Roll No.												

GAIN MORE KNOWLEDGE
REACH GREATER HEIGHTS

PRESIDENCY UNIVERSITY
BENGALURU

SCHOOL OF ENGINEERING

TEST - 1

Sem & AY: Odd Sem. 2019-20
Course Code: MEC 315
Course Name: Tribology and Bearing Design
Program & Sem: B. Tech. (MEC) & V DE

Date: 27.09.2019
Time: 2.30 PM to 3:30 PM
Max Marks: 40
Weightage: 20%

Instructions:

(i) Answer all the questions!

Part A [Memory Recall Questions]

Answer **both** the Questions. (2Q=13M)

1. State whether the following statements are true or false. Justify your answer.
   (a) Roller bearings are a type of antifriction bearing. (2 Marks) (C. O. No. 1) [Knowledge]
   (b) The load carrying capacity of a roller bearing is greater than that of a ball bearing. (2 Marks) (C. O. No. 1) [Knowledge]
   (c) The hydrodynamic bearing, in theory, has infinite life. (2 Marks) (C. O. No. 1) [Knowledge]
   (d) The contact area between surfaces in bearings with nonconformal surfaces decreases with the increase in load. (2 Marks) (C. O. No. 1) [Knowledge]
2. This question will test your knowledge of the various lubrication regimes in bearings.
   (a) List the four types of lubrication regimes in increasing order of losses due to friction. (1 Mark) (C. O. No. 1) [Knowledge]
   (b) Describe the mechanisms of partial and boundary lubrication with suitable figures. (3 Marks) (C. O. No. 1) [Knowledge]
   (c) State the sequence of lubrication regimes seen in the life of hydrodynamic bearing. (1 Mark) (C. O. No. 1) [Knowledge]

Part B [Thought Provoking Questions]

Answer the Question. (1Q=13M)

3. The following questions will test the dept of your knowledge on the development of Petrov's equation from Newton's work on fluids.
   (a) Define Newtonian fluids explaining all the terms in the definition with their S. I. units. (3 Marks) (C. O. No. 1) [Knowledge]
   (b) Explain Newton's postulate pointing out exactly where the assumption of Newtonian fluids fits into the postulate. (3 Marks) (C. O. No. 1) [Comprehension]

Petrov took up Newton's postulate about two hundred years after Newton articulated his postulate and derived Petrov's equation.

(c) Explain how Petrov's equation manipulates the geometry used in Newton's Postulate to estimate fictional losses in a hydrodynamics journal bearing?

(2 Marks) (C. O. No. 1) [Comprehension]

(d) State the assumptions made by Petrov in deriving the equation.

(2 Marks) (C. O. No. 1) [Knowledge]

(e) Derive Petrov's equation. (3 Marks) (C. O. No. 1) [Comprehension]

Part C [Problem Solving Questions]

Answer **both** the Questions. (2Q=14M)

4. A team of engineers in Kingsbury, Inc. have been asked to design a journal bearing for a steam turbine. It is standard procedure in Kingsbury to initiate any design with first cut analytical work and then proceed to more sophisticated computations fluid dynamics based design. As a member of the team you have been entrusted with the responsibility of the determination of power loss in the journal bearing whose specifications from the the first cut analytical design are as follows:
   (i) journal diameter = 50 mm,
   (ii) width of the bearing = 100 mm,
   (iii) rotational speed = 1500 RPM,
   (iv) SAE 10 lubricating oil operating at 100^o C with a viscosity of 11.877 mPa·s,
   (v) bearing load 3 kN, and,
   (vi) the bearing clearance is one-hundredth of the journal radius.

[6 Marks] (C. O. No. 1) [Application]

5. The problem will test your knowledge of viscous flow between flat plates in the context of hydrodynamic journal bearings.
   Figure 1 represents two flat plates in between which we have a fluid. The bottom plate is stationary and the top plate moves with a constant velocity u_a. The viscosity of the fluid between the plates is η, its density is ρ and the pressure distribution in the fluid is only a function of x. The objective of this problem is to find the velocity u of the fluid as a function of z.

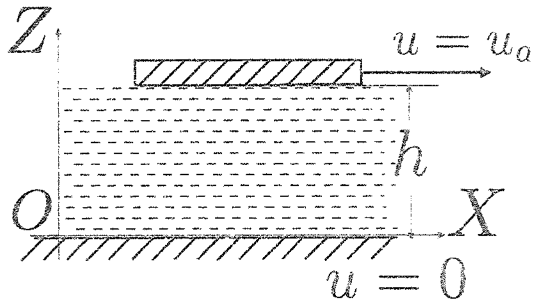


Figure 1: Viscous Flow Between Flat Plates

   (a) Explain how this problem is connected to design and analysis of journal bearings.

