M.E. 80 - DYNAMICS OF MACHINERY

SEPTEMBER 1959

Instructor________Office________Phone________Hours________

TEXTS: Mechanisms and Dynamics of Machinery, Mabie and Ocvirk, Wiley.
Machine Analysis and Design Problems, Alvord, Pearson, Hall.

OBJECTIVES: (1) To Apply the Principles of Dynamics to Machine Elements and Assemblies.

(2) To Study Some Typical Accepted Designs.

(3) To Further Develop Engineering Analytical Ability.

SCHEDULE

Date	Period	Reading Assign. Chapt.	pp.	Topic	Prob. Assign.
	1	---	---	Introduction: Schematics	#8a
	2	3	40-47	Cams	#7a4
	3	3	48-55	Motion	#8 bcd
	4	Lecture		Differentiation By Finite Diff.	#8e,f,g
	5	10	209-223	Velocity - Cams and Linkages	#14
	6	10	223-227	Velocity - Rolling	#17
	7	---	---	Bluebook #1 Lect. 1-4	---
	8	Lecture		Related Scales and Acceleration	#23
	9	10	Ex. 1,2	Acceleration - Quadric Linkage	---
	10	10	227-231	Acceleration - Coriolis	#24
	11	10	231-234	Acceleration - Sliders	---
	12	---	---	Acceleration	---
	13			Bluebook #2 Lect. 6-11	

Date	Period	Reading Assign. Chapt.	pp.	Topic	Prob. Assign.
	14	Lecture		Static Force Analysis	#33
	15	Lecture		Friction	#41
	16	11	267-276	Inertia Force Analysis	51
				8 WEEKS!	
	17	11	276-280	Inertia Force Analysis	53
	18	11	280-284	Superposition	---
	19		-----	Dynamic Superposition	59
-----	----	------		THANKSGIVING	-------
	20			Bluebook #3 Lect. 12-18	
	21		-----	Dynamic Force Analysis	59
	22	11	284 ---	Engine Dynamics	---
	23	11	--- 298	Engine Dynamics	---
	24	11	299-305	Flywheels	#63
	25	12	341-351	Balancing	#68, 70
-----	----	---------		CHRISTMAS	--------
	27			Bluebook #4 Lect. 19-24	
	28	12	351-353	Balancing	#~~8~~73
	29	12	353-365	Balancing	
	30	--	--------	Balancing	

Date	Period	Subject	Read	Problems
____	17	Dynamic Force Analysis	Chap. 11 par. 7-8	
____	18	Dynamic Force Analysis	Chap. 11 par. 9	
____	19	Dynamic Force Analysis	Chap. 11 par. 10-12	
____	20	Energy Storage - Flywheels	Chap. 13 par. 11 (See also p. 490, prob. 12-21)	
____	21	Energy Storage - Flywheels		
____	22	Bluebook #3		
____	23	Balancing - Rotation	Chap. 12 par. 1-7	
____	24	Balancing - Reciprocation	Chap. 12 par. 11-14	
____	25	Engine Balance	Chap. 12 par. 15-31	
____	26	Engine Balance		
____	27	Vibrations - Free	Chap. 14 par. 1-5	
____	28	Vibration Analysis - Forced	Chap. 14 par. 6-8	
____	29	Bluebook #4		
____	30	Vibration Analyses - Self Excited		
____	31	Vibration Analyses - Critical Speeds		

Date	Period	Subject	Read	Problems
____	18	Dynamic Force Analysis	Chap. 11 par. 10-15	48
____	19	Dynamic Force Analysis	Chap. 11 par. 10-15	60
____	20	Flywheel Analysis	Chap. 13 par. 11	63,67
			(See also p. 490, prob. 12-21)	
____	21	Balancing Rotating Masses	Chap. 12 par. 1-7	69,70
____	22	Bluebook #3		
____	23	Balancing Machines	Chap. 12 par. 11-14	72
____	24	Reciprocating Balance	Chap. 12 par. 15-31	73
____	25	Vibration Analysis	Chap. 14 par. 1-5	75
____	26	Vibration Analysis	Chap. 14 par. 6-8	76
____	27	Vibration Analysis		78
____	28	Vibration Analysis		79
____	29	Bluebook #4		
____	30	Review		
____	31	Final Examination		

ME 80 - Dynamics of Machinery

Instructor________________________Office__________Hours____________

Text: Mechanics of Machinery, Ham, Crane & Rogers, McGraw Hill.

Course Objectives:
1. To acquire facility in the application of dynamics to machinery.
2. To obtain knowledge of common practice in the construction of machinery.

Schedule: (The reading assignments listed should be read before the period indicated.)

Date	Period	Subject	Read	Problems
____	1	Introduction and Motion Analysis	Chap. 1	1,2
____	2	Motion Analysis	Chap. 2 par. 1-36	3,4
____	3	Motion Analysis	Chap. 3	7
____	4	Cam Analysis	Chap. 3	8
____	5	Velocity Analysis	Chap. 8 par. 1-14	11, 10
____	6	Velocity Analysis	Chap. 8 par. 15-26	12,16
____	7	Velocity Analysis	Chap. 8 par. 23	17, 19
____	8	Bluebook #1		
____	9	Acceleration Analysis	Chap. 9 par. 1-8	23
____	10	Acceleration Analysis	Chap. 9 par. 1-8	24
____	11	Acceleration Analysis		25
____	12	Acceleration Analysis	Chap. 8 par. 27 Chap. 9 par. 17	27
____	13	Static Forces	Chap. 10 par. 1-4	33
____	14	Static Forces	Chap. 10 par. 6-16	35
____	15	Bluebook #2 - Closed Book		
____	16	Inertia Forces	Chap. 11 par. 1-9	44,47
____	17	Inertia Forces	Chap. 11 par. 1-9	50

ME 80 - Dynamics of Machinery

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Date	Period	Subject	Read	Problems
____	1	Introduction & Motion Analysis	Chap. 3	
____	2	Cams	Chap. 3	A-1,2,3
____	3	Graphical Differentiation	Lecture	A-4
____	4	Diff. by Finite Differences	Lecture Chap. 3	A-5
____	5	Velocity Analysis - Quadric Linkages	Chap. 8 par.1-14	12
____	6	Velocity Analysis - Cams	Chap. 8 par. 10	B
____	7	Velocity Analysis - Rolling	Chap. 8 par. 23	21
____	8	Bluebook #1		
____	9	Acceleration Analysis - Quadric Linkages	Chap. 9 par. 1-8	
____	10	Acceleration Analysis - Coriolis	Lecture	
____	11	Acceleration Analysis - Sliders	Chap. 9 par. 11-14	
____	12	Acceleration Analysis - Cams	Chap. 9 par. 15 Chap. 9 par. 17	
____	13	Inertia Forces	Chap. 11	
____	14	Inertia Forces	Chap. 11 par. 5-6	
____	15	Bluebook #2		
____	16	Static Forces & Friction	Chap. 10	

MACHINE ANALYSIS AND DESIGN PROBLEMS

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THE UNIVERSITY OF MICHIGAN

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CONTENTS

PREFACE

This problem book and the accompanying illustrations are intended for use in courses in DYNAMICS OF MACHINERY and MACHINE DESIGN.

The presentation of these problems is believed to be unique in three respects: (1) most of the problems refer to one or more machines shown by assembly drawings, (2) the Dynamics of Machinery problems emphasize the application of dynamics to actual machines, and (3) the Machine Design problems emphasize synthesis of machine elements as well as analysis of these elements. It is felt that this presentation will help to make the student familiar with the construction and use of machinery and its elements, and will make the analysis of accelerations, inertia, forces, vibrations, etc., more meaningful to the student, and will teach the student how to combine his knowledge of mechanics, materials, and manufacturing with his own judgement and common sense to design machinery. Knowledge of the performance of common driving and driven machines, a better understanding of machine drawings, and an improved ability to write brief, clear, descriptions and explanations should also result from this presentation.

In addition to the problems in this book, each instructor will be able to make up many other problems based on the illustrations, if he so desires. It is hoped that such problems will use this same presentation, and not revert to the formula plugging and manipulation exercises so commonly found in machine design courses. It is also felt that the descriptions asked for in the Machine Design problems are very worthwhile, but should be omitted when a particular machine has already been described in a previously assigned problem.

The authors wish to express their thanks to the many industrial concerns whose drawings and illustrations were used to provide the illustrations for these problems.

DYNAMICS OF MACHINERY

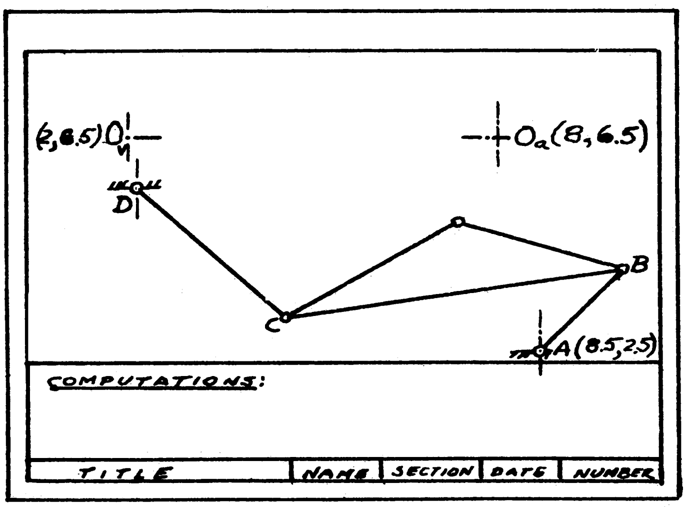
GENERAL DIRECTIONS

All problems have been planned for $8\frac{1}{2}$ x 11 paper with the long edge vertical except where otherwise indicated. Transparent paper will be convenient so that space line diagrams can be traced directly from the drawings. Curves should be drawn on standard decimal graph paper of the same size.

Figure, space and vector diagram scales are given in the following form: Space scale is 2 inches per inch. This means 2 inches on the machine per inch measured on the figure, or the machine is twice the size of the drawing. Velocity scale is 20 inches per second per inch. The velocity then is the length of the vector multiplied by 20 inches per second. Accelerations and forces are treated similarly with appropriate units. Where scales are to be determined by the student, they should be selected to give the largest drawing, diagram, or curve possible for the space available.

In most problems it is necessary to determine machine dimensions as part of the required data. It is intended that this be done by measurement of the figure and multiplication by the scale.

Location of vector polygon poles and other points are given by x and y coordinates with the lower left corner as the origin. The figure below is a typical layout.



I - MOTION ANALYSIS AND CAMS

PROBLEM 1

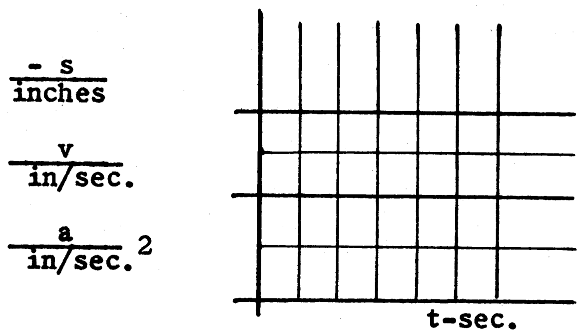
a. A cam displacement easement curve has the following characteristics:

The acceleration, a, = 2 inches per second per second.

Time range-sec.	Action	Displacement	Motion	Equation
from t=0 to t=1	advance	1 inch	parabolic	$s = t^2$
from t=1 to t=2	advance	1 inch	parabolic	$s = -2+4t-t^2$
from t=2 to t=3	dwell	-	-	$s = 2$
from t=3 to t=6	return		symmetrical	about t=3

1. Plot the displacement-time curve.
2. Derive the velocity-time curve analytically and plot.
3. Derive the acceleration-time curve analytically and plot.
4. Check a few significant points by graphical differentiation.

Note: lay the curves out on graph paper in the manner shown below. Draw the cruves as large as the graph paper will permit.



PROBLEM 2

a. A cam displacement easement curve has the following characteristics:

Time range-sec.	Action	Displacement	Motion	Equation
from t=0 to t=2	advance	2 inches	S H M	$s=1-\cos\frac{\pi}{2}t$
from t=2 to t=3	dwell	none	none	s=2
from t=3 to t=6	return	-	symmetrical	about t=3

1. Plot the displacement-time curve.

2. Derive the velocity-time curve analytically and plot
3. Derive the acceleration-time curve analytically and plot
4. Check a few points by graphical differentiation

Note: Lay the curves out as indicated in problem 1.

PROBLEM 3

a. A cam displacement easement curve has the following characteristics:

Time range-sec.	Action	Displacement	Motion	Equation
from t=0 to t=2	advance	2 inches	cycloidal	$s=t-\frac{1}{\pi}\sin\pi t$
from t=2 to t=3	dwell	none	none	s=2
from t=3 to t=6	return	-	symmetrical	about t=3

1. Plot the displacement-time curve
2. Derive and plot the velocity-time and acceleration-time curves in the manner indicated in problem 1.
3. Check the velocity and acceleration by graphical differentiation at t=0, t=0.5; t=2.00; and t=2.25.

PROBLEM 4

a. Compare the curves of problems 1, 2, and 3

1. Assuming the weight of the follower to be 1.5 lbs., which of these motions will result in the largest dynamic force on the follower and what is its value ?
2. Which of these three motions will give the greatest pulse values ? Explain.

PROBLEM 5

a. Lay out the cam profile to give the motion described in problem 1 to a roller follower. Base circle for the roller center of the cam has a 4 inch radius with center O_b (4,5.5). The path is vertical and radial.

Follower roller has a 0.5 inch radius. S_s = 2 inches/inch.

PROBLEM 6

a. Lay out the cam profile to give the motion described in problem 2 to a roller follower. Base circle for the roller center of the cam has a 4" radius with center O_b (4,5.5). The path is vertical and offset by 1.5 inches from the vertical radius of the base circle. Follower roller radius is 0.5 inches. S_s = 2 inches /inch.

PROBLEM 7, FIGURE 1, DIESEL ENGINE

a. The required motion for the diesel engine injector cam roller center is as follows:

Cam rotation, degrees	0	5	10	15	20
Roller lift, inches	0.0000	0.0038	0.0150	0.0338	0.0599

25	30	35	40	45	50	55	60
0.0924	0.1254	0.1584	0.1854	0.2028	0.2178	0.2328	0.2478
65	70	75	79	80	86	90	96
0.2627	0.2742	0.2807	<u>0.2823</u>	0.2833	0.2774	0.2702	0.2534
100	106	110	116	120	126	130	136
0.2382	0.2094	0.1867	0.1525	0.1297	0.0955	0.0729	0.0441
140	146	150	156	158			
0.0288	0.0121	0.0049	<u>0.0001</u>	0.0000			

1. Trace the flow of force from cam to injector piston.
2. Plot the displacement-time curve for one revolution of the cam. See the figure of problem 1 for the layout of the curve.
3. Draw the velocity-time and acceleration-time curves by graphical differentiation.
4. Design the cam profile to produce this motion. Locate the center of the base circle, O_b, at 4,6. S_s = 0.2 inches/inch. Note that the drawing will be 5 times larger than the machine piece.
5. Determine the maximum inertia force of the follower slide cylinder and roller assembly.

PROBLEM 8, FIGURE 24, INDEXING MECHANISM

The figure scale is 1 inch per inch. The automatic screw machine tool turret table rack is driven by the gear sector. The sector is an integral part of the cam follower rocker which is driven by the cam. The camshaft rotates at 2 rpm. The length of the rack is 1.300 inches. The total weight of the moving parts on the table is 15 lbs.

Required:

a. Construct a skeleton linkage diagram of the cam, gear sector rocker, and rack for the position shown at full scale. Locate the camshaft center at 6:3, paper horizontal.

b. Lay out the path of the follower roller center showing successive positions for every 30 degrees of cam rotation and for any other critical intermediary positions.

c. Lay out the path of the rack showing positions corresponding to those of "b". Use the right end of the rack as a point of reference.

d. Draw a displacement-time curve for the rack.

e. Graphically differentiate the displacement-time curve and draw the velocity-time curve.

f. Graphically differentiate the velcoity-time curve for the acceleration-time curve and draw it.

g. Determine approximately the value of the maximum inertia force of the table assembly.

II - VELOCITY ANALYSIS

PROBLEM 9, FIGURE 1, DIESEL ENGINE

Engine rpm is 2200. S_s = 2.5 inch/inch. Determine the relative (sliding) velocity between the connecting rod bushing and the crank pin.

PROBLEM 10, FIGURE 1, DIESEL ENGINE

Engine rpm equals 1800. S_s equals 2.5 inch/inch.

Locate the space diagram with crank center at 2,4. Locate the velocity vector polygon poles at 5,10 for (a), 5,7 for (b), 5,2 for (c).

Required:

a. Determine the velocity of the piston for a crank position of 45 degrees from top dead center. The crank pin velocity vector length is 2".

b. Same for crank angle of 120 degrees.

c. Same for crank angle of 270 degrees.

PROBLEM 11, FIGURE 1, DIESEL ENGINE

Engine rpm equals 2000. Engine blower drive-camshaft speed ratio is 2:1. The velocity vector for the blower blade tip is 2" in length. For the space diagram, locate the upper impeller center at 2,8.5 for (a) and 6,8.5 for (b).

Required:

a. Determine the relative velocity of the blades at the tip for the position shown. Clockwise rotation.

b. Determine the relative velocity for the position in which the tip is just leaving contact.

