MARINE ENGINEERING

By

Prof. Abdus Samad

IIT Madras

Lecture70

Shaft

Good morning everybody. We have started the topic on power transmission system, especially mechanical power transmission system. So, you have seen this marine engine is producing power or torque. We are getting torque or power or rpm. That power must be transferred to your propeller.

Propeller is the right hand side. You can see. I am drawing here. This is your propeller. These are propeller blades.

This is blade of propeller. Okay. And this is shaft. Shaft is transferring power from engine to your propeller. Okay.

This is shaft. Now shaft is not directly connected to your propeller. There will be several fittings and other things. You have seen here journal bearing is here. Then some couplings is here.

And there will be some other radial bearing. Okay. And these are intermediate shaft. So one shaft is here. This is intermediate shaft.

Another shaft is also here. Intermediate shaft. But another shaft is here. It's called tail shaft. Tail shaft.

Okay. So from engine or shaft is coming. Normally we say engine shaft. Then there will be thrust shaft. Then intermediate shaft 1, 2, 3.

Then tail shaft. Tail shaft will be connected to your propeller. So propeller will have blade. It may be controllable pitch propeller or fixed pitch propeller. Now propeller blades will be fixed on hub or boss.

Hub or boss. And the propeller and its tail tube. Now tail tube will be connected to propeller and it will be passing through stern tube. So this is called stern tube. So, purpose of stern tube is that it will not allow water, seawater into your engine area or the stern tube lubrication system that oil or grease or lubricating oil will be there.

So, that should not go into water. So, if it is going to water, it will be harmful to environment. So, you have to prevent the oil going into water. Again, water going into your engine area also you must be preventing. That is why stern tube must have sealing and bearing arrangement.

So, stern tube lubrication. must have bearing and seal. Now if you have bearing, so there are different types of bearing. One is radial type bearing and there will be sleeve bearing or muff bearing. So this will be normally sleeve or muff bearing.

or journal bearing. So, there will be no ball or roller bearing. So, we will discuss later what are the different types of bearings like journal bearing, sleeve, muff, different types of bearing. Another thing is that when engine is being powered to propeller, you have to reduce the speed. When you are reducing speed and if you remember the cycle gearing system, you change gear and you change your cycle wheel speed.

So, here also similar mechanism will be there, gear mechanism. So, it will be reducing speed. Normally, your engine RPM will be like say 1500 rpm more or less and propeller speed will be like 100 to 100 rpm so that means you have to reduce your speed so when you are reducing speed so some gearing mechanism must be there in some cases in some power transmission system the whole shaft can be removed and you have engine then you fix one generator so generator will be producing electricity Then that electricity will be transferred to one motor.

So, motor will be running your propeller. So, in that case you are not transferring power through your shaft. Rather you are using electricity to run your propeller. Many thrusters and other equipment also can be run using electricity. So, we will discuss one by one all the systems.

So, whenever I am talking about shaft. So, shaft will be there in different types. You can see the right side picture. Plane transferring shaft is a simple rectangular cylinder. And there will be step shaft.

Step shaft means like shaft diameter is like this. Then maybe there will be one necking option and reducing diameter. Why reducing diameter? Because certain area you may need very higher amount of strength. Certain area you need lesser amount of strength.

So you need certain area larger diameter. In certain area you need smaller diameter. Now why smaller and larger? You can make larger diameter everywhere. Then you are increasing material.

So, it will be more heavier and you are unnecessary you are giving extra material. So, extra material you are giving means problem is that your bearing is holding load. So, if you are giving extra material means extra load. So, bearing will have more load. So, bearing failure rate will be higher or you have to buy a bearing with larger capacity range.

So, just to reduce that one you reduce shaft size according to your requirement. So, There are other types of shafts. Railway axle you have seen. That is not shaft axle.

That is called axle. So axle in cycle wheel if you see. Bicycle just you remember. Spokes are there and wheel will be here and will be axle. So over axle the wheel will be rotating.