   (2 Marks) (C. O. No. 1) [Knowledge]

   (b) Find the velocity function $u(z)$ assuming the inertia and body forces are negligible and the density and viscosity are constant. You may find the following relations to be of use in solving the problem:

$$\sigma_x = -p + \lambda_z(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z}),\ \tau_{xy} = \eta(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}),\ \text{and}\ \tau_{xz} = \eta(\frac{\partial u}{\partial z} + \frac{\partial w}{\partial x}).$$

   (6 Marks) (C. O. No. 1) [Application]

The End

Annexure I: Summary of Question Distribution [C. O. Wise and Bloom's Level Wise]

SCHOOL OF ENGINEERING

GAIN MORE KNOWLEDGE
REACH GREATER HEIGHTS

Semester: Odd Semester

Course Code: MEC 315

Course Name: Tribology and Bearing Design

Branch & Sem: MEC V Sem

Date: September 27, 2019

Time: 2:30 PM to 3:30 PM

Max Marks: 40

Weightage: 20%

Extract of Question Distribution [Outcome Wise and Level Wise]

Q. No.	C. O. No.	Module No. and Title	Memory Recall Type [Marks Allotted] Bloom's Level	Thought Provoking Type [Marks Allotted] Bloom's Level	Problem Solving Type [Marks Allotted] Bloom's Level	Total Marks
			K	C	A	
1	1	Dynamics of Particles and Systems of Particles	8	-	-	8
2	1		3	-	-	3
3	1		-	9	-	9
4	1		-	6	-	6
5	1		-	-	7	7
6	1		-	-	7	7
		Total Marks	11	15	14	40

K: Knowledge Level, C: Comprehension Level, A: Application Level

Note: While setting all types of questions the general guideline is that about 60% of the questions must be such that even a below average students must be able to attempt, About 20% of the questions must be such that only above average students must be able to attempt and finally 20% of the questions must be such that only the bright students must be able to attempt.

SCHOOL OF ENGINEERING

SOLUTION

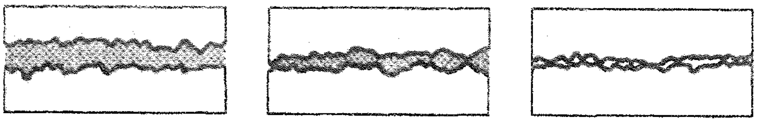
Semester: Odd Semester
Course Code: MEC 315
Course Name: Tribology and Bearing Design
Branch & Sem: MEC V Sem

Date: September 27, 2019
Time: 2:30 PM to 3:30 PM
Max Marks: 40
Weightage: 20%

Part A

(2Q=11M)

Q. No.	Solution	Scheme of Marking	Maximum Time Needed for Each Question
1	(a) True! This is just how bearings have been classified.	✦ 1 M for each truth value. ✦ 1 M for justifying each truth value.	5 Minutes
	(b) True! The bearing surfaces in ball bearings have point contact whereas the bearing surfaces in roller bearings have line contact. Since roller bearings have larger contact area they can withstand greater stresses and larger loads. (c) True! Hydrodynamic bearings that are designed well and run at the design speeds with lubricants of design viscosity and design clearance and are maintained well will have no contact between bearing surfaces. This lack of contact between bearing surfaces ensures no wear. Therefore, hydrodynamic bearings have infinite life in theory. (d) False! The contact area actually increases with the increase in load.		
2 (a)	The four lubrication regimes in increasing order of frictional losses are as follows: hydrodynamic lubrication, elastohydrodynamic lubrication, partial lubrication and boundary lubrication	(a) 1 M for the correct order. (b) 2 M for labeled figures and 1 M for the descriptions. (c) 1 M for right sequence.	10 Minutes

2 (b)	 The three figures starting from the left show us fluid film lubrication, partial lubrication and boundary lubrication. In the fluid film lubrication we see that the
2 (b)	bearing surfaces are not in contact with each other because the fluid film is thick enough to create a separation. In the figure on partial lubrication (the figure in the middle) we see that the bearing surfaces are closer and may come in contact during operation because the fluid film is very thin. In the right most figure on boundary lubrication we that the bearing surfaces are not separated by any fluid film and are in direct contact.
2(c)	The life of a hydrodynamic bearing begins in the hydrodynamic lubrication regime after which it shifts to the partial lubrication regime. The bearing ends its life in the boundary lubrication regime.