PROBLEM 12, FIGURE 2, TRANSPORT

S_s = 5.00 inch/inch. The transport is used to transfer ingots from one operation to another. It is driven by a 2 HP, 900 rpm motor. The drive is through a bevel gear reducer of 5.28:1 speed ratio; 2 chain drives of 1:1 and 3:1 speed ratio; and a pair of gears of 1.5:1 ratio.

Required:

a. Trace the flow of power from motor to finger link.

b. Draw the linkage skeleton space diagram for the position shown at a size 2 times that of the figure. Set the paper horizontal and locate the drive crank center at 8.5.

c. Draw the path of the finger link-coupler pin joint showing positions for every 30 degrees of crank rotation starting at extended dead end for the four bar linkage.

d. Determine the velocity of the ingots for 30 degree intervals of crank angle. Velocity vector length for the driver crank-coupler pin is 1.5 inches. Locate the velocity vector polygon poles along a line 6.5 inches up from the bottom, starting at 1,6.5.

e. Plot distance vs. time and velocity vs. time on graph paper. Use a common abscissa and check points of maximum velocity by graphical differentiation. Start at extended dead center.

PROBLEM 13, FIGURE 24, SCREW MACHINE GENEVA INDEXING MECHANISM

Figure scale, S_s,is 0.733 inches/inch. In put shaft rotates at 240 rpm. Speed ratio of input to crankshaft is 1:1. Drive disk pin circle diameter is 1.100 inches.

Required:

a. Trace the power flow for actuation of the Geneva Motion.

b. Explain the function and the operation of the shot pin.

c. Determine the angular velocity of the turret shaft 15 degrees after pin engagement.

d. Same for 21.5 degrees after engagement. Locate the center of the drive pin disc at 3,7 for the space diagram. Scale of space diagram is 2 inches per inch. Locate velocity vector polygon pole at 3,5. Pin velocity vector length is 2 inches.

e. What is the maximum angular velocity of the turret ?

f. What is the maximum relative velocity between pin and slot surface ?

PROBLEM 14, FIGURE 25, SHAPER

Figure scale is 5.00 inches per inch. The ram of the shaper is driven by a quick return linkage designed to reduce the non-cutting time of the machine to a minimum. The linkage is driven by the motor through a V-belt and gear train. The motor is a 5 HP, 1725 rpm squirrel cage induction type driving through the V-belt drive with a 1.5 speed ratio and drives a 40 tooth pinion on the output shaft. The pinion meshes with a 73 tooth gear. A second speed reduction is effected through a 56 tooth-96 tooth pair and the final reduction is from a 48 tooth pinion to the 171 tooth bull gear.

Required:

a. Determine the speed of the bull gear-driveR crank.

b. Draw the space diagram of the quick return linkage in the dead end position at the beginning of the cutting stroke. The space diagram scale is 5.00 inches per inch. Locate the bull gear crank center at 8.5,4.25. Paper horizontal.

c. Determine the ram velocity for 12 positions including the two dead end positions and the two positions for which the follower crank is vertical. Locate the velocity vector polygon poles along horizontal lines 4 inches and 3 inches up. The driver-crank pin velocity vector length is 1.5 inches.

d. Plot a slider position vs. velocity curve using the values of part b.

e. Determine the approximate maximum cutting speed.

f. Determine the ratio of cutting to idling (return) time.

PROBLEM 15, FIGURE 1, DIESEL ENGINE

Engine rpm is 1800. Figure scale is 2.5 inches per inch.
Draw space diagrams twice natural size of the Diesel injector cam and follower roller at cam angles of 30 degrees, 60 degrees, and 90 degrees from the position shown. Locate base circle centers at 2.5,3; 2.5,8; and 6,5.5.

Required:

a. Determine the velocity of the follower roller center for each of the three positions with velocity vector polygons. Locate polygon poles at the cam base circle centers. The velocity vector for a point on the base circle is 2 inches in length.

PROBLEM 16, FIGURE 1, DIESEL ENGINE

Engine rpm is 2400. Scale of figure is 2.5 inches per inch.

Required:

a. Draw a space diagram of the injector drive linkage from cam to injector piston with the cam at 45 degrees from the position shown. Lay the paper horizontally right over the drawing and locate the cam base circle center at 2,2.5.

b. Draw the velocity vector polygon for the linkage with the pole located at 8,4. The velocity vector length for a point on the base circle is 2 inches.

c. Determine the velocity of the injector piston.

d. Determine the relative velocity of rocker arm to piston.

e. Determine the rotational velocity, ω, of the rocker arm.

PROBLEM 17, FIGURE 9, SCRAPER HOIST

The drive motor of the scraper hoist runs at 1725 rpm. The power flows through the reverted gear train which has a 26 tooth drive pinion, a countershaft with a 70 tooth gear and a 32 tooth pinion coupled, and a 64 tooth output gear. Power then flows into the planetary gear trains. In the left planetary the sun gear has a pitch diameter of 2.500 inches. The planets have pitch diameters of 3.500 inches.

Required:

a. Determine the pitch diameter of the annular ring gear.

b. Make a space diagram of the planetary train showing both front and side views Space scale is 2.5 inches/inch. Set the paper horizontal and locate the center of the sun pitch circle at 4,4.

c. Indicate the flow of power in the side view.

d. Determine by graphical velocity vector analysis the velocity of the planet-carrier bearing center when the brake is applied to the ring gear. The sun gear-planet pitch point velocity vector is 2 inches in length.

e. Determine the output rpm.

f. Derive a general expression for the speed ratio of the train, $rpm_{input} / rpm_{output}$ in terms of the numbers of teeth on the gears.

g. Write a general equation for the number of teeth on the ring gear in terms of the numbers of teeth on sun and planets.

PROBLEM 18, FIGURE 28, STRAIGHT PRESS

Figure scale is 8 inches/inch. Power flow is from 1140 revolutions per minute motor through the V-belt drive and pinion and gear to the crankshaft. Crank rotates counterclockwise.

Required:

a. Locate the crank center at 6,8 and draw the space diagram at 2 inches per inch for the position shown.

b. Draw the velocity vector polygon with the pole at 4,9.5 and the velocity vector for the crankpin 4.00 inches in length. Determine the velocity of the crosshead.

c. Determine the velocity of the crosshead analytically.

d. Determine the maximum velocity of the crosshead and the crank angle at which it occurs.

PROBLEM 19, FIGURE 29, WORM GEAR SPEED REDUCER

Figure scale is 2 inches per inch. Single worm drives a 47 tooth gear. The lead angle on the worm equals the helix angle of the gear and is 20 degrees. Input worm rotates at 760 revolutions per minute clockwise from input end.

Required:

a. Determine the pitch line velocity of the gear.

b. Determine the direction of rotation of the output gear.

c. Draw the velocity vector polygon for the pitch point with the worm pitch point velocity vector 8 inches long. Locate the pole at 4,1.5.

PROBLEM 20, FIGURE 30, OVERHEAD CRANE

Figure scale is 4.00 inches per inch. Cable drum rotates at 12 rpm.

Required:

a. Determine the velocity of the hook.

b. Determine the hook sheave angular velocities.

PROBLEM 21, FIGURE 12, BEVEL GEAR SPEED REDUCER

Figure scale is 2 inches per inch. INPUT PINION SPEED = 1200 R.P.M. Input pinion has 23 teeth. Output gear has 94 teeth. Diametral pitch is 8 teeth per inch of diameter at the maximum pitch diameter.

Required:

a. Determine out put Speed

b. Determine the mean pitch line velocity.

c. Determine the velocity of the point of contact between the inner race and the tapered roller of the bearing. on out put shaft.

d. Determine the rpm of roller axis. on out put shaft.

PROBLEM 22, FIGURE 14, AUTOMATIC TRANSMISSION

Diameter of the forward sun gear, D_{fs}, is 1.800 inches; of the rear sun gear, D_{rs}, is 1.550 inches; of the planets, D_p, is 0.950 inches; of the ring gear, D_r, is 3.700 inches. The numbers of teeth are T_{fs} = 36; T_{sr} = 31; T_p = 19; T_r = 74. Flywheel speed is 2700 rpm. The following chart indicates the combination of clutches and brakes engaged for the various speeds.

"Speed"	Clutches Forward	Clutches Rear	Brakes Forward	Brakes Rear	Power Flow	Output Speed	Speed Ratio
First	X			X			
Second	X		X				
High	X	X					
Reverse		X		X			

Required:

a. Trace the power flow for each case.

b. Determine by velocity vector analysis the pitch line velocity of the ring gear.

c. Determine the ring gear output speed in rpm for each case.

d. Determine the speed ratio, rpm_{in}/rpm_{out} for each case. Use cross-section A-A for the space diagram for (b) with paper center over sun center and paper horizontal. Use the rear sun planet pitch points for polygon poles. Forward sun pitch point velocity vector length is 1.5 inches.

III - ACCELERATION ANALYSIS

PROBLEM 23, FIGURE 2, TRANSPORT

Figure scale is 5.00 inches / inch. See problem 12. The transport quadric linkage is driven by a 900 rpm motor through a bevel gear speed reducer of 5.28/1 ratio, 2 chain drives of 1:1 and 3:1 ratios and finally through a pair of gears of 1.5:1 ratio.

Required:

a. Draw the quadric linkage space diagram for the position shown at a scale of 2.5 inches / inch. Set the paper horizontally and locate the drive crank center at 8.5,2.

b. Determine the velocity scale. Velocity vector length for the driver crank-coupler pin is 1.500 inches.

c. Determine the acceleration scale by the related scales method.

d. Draw the acceleration vector polygon for the linkage in the position shown using the related scales method. Locate the velocity vector polygon pole at the drive crank-coupler pin and the acceleration pole, q, at the follower crank-coupler pin.

e. Determine the acceleration of the coupler-follower crank pi...

f. Determine the acceleration of the coupler-finger link pin.

g. Determine the acceleration of the ingots for 30 degree intervals of the driver crank and plot on graph paper. Start at extended dead center. Locate poles on a horizontal line 6.5 inches up from the bottom.

PROBLEM 24, FIGURE 25, SHAPER

Figure scale is 5.00 inches per inch. The drive of the shaper is described in problem 14.

Required:

a. Determine the ram acceleration for 12 positions including the 2 for which the follower crank is vertical (position shown) and the 2 dead center positions. Use the related scales method with a drive crank pin velocity vector length of 1.5 inches. Space diagram scale is 5.00 inches per inch. Locate the bull gear crank center at 8.5, 4.25. Locate poles on horizontal lines 1.5, 3.5, 5.5, and 7.5 inches up from the bottom. Paper is horizontal.

b. Plot a slider position-acceleration curve on graph paper.

PROBLEM 25, FIGURE 1, DIESEL ENGINE

Figure scale is 2.500 inches per inch. Assume an engine speed of 2400 rpm.

a. Lay out the piston-crankshaft linkage space diagram at the same scale as the figure with the crankshaft center located at 4.25, 4.5. Use the position shown in the end view.

b. Determine the displacements of the piston for 30 degree intervals of the crank angle.

c. Lay out coordinates on graph paper for the s-t, v-t, and a-t curves in the fashion recommended in problem 1. Plot the displacements of part (b) thereon.

d. Determine the velocity and acceleration of the piston for the 12 positions by Klein's Method and plot.

e. Superimpose the simple harmonic motion acceleration curve on the piston acceleration curve and study the deviation. (Note: the corresponding simple harmonic motion curve is $s = R\ (1-\cos \omega t)$ where R equals the crank throw and equals the crankshaft speed in radians per second.).

f. Where does the maximum velocity occur ? Where does the maximum acceleration occur ? Are dead end accelerations the same ? What would be the magnitude of the maximum inertial force at the wrist pin if the piston weighs 4.00 lbs. ?

PROBLEM 26, FIGURE 1, DIESEL ENGINE INJECTOR CAM

Figure scale is 2.5 inches per inch. Positions of cam and follower roller are indicated in problem 7.

a. Draw the cam profile and follower in the position for which cam angle is 30 degrees at a scale of 0.200 inches per inch. Locate the camshaft center at 3.5, 2.5.

b. Draw the velocity vector polygon and determine therefrom the velocity of the follower center. Engine speed is 2400 rpm. Locate pole at 3,5.5 and take the velocity vector length of a point on the base circle at 1.500 inches.

c. Draw the acceleration vector polygon and determine the acceleration of the follower. Locate the pole at 6,10. Use the related scales method.

d. Compare the result with the curve of problem 7.

PROBLEM 27, FIGURE 11, V-8 ENGINE

Figure scale is 2 inches per inch.

a. Determine the value and crank angle location for the maximum velocity and acceleration analytically.

b. Compute the displacement, velocity, and acceleration of the piston for 60 degree intervals of the crank angle and plot on graph paper in the manner described in problem 1.

c. Superimpose the simple harmonic motion acceleration curve for the same crank throw and compare.

PROBLEM 28, FIGURE 11, V-8 ENGINE CAM AND FOLLOWER

Figure scale is 2 inches per inch. Engine speed is 3600 rpm.

a. Draw a space diagram at a scale of 0.5 inches per inch of the exhaust cam and follower of the right bank cylinder. Set the angular position of the cam to correspond with a crank angle of 210 degrees after extended dead center. Locate the cam center at 2,6.

b. Determine the velocity of the follower. Locate velocity vector polygon pole at 3,2. Velocity vector length of a point on the base circle is 1.5 inches.

c. Determine the acceleration of the follower. Relate the scales and locate the pole at 7,4.

PROBLEM 29, FIGURE 11, V-8 ENGINE VALVE LINKAGE

Figure scale is 2 inches per inch. Engine speed is 2400 rpm.

a. Draw the space diagram of the right bank cylinder exhaust valve cam and linkage at the figure scale. Locate the cam center at 1.5,6 and the crankshaft center vertically below it. Rotate the cam 150 degrees from the position shown.

b. Draw the velocity vector polygon with pole at 6,5 and the pitch line velocity vector length equal to 1.0 inches.

c. Draw the acceleration vector polygon with pole at 4,4. Relate the scales.

PROBLEM 30, FIGURE 11, V-8 ENGINE VALVE LINKAGE SPRING

Figure scale is 2 inches per inch. Engine speed is 2400 rpm.

a. Assume that the exhaust valve opens with uniformly accelerated and decelerated motion. Determine the acceleration of an element of mass on the helical spring at the third coil down from the top.

b. Explain the meaning of surge in helical springs.

PROBLEM 31, FIGURE 20, CRUSHER

Figure scale is 10 inches per inch. Flywheel speed is 60 rpm. The toggle joints are designed for pure rolling to reduce friction and simplify lubrication.

a. The contour on the connecting rod block at the toggle joint is circular with radius of 1 inch. Develop the contour for the coupler block at full size.

b. Draw the space diagram at a scale of 10 inches per inch with the drive shaft center at 9,6. Paper horizontal. Set the crankshaft at 135 degrees from the position shown.

c. Draw the velocity vector polygon with the pole at 8,1 and the velocity vector length of the eccentric center equal to 2.00 inches.

d. Draw the acceleration vector diagram with pole at 1.5,7. Relate the scales.

e. Determine the velocity and acceleration of the extreme end of the crusher jaw plate.

PROBLEM 32, FIGURE 24, GENEVA INDEXING MECHANISM

Figure scale is 0.733 inches per inch. Geneva drive shaft rotates at 240 rpm.

a. Draw the space diagram of the Geneva driver and driven disks 45 degrees after engagement at a scale of 0.25 inches per inch. Locate the drive disk center at ~~6,7~~ 2.4, 2.6 with paper horizontal.

b. Draw the velocity vector diagram with pole at ~~8,8~~ 6.5, 8.3. The velocity scale is ~~15.70~~ 4.00 inches per second per inch.

c. Draw the acceleration vector polygon for the Geneva disks with pole at ~~1,4~~ 6.5, 8.3. Relate the scales.

d. Determine the angular acceleration of the turret shaft.

IV - STATIC FORCES

PROBLEM 33, FIGURE 2, TRANSPORT

The transport moves 4 x 4 x 30 inch steel ingots from one operation to the next. The ingot rail coefficient of friction is 0.90. The overall speed ratio is 25:1 and the motor speed is 900 rpm.

a. Set up each member of the linkage as a free body diagram.

b. Draw the force vector polygon for the position shown at a scale of 75 lbs. per inch. Locate the pole at 3,7. Neglect joint friction.

c. Determine the force on the follower crank pin.

d. Determine the motor torque.

PROBLEM 34, FIGURE 20, CRUSHER

Figure scale is 10 inches per inch. The rock crusher delivers a force of 20 tons 15 inches up from the bottom edge of the swinging jaw. Output speed is 60 cycles per minute.

a. Trace the flow of power from input shaft to output jaw.

b. Draw a space diagram of the linkage at the figure scale with the eccentric center at 3,8.

c. Following the path of force set up each link as a free body diagram.

d. Draw the force polygon at a scale of 10,000 lbs. per inch with origin of the load vector at 1.5,4. Neglect frictional forces.

e. Determine the torque on the eccentric shaft.

PROBLEM 35, FIGURE 15, THRUSTOR BRAKE

Figure scale is 2.5 inches per inch. The torque on the brake drum is 1200 lb. ft.

a. Draw a free body diagram of each link.

b. Draw the static force polygon at a scale of 400 lbs. per inch with the origin of the brake shoe pivot bolt force vector at 4,5.5.

c. Determine the spring force necessary for engagement.

d. Determine the thrustor solenoid force necessary for disengagement.

