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Lecture – 23
Wind Energy: Parts and Materials

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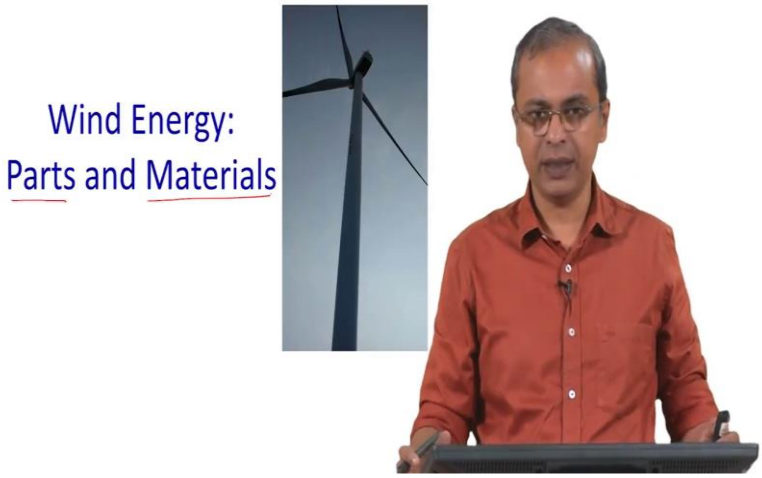

Hello there. So, we have in the last few classes been discussing about wind energy we will do so for another couple of classes there which includes today and basically we have had an overview of the wind energy process and we have looked at you know what are the geographical aspects associated with it, what is the wind speed aspect associated with it and how much of a difference that makes and we also did a lot of calculations what is the power, how does it relate to the wind speed. We also did the calculation associated with the Betz efficiency, we looked at some parameters associated with it to understand you know maybe what are sort of limits associated with it, how you should think about it, and so on.

We looked at the fluid flow through the wind turbine and then came up with that Betz efficiency which is about 59 percent. And I also told you that you know those calculations are sort of the best case calculation and, so typically efficiencies are going to be less than that maybe 30-40 percent efficiency you are looking at its still a pretty good efficiency because you simply have to keep this out there and it generates electricity for you.

I also told you that designs could be different. So, there are some assumptions on the design of the turbine which is used in the deficiency calculation and therefore, we had one you know one specific location where the turbine was located and the interaction between the wind and the turbine took place at that location. Whereas, you could have other designs where the interaction is spread out across range of you know locations and therefore, the interaction with whatever is the forward part of the turbine could be different from what is the interaction with the you know rear part of the turbine relatively speaking relative to the wind direction.

And therefore, those factors would also have to be accounted for in your calculations if you really want to get a much more you know realistic or accurate idea of what is the real limit. So, there are various aspects associated like that and we should atleast be aware, but we have gone through the basic calculation which is I think a very useful value to keep in mind and also the fact is that very large fraction of the windmills that are being put up there essentially conformed to this design that they are horizontal axis and they sort of encounter the wind in one particular direction or on one particular plane and therefore, the Betz calculation applies to them perfectly fine.

So, with that kind of a background that level of detail that we have developed. In today's class we will look at we continue to look at wind energy we will look more at the parts associated with this wind turbine and to the extent that those parts have specific applications we will also look at what are some material requirements that are being placed on those parts performance requirements which therefore, require some material requirements. And therefore, the parts and materials combination is sort of what we will look at and we will see how that impacts the overall idea of this wind power okay.

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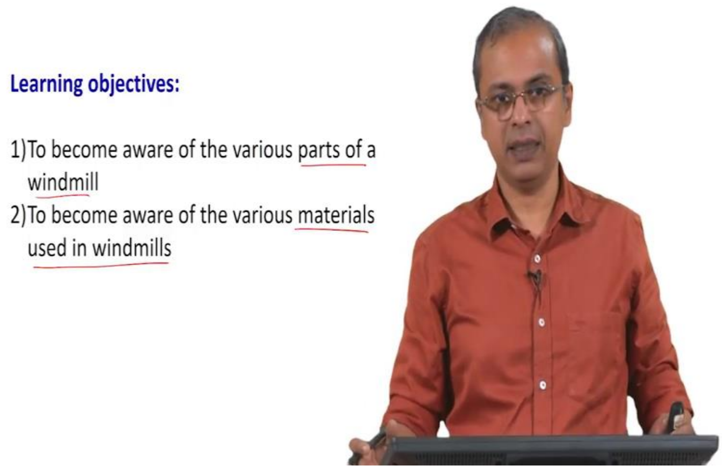

So, our learning objectives for today's class are to become aware of the various parts of a windmill, various important parts of the windmill in the most you know common design that seems to be getting implemented these days and to also become, to that degree aware also of the various materials being used in the windmill, various materials being used in windmills of course, across various locations in the windmill.

So, of course, this term windmill itself is a general term often. In fact, in the context of electricity generation they tend to use the term wind turbine because there is a turbine associated with it, but I think in a common place you said we could still call it windmill. So, that's in that context it is this term is being used okay. So, with that idea of our learning objectives we will take a look at the windmill that of the various parts of the windmill.

As I told you also that you know we saw in one of our earlier classes that you could have this vertical axis wind turbine in which case you do have still have a some kind of a tower and something at the base within many of the parts up in the base itself at the ground level then, but most of the turbines that we see these days are horizontal axis turbines and for them many of the parts are placed on top of the tower. So, this is the general you know design philosophy that is followed with most of these wind turbines and it seems to be getting followed across a wide range of manufacturers. So, that's something that we have to contend with and that's something that we will keep in mind as we put the diagrams together. Of course, I also pointed out that you know we had this relationship that the power is proportional to V cube.