Part B

(2Q=15M)

Q. No.	Solution	Scheme of Marking	Maximum Time Needed for Each Question
3	(a) In a Newtonian fluid the shear stress at a point is directly proportional to the strain rate at the point. The constant of proportionality is called viscosity. Let τ denote the shear stress at a point, s be the strain rate and η be the viscosity of the fluid. Then $\eta = \frac{\tau}{s}$ for a Newtonian fluid. (b) Newton's postulate helps us determine the frictional force at a point in the fluid. This is done as follows. We write the shear stress $\tau = \frac{f}{A}$ where f is the frictional force and A is the area on which the stress is acting, the strain rate $s = \frac{u}{h}$ where u is the velocity of the moving plate at the top and h is the distance between the plates. When we assume the fluid between the plates is a Newtonian fluid we get $f = \frac{\eta A u}{h}$.	(a) 3 M for the explanation of Newtonian fluids in words and in mathematical form. (b) 2 M for the explanation of Newton's postulate. 1 M for linking it to Newtonian fluids.	15 Minutes

3	(c) Petrov's equation gives us an estimate of frictional losses in a journal bearing. It creates an analog between the circular geometry in journal bearings to rectangular geometry in the flow between flat plates seen in Newton's postulate. (d) The assumptions made in the derivation of Petrov's equations are: the radial load on the shaft is small, the viscosity of the lubricant is high and the journal spins at a very high speed. (e) For a journal bearing with width b, clearance c, with the journal of radius r rotating at N RPM the frictional force acting on the journal is given by $f = \frac{4\pi^2 r^2 \eta N b}{60c}$.	(c) 2 M for the explanation. (d) 2 M for the assumptions. (e) 3 M for the derivations with definitions of each term.	

Part C

(2Q=14M)

Q. No.	Solution	Scheme of Marking	Maximum Time Needed for Each Question
4	Petrov's equation to determine the frictional force f in a journal bearing is $f = \frac{4\pi^2 r^2 \eta N b}{60c}$ where r is the radius of the bearing, η is the viscosity of the lubricant in the bearing, N is the angular speed of the journal in RPM, b is the journal width and c is the clearance in the journal. We find the frictional force $f = \frac{4\pi^2(25 \times 10^{-3})^2(11.877 \times 10^{-3})1500(100 \times 10^{-3})}{60(\frac{25}{100} \times 10^{-3})}$ $\implies f = 2.93$ N. The torque due to this friction is force is $T_f = fr = 2.93 \times .025$ $= 0.07325$ N·m. Finally, the power loss in the bearing is $P_\ell = T_f \frac{2\pi N}{60}$ $= 0.07325 \cdot \frac{2\pi(1500)}{60} = 11.5$ W. □	✦ 3 M for three formulas. ✦ 3 M for three values.	10 Minutes

5	(a) This problem is linked to the determination of frictional losses in a hydrodynamic bearing as shown by Petrov but it goes a step further. The solution to this problem will give us a more accurate means of determining strain rate and will lead to a more accurate determination of frictional losses in journal bearings. (b) The Navier-Stokes (N-S) equation in the $X-$direction is: $\frac{\partial \sigma_x}{\partial x}+\frac{\partial \tau_{xy}}{\partial y}+\frac{\partial \tau_{xz}}{\partial z}+\rho g=\rho\frac{Du}{Dt}$. Since the body forces and inertia forces are negligible we reduce the N-S equation to $\frac{\partial \sigma_x}{\partial x}+\frac{\partial \tau_{xy}}{\partial y}+\frac{\partial \tau_{xz}}{\partial z}=0$. Since the density of the fluid is constant and the velocity u is not a function of x and y the N-S reduces to $-\frac{dp}{dx}+\eta\frac{d^2u}{dz^2}=0$. This	(a) 2 M for explaining the link. (b) 1 M for reducing the N-S equation. 1 M for integrations. 1 M for using the boundary conditions. 1 M for $u(z)$.	15 Minutes

can be rewritten as $\eta\frac{d^2u}{dz^2}=\frac{dp}{dx}$. Integrating this once with respect to z gives us $\frac{\partial u}{\partial z}=\frac{1}{\eta}\frac{dp}{dx}z+c_1$. Integrating this again with respect to z gives us $u=\frac{1}{\eta}\frac{dp}{dx}\frac{z^2}{2}+c_1z+c_2$. Using the boundary conditions $u(0)=0$ and $u(h)=u_a$ gives us $c_1=\frac{u_a}{h}-\frac{1}{\eta}\frac{dp}{dx}\frac{h}{2}$ and $c_2=0$. Therefore,

$$u(z)=\frac{1}{\eta}\frac{dp}{dx}\frac{z^2}{2}+\frac{u_a}{h}-\frac{1}{\eta}\frac{dp}{dx}\frac{h}{2}. \square$$

The End

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GAIN MORE KNOWLEDGE
REACH GREATER HEIGHTS

PRESIDENCY UNIVERSITY
BENGALURU

SCHOOL OF ENGINEERING

TEST - 2

Sem & AY: Odd Sem, 2019-20	**Date**: 16.11.2019
Course Code: MEC 315	**Time**: 2:30 PM to 3:30 PM
Course Name: TRIBOLOGY AND BEARING DESIGN	**Max Marks**: 40
Program & Sem: B. Tech. (MEC) & V DE	**Weightage**: 20%

Instructions:
 (i) Answer all the questions.

