we understood what the signal is, we understood the contrast mechanism.

Now, how do we in fact, we also pretend that we saw several images as well, but we did not really answer the question as to is all the development material we did was taking a small work cell and we were talking about the spin physics and how to manipulate the spin.

But, how did different locations have different properties right, how did we execute that, how do we realize that? That part we have not covered. So, that is a question here, how do we do this? Because if you want to do this say imaging we need to measure at each location therefore, we should be able to tell, this is the proton density here, density there and therefore, you get a image, how do we do that right?

So, before we go into the details broad side, think about the first principles what we covered. What we covered is in nuclear magnetic resonance NMR the nuclear spin is a important guy and we described that if you are biomedical we are interested in hydrogen proton.

So, hydrogen proton had one gyro magnetic ratio that is the Larmor frequency if you were to spin the Larmor frequency is unique right for hydrogen and it was some 42.8 megahertz per tesla. So, you have signature Larmor frequency and I want to see how the hydrogen or proton density is distributed in the body. So, the logic would be straightforward, right.

How do I change? Can I change the Larmor frequency? Well the Larmor frequency for hydrogen is unique however; it is a function of tesla or the field strength what happens if they change my field strength at different locations what will happen? Different locations will have different frequencies.

So, then I can if I know how that distribute if I manipulate the difference in different magnetic field at different locations. Then I also know where the frequency is coming from I can say it is coming from that location right very intuitive very simple concept ok. So, that is what we will do, we will talk about using gradient coils right to encode your magnetic field at different locations in x, y, z.

So, that the Larmor frequency changes. So, therefore, from the signal frequency we know where it came from right very bird's eye view that is the concept. Then we will talk about applying right that is first is generation of your magnetic field and then apply magnetic field and manipulate. So, you have to have RF pulses that you can apply when you want.

So finally, you know apply you measure the signal again we will get to this when we get to the reconstruction, but this is the challenge in MRI we are always worried about signal measuring in time domain that itself is complicated. And then doing all the measurement signal processing the typical way we do. That the beauty and also the challenge in understanding MRI comes the data you are actually measuring we are actually measuring sampling the frequency spectra right, it looks very difficult to understand if you.

But imagine what you are doing I am saying you are changing the Larmor frequency and you are measuring the signal what was your signal free induction decay. So, I am just having so I can take the you know power spectra of that that will have the frequency that you are taking up the Larmor frequency. So, I have the energy remember the Parseval's theorem.

So, I have some signal I have some energy for that particular frequency. So, the energy at that particular frequency when the frequency is changing at different locations that means, I am having the frequency spectral information at different locations. So, I have the Fourier transform directly; I am measuring the Fourier transform directly what I want is the object not the Fourier transform of the object. So, we should be able to reconstruct.

So, what we are measuring turns out is nothing but you are measuring the energy in different frequency which is nothing but your Fourier spectra, Fourier transform right. So, we will get to that, but start to appreciate that we go to instrumentation first. So, how do we enable this that is what is the first goal.

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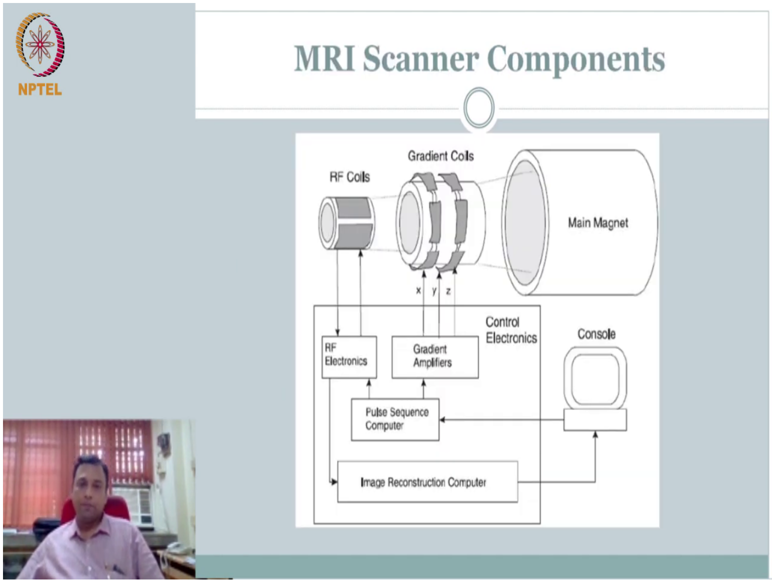