PROBLEM 36, FIGURE 24, INDEXING MECHANISM TURRET TABLE DRIVE

Figure scale is 0.75 inches per inch. Rack and gear sector have teeth of 20 degree pressure angle. Load at the turret is 1.5 lbs.

a. Trace the flow of force from the turret to the cam shaft.

b. Draw a space diagram of the turret table, gear sector cam follower, cam, and shaft at the figure scale with the cam-shaft center at 5,2. Paper horizontal. Set cam at 30 degrees counterclockwise from position shown.

c. Draw each member as a free body diagram.

d. Set up the force polygon with the origin of the load vector at 10.5, 2.5 at a scale of 0.5 lbs. per inch. Neglect friction.

e. Determine the torque of the cam shaft.

PROBLEM 37, FIGURE 3, POWER STEERING UNIT

Figure scale is full. Hydraulic pressure in the actuator is 100 lbs. per square inch. Pressure angle of the rack and sector teeth is 20 degrees.

a. Set each member up as a free body diagram.

b. Draw the force vector polygon at a scale of 100 lbs. per inch; actuator piston force vector origin at 7,8. The piston is moving to the left.

c. Determine the torque on the gear sector shaft.

d. Determine the torque at the steering wheel.

PROBLEM 38, FIGURE 14, AUTOMATIC TRANSMISSION SECTION A-A

Figure scale is 1 inch per inch. The pressure in the hydraulic actuator is 40 psi.

a. Draw the force polygon at a scale of 75 lbs. per inch with the origin of the actuator piston force vector at 4,4.

b. Determine the force applied by the rocker to the brank band.

c. Determine the force on the rocker pivot pin.

PROBLEM 39, FIGURE 28, STRAIGHT PRESS

Figure scale is 5 inches per inch. Capacity of the press is 80 tons.

a. Draw a space diagram of the ram,coupler,and crank at a crank angle of 40 degrees from bottom dead center at a scale of 2.5 inches per inch. Locate the crank center at 1.5,9.

b. Set up each member as a free body diagram.

c. Neglecting friction, draw the force polygon at a scale of 20 tons per inch. Locate the origin of the load vector at 3.5, 4.5.

d. Determine the torque on the crankshaft.

e. Draw a force polygon including friction with the force vector origin at 3.5, 6.5. Assume the coefficient of friction to be 0.25 at all points. (This value is exaggerated).

f. Determine the input torque.

g. What is the efficiency of this part of the drive for such a coefficient of friction ?

PROBLEM 40, FIGURE 2, TRANSPORT

Figure scale is 5 inches per inch. Ingots are 27.5 inches long. The coefficient of friction for ingot to rail is 1.00 and for all bearings is 0.15. Overall speed ratio of the power train is 25/1 and motor speed is 900.

a. Draw a space diagram at a scale of 2.5 inches per inch with the paper horizontal and the follower crank center at 0.5, 7.5 for the position shown.

b. Set up each member as a free body diagram.

c. Draw a force vector polygon at a scale of 75 lbs. per inch with the load vector origin at 5,1, friction omitted.

d. Draw a force vector polygon with friction considered, load vector origin at 10,1.

e. Determine the efficiency for the crank angle position shown and for the assumed coefficients of friction.

f. Approximately how will the efficiency vary with respect to input crank angle ?

g. About where will the minimum efficiency occur ?

PROBLEM 41, FIGURE 11, V-8 ENGINE CRANK,ROD,AND PISTON LINKAGE

Figure scale is 2 inches per inch. Main bearing is 2.500 inches in diameter. Coefficient of friction for all bearing surfaces is 0.25. (This is an exaggerated value).

a. Set up each member as a free body diagram.

b. Draw a force vector polygon. Assume the pressure in the cylinder is 100 lbs. per square inch in the left bank cylinder. Force scale is 200 lbs. per inch. Locate the origin of the load vector at 2,8.

c. Determine the torque on the crank shaft.

d. What would the torque be if the friction were neglected ?

PROBLEM 42, FIGURE 24, INDEXING MECHANISM TURRET TABLE DRIVE

Figure scale is 0.75 inches per inch. Rack and gear sector have teeth of 20 degree pressure angle. Load at the turret is 20 lbs.

a. Draw a space diagram of the turret table and drive with the cam rotated counterclockwise 135 degrees at the figure scale. Locate the cam shaft center at 5,2. with the paper horizontal.

b. Draw each member as a free body diagram.

c. Assuming the coefficient of friction to be 0.2 at all bearing surfaces, draw a force polygon at a scale of 5 lbs. per inch. Locate the origin of the load vector at 10.5, 2.5.

d. Determine the roller cam load, the camshaft load, and the camshaft torque.

PROBLEM 43, FIGURE 25, SHAPER

Figure scale is 5 inches per inch. Cutting load is 300 lbs. Assume the coefficient of friction for flat sliding joints to be 0.25 and for pin joints to be 0.50. These are exaggerated values. Force scale S_f is 150 lbs. per inch.

a. Draw a space diagram of the drive linkage at a scale of 5 inches per inch with the crank angle at 135 degrees from position shown. Locate the bull gear center at 4,4.5.

b. Draw free body diagrams of all links.

c. Draw a force polygon including friction forces. Locate the origin of the load vector at 9,3.

d. Determine the torque input at the bull gear shaft.

V - INERTIA FORCES

PROBLEM 44, FIGURE 22, TRUCK CHASSIS

Figure scale is 15 inches per inch. The truck when loaded weighs 3 tons. The center of gravity of the whole unit is located 60 inches to the rear of the front axle and 30 inches above the ground level.

a. What is the ground load on the front left wheel with the vehicle standing ?

b. What is the ground load on the left front wheel if the truck is accelerated from rest to 20 miles per hour in 4 seconds ?

c. What is the ground load if the brakes are applied and the truck decelerated from 20 miles per hour to rest in 4 seconds ?

d. Which way will the springs deflect in each case ?

PROBLEM 45, FIGURE 20, CRUSHER

Figure scale is 10 inches per inch. The center of gravity of the swinging jaw is at 9 inches to the right of the jaw face and 25 inches from the pivot center on a line parallel to the jaw face. The velocity of the jaw coupler joint is 15 inches per second and the acceleration of the jaw is 0.20 radians per second per second. The weight of the jaw is 1000 lbs.

a. Draw a space diagram of the jaw showing the center of gravity of the jaw-coupler joint, and the pivot center.

b. Determine the inertia force on the jaw and show its value, direction and location on the diagram.

PROBLEM 46, FIGURE 24, INDEXING MECHANISM

Figure scale is 1.00 inches per inch. The center of gravity of the rocker-follower is 0.75 inches from the pivot pin center at 45 degrees up from the horizontal in the position shown. Cam turns at 10 rpm.

a. Draw a space diagram of the cam and follower at 120 degrees of cam angle from the position shown, at full scale. Locate the cam center at 2,3.

b. Determine the acceleration of the roller center with an acceleration polygon. Locate the pole for velocity at 6.5,7 and for acceleration at 6.5,4. Make the velocity vector for a point on the base circle of the cam 1 inch and use related scales.

c. Determine the acceleration of the center of gravity.

d. Determine the inertia force and locate it properly by vector on the space diagram. (The moment of inertia is 0.0013 lb-in-sec.^{2}).

e. Determine the distance from pivot center to center of percussion on the space diagram.

f. Determine the radius of gyration about the center of gravity.

PROBLEM 47, FIGURE 5, BEVEL GEAR REVERSING UNIT

Figure scale is 1 inch per inch. An AC induction motor rated at 10 HP and 1160 rpm drives a pulley through the reversing unit. The motor characteristics are those of design B on the performance curves of Figure 31. The moment of inertia of the motor armature is 1/10th that for pulley plus reversing gear elements. The motor comes up to speed in 4 seconds.

a. Assuming a constant acceleration determine the approximate moment of inertia of reversing gear plus pulley and of the motor armature.

b. Is the assumption of constant acceleration reasonable? Explain.

PROBLEM 48, FIGURE 11, V-8 ENGINE

Figure scale is 2 inches per inch. Engine speed is 2700 rpm. Piston weight is 2 lbs. and connecting rod weight is 1.5 lbs. The radius of gyration of the rod is ~~4.25~~ 2.00 inches and its center of gravity is 2 inches from the crank pin center.

a Draw a space diagram at 2 inches per inch with the crankshaft center located at 3.5, 4.5.

b. Determine the accelerations of both wrist pins and the gravity centers for both rods. Make the crankpin velocity vector 1.75 inches long. Locate velocity polygon poles at the wrist pins and acceleration polygon poles at the crankshaft center.

c. Determine the connecting rod inertia forces and draw them in as vectors properly located and oriented.

d. Determine the piston inertia forces and show them as vectors on the space diagram.

e. Give the magnitude and location of the inertia force for the crank ~~shaft~~ pin & counterweight assembly.

PROBLEM 49, FIGURE 1, DIESEL ENGINE

Figure scale is 2.5 inches per inch. Engine speed is 1800 rpm. Piston weight is 2.5 lbs. and connecting rod weight is 2.0 lbs. The center of gravity of the rod is at 7.5 inches below the wrist pin center. The rod is suspended from the wrist pin center and swung as a pendulum to determine its full cycle period of one second.

a. Draw space diagrams of the linkage for the position shown; with crank perpendicular to connecting rod; at 135 degrees from top dead center; and at 180 degrees from top dead center. Locate the crankshaft centers 2.5 inches up and at 1,3,5, and 7 from left edge.

b. Determine the acceleration of the piston and center of gravity for each case. It is suggested that you use Klein's construction. In any case make the crankpin velocity vector equal to the drawing length of the crank and locate both acceleration and velocity vector polygon poles at the crankshaft center. Relate the scales.

c. Determine the inertia force of the pistons and connecting rods, and show them properly located and oriented as vectors on the space diagram.

VI - DYNAMIC FORCE ANALYSIS

PROBLEM 50, FIGURE 2, TRANSPORT

Figure scale is 5.00 inches per inch. The speed of the linkage drive crank is constant at 120 rpm. All elements are of uniform thickness. Weights and Moments of Inertia are as follows:

Element	Crank	Coupler	Rocker	Finger Link	Unit
Weight	1.5	3.5	2.0	75	pounds
Moment of inertia	0.026	~~0.625~~ 0.167	~~0.115~~ 0.029	400	lb-in-sec.^{2}

a. Draw a space diagram of the linkage in the position shown at a scale of 2.5 inches per inch with the follower rocker center located at 0.5, 7.5. Paper horizontal.

b. Draw the velocity vector polygon with pole at 4,2.5 and driver crankpin velocity vector length of 2.5 inches.

c. Draw the acceleration diagram with pole at 10,5.5. Relate the scales.

d. Determine the acceleration of the center of gravity for crank, coupler, and rocker.

e. Determine the inertia force for each of those members.

f. Show by vector the proper location and orientation of each on the space diagram.

g. Determine the inertia force of the finger link and its location and orientation.

h. What will be the reaction to this force on the rear coupler finger-link joint pin ?

PROBLEM 51, FIGURE 25, SHAPER

Figure scale is 5.00 inches per inch. Speed of the bull gear is 106 rpm. Weights and Moments of Inertia are as follows:

Element	Bull Gear Crank	Slider	Rocker	Coupler	Ram	Units
Weight	100	6.00	85	10	200	pounds
Radius of gyration about c.g.	6	2.50	16.5	4.5	30	inches

a. Draw a space diagram of the linkage in the position for a crank angle 315 degrees later than that shown at a scale of 5.00 inches per inch. Locate the bull gear center at 2.0,4.5, with paper horizontal.

b. Draw the velocity vector polygon with pole at 7,2.5 and crank pin velocity vector length 2 inches.

c. Draw the acceleration vector polygon with pole at 10,4.5. Relate the scales.

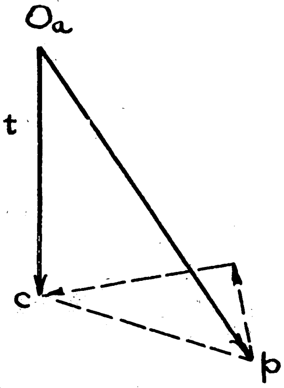
d. Assume the center of gravity of the drive crank bull gear to be located at 5/8 inches from the center toward the crank pin. All other gravity centers are at midpoints. Determine the acceleration of the gravity centers.

e. Determine the inertia force for each member. Locate and orientate them on the space diagram.

PROBLEM 52, FIGURE 28, STRAIGHT PRESS

Figure scale is 5 inches per inch. The data and acceleration diagram for the linkage is as shown: $S_a = 100$ in/sec.^{2}/in.

	Weight	Moment of inertia	Center of gravity (on axis)
Crank	16	0.160	1.5 from crankshaft
Conn. Rod	30	2.500	2.5 from crankpin
Crosshead	100	-	2.5 from balljoint
Units	pounds	lb-in-sec.^{2}	inches



a. Draw a space diagram of the linkage in the position shown at a scale of 5 inches per inch; paper horizontal. Locate the crankshaft center at 2,6.

b. Draw each member as a free body diagram showing static and inertia forces.

c. Construct the force polygon at a scale of 25 lbs. per inch with the origin of the weight vector at 8,6.

d. Determine the force from frame to crosshead.

e. Determine the torque input on the crank shaft.

PROBLEM 53, FIGURE 1, DIESEL ENGINE

Figure scale is 2.5 inches per inch. Engine speed is 1800 rpm. Gas pressure after injection is 1200 lbs. per square inch and 900 lbs. per square inch 30 degrees of crank angle later. Pertinent mass data is as follows:

	Weight	Moment of inertia	Center of gravity
Crank	8.00	0.326	1.5 from crankshaft axis
Conn. Rod	12.00	1.280	6.5 from wristpin
Piston	9.00	-	0.625 above wristpin
Units	pounds	lb-in-sec.^{2}	inches

a. Draw a space diagram with crank angle 30 degrees from top dead center and crankshaft center at 2, 1.5.

b. Determine the acceleration of centers of gravity by Klein's construction.

c. Determine the inertia forces for each element and show them on the space diagram.

d. Draw a force polygon including inertia forces but neglecting friction, locating origin of the gas pressure force vector at 5,6. Make that vector 4 inches in length.

e. Determine the crankpin and wristpin loads.

f. Do the same for the position shown, i.e., top dead center after injection.

PROBLEM 54, FIGURE 11, V-8 ENGINE

Figure scale is 2 inches per inch. Engine speed is 3000 rpm. Gas pressure for the position shown is 500 lbs. per square inch in the right bank cylinder and 100 lbs. per square inch in the left bank cylinder. Pertinent mass data is as follows:

	Weight	Moment of inertia	Center of gravity
Crank	4.00	0.042	0.75 from crank center
Conn. Rod	4.50	0.268	4.00 from wrist pin
Piston	5.00	-	0.75 from wrist pin
Units	pounds	lb-in-sec.^2	inches

a. Draw a space diagram of the linkage in the position shown at a scale of 2 inches per inch with the crankshaft center located at 3,4.5; paper horizontal.

b. Determine the acceleration of the centers of gravity by Klein's construction. (draw the inertia force vectors on the space diagram).

c. Draw a force polygon including inertia forces but neglecting friction, locating the origin of the gas pressure force for the right bank cylinder at 8,6. The force scale is 1000 lbs. per inch.

d. Determine the crankpin, wristpin, and cylinder wall-piston loads.

PROBLEM 55, FIGURE 24, INDEXING MECHANISM GENEVA LINKAGE

Figure scale is 0.75 inches per inch. The output shaft with tools, turret, shaft and Geneva cross has a combined weight of 1.5 lbs. The unit is suspended by a wire as a torsional pendulum to determine its moment of inertia. The wire has a torsional spring stiffness of 0.05 lb. inches per radian and the period is measured at 7.9 seconds. The clutch shaft speed is 240 rpm.

a. Make a space diagram of the Geneva drive disk and cross at a scale of 0.25 inches per inch, drive disk center located at 2,7. Set the position so that the drive pin center is at midstroke in the groove.

b. Determine the angular acceleration of the output shaft unit.

c. Determine the inertia torque of the output shaft.

d. Determine the torque at the clutch. What effect would the addition of tools to the turret have ?

PROBLEM 56, FIGURE 2, TRANSPORT

Figure scale is 5.00 inches per inch. Speed of the driver crank is 120 rpm. The mass data is given in problem 50. The product being transferred weighs 75 lbs per unit. The coefficient of friction between product and frame is 0.4.

a. Using the inertia forces determined in problem 50, make a dynamic force analysis. Locate the force polygon pole at 2,2. Force scale is 30 lbs per inch. Draw free body diagrams.

b. Determine the forces on the two frame bearings.

c. Determine the input torque on the drive crank.

PROBLEM 57, FIGURE 2, TRANSPORT

Figure scale is 5 inches per inch. Mass data is given in problem 50. Speed of the driver crank is 120 rpm. The product being transferred is 75 lbs per unit. The coefficient of friction between product and rails is 0.4. The crank angle is 45 degrees later than that shown.

a. Make a space diagram at a scale of 2.5 inches per inch with follower rocker center located at 0.5,7.5 with paper horizontal.

b. Draw a velocity vector polygon with driver crank pin velocity vector length of 2.5 inches and with pole located at 8.5,6.

c. Draw an acceleration vector polygon with pole at 10.5,7. Relate the scales.

d. Show the inertia forces at the centers of gravity on the space diagram.

e. Draw a force polygon including static and inertia forces with the pole located at 2,2.

f. Determine the frame bearing forces.

g. Determine the torque input.