Part A [Memory Recall Questions]

Answer the Question. (1Q=12M)

1. State whether the following statements are true or false. Justify your answer.
   (a) The velocity vector function is one of the unknowns in the Navier-Stokes equations when analysing hydrodynamic bearings for frictional losses. (2 M) (C. O. No. 2) [Knowledge]
   (b) The continuity equation is added to the Navier-Stokes equations in order to match the number of unknowns and the number of equations to analyse hydrodynamic bearings. (2 M) (C. O. No. 2) [Knowledge]
   (c) Our analysis of hydrodynamic bearings is based on the assumption that the bearings operate in the partial lubrication regime. (2 M) (C. O. No. 2) [Knowledge]
   (d) Analysis of hydrodynamic bearings using analytical methods, when such methods are available, lead to results that are not as accurate as the results from computational methods. (2 M) (C. O. No. 2) [Knowledge]
   (e) The Reynolds equation is *the common* starting point for the analysis of hydrodynamic thrust bearings and hydrodynamic journal bearings. (2 M) (C. O. No. 2) [Knowledge]
   (f) The Reynolds equation is obtained from the Navier-Stokes and continuity equations. (2 M) (C. O. No. 2) [Knowledge]

Part B [Thought Provoking Questions]

Answer the Question. (1Q=14M)

2. The following questions will test the your knowledge of the hydrodynamic thrust bearing and how to initiate an analysis of the losses in these bearings.
   (a) Explain the set-up and working of the hydrodynamic thrust bearing with a neat sketch. Label all the parts in your sketch. (6 M) (C. O. No. 2) [Knowledge]
   (b) Bring out one difference between a hydrodynamic thrust bearing and a hydrodynamic journal bearing. (2 M) (C. O. No. 2) [Comprehension]

(c) Explain how the Navier-Stokes equations, the continuity equation and the Reynolds equation fit into the determination of frictional losses in a hydrodynamic thrust bearing? (6 M) (C. O. No. 2) [Comprehension]

Part C [Problem Solving Questions]

Answer the Question. (1Q=14M)

3. This question will test your problem solving skills in the context of the derivation of the Reynolds equation from the Navier-Stokes and the continuity equations. Answer the following questions on the Navier-Stokes equation in the X-direction, which is:

$$\rho\frac{Du}{Dt} = \rho g - \frac{\partial p}{\partial x} - \frac{2}{3}\frac{\partial}{\partial x}(\eta\xi_a) + 2\frac{\partial}{\partial x}(\eta\frac{\partial u}{\partial x}) + \frac{\partial}{\partial y}[\eta(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x})] + \frac{\partial}{\partial z}[\eta(\frac{\partial u}{\partial z} + \frac{\partial w}{\partial x})].$$

(a) Define the quantities $x, y, z, t, u, v, w, \eta$ and p from the Navier-Stokes equation in the X-direction. [1 M] (C. O. No. 2) [Knowledge]

(b) Non-dimensionalize these quantities. [2 M] (C. O. No. 2) [Application]

(c) Show that the term $\rho\frac{Du}{Dt}$ can be non-dimensionalised to obtain:

$$\frac{\ell_o}{u_o t_o}\frac{\partial\bar{u}}{\partial T} + \bar{u}\frac{\partial\bar{u}}{\partial X} + \frac{v_o}{u_o}\frac{\ell_o}{b_o}\bar{v}\frac{\partial\bar{u}}{\partial Y} + \frac{w_o}{u_o}\frac{\ell_o}{h_o}\bar{w}\frac{\partial\bar{u}}{\partial Z}.$$

[4 M] (C. O. No. 2) [Application]

(d) Define the Reynolds number and state the mathematical expressions for this number in the $X-$, $Y-$ and $Z-$directions. [2 M] (C. O. No. 2) [Knowledge]

(e) State the mathematical expression for the squeeze number σ_s.

[1 M] (C. O. No. 2) [Knowledge]

(f) Show that these numbers help reduce $\frac{\ell_o}{u_o t_o}\frac{\partial\bar{u}}{\partial T}$ to $\sigma_s\frac{\partial\bar{u}}{\partial T}$.