So this is not transferring torque. This is holding the wheel. And it will be acting as. It will get only bending load. You are riding on cycle.

So you are giving force here and here. But your wheel is pushing upward. So it is holding only bending load. It is not transferring any torque. So axle is not transferring torque.

So axle not transferring torque. But shaft is transferring torque. The cycle axle, car axle, anywhere axle when you are talking about so it is not transmitting torque. But whenever you are talking about shaft, shaft must be transmitting torque. So shear force will be acting over it.

But in axle bending force will be there. Only bending force. And another is crank shaft. So crank shaft will have lots of bending and torque both actually. Crank shaft is like this.
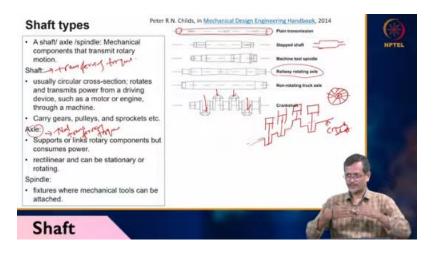
I have one piston. You can remember IC engine. Piston is here and it will be like this. So shaft will be, I am drawing wrongly, this will be one straight line and there will be many pistons connected, inline pistons, they call inline pistons.

So if you rotate this crank shaft, if you rotate the crankshaft the piston will be moving one by one so if you have only single cylinder that in that case you are getting pressure pulses like this or forces but if you have multiple cylinder your forces will be more smoothing

okay that's why in many big engines they will have multiple cylinder engine many type v engines will be there inline engines will be there so many type ice engines will be there so that will be a smoothing your power but that that shaft that specially designed this one you can see this is called crank shaft okay so crank shaft is transferring torque and holding bending moment also so shaft transferring torque and holding bending moment and bending torsional moment also will be there it will be holding bending and torsional moments okay so usually circular section cross section the shaft will be rotates and transmit power from driving device such motor engine okay it can carry gear pulley sprocket and many other fittings will be there axle supports and links rotary component but consumes power for some uh basically to be holding bending load uh and sometimes spindle also circular shape but this is not transferring any power or it is not holding any bending moment okay Okay, shaft design considerations.

Whenever you are buying or designing any shaft, so what are the different points you have to remember? So you have to check how much space you have, how much power you are transmitting. Let's say you have very thin diameter shaft and you are transmitting 1 megahertz power, it's not possible. So first you have to check how much power you are transmitting. And what are the loading conditions?

Loading condition means whether fluctuating load is there or smooth loading is there. Fluctuating load means like one machine is working, vibrating machine. So continuously you are getting alternating force, extra impact force. So then sub design criteria will be changing. But if you have normal shaft which is transferring power from engine to your propeller shaft, so in that case design criteria will be little bit easier, simpler.

so material selection important part because if you are working in the ocean so ocean is corrosive ocean water so you have to select proper material okay uh deflection and rigidity how much deflection and how much duty is there that also you have to consider bending deflection so whether shaft is having lots of bending load torsion load already there because it is transferring torque shear deflection shear and strength fatigue strength fatigue means how many cycles alternating force you are giving so that because of that material can fail that is called fatigue okay reliability is their frequency response manufacturing constraints like say you are making a big shaft but you don't have any manufacturing capability of making that one because that can be very heavy and you don't have that sort of machine to handle that one So that also you have to consider. That's why a very big and long shaft cannot be made from single material. It will be small, small part will be there and will be joining later.

Shaft

Key is a bicycle you have seen here. So here this one, this bicycle pedal is connected to one axle. Then you have pedal and there is connection. So this one connection or this one you can see. So this one pin is here.

This is key actually. This is called key. So key is to stop relative motion. When you are pedaling, pedal is rotating, your axle also must be rotating. Now shaft must be rotating.

So to prevent relative motion between shaft and your pedal, You must have that key. Okay. So many cycle will have that key like one hole is here and you make one hole here and you put this pin. Okay.

