MARINE ENGINEERING

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Lecture71

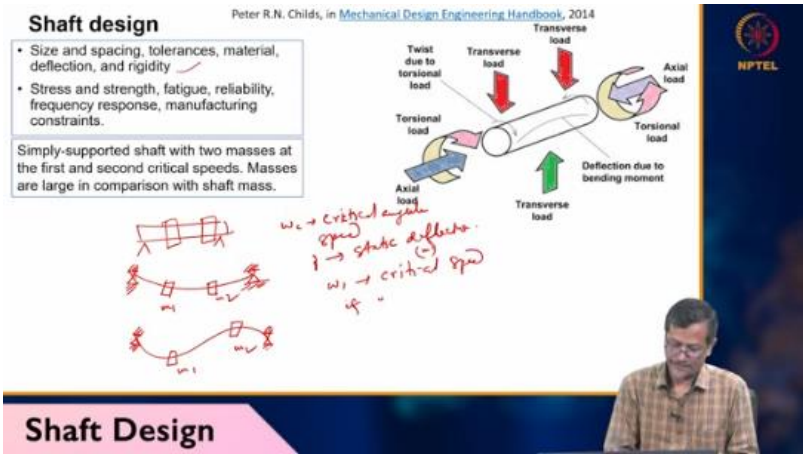
Shaft Design

Good morning, I'll start today's topic on shaft design. So shaft design is basically you are considering size, spacing, tolerance, material, deflection and rigidity. Stress, strength, fatigue, reliability, all those parameters also should be considered. Simply supported shaft with two masses in the first and second critical speed. Masses are large compared to the shaft speed.

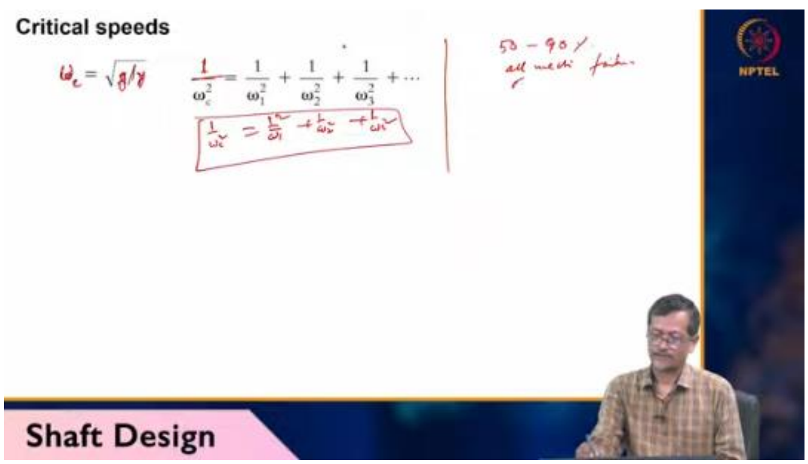
So simply supported shaft with two masses. This is simply supported shaft and masses are there. Okay, that critical speed will be changed. How the critical speed will change? I'll show you.

Let's, one shaft is here and this is your fixed element. Okay, and mass m1, this is m2. Okay. now because of bending it will be happening like this and mass is here mass is here okay so wc is critical speed wc is your critical critical speed, critical angular speed, critical angular speed, gamma is your static deflection at the location of the mass, and g is acceleration due to gravity, omega 1 is the critical speed,

if mass m 1 is present okay then the expressions will be if w c equals root over g y 1 by omega c square 1 by omega c square equals 1 by omega 1 square plus 1 by omega 2 square plus 1 omega 3 square Omega critical. So combined critical speed will be calculated like this. Now here in the previous slide you can see if I have a shaft, the shaft is facing like axial load. It can have torsional load, it can have transverse load or bending load.