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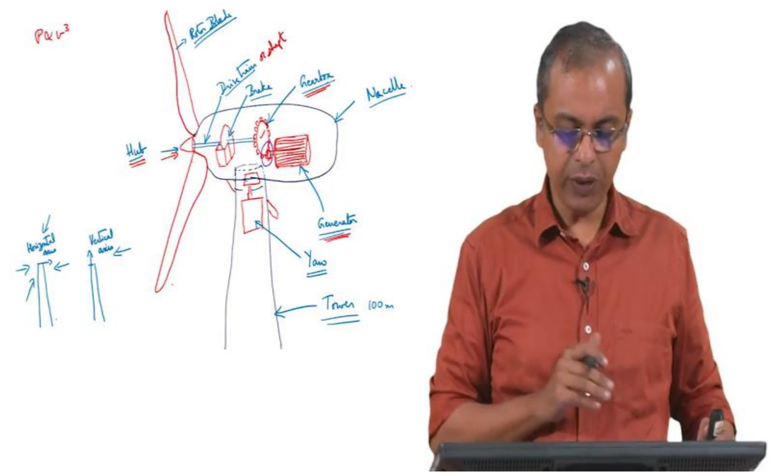

So, much of the design of wind turbines you know strongly acknowledges this aspect that the power is proportional to V cube and therefore, both in terms of cite, citing of the wind turbine as well as the general you know stature of the physical stature of the wind turbine is designed specifically to take advantage of higher wind speeds and therefore, those structures are typically pretty tall. So, that's something that we would have to keep in mind okay.

So, with that background let us put down some parts for the windmill. So, I am just going to draw a rough sketch a label some parts and then we will discuss what we are interested in looking at.

Okay so, we will start by saying that we have the central part which is some kind of a hub and then from that you have a blade. So, blade will typically have. So, let me just clear this so, something like that, some some design like that and something like that we will keep that for the moment and then little further down the other major part that, so this will be the blade. So, there is a third blade I will just put that down in the end. So, that we get this diagram completed. A little bit behind it is a structure that looks something like this. So, this is actually a break sort of similar to the break you would see maybe in automobile or something. So, it's a breking system and then further down we have something like a gear we basically we do have a gear. So, you will; the teeth of the gear will be there and then further down we have a generator so that links up to this gear, that's our generator and we also have a a system down here of some form here which is just I am just drawing this as a schematic some kind of a system down here which we will talk about in just a moment. And through all this we also have a shaft. So, that's what we would have there and yeah then we have a tower okay.

So, these are our major parts and of course, we will have the third blade somewhere down there we are only seeing part of the blade here and that disappears behind somewhere there something that is your third blade. So, this is these are the major parts of our wind turbine we just a schematic of it. So, we will just go over it. So, this would be our look me just. So, this is our rotor blade, that's the primary part of the wind turbine that is what you know interacts with the wind to get us the breeze. This central part here is referred to as the hub and from that you have a shaft that comes through some kind of a drive train that comes through of some sort comes through. What you have here this arrangement that you see here is the brake, then we have a gear gearbox and it is the one that you know enables the linking to the generator.

So, the generator sits here, sits here and then we have a mechanism here called the yaw mechanism, yaw mechanism that's what is sitting there. This tall structure here is the tower and finally, what we have here is the nacelle right. So, this is the nacelle. So, that is what we have here. So, these are the major parts of our the wind turbine right. So, we will actually look at all of these parts we will try to understand what material restrictions are there and what requirements are there pretty much all the major parts we will look at. So, if you look at it the wind the rotor blade is what interacts with the wind, so to speak. So, that's the first in primary part of the windmill there is a hub which holds all the rotor blades together that's what this hub does. So, this rotor blade is attached to the hub and then from the hub comes the drive train to which is attached the brake.

We discussed in one of our earlier classes that you know if the wind speeds start exceeding about 70 kilometers an hour then for most of the existing windmill wind turbine structures that is quite dangerous. So, it can actually damage the wind turbine the blades and therefore, we need a braking mechanism to stop the wind turbine if you want to stop the wind turbine for any reason, it could even also be for routine maintenance if you wish, but in any case for the for the these to deal with the idea of the situation that you may have very strong winds you do need a braking system to stop the windmill if you desire to do. So, the braking system is there.

Then there is a gearbox we will as I said the primary purpose of the gearbox is to link the rotors the rotating blades to the generator. You can ask why not directly connect to the generator. So, again in fact, there is a reason for it we will discuss that shortly. It has got primarily to do with rpm control, but there are that the idea that you can connect directly to a generator is also not out of the; you know out of the realm of possibilities. So, that is also being considered and is also being implemented.

So, we will look at that then there is this, that’s the generator that is sitting there. All of these parts the you know especially the drive train, the brake, the gearbox, the generator are all hold housed in this structure called the nacelle which is the you know outer covering, so to speak of this structure. And then at the at just below it you have the tower or at the bottom you have the tower which is the tall structure which holds the you know the all the top items all the items that you just saw are held on top of this tower and tower can be quite tall. I mean if you see the modern designs of wind turbines you are already looking at blades that are you know approaching say 50 meter, 60 meters in length and therefore, the tower is actually taller than that because at the at the lowest point you don’t want the turbine to be I know the blades to be close to the ground to hit something on the ground or you know be unsafe for any such reason. Plus you also wanted little bit off the ground to ensure some steady flow of wind even at the lowest point and therefore, usually the blade itself is the lowest point of the blade when it comes in that circle is still several tens of meters off the ground.

So, you are looking at tower structures which are of the order of 100 meters, of the order of that 100 meters length is what you are looking at them I mean you can have variation it really depends on your wind I mean the windmill blade, but you are looking at this kind of a number maybe 60 meter, 70 meters, 80 meters something like that you know some several tens of meters usually more than 50 meters is what we are looking at.

Now, as you can imagine we when we discussed this idea of you know horizontal axis vs a vertical versus a vertical axis. So, I pointed out that you know in the horizontal axis you have the tower and the axis is like this pointing towards the wind this is horizontal axis. You can also have vertical axis where the axis is pointing upward. So, when we discussed horizontal axis versus vertical axis I pointed out that when you have a vertical axis and you have the blades in a oriented such the axis is vertical then orienting it with respect to the wind does not matter because the wind is anyway always perpendicular to it right. So, the wind is always perpendicular to it, it doesn't matter from which direction it comes in whether it comes from the front or from the right or from the left or from the back. The axis is vertical the blades are rotating about that axis in in this direction and therefore, it doesn't really matter which side the wind is coming from. So, there is no issue of orientation.

Whereas, in the horizontal axis when you have the breeze coming from you know in a horizontal direction based on which direction the breeze is coming from, based on which direction the breeze is coming from the blades have to be oriented so that the breeze comes perpendicular to them okay. So, only then the blades can completely benefit from the movement of the wind.