So, this is a block diagram version of the components right. So, you have main magnet you are expected to have gradient coils what is gradient? Gradient means slope; that means, there is a change coils. So, you have a gradient coils in x, y, z means you have to be able to change something in x, y, z what is that something that something is your magnetic field

So, you have a main magnet and you have the ability using gradient coils to change the magnetic field in different locations of x, y, z and then what do you need? You need to apply excitation and receive. So, you have the RF coils right that is going to the RF electronics will come in to enable the excitation. And then you have to have some computer.

So, that you can code the sequence remember the controller sequence the pulse sequence programming that we talked about. So, you need some sequence computer and then of course, get the data you have to do some image reconstruction and you have to have a big console that can control all of this, ok.

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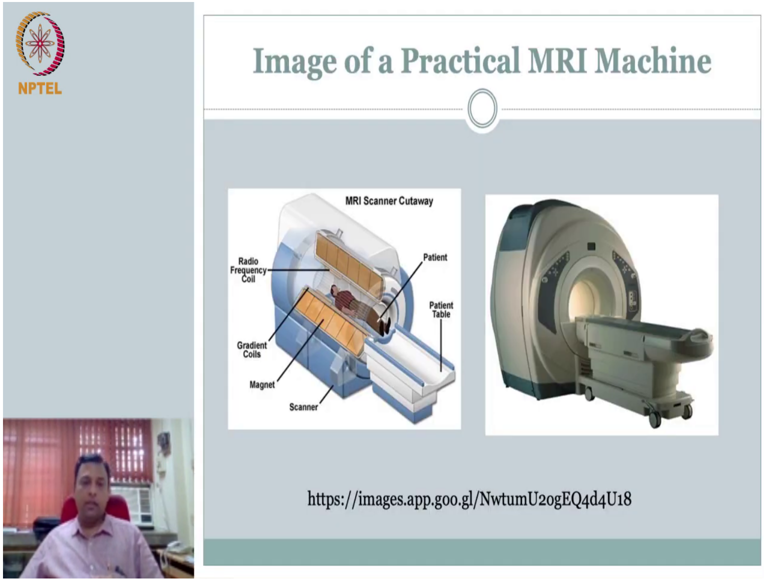

This is our typical MRI I am sure you would have seen it you have a bench you go that is the big bore that you see people patient goes in a very important point that I would like for you to alert until now, we covered physics I have been always saying floor to roof as your z because it is easy for me to do this and the transverse was txy of my floor.

Here I am going to make a switch because the patients are not standing right they are lying down in the bed and going in. So, starting now almost all reconstruction all the analysis that we will do, we will relate this axis of the patient going in as the z axis ok and therefore, the axis now is rotated. So, now, whatever I am saying z is not going to be here z is going to be the bore inside that the patient along the patients foot to head.

It goes foot to head before also just that I was standing or I was sitting here therefore, this was z. Now the patient is lying and therefore, z axis is also lying ok it is from foot to head that is my z axis that is the only change. Otherwise you look how complicated it is right. So, this is big you need a certain special room. So, the cost and complexity goes up, but let us go into the details.

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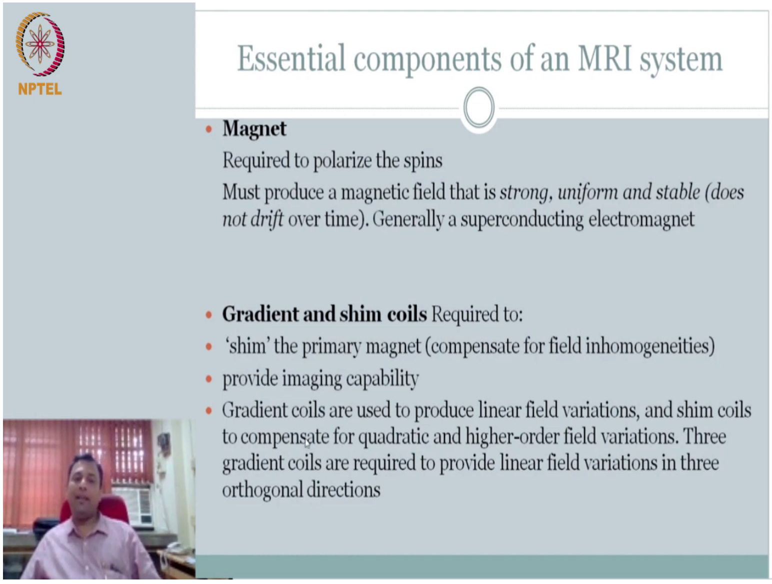