Soft will have its own weight, so it will have sagging tendency. It will have some pulleys or gears mechanism, so that soft will try to bend or it will shear. So, we will just try to discuss how to design using all these forces. So, ASME document, they are saying like 50 to 9% of all mechanical failures are due to fatigue failure. 50 to 90 percent of all mechanical failure of shaft mechanical failure of shaft is fatigue failure now we have seen sharp material sharp material



Okay, we have seen there are several types of materials available for shop. So, few shop material, common shop material you can remember C45, it will have ultimate tensile strength 600 to 750 Newton per millimeter square UTS, ultimate tensile strength and in strength will be 380. newton per millimeter square so similarly we have other materials c 40 c 50 etc so in if i give any problem normally i'll give the value so you don't have to remember but you should have rough idea what should be the values in exam if something goes wrong in giving writing digits or point putting point or zeros you should have some idea that it may be out of range of the values So shaft can be simple tension, can have simple bending moment, combined torque and bending moment, combined axial loading. So several types of loading will be there.

So loading will be like simple torsion, simple torsion, simple torsion, bending moment, simple bending moment, combined torsion. combined torsion and bending, then combined axial, axial loading will be there, torsion will be there, bending will be there. So, this sort of force can be there when we are working with shaft. So, subject to simple loading, let us say simple torsion. If we have simple torsion, the shear stress, shear strength tau equals 16 mt pi d, pi small d.

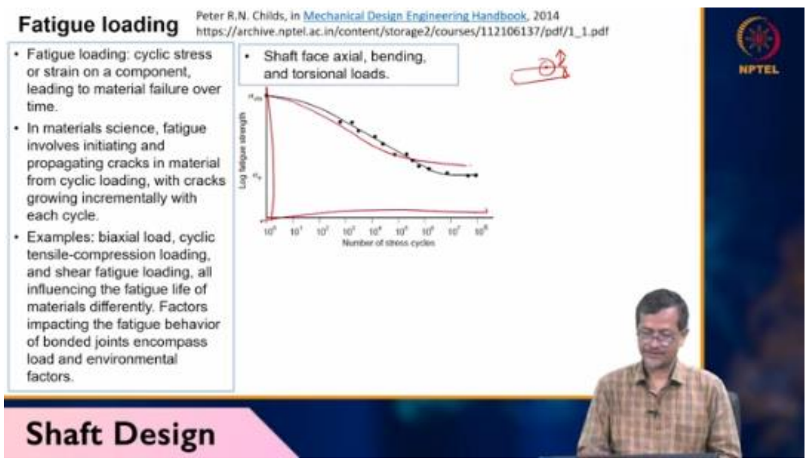
for solid shaft and equals 16 mt do pi do square minus di d power 4 for hollow shaft and the parameters mt torsional moment Newton per millimeter, D, dia, millimeter, and DO, outer dia, solid shaft, telemillimeter, solid shaft, DO, outer diameter, hollow shaft, DI, inner diameter, millimeter, hollow shaft, tau allowable shear strength 0.5 to 0.577 into sigma y. Now, sharp subject to simple bending. Simple bending. In the simple bending, what happens?

Sigma B, maximum stress. Max stress equals sigma B equals 32 mb pi dq solid sharp. and equals 32 mb do pi do power 4 di power 4 hollow shaft ok mb is your bending moment mb bending moment ok. now combine loading bending combine torque and bending so in that case tau max equals half sigma b plus 4 tau square per half equals half into 32 mb pi d q square plus 4 16 mt pi d q square okay so maximum shear stress theory now simplifying

tau max equals 16 pi dq mb square plus mt square power half solid shaft now for hollow shaft it will be 16 m b square plus m t square half divided by pi d o cube 1 minus d i by d o power 4 hollow okay now from solid okay design shaft for rigidity so angle of twist angle of twist So, theta equals mtljg. So, j equals polar moment of inertia equals pi by 32 d power 4.

g equals modulus of rigidity modulus rigidity of the shaft material l equals length of the shaft now theta equals 584 584 LMT G D power 4 solid solid shaft because 584 LMT G DO power 4 DI power 4 hollow When the value permissible shall stress tau and allowable stress to be specified, the limiting length of the solid shaft theta equals to mtl by gd. So whenever you are designing a shaft or any machine element, so you have to consider fatigue loading. Fatigue loading is how much alternating cycle you are applying on machine element.