So, the blades have to keep getting reoriented based on the wind direction which would change season to season and typically will change even during time of the day based on you know especially based on your location if you were closer to the coast you may have sea breeze at some point, you may have land breeze at another point. So, you will have distinct variations in the direction of the breeze and you need to reorient your turbine. So, therefore, you this top nacelle arrangement nacelle with all the parts has to get reoriented so that the blades these specific rotor blades you can face the wind. And therefore, you have this your arrangement. So, it is an arrangement which is fixed on the tower on the tower and it attaches to that nacelle and then you know rotates that nacelle around so that you get the direction oriented appropriately.

So, you need to have some wind sensors, you need to have some control system which decides how much to rotate so that it orients correctly. So, all that is also included in this overall system which even though I don't I am not showing you the exact those parts here. So, there will be some control system which keeps takes care of all these orientation issues. So, these are the major parts.

Now, we will go through most of these major parts and try to understand what are some specific restrictions associated with those parts and to that degree also some aspects associated with the material issues associated with these parts.

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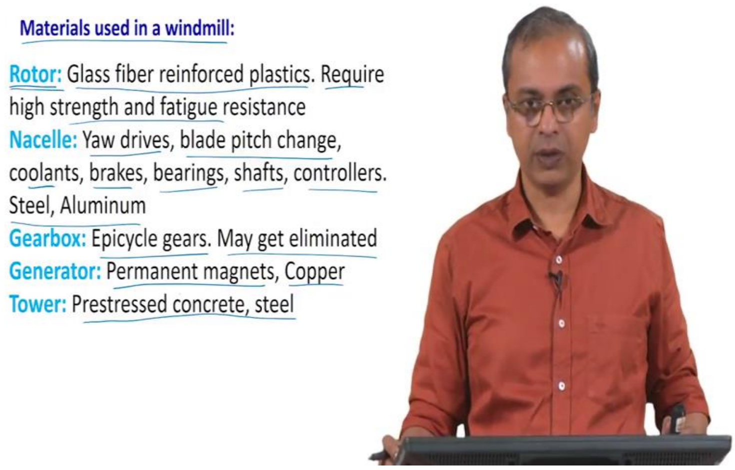

Okay so typically if you see in this is sort of a summary we will come back to summary again as we close the class. So, it typically for example, the rotors many of the companies these days have been using glass fiber reinforced plastics. So, plastic based blades rotor blades are being made quite regularly. So, the most common one that you typically see as you you know if you drive around and see wind turbines a certainly most places in India and even internationally they are some plastic based blade that you are seeing. And the glass fibers are included there to give them you know good stiffness and strength and people are looking at various types of fibers, usually you are looking at high strength and high fatigue we will talk about these in in a short while.

The nacelle houses all of these in the yaw drive that we spoke about to and the there is something for bade blade pitch change we will look at that shortly; coolants, brakes, bearings, shafts, controllers and it has you know it could be made of steel or aluminum or other such materials and it would also have such parts in it.

The gearbox has something called epicycle gears we will discuss that shortly, but it may get eliminated. So, that’s again something that we will look at shortly in the in this class. Most of the generators are requiring permanent magnets and so this magnets are present and you have a fair bit of copper inside that permanent magnet and the tower itself consists of either prestressed concrete or steel or some combination there off. So, broadly although I am going to get into the details of most of these parts in just a moment this slide sort of captures a reasonable summary of what you are going to see and then we will look at them in greater detail.

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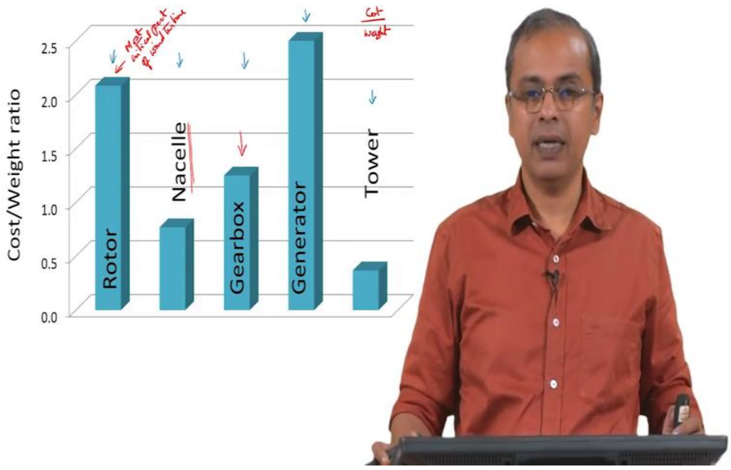

Okay so if you actually look at these parts and I also got together some data which tells us what is the relative cost to weight ratio okay. So, if you look at that you have here the rotor, the nacelle, the gearbox, the generator and the tower.

So, if you look at it the, if you take the tower for example, it is an extremely heavy part of the structure. In fact, more than almost 50 percent or even more than 50 percent of the weight of the overall wind turbine is essentially the tower okay. So, the tower is pretty much the main heavy component of the structure and, so if you look at costs to weight ratio. So, if I have cost by divided by weight right it has very high weight. So, it has some amount of cost, but significantly more weight is there. So, relatively you have you know lower cost and higher weight associated with the tower it does have cost it is not that it is you know free or any such thing. In fact, in terms of transportation costs and all there is lot of things involved with the tower. So, cost to weight if you see that is it.

The generator actually is in the scheme of the overall scheme of things relatively the cost is more and as a fraction of the overall weight it is also reasonably heavy, but it is not that heavy. So, the generator has this kind. So, you can see the cost factor is higher weight factor is a little bit relatively less.

The gearbox is also is similarly you know it's only one small component relatively speaking in terms of the overall structure. So, weight is also somewhat mediocre the cost is also mediocre and I will say that you know the gearboxes there is a very large industry which makes gearboxes for a wide range of applications. So, in terms of mass production gearbox is perhaps the relatively less costing component simply because there is such a large industry which produces gears for so many different applications automotive applications and a wide range of other applications require gearboxes. So, gearboxes are available in in a sort of a generic form or at least you can order a particular gearbox and it's not going to be that complicated for some manufacturer to make it. Of course, specifications may be different. So, you might have to make something specific, but the industry is already in place.