So, the essential components that we are going to look into little more detail is, we have to have a magnet. Why do you need a magnet? You need a magnet to polarize everything know align in a particular field direction. And what you need it has to be strong it has to be uniform and it should not change with the time right, I am supposed to have same magnetic field while I am doing the experiments right.

If it changes unknowingly randomly then it will become difficult for me to encode where that frequency came from so, that is. Generally, superconducting electromagnet is used for that we go into the details of different types of magnet in a while then you have to have gradient and shim coils. Gradient we already talked about some sense you understand you have to change the magnetic field that means, you have to create a gradient.

So, you need a coil and that will change the shim coil is a new one, what is the shim coil? Shim is nothing but see we want homogeneous magnetic field the B naught right and it should change only as per our design requirement the gradient should be as per our requirement.

So, we know which frequency came from where, but magnet being magnet I mean it is a material it can have some inhomogeneity fluctuations right you do not want that. So, how do we smooth it, how do we make sure that the field is homogeneous? You need to have shim coil the shim coil essentially tries to compensate for any inhomogeneity. So, that the magnetic field it turns out to be homogeneous.

And your gradient coil like this we should be able to change the p like yours magnetic field in linear fashion over x, y and z the three orthogonal directions. Let us go into first magnet and then we will the next video lecture we will cover gradient and shim coils, so going to magnet right.

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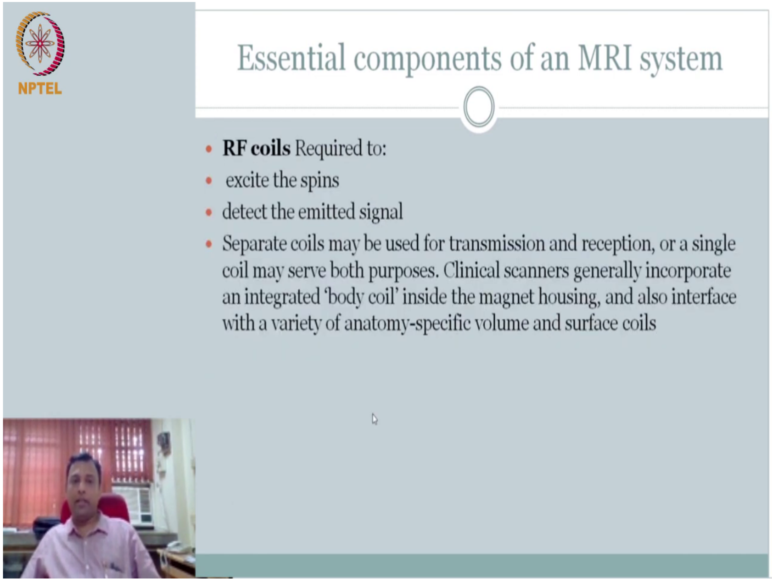

After the then the component that we will cover is RF coil you need the RF coil to both excite and then detect the transverse component right. So, there are several ways to do it you could do it separately you can have a transmit coil separate, receive coil separate, but typically you know it is a hybrid most systems have a body coil that will be used. But the in top of on top of it for getting higher signal to noise ratio they also do a specific anatomy specific coil.

If you go for scan on your elbow you can have a coil here you do not want to do the whole body right, whole body might be there you might find a fracture in the knee, then they will put a surface coil on the knee to understand the knee even more better. So, you mostly it is a hybrid, but generally there is a body coil that comes in built with the scanner system. So, we will look at this also when we get into the RF coils.

