SAULT COLLEGE OF APPLIED ARTS & TECHNOLOGY

SAULT STE. MARIE, ONTARIO

COURSE OUTLINE

Course Title:	MACHINE DESIGN
Code No.:	MCH 307
Program:	MECHANICAL TECHNOLOGY
Semester:	FIVE
Date:	JUNE, 1983
Author:	COLIN RISING

New: Revision

APPROVED, z^Vf $h9<3LtZfc'

Chairperson Date

MACHINE DESIGN
Course Name

MCH 307
Course Number

PHILOSOPHY/GOALS:

To have the student aware of, and able to solve fundamental problems of design with respect to: lubrication, bearings, stress concentratioins, their causes and applicable theories, and stress analysis.

METHOD OF ASSESSMENT (GRADING METHOD):

"A", "B", "C" & "X"

Grading will be on logical solutions, layout, sketches, diagrams and general tidiness of presentation.

TEXTBOOK(S):

Mechanical Engineering Design - Shigley (McGraw-Hill)

REFERENCE TEXT:

"Gear Handbook" - Dudley (McGraw-Hill)

"Design of Machine Elements" - Spotts (Prentice-Hall)

"Design of Machines Elements" - Faires (McMillan)

"Machine Design" - Myatt (McGraw-Hill)

MACHINE DESIGN

MCH 307

Topic No,	Periods	Topic Description
	15	Lubrication and Journal Bearings
	20	Anti-friction Bearing
	12	Review of Stress Analysis
	10	Stress, Concentration, Theories of Failure, Fatigue and Endurance Limits
		Selection of Materials Consideration of Production Methods

MACHINE DESIGN 1

Part #1 - "Lubrication & Journal Bearings"

GENERAL OBJECTIVES:

To have a basic understanding of lubrication and be able to carry out a basic journal bearings design.

SPECIFIC OBJECTIVES:

1- To be able to define: a) lubrication or b) lubricant.

2. To be able to list the type of relative motion in a:

   a) sleeve bearing
   b) antifriction bearing
   c) cam follower
   d) gear teeth
   e) piston

3. To be able to define:

   a) hydrodynamic lubrication
   b) boundary lubrication
   c) hydrostatic lubrication

   and list the criteria for obtaining the above conditions.

"VISCOSITY"

4. To be able to understand the derivation of the formula

   $= \frac{I}{A} = \frac{1}{h}$

   and to use it to solve viscosity.

5. To be able to list the English and metric units of viscosity.

6. To be able to use the formula: = 6.$\frac{Z}{9}$ 10)6

7. To have an understanding of how viscosity measurement in Saybolt Universal Second is carried out.

8. To be able to list that Saybolt Universal Seconds are units of Kinematic Viscosity and not absoltue viscosity such as Regas and poise.

9. To be able to use the formual $Z = (0.22t - \frac{180}{t})$ for converting between centripoises and S.V.S.

10. To be able to state what American Petroleum Institute gravity is.

11. To be able to use the formulas:

$$60 = \frac{141.5}{131.5 + P.A.P.I.} \quad \text{and} \quad _T = \quad _{60} - 0.00035 \ (T-60)$$

for finding specific gravity.

12. To be able to understand and discuss the development of Petroffs Law (Note: how pressure "P" is obtained).

13. To be able to discuss "Stable Lubrication" as opposed to unstable lubrication (article 10-4).

14. To be able to duscuss Thick-film lubrication as opposed to boundary lubrication (article 10-5).

15. To be able to duscuss "Hydrodynamic theory" as applied to journal bearings (article 10-6) and the pressure-distribution curves obtained by Mr. Tower.

16. To have a general knowledge of the development of Sommerfeld's equation:

r
cH

17. The student will bve able to list and discuss the basic design factors involved in the design of sliding bearings, as well as state which factors he, as a designer, has control over.

18. The student should have a sound understanding of the relationships between the variables used in journal bearing desing (article 10-8)

19. To be able to recognize the equation for the Bearing-Characteristic Number, or better known as the Sommerfeld Number, and solve for "S" given suitable information.