[4 M] (C. O. No. 2) [Application]

The End

Annexure I: Summary of Question Distribution [C. O. Wise and Bloom's Level Wise]

SCHOOL OF ENGINEERING

GAIN MORE KNOWLEDGE REACH GREATER HEIGHTS

Sem & AY: Odd Sem, 2019-20

Course Code: MEC 315

Course Name: Tribology and Bearing Design

Program & Sem: B. Tech. (MEC) & V (DE)

Date: 16.11.2019

Time: 2:30 PM to 3:30 PM

Max Marks: 40

Weightage: 20%

Extract of Question Distribution [Outcome Wise and Level Wise]

Q. No.	C. O. No.	Module No. and Title	Memory Recall Type [Marks Allotted] Bloom's Level	Thought Provoking Type [Marks Allotted] Bloom's Level	Problem Solving Type [Marks Allotted] Bloom's Level	Total Marks
			K	C	A	
1	1	The Reynolds Equation	12	-	-	12
2	1		-	14	-	14
3	1		-	-	14	14
		Total Marks	12	14	14	40

K: Knowledge Level, C: Comprehension Level, A: Application Level

Note: While setting all types of questions the general guideline is that about 60% of the questions must be such that even a below average students must be able to attempt, About 20% of the questions must be such that only above average students must be able to attempt and finally 20% of the questions must be such that only the bright students must be able to attempt.

SCHOOL OF ENGINEERING

SOLUTIONS

Sem & AY: Odd Sem, 2019-20 | **Date**: 16.11.2019

Course Code: MEC 315 | **Time**: 2:30 PM to 3:30 PM

Course Name: Tribology and Bearing Design | **Max Marks**: 40

Branch & Sem: B. Tech. (MEC) & V (DE) | **Weightage**: 20%

Part A

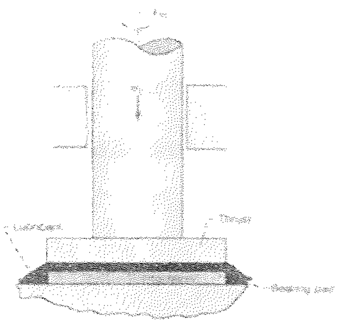
(1Q=12M)

Q. No.	Solution	Scheme of Marking	Maximum Time Needed for Each Question
1	(a) True! They are the <u>true</u> unknowns after writing terms, like stresses, as functions of velocity.	✦ 1 M for each truth value. ✦ 1 M for justifying each truth value.	10 Minutes
	(b) True! The Navier-Stokes equations are three in number and have four unknowns. The continuity equation is the fourth equation to help solve for the four unknowns. (c) False! Hydrodynamic bearings operate in the hydrodynamic lubrication regime. (d) False! Analytical methods lead to exact solutions to differential equations whereas computational methods lead to approximate solutions. (e) True! The Navier-Stokes equations and the continuity equation lead to the Reynolds equation which is the starting point of our analysis. (f) True! We know this from the derivation of the Reynolds equation.		

Part B

(1Q=14M)

Q. No.	Solution	Scheme of Marking	Maximum Time Needed for Each Question
2. (a)	From the figure we see that the bearing takes up thrust loads in machinery. The thrust load can be vertical of horizontal so the bearing must be placed accordingly.	This detail is on the following page!	

2. (a)	 The shaft is located above the bearing pad. Between the bearing and the shaft there is a film of lubricant to take up the thrust load.	✦ 4 M for the figure with all the parts labelled. ✦ 2 M for the explanation.	10 Minutes
2. (b)	The hydrodynamic thrust bearing is used to take up thrust loads, which act along the axis of the shaft. The hydryodynamic journal bearing is used to take up radial loads.	✦ 2 M for explaining the difference.	2 Minutes
2. (c)	First, the Navier-Stokes (N-S) equations are derived by applying Newton's second law of motion, $\Sigma\overrightarrow{F} = m\overrightarrow{a}$, to an infinitesimal element in the lubricant of the bearing. This gives us three partial differential equations in terms of viscosity, pressure, velocity and stresses. If we are able to determine the stresses, then we can determine the forces, especially the frictional forces, which give us the losses. Unfortunately, the (N-S) equations are three in number and we have four unknowns. So we add the continuity equation to match the number of unknowns and the equations. Next, we non-dimensionalize these equations and drop the terms that have very little contribution to the dynamics. Dropping the terms leads to the Reynolds equation, which can used to analyse hydrodynamics bearings.	✦ 2 M for explaining the role of the N-S equation ✦ 2 M for explaining the role of the continuity equation ✦ 2 M for the role of the Reynolds equation	5 Minutes

Part C

(1Q=14M)

Q. No.	Solution	Scheme of Marking	Maximum Time Needed for Each Question
3. (a)	The variables x, y and z are spatial coordinates, t represents time, u, v and w are the velocity components in the $X-$, $Y-$ and $Z-$directions, η is the viscosity of the fluid and ρ is the density of the fluid.	✦ 1 M for all definitions.	5 Minutes