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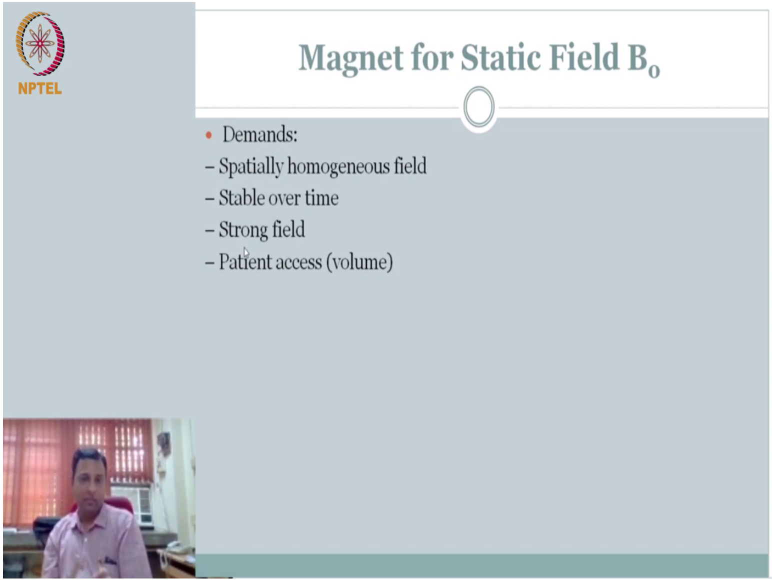

So, first is the magnet part. So, magnet what do we want? We want is the static magnetic field. So, what are the demands, we know the demands before we go in. One is, it should be homogeneous it should not change. So, two is it should not change with the time right thus it is stable with time by a machine by a magnetic field as a magnet today.

That magnetic field strength should be same, whatever is calibrated whatever is listed it is a 1.5 tesla machine it has to be 1.5 tesla over a long period of time it cannot be 1.5 tesla only for the first month then you are in trouble. So, demands are you have to have spatially homogeneous field should be stable over field thus have a strong field, we will define what that strong field means right.

I mean what the strong what is weak is relative, but you need a strong field you know that from before, why do you need a stronger field? More the field better is the signal quality go recall the signal equation that we got; it was a function of magnetic field strength right.

So, want better quality signal you have to have better field strength. And then of course, patient access the magnet should not be small it should be big enough. So, a patient can go in and come came ok. That means, you have to keep all this for spatial homogeneous field over a larger volume.

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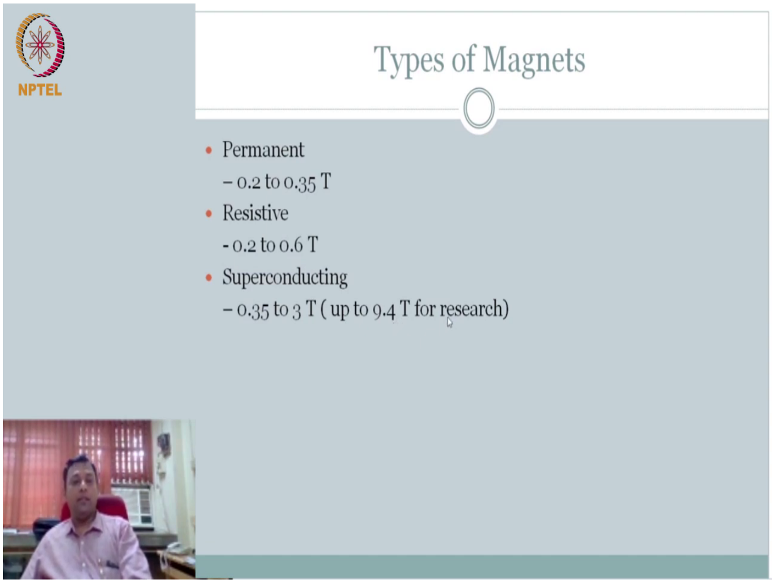

So, there are different types of magnets permanent, resistive, super magnet superconducting I am sure you are familiar with permanent magnets right several small scale you would have seen or the you know in the refrigerator we put souvenirs, like a small it always has magnet there is always a field strength to it is so small that it holds your souvenir in place, but otherwise it is already it is permanent it is always on the magnetic field is always on here.

But, you see the strength is we do not know much at this point of time, but we know it is right now in fractions of tesla whether that is good or not we will see. Then there is a resistive where again the magnetic field strength that you see is also fraction. And then there are superconducting, which you see that it is from fractions to 3 in some cases research there are 9.4 tesla.