20. The student will be able to use Fig. 10-11 and obtain viscosity values, given temperatures and types of oils.

21. The student will be able to obtain a value for the Friction Variable £ from Fig. 10-15 given the "_" ratio and the value of "S".
c f

22. The student will be able to solve for the co-efficient of friction given the Friction Variable.

23. To be able to solve for friction torque (T).

i.e. $T = fwr$; power lost-i.e. $H.P. = \frac{TN}{1050}$; or heat generated

ie. $H = \frac{2 \quad TN}{(778)\ (12)}$

24. To be able to obtain the value of the Minimum Film Thickness Variable JTO from Figure 10-13 and solve for the minimum film
c
thickness "ho".

25. To be able to obtain a value of the Flor Variable $\frac{Q}{rcN}$ from Figure 10-16 and solve for the oil flow Q.

26. To be able to obtain a value of the Flow Ratio Qs from Figure 10-17 and solve for the side flow Qs. (J

27. To be able to obtain a value of the Pressure Ration $\frac{P}{P_{max}}$ from Figure 10-18 and solve for Pmax.

28. To be able to solve for the increase in temperature T when all the oil flow carries aw^y all the heat generated.

29. To be able to obtain the location of maximum BPmax and minimum 0Pmin film pressure from Figure 10-19.

30. To be able to solve for the increase in temperature (T) when side flow is considered*

31. To be able to understand and discuss the four assumptions listed at the end of article 10-8.

32. To be able to solve for the average temperature

i.e. $T_{av} = T_i + \frac{T}{2}$

33. To be able to solve for the correct viscosity value to use in a bearing design problem by taking temperature into account (article 10-9).

34. To be able to solve problems 10-1 to 10-18 or problems similar to them.

35. To read over the last half of chapter ten and have a general understanding of the information covered on specific journal bearing designs.

Part #2 - "Antifriction Bearings"

GENERAL OBJECTIVE:

To have a basic understanding of the fundamentals and terminology of antifriction bearings and to be able to select a bearing to suit a particular set of requirements.

SPECIFIC OBJECTIVES

1. To be able to state that the term antifriction bearing describes that class of bearing in which the main load is transferred through elements in rolling contact rather than sliding contact.

2. To understand that as a technologist he will mainly be a selector of bearings not a designer, since the field of design is so narrow and highly specialized.

3. To be able to state that bearings are manufactured to take (a) pure thrust loads, (b) pure radial loads, (c) combination of the first two.

4. To be able to list the four essential parts of a ball bearing.

5. To be able to list the ten main types of ball bearings, and state their main advantages and disadvantages, if any.

6. To be able to list the four essential parts of a roller bearing.

7. To be able to state the advantagesd and disadvantages of a straight roller bearing as compared to a simple ball bearing.

8. To be able to list the eight main types of roller bearings and state their advantages and disadvantages, if any.

9. To be able to state how friction affects the maximum operating speed of an antifriction bearing.

10. To be able to use the formual $T = \frac{uFB}{2}$ to solve for friction torque in an antifriction bearing.

11. To be able to use the formual $\frac{(B + D)_n}{2}$500.000 to find a rule of thumb value for maximum operating speed of a bearing.

12. To be able to define:

    a) Life of a Bearing
    b) The Rating of a Group of Identical Bearings
    c) The Average Life of a Group of Identical Bearings

13. To be able to use the formula $\frac{L_1}{L_2} = \left(\frac{F_2}{F_1}\right)^a$ to solve the life L_1 or L_2, or the load on the bearing F_2 and F_1.

14. To be able to use the formula L =c orc= L 1/3 to solve for the

T 7

Life (L) of a bearing with load (F) of the basic load (F) given the required life (L).

15. To be able to define:
    a) Basic Load Rating
    b) Equivalent Radial Load
    c) A.F.B.M.A.

16. To be able to use the formulas Re = VFr or Re = VFr + YFa to solve for the RADIAL EQUIVALENT LOAD.

17. To be able to use the formula = 10 = L

to solve for the life "L" of a bearing given a Reliability "R"

18. To be able to use a graph such as Figure 9-7 to solve for the basic load rating of a bearing given a certain life, reliability and equivalent radial load.