Many cases it can be like this. Square shaped. Square shaped hole is there and your shaft end also will have square shaped. Okay. So just you put inside it will be rotating smoothly.
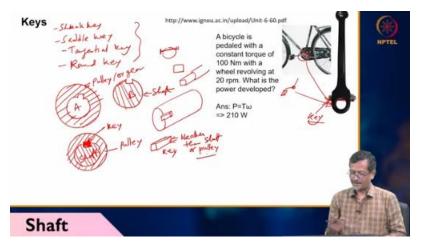
So, just to prevent the relative motion between these two. So, that you can transfer torque. Now, there are different types of keys. One will be shunt keys. S-H-U-N-K Saddle keys.

We are not going to discuss in details of all the keys. Just one key I will take and I will try to discuss how the forces are getting transferred in the key and what is the purpose of that one. See, tangential key. tangential key and round key okay then main types of keys are there so key is like this one sharp is here so when I'm making sharp at the end of the sharp let's say I have sharp is here okay and like this and I'll cut a groove like this okay shaft will be having a groove like this now shaft and one pulley or hub

so you can see this is let's say pulley pulley or some gear or gear okay this is your shaft now if shaft is going inside the gear so gear shaft is rotating but gear will not rotate now if I put a key in between these two then it will be looking like this so you can see this gear shaft and pulley this is your key okay this is your key and this is shaft this is your pulley

or gear okay now if i put one key key shape would be rectangular shape or many other shapes also possible okay this is a key so just put the key in between this pulley and shaft so there will be no relative motion when shaft is rotating pulley also will be rotating at the same speed but if you remove the key pulley and shaft will have a relative motion so although shaft is rotating your pulley or gear will not rotate so you will not transfer the power so when you are transferring power the key will be but why why key is there you can weld also you can put a nut bolt and tighten it so key normally it will be very easy to remove just one shaft is here put the pulley and just hammer the key done and things will be rotating and what happens key will be made very weaker weaker than pulley or shaft what happens if there is any a problem because of heavy load uh shaft cannot carry or pulley cannot carry we are not we are we design shaft and pulley for certain specific load but because of certain reason the load increase suddenly what will happen this key is weaker so key will be broken So, key is broken means shaft will be rotating, pulley is not rotating.

Okay. So, the purpose of key is that easy removal and fixing. And when is there any adversity, the key will be getting broken. For example, your electric circuit, there will be a fuse wear. So, if there is no overload, fuse will be burnt and everything will be safe.

Here also, the key will be getting broken and everything will be safe. So, when you are designing a key or you are buying a key, key strength will be lower than the shaft or your pulley or gear. Then you are making everything safe. So this will be weaker than your shaft or pulley or gear. And one way is that you have rectangular key and you are inserting into that hole and you are making safe.

Some other options also there to stop relative motion between shaft and gear. One is that spline you create. Spline like this. Your shaft is here. So I will make one shaft like this.

Now my gear will be like this. Gear will have this much of thing. okay okay so you can see the if shop And this is gear. If shaft is rotating, gear also will be rotating.

So there is no extra key you are inserting. Rather you are giving one spline. So it is like this. You have one shaft and you have one pulley. And you are inserting it.

And it will fix this teeth like structure will be fixed here. And when you are rotating, both will be rotating together. So one beauty is that you can have axial misalignment. Axial means like one shaft is moving forward backward. It can allow forward backward motion.

