

GEORGE W. WOODRUFF SCHOOL OF MECHANICAL ENGINEERING
GEORGIA INSTITUTE OF TECHNOLOGY

DESIGN QUALIFIER

SPRING 2004

WRITTEN EXAMINATION

We are interested in learning what you know and your ability to reason in the formulation and solution of design problems.

If you find any question or part of this exam confusing, please state your assumptions and rephrase the question and proceed.

Please read the entire exam first.

Questions 1 and 2 carry equal points. Both have multiple parts.

Allocate your time carefully so that you cover all three parts that you are being examined on in these two questions, namely, Methods, Realizability and Analysis.

A document containing some formulae is available for you to use in answering Question 2

ORAL EXAMINATION

Please arrive half an hour before the scheduled time for the oral exam. During this period we will give you a question to think about. The scope of the oral exam is as follows:

- * provide an opportunity for you to state how design fits into your research activities;
- * probe your understanding of the question that we posed to you in the preceding half hour.

QUESTION 1 – METHOD & REALIZABILITY (20 pts.)

Background

An ever increasing number of people rely on electronic devices to keep their heart beating normally – nearly 200,000 pacemakers are implanted annually in the United States. A pacemaker is a small electronic device that when implanted in the chest regulates the heart's rhythm, resulting in a significant improvement in quality of life. Although pacemakers are very reliable, they are not completely immune to failures, and common electronic devices such as cell phones and microwave ovens may interfere with the pacemaker's operation. Given the dramatic consequences of failure, pacemaker users are required to visit their physicians regularly to monitor the device and adjust its settings.

Task

To reduce the cost of frequent doctor's visits, you are asked to design a system that can monitor the operation of a pacemaker remotely.

Ideally, such a remote monitor system would be able to check the proper operation of the pacemaker continuously and unobtrusively, and send regular status reports to the physician's office. At the very least, the patient should be able to use the device in the morning and evening from home. The device needs to check the status of the battery and the pulse generator. In order to check the proper pulse rate of the pacemaker, the device also needs to monitor the patient's heart beat. When an abnormality is detected, a physician would call in the patient for a visit. But, eventually, a physician should be able to reprogram the device remotely without the patient leaving home.

To improve the profitability of the device, your company has decided to make it part of a product family of remote health monitoring devices. The same communication infrastructure will be used to monitor implantable defibrillators, and to relay information coming from heart rate monitors, blood pressure monitors, body temperature monitors, etc.

Your boss wants you to start from scratch and document your design process thoroughly – but this is not possible for lack of time. A senior engineer has suggested that you follow the general guidelines given below and turn in a report documenting each of the six steps.

Deliverables

Method

1. *Clarify the Task:* State the overall function of your system. What are the most important drivers/design criteria?
2. *Conceptual Design:* State and implement the steps (including a specification list and functional diagrams/decomposition) for transforming the overall function that you have identified into at least three alternative design solutions. Ensure that you have identified the important sub functions for each of modes of operation of the system. Sketch and describe the workings of these alternatives.
3. *Selection:* Suggest a structured approach to select one of the alternatives for further development.

Realizability

4. *Embodiment*: Further develop the alternative that you have selected.
5. *Costing*: How would you estimate the cost of your design? You may critically evaluate the design in terms of manufacturability, initial cost, maintenance cost, reliability, manipulation performance, and other criteria that you feel are important to consider in this phase of design.
6. *Pricing*: Based on the preceding analysis, how would you estimate the market size for such a system and set the price for selling such a system? Be brief.

Your Exam #:

You MUST write your solutions to QUESTION 2 on this exam sheet.

2A. (10 pts.)

Problem: Determine the lifting and lowering torques and the efficiency of the power screw shown in Figure 1 using an Acme screw and nut. Is it self-locking? Explain.

(i) Given: The screw is single-start Acme 1.25-6 thread. The axial load (P) is 1000 pounds. The mean collar diameter is 1.75 inches.