19. To list and be able to use the DIMENSION SERIES CODE to identify bearings.

20. To be able to list and use the five grades or classes of precision annual bearings, i.e. ABEC 1, 3, 5, 7 and 9.

21. To be able to list and use the two classes of cylindrical roller bearings, i.e. RBEC 1 and RBEC 5.

22. To be able to list and use the classes of tapered roller bearings, i.e. 4, 2, 3, 0, & 00.

23. To be able to use the formula $RRR = \frac{RE \times LF \times AF}{5F}$ to solve for required radial rtating at 500 RPM.

24. To be able to use the formula $RTR = \frac{T \times LF \times AF}{SF}$ to solve for the required thrust rating at 500 RPM.

25. To be able to use the formula:

    a) RE = 1.25R to solve for radial equivalent load when cup rotates.
    b) Tr = 0.47R/K to solve for thrust component in a tapered roller bearing carrying pure radial load R.
    c) $K = \frac{\text{Radial Rating of Bearing}}{\text{Thrust Rating of Bearing}}$ to solve for K required in the previous formula.

26. To be able to use the formula T = 0.47R to solve for the net thrust
" X ~
on a tapered roller bvearing when the included thrust Tr opposes the applied thrust T.

27. To be ale to use the formula: RE = R + K(T - 0.47R = 0.53 + KT

to solve for radial equivalent load with a rotating cone; or
RE = 1,25 R+ K(T - 0.47R = 0.78R + KT to solve for radial equivalent

load with a rotating cup.

28. To be able to solve problems such as example 9-4 in the text and others similar to it.

29. To have a general idea of how to select thrust bearings.

30. To be able to list the four general purposes of antifriction-bearing lubricant.

31. To be able to state three conditions which dictate the use of grease, and three for oil.

32. To have a general knowledge of enclosures and shaft and housing details with respect to antifrication bearings.

Part #3 - "Stress Analysis"

GENERAL OBJECTIVES:

To be able to analyze where maximum, stresses occur in machine members and to be able to calculate these maximum values.

SPECIFIC OBJECTIVES:

Mohr's Circle Diagram

1- To be able to state the definition of "STRESS".

2. To be able to resolve a stress vector into components perpindicular and parallel to a surface.

3. To be able to state and discuss three assumptions that are made when the formulas are:

$$= \frac{F}{A} \quad \text{and} \quad = \frac{F}{A}$$

4. To be able to state an example of a machine part being subjected to combimed stresses.

5. To be able to draw and label a "STRESS ELEMENT" properly oriented on the x-y axis for general situation.

6. To be able to draw and label a "STRESS ELEMENT" cut on any plane m-n and oriented on the x-y co-ordinates.

7. To be able to state that the two stresses *i* and 2 are called the "PRINCIPAL STRESSES" and the planes are called "PRINCIPAL PLANES".

8. To be able to list and use the formulas to solve for , , and max.

2

9. To be able to construct a Mohr's Circle Diagram to solve for $\pm_t$ 2 and max.

10. To be able to solve problems either with the equations or Mohr's Circle Diagram to find ^, 2 anc, max given x, y and xy. Also construct stress elements oriented in the principal directions.

Torsional Stress

11. To be able to list the formula and solve for torsional stress and state four assumptions that apply to the formula:

N = Tr =
r T~

12. To be able to list the formula: HP = 2 Tn (33,0UU) 112) where HP = horsepower; T = torque; and n = shaft speed R.P.M.

Bending Stress

13. To be able to state and discuss the formula relating shear forces and bending stress:

$$V = \frac{dM}{dx} \text{ and } \frac{dV}{dx} = \frac{d. \pounds M}{d_x 2} = -W$$

where V = the summing forces to the left of a section; M = the summation of all forces to the left of section multiplied by their respective distances to the left of the section: and w = the uniform load lbs/unit length.

14. To be able to state and use the formula for normal stress in a beam subjected to a bending moment and list 5 assumptions based on this formula:

+ Mc = + M I
= " T ~ TR h

where M = being moment (in lbs.), I - moment of inertia (in^) and I/c = section modules (in^).

15. To be able to determine the diameter of a solid round shaft, given the loading, the length and the design stress. Also, draw the shear force and loading diagrams.