The tower on the other hand is very specific to the wind turbine, the specific tower that you use for the wind turbine is an onsite construction of in many ways and therefore, of course, the materials use our common materials relatively speaking. So, you are using concrete and so on, but it is still it is something that at least has to be assembled block by block in that location or built in that location. Generators also are you know available in a wide range of capacities you know several tens of kilowatts to megawatts generators are available.

So, again there is an industry associated with that from where you can get it. The nacelle and the rotor the nacelle is basically just the casing and the box that holds everything together. So, that is of course, going to be specific to that particular wind turbine so, but it is not I mean it holds everything together functionally it keeps everything you know enclosed and in compact, but beyond that it is not an you know very expensive part of the turbine so to speak and even functionally it is not the most critical in terms of the requirements of the overall turbine.

The rotor on the other hand is very functionary very critical. So, this is the most critical. In some fundamental sense it is most critical because the design is very specific to the wind turbine I mean of course, it takes you makes use of aerodynamic principles which are there I mean which are common across a wide range of you know technologies. But it is in terms of sizing you typically don't have blades this size being used for almost anything else. So, manufacture of this blades is a challenge you need to make you know 60 meter long blades which is not a common thing that is done in the most places.

So, that takes some effort and so there are companies which specialize in it. So, it is not a mass market product in the sense that you do not find a wide range of companies making these blades there are companies which specialize in this kind of activity which make these blades unlike say gearboxes. Gearboxes also if you want to get technical about them are you know sophisticated piece of equipment, but it is not, it is still distinctly more commonplace because wide range of technologies use them, but these blades in the manner that they are made for the windmills or wind turbines are exclusively only for the wind turbine. So, the wind turbine industry is the pretty much the only customer for the blades of this nature. So, and it is also the first part that interacts with the wind and therefore, it defines many of the characteristics they are required of the rest of the turbine and places limits on what the turbine can do it also places an upper limit in terms of what we can expect from the turbine.

So, given all this that’s the perhaps the most critical part of the wind turbine and even in terms of costing it is significantly expensive.

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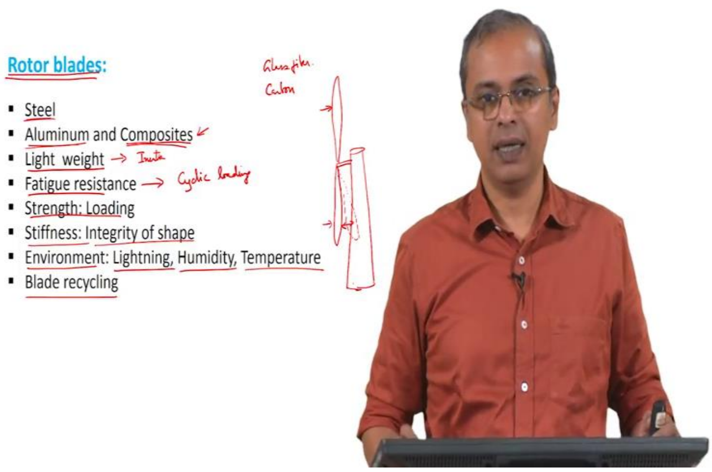

Okay so if you look at rotor blades. So, we will start with the rotor blades and see what materials are used what are some issues associated with them. So in fact, commonly these days as I mentioned composites is what is being used mostly it is glass fiber reinforced, glass fiber reinforced, but people are also looking at other reinforcements. So, you can have carbon fiber based carbon fibers can be used carbon nanotubes are something that people are looking at. Primarily to ensure that it has lightweight and many other properties, but light weight and strength are two you know dominant properties, but many of the other properties are also there we will discuss them in detail in just a moment. But glass fiber and carbon are significantly being used.

You may wonder why we mentioned steel and aluminum it appears to be a little bit old fashioned, but actually it is both old fashioned and current. So, in many ways this the metal industry is like that we always keep thinking that you know you can get by without the metals and move way to something else which is all plastic and so on, but there are significant both performance issues as well as environmental issues associated with the nonmetallic materials including you know polymers and plastics that are used. So, the first thing most important thing with about all these plastics is that since you don’t want them to degrade very easily in the environment, you don’t want them to get spoiled, they are basically typically not biodegradable the ones that are used. So, that may not seem like much when you know you just have one wind turbine being set up in one locality, but if you are looking at you know trying to power a significant fraction of the world using wind energy then you are going to have wind turbines all over the place right. So, it is estimated that you know pretty soon we will have 15 20 percent of the worlds energy requirements being met by wind turbines and lot of countries are pushing hard to you know get these wind turbines located in as many places as possible.

So, then we have an issue it is not just one turbine you are looking at hundreds of thousands of wind turbines maybe even millions of wind turbines distributed across you know various locations. Again when it is new it doesn’t seem like an issue at that point only the manufacturing issue is there because there will be chemicals associated with that and you have to find a way to you know either consume the chemical completely or dispose it safety. So, that disposing waste waste safely. So, that issue is always going to be there. Any of these fibers, glass fibers etcetera can be you know hazardous. So, you have to worry about those glass fibers carbon fibers etcetera you have to worry about those in large scale manufacturing processes, but more importantly if you put a million turbines out there or you know say tens of millions of turbines out there they will all have some finite lifetime.

So, you are looking at you know let’s say 30 years down the road something like that let us say 20-30 years down the road when suddenly these turbines come to the end of their life say eventually those blades start wearing out or they start cracking up in some way and then and let's say they reach a point when eventually they are beyond repair at that point you will have to dispose those blades. Then when you have about hundred million you know or maybe say 10 million such windmills around and they are all discarding their blade, blades you have a huge environmental mess. So, in the form of while you are addressing the environmental issue by using this wind clean energy solution of wind energy you have to be aware that the manner in which you use that wind energy shouldn't create a problem again 20 years down the line right. So, we have to guard against that right away.

So, that is where things like steel and aluminum actually still have significant role to play. So, if you take steel and aluminum there is no problem at all in terms of recycling it you simply have to heat it melt it back and then you can recreate the blade in whatever manner you want you can always or you can even just do heat treatment to relieve any stresses etcetera if it is possible may not be that easy because it's a longish structure and then you know bring it back into service.