PROBLEM 58, FIGURE 2, TRANSPORT

The same as problem 57 with a crank angle of 180 degrees from the position shown.

PROBLEM 59, FIGURE 25, SHAPER

Figure scale is 5 inches per inch. Data is as indicated in problem 51.

a. Draw a space diagram of the linkage in the position for a crank angle of 315 degrees later than that shown at a scale of 5 inches per inch. Locate the bull gear center at 5,7.

b. Using the inertia force values determined in problem 51, make a dynamic force analysis with force polygon pole at 2,2. Neglect friction. Force scale is 200 lbs. per inch.

c. Determine the loads on all bearings.

d. Determine the torque input.

PROBLEM 60, FIGURE 25, SHAPER

Figure scale is 5 inches per inch. Cutting load is 300 lbs. Other data is as found in problem 51.

a. Draw a space diagram of the linkage in the position for a crank angle 135 degrees later than that shown.

b. Draw a velocity vector polygon with the crank pin vector length 1.5 inches and pole at 6,8.

c. Draw the acceleration vector polygon with related scale at 1.5,8.

d. Determine the inertia forces and show them in proper location and orientation on the space diagram.

e. Do a dynamic analysis with force polygon pole at 7.5,3 and a force scale of 200 lbs. per inch.

f. Determine the torque input.

g. Determine the shaking force on the frame.

PROBLEM 61, FIGURE 25, SHAPER

Same as problem 60 but add friction forces. Assume coefficient of friction to be 0.25 for flat sliding joints and 0.50 for pin joints. These values are, of course, exaggerated, but will illustrate the effect of friction on the polygon.

PROBLEM 62, FIGURE 9, SCRAPER HOIST

Figure scale is 4 inches per inch. The sun gear of the planetary gear train on the left is accelerated from 0 to 120 rpm in 6 seconds with a 150 lb. load at the root of the left cable drum. The moments of inertia of the sun gear, planet gear, carrier and drum are 0.085, 0.500, 0.935, and 4.140 lb-in-sec.^{2} respectively.

a. Make a force analysis for the condition of constant speed at 120 rpm.

b. Determine the planet bearing loads; the sun gear bearing load.

c. Determine the torque on the sun gear and on the ring gear.

d. Do the same for the period of acceleration.

VII - FLYWHEELS

PROBLEM 63, FIGURE 21, "C" FRAME PRESS

Figure scale is 4 inches per inch. The press is driven by a design B electric motor rated at one HP and 570 rpm. See the performance curves of Figure 31 for torque speed characteristics. A multiple V-belt drive reduces the speed by 8/1. The press is to be used to punch a hole of 1 inch diameter in $\frac{1}{4}$ inch SAE 1020 cold rolled steel plate with an ultimate shear strength of 50,000 lbs. per square inch.

a. Determine the coefficient of speed fluctuation in the flywheel.

b. Determine the maximum and minimum flywheel speeds.

c. Determine the maximum and minimum torque output of the motor.

d. Determine the motor horsepower that would be necessary without the flywheel.

PROBLEM 64, FIGURE 20, CRUSHER

Figure scale is 10 inches per inch. The crusher flywheel turns at a maximum speed of 114 rpm and has a speed fluctuation coefficient of 0.2. Assuming that the crushing takes place in 0.1 of the total cycle time:

a. Determine the horsepower load on the motor. Recommend the motor design.

b. Estimate the resultant load at 15 inches up from the bottom edge of the swinging jaw.

c. Explain why the flywheel is necessary.

PROBLEM 65, FIGURE 2, TRANSPORT

Figure scale is 5.00 inches per inch. The transport is driven by an electric motor rated at 855 rpm. The speed is reduced through the drive to 120 rpm, at the linkage drive crank shaft. A load of 900 lbs. imposed on the finger link is moved 6 inches each cycle of the machine. The load is in contact with the finger link for 90 degrees of rotation of the crank angle. A flywheel coefficient of speed fluctation of 0.05 has been recommended.

a. Design a flywheel for the transport to be mounted on the motor shaft. Give material, mean rim radius, and rim cross-sectional dimensions.

b. Design a flywheel to be mounted on the linkage drive crank shaft.

c. Determine the saving in motor horsepower demand by use of the flywheel.

d. Recommend a motor rating and design type.

PROBLEM 66, FIGURE 16, CONE CLUTCH

Figure scale is 2 inches per inch. The cone clutch assembly varies in speed from 1140 to 1026 rpm in 36 degrees of rotation and regains its speed in the remainder of the revolution.

a. Determine the energy available in the flywheel effect of the assembly.

b. Determine the horsepower transmitted through the clutch.

PROBLEM 67, FIGURE 1, DIESEL ENGINE and FIGURE 10, MARINE REDUCTION AND REVERSE GEAR

Figure scales are 2.5 inches per inch for Figure 1 and 2 inches per inch for Figure 10. You have been presented with a proposal to combine the marine reduction and reverse gear with a 6 cylinder diesel engine of the same design as that of Figure 1, except that it has 3 more cylinders.
The specific problem posed to you here is to determine whether the flywheel effect of the fluid coupling housing is sufficient. If it is not you are

to redesign the housing for proper flywheel effect and attachment to the engine crankshaft.

The turning effort diagram of the engine has a force scale (ordinate) of 1200 lbs. per inch and a space (abscissa) scale of 1 inch per inch. It shows a mean tangential effort value of 2.7 inches. The area above the mean turning effort line under one of the loops is 4.00 square inches. The coefficient of speed fluctuation recommended for engines is 0.033.

a. Check the weight of the fluid coupling housing to see whether it will serve as a flywheel.

b. Check the weight of the flywheel on the engine.

c. Make any design modifications necessary and present them on a scaled drawing, dimensioned.

VIII - BALANCING

PROBLEM 68, FIGURE 2, TRANSPORT

Figure scale is 5 inches per inch. The drive crank pin rod is of cold rolled steel and the cranks are of cast iron.

a. What are the loads on the crank shaft by cranks and crankpin only, for 120, 240, and 2400 rpm ?

b. Determine the magnitude, location, and orientation of counterweights necessary to balance cranks and crankpin.

c. Are counterweights necessary for this machine ? Explain.

PROBLEM 69, FIGURE 14, AUTOMATIC TRANSMISSION

Figure scale is 1 inch per inch. The double planet gears in mesh with forward sun and ring gears weigh 0.250 lbs. The single planets in mesh with the forward sun gear weigh 0.125 lbs. The planetary system is locked in high gear and rotating at 3000 rpm.

a. Compute the forces imposed on the carrier.

b. Draw a force vector polygon including the forces for all 6 gears to check the balance of the planetary assembly. Locate the pole at 5,4 and make the force vector for the double planet gear 4 inches long.

c. Is there any dynamic unbalance on the assembly ? Explain.

PROBLEM 70, FIGURE 1, DIESEL ENGINE

Figure scale is 2.5 inches per inch. Engine speed is 1800 rpm. The counterweight on the forward end of the cam shaft weighs 3 lbs. Its center of gravity is at a radius of 2.2 inches. The camshaft drive gear on the rear of the shaft has a counterwieght built integrally into it.

a. Design a counterbalance sector to be integrated into the gear giving weight and location of center of gravity.

b. Will this camshaft be statically balanced ? Prove it.

c. Will this camshaft be dynamically balanced ?

d. Determine the loads imposed on the camshaft bearings by the counter-balances. Assume two end bearings only.

PROBLEM 71, FIGURE 1, DIESEL ENGINE

Figure scale is 2.5 inches per inch. The unbalanced weight of the crank in the center cylinder is 20 lbs. The connecting rod weighs 18 lbs. and its center of gravity is located 6.5 inches down from the wristpin.

a. Draw the vector polygon to determine the dynamic unbalance of the crankshaft without any counterweights. Locate the pole at 4,4 and make the vector for crank in the middle 2 inches long.

b. Draw the vector polygon to determine the static unbalance. Locate the pole at 4,7 with the middle crank vector 2 inches long.

c. Determine the weight and orientation of counterweights to be located in planes of cylinders 1 and 3.

d. Design the counterweights. Submit a sketch with material and dimensions, indicating size and location of center of gravity.

PROBLEM 72, FIGURE 1, DIESEL ENGINE

Figure scale is 2.5 inches per inch. Weight data for the crank, rod, and piston and the location of the rod center of gravity are as given in problem 53. Engine speed is 2100 rpm.

a. Draw a polar shaking force diagram for the middle cylinder only, disregarding all counterbalance effects. Force scale is 5000 lbs. per inch.

b. Add a counterweight equal to the total weight of rotative and reciprocative masses and draw in the shaking force curve.

c. Add a counterweight equal to the total weight of rotative and one half reciprocative masses and draw in the shaking force curve.

d. Devise a method by which a single cylinder engine might be completely balanced.

PROBLEM 73, FIGURE 1, DIESEL ENGINE

Figure scale is 2.5 inches per inch. Weight data for the crank, rod, and piston and location of the rod gravity center are given in problem 53.

a. Draw the unbalance vector polygons arranged in the tabular form indicated below, at twice that size.

b. State the type (force or moment) and cause (rotative, primary reciprocative or secondary reciprocative) of unbalance.

c. Explain how each factor was counterbalanced in this engine.

d. Determine the magnitude of all counterweights.

e. Draw a curve of moment vs. crank angle to show the debit unbalance after counterweights have been credited.

f. Suggest a method by which the engine might have been completely balanced.

Cause / Type	Rotative	Reciprocative	
		Primary	Secondary
Forces	S_f 4000 lbs/in.		
Moments	S_m 3000 $\frac{\text{lbs.ft.}}{\text{in}}$		

PROBLEM 74, FIGURE 11, V-8 ENGINE

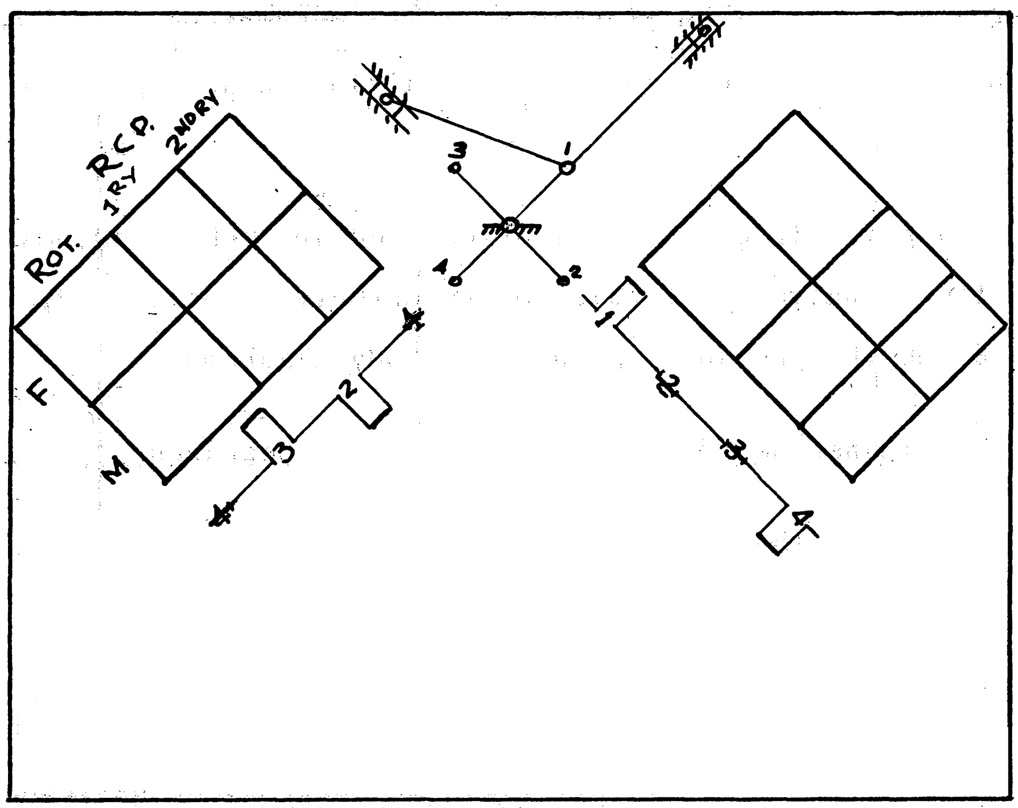
Figure scale is 2 inches per inch. Weight data for the engine is as indicated in problem 54. Crank configuration is 0-90-270-180 taken clockwise. Bank angle is 90 degrees.

a. Lay out a space diagram as indicated below at twice that size. The unbalance analysis tabular arrangement is as indicated in problem 73.

b. Draw the force and moment polygons in the positions indicated for each bank separately. Use scale to provide polygons as large as the space will permit.

c. State type and cause of unbalance.

d. Determine the magnitude, location, and orientation of the counterweights necessary to completely balance the engine.



IX - VIBRATIONS

PROBLEM 75, FIGURE 2, TRANSPORT

Figure scale is 5 inches per inch. Transport carries 12 ingots of steel of the section size indicated and 30 inches long. Beams and columns are standard structural steel 3 x 2 3/8 I bars with a weight of 5.7 lbs. per ft. length. The moment of inertia about the neutral axis perpendicular to the web at center is 2.55 inches^4, and about the neutral axis parallel to the web at the center is 0.56 inches^4.

a. What would be the natural frequency of vibration for motion along the length of the transport ?

b. Determine the natural frequency for transverse vibrations.

c. Is the operating speed of 240 rpm critical ? Explain.

d. Assume that the machine is transporting hot ingots with a coefficient of friction equal to 1.00 and that the frictional force is an harmonic shaking force. Assume also that the damping factor is 0.15. Determine the amplitude of the vibration. Are these assumptions valid ? Explain.

e. Under the condition assumed in d, what would the amplitude be for the shaking force frequency equivalent to 240 rpm of the linkage ?

PROBLEM 76, FIGURE 9, SCRAPER HOIST

Figure scale is 4 inches per inch. The weight of the left planetary sun gear is 6 lbs. and of the right planetary sun gear is 3 lbs. Assume that 6.500 inch pitch diameter drive gear on the right end of the shaft has a negligible effect.

a. Determine the natural frequency of transverse vibration of the shaft.

b. Is the shaft operating at critical speed with a motor speed of 1800 rpm ?

PROBLEM 77, FIGURE 7, HELICAL GEAR SPEED REDUCER

Figure scale is 2 inches per inch. Motor speed is 1800 rpm. Gear reduction ratio is 18/70.

a. Determine the critical speed of the shaft as drawn.

b. Is the operating speed critical? Explain.

c. Assume that the frequency of tooth engagement is a disturbing force frequency and that the damping factor is 0.2, and determine the amplitude magnification factor.

PROBLEM 78, FIGURE 4, REAR AXLE

Figure scale is 4 inches per inch. The moment of inertia of wheel plus tire is 4.50 lbs-in-sec.^{2} and of gears etc., inside the differential is 0.280 lb-in-sec.^{2} Assume the shaft to be uniform in diameter at 1.250 inches.

a. What is the critical speed for torsional vibration of the axle?

b. Approximately how far from the differential end of the axle will the node occur ?

c. Is resonance likely to occur ?

PROBLEM 79, FIGURE 11, V-8 ENGINE

The crankshaft of the engine can be reduced to a system in which the polar moments of inertia $I_1 = I_2 = I_3 = I_4 = 0.15$ lb-in-sec.^{2}. The shaft stiffness between cylinder centers is 6×10^6 lbs-inches per radian.

a. Show the "normal" curves to indicate the configuration of the system for the first, second, and third nodes.

b. Determine the fundamental natural frequency and the second and third harmonics.

c. Put all three cases into a Holzer tabulation to check the values.

PROBLEM 80, FIGURE 1, DIESEL ENGINE

The engine can be reduced to a dynamically equivalent system as indicated below in which $I_1 = I_3 = 0.600$ lb-in-sec.^{2} $I_2 = 0.250$ and $I_4 = 12.00$ lb-in-sec.^{2} The torsional stiffnesses are $k_{t1} = k_{t2} = 36 \times 10^6$ and $k_{t3} = 180 \times 10^6$ pound inches per radian.

a. Reduce the system to an approximately equivalent two mass system and compute the first estimate of the fundamental natural frequency.

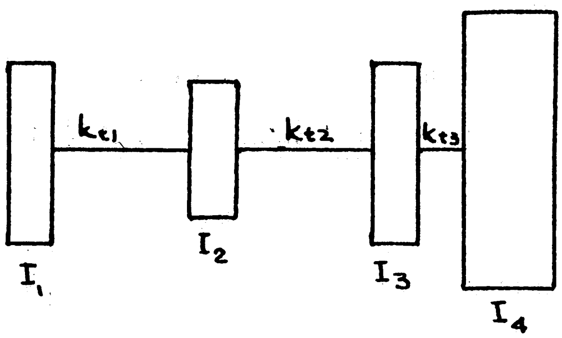
b. Use the first approximation of part "a" in a Holzer tabulation check.

c. Plot the residual torque values of trials to date against the frequency estimates.

d. From the curve of "c" make an estimate of the second harmonic.

e. Follow the same procedure to get the third harmonic.

f. Draw the configuration curves of angular displacement amplitude, O, against position on shaft.