So, now, maybe if you have a general experience you would have seen MRI scanners advertise they have 1.5 tesla is very common there are 3 tesla. So, none of the permanent or resistive is in that range. So, you can already understand most of the existing MRI scanners use superconducting magnet. And you get the tesla field strength in the range that is currently used.

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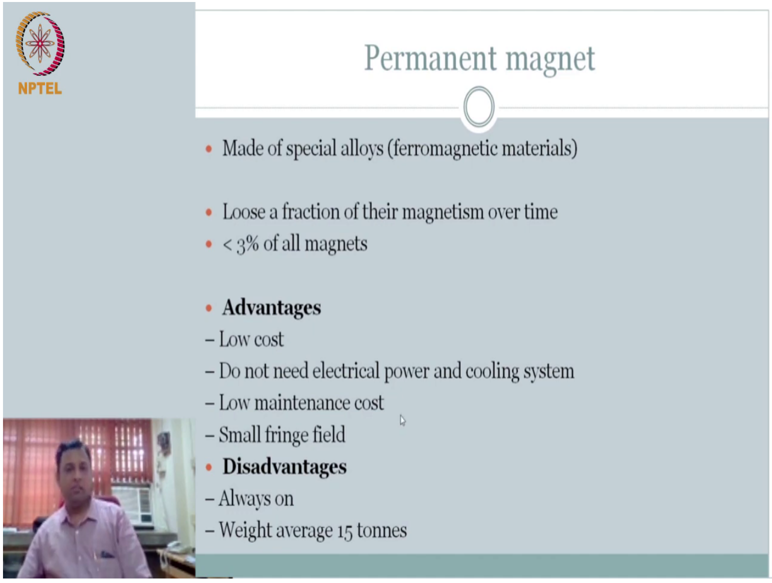

So, why is it so permanent magnet even though I said what it is, it is you know it is a special alloy it has its good property it loses very fraction of magnetism over time several of your magnets that you put in the refrigerator is you know is there for a long time. However it is only less than 3 percent of all magnets that are used in this business, why?

Because although it has these advantages of low cost you do not have to have any electrical system, where to power it or power its always on that is it and low maintenance cost and also the fringe field is very small. So, these are all advantage despite that it is not used very much because of these two major disadvantages ok always on. So, that is desirable that is not undesirable.

You know in case of a small field strength that you use in your fridge it is not going to affect us. So, it is ok, it can be always on whereas, here if you have a magnetic MRI machine then it is always on then you have to be careful right your safety everything is going to have a issue with it. So, it cannot have always on and of course, it weights over 15 tonnes. That means, its huge you need a special infrastructure to even house it ok of course, the field strength as we saw is also very low that is another major issue.

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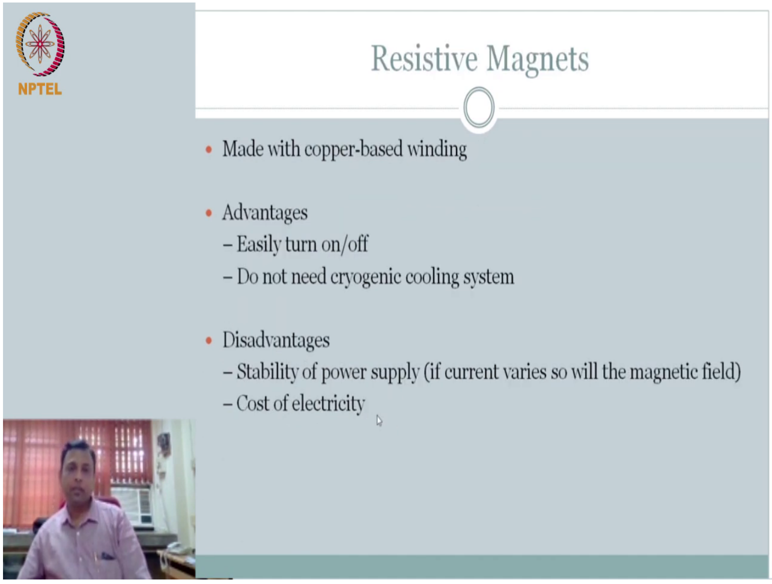

So, what about the resistive magnets, again resistive magnets are slightly better than your permanent magnets with respect to its advantages in the sense that you can turn it on and off ok and it does not need, you can turn it on and off and you do not need to have any special cooling system ok.