For example, you have one axle or shaft, let us say shaft and it is hanging. So let us say one moment shaft is getting load here, this upper layer is getting tension, lower layer is getting compression. now after 90 degree turn after 90 degree what happens that another layer will be in tension another layer will be in compression so the layers are getting alternating compression and tension upper layer compression again after some time upper layer getting tension so compression tension happening so they will fluctuating or cyclic loading when cyclic loading is there the machine life will be lower so in material science fatigue involves initial propagation of crack so whenever you have continuous cyclic loading or trending loading here so possible that there will be some crack development somewhere and system can fail and because of fatigue loading how your life is reducing in this figure you can see so gradually this fatigue load strength is going down okay with increasing number of cycles number of cycles means how many times it is getting load or trending okay So, stress concentration, a point where stress is significant higher than its surrounding.



This occurs due to irregularities in the object's geometry or material, such as holes, grooves, notches, disrupting stress flows. A non-dimensional factor called stress concentration factor is used. For example, you have one shaft, and you have a small crack here. What is happening? The total area is here, A.

pi by 4 d square but at this location the area reduced actually okay a dash so here my diameter is maybe d dash so area became pi by 4 d dash square okay so what is happening so if force is same let's say this is applied force okay then stress development We will be like this F by A. Now in second case where crack got developed so their area reduced. Area reduces means P increased. So crack developed implies stress increased. okay so any micro crack also it will increase stress concentration or stress level at a specific location so that will lead to further growth of crack and will fail in many cases you have sharp they said bend so your stress concentration will be there at the neck area or if you have any bend like this your stress concentration will be here somewhere

So stress will be concentrated in certain area then other areas. When stress is concentrated in certain area so that area failure probability is higher. Whenever you are designing shaft or any machine element you have to check where stress concentration possible or where the weakest position possible on shaft or any machine element. So the weakest portion if you can identify design that one check that one if that is safe. If that is safe then other portion will be safe anyway because you are considering that is the weakest area.

So ductile material allows localize plastic deformation at stress concentration. So it redistributes the stress. So failure probability and its safety will be better. But you have any brittle material. Brittle material, if there is any micro crack, so crack will be propagating quickly and failure will be quicker.

So normally this bicycle and other frames will be made of mild steel. So that if any crack is there, it will be distributing the material stress concentration the stress to other nearby zone so system will be safe but brittle material will not transfer it will keep just growing the crack and it will fail. Fracture modes whenever you are talking about failure shock or any machine element Then you have to see what are the different fracture modes.

So there will be ductile fracture mode, brittle fracture mode. Ductile fracture means you are having one specimen and you are giving lots of pulling action. Because of pulling, let's say rubber band if you pull, what will happen? Initially it will create some narrow area. So narrow area created means narrow area reduced.

So same force you are applying but area reduced. What will happen? Stress will be increasing. When stress increasing, further it will be creating necking so this is called neck formation okay the small area you are creating so neck formation is there so neck formation means stress increase so stress increase means that area will be failed okay but in brittle material the neck formation will not be there okay no neck formation

Because no neck formation is there and you have small micro crack. So micro crack will be giving your stress concentration. Because of stress concentration it will fail and it will not give any warning. But in ductile material it will give warning because it will be elongating. before it fails and so you will know okay it's getting elongated or neck formation is happening so you have to take immediate action brittle material will not tell that one it it is having some stress concentration it will fail immediately done okay so brittle fracture crack propagation without significant deformation around the crack tip