16. To be able to solve for the location and value of the maximum bending moment of a shaft having horizontal and vertical components of shaft radial loads acting on it.

17. To be able to state the formula for shear stress in a beam when a bending moment varies along the length of the beam.

18. To be able to list the formula for maximum, shear stress in:

a) Rectangular beam - max =

b) Solid Circular beam - max =

c) Hollow Circular Section - max =

d) and I shapes - max = (Aw = area of the web only, approx.)

19. To be able to solve for the combined mormal stress at a point on the web of a WF, given the length, load, material in the beam and the design stress.

20. To be able to use the Method of Superposition to calculate stress.

Strain

21. To be able to list the formula and use it to solve for:

a) Unit strain b) Shear Strain

where = Unit Strain (in/in); = Total Elongation (in);
= Length of Bar (in)

22. To be able to define "ELASTICITY".

23. To be able to list and use the following formulas:

a) Stress strain i) = E ; E = Modules of Elasticity
ii) = G ; G ~ Modules of Rigidity

b) Total elongation = AE

c) Total Sheat Deformation = GJ (Radians)

$\frac{585\ T}{4}$ (Degrees) solid round bar
Gd

d) Poisson's Ratio = $\frac{\text{Lateral Strain}}{\text{Axial Strain}}$

e) Relationship between E. G. and E = 2G (1 +)

Stress in Thin Walled Cylinders:

24. To be able to list and describe Hoop Stress (Tangential) and Transverse stress (Longitudinal).

25. To be able to list and use the formulas:

    a) Tangential Stress $i = \frac{pD}{7t}$

    b) Longitudinal Stress 2 - $\frac{pD}{4t}$

    and state the assumptions that are understood.

Curved Beams

26. To have a general understanding of how the formula for curved beams are derived.

27. To be able to list and use the formulas for finding maximum stress in curved beams.

$$= \frac{My}{Ae \quad ir\text{-}y)} \qquad r= \frac{A}{dA/V} \qquad e = R - r$$

$$\frac{Mhi}{I \quad - Aert} \qquad \frac{Mho}{0 = Aero}$$

Inner Fibre — Outer Fibre

28. To be able to calculate the stress in the outer or inner firbre of a curved beam subjected to a given moment and having a definite x-section.

29. To be able to solve for the stress in the outer and inner fibres of a curved beam by the approximate method.

Thermal Stesses and Strains:

30. To be able to list and use the following formulas:

    a) UNIT ELONGATION OF AN UNRESTRICTED BAR: = T

    b) STRESS OF A RESTRICTED BAR SUBJECTED TO TEMPERATURE CHANGES
       E = TE

    c) STESS IN A UNIFORM FLAT PLATE RESTRAINED AT THE EDGES AND SUBJECTED TO A TEMPERATURE RISE: = TE
       T=—

31. To be able to define a THERMAL STRESS.

Part #4 - "STRESS, Concentration, Theories of Failure, Fatigue and Endurance LinritT"

GENERAL OBJECTIVE:

To have a basic understanding of the theory and use of stress concentration factores, and to have a general understanding of the theories of failure and fatique.

SPECIFIC OBJECTIVES:

1. To be ale to list and recognize the notation used in this area to designate "NORMAL STRESS", etc.

2. To be able to define "STRESS RAISERS" and "STRESS CONCENTRATION".

3. To be able to list and use the following formulas to find:

   a) K = max (STRESS CONCENTRATION FACTOR FOR NORMAL STRESS)

   b) K = max (STRESS CONCENTRATION FACTOR FOR SHEAR STRESS)

4. To be able to state that the subscript t in K_t means that this stress concentration factor depends for its value on the geometry of the part. The material used has no effect on Kf

5. To be able to state that the normal stress Q and Q is calculated by using the elementray stress equation and the NET AREA or NET CROSS SECTION.

6. To be able to use the formal a max = o d + 2b a) to solve for the maximum normal stress in an infinite slate steessed uniformly in tension with a small elliptical howl in the plate.