We did not have cooling system even in the permanent magnet, why is this an advantage here? Because the superconducting magnet that we are going to talk you will need all special systems I mean. So, that sense this is advantage because it does not need any dedicated cooling system. But again here the disadvantage is this the disadvantage is now you are running it out of electricity.

So, if you are running electricity there is fluctuation in your power supply which is very common right. Then your current is going to change and that current is going to change the magnetic field you do not want your magnetic field strength to change that is a; that is a first requirement. So, this has a basic limitation and also you saw that because of that reason our tesla was also in the fractions ok. So, this is also not that advantageous to use.

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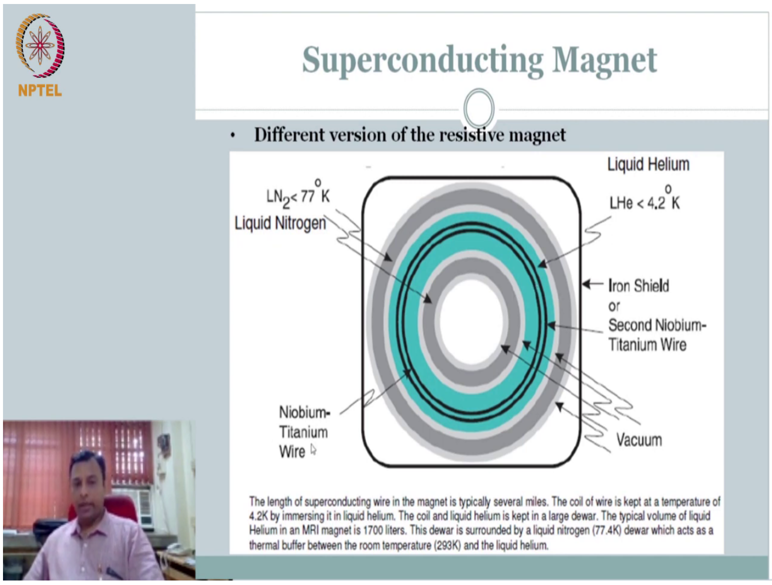

So, comes the super conducting magnet what is super conducting it is kind of another resistive like what super conducting is also like resistive, but I am sure you would have understood what super conducting means, so now, less resistance. So, it is also resistance, but the resistance goes down with the temperature.

So, it is a different you can think about it as a different version of resistive magnet, which has the advantages of the resistive magnet, but it overcomes some of the limitations, right. So, essentially you have a nio titanium wire niobium titanium wire is a superconducting material. So, if you are superconducting you have to keep it at low temperature here liquid helium is used essentially to cool this nio titanium niobium titanium at less than 4 kelvin.

So, from room temperature to this temperature there is a real rapid jump. So, in order to avoid that you also have secondary coolant which is liquid nitrogen, so which is at 77 kelvin. So, you have a gradient ray from the room temperature you have liquid nitrogen and then you have the superconducting material cooled by liquid helium.

And then you have to have iron shield. So, that you know do not let the stray fields affect it and you have to have vacuum. So, you already see that the sophistication of the setup has increased ok. But clearly this is having more advantages than the limitation and therefore, this is popularly used ok.

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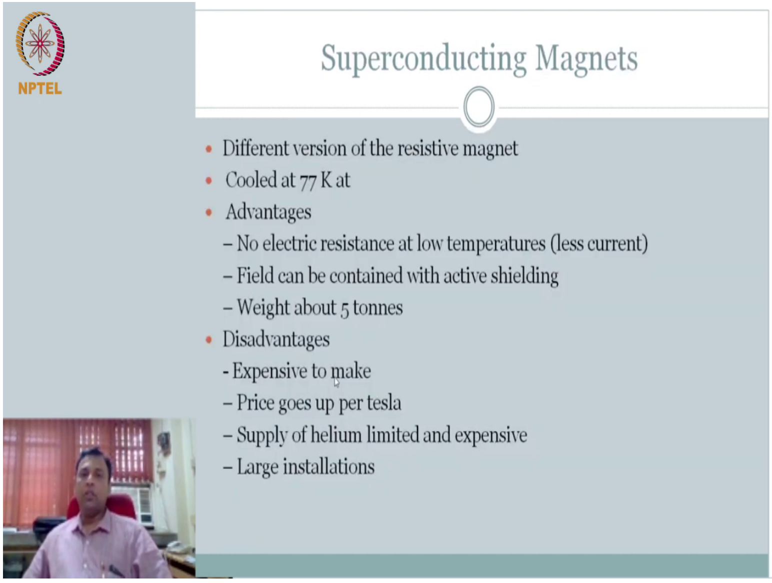