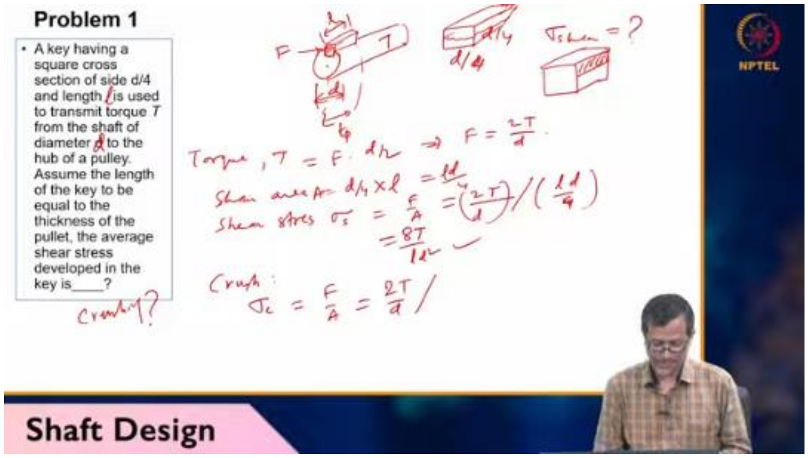
leading to rapid material failure ductile failure plastic deformation will be happening before failure okay if you see the stress strain curve strain stress okay so proportion limit is there then ductile material will have lots of transformation like it will be elongating then it will fail but brittle material done done done okay there will be no indication of long zone where it is getting absorbing energy and it is giving indication that will fail brittle or ductile fracture depends on factors such as stress level loading type static cyclic strain pre-existing crack or defect material properties environmental and temperature so same material i will be behaving brittle or ductile based on temperature also at very low temperature certain material can be brittle but normal temperature maybe it will be tactile, so that also will be affecting. Now, we will try to solve some problem. A key is having square cross section of side D by 4 and length L, is used to transmit torque T from shaft diameter D

So, I have one key here, shaft is here, so my shaft is like this. So, diameter, shaft diameter is D and cross section area D by 4, this area, this is square shape, this is D by 4, this is also D by 4. uh transmittor t um diameter d transmitter diameter pulley hub assume that length of the key to be equal so length also we have to calculate l equal to the thickness of the pulley so pulley thickness uh t uh pulley okay the average shear stress developed in the key shear stress How much you have to calculate? So, torque T equals P or F, F into D by 2.

So, let us say this is force is F. So, torque is F into D by 2 implies force equals 2 T by D. Now, shear area will be this one. So, this is your shear area. So, this area is your shear area. So, shear area equals d by 4.

a is d by 4 into a length of this key l so l d l d by 4 now shear stress sigma s equals f by a equals 2 t by d f value divided by a a value is already calculated l d by 4 so this is giving a t by l d square l d square okay and if we calculate crushing also so crushing area will be changing only so crushing area will be this one is my crushing area okay This is my crushing area. So crushing area. Crushing sigma C equals force by area.

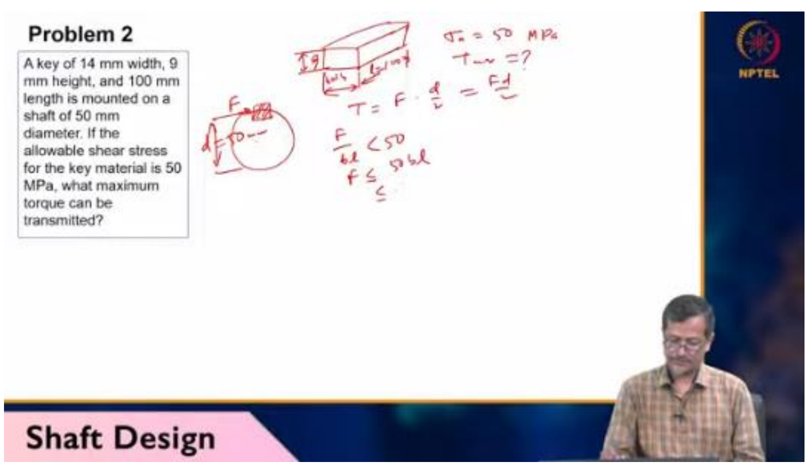
Force again same. 2T by D. Area changed. Area is now D. This is D by 4 into half. So D by 8 into L. So, this is giving 16TLD square.



So, next see another problem on key. A key of 14 millimeter width, 14 millimeter width, 9 millimeter height and 100 millimeter length, 100. This is 100 millimeter. So, I am not writing unit. If the allowable shear stress for the key material is 15, sigma A equals 50 MPa, maximum torque can be transmitted.