3. (b)	We can non-dimensionalize these quantities as follows: $X = \frac{x}{\ell_o}, Y = \frac{y}{b_o}, Z = \frac{z}{h_o}$, $T = \frac{t}{t_o}, \bar{u} = \frac{u}{u_o}, \bar{v} = \frac{v}{v_o}, \bar{w} = \frac{w}{w_o}, \bar{\eta} = \frac{\eta}{\eta_o}$ and $\bar{\rho} = \frac{\rho}{\rho_o}$.	✦ 2 M for the entire solution.	5 Minutes
3. (c)	$\rho \frac{Du}{Dt} = \rho\left(\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z}\right)$ $= \rho_0\bar{\rho}\left(\frac{u_0}{t_0}\frac{\partial \bar{u}}{\partial T} + u_0\bar{u}\frac{u_0}{\ell_0}\frac{\partial \bar{u}}{\partial X} + v_0\bar{v}\frac{u_0}{b_0}\frac{\partial \bar{u}}{\partial Y} + w_0\bar{w}\frac{u_0}{h_0}\frac{\partial \bar{u}}{\partial Z}\right).$ Multiply this by $\ell_0/(u_0^2\rho_0\bar{\rho})$ to get: $\frac{\ell_0}{u_0 t_0}\frac{\partial \bar{u}}{\partial T} + \bar{u}\frac{\partial \bar{u}}{\partial X} + \frac{v_0 \ell_0}{b_0 u_0}\bar{v}\frac{\partial \bar{u}}{\partial Y} + \frac{\ell_0 w_0}{h_0 u_0}\bar{w}\frac{\partial \bar{u}}{\partial Z}.$	✦ 4 M for the entire solution.	10 Minutes
3. (d), (e)	$\mathcal{R} \triangleq \frac{\text{inertia force}}{\text{viscous force}} = \frac{\rho_0 u_0 \ell_0}{\eta_0}$ math way of saying "defined as". We can't question this at our level. Modified Reynolds numbers $R_x \triangleq \frac{\rho_0 u_0 h_0^2}{\eta_0 \ell_0}$, $R_y \triangleq \frac{\rho_0 u_0 h_0^2}{\eta_0 b_0}$, $R_z \triangleq \frac{\rho_0 w_0 h_0}{\eta_0}$. The squeeze number $\sigma_s = \frac{\rho_0 h_0^2}{\eta_0 t_0}$	✦ $\frac{1}{2}$ M for each number.	3 Minutes
3. (f)	Multiply equation (7.2) by $R_x = \frac{\rho_0 u_0 h_0^2}{\eta_0 t_0}$ and then use the appropriate Reynolds number R_x, R_y and R_z and the squeeze number σ_s. We do this term by term in equation (7.2). We have: $\left(\frac{\ell_0}{u_0 t_0}\frac{\partial \bar{u}}{\partial T}\right)\cdot \overbrace{\frac{\rho_0 u_0 h_0^2}{\eta_0 \ell_0}}^{R_x} = \frac{\rho_0 h_0^2}{\eta_0 t_0}\frac{\partial \bar{u}}{\partial T} = \sigma_s \frac{\partial \bar{u}}{\partial \mathfrak{z} T}$, which	✦ 4 M for the entire solution.	5 Minutes

The End

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GAIN MORE KNOWLEDGE
REACH GREATER HEIGHTS

PRESIDENCY UNIVERSITY
BENGALURU

SCHOOL OF ENGINEERING

END TERM FINAL EXAMINATION

Semester: Odd Semester: 2019-20
Date: 23 December 2019

Course Code: MEC 315
Time: 9:30 AM to 12:30 PM

Course Name: TRIBOLOGY AND BEARING DESIGN
Max Marks: 80

Program & Sem: B. Tech. (MEC) & V (DE-II)
Weightage: 40%

Instructions:

*(i) **Answer all the questions.***

Part A [Memory Recall Questions]

(4Q=23M)

Answer all the Questions.

1. (a) Define tribology. (2 M)(C. O. No. 1) [Knowledge]
   (b) List the unknowns in the Navier-Stokes equations used to analyse hydrodynamic bearings. (4 M)(C. O. No. 2) [Knowledge]
   (c) List the types of antifriction bearings. (2 M)(C. O. No. 1) [Knowledge]
   (d) List the lubrication regimes in increasing order of frictional losses. (4 M)(C. O. No. 1) [Knowledge]

2. List the assumptions made in the analysis of hydrodynamic thrust bearings. (4 M)(C. O. No. 3) [Knowledge]

3. Sketch a hydrodynamic bearing showing all its salient features. (4 M) (C. O. No. 1) [Knowledge]

4. Sketch a hydrostatic bearing and explain how it is an improvement on the regular hydrodynamic bearing. (3 M) (C. O. No. 1) [Knowledge]

Part B [Thought Provoking Questions]

Answer all the Questions. (2Q=24M)

5. (a) Comment on the accuracy of the results from Petrov's equation when applied to the analysis of bearings in comparison to the results from more sophisticated analyses that have their foundations in the Reynolds equation. (6 M)(C. O. No. 3) [Comprehension]

   (b) Determine the power loss in a journal bearing whose specifications from the first cut analytical design are as follows:
   (i) journal diameter = 50 mm,
   (ii) width of the bearing = 100 mm,

(iii) rotational speed = 1500 RPM,

(iv) SAE 10 lubricating oil operating at 100^o C with a viscosity of 11.877 mPa·s,

(v) bearing load 3 kN, and,

(vi) the bearing clearance is one-hundredth of the journal radius.