(ii) Given: The screw is double-start Acme 1.25-6 thread. The axial load (P) is 1000 pounds. The mean collar diameter is 1.75 inches.

Assumption The screw and nut are lubricated with oil. Sliding (thread) friction, $\mu = 0.15$, and rolling friction (due to rolling-element bearing) $\mu = 0.02$.

(iii) Comment on the torques and efficiencies you calculated in (i) and (ii).

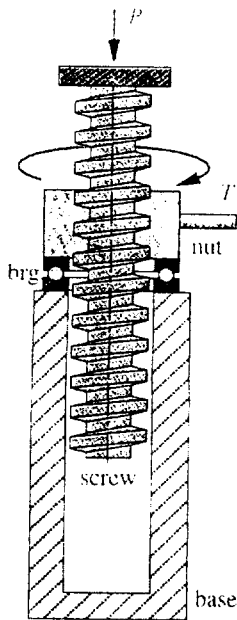


FIGURE 1
An Acme-Thread
Power-Screw Jack

2B. (10 pts.)

1. List two advantages of set removal (presetting).
2. In a triple threaded bolt or screw, the load, $L =$?
3. Why is preload important in a joint connection?
4. Can you use stress-concentration factor with ductile materials when they are subject only to static load?
5. What will be the consequence if you apply a reverse loading in a spring?

Table 14-3 Principal Dimensions of American Standard Acme Threads

See Reference 2 for More Complete Dimensional and Tolerance Information

Major Diameter (in)	Threads per inch	Thread Pitch (in)	Pitch Diameter (in)	Minor Diameter (in)	Tensile Stress Area (in ²)
0.250	16	0.063	0.219	0.188	0.032
0.313	14	0.071	0.277	0.241	0.053
0.375	12	0.083	0.333	0.292	0.077
0.438	12	0.083	0.396	0.354	0.110
0.500	10	0.100	0.450	0.400	0.142
0.625	8	0.125	0.563	0.500	0.222
0.750	6	0.167	0.667	0.583	0.307
0.875	6	0.167	0.792	0.708	0.442
1.000	5	0.200	0.900	0.800	0.568
1.125	5	0.200	1.025	0.925	0.747
1.250	5	0.200	1.150	1.050	0.950
1.375	4	0.250	1.250	1.125	1.108
1.500	4	0.250	1.375	1.250	1.353
1.750	4	0.250	1.625	1.500	1.918
2.000	4	0.250	1.875	1.750	2.580
2.250	3	0.333	2.083	1.917	3.142
2.500	3	0.333	2.333	2.167	3.976
2.750	3	0.333	2.583	2.417	4.909
3.000	2	0.500	2.750	2.500	5.412
3.500	2	0.500	3.250	3.000	7.670
4.000	2	0.500	3.750	3.500	10.321
4.500	2	0.500	4.250	4.000	13.364
5.000	2	0.500	4.750	4.500	16.800