So, in terms of recycle ability the traditional materials are actually like steel and aluminum are still very promising and the steel and there is also a large industry there is a steel industry there is a lot of machine tools industry there is a machining industry etcetera. So, even if you want to change shapes you want to get some complex shape etcetera there is a lot of people, there are a lot of people who are experienced in this area and a lot of industries that are there a lot of machinery that is already in place which can create what you want. And therefore, this is still an industry that competes in almost any technological sphere and the wind mill or wind turbine sphere is not an exception. So, there also you have the metal industry trying to make its case and I mean people are continuously doing research to see if that can be done, but still as of now what is coming out is typically composite. So, that is the largest contributor at this point to the rotor blades.

So, what are we looking for? Of course, we are looking for lightweight this is important because wind has to push the turbine right, it has to or rather I mean the base based on the lift that is generated the turbine should start rotating now the heavier the turbine is due to gravitational forces etcetera you are basically going to have a lot of inertia right. So, you are going to have a lot of inertia you have to push past the inertia and to get this or you have to have enough lift which is over and above this inertia to get this turbine to rotate. So, it may not move as effectively and therefore, light weight is a very important aspect of the turbine design. So, inertia is an issue okay. So, this is inertia is an issue.

Fatigue resistance, fatigue is actually the idea that materials deteriorate or fail at loadings well below they are rated loading. So, you take a material you do a test to make a new component you do a test you put a tensile test and you would you know pull it apart and see at what at what level of loading the material fails okay. So, based on some standards and standards ways of testing you can say that the you know failure of this material will happen at this load if you make this is the material with these standard dimensions failure will happen at this load or at this stress value okay some specific stress value it will fail. So, the stress will take care of the cross sectional area you do not have to worry about whether it’s a larger part or a smaller part all that is accounted for if you look at the stress its normalized with respect to the cross sectional area. So, its load per unit area.

Now, that will be some reasonably high value let’s say there is some particular value and therefore, you feel that this is adequate for the utility that you are trying to put this structure to, but if you have cyclic loading and almost all components in regular use have some cyclic loading right. So, cyclic loading in the sense you load the component a little bit then you release the component it could be anything if you are on a vehicle. So, the vehicle goes over bumps and you know various roughness factors in the road just because it goes in you know poorly built road does not mean all the parts in the vehicle have failed.

But those parts have been stressed in one direction and stressed in the other direction repeatedly, but with very small stress levels the stress level was not so, high enough to damage the part, but it did go through an increase in stress, a decrease in stress, increase in stress, decrease in stress and it may not even have been periodic it will just go up and then stay up for a little while and then suddenly drop down come back up etcetera. So, you will have wide range of loading. So, people test that for tests to see if the materials will fail under such cyclic loading conditions okay.

So, it’s generally found that our large vast set of materials actually have a situation where if you put them through cyclic loading and of course, in a in a in a systematic test you put them through a known frequency loading and known you know load level etcetera when you do that you find that many of these materials will actually fail at a value of stress which is significantly lower than the rated stress of that material. So, you did the original test and you came up with some value, but under cyclic loading even though you are loading it up with much less load just because it is cycling repeatedly over a long period of time it fails. So, fatigue is a very important and this phenomenon is called fatigue. So, it is repeatedly loading and unloading a structure and it tend it will fail at a value of load significantly less than the rated load.

So, the fatigue is very important for most structures which are facing cyclic loading and a wind turbine is a classic example of it because wind will come on at some point wind is not going to be steady you will have wind you know velocity is continuously varying even as the you know over several minutes. So, you will have suddenly a slightly faster way and slightly slower wind. So, you push the blade a little bit more, it comes back to the front direction even as and that is also that is when you have just variations in the wind flow.

Even if you take the windmill structure itself if you look at the fact that you have a blade there, and a blade here and I am just drawing two blades at the moment and let’s say you have a tower here. Then clearly the blade that is at the bottom is getting some shielding because there is a tower right behind it right whereas, the blade at the top is not getting any shielding because there is nothing behind it. So, even if the wind were steady you have a steady breeze that is flowing as the blade rotates through the, you know through its standard cycle. When it comes to the top or for a significant fraction of the cycle it is you know not having anything the back and so the wind is continuously relatively uniform, but then when it comes down and it gets shielded by the or gets some kind of you know blockage effect because of the fact that there is a tower right behind it suddenly there is a drop in the wind loading on the blade. So, the stress on the blade suddenly decreases as it comes off the shadow of that the tower it will again go up in loading.

So, you are guaranteed that in every circle, every circle that it makes the there will be cyclic loading you will be loaded up and then you will release the load you will again load it up and so on. So, every cycle that every time it rotates once, it is going to be loaded once and released after that and every blade is going to undergo this. So, you are guaranteed of cyclic loading. So, this is guaranteed to happen.

If the windmill is operating you are guaranteed to have cyclic loading. So, this is something. So, therefore, we need to look at fatigue resistance. The strength is overall loading that is there because of you know its own weight the wind that is pushing against it etcetera. So, you do need to have significant strength and you are looking at longer and longer blades because that helps you reach access more you know higher wind speeds etcetera. So, that is something we have to look at.

Stiffness, so this relates to the integrity of the shape. So, if the blade is not stiff then it will a flap around in the winds in strong winds and you have to keep in mind that there is not much of a distance here between the tower and the blade. So, if the blade were twisted too much it can even hit the tower right if if it were, if it were not so stiff and it and you could actually you know go down go backwards. So, the wind if the blade tended to was not so stiff and it could just bend backwards it can it can even hit the tower. So, for a wide range of wind speeds you have to be confident that the blade is stiff enough that it will not go and hit the tower. So, that's something that you have to keep in mind. And that is why again you have some rating some wind speed rating and you say that you know it is only within the scope of this rating that you will use this wind turbine if the wind speeds are higher you will stop the turbine.

Then there is the issue of how it interacts with the environment. So, given that it is out out there you are not you know shielding it in any manner you are just putting it out there in the sum. So, it is going to face a lot of heat and cold. So, cyclic temperature is going to be there, the night it is going to be cold, the day it's going to be hot. There's a lot of humidity you could have rain you could have dry conditions wide range of conditions and of course, lightning strikes you are going to put this out there and you are bound to have I mean it is guaranteed to have lightning hits because you have put this tall structure out there and typically an open area you put a tall structure that is exactly what is required to you know attract lightning and it will get a lightning strike. So, you have to be prepared that materially it is in a position to handle it there are lightning arresters. So, there is ways to take the lightning hit down to the ground and have it grounded okay. So, this is something that you have to be worried about.