(6 M)(C. O. No. 1) [Application]

(c) With the first cut analytical work done suggest the next steps to be taken to refine the results in the context of the contents of this Course. (4 M)(C. O. No. 3) [Application]

6. (a) Explain the set-up and working of the hydrodynamic thrust bearing with a neat sketch. Label all the parts in your sketch.

(6 M)(C. O. No. 2) [Knowledge]

(b) Bring out one difference between a hydrodynamic thrust bearing and a hydrodynamic journal bearing.

(2 M)(C. O. No. 2) [Comprehension]

Part C [Problem Solving Questions]

Answer all the Questions. (2Q=33M)

7. Derive an expression for power loss in a sector of a hydrodynamic thrust bearing in terms of bearing clearance h, lubricant pressure p, bearing length ℓ, lubricant viscosity η and shaft speed u_b.

The following information may be useful to you.

$$\int_b^a uv'dx = (uv)\,|_a^b - \int_a^b u'vdx.$$

$$(\tau_{xz})\,|_{z=o} = -\frac{h}{2}\frac{dp}{dx} - \eta\frac{u_b}{h}.$$

$$(\tau_{xz})\,|_{z=h_o} = -\frac{h}{2}\frac{dp}{dx} + \eta\frac{u_b}{h}.$$

(10 M)(C. O. No. 3) [Application]

8. The following questions will test your ability to analyse hydrodynamic thrust bearings.

(a) Determine an expression for the pressure distribution in a parallel surface slider bearing. (4 M)(C. O. No. 3) [Application]

(b) Based on the expression for pressure distribution comment on the suitability of the parallel surface slider bearing in a hydrodynamic thrust bearing.

(2 M)(C. O. No. 3) [Comprehension]

(c) Determine an expression for the pressure distribution in a fixed-incline slider bearing.

(15 M)(C. O. No. 3)[Application]

(d) Based on the expression for pressure distribution comment on the suitability of the fixed-incline slider bearing in a hydrodynamic thrust bearing.

(2 M)(C. O. No. 3) [Comprehension]

The End

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END TERM FINAL EXAMINATION

Extract of Question Distribution [Outcome Wise and Level Wise]

The numbers and titles of the modules in this Course are:

1. Unit 1: Fundamentals of Tribology,
2. Unit 2: The Reynolds Equation,
3. Unit 3: Analysis of Hydrodynamic Thrust Bearings.

Q. No.	C. O. No.	Module No. and Title	Memory Recall Type [Marks Allotted] Bloom's Level	Thought Provoking Type [Marks Allotted] Bloom's Level	Problem Solving Type [Marks Allotted] Bloom's Level	Total Marks
			K	C	A	
1	1, 2, 3	Units 1,2 and 3	12	-	-	12
2	3	Unit 3	4	-	-	4
3	1	Unit 1	4	-	-	4
4			3	-	-	3
5	1, 3	Units 1 and 3	-	6	10	16
6	2	Unit 2	6	2	-	8
7	3	3	-	-	10	10
8			-	4	19	23
		Total Marks	29	12	39	80

K: Knowledge Level, C: Comprehension Level, A: Application Level

Note: While setting all types of questions the general guideline is that about 60% of the questions must be such that even a below average students must be able to attempt, About 20% of the questions must be such that only above average students must be able to attempt and finally 20% of the questions must be such that only the bright students must be able to attempt.

Faculty Signature:

Reviewer Commend:

Annexure II: Solutions and Scheme of Marking

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SOLUTION

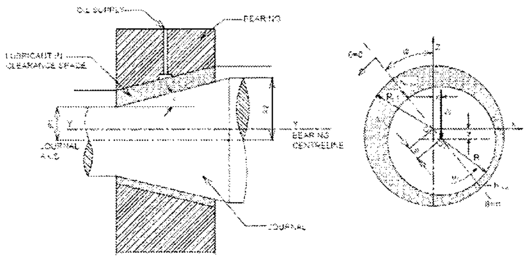
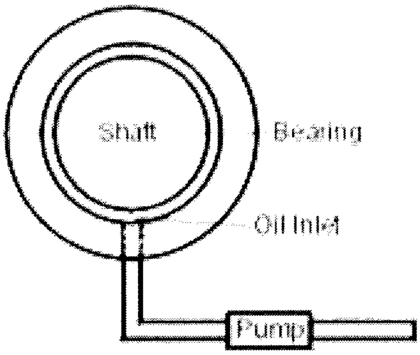
Sem & AY: Odd Sem, 2019-20
Course Code: MEC 315
Course Name: TRIBOLOGY AND BEARING DESIGN
Program & Sem: B. Tech. (MEC) & V (DE-II)

