Sample Questions for the ME328 Machine Design Final Examination
Closed notes, closed book, no calculator.

The following is from the first page of the examination. I recommend you read it before the exam. I fully expect NO DISCUSSION WHAT SO EVER between students who have taken the exam – including “the exam was easy…” or “the exam was difficult”…etc. NOTHING! Once you take the exam, ALL COMMUNICATION in all forms, regarding the exam must end!

The first page of the exam is shown below:

ME 328 – Machine Design, Spring 2019, Final Examination
CLOSED BOOK, NO NOTES, NO CALCULATOR
*** "**Briefly explain**" means **one good sentence** typically will suffice. ***
*** **Credit will not be given without an explanation when requested**!!! ***
For problems involving calculations, show equations in variable form (aka symbolic form) before introducing numerical values.
*** All problems are worth 4 points ***

I will not share ANY information about this exam with anyone nor have I in anyway received information about this examination from anyone.

On my honor, my signature attests to this fact:________________________________

TABLE 1: Use the following material properties for this exam (**unless given other properties**):

Material	Yield Strength, S_{ys} (T & C)*	Tensile Strength, S_{UT}	Compressive Strength	Modified Endurance limit, S_e	Shear Modulus, G	Modulus of Elasticity, E	Poisson's ratio, ν
	Kpsi	Kpsi	Kpsi	Kpsi	Mpsi	Mpsi	---
"Steel"	40	60	90	40	12	30	0.30
"Ceramic"	---	50	150	20	16	40	0.20

***Yield strength is same in (T) tension and (C) compression**

Geometric parameters: $C=\pi D$, $A=\pi D^2/4$, $J=\pi D^4/32$, $I=Ak^2$; $I=1/12\ bh^3$, $I=(\pi/4)D^{64}$

Basic solid mechanics: $\sigma = F/A$, $\sigma = My/I$, $\tau = Tr/J$, $E=\sigma/\varepsilon$
$\delta=PL/EA$ (axial prismatic bar), $\delta = PL^3/3EI$ (cantilever beam)

Energy and Power: $E=mc^2$; $PE = mgh$; $KE= ½\ mv^2$; $\text{Energy} = \int F\,dx$;

Hertzian contact: $P_{max} = 3F/(2\pi a^2)$, $P_{max} = 2F/(\pi bl)$

Vibrations: $\omega_n = \sqrt{k/m}$ $\quad r = \omega_f/\omega_n$ $\quad c_c = 2m\omega_n$ $\quad \zeta = c/c_c$

$$MF = \frac{X}{X_o} = \frac{1}{\sqrt{(1-r^2)^2+(2\zeta r)^2}} \quad ; \quad TR = \frac{F_T}{P_o} = \frac{\sqrt{1+(2\zeta r)^2}}{\sqrt{(1-r^2)^2+(2\zeta r)^2}};$$

(MF and TR graphs may also be provided)

Fastener equations:

FOS for permanent bolt elongation: $n_p = S_p / \sigma_b = S_pA_t/(F_i + PC)$

FOS for joint separation: $n_{sep} = P_0 / P = F_i / P(1-C)$, Load factor: $n_L = (S_pA_t - F_i) / CP$

$T=KdF_i$; $F_i = (\%Proof)(S_p)(A_t)$, $k_b = E_bA_b/L_{grip}$; $C = k_b / (k_b + k_m)$; $F_b = F_i + PC$

$F_m = F_i - P(1-C)$, $P_0 = F_i / (1 - C)$

Fatigue: $K_f\{\sigma_a / S_e\} + K_f\{\sigma_m / S_{UT}\} = 1/n$

Gears: $P = T_1\omega_1 = T_2\omega_2$; $\omega_1/\omega_2 = T_2/T_1 = d_2/d_1 = N_2/N_1$

…now on to the study guide:

The following few questions are provided to give you a sense of the scope and type of questions to expect. NOTE: almost all questions ask for a brief explanation – if it asks for it, it is critical you provide it!

Required equations, tables, and graphs will be provided, except for the most basic equations. I assume you have memorized equations for determining areas of circles and rectangles, uniaxial stress, bending stress, torsional loading in a circular shaft, relating nominal stress to stress at a stress-concentration, 1-dimensional Hooke's Law (i.e. Hooke's Law for uniaxial loading), natural frequency of undamped 1 DOF, and other such very basic equations. Also memorize Young's modulus of steel and aluminum (in both psi and GPa). Create free body diagrams and kinetic diagrams. You should be able to recognize and apply appropriate equations and understand their limits (assumptions).

The test is not meant to evaluate your ability to plug numbers into an equation or to solve algebra problems. It is meant to evaluate your ability to apply and use appropriate equations properly, and to evaluate your understanding of basic concepts and necessary assumptions (limits of viability of equations).