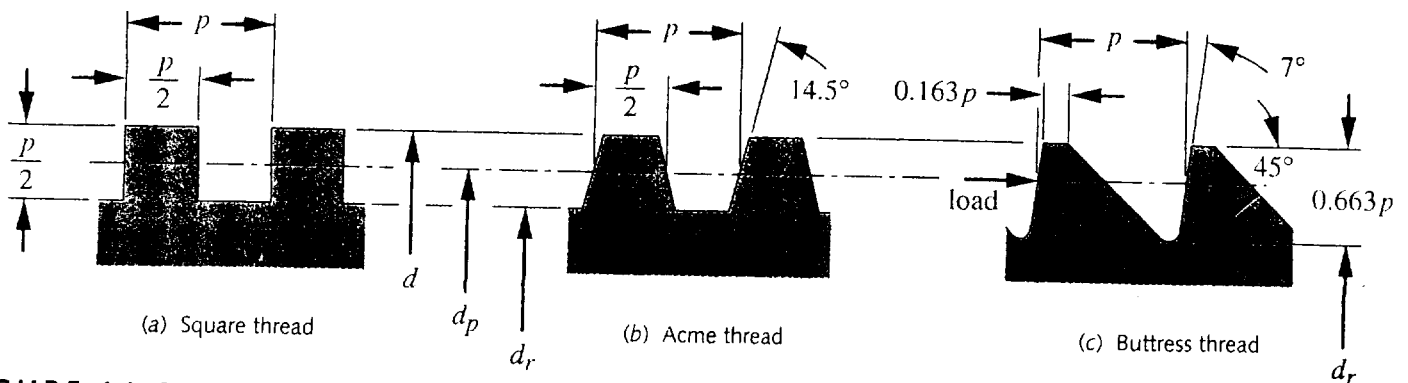


FIGURE 14-3

Square, Acme, and Buttress Threads

This expression accounts for the screw-nut interface of a square thread, but the thrust collar also contributes a friction torque, which must be added. The torque required to turn the thrust collar is

$$T_c = \mu_c P \frac{d_c}{2} \quad (14.4f)$$

where d_c is the mean diameter of the thrust collar and μ_c is the coefficient of friction in the thrust bearing. Note that the torque needed to overcome collar friction can equal or exceed the screw torque unless rolling-element bearings are used in the thrust collar. Smaller collar diameters will also reduce the collar torque.

The total torque T_u to lift the load with a square thread is then

$$T_u = T_{s_u} + T_c = \frac{Pd_p}{2} \frac{(\mu\pi d_p + L)}{(\pi d_p - \mu L)} + \mu_c P \frac{d_c}{2} \quad (14.4g)$$

The same analysis can be done for the case of lowering the load, as shown in Figure 14-6b. The applied- and friction-force signs change, and the torque T_d to lower the load is

$$T_d = T_{s_d} + T_c = \frac{Pd_p}{2} \frac{(\mu\pi d_p - L)}{(\pi d_p + \mu L)} + \mu_c P \frac{d_c}{2} \quad (14.4h)$$

ACME THREADS The radial angle of an Acme (or other) thread introduces an additional factor in the torque equations. The normal force between screw and nut is angled in two planes, at the lead angle λ as shown in Figure 14-6, and also at the $\alpha = 14.5^\circ$ angle of the Acme thread as shown in Figure 14-7. A similar derivation as done for the square thread will give expressions for lifting and lowering torques of

$$T_u = T_{s_u} + T_c = \frac{Pd_p}{2} \frac{(\mu\pi d_p + L \cos \alpha)}{(\pi d_p \cos \alpha - \mu L)} + \mu_c P \frac{d_c}{2} \quad (14.5a)$$

$$T_d = T_{s_d} + T_c = \frac{Pd_p}{2} \frac{(\mu\pi d_p - L \cos \alpha)}{(\pi d_p \cos \alpha + \mu L)} + \mu_c P \frac{d_c}{2} \quad (14.5b)$$

These equations reduce to those for the square thread when angle $\alpha = 0$.

The condition of self-locking for a power or lead screw is easily predicted if the coefficient of friction in the screw-nut joint is known. The relationship between the friction coefficient and the screw's lead angle determines its self-locking condition. A screw will self-lock if

$$\mu \geq \frac{L}{\pi d_p} \cos \alpha \quad \text{or} \quad \mu \geq \tan \lambda \cos \alpha \quad (14.6a)$$

If it is a square thread, $\cos \alpha = 1$, and this reduces to

$$\mu \geq \frac{L}{\pi d_p} \quad \text{or} \quad \mu \geq \tan \lambda \quad (14.6b)$$