So, here torque equals F D by 2. D means sharp diameter. This is D. and this is force it is applying okay so f d by 2 b is 14 and l is 100 and d 50 d is given 50 50 millimeter okay and tau is 50 mpa So F by BL less than 50.

So F less than equals 50 BL. So less than equals 50 into 14 into 100 equals 17 kilonewton. So torque T equals F d by 2 equals 70 into 0.025 equals 1750 newton meter newton meter a shaft 70 750 meter millimeter long 750 750 subject to shear stress 40 mpa sigma shear 40 and has angle of twist Theta is given 0.017 radian.



G value they are asking for the rigidity 0.08 into 10 to the power 5 MPa. Diameter of the shaft D you calculate writing like this. So modulus of rigidity 0.8 into 10 power 5 newton per millimeter square so 40 newton per millimeter square okay so m t equals pi by 16 tau or sigma s tau dq okay theta equals m t l g j so pi by 16 tau dq l pi d power 4 32 into g so equals to tau l g d so this is giving 0.017 equals 2 into 40 into 750 0.8 into 10 power 5 into d so j equals polar moment of inertia of

inertia for solid shaft. So, this is given D equals 44.11 millimeter. So, problem 4, here marine engine producing 500 kilowatt power and shaft speed 1000, the propeller efficiency 75 percent, 20 knot speed, permissible shear stress also given. direct axial load okay it is asking to calculate actual load so power p equals 500 kilowatt so whenever you are writing kilowatt write k small w capital okay so this is a standard practice n equals 1000 rpm eta equals 75 percent or 0.75 So, velocity 20 knots equals 20 into 1085.

It is given in the problem. So, 6.028 meter per second. So, P equals power equals to n pi by 60 into torque mt. So, this is giving 500 into 10 to the power 3 equals 2 pi 1000 mt divided by 60. So, mt equals 4774.65 Newton meter.

Let axial load is Pa. P equals PA into velocity by eta. So therefore 500 into 10 power 3. equals PA into 6.028 0.75 so this is given PA equals 62209.7 Newton okay this is your answer a 750 millimeter long uniform solid circular shaft is simply supported at the ends and carries two pulleys of weights 2 kilo Newton the pulleys are 250 millimeter and 5 and a millimeter from the left end a pull of 10,000 Newton vertically downward on the right pulley is applied.

The shaft transmitter torque 3000 Newton meter between the pulleys. Assume KBKT to constant 1.5, allowable shear is just 70. So, how to solve with this one? So, first you draw the pulleys and shaft. Okay.

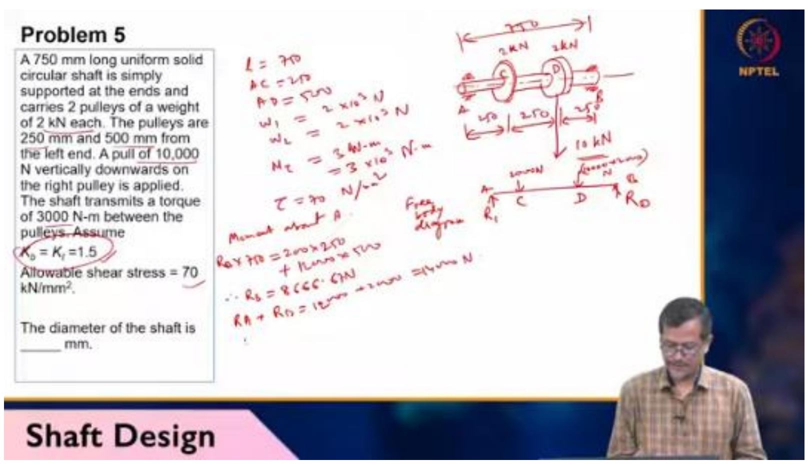
So, first central line then shaft is coming here. It is like this. Pulleys here. then shaft is going to next pulley next pulley then shaft okay then shaft is passing through to bearings okay now C D A B A and B is giving reaction C D is hanging its own weight So, distance L is 750.