X - MATERIALS

PROBLEM 81

a. Briefly explain the difference between cast iron and steel so far as chemical composition is concerned.

b. Give the approximate carbon content of low, medium, and high carbon steels.

c. State 2 ways of changing the composition of steel to increase its strength.

d. A piece of 1040 steel is to be hardened by heat treating. State the 3 main steps of this heat treating process.

e. What carbon content would you specify for steel to be used for each of the following: (1) structural beam, (2) high strength machine shaft, (3) a spring, (4) a piece to be carburized, (5) a lathe tool bit ?

f. Describe the carburizing process, and explain why a steel such as 1050 is not used for carburizing.

g. What approximate relationship exists between the tensile strength and shear strength of steel ?

h. What approximate relationship exists between the Brinell hardness and the tensile strength of steel ?

PROBLEM 82

List what you would consider to be the comparative advantages and disadvantages of the following materials so far as use in machinery is concerned:

1. steel	4. magnesium
2. cast iron	5. brass
3. aluminum	6. bronze

PROBLEM 83

A beam having a rectangular cross section is to be made from each of the following materials:

1. Rolled 4640 steel, quenched and tempered at 1000 ^{o} F
2. Aluminum 24 S alloy, T 4, HT
3. Extruded AZ 61 X magnesium

In each case the beam width is to be 1", and all 3 of the beams are to have the same strength in bending. Compare the weights of the 3 beams.

XI - STRESS AND STRENGTH

PROBLEM 84

a. Using words, not equations, define "stress" and "strength", and discuss the relationship that must exist between "stress" and "strength" in a properly designed machine part.

b. List the main reasons for using a safety margin, or safety factor, when designing machine parts.

c. Explain why lower safety margins are commonly used in aircraft design, where failure may be disastrous, than in many industrial machines where failure endangers no one.

PROBLEM 85 - FIGURE 19, EXTERNAL SHOE BRAKE

a. Describe the construction and operation of the brake.

b. A brake similar to that shown is applied by a spring which exerts a downward force of 800 lbs on the cylinder rod. The rod is to be made of 1020 steel as rolled. What rod diameter would you recommend to carry the 800 lb load ?

c. Discuss what considerations, other than the ability to carry the 800 lb load, might influence the final decision as the diameter of rod to be used.

PROBLEM 86, FIGURE 19, EXTERNAL SHOE BRAKE

a. Describe the operation and construction of the brake.

b. A brake similar to that shown is applied by a spring which exerts a downward force of 800 lbs on the cylinder rod. The bell crank link which is pin connected to the top of the right hand brake shoe lever is to be made of ASTM A47-33 malleable iron. The distances between pin joints can be taken as 4 times the distances shown on the drawing. Establish the cross section dimensions needed on the horizontal arm of the bell crank link midway between the two pins, making the depth 4 times the thickness.

c. Discuss what considerations, other than the strength of the link, might influence the decision as to the actual dimensions to be used for the link.

PROBLEM 87

a. State the maximum shear theory of failure, and the maximum normal stress theory of failure, and name the common materials to which each theory is considered to apply.

b. Discuss fatigue failure of metals, and the loading conditions which cause this type of failure.

c. Define the following in words:

1. completely reversed bending
2. partially reversed loading
3. endurance limit
4. stress concentration factor
5. notch sensitivity

d. Discuss the relationship of Brinell hardness, ultimate tensile strength, and flexural endurance limit for steel.

PROBLEM 88

a. Two pieces cut from a common steel bar are hardened to 250 and 500 Brinell respectively. Discuss how the ultimate strength in tension, and the endurance limit in completely reversed bending, would compare for these two pieces.

b. Formulate some general rules to be followed when designing parts to carry variable loads.

PROBLEM 89, FIGURE 1, DIESEL ENGINE

a. Describe the construction and operation of the engine.

b. An engine similar to that shown has a $4\frac{1}{4}$" cylinder bore. When this engine is developing its rated horsepower at 2000 rpm, the piston exerts a force on the piston pin which varies from zero to 15,000 lbs during each revolution of the engine. To obtain sufficient bearing area, the outside diameter of the pin is to be $1\frac{1}{2}$", and to provide a hard surface the pin is to be carburized. Select a material for the pin, and determine the inside diameters of the pin. Show these diameters on a neat sketch, drawn full scale.

PROBLEM 90, FIGURE 1, DIESEL ENGINE

a. Describe the construction and operation of the engine.

b. An engine similar to that shown has a $4\frac{1}{4}$" cylinder bore. The load on the push rod which actuates the fuel injector rocker arm varies from zero to 1000 lbs during each revolution of the engine. Establish a satisfactory combination of:

1. pushrod material and hardness
2. pushrod diameter

XII - FITS AND TOLERANCES

PROBLEM 91

a. Explain why tolerances are necessary on manufactured machine parts.

b. Discuss the way in which the design and construction of the following are affected by the necessity of having tolerances:

1. The coupling which connects the motor shaft to the pinion shaft on the Helical Gear Speed Reducer, Figure 7.
2. The pinion mounting of the Bevel Gear Speed Reducer, Figure 12.
3. The operating linkage of the Thrustor Brake, Figure 15.

PROBLEM 92, FIGURE 7, HELICAL GEAR SPEED REDUCER

a. Describe the construction and use of the speed reducer.

b. The cast steel gear is to be a shrink fit on the 4" diameter steel shaft. Establish the maximum and minimum dimensions for the shaft diameter, and for the hole in the gear. State the type of machining operation you would recommend to finish the shaft and bore.

c. Determine a satisfactory hub diameter for the shaft and hole dimensions found above.

PROBLEM 93

Discuss the "basic hole" system of dimensioning, why it was developed, and wnether or not it should be used for dimensioning the shaft and gear hole of problem 92.

PROBLEM 94, FIGURE 12, BEVEL GEAR SPEED REDUCER

a. Describe the construction and use of the speed reducer.

b. An actual speed reducer is to be the size shown. Make a neat sketch, to scale, of the cartridge which contains the input shaft bearings. On this sketch show the following dimensions with suitable tolerances:

1. locating or piloting diameter of cartridge
2. diameter of housing bore into which cartridge pilots or fits
3. bearing diameters
4. diameter of bore into which bearings fit
5. concentricity limits of bearing bore diameter and cartridge pilot diameter
6. distance between bearing shoulders

PROBLEM 95, FIGURE 12, BEVEL GEAR SPEED REDUCER

a. Describe the construction and use of the speed reducer.

b. The drawing is ½ the size of an actual speed reducer. All lengthwise dimensions parallel to the output shaft are to have a tolerance of 0.010", except for the bearing assemblies which have a tolerance of 0.005". A 0.015" thick gasket is to be used between the housing and the top cover. Plastic shims beneath the end caps are to allow correct positioning of the bevel gear, and to remove clearance from the bearings. The minimum shim thickness at either cap is to be 0.010". Determine all necessary linear dimensions of the output shaft assembly and the housing assembly. Show these dimensions on a neat sketch, and determine the maximum combined shim thickness that could be required at the two caps.

XIII - SPRINGS

PROBLEM 96, FIGURE 19, EXTERNAL SHOW BRAKE

a. Describe the construction and operation of the brake.

b. To apply a brake similar to that shown, the spring must exert a force of 800 lbs. The brake is to be released by compressed air at 80 psi, which will move the plunger ½". To hold the spring in position, the inside diameter of the cylinder is to be no more than ¼" larger than the outside diameter of the spring. The brake is to be applied and released at an average rate of once every 10 minutes during a normal 8 hour work day.

Design the spring, stating a satisfactory combination of:

1. outside diameter of coil
2. wire diameter (W-M std. gage)
3. wire material
4. number of coils
5. type of ends
6. pitch of coils
7. approximate free length
8. inside diameter of air cylinder

PROBLEM 97, FIGURE 8, CLUTCH AND TRANSMISSION

a. Describe the construction and operation of the clutch, including the way in which the clutch is engaged and dis-engaged.

b. A force of 1000 lbs is required to apply a clutch of the type shown. This force is to be supplied by 6 springs equally spaced around the pressure plate. Available space limits the outside diameter of the springs to $1\frac{1}{4}$" maximum, and the length of the springs to 1 3/4" when the clutch is engaged. The pressure plate must move 1/8" to disengage the friction surfaces, and the lowest spring rate reasonably possible is desired.

Design the springs, stating a satisfactory combination of:

1. outside diameter of coil
2. wire diameter
3. wire material
4. number of coils
5. type of ends
6. pitch of coils
7. approximate free length

PROBLEM 98, FIGURE 15, THRUSTOR BRAKE

a. Briefly describe the construction and operation of the brake.

b. A spring force of 300 lbs is required to apply a brake similar to that shown. When the brake is released by the thrustor, the spring is further compressed $\frac{1}{4}$", which should increase the spring force by no more than 25%. Design the spring, stating a satisfactory combination of:

1. outside diameter of coil
2. wire diameter
3. wire material
4. number of coils
5. type of ends
6. pitch of coils
7. approximate free length

PROBLEM 99, FIGURE 11, V8 ENGINE

a. Describe the construction and operation of the engine, including the valve operating linkage.

b. An exhaust valve spring is to be designed for an engine with performance as shown by the curve of Figure 31. Valve lift is to be 3/8", and the spring is to exert a force of 40 to 45 lbs when the valve is closed, and 88 to 93 lbs when the valve is fully open. Available space limits the outside diameter of the spring to 1 5/8" maximum, and limits the length of the spring to 1 5/8" maximum when the valve is closed. Determine a satisfactory combination of:

1. mean coil diameter
2. wire diameter (W-M std. gage)
3. wire material and treatment
4. number of coils
5. type of ends
6. pitch of coils
7. approximate free length

PROBLEM 100, FIGURE 1, DIESEL ENGINE

a. Describe the operation of the Diesel engine, including the valve operating linkage.

b. A valve spring is to be designed for a Diesel engine similar to that shown. Valve lift is to be 0.390". The spring is to exert a force of 140 lbs when the valve is fully open, and 44 lbs when the valve is closed. Available space limits the length of the spring to $2\frac{1}{2}$" maximum when the valve is closed. and limits the outisde diameter of the coil to a maximum of $1\frac{1}{2}$". Engine speed is to be 2100 rpm. Establish a satisfactory combination of:

1. mean coil diameter
2. wire diameter (W-M std. gage)
3. wire material and treatment
4. number of coils
5. type of ends
6. pitch of coils
7. approximate free length

PROBLEM 101, FIGURE 9, SCRAPER HOIST

a. Describe the construction and operation of the hoist.

b. The two tension springs which pull the band brake free of the ring gear are to exert a force of 30 lbs each, are to have a spring rate of 60 lbs/inch, and are to be wound with an initial tension of 10 lbs. Design the springs, stating a satisfactory combination of:

1. mean coil diameter
2. wire diameter
3. wire material
4. number of coils
5. type of ends
6. approximate free length of coiled section

PROBLEM 102, FIGURE 14, AUTOMATIC TRANSMISSION

a. Describe the operation of the band brake operating linkage.

b. Neatly sketch a characteristic load vs. deflection curve for a conical coil spring like that used in the brake actuating cylinder. Discuss the shape of the curve, and label any significant points.

c. What is the probable advantage of the conical coil spring as compared to a cylindrical coil spring in the installation shown ?

PROBLEM 103, FIGURE 22, TRUCK CHASSIS

a. Describe the three separate functions performed by the leaf spring in the suspension shown.

b. Sketch and describe what is commonly known as a "torque-tube" drive for automobiles.

c. Discuss the comparative advantages and dis-advantages of coil springs and leaf springs when used in passenger automobile rear suspensions so far as comfort, stability, and steering are concerned.

d. Explain the function of the rebound clips used on the leaf springs.

PROBLEM 104, FIGURE 22, TRUCK CHASSIS

a. Describe the construction and operation of the rear suspension shown on the truck.

b. The rear springs of a small truck are to hold a maximum load of 750 lbs each, and to have a deflection rate of 250 lbs/inch. The engine develops a maximum torque of 200 lbft, the rear end ratio is 3:1, and the 4 ply tires are size 6.70 x 15.
Design the leaf spring, and make a neat sketch showing all necessary dimensions. Tabulate a satisfactory combination of:

1. spring length and width
2. number of leaves
3. thickness of leaves
4. camber in free position
5. material and treatment
6. length of each leaf

XIV - THREADED FASTENERS

PROBLEM 105

a. When machine parts are bolted together, what condition commonly exists which causes the bolts to be relatively more elastic than the parts being fastened ?

b. Discuss the significance of the initial tightening load, and of the applied load, so far as bolts are concerned. Explain which of the above loads must be the larger for a properly designed bolted joint, and how each affects the total load on the bolt.

c. Discuss the problem of establishing bolt loads with reasonable accuracy when the bolts are tightened with ordinary box-end or socket wrenches.

d. Explain why the connecting rod bolts of the Diesel Engine, Figure 1, have a reduced diameter along the body of the bolt.

PROBLEM 106, FIGURE 9, SCRAPER HOIST

a. Describe the construction and operation of the scraper hoist.

b. A scraper hoist which is 5 times the size shown is to be fastened down to a foundation by a row of bolts along the flange of each skid. The hoist is powered by an AC induction motor having characteristics as shown by the curve of Figure 31 for design D motors. When the motor develops its rated horsepower, the shorter of the two drums is to be capable of exerting a pull of 4000 lbs on a wire rope. Determine a satisfactory combination of:

1. number of bolts to be provided in each flange
2. bolt diameter
3. bolt material

PROBLEM 107, FIGURE 9, SCRAPER HOIST

a. Describe the operation and use of the scraper hoist.

b. Discuss the problem of establishing the size bolts to be used where parts of the frame or supporting structure are bolted together, and where the side pieces are bolted to the ring gears.

PROBLEM 108, FIGURE 28, STRAIGHT PRESS

a. Describe the construction and operation of the press.

b. A 40 ton capacity press is 8 times the size shown. The 3 piece cast iron frame of the press is held together by 4 tie rods as shown. Determine a satisfactory combination of:

1. tie rod diameter, material, and heat treatment
2. recommended tightening torque

PROBLEM 109, FIGURE 27, AIR CYLINDER

a. Describe the construction and use of the cylinder.

b. A cylinder having a 6" bore and a 10" stroke is to be actuated by air at 100 psi. Determine a satisfactory combination of:

1. number of tie-rod bolts to be used
2. diameter, material, and heat treatment of tie-rod bolts
3. recommended tightening torque

c. It is proposed that the construction by changed to have the end pieces extend further into the cylinder. Sealing of the ends would then be accomplished by an "O" ring static seal, rather than by the compression gasket shown. Sketch this new construction and discuss its advantages and dis-advantages so far as the tie-rod construction is concerned.

PROBLEM 110, FIGURE 14, AUTOMATIC TRANSMISSION

a. Describe the construction of the hydraulic torque converter.

b. The drawing is 3/4 of the actual size of an automatic transmission used with a gasoline engine which performs as shown by the curve of Figure 31. To prevent overheating, oil is pumped through the converter at 30 psi by the front pump of the transmission. Establish a satisfactory combination of:

1. number of bolts required to fasten the converter cover to the converter pump
2. size, material, and heat treatment of bolts
3. recommended tightening torque

PROBLEM 111, FIGURE 1, DIESEL ENGINE

a. Describe the construction and operation of the engine, and explain why a flywheel is necessary.

b. The drawing is $\frac{1}{2}$ the size of an actual engine which performs as shown by the curve of Figure 31. Design the bolts which fasten the flywheel to the crankshaft, stating a satisfactory combination of:

1. number of bolts
2. bolt diameter, material, and heat treatment
3. bolt circle diameter
4. recommended tightening torque

PROBLEM 112, FIGURE 1, DIESEL ENGINE

a. Describe the construction and operation of the engine.

b. A Diesel engine has a $4\frac{1}{4}$" bore and a 6" stroke. When firing, the maximum cylinder pressure is 1200 psi. The cylinder head and block are made of cast iron, and a copper-asbestos gasket 3/32" thick is used between the head and block. Each of the 3 heads are fastened to the block by 4 stud bolts. Determine a satisfactory combination of:

1. Bolt diameter and number of threads/inch
2. bolt material and heat treatment
3. length bolt threads into block
4. recommended tightening torque

XV - POWER SCREWS

PROBLEM 113

a. Discuss the desirable and undesirable characteristics of a power screw as a means of obtaining linear motion in a machine.

b. Describe the relative advantages and dis-advantages of the square, Acme, and Buttress threads.

c. Considering the power screw to be an inclined plane, show that if the screw is self-locking, the efficiency can be no more than 50%.

PROBLEM 114, FIGURE 21. C FRAME PRESS

a. Describe the construction and operation of the press, including the power screw in its base.

b. The power screw in the base of the press is to be capable of exerting a force of 3000 lbs and is to have a linear travel of 12 inches. Establish a satisfactory combination of:

1. screw diameter and number of threads/ inch.
2. number of independent threads on screw
3. thread form
4. length and outside diameter of nut
5. material and heat treatment of screw and nut
6. length of handle to be used for turning nut

PROBLEM 115, FIGURE 6, SCREW JACK

a. Describe the construction and operation of the jack.

b. A jack similar to that shown is to be used as an adjusting and positioning device in a large conveyor system. The jack will be permanently installed in the conveyor machinery and must be capable of raising or lowering a 4 ton piece of equipment 3 feet in approximately 4 minutes. Operation of the jack will be infrequent, but to allow remote control, the jack is to be driven by an AC induction motor, with performance as shown by the curve of Figure 31 for design D motors. It is estimated that the efficiency of the worm will be approximately 40%.
Establish a satisfactory combination of:
1. screw diameter and numberof threads/inch
2. number of independent threads
3. thread form
4. material and treatment of screw and nut
5. length of nut
6. worm gear ratio required
7. rated HP and synchronous speed of motor

PROBLEM 116, FIGURE 6, SCREW JACK

a. Describe the construction and operation of the jack.

b. A jack similar to that shown requires a torque of 200 lb-inches applied to the nut by the worm to raise a given load, and a torque of 120 lb-inches applied to the nut to lower this same load. What is the efficiency of the screw ?