Since calculators will not be permitted, any calculations required will be very straight forward. If you aren't able to do simple math in your head (example: 2/5=0.4), partial credit may be obtained by expressing/discussing the appropriate equations.

Topics for the exam:

- (0-3 problems) Definitions (you may be asked to define or describe the following with words and/or equations): ductility, brittle, toughness, hardness, proof strength, yield strength, tensile strength, Young's modulus, Poisson's ratio
- (2-3 problems) Mohr's circle for plane stress, understanding what is meant by "stress at a point" and how to transform the stress for different directions at the point. You should be able to create and use Mohr's circle to determine principal stresses and maximum shear stress at a point (graphically, without equations).
- (3-6 problems) Static failure theories (Maximum Shear Stress Theory, Distortion Energy Theory, Maximum Normal Stress Theory); how to apply them (for what sort of materials and loading conditions). You should "memorize" equations for Maximum Shear Stress Theory and Maximum Normal Stress Theory (which really means "you should understand the theories" since the equations are inherent in the definitions). You do not need to memorize the Distortion Energy Theory equation. Do understand the importance of stress concentrations. For stress concentrations, do memorize $\sigma_{max}=K_t\sigma_{nom}$
- (0-2 problems) Hertzian contact stresses (do not need to memorize equations - but do understand how the principal stresses and maximum shear stress vary in the parts)
- (0-2 problems) Impact loading (do not need to memorize equations for beam deflections – but understand how to determine energy given F-δ graph)
- (4-6 problems) Fatigue: you will not be asked to calculate endurance limits nor use the "log" equations for relating N to S for finite life fatigue. No need to memorize equations,

but do know when to use what forms of Goodman equation, and be able to use/apply the various fatigue equations when given them. Know what S_e and S_{fail} mean.

- (2-4 problems) Tension fastened joints. Determining various factors of safety, force in the bolts, compression loads, joint separation forces, fatigue, etc.
- (0-2 problems) Gear ratios (power transmission, relating pitch diameter (aka "gear diameter") and/or number of teeth on a gear set, speed and/or torque ratio given number of teeth and/or pitch diameter of mating gears) – the sorts of calculations you did with the project.
- (0-2 problems) Vibration problems – no need to memorize equations, but understand natural frequency, forcing frequency, and the effects of damping (over and under damped systems). Understand how general system behavior (MF and TR) is affected for increasing or decreasing values of frequency ratio, r, and damping factor, ζ (even without charts or equations provided).
- (0-2 problems) Components: conceptual problems from the most recent homework(s) regarding component design. May also include self-help concepts and/or proper constraints.

Do NOT bring extra paper, there should be enough room on the exam that no extra paper will be required. I will bring extra paper should you need it. Bring a straight edge (your student ID should work fine) and a circle template for drawing Mohr's circle. **No calculators.**

There will be a total of 20 to 30 problems. All problems are of equal weight. There should be plenty of time to complete the exam – so do not rush through it.

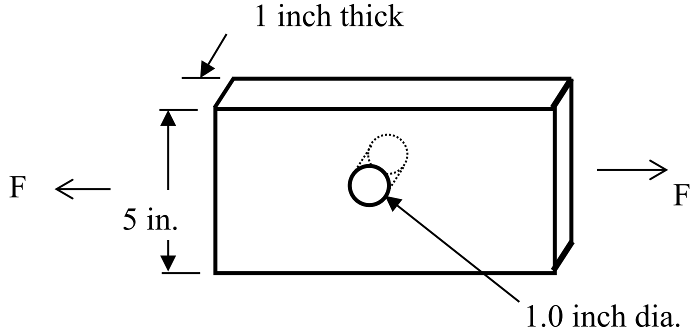
***** S T O P *****

The following example problems should be the last step in studying. You should first be comfortable with all concepts. Only then should you attempt the sample problems. If the problems are easy for you, then you probably have a good understanding of the concepts. If they are not easy, then re-study the basic concepts – do NOT focus on understanding specific details, since details will be different on the exam.

I do not provide solutions for example examinations. Solutions can only confirm that you have properly applied equations. That is NOT an adequate level of understanding. Engineers need to understand what they are doing so that ***they are confident*** in the results. If you need to "check the answer" it means you don't have confidence in your understanding. Refer to homework (solutions are posted), the textbook, exams that have been returned, etc. to help develop your confidence FIRST. Then work through this practice exam.