And of course, as I mentioned right at the beginning blade recycling in terms of material recycling and this is something which may not be an issue today because today is when we are you know all into this wind energy field and every country is putting all this effort to put these windmills out there if you look 30 years down the line this is an issue. And this is something that we need to address right away. We have already made this mistake in the past where we said you know oh we found petroleum great, let’s use the petroleum that is exactly why we are in this situation today that we need to worry about the environment right. So, 30-40 years of extensive petroleum usage and we suddenly have this problem and now we have to do something urgently to deal with it. So, we don’t want to wait 30 years and then have a major problem we would like to address it ahead of time so that we are, because now we are seeing this cycle of you know how something we use hits us 30 years down the line. So, we might as well plan for it and you know do something appropriate. So, that’s the rotor blades I spend significant time on it because it is the as I said the most important critical part of the wind turbine and the first part that gets the whole thing operational.

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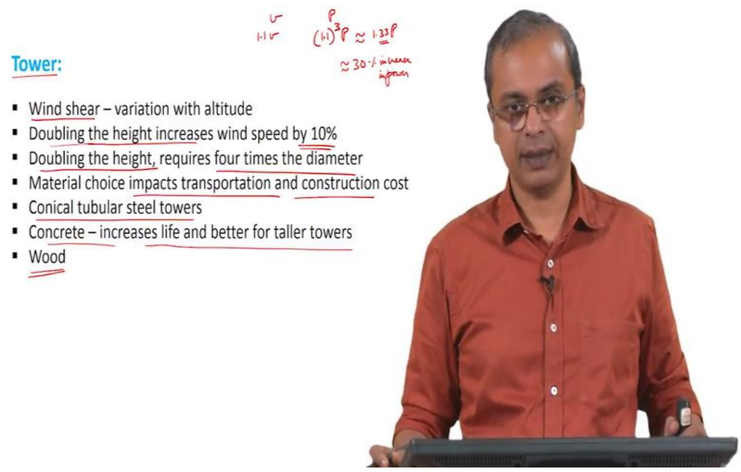

Then you have the tower, the tower structure itself. As I said mass wise that is the most massive of part of the wind turbine in structure, the blades are very light, the tower is actually quite heavy. So, it has to actually deal with wind shear this is simply the variation in wind speed as a function of altitude, it may not be much I mean it may be you know difference of say 10-20 kilometers per hour something like that. So, for example, if you double the height of the structure your wind speed increases by about 10 percent okay so, but at the same time, it’s a difference of 10 percent of stress from the top of the structure to the bottom of the structure and it is there continuously, I mean based on the you know height of the tower. So, you have to have a structure that deals with this wind shear and does not get affected by it.

As I said we are always interested in increasing the height of the wind turbine because the power available in the wind increases as cube of the velocity of the wind. So, if the wind speed for example, you double the height of the structure right and I said wind speed goes up by a factor of 10 percent. So, if you have wind original wind speed was v we now have 1.1 v, 10 percent mode. So, what will happen to the power? If you originally had P if you do the calculation this is 1.1 into I mean 1.1 into 1.1 into 1.1. So, 1.1 cubed is what the power will become times P and that is approximately equal to some 0.3 some something some 1.33 p something like that approximately.

So so, this means this is approximately 30 percent increase, by doing nothing by simply pushing the windmill to a higher location that's it you just pushed it to a higher location it caught you 33 percent or not that, it is some 30, 30 plus percent of increase in power that's a huge increase in power for you know nothing else changing everything else is the same you simply push the windmill up to a higher location you are getting 30 percent more power. So, naturally there is you know interest to get this windmill to be as high as possible so that you can get this benefit out of the power that is available and therefore, people try to have tall towers.

But at the same time if you double the height of the windmill you are you are going to have to also double you have to also do something about the diameter of that tower so that it stays stable and usually. That means, 4 times the diameter these are you know approximate numbers they do not they are not hard and fast numbers I it will really depend on the type of structure you are making and all, that just to give you an idea that material required for that turbine is going to I mean for the tower itself is going to go up significantly if you sort of double the height of the turbine. The material choice will impact things like transportation and construction of that structure because if you are using for example, the there are people who use tubular stainless steel based structures. So, those tubes have to be transported to that site and in fact, with respect to windmill construction this transportation is a fairly significant activity maybe over the lifetime of the wind turbine the cost is perhaps not that much it is distributed across the cost of that lifetime.

But still transportation is a major activity if you ever go to one of these sites where they are setting this up you have to keep in mind that let's say even the wind windmill blade is you know say 50 meters long. So, you need to actually have a truck which has 50 meter long carrying capacity behind it and place this you know single blade there and then carry it carefully to that site. So, it is a fairly you know involved activity they have I ensure that the roads are capable of handling a truck that long it is not heavy, but it is just long it's an awkward shape. So, you have to find a way in which that the road will be able to handle this structure and this truck will have to be guided to the location.

So, with respect to these tower itself people use concrete it increases the life and its better for taller towers. So, therefore, this is the way in which people are working with it in more, specifically they used what is referred to as pre stressed concrete. So, that helps increase the life and is ideally suited for taller towers.

Interestingly, there are also people who are even you know relatively recently looking at wood as a way in which you can make these constructions it has good fatigue properties and therefore, this is something that they are actively looking at. So, this is related to the kinds of you know design restrictions and construction ideas and aspects associated with the tower design.