But it will not allow relative motion. This is called spline. So spline can be rectangular shape, triangular shape, any shape you can create. So key purpose is joining two shafts. So purpose of key is joining joins joins two shafts

and allow misalignment and flexibility or relative motion flexibility okay so if you have welded joint or very fixed joint shop then you will not have any flexibility But if you have some misalignment the shaft can allow actually because spline shaft I said like axial misalignment possible in some key it will allow some relative motion of angularity and other motion also it can allow. So there are different types of keys one can be different types of keys one can be like square shaped keys. square cross section so this is b this is b b let us say this is t this is maybe w this is l ah t thickness of the t okay w equals t square t if w is wider than t then it will be rectangular t okay and length will be longer anyway and wood rough key another key will be wood rough key it is looking like this wood this is square key then it will be rectangular key and then wood rough wood rough key will be like this

okay so same like semicircular cross section one double t like one pin circular section and one spline p already said this spline can be square shaped another shape also possible now if we want to calculate how much force or torque you can accept so you have to follow two theories one will be crushing stress and as with shearing stress so crushing stress and shearing stress. So, crossing stress, sigma c equals your area. Which area? Area means like if I have one key.

Okay, first I will draw this shaft and my key. Okay. And this is my shaft. this is my pulley when shaft is rotating pull will be rotating okay when shaft is rotating pull is rotating so shaft is giving torque okay so torque will be applied on this surface right but it is resisting in this surface pulley let's say we can assume this pulley is resisting shaft rotation okay so my system is getting force from opposite so this area will be crushed this is this area will

be sheared okay so what is my sharing area now sharing area w this is t by 2 this is l this is your l

Okay, so shearing area W into L. Shearing area equals W into L. Where crushing stress, crushing actually the area will be this one. This is your crushing area. Okay, so other side here crushing area. So crushing area. crushing area ac will be t by 2 into length okay so how much torque it is transferring torque torque or moment torque equals

F into D2 F means force how much force it is giving and D means diameter diameter of the shaft so D by 2 means radius of the shaft so it is giving torque so D by 2 into amount of force this equals torque okay so now crushing crushing will be giving ah if i do this one f equals l into t by 2 into sigma c crushing stress okay and for shearing if i consider for shearing f equals l into w into tau shear force this is your crushing stress so now the key is equally strong in shearing and caching we are assuming the key is equally strong in Shearing and crashing. So that means LW tau D by 2.

Now here F this one. So T equals LW D tau by 2. This is for crushing. And for shearing, this is for, no, this is wrong. This is force equals this one for crushing.

And for shearing, F L, and what is D? So, T equals F D by 2. So, it is giving L T D sigma C by 4. So, L tau omega D by 2 equals L T by 4 sigma C D. So, this is giving W by T equals sigma C by 2 tau. This is your relationship if we assume that equally strong shearing and crushing.

Shaft

Usual proportion W equals D by 4. t equals 2w by 3 equals d by 6 okay so normally taper taper is like this i have one shaft and i have one key here so key will have some slenderness here taper one is two hundred okay so taper is given one is two hundred okay square shanky square shanky W equals T equals D by 4 okay so we should remember these things okay

when you are getting to shop I said like one shop can be manufactured because several issues are there what is happening one propeller is here and your engine is there and you are transferring power from engine to propeller so engine is transferring torque so shaft main purpose is transfer torque but propeller what is happening when it is rotating it is pumping fluid or it is delivering fluid so it is giving energy to fluid so fluid will be reacting so it is giving reaction force to propeller so propeller will be transferring that force to propeller shaft so propeller shaft is getting that force so that force should not go to your engine because engine will be producing only torque but it will not take any extra force it is not designed for that one Then what you have to do?

You have to transfer that axial force to your ship. So that ship will be moving. So that is called thrust. Now, whenever you are transferring that thrust to ship, that means you must have several small shafts also. One will be propeller shaft or tail shaft, intermediate shaft, engine shaft.

Now, when you have one shaft and another shaft, how to connect these two? Because it must be transferring torque. And if there is any misalignment, it must be holding also. So, good shaft coupling must be easy to connect and disconnect. Transmit the power without losses.

Align the shaft perfectly. Reduce transmission of shaft load. No projecting part. And there will be two types basically shaft coupling. One will be rigid coupling.

One will be flexible coupling. Rigid coupling means one shaft is there. Another shaft is there. Just weld it. Or put some flange.

