

SAULT COLLEGE
of Applied Arts and Technology
Sault Ste. Marie

COURSE OUTLINE

MACHINE DESIGN I

MCH 307 - 3

revised June 1981 by C. Rising

MACHINE DESIGN

MCH 307-3

(Mechanical Technology)

TEXT

"Mechanical Engineering Design" - Shigley - (McGraw-Hill)

OTTrePENra 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 I

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Topic No.	Periods	<u>Topic Description</u>
1	6	Lubrication and Journal Bearings
2	8	Anti-friction Bearing
3	10	Review of Stress Analysis
4	5	Stress, Concentration, Theories of Failure, Fatigue and Endurance Limits Selection of Materials Consideration of Production Methods

MACHINE DESIGN I

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 $J = \frac{rO}{A} = \frac{p}{Ac} \frac{v}{n}$ 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: $X = \frac{Z}{10^{(Z-10)}}$ {.
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 absolute viscosity such as Regas and poise.
9. To be able to use the formula $2 = j (0.22t - \text{---})$ for converting between centripoises and S.V.S.
10. To be able to state what American Petroleum Institute gravity is.
11. To be to use the formulas:
 $f^{60} = 131.5 \text{ "P" .L.I.}$ and $? T = ^60 \text{ " o_o}^{0035} (T_{60})$ for finding specific gravity.
12. To be able to understand and discuss the development of Petroff's Law (Note: how pressure "P" is obtained).
13. To be able to discuss "Stable Lubrication" as opposed to unstable lubrication (article 1.-4).

- 14 To be able to discuss Thick-film lubrication as opposed to boundary lubrication (article 10-5).
- 15 To be able to discuss "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:

$$\frac{f}{c} = \frac{P}{rcN^2}$$

- 17 The student will be 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 design (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 $\frac{f}{c}$ from Fig. 10-15 given the $\frac{f}{d}$ ratio and the value of "S".
- 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. $f_w r$; power lost-i.e. H.P. = $\frac{TN}{1050}$ or heat generated i.e. H= $\frac{2\pi rTN}{(778)(12)}$
- 24. To be able to obtain the value of the Minimum Film Thickness Variable $\frac{h_o}{c}$ from figure 10-13 and solve for the minimum film thickness "ho".
- 25. To be able to obtain a value of the Flor Variable rcN^2 from figure 10-16 and solve for the oil flow Q.
- 26 To be able to obtain a value of the Flow Ratio $\frac{Q_s}{Q}$ from figure 10-17 and solve for the side flow Qs.
- 27 To be able to obtain a value of the Pressure Ratio $\frac{P}{P_{max}}$ from figure 10-18 and sol' for Pmax.
- 28. To be able to solve for the increase in temperature ΔT when all the oil flow carries away all the heat generated.

i.e. $\Delta T = 0.103P \frac{r}{Q/rcN^2}$
- 29. To be able to obtain the location of maximum P_{max} and minimum S_{min} film pressure from figure 10-19.
- 30. To be able to solve for the increase in temperature (ΔT) when side flow is considered.

$$\text{i.e. } \Delta T = \frac{0.103P}{1 - (2\frac{f}{c})} \frac{A f}{Q/rcN^2}$$

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.

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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.

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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 advantages 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 formula $T = \frac{liFB}{9}$ to solve for friction torque in an antifriction bearing.
11. To be able to use the formula $(\frac{R}{n}) < 500,000$ to find a rule of thumb value for maximum operating speed of a Searing.
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 $L_2 = L_1 \left(\frac{F_1}{F_2}\right)^{1/3}$ to solve the life L_2 , or L_1 , or the load on the bearings F_2 and F_1 .
14. To be able to use the formula $L = \left(\frac{C}{F}\right)^3$ or $\frac{C}{F} = L^{1/3}$ to solve for the Life (L) of a bearing with load (F) of the basic load (C) 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 $R_e = V F_r$ or $R_e = X V T_r + Y F_a$ to solve for the RADIAL EQUIVALENT LOAD.
17. To be able to use the formula $L_{10} = \frac{L}{6.84} \left(\frac{C}{F}\right)^{10/3}$ 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 & C
23. To be able to use the formula $RRR = \frac{C}{F}$ to solve for the required radial rating at 500 RPM.
24. To be able to use the formula $RTR = \frac{C}{F} \left(\frac{V}{V_{AT}}\right)^{10/3}$ to solve for the required thrust rating at 500 RPM.
25. To be able to use the formula:
- a) $R_E = 1.25R$ to solve for radial equivalent load when cup rotates.
 - b) $T_r = 0.47R/K$ to solve for thrust component in a tapered roller bearing carrying pure radial load R.
 - c) $K = \frac{R}{T_r} \left(\frac{V}{V_{AT}}\right)^{10/3}$ to solve for K required in the previous formula.
26. To be able to use the formula $T = K T_r$ to solve for the net thrust on a tapered roller bearing when the included thrust T_r opposes the applied thrust T .
27. To be able to use the formula: $P_E = R + K(T_r - T) = 0.53 + KT$ to solve for radial equivalent load with a rotating cone; or $R_E = 1.25 R + K(T - \frac{0.47R}{K}) = 0.78R + KT$ to solve for radial equivalent load with a rotating cup.