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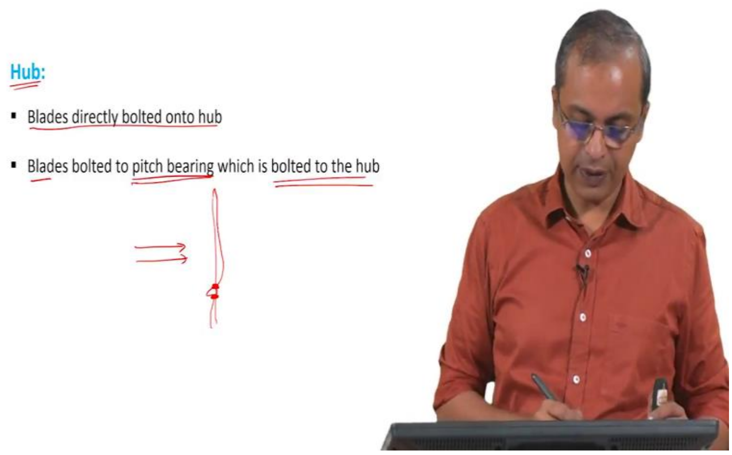

Then we will look at the hub, the hub if you go back to our diagram here this is the hub this part here is the hub okay. So, this is the central part of the wind blade arrangement.

So, it does a specific activity primarily the blades are bolted to the hub. So, the bolt blades are attached to the hub, and you could do it two ways you can actually directly bolt the blade onto the hub, but usually that is not the preferred way to do it instead the blades are actually bolted to something called the pitch bearing and this pitch bearing is bolted onto the hub okay. And the idea is simply that you may have you know wind maybe coming at some velocity and then the blade will have a particular we will talk about this how you angle the blade with respect to the; how you angle the blade with respect to the that wind, incoming wind we will actually depend on ideally it depends on the wind speed only then you get the best benefit out of the wind that is flowing.

So, if you actually get it fixed rigidly to the hub you are not in a position to reorient the blade the blade gets stuck in that one position and therefore, it’s not ideally suited to pick up the best you know energy from the wind. So, it is better to actually fix it to some other bearing which is referred to as the pitch bearing which would sit somewhere here. So, some pitch bearing that sits there and using that you can reorient the blade based on the location of the breeze and in fact, you can also use this to help stop the blades to assist you in stopping the blades in the event that you know you want to shut down this generator for some purpose. So, there is a pitch bearing on which the blades are attached and that pitch bearing is attached to the hub and then that hub is attached to the rest of the structure.

So, this is the other way in which this is done and so this is the central part of the wind turbine.

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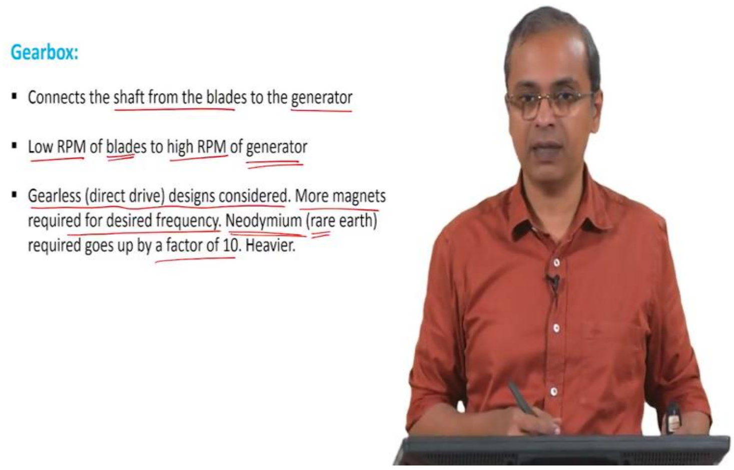

And then we have the gearbox. So, there is a shaft which comes from the blade and that goes to the generator right and this shaft that goes from the blade to the generator does not go typically does not go directly to the generator although we are going to discuss that right now it actually goes through a gear. So, if you go back to our drawing which we just put down you can see that. So, this is the drive train or the shaft and this is coming from the blades from the hub right, it is coming from the hub, it comes to this gearbox that you that you are seeing here this gearbox and from the gearbox it is attaching to the generator. So, it is attaching to the generator out here. So, that is where; you can see that it is attaching in this region right.

So, this gearbox is there to attach, to connect the blades the rotating blades to the generator. So, why do we need it? Okay so, it is specifically required because if you actually go and stand in front in one of these locations where these wind turbines are operating you will find that the winds the turbines are rotating, but you can easily see the you know road each blade can be comfortably seen with your right you don’t your I mean it is not rotating. So, fast that you do not see anything even you are the ceiling fan in your house is rotating much faster than the wind turbine is rotating right.

So, typically you are only looking at about say 10 to 20 rpm that’s really all that you are looking at if you are looking at what is what is there in the, what the wind turbine is actually doing as it rotates. But if you look at the generator if you want to set it up such that the electrics electricity generated by the generator is directly is something that can be directly fed into the grid so to speak or with minimal processing be fed to the grid it is typically desired that the rpm at the generator should be very high revolutions per minute at the generator should be very high. So, even though the shaft coming from the wind blades is rotating at a lower revolution per minute you want the shaft going into the generator rotating at higher revolutions per minute and the difference could be several orders of magnitude you know you are looking at some 10 rpm going to several 100 maybe thousand rpm kind of situation. So, you definitely need a gearbox. So, that is the reason why you need this gearbox to convert this low rpm coming from the blades to the high rpm required by the generator. So, that is why we need this gearbox.

So in fact, in order to you know save to reduce the complexity of this of the structure and to make it easier to handle people are actually looking at gearless or directed drive designs. So, there is a catch there, I mean it’s a little bit of you know you get some you gain some advantage you do some advantage also. So, one of the things that is being done here is then we say that you know let’s not worry about what is being generated by the wind mill let it generate whatever it can generate.

So, we will not restrict the wind turbine. So, in some of these gear structures in some of the other structures where you are trying to get the electricity out from the generator to match what is required we put actually restrictions on the wind turbine. So, we try to keep the wind turbine within a small range of operation operating points so that the electricity generated is appropriate. But the other option is to just let the wind turbine generate whatever electricity it can and then work with the electronics later on to get it to whatever condition that you want. So, so that is also being looked at.

And more specifically in this case they will have what they will do is they will add more magnets in the generator itself, so that you will get the desired frequency of electricity being generated okay. So, these magnets are typically permanent magnets and so Neodymium is used it’s a rare earth and if you actually want these permanent magnets to be increased you would actually end up having to increase it by a factor of 10 and the number of permanent magnets and so the overall structure actually becomes heavier. So, even though it is less complex in the sense that your release the removed the gearbox, but it becomes heavier because you have had to put more permanent magnets to help you with this rpm issue.