*** *** CONTINUE WHEN PROPERLY PREPARED *** ***

1) The part shown below is made from steel with S_{ys}=70ksi and S_{ut}=100ksi. The stress concentration (K_t) at the hole is equal to 2. If a quasi-static **tension** force of (F) 200,000 pounds is applied, will the part fail? Failure is defined as either fracture or "bulk yielding" ("gross plastic deformation") not just local yielding. **Show your work and briefly explain (including how it will fail if it does).**



2) The part shown in problem 1 above is made from a ceramic with S_{ut}=100ksi. The stress concentration (K_t) at the hole is equal to 2. What tension force (F) would be required to cause the part to fail? Failure is defined as either fracture or "bulk yielding" ("gross plastic deformation") not just local yielding. **Show your work and briefly explain (including how it will fail if it does).**

3) The part shown in problem 1 above is made from steel with S_{ys}=70ksi and S_{ut}=100ksi. The applied force (F) cycles between zero and 200,000 pounds **tension**. Assume K_t=K_f= 2. Which is the appropriate Goodman equation to apply? **Briefly explain and show appropriate work if applicable**.

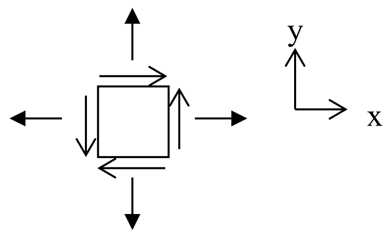
a) $\{\sigma_a / S_e\} + \{\sigma_m / S_{UT}\} = 1/n$
b) $\{\sigma_a / S_e\} + \{0 / S_{UT}\} = 1/n$
c) $K_f\{\sigma_a / S_e\} + K_f\{\sigma_m / S_{UT}\} = 1/n$
d) $K_f\{\sigma_a / S_e\} + \{\sigma_m / S_{UT}\} = 1/n$
e) $K_f\{\sigma_a / S_e\} + \{0 / S_{UT}\} = 1/n$

4) For a given loading condition and material, the fatigue factor of safety is determined to be 1.0. What would happen to the fatigue factor of safety if the only thing changed was an increase in the endurance limit? Would the fatigue factor of safety increase, decrease, stay the same, or "cannot be determined" even with a calculator?

5) Briefly describe where (and why) you would expect fatigue cracks to initiate in a spherical roller used in spherical ball bearings.

6) An element in plane stress on the surface of a part is subjected to the following stresses: σ_x = 35ksi **tension**, σ_y = 15ksi **compression**, τ_{xy} = 10psi. Create Mohr's circle, and from it, determine the principal stresses and the maximum shear stress. Label the principal stresses and maximum shear stress on the Mohr's circle.

Briefly explain why and/or show your work:



7) Some people have identified a curious phenomenon when they use a lawn mower. Namely, the mower does **not** shake noticeably when it is operating. However, when the motor is shut down, as the motor's speed decreases from operation speed to rest, the mower shakes noticeably for a brief moment. Why does it shake momentarily just before the motor comes to rest but not shake noticeably while running?

Hints…

Hints are provided here for this SAMPLE exam, but will NOT likely to be provided on the final exam. Hints:

1) Since yield strength is provided, you are safe to assume this is a ductile material; therefore, bulk yielding will occur before it fractures due to an overload (this is NOT a fatigue loaded part – don't confuse "fatigue fracture" with static overload fracture). Since local yielding is not a concern in this problem, the stress concentration factor is not relevant. However, the hole itself is relevant – there is less material to carry the load in the cross-section of the hole. Bulk yielding will therefore begin in that cross-sectional area; A=(W-d)t. Nominal stress through this cross section would be 50kpsi which is less than S_{ys} so there will be no bulk yielding. FYI: The concentrated stress right near the hole (at the top and bottom of the hole in the sketch) is calculated to be K_t times the nominal stress (2*50ksi=100ksi) – which is greater than S_{ys} so there will be local yielding (which for this problem does **not** constitute failure).
2) Ceramics are typically brittle materials and since no yield strength was provided, it is safe to assume this ceramic is brittle. According the Maximum Normal Stress theory, brittle materials fail due to fracturing when the first principal stress reaches the magnitude of the tensile strength. Although the "stress concentration effect" is very localized near the stress concentration, once the stress in material reaches the tensile strength, the material will fracture at that point. Once the crack initiates in the brittle material due to excessive stress magnitude (at the stress concentration or elsewhere), the crack will near-instantaneously propagate (your coffee cup will shatter). Broken-fractured-failed ---

whatever you want to call it--- at the stress concentration, $\sigma_{max} = K_t\sigma_{nom}$ --- and for this problem, failure will occur when $\sigma_{max} = \sigma_1 > S_{ut}$

3) Fatigue with non-zero mean stress and the presence of a stress concentration…. Task 1 – determine if there will be yielding at the stress concentration ("local yielding"). If you are unable to determine that, then make an assumption (STATE IT), do the work, and then check the assumption once enough information has been obtained. If the assumption was correct, you are done. If not, you have to redo the analysis. For help with understanding how stress concentrations with non-zero mean stress affects the Goodman equation see the link on the course web page: http://faculty.up.edu/lulay/me401/fatigue