PROBLEM 117, FIGURE 3, POWER STEERING UNIT

a. Describe the construction and operation of the power steering mechanism.

b. A power screw with a circulating ball nut is to be designed for a power steering mechanism. The nut is to be capable of exerting a linear force of 600 lbs when a torque of 80 lb-inches is applied to the steering wheel shaft, and the nut is to travel ½" for each complete revolution of the steering wheel shaft. Establish a satisfactory combination of:

1. screw diameter and number of grooves/inch
2. number of independent grooves
3. ball diameter
4. length of nut
5. material and heat treatment for screw, nut, and balls

XVI - BELTS AND CHAINS

PROBLEM 118

a. Does the following equation correctly describe the relation of the tensions in a flat belt for all conditions of operation ? Discuss briefly.

$$\frac{F_1 - F_c}{F_2 - F_c} = e^{f\theta}$$

b. Explain why the small pulley of a flat belt drive is often made of wood or leather, while the large pulley is made of cast iron.

c. Show why a V belt can develop a greater friction force than a flat belt.

d. Explain in words, not equations, the conditions under which a V-flat drive would perform as satisfactorily as a regular V belt drive.

PROBLEM 119, FIGURE 28, STRAIGHT PRESS

a. Describe the construction and operation of the press.

b. A press similar to that shown is to punch holes in parts formed from steel plate. The press is to make 40 punches/minute, with each punch requiring 5000 ft-lbs of energy. The bull gear and pinion will provide an 8:1 ratio, and the flywheel will be designed so that the speed variation during a punching cycle is no more than 10% of the maximum speed. A 1200 rpm AC induction motor is to drive the press through

V belts as shown. Establish a satisfactory combination of:

1. belt size and number of belts
2. sheave diameters (do not design flywheel)
3. approximate center distance of sheaves

PROBLEM 120, FIGURE 20, CRUSHER

a. Describe the construction and operation of the crusher.

b. A crusher similar to that shown is to be V-belt driven from a 30 HP, 1200 rpm AC motor. The flywheel is to act as the large V-belt sheave, and the belt drive is to provide a 5:1 spe
satisfactory combination of:

1. belt size and number of belts
2. sheave diameters (do not design flywheel)
3. approximate center distance of sheaves

c. Using the belt size, sheave diameters, and center distance found above, determine how many additional belts would be needed for a V-flat drive.

PROBLEM 121, FIGURE 25, SHAPER

a. Describe the construction and operation of the shaper.

b. A shaper similar to that shown is to be V-belt driven from a 5 HP, 1200 rpm motor. The motor weighs 170 lbs, has a 12 3/4" diameter, is $17\frac{1}{4}$" long, has a bearing span of 15", and the center of the sheave is 4" from the first bearing.
Five size A belts are to be used, with sheave diameters of 5" and 15", and a center distance of 22". A pivoted motor mounting is to be used. Design such a mounting, and make a neat sketch, to scale, showing the location of the pivot point, motor location, and other significant dimensions.

c. Determine the motor bearing loads due to the belts only.

PROBLEM 122

a. Discuss the relative advantages and dis-advantages of belts, chains, and gears as means of transmitting power.

b. What consideration dictates the minimum number of teeth in a roller chain sprocket ?

c. Explain why roller chains tend to be noisy when they become worn. Illustrate the explanation with a neat sketch, and describe how the cause of the noise can be partially eliminated by the proper shape of the sprocket teeth.

d. Sketch the rocker pin construction commonly used with silent chains. Describe the operation of the rocker pins, and discuss the advantages of this construction.

PROBLEM 123, FIGURE 2, TRANSPORT MACHINE

a. Describe the construction, operation, and use of the transport machine.

b. The transport machine is driven by a 3 HP, 900 rpm AC induction motor. The enclosed bevel gear speed reducer provides a 6:1 reduction, and has a 2" diameter output shaft. The roller chain is to provide a 1.5:1 reduction, with a center distance of approximately 30". Establish a satisfactory combination of:

1. pitch of chain
2. number of strands
3. number of links per strand
4. numbers of teeth in sprockets

XVII - WIRE ROPES

PROBLEM 124

a. Explain why there is no strand of wire in the center of most wire ropes.

b. Explain briefly in words, not equations, the meaning of the "bending load" in wire ropes.

c. Derive the equation for the bending load

PROBLEM 125

a. Neatly sketch and label a 4 rope "independent" suspension, as might be used on a passenger elevator.

b. Neatly sketch and label a 4 rope "dependent" suspension, as might be used on an overhead travelling crane.

c. Discuss the need for using rather large safety margins when selecting wire ropes for hoisting equipment.

PROBLEM 126, FIGURE 9, SCRAPER HOIST

a. Describe the construction and operation of the scraper hoist.

b. A scraper hoist similar to that shown is to be capable of pulling a 2700 lb load at 200 ft/min., when the AC induction motor is developing its rated horsepower. Motor characteristics are shown by the curve of Figure 31 for design D motors. Establish a satisfactory combination of:
   1. rope diameter and pattern
   2. rope material
   3. hoist drum diameter

c. Select a standard 1200 or 1800 rpm AC induction motor, and establish the total gear ratio needed.

PROBLEM 127, FIGURE 30, OVERHEAD CRANE TROLLEY

a. Describe the construction and operation of the crane trolley.

b. An overhead crane like that shown is to have a hoisting speed of 22 ft/min. when lifting its rated capacity of 20 tons. Maximum lift is to be 45 feet.
The direct current hoist motor has operating characteristics as shown by the curve of Figure 31. The motor should run at approximately rated speed when the crane is lifting its rated capacity. A current control

limits the maximum torque which the motor can develop to 130% of rated motor torque. Crane motors having ratings of 25 HP at 575 rpm, 35 HP at 525 rpm, and 50 HP at 500 rpm are available. Establish a satisfactory combination of:

1. rope diameter and pattern
2. rope material
3. drum and sheave diameters

c. Select a suitable motor and establish the total reduction gear ratio for the crane.

XVIII - SPUR GEARS

PROBLEM 128

a. Explain why "conjugate" curves must be used for tooth profiles, rather than just any curved surfaces which might be arbitrarily selected.

b. Define an involute curve, and show on a neat sketch how the curve is developed.

c. State the two most important reasons why involute curves are used instead of any other conjugate curves for gear tooth profiles.

PROBLEM 129

a. By means of a neat sketch and brief explanation, show that when one involute drives another, the angular velocity ratio is constant. Do not refer to the pitch point, nor to the "law of gearing", in the explanation.

b. Describe the hobbing operation for cutting gear teeth, and state the property of the involute curve which makes this possible.

c. What is the purpose of having standard pitches, pressure angles, and tooth proportions ?

PROBLEM 130, FIGURE 2, TRANSPORT MACHINE

a. Describe the construction and operation of the transport machine.

b. The final drive pinions and gears of a transport machine have 20 and 42 teeth respectively. The diametral pitch is 4, the pressure angle is 20°, and the teeth have full depth proportions. Using a compass and straight edge, make a full scale sketch showing the following for the gear and pinion.

1. pitch circles
2. root circles
3. base circles
4. addendum circles
5. pressure angle
6. length of the path of contact

c. Prove on your sketch that if the 20 tooth pinion is cut with a hob, the teeth will not be undercut.

PROBLEM 131, FIGURE 13, 2 SPEED DIFFERENTIAL

a. Describe the construction and operation of the two speed differential.

b. A spur pinion and gear in the differential are to have 14 and 24 teeth respectively. The teeth are to be cut with a 5 pitch 20° full depth hob. The two gears are to operate with the theoretically correct center distance with 0.007" backlash. Neither the pinion nor the gear are to be undercut. Determine the following for the pinion and gear:

1. outside diameter
2. addendum
3. whole depth
4. circular tooth thickness at the pitch diameter

PROBLEM 132. FIGURE 2. TRANSPORT MACHINE

a. Describe the construction and operation of the transport machine.

b. The final drive pinions and gears of a transport machine have 20 and 42 teeth respectively. The diametral pitch is 4, the pressure angle is 20°, and the teeth have full depth proportions. The teeth are in contact at the pitch point, and the pinion torque is 2000 lb-inches. Using a compass and straight edge, make a full scale sketch showing:

1. pitch and base circles
2. the total force exerted on the driven gear
3. the components of the total force

PROBLEM 133

a. Apply the beam stress equation:

$$S = \frac{M\ c}{I}$$ to a gear tooth, and derive the Lewis equation:

$$S = \frac{F\ P}{f\ Y}$$

b. What is the significance of the parabola commonly used in the derivation of the Lewis equation ?

c. Discuss the probable accuracy of the Lewis equation as a means of determining the stress which actually occurs in a gear tooth.

PROBLEM 134

a What is the visual evidence of gear tooth failure by bending fatigue and of failure by surface fatigue ?

b. What surface treatments could be used to increase the bending fatigue life and surface fatigue life of gear teeth ?

PROBLEM 135, FIGURE 30, OVERHEAD CRANE TROLLEY

a. Describe the construction and operation of the crane.

b. An overhead crane has a rated capacity of 20 tons, which it hoists at 22 ft/min. when the DC motor is developing its rated horsepower. The motor characteristics are shown on the curve of Figure 31. A current relay limits the maximum motor torque to 130% of its rated torque. The rope drum diameter is 30", and the sheave diameters are 20". The rope drum is driven by the DC motor through several sets of enclosed spur gears, The final pair of spur gears are to provide a 3:1 ratio, with the gear keyed to the 5" diameter shaft of the rope drum, and the pinion keyed to a 3.5" diameter shaft.

Design the teeth for the final pair of spur gears, tabulating a satisfactory combination of:

1. pitch diameters
2. diametral pitch
3. numbers of teeth
4. face width
5. pressure angle
6. depth of teeth
7. required accuracy of manufacture
8. material and hardness

c. Make a neatly dimensioned sketch, to scale, showing the cross section of your gear and pinion.

PROBLEM 136, FIGURE 28, STRAIGHT PRESS

a. Describe the construction and operation of the press.

b. In a press like that shown, maximum crank torque occurs when the crank is 20^{o} before bottom center, and a force of 10 tons is being exerted. The crank requires 1.5 seconds to make one complete revolution. The stroke of the press is 12", and the length of the **Pitman** rod is 28". The bull gear and pinion are to provide an 8:1 ratio. Design the teeth for these gears, stating a satisfactory combination of·

1. pitch diameters
2. diametral pitch
3. numbers of teeth
4. face width
5. pressure angle
6. depth of teeth
7. required accuracy of manufacture
8. material and hardness

c. Make a neatly dimensioned sketch, to scale, showing the cross section of your gear and pinion.

PROBLEM 137, FIGURE 9, SCRAPER HOIST

a. Describe the construction and operation of the scraper hoist.

b. A scraper hoist is to be powered by a 20 HP, 1800 rpm AC induction motor with characteristics as shown by the curve of Figure 31 for design D motors. The double reduction gears next to the motor provide a total ratio of 5:1. The shorter rope drum has a 15" diameter, and is to be capable of pulling a ½" wire rope at approximately 193 ft/min. when the motor is developing its rated horsepower.

Considering the motor to operate at its rated horsepower most of the time, design the teeth for the planetary gears which drive the shorter drum. Use the Buckingham equations to check the load carrying capacity, and tabulate a satisfactory combination of:

1. number of planets
2. pitch diameters of sun, planet, and ring gears
3. diametral pitch
4. numbers of teeth
5. pressure angle and tooth depth
6. face width
7. required accuracy of manufacture
8. material and hardness

XIX - HELICAL GEARS

PROBLEM 138

a. State the comparative advantages and dis-advantages of helical gears and straight spur gears.

b. Show that for helical gears cut with a standard pitch hob the following relationship is correct:
Nº teeth = (pitch diameter) x (diametral pitch) x (cosine of helix angle)

c. Using a 3 dimension sketch, derive an equation relating the pressure angle in a plane normal to the teeth, the pressure angle in the plane of rotation, and the helix angle.

PROBLEM 139, FIGURE 9, SCRAPER HOIST

a. Describe the construction and operation of the scraper hoist.

b. The planetary spur gears which drive the short rope drum are to be replaced with helical gears. The original planetary gear speed ratio of 5:1 is to be maintained, and the helical sun and planet gears are to be cut with the same hob with which the spur gears were cut. The carrier, ring gear mountings, etc., are to be unchanged. The spur sun gear has 22 teeth, 6 pitch, 20° pressure angle.
Determine a satisfactory combination of the following for the new sun, planet, and ring gears:
1. pitch diameters
2. numbers of teeth
3. helix angle and hand

PROBLEM 140, FIGURE 7. HELICAL GEAR SPEED REDUCER

a. Describe the construction and use of the speed reducer.

b. A helical gear speed reducer similar to that shown is to be capable of transmitting 50 HP continuously from a 1750 rpm driving motor, and is to provide a 3.5:1 reduction.
Using the Buckingham equations to calculate the load carrying capacity, design the helical gear teeth. Tabulate a satisfactory combination of:
1. pitch diameters
2. diametral pitch
3. numbers of teeth
4. helix angle and hand
5. pressure angle
6. tooth depth
7. face width
8. required accuracy of manufacture
9. material and hardness

PROBLEM 141, FIGURE 10, MARINE REDUCTION AND REVERSE GEAR

a. Describe the construction and operation of the reverse gear.

b. A reduction and reverse gear similar to that shown is to be used with a Diesel engine which performs as shown by the curve of Figure 31, and is to provide a 1.5:1 ratio both forward and reverse. Using the Buckingham equations to calculate the load carrying capacity, design the helical teeth for the forward ratio only. Tabulate a satisfactory combination of:

1. pitch diameters
2. diametral pitch
3. numbers of teeth
4. helix angle and hand
5. pressure angle
6. tooth depth
7. face width
8. required accuracy of manufacture
9. material and hardness

c. If the gears in the reverse ratio are to have the same pitch and helix angle as those in the forward ratio, would it be satisfactory to use the same numbers of teeth in the reverse gears as in the forward gears ? Explain briefly.

PROBLEM 142. FIGURE 7. HELICAL GEAR SPEED REDUCER

a. Describe the construction and use of the speed reducer.

b. A speed reducer which is exactly 5 times the size shown, has teeth with a 20° pressure angle and a 25° helix angle. The motor rotates at 1160 rpm and develops 20 HP.
Determine the total force which the pinion teeth exert on the gear teeth, the 3 components of this force, and the bearing reactions due to these components. Show the forces, components, and reactions for both the gear and pinion on neatly labelled 3 dimension sketches.

PROBLEM 143, FIGURE 8, CLUTCH AND TRANSMISSION

a. Make a schematic sketch of the transmission and describe with reasonable detail how it operates to provide a neutral. 3 speeds forward. and a reverse.

b. The sliding gear has 28 teeth, 7 pitch, and 23° helix angle. The pitch diameter of the spline on which it slides is 1.5". Determine the helix angle required for the spline teeth so that the thrust on the helical gear teeth will not move the sliding gear axially along the spline teeth, and whether the gear teeth and spline teeth should have the same or opposite hand helices.

PROBLEM 144, FIGURE 8, CLUTCH AND TRANSMISSION

a. Make a schematic sketch and describe the operation of the transmission.

b. The transmission is to provide a total ratio of 1.61:1 when in second gear. The countershaft gears used when the transmission is in second gear are to be designed so that the resulting axial thrust on the countershaft bearings is as near to zero as reasonably possible. Using a pitch of 7, and a 3.00" center distance, determine a satisfactory combination of pitch diameters and helix angles for the 4 gears used when in second gear. State whether the 2 gears on the countershaft should have the same or opposite hand helices.

c. To obtain lengthwise dimensions, such as the distances from a gear to its bearings, consider the drawing shown to be 2/3 of the actual size of the transmission. The engine develops a torque of 200 lb-ft at 2100 rpm when the transmission is in second gear. Using the numbers of teeth, helix angles, and diameters found in part b, make a complete force analysis of the countershaft assembly when in second gear. Make a 3 dimension sketch showing the normal forces at the teeth, the components of the normal forces, and the housing reactions due to each of these components. Label each vector and show magnitude and direction.

XX - BEVEL GEARS

PROBLEM 145

a. A straight tooth bevel gear and pinion provide a 4:1 ratio and have perpendicular axes. Could this same pinion be used with a smaller gear in another installation with perpendicular axes to provide a 3:1 ratio ? Explain briefly.

b. Why must bevel gear assemblies be constructed so that the position of the gear and pinion can be adjusted lengthwise along their shafts at assembly ?