So, that's a mix and match of things and you are using a rare earth material there and in fact, the stock of the rare earth that material is not there by definition it's a rare earth it's not you know commonly available. So, it's not commonly available material it is a rare earth. So, you have to worry about it, worry about its availability, worry about you know how you are going to use it. And if you go this route and that is a danger you face because you will run out of that material and then if you are saying I am going to power significant fraction of the worlds requirement using this approach you you are going to face some limitations. So, right now still geared versions are used and it is something that we have to stay aware of.

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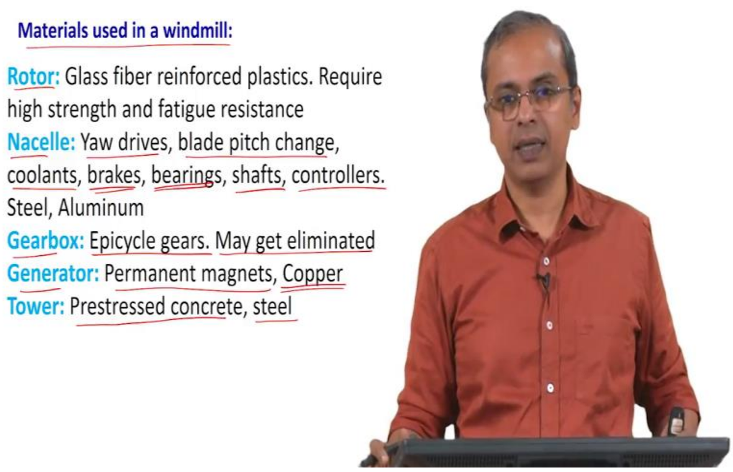

So, again as I said you know this is sort of a summary of what is being used in a windmill, you could use rotors which are glass fiber based, but as I said we could also look at aluminum, you could look at steel, The nacelle actually how solve of these or has connections to all of these it has the gore drives. The blade pitch change mechanism, I told you that the hub is helping you change the pitch of the blade, but that mechanism will be host somewhere in the nacelle the coolants associated with the whole process I mean your generator may generate end up getting hot. So, you need some coolants for it.

A break, that break is what is required to slow down the windmill or you know increase the speed of the windmill I mean not increasing at least release the windmill. The bearings, all the bearings a considerable number of bearings that are going to be there because we have a shaft, that is running through, you have gears mounted on the shaft you have you know you have the generator attaching to it. So, many places you are going to have bearings, there is a shaft. There is a controller there which takes care of many things including orienting of the structure.

Then I spoke about this gearbox, these days they are looking at something called the epicycle gears which helps you know reach wide range of rpm's if you try to utilize it. But as I said they are also looking at options where you can actually eliminate the gearbox altogether so that the structure becomes less complicated to make, but because of the requirements then getting pushed on to the magnets of the generator the weight of that structure may actually go up.

So, as I said the generator itself they are looking at permanent magnets and considerable amount of copper that you will need therefore, all those coils that are required. So, that's the sort of the material requirement on the generator. And with respect to this tower people primary look at pre-stressed concrete and steel some you know people also dabble with other kinds of materials as I said you know recently there was also some demonstration of a wood based structure which may which may see mold fashioned, but it has its own you know advantages and disadvantages. So, this is sort of the overview of the materials used in a windmill.

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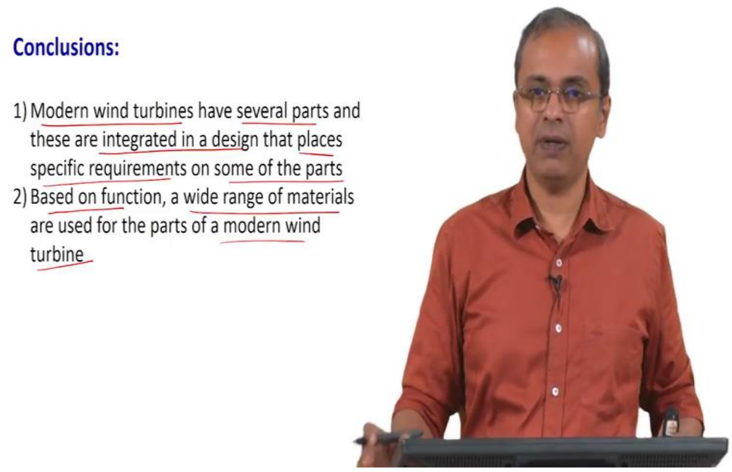

And so in conclusion we have just seen that the modern wind turbine has several parts, wide range of parts which have wide range of requirements because those parts are serving specific purposes. And in terms of you know material property itself there is a requirement, in terms of the you know shape and sizing weight etcetera there is a whole bunch of requirements. And these are all integrated in design that places these specific requirements on some of these parts.

So, based on the design of that structure for example, the blade because of the shape of the blade and the size of the blade, and the location of the blade it has to have some properties, the tower has some properties required of it because of the load on it and so on. And based on the function a wide range of materials are being used for the various parts of a modern wind turbine and as you can expect with any technology this is always a varying you know, this is always an evolving situation. And that is why there is so much research in all of this there is all these R&D groups both in research in universities as well as in companies that make these parts which are trying actively to get a better part or a better material which will satisfy those you know property requirements while also meeting cost, lifetime, recycle, ability and so on. So, that’s something that is always ongoing and perhaps you will also get an opportunity to work on it.

I must again say that you know this is a technology that people are pushing hard to you know set up in large scale across countries in various countries in the world. So, it is actually a very actively growing market with many companies pushing hard to get these products out and be part of this growing market okay. So, there is a lot of scope in this market.

So, with that we will conclude today we will look at some more aspects in the next class.

Thank you.

KEYWORDS:

Parts of windmill; Materials used in Windmill; Horizontal Axis Wind Turbine; Vertical Axis Wind Turbine; Hub; Blade; Breaking system; Gear; Generator; Shaft; Rotor Blade; Yaw Mechanism; Nacelle; Drive Train; Glass Fiber Reinforced Plastic Rotor Blades; Blade Pitch; Epicycle Gears; Gear Box; Fatigue Resistance; Blade Recycling; Pitch Bearing; Gearless; Directed Drive Designs; Epicycle Gears

LECTURE:

The structure of a wind mill, the various parts, and materials used to make those parts and its requirements are listed, illustrated and discussed briefly.