Part #2 Continued

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 antifriction bearings.

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Section #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 perpendicular and parallel to a surface.
3. To be able to state and discuss three assumptions that are made when the formulas are:

$$G = \frac{F}{A} \quad \text{and} \quad \frac{\Delta S}{J} = \frac{F}{A}$$
4. To be able to state an example of a machine part being subjected to combined stresses
5. To be able to draw and label a "STRESS ELEMENT" properly oriented on the x-y axis for a 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 (σ_1 and σ_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 σ_1 , σ_2 , & σ_{xy}

$$\sigma_{1,2} = \frac{\sigma_x + \sigma_y}{2} \pm \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}^2}$$
9. To be able to construct a Mohr's Circle Diagram to solve for G , σ_1 and J_{max} .
10. To be able to solve problems either with the equations or Mohr's Circle Diagram to find σ_1 , σ_2 and J_{max} given (σ_x , σ_y and τ_{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:

$$\tau = \frac{T r}{J}$$

12. To be able to list the formula: $HP = \frac{Tn}{550}$ 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:

$$V = \frac{dM}{dx} \quad \text{and} \quad \frac{dV}{dx} = -\frac{d^2M}{dx^2} = -w$$

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 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:

$$\sigma = \frac{My}{I}$$

where M = bending moment (in lbs.); I = moment of inertia (in⁴) and I/c = Section modulus (in³).

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.

$$\tau = \frac{VQ}{J} \frac{fc}{y}$$

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

- a) Rectangular beam - $\tau_{max} = \frac{3V}{2A}$
- b) Solid Circular beam - $\tau_{max} = \frac{4V}{3A}$
- c) Hollow Circular Section - $\tau_{max} = \frac{2V}{A}$
- d) and I shapes - $\tau_{max} = \frac{VQ_w}{J}$ (Aw = area of the web only, approx.)

19. To be able to solve for the combined normal 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 $\epsilon = \frac{\Delta L}{L}$ b) Shear Strain $\gamma = \frac{\Delta x}{h}$
 where ϵ = Unit Strain (in/in); ΔL = Total Elongation (in); L = Length of Bar (in)

31. To be able to define a THERMAL STRESS

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Section #4

GENERAL OBJECTIVES:

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

SPECIFIC OBJECTIVES:

1. To be able 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;

$$a) K_t = J_{t, \sigma} \quad (\text{STRESS CONCENTRATION FACTOR FOR NORMAL STRESS})$$

$$b) K_{ts} = J_{t, \tau} \quad (\text{STRESS CONCENTRATION FACTOR FOR SHEAR STRESS})$$

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 K_t .

5. To be able to state that the normal stress $\sigma_{max} = \sigma_0 (1 + K_t)$ is calculated by using the elementary stress equation and the NET AREA or NET CROSS SECTION.

6. To be able to use the formula $\sigma_{max} = \sigma_0 (1 + K_t)$ to solve for the maximum normal stress in an infinite plate stressed uniformly in tension with a small elliptical hole 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 hole
- b) maximum stress where $a \ll b$, i.e. a transverse crack
- c) maximum stress where $b \ll a$, 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 GAUGE

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 loads acting at specific points.

Failure Theories:

12. To be able to state the **MAXIMUM STRESS THEORY**.

13. To be able to list the formulas $S_{yp} = \sigma_1$ and because of theory disregard

Criteria of failure is: $\sigma_1 = S_{yp} (T)$

$$G_{\pm} \leq S_u (j)$$

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 PRINCIPAL STRESSES 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) $J_{max} = \frac{r_f S_{yp}}{h}$

b) $J_{max} = h \left\{ \begin{array}{l} \sigma_1 \\ \tau_{xy} \end{array} \right.$ (Maximum combined shearing stress for biaxial stresses.)

c) $S_{yp} = \frac{\sigma_1 - \sigma_2}{2}$ (or when failure is defined by ultimate strength.)
 $S_u = \sigma_1 - \sigma_2$

* 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 state 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:

$$S_{yp} = 0.577 \sqrt{\frac{\sigma_1^2 + \sigma_2^2 - \sigma_1 \sigma_2}{3}}$$

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 (S_{av}) and the fluctuating component (G_r) in the formulas:

$$a) S_{AV} = \frac{S_{max} + S_{min}}{2} \quad b) G_r = \frac{S_{max} - S_{min}}{2}$$

For: Fluctuating Stresses, 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.

$$a) \frac{C_r S_{AV}}{S_e} \leq \frac{S_{AV}}{S_e} \quad \text{or} \quad b) G_r = \frac{S_{AV}}{S_e} \left(1 - \frac{S_{AV}}{S_e} \right)$$

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

$$\frac{S_{AV}}{F.S.} \leq \frac{S_e}{F.S.} \left(1 - \frac{S_{AV}}{S_e} \right)$$

32. a) To be able to find the safe area of a bar given a tensile load which 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.