PROBLEM 146, FIGURE 12, BEVEL GEAR SPEED REDUCER

a. Describe the construction and use of the speed reducer.

b. Explain how the position of the gear and pinion are adjusted axially, and why this is necessary.

c. A reducer similar to that shown is to be capable of transmitting 20 HP continuously from a 900 rpm motor, and is to provide a 4:1 reduction. Design the straight bevel gear teeth for the speed reducer, stating a satisfactory combination of:

1. pitch diameters
2. diametral pitch
3. numbers of teeth
4. pressure angle
5. addendum and dedendum
6. face width
7. material and hardness

PROBLEM 147. FIGURE 12, BEVEL GEAR SPEED REDUCER

a. Describe the construction and use of the speed reducer.

b. Straight tooth bevel gears with a 20^{o} pressure angle are to be used in a speed reducer similar to that shown. The gears are to transmit 20 HP at 1160 rpm of the bevel pinion. The figure shown is exactly $\frac{1}{2}$ of the actual size of the speed reducer.
Determine the magnitude of the normal force on the teeth, the three components of this normal force, and the reactions due to each of these components on the bearings of the gear and pinion. Make a neat, 3 dimension sketch showing the location and direction of the forces, components, and reactions.

PROBLEM 148. FIGURE 12. BEVEL GEAR SPEED REDUCER

a. Describe the construction and use of the speed reducer.

b. Spiral tooth bevel gears with a 15^{o} spiral angle and a 20^{o} pressure angle are to be used in a speed reducer similar to that shown. The pinion has a right hand spiral, and the gears are to transmit 20 HP at 1160 rpm of the pinion. The figure shown is exactly $\frac{1}{2}$ of the actual size of the speed reducer.

Determine the magnitude of the normal force on the teeth, the three components of this normal force, and the reactions due to each of these components on the bearings of the gear and pinion. Make a neat, 3 dimension sketch showing the location and direction of the forces, components, and reactions.

PROBLEM 149, FIGURE 4, REAR AXLE

a. Describe the construction and operation of the rear axle assembly, including the action of the differential when the automobile is traveling straight ahead, and when the automobile is turning a corner.

b. Explain why, when the automobile is stuck with one rear wheel on ice and the other wheel on dry pavement, the wheel on the ice spins while the wheel on the pavement does not turn. Show any analysis necessary to prove your answer is correct.

PROBLEM 150, FIGURE 4, REAR AXLE

a. Describe the construction and operation of the rear axle assembly, including the action of the differential when the automobile is traveling straight ahead, and when the automobile is turning a corner.

A rear axle similar to that shown is to be used with the V-8 engine of Figure 11, and a clutch and transmission of Figure 8, in a modern American passenger automobile. The horsepower developed by the engine is shown on the curve of Figure 31, while the horsepower required to drive the automobile on level ground and up a 35% grade are shown by the curves of Figure 32. Estimating the overall efficiency of the transmission, differential, etc., to be about 85%, determine the following:

1. the reduction ratio needed at the rear axle to obtain the maximum possible speed of the vehicle on level ground.
2. the transmission ratio needed to obtain the maximum possible speed of the vehicle when climbing a 35% grade in low gear.

c. The above automobile is stuck with one rear wheel on ice, the other on pavement. The coefficient of tire friction on ice is about 0.10, while on pavement it is approximately 0.70. With the transmission in low gear, and the engine throttle partially open, the engine turns at 2000 rpm. The wheel on the ice slips as it rotates, but the automobile does not move. Approximately what horsepower is the engine developing ?

PROBLEM 151, FIGURE 13, TWO SPEED DIFFERENTIAL

a. Describe the construction and operation of the two speed differential.

b. Discuss the relative advantages and dis-advantages of spiral bevel gears and hypoid bevel gears, when used in the rear axle of passenger automobiles and trucks.

XXI - WORM GEARS

PROBLEM 152

a. State the most important advantages and dis-advantages of worm gearing compared to other common types of gearing.

b. Considering the worm and gear to be a simple inclined plane, show that if a worm and gear are self locking, the efficiency of the worm and gear can be no more than 50%.

c. Explain why bronze gears are commonly used with hardened steel worms, rather than having both the worm and gear made of hardened steel.

d. Explain how the position of the gear is adjusted axially in the Worm Gear Speed Reducer, Figure 29, and why this adjustment is necessary.

PROBLEM 153. FIGURE 23. CAPSTAN WINCH

a. Describe the construction and use of the capstan winch.

b. The capstan winch shown is to be capable of pulling 1500 lbs at 40 ft/min. with either or both drums. Service will be intermittent.

The rope drums are to have 8" diameters, and are to have clockwise rotation when viewed from the right hand end. The winch is to be powered by an 875 rpm AC motor having clockwise rotation when viewed from its shaft end.

Design the worm and gear stating a satisfactory combination of:

1. pitch diameters
2. linear pitch
3. number of threads in worm
4. number of teeth in gear
5. pressure angle
6. lead angle and hand
7. helix angle and hand
8. face width of gear
9. material and hardness of worm and gear

c. Determine the horsepower rating of the motor required to drive the winch.

PROBLEM 154, FIGURE 23, CAPSTAN WINCH

a. Describe the construction and use of the capstan winch.

b. A winch similar to that shown is to be capable of pulling 2500 lbs at 20 ft/min. with either or both drums. The worm has 2 threads, and the gear has 60 teeth. The winch is ten times the size shown on the drawing. Determine the normal force and friction force at the teeth, the components of these forces, and the bearing reactions due to each of these components. Make a neat, 3 dimension sketch showing these forces, components, and reactions.

c. Are the worm and gear self-locking ? Explain briefly and show calculations.

PROBLEM 155, FIGURE 29, WORM GEAR SPEED REDUCER

a. Describe the construction and use of the worm gear speed reducer.

b. A speed reducer similar to that shown is to be capable of transmitting 25 HP continuously from a 1750 rpm driving motor, and is to provide a 15:1 reduction. The input and output shafts must both rotate clockwise as viewed from their outer ends. Determine a satisfactory combination of:

1. pitch diameters
2. linear pitch
3. number of treads in worm
4. number of teeth in gear
5. pressure angle
6. lead angle and hand
7. helix angle and hand
8. face width of gear
9. material and hardness of worm and gear

c. Estimate the external surface area which will be present on the housing which encloses the above worm and gear, approximate the temperature rise above ambient with continuous operation, and state whether or not this temperature rise would be permissible.

PROBLEM 156, FIGURE 13, TWO SPEED DIFFERENTIAL

a. Describe the construction and operation of the two speed differential.

b. The differential is to be re-designed to replace the spiral bevel pinion and gear with a worm and gear. Make 2 neat, complete sketches of the differential with the worm and gear, sectioned to show the method of supporting both the worm and the gear.

c. If a worm and gear were to be used in a differential, would it be best to have a worm with a rather large number of threads, say 6 or 8, or with a smaller number of threads, such as 2 or 3 ? Discuss briefly and explain clearly.

XXII - COUPLINGS AND CLUTCHES

PROBLEM 157

a. Why are flexible couplings more commonly used than rigid couplings ?

b. A flanged coupling is to be designed to fit a 40 HP, 1770 rpm AC motor. The motor shaft diameter is 2". Show your design on a neat sketch, drawn to scale and completely dimensioned, and specify the necessary materials.

PROBLEM 158, FIGURE 14, AUTOMATIC TRANSMISSION

a. Describe the operation of the over-running clutch in the torque converter of the transmission.

b. A torque converter similar to that shown has an outside fluid diameter of 12". The engine delivers a maximum torque of 150 lb-ft and the converter provides a 2.3:1 torque ratio at stall. Design a roller type of over-running clutch for the stator of this torque converter, showing the following on a neat sketch, drawn to scale:

1. roller diameter
2. number of rollers
3. inner and outer race dimensions
4. ramp angle
5. material and heat treatment

PROBLEM 159, FIGURE 5, BEVEL GEAR REVERSING UNIT

a. Describe the construction and operation of the bevel gear reversing unit.

b. Make a neat sketch of the clutch engaging mechanism, and explain how it operates.

c. Explain why such an elaborate mechanism is required with the disk clutch.

PROBLEM 160, FIGURE 5, BEVEL GEAR REVERSING UNIT

a. Describe the construction and operation of the bevel gear reversing unit.

b. The reversing unit is to be supplied with a 10 HP, 1200 rpm AC induction motor, which performs as shown by the curve of Figure 31 for B design motors. The bevel gears provide a 3:1 reduction, and it is anticipated that the clutches will be engaged and dis-engaged frequently. Design the disk clutch, stating a satisfactory combination of:

1. inside and outside diameters of the disks
2. disk surface materials
3. number of inner and outer disks
4. force required at the disks to engage the clutch

c. Design an engaging mechanism so this clutch can be operated manually. Make a neat sketch showing the handle, fork, rocker linkage, etc., with all important dimensions. Show force and motion analysis clearly.

PROBLEM 161, FIGURE 28, STRAIGHT PRESS

a. Describe the construction and operation of the press.

b. A press is 10 times the size shown in the drawing. Maximum crank torque occurs when the crank is 30^{o} before dead center, and is exerting a force of 25 tons. The motor and flywheel run continuously, and a friction disk clutch at the flywheel engages and dis-engages the jack-shaft as the operator wishes. The motor runs at approximately 1170 rpm when the clutch is disengaged.

Design a friction clutch for the press, stating a satisfactory combination of:

1. inside and outside diameters of the disks
2. disk surface materials
3. number of inner and outer disks
4. force required at the disks to engage the clutch

PROBLEM 162. FIGURE 8, CLUTCH AND TRANSMISSION

a. Describe the construction and operation of this clutch, including the means of engaging and disengaging.

b. Describe the features commonly found in an automobile clutch which would not be commonly found in clutches used with industrial machinery.

c. A clutch and transmission similar to that shown are to be used with the engine of Figure 11, which performs as shown by the curve of Figure 31. Design the clutch, stating a satisfactory combination of:

1. inside and outside diameters of the disks
2. disk surface materials
3. spring force required

PROBLEM 163, FIGURE 14, AUTOMATIC TRANSMISSION

a. Describe the operation of the transmission during three speeds forward and one speed in reverse, including the method of applying and releasing the disk clutches.

b. The transmission is to be used with an engine which performs as shown by the curve of Figure 31. The torque converter provides a maximum torque ratio of 2:1. To provide sufficient space for other parts of the transmission, the inside diameter of the disks of the front clutch can be no smaller than $3\frac{1}{2}$". Design the front clutch, stating a satisfactory combination of:

1. inside and outside diameters of the disks
2. number of inner and outer disks
3. disk materials
4. force required to apply clutch

PROBLEM 164. FIGURE 10, MARINE REDUCTION AND REVERSE GEAR

a. Describe the operation of the marine reduction and reverse gear.

b. The marine gear is to be used with a Diesel engine which performs as shown by the curve of Figure 31. Available space limits the outside diameter of the clutch disks to 10" maximum. Design the disk clutch, stating a satisfactory combination of:

1. inside and outside diameters of the disks
2. number of inner and outer disks
3. disk material
4. force required to apply the clutch.

PROBLEM 165, FIGURE 16, CONE CLUTCH

a. State the relative advantages and dis-advantages of cone and disk clutches.

b. A cone clutch is to be engaged with both parts stationary. Derive the equation for the force required to engage the clutch in terms of the normal force, the friction coefficient, and the cone angle.

c. Is the engaging force found by the equation derived above satisfactory if the clutch is engaged when one part is rotating and the other part stationary ? Explain briefly.

PROBLEM 166, FIGURE 16, CONE CLUTCH

a. Show that a cone clutch will hold itself in engagement if the tangent of the cone angle is less than the coefficient of friction.

b. A cone clutch is to transmit 200 lb-ft of torque at 200 rpm, and is to hold itself in engagement. Design the clutch, stating a satisfactory combination of:

1. mean diameter of cone
2. cone face width
3. cone angle
4. friction surface materials
5. force required to apply clutch

XXIII - HYDRAULIC COUPLINGS AND TORQUE CONVERTERS

PROBLEM 167

a. Explain in words, not equations, the principle of operation of a hydraulic coupling.

b. Establish the relationship of the input torque to the output torque of a hydraulic coupling, and derive an equation for the efficiency of the coupling in terms of the speed ratio.

c. Discuss the advantages and dis-advantages of a hydraulic coupling as a means of transmitting power.

PROBLEM 168, FIGURE 10, MARINE REDUCTION AND REVERSE GEAR

a. Describe the operation and use of the marine gear

b. The marine gear is to be used with a Diesel engine similar to that shown in Figure 1, except with more cylinders. Typical engine performance with wide open throttle is shown by the curve of Figure 31. Engines capable of developing horsepowers of 200, 250, 300, and 350, all at 1800 rpm, are available.

The curves of Figure 32 show the performance of a 15" hydraulic coupling of the type used with the marine gear. Figure 32 also shows the power required to drive the propeller of a boat.

A boat is to be built to cruise with a propeller speed of 300 rpm when the engine develops 80% of its horsepower rating as mentioned above, and coupling slip is 3%.

Determine a satisfactory combination of:

1. size of Diesel engine to be used
2. diameter of geometrically similar coupling to be used
3. gear ratio required

c. Would it be more economical to obtain the 80% of rated horsepower by operating the engine at part throttle or by operating at full throttle at a lower speed ? Explain briefly.

PROBLEM 169

a. Explain the fundamental difference in construction of the hydraulic coupling and the hydraulic torque converter, and prove that this difference is necessary.

b. By means of a neat sketch and brief explanation, show how the converter increases torque, and why the efficiency decreases rapidly as the speed of the turbine approaches the speed of the pump.

c. Discuss the desirability of mounting the stator on a one-way clutch in a converter to be used in a passenger automobile, a converter to be used in a crawler tractor, and a converter to be used in a city bus.

PROBLEM 170, FIGURE 14, AUTOMATIC TRANSMISSION

a. Describe the construction and operation of the torque converter.

b. The 12" converter used with the automatic transmission performs as shown by the curves of Figure 32. Using $8\frac{1}{2}$" x 11" graph paper, neatly plot the following curves for this same converter:

1. input torque to converter, lb-ft (ordinate), vs. input speed of converter, rpm (abscissa), for a 1.5:1 torque ratio.
2. output speed of converter, rpm (ordinate), vs. input speed of converter, rpm (abscissa), for a 1.5:1 torque ratio.

Both curves are to be plotted on the same sheet with a common abscissa. The torque scale is to go to 300 lb-ft, the speed scales to 3000 rpm.

c. Under certain operating conditions of a modern American automobile, the engine runs at 2000 rpm and the above converter develops a 1.5:1 torque ratio. Determine the horsepower the engine is developing, and the approximate speed of the vehicle in miles per hour.

XXIV - BRAKES

PROBLEM 171, FIGURE 15, THRUSTOR BRAKE

a. Describe the construction and operation of the brake.

b. A brake similar to that shown is to hold a torque of 200 lb-ft. Design this brake, stating a satisfactory combination of the following, and make a neat sketch, drawn to scale, of your design.

1. drum diameter and width
2. drum material
3. shoe lining material
4. shoe angle
5. lengths of levers and position of all pivots (show dimensions on sketch)
6. spring force required to apply brake
7. thrustor force required to release brake

PROBLEM 172, FIGURE 30, OVERHEAD CRANE TROLLEY

a. Describe the construction and operation of the crane.

b. A crane similar to that shown is to have a capacity of 15 tons, a rope drum diameter of 20", and a 40:1 gear reduction between the DC motor and the rope drum. The lowering speed of the 15 ton load is 20 ft/min., held constant by regenerative braking of the DC motor.
The external shoe brake, which is applied by a spring and released electrically, is to be capable of bringing the load to a stop in 6 inches in case of motor failure while lowering. Design the shoe brake, stating a satisfactory combination of the following, and make a neat sketch, drawn to scale, of your design:
1. drum diameter and width
2. drum material
3. shoe lining material
4. shoe angle
5. lengths of levers and position of all pivots (show dimension son sketch)
6. spring force required to apply brake
7. thrustor force required to release brake

PROBLEM 173, FIGURE 19, EXTERNAL SHOE BRAKE

a. Describe the construction and operation of the brake.

b. A brake similar to that shown is to be designed for use on a passenger elevator. Because of the safety problem involved, the brake drum and elevator rope drum are to be fastened together and rotate on the same shaft. The maximum gross load of the elevator is to be 3000 lbs., and the lowering speed is to be 240 ft/min. The brake is to be capable of stopping the elevator in the shortest distance possible without causing discomfort to the passengers. Make a neat sketch, drawn to scale, of your brake design, and tabulate the following:
1. drum diameter and width
2. drum material

3. shoe lining material
4. shoe angle
5. shoe pivot location for minimum wear (show on sketch)
6. spring force required to apply brake
7. lever lengths and pivot locations (show on sketch)

PROBLEM 174, FIGURE 17, INTERNAL SHOE BRAKE

a. Describe the construction and operation of the brake.

b. The brake shown is used on the front wheels of a passenger automobile. Would it be desirable to have brakes of this same construction on all 4 wheels ? Explain briefly.

c. Explain briefly how the construction of the brake shown differs from that of the most popular brake construction in use today.

PROBLEM 175, FIGURE 17, INTERNAL SHOE BRAKE

a. Describe the construction and operation of the brake.

b. A modern American automobile is to have front wheel brakes like that shown. For calculating purposes, it can be considered that during a fast stop, approximately 60% of the total weight of the loaded vehicle will be equally divided between the 2 front wheels. The brakes are to be capable of stopping the vehicle from 60 mph in the shortest possible distance without skidding the wheels.