Date: 23.12.2019
Time: 9:30 AM to 12:30 PM
Max Marks: 80
Weightage: 40%

Part A

(4Q=25M)

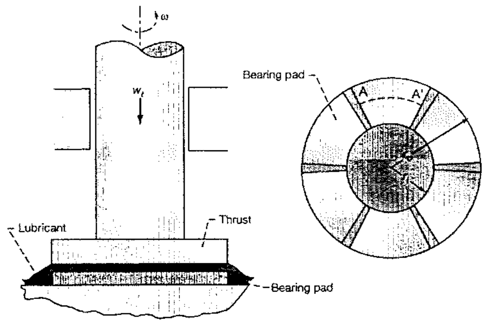
Q. No.	Solution	Scheme of Marking	Maximum Time Needed for Each Question
1. (a)	Tribology is defined as the science, technology and practices related to interacting surfaces.	✦ 2 M for the definition	5 Minutes
1. (b)	The lubricant pressure p and the three velocity components of the lubricant u, v and w.	✦ 4 M for naming the 4 unknowns	5 Minutes
1. (c)	Roller bearing and ball bearing.	✦ 2 M for naming the 2 bearings	5 Minutes
1. (d)	Hydrodynamic lubrication, elastohydrodynamic lubrication, partial lubrication, boundary lubrication.	✦ 4 M for the right sequence	5 Minutes
2	1. We assume no side leakage in our analysis using the Reynolds equation. 2. We assume the effects of pressure and temperature on density and viscosity of the lubricant to be negligible. I. e., we assume density and viscosity of the lubricant to be constant.	✦ 4 M for the 2 assumptions	5 Minutes

Q. No.	Solution	Scheme of Marking	Maximum Time Needed for Each Question
3		✦ 2 M for a sketch ✦ 2 M for the labels	10 Minutes
4	 This set-up reduces frictional losses and wear when starting and stopping the shaft.	✦ 1 M for a sketch ✦ 1 M for the labels ✦ 1 M for the explanation	10 Minutes

Part B

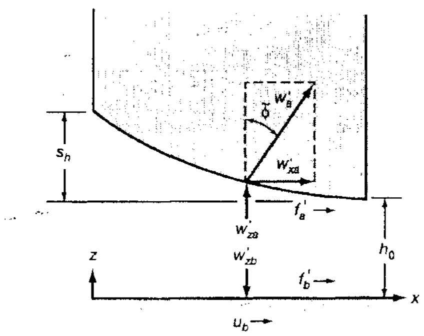
(2Q=24M)

Q. No.	Solution	Scheme of Marking	Maximum Time Needed for Each Question
5. (a), (b), (c)	Petrov's equation to determine the frictional force f in a journal bearing is $f = \dfrac{4\pi^2 r^2 \eta N b}{60c}$ where r is the radius of the bearing, η is the viscosity of the lubricant in the bearing, N is the angular speed of the journal in RPM, b is the journal width and c is the clearance in the journal.	✦ 2 M for accuracy of results from Petrov's work ✦ 2 M for discussing the accuracy of results from the Reynolds equation	30 Minutes

5. (a), (b), (c)	We find the frictional force $f = \frac{4\pi^2(25\times10^{-3})^2(11.877\times10^{-3})1500(100\times10^{-3})}{60(\frac{25}{100}\times10^{-3})}$ $\Longrightarrow f = 2.93$ N. The torque due to this friction is force is $T_f = fr = 2.93 \times .025 = 0.07325$ N·m. Finally, the power loss in the bearing is $P_\ell = T_f \frac{2\pi N}{60}$ $= 0.07325 \cdot \frac{2\pi(1500)}{60} = 11.5$ W. ☐	✦ 2 M for comparing the accuracy from the two methods ✦ 3 M for three formulas. ✦ 3 M for three values. ✦ 4 M for discussing the steps after the first cut solution.	
6. (a), (b)	 A hydrodynamics journal bearing takes loads in the radial direction while a hydrodynamic thrust bearing takes loads in the normal to the radius.	✦ 2 M for sketch ✦ 2 M for labels ✦ 2 M to explain the working principle of the hydrodynamic thrust bearing ✦ 2 M to bring out the difference between the hydrodynamic journal and thrust bearing	10 Minutes

Part C

(2Q=33M)

Q. No.	Solution	Scheme of Marking	Maximum Time Needed for Each Question
7		✦ 4 M for the figure ✦ 6 M for the derivation of the final expression	25 Minutes