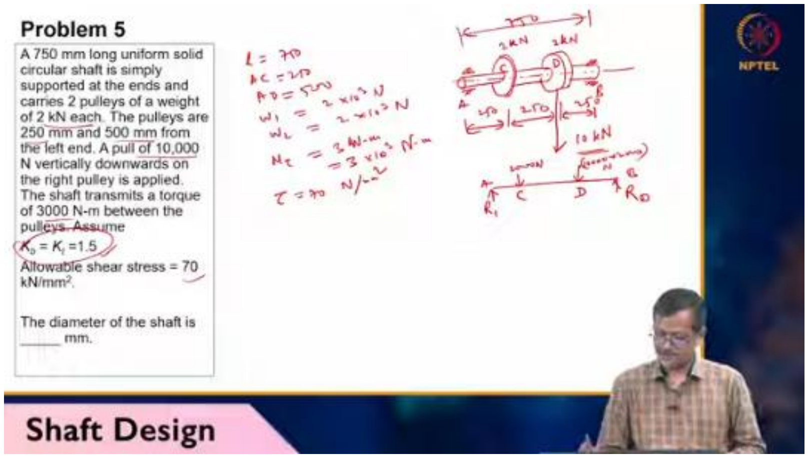
So, distance are given 250. This is 250. This is 250. This is 2 kilonewton each. Kilonewton, 2 kilonewton.

Then it is having force 10 kilonewton. okay uh the sharp 75 long supported by ends two pulleys 250 millimeter five millimeter okay pull on the right pull it 10 kilo newton vertically downward okay this is vertically downward the sharp transmit three kilo newton okay so l is given seven five zero okay seven five zero millimeter ac equals 250 equals AD given in the problem AD equals 500 millimeter W1 equals 2 into 10 power 3 Newton W2 equals 2 into 10 power 3 Newton MT torque is given 3 kilo Newton meter because 3 into 10 power 3 Newton meter and shear stress given 70 Newton per millimeter square and K a K B values also given there the weight of is fully 2000 Newton which acts vertically downward and pull of 10,000 Newton vertically downward Now, draw the load diagram.

Load diagram is like this. Reaction is happening here. Reaction is happening here. So, R A, R B and vertically downward 2000 Newton and here it is giving force 10000 plus 2000 Newton. This C, this is D, this A, this is B.

okay this is called free body diagram so okay free body diagram how to draw you have to go to your first year second year course of strength of material uh course now uh calculate the bearing moment at all the moment uh all the points r a r b uh reaction force okay so moment about a about a rb so rb how much force force will be upward force so rb into 750 equals 2000 in c 2000 in c into 750 not 750 250 plus uh ten thousand twelve thousand twelve thousand into five hundred i mean because a to d is five hundred okay So, total here RB is giving 8666.6 Newton, 8666.67 Newton. Now, RA plus RB, total force they are holding, so 12,000 plus 2,000, so 14,000. newton force is there holding so r is 14000 minus rb whatever you got 866 6.67 equals 533 3.3 newton okay so bending moment b m bending moment at a if i take bending moment at a equals zero





okay because we are taking moment about a so bending moment is zero so BMFC are a into 250 equals five three three point three into 250 equals one three three point one three three one point three three three into ten power six Newton Newton millimeter okay BM at D RB into 250 equals eight six six six point six seven into two five zero equals to one six six into ten power six Newton millimeter So, Bm at D. So, maximum bending moment occurs at D implies M bending moment maximum is taken to 2.166 into 10 power 6 Newton millimeter. So, equivalent twisting moment. twisting moment MTS equals root over KBMB square plus KTMT square equals

1.5 into 2.166 10 power 6 square plus 1.5 into 3 into 10 power 6 square. So that is giving MTS equals 5.55 into 10 power 6 Newton millimeter. And we know MTS equals pi by 16 tau DQ. So, this is giving D equals 73.9 millimeter. So, this is your answer.

Next day, we will start a new topic. Thank you very much.