So, what does this do? You can think about it as a different way of resistive magnet the major advantages here are look superconducting so, the no electric resistance at low temperature. And therefore, you know all the less current is needed your loss are less right and your active shielding by putting an active shield you can contain the field strength to a restricted location.

And now, maybe I mean weight about 5 tonnes is registered as an advantage here. You might wonder 5 tonne is still huge you know why is this an advantage? I think it is the relative context we covered resistance magnets or permanent magnets before what did we say permanent magnets there is 15 tonnes.

So, this is advantage is this is lighter than that, but it has certain advantages you can on and off when you want, but it has more advantage than resistance there also you can on and off, but here you can on and off without much resistance. And therefore, and you can do active shielding and so you can drive up more field strength.

Of course, it has its own disadvantages, disadvantage mostly to do with the complexity and expensive it is expensive to make and therefore, the price actually goes up with the per tesla that is per this is how they. Now, if you go from 3 tesla imaging 1.5 tesla to 3 tesla your complexity of the infrastructure is going to go up and therefore, cost goes up. So, if you are referred to go to a diagnostic center if they have 1.5 tesla you will be charged some amount, but if you go for a 3 tesla you it will be no you may think it is the same MRI scan of my knee.

For example, but the cost is different because its different tesla. What do you gain? Higher the tesla from your image quality is going to be better, yes so that is the price that you end up paying for ok. And so large installation this is generic disadvantage from the MRI modality it is fantastic, but you know technically it is fantastic, but operationally it has disadvantages of large infrastructure requirements.

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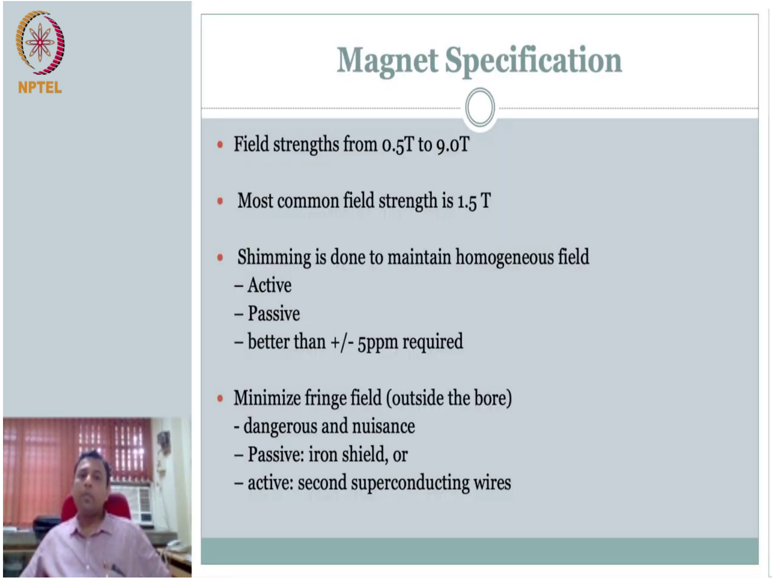

So, what is typical specification that you get you can get field strength from half a tesla to 9 tesla, most common is 1.5 tesla. You also get it with the shimming we already talked about shimmy, what is shimming? A homogeneous field you can maintain homogeneous field. So, there are several techniques of shimming passive shimming, active shimming.

So several machines that come out with you know superconducting magnet as the as a component you get it better than plus or minus 5 parts per million, right. So, this is the shimming that you get and you can of course, you get this magnet with also minimized fringe field. So, these are specifications that are typically available with the superconducting magnets, which is why it is popularly used clear.