Flange is like this. One shaft I have. And make one flange arrangement like this at the end. Another shaft I have. Coaxial.

Coaxial means axis will be same. Whenever. Here engine drawing actually some teaching. Whenever drawing coaxial. So you draw first center line.

Center line means like one small line. Then longer line. Small line. Longer line. This is center line.

Okay. Then you draw the shaft. Okay, the both flanges you draw, then you draw the shaft. In shaft one end I can make like this, another end I can make like this. Okay, now I got two shaft disconnected.
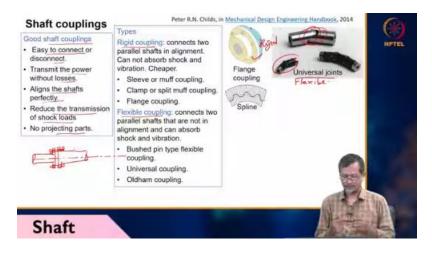
How to connect this one? So make hole on this flange. Okay, now put two nut bolt. Okay, then you put nut bolt here. And if flange is circular, so you will have 6 or 8 or many number of nut and bolts so that both shaft can be connected strongly.

So those can be called rigid coupling because you are not allowing any other motion. No axial motion, no lateral motion, other motion you are not allowing. So this is called rigid coupling. okay but in certain case you are allowing certain misalignment for example one shaft is here another shaft is here and because of certain reasons one shaft is getting certain amount of angle and if you have rigid coupling then that will be a problem because it is trying to move but you are forcing to be straight so it will have extra load so extra load is not allowed it will fail So what you do in that case you use this universal type joining or some other type of joining for example spline coupling.

Spline coupling means like one end is there another end is there just put it like this so that they will have lots of flexibility but it will be rotating together. Another is that universal coupling. Universal coupling is like this one end you make like this another end you make like this and you fix like this. So whenever one is rotating another will be rotating but all type of extra motion will be there. So actual flexibility will be there.

Angular flexibility will be there, lateral flexibility will be there, all type of flexibility will be there. But they will be rotating together in the same rpm. So that is called universal coupling. So these are universal coupling actually. So these are more flexible.
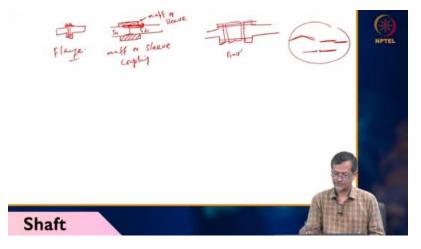
whenever you have a long shaft of several meters you cannot make very straight shaft and all the bearing must be aligned properly so there will be certain amount of misalignment if there is any misalignment there will be vibration wear tear and other failure option possible so in that case just you use some flexibility or flexible coupling when you are joining two shafts so that it will be transferring torque but it will not give extra load to your bearings for other units so one coupling I said like flange coupling all right this is flange coupling so you put nut bolt and you connect together and the sleeve coupling sleeve coupling means like you have two shaft one shaft is here s1 s2 and you put another another mop or sleeve and put one key here okay so this is your key so key key will not allow relative motion between the this is called muff or sleeve okay so just you insert mop or slip this one shop there is another shop and put one key so the relative motion among these three muff shaft 1, shaft 2 will not be there. So, in that case, you are joining two shafts, but you are giving axial misalignment little bit okay.

Axial means like if shaft is making little bit distance from each other, that will be okay. This is called muff or sleeve coupling. Muff or this is called flange coupling. Okay. Another coupling you have seen using only pin or key.

Okay. Another will be bush or flexible coupling. Bush or flexible coupling actually you have maybe flange is here. Okay. In between you put some bush and another coupling will be here.

Okay. Then you put long knot and they will have lots of axial and other alignment issues will be solved. For example, some angle they are creating or some misalignment is there, axial misalignment or maybe axial distance misalignment is there. So all this will be captured using your bush pin flexible coupling. Bush pin flexible

Thank you very much for today's class.