Screw Efficiency

The efficiency of any system is defined as *work out / work in*. The work done on a power screw is the product of torque and angular displacement (in radians), which for one revolution of the screw is

$$W_{in} = 2\pi T \quad (14.7a)$$

The work delivered over one revolution is the load-force times the lead:

$$W_{out} = PL \quad (14.7b)$$

The efficiency is then

$$e = \frac{W_{out}}{W_{in}} = \frac{PL}{2\pi T} \quad (14.7c)$$

Substituting equation 14.5a (neglecting the collar-friction term) gives

$$e = \frac{L}{\pi d_p} \frac{\pi d_p \cos \alpha - \mu L}{\pi \mu d_p + L \cos \alpha} \quad (14.7d)$$

This can be simplified by substituting equation 14.3:

$$e = \frac{\cos \alpha - \mu \tan \lambda}{\cos \alpha + \mu \cot \lambda} \quad (14.7e)$$

Note that efficiency is a function only of the screw geometry and the coefficient of friction. For a square thread, $\alpha = 0$ and

$$e = \frac{1 - \mu \tan \lambda}{1 + \mu \cot \lambda} \quad (14.7f)$$

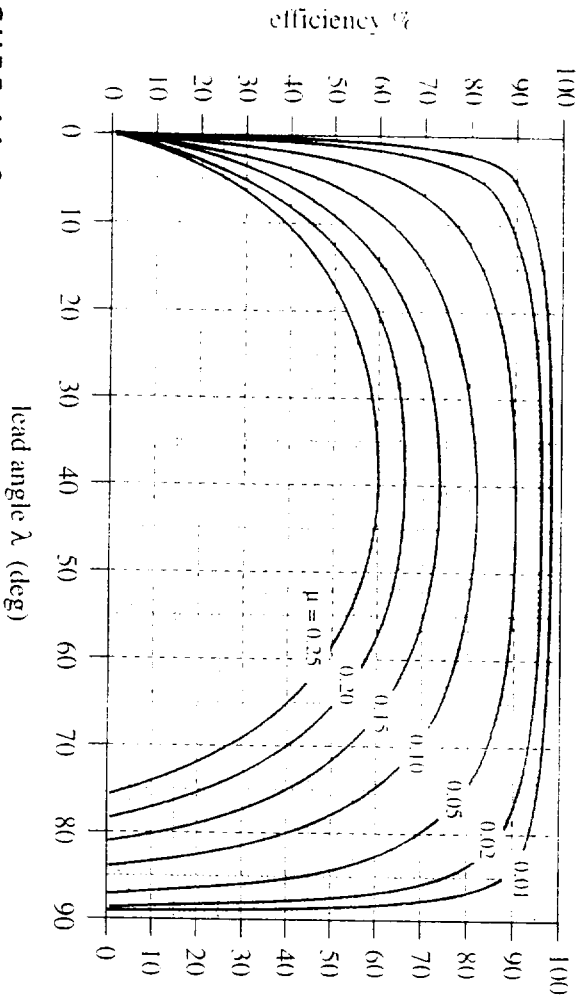


FIGURE 14-8
Efficiency for an Acme-Thread Power Screw (Neglecting Thrust-Collar Friction)

Table 14-4
Lead Angle and Efficiency for Standard Acme Threads with Coefficient of Friction $\mu = 0.15$

Size	Lead Angle (deg)	Efficiency %
1/4 - 16	5.2	36
5/16 - 14	4.7	34
3/8 - 12	4.5	34
7/16 - 12	3.8	30
1/2 - 10	4.0	31
5/8 - 8	4.0	31
3/4 - 6	4.5	34
7/8 - 6	3.8	30
1 - 5	4.0	31
1 1/8 - 5	3.6	28
1 1/4 - 5	3.2	26
1 3/8 - 4	3.6	29
1 1/2 - 4	3.3	27
1 3/4 - 4	2.8	24
2 - 4	2.4	21
2 1/4 - 3	2.9	25
2 1/2 - 3	2.6	23
2 3/4 - 3	2.4	21
3 - 2	3.3	27
3 1/2 - 2	2.8	24
4 - 2	2.4	21
4 1/2 - 2	2.1	19
5 - 2	1.9	18