7. To be able to use the above formula to solve for:

   a) maximum stress where a = b, i.e. a circular hold
   b) maximum stress where a b, i.e. a transverse crack
   c) maximum stress where b a, i.e. a longitudinal crack

8. To be able to describe the following methods of determining stresses at a point:

   a) PHOTOELASTICITY
   b) GRID METHOD
   c) BRITTLE COATING
   d) BRITTLE MODEL
   e) STRAIN GUAGE

9. To be able to use the "INTUITIVE METHODS" to determine stress concentrations.

10. To be able to use the "STRESS CONCENTRATION CHARTS" to solve for maximum stresses taking stress concentration factors into account.

11. To be able to solve for the maximum stress at given points on a rotating shaft which has specified laods acting at specific points.

Failure Theories:

12. To be able to state the MAXIMUM STRESS THEORY

13. To be able to list the formulas \ 2 anc* because of theory disregard

    Criteria of Failure is: =Syp *1*

    =Su 2

    Equation #1 defines failure of a member if the material has a yield strength and if yielding of the member will destroy its usefulness.
    Equation #2 defines failure whenever yield strength of the material is not defined.
    Equation #1 and #2 hold for either tension or compression.
    {* WHEN PRINCIPLE STESSSES HAVE OPPOSITE SIGNS, RESULTS OR THEORIES DO NOT AGREE WITH TEST RESULTS.)

14. To be able to determine the diameter of a solid round section of a machine part twisted by a static torsion load and acted upon by a bending load, given the material, the factor of safety to be used, and using the Maximum stress theory.

15. To be able to state the "MAXIMUM SHEAR THEORY".

16. To be able to state that in a specimen stressed in simple tension, the maximum shearing stress occurs when the material begins to yield, if yield is the criteria of failure.

17. To be able to list and use the formulas.

    a) max =

    b) max = 1/2 (-) (Maximum combined shearing stress for biaxial stresses.)

    c) Syp = (or when failure is defined by ultimate strength.)

    Su =

* THE MAXIMUM SHEAR THEORY IS ON THE SAFE SIDE OF TEST RESULTS.

18. To be able to determine the diameter of a solid round section of a machine part twisted by a static torsion load and acted upon by a bending load, given the material factor of safety and using the Maximum Shear theory.

19. To be able to state the "DISTORTION ENERGY THEORY".

20. To be able to stete the failure of the material is caused by only the energy which causes shearing deformations.

21. To be able to list and use the formula:

Syp2 = + for two dimensional

stress.

22. To be able to state.

a) the Maximum stress theory is the poorest agreement with test results but is most often used for brittle materials for conditions of fatigue loading.

b) for ductile materials having the same strength in tension as in compression either the maximum shear or the distortion energy theory should be used.

c) the distortion energy theory gives the most accurate results but the maximum shear theory is the easiest to apply.

Fatigue:

23. To be able to define "FATIGUE FAILURE".

24. To be able to state that fatigue failure is characterized by: a) progressive development of a crack, and b) sudden fracture.

25. To be able to define "FATIGUE OR ENDURANCE STRENGTH".

26. To be able to define "ENDURANCE LIMIT".

27. To be able to solve for average stress ( ) and the fluctuating component (r) in the formulas.

a) $AV = \frac{max + min}{2}$

b) $r = \frac{max - min}{2}$

For: Fluctuating Stessses, Repeated Stresses and Reversed Stresses

28. To be able to state the methods of constructing an average stress vs. variable stress graph.

29. To have a basic understanding of the "MODIFIED GOODMAN LINE".

30. To be able to use the SODERBERG LAW to design for fatigue conditions

a) $\frac{r}{S_{yp} - S_{AV}} = \frac{S_e}{S_{yp}}$

b) $r = S_e \left(1 - \frac{S_{AV}}{S_{yp}}\right)$

31. To be able to use the following formula to take a factor of safety into account when designing for fatigue conditions.

$$r' = \frac{S_e}{F.S.}\left(1 - \frac{S'_{AV}}{\frac{S_{yp}}{F.S.}}\right)$$

32. a) to be able to find the safe area of a bar given a tensile load wich varies between a minimum and maximum, the yield strength and enduring limit, in reversed bending and the factor of safety.

b) To be able to solve the above problem by means of a graph.