Design the front wheel brakes, stating a satsifactory combination of the following, and make a neat sketch, drawn to scale, of your design:

1. drum diameter and material
2. shoe lining material
3. shoe angle and shoe width
4. force required to apply brake
5. location of pivots (show on sketch)

PROBLEM 176, FIGURE 9. SCRAPER HOIST

a. Describe the construction and operation of the scraper hoist.

b. A scraper hoist is to be driven by an 1800 rpm AC induction motor, design D with characteristics as shown in Figure 31. The hoist is to be capable of pulling 4000 lbs at 140 ft/min. when the motor is developing its rated horsepower. The rope drum diameter is 15", the planetary gear provides a 5:1 speed reduction, and the pitch diameter of the planetary ring gear is 20". The band brake which holds the ring gear is to be designed so that it can be manually operated at an average rate of about once per minute by an operator standing at the hoist.
Make a neat sketch, drawn to scale, of your brake design, using the construction shown in the figure. State a satisfactory combination of the following:

1. brake drum diameter
2. material, thickness, and width of band
3. material, thickness, and width of band lining
4. angle of contact (show on sketch)
5. lever and handle lengths, pivot locations, etc., (show on sketch)
6. force required on handle to apply the brake

c. With the brake construction shown, should the pulling rope come onto the drum at the top of the drum or at the bottom of the drum ? Explain briefly.

PROBLEM 177, FIGURE 14, AUTOMATIC TRANSMISSION

a. Describe the operation of the transmission during 3 speeds forward and one reverse, including the methods of applying and releasing the band brakes.

b. The planetary gears of the transmission shown provide the following ratios:

first gear ratio = 2.4444
second gear ratio = 1.4815

third gear ratio = 1.0000

reverse ratio = 2.0000

The torque converter provides a 2:1 torque ratio at stall. The transmission is used with an engine having the performance shown in Figure 31. Space available limits the rear brake drum diameter to $5\frac{1}{2}$" minimum and $6\frac{1}{2}$" maximum. Design the rear brake, stating a satisfactory combination of:

1. drum diameter
2. drum material
3. band material
4. contact angle
5. band lining material
6. band width
7. force required at band to apply brake

c. Considering this transmission to be used in a conventional American automobile, is the proper end of the band anchored and the proper end actuated ? Explain briefly.

PROBLEM 178

a. List the comparative advantages and dis-advantages of external shoe brakes, internal shoe brakes, band brakes, and disk brakes.

b. The scraper hoist of Figure 9 uses a planetary gear with a band brake as a means of engaging and disengaging the rope drums. List the advantages and dis-advantages of planetary gearing as an engaging device as compared to disk or cone clutches.

PROBLEM 179, FIGURE 18, DISK BRAKE

a. Describe the construction and operation of the disk brake.

b. A brake of the type shown is to be used to control the speed of a processing machine. To do this, the brake will operate on a regular cycle in which the brake is applied for 4 seconds of every minute. During this 4 seconds the brake must absorb 10,000 ft-lbs of energy with an average speed of 200 rpm for the rotating disks.
Design the brake to perform as described without over heating. Tabulate a satisfactory combination ot,

1. number of inner and outer disks
2. thickness of inner and outer disks
3. inside and outside diameters of disks
4. disk surface materials
5. force required to apply brake
6. approximate operating temperature of disks

XXV - SHAFTS

PROBLEM 180

a. Explain why machine shafts are seldom made with a constant diameter from end to end.

b. State the reason for each change of diameter on the output shaft of the Bevel Gear Speed Reducer, Figure 12.

c. What range of carbon content and Brinell hardness are best suited for steel shafts which carry heavy loads ?

'ROBLEM 181, FIGURE 7, HELICAL GEAR SPEED REDUCER

a. Discuss the problem of accurately determining the loads which the input shaft and output shaft must carry if the reducer shown is to be sold on the open market.

b. Discuss the effects of combined torsion and bending on the strength of a shaft which has shoulders and keyways.

c. Considering shaft strength, smooth operation of the gear teeth, and the problems of manufacturing, discuss the desirability of having the gear be either a press fit or a clearance fit on the output shaft. What type of fit would you recommend ?

PROBLEM 182

Describe the type of loading, such as bending, torsion, etc., which the following shafts carry, neglecting the weight of the parts:

1. The shaft which connects the torque converter turbine to the front clutch in the Automatic Transmission, Figure 14.
2. The shaft which holds the 4 rope sheaves at the hook on the Overhead Crane Trolley, Figure 30.
3. The countershaft which supports the cluster gear of the Transmission, Figure 8.
4. The countershaft of the Marine Reduction and Reverse Gear, Figure 10.
5. The input shaft of the Bevel Gear Speed Reducer, Figure 12.
6. The shaft of the rear sun gear in the Automatic Transmission, Figure 14.

PROBLEM 183, FIGURE 14, AUTOMATIC TRANSMISSION

a. Describe the construction and operation of the transmission.

b. The transmission shown is to be used with an engine having the performance shown in Figure 31. The performance of the torque converter is shown in Figure 32.

Design the shaft which connects the turbine of the torque converter to the first disk clutch, stating a satisfactory combination of:

1. outside and inside shaft diameters
2. shaft material and heat treatment
3. length of spline at the converter turbine

PROBLEM 184, FIGURE 14, AUTOMATIC TRANSMISSION

a. Describe the construction and operation of the transmission.

b. The transmission shown is to be used with an engine having the performance shown in Figure 31. The performance of the torque converter is shown in Figure 32. The rear sun gear has 27 teeth, a normal pitch of 14, with a 20° pressure angle and a 20° helix angle.

Design the shaft for the rear sun gear, stating a satisfactory combination of:

1. inside and outside diameters
2. material and heat treatment

PROBLEM 185, FIGURE 30, OVERHEAD CRANE TROLLEY

a. Describe the construction and use of the crane.

b. The shaft which holds the 4 rope sheaves at the hook is to be designed for a crane having a rated capacity of 10 tons. The crane is to be driven by a DC motor having the performance shown in Figure 31. A controller limits the motor torque to the maximum shown. Dimensions along the shaft can be found by considering the actual crane to be 8 times the size shown. Needle bearings inside each sheave, with the needles rolling directly on the shaft, allow the sheaves to rotate on the shaft. Determine a satisfactory combination of:

1. shaft diameter
2. shaft material and heat treatment

PROBLEM 186, FIGURE 7, HELICAL GEAR SPEED REDUCER

A speed reducer is to be driven by a 25 HP, AC induction motor having a synchronous speed of 1800 rpm. The performance of the motor corresponds to that of design B shown in Figure 31.

The reducer is to provide a 3:1 reduction. The pinion has 20 teeth, a normal pitch of 8, a 20^{o} pressure angle and a 23^{o} right hand helix angle. The output shaft is to be capable of carrying a 2000 lb overhung load to allow for possible belt loads, chain pull, etc. To obtain trouble free operation of the gears, it is desirable that the output shaft deflect no more than about 0.002" at the center of the gear when operating at rated capacity. Linear dimensions can be obtained by considering the actual machine to be 6 times the size shown in the figure.

Design the output shaft, and make a neat sketch, to scale, of your design. Show all diameters, fillet radii, and keyway dimensions. State the material and heat treatment to be used.

PROBLEM 187, FIGURE 12, BEVEL GEAR SPEED REDUCER

A speed reducer 4 times the size shown is to be used with a 50 HP, AC induction motor having a synchronous speed of 1800 rpm. The performance of the motor corresponds to that of design B shown in Figure 31.

The output shaft of the reducer is to be capable of holding a 4000 lb overhung load to allow for belt tensions, chain pull, etc. To obtain smooth operation of the bevel gears, the shaft deflection at the bevel gear should be no more than about 0.002" when operating at its rated capacity.

Design the output shaft, and make a neat sketch, to scale, of your design. Show all diameters, fillet radii, and keyway dimensions, and state the material and heat treatment to be used.

PROBLEM 188, FIGURE 5, BEVEL GEAR REVERSING UNIT

a. Describe the construction and operation of the reversing unit.

b. A reversing unit 3 times the size of that shown is to be driven by a 20 HP, AC induction motor having a synchronous speed of 1200 rpm. The performance of the motor corresponds to that of design B shown in Figure 31.

The bevel pinion has a 20° pressure angle and a 15° right hand spiral angle. This unit is to be produced and sold on the open market.

Design the output shaft, establishing a satisfactory combination of diameters, fillet radii, thread dimensions, and keyway dimensions.

Make a neat sketch, to scale, of your design, show all dimensions, and specify a material and heat treatment.

XXVI - SLIDING BEARINGS

PROBLEM 189

a. Briefly describe the mechanics of thick film lubrication.

b. What is the most important property of the lubricating oil so far as thick film lubrication is concerned ?

c. Make a neat sketch showing typical pressure distribution in a bearing with thick film lubrication.

d. What 4 factors most influence the formation and maintenance of the thick film ?

PROBLEM 190

a. What are the most important physical characteristics of a good bearing material ?

b. Why is the material from which the bearing is made of any concern when the lubrication is such that a film of oil separates the shaft from the bearing ?

c. Sketch and describe how grooves might be put in the bearing surface to improve a bearing with thick film lubrication, and a bearing with grease lubrication.

PROBLEM 191, FIGURE 2, TRANSPORT MACHINE

a. Briefly describe the operation and use of the transport machine.

b. An actual machine is exactly 5 times the size shown, and is driven by a 3 HP, 900 rpm AC induction motor. The idler shaft which carries the large chain sprocket and the small pinion, rotates at 75 rpm and is mounted in 2 sliding bearings as shown. Design these bearings, stating a satisfactory combination of:

1. bearing diameter and length
2. bearing material
3. lubricant to be used
4. desired clearance between shaft and bearings

PROBLEM 192, FIGURE 28, STRAIGHT PRESS

a. Describe the operation and use of the press.

b. A press similar to that shown is to be capable of exerting a force of 20 tons when the crank is 20° before bottom center. The press is exactly 10 times the size shown, and the crank requires 1.5 seconds to complete one revolution. Design the crankshaft main bearings, stating a satisfactory combination of:

1. bearing diameter and length
2. bearing material
3. lubricant to be used
4. desired clearance between shaft and bearing

PROBLEM 193, FIGURE 11, V-8 ENGINE

a. Describe the operation of the engine and its lubricating system.

b. A main crankshaft bearing is to be designed for an engine similar to that shown. At 3800 rpm the maximum load on the bearing during each cycle is about 4200 lbs., while the average load is 2800 lbs. Lubricating oil entering the bearing will have a temperature of approximately 205° F., and should leave the bearing with a temperature of about 220° F. Determine a satisfactory combination of:
   1. Bearing diameter and length
   2. bearing material
   3. SAE lubricating oil
   4. desired clearance between shaft and bearing
   5. surface finish of shaft and bearing.

c. Determine the amount of oil, in gallons/min., that must flow through the bearing to have the oil leave with the temperature mentioned above.

PROBLEM 194, FIGURE 1, DIESEL ENGINE

a. Describe the operation of the engine and its lubrication system.

b. A connecting rod bearing is to be designed for an engine similar to that shown. At 1800 rpm the maximum load on the bearing during each cycle is 12000 lbs., while the average load is 6000 lbs. Temperature of the lubricating oil entering and leaving the bearing is to be approximately 205° F and 230° F respectively. Determine a satisfactory combination of:
   1. bearing diameter and length
   2. bearing material
   3. SAE lubricating oil

4. desired clearance between shaft and bearing
5. surface finish of shaft and bearing

c. Determine the amount of oil, in gallons/min., that must flow through the bearing to have the oil leave with the temperature mentioned above.

XXVII - ROLLING BEARINGS

PROBLEM 195

a. Discuss the relative advantages and dis-advantages of ball and roller bearings as compared to sliding bearings.

b. Discuss the relative advantages and dis-advantages of ball bearings, straight roller bearings, needle roller bearings, and tapered roller bearings.

c. Describe the means by which the tapered roller bearings of the Bevel Gear Speed Reducer, Figure 12, are adjusted axially, and explain why such adjustment is necessary.

d. Describe the construction of the tapered roller bearings which support the worm gear in the Screw Jack, Figure 6, compared to those used in the Bevel Gear Speed Reducer, Figure 12. Discuss the reasons for the two different bearing constructions.

PROBLEM 196

a. Describe the way in which the countershaft assemblies are held axially in the Transmission, Figure 8, and the Marine Reduction and Reverse Gear, Figure 10.

b. Sketch and describe a method of pre-loading a pair of angular contact ball bearings, and discuss the use of such a construction.

c. Discuss the problems involved when supporting a shaft in 3 bearings as shown in the Bevel Gear Reversing Unit, Figure 5.

PROBLEM 197, FIGURE 28, STRAIGHT PRESS

The shaft of the motor which drives the press is to be mounted in one ball bearing and one straight roller bearing. Both bearings are to have exactly the same inside diameter, outside diameter and width. Make a neat sketch showing the shaft mounted in these bearings, with the necessary shoulders, seals, the rotor, and the belt sheave.

PROBLEM 198

a. Describe the mechanics of failure of a ball or roller bearing, and discuss the effects of speed and desired life on the load carrying capacity of the bearing.

b. Approximately what relationship exists between the BL-10 life and the average life for a group of ball or roller bearings ? Illustrate this by sketching and neatly labelling a typical normal distribution curve.

c. Describe the phenomena of "stress corrosion" and how it affects ball or roller bearings subjected to vibratory loads with no rotation.

PROBLEM 199, FIGURE 9, SCRAPER HOIST

a. Describe the operation and use of the scraper hoist.

b. An actual scraper hoist is 5 times the size shown on the drawing. The double reduction helical gears next to the motor have 20° pressure angles and 24° helix angles. Both gears on the countershaft have right hand helices. The motor rating is 20 HP at 1725 rpm. Considering the motor to operate at its rated capacity most of the time, select a pair of ball bearings for the countershaft which will provide an average life of 8,000 hours per bearing.

PROBLEM 200, FIGURE 9, SCRAPER HOIST

a. Describe the operation and use of the scraper hoist.

b. An actual scraper hoist is 5 times the size shown. The shorter rope drum is to be able to exert a pull of 4000 lbs at 175 ft/min., when the motor is developing its rated horsepower. The bearings which support the planet pinions are to have an average life of 10,000 hours at this rated load condition. Select a pair of ball bearings for the planet pinions.

XXVII - MISCELLANEOUS PROBLEMS

PROBLEM 201, FIGURE 14, AUTOMATIC TRANSMISSION

a. Describe the operation of the transmission to provide 3 speeds forward, a neutral, and a reverse.

b. The low and intermediate gear ratios of the transmission are 2.4444 and 1,4815 respectively. Determine the numbers of teeth for each gear in the transmission, and the resulting reverse ratio, if none of the gears have less than 16 teeth.

PROBLEM 202, FIGURE 14, AUTOMATIC TRANSMISSION

a. Describe the hydraulic actuating system of the transmission, including the location and function of the 2 oil pumps, the means of driving these pumps, and the way in which oil gets into and out of the torque converter.

b. An internal gear type of oil pump, as used in the transmission, is to be designed to deliver approximately 4 gallons/min., at 2000 rpm of the pump driving shaft. Make a neat sketch, to scale, showing the following for your design:

1. location and size of gears
2. number of teeth in gears
3. face width
4. location of inlet and outlet ports

c. The discharge pressure of the pump is held at 95 psi by a relief valve in the hydraulic circuit. The transmission is used with an engine which performs as shown by the curve of Figure 31. How much horsepower is required to drive the pump designed above when the engine is developing its maximum horsepower ?

PROBLEM 203, FIGURE 23, CAPSTAN WINCH

A winch similar to that shown is to be used with a fiber rope to handle cargo. By wrapping the fiber rope around the drum a number of turns, and then pulling on the free end, an operator standing at the winch is to be capable of hoisting a 500 lb load at a uniform rate of about 25 ft/min. It is anticipated that the efficiency of the worm drive will be about 40%. Determine a satisfactory combination of:

1. rope drum diameter
2. size and material of rope
3. number of turns needed on drum
4. pounds pull to be exerted on rope by operator
5. size and speed of AC induction motor to drive winch
6. worm gear ratio needed

PROBLEM 204, FIGURE 20, CRUSHER

a. Describe the construction and use of the crusher.

b. A crusher which is 10 times the size shown has jaws which are 2 ft. wide. The toggle linkage must exert a maximum force of 10 tons on the crusher jaw, at an average rate of 100 times/min.
Determine a satisfactory combination of thickness, width, and material for the toggle links, and the torque required to turn the crank when in the position where this maximum force is exerted on the jaw.

PROBLEM 205, FIGURE 26, HYDRAULIC CYLINDER

a. Describe the construction and use of the cylinder, including the purpose of the protrusions on the piston and the receptacles in the cylinder ends.

b. A hydraulic cylinder similar to that shown is to have a 12" stroke and be capable of exerting a force of approximately 3 tons when using oil at 500 psi pressure. Determine a satisfactory combination of:
   1. cylinder diameter and wall thickness
   2. cylinder material

PROBLEM 206, FIGURE 21, C FRAME PRESS

a. Describe the construction of the press.

b. The following data is given for a press similar to that shown:

1. stroke = 8"
2. Pitman rod length = 20"
3. maximum force exerted = 25 tons
4. crank position at maximum force = 20° before dead center
5. maximum press opening = 15"
6. throat depth = 15" from centerline of punch

Design the vertical, straight section of the press frame, and make a neat sketch, drawn to scale and completely dimensioned, showing a cross section of the frame where vertical, and the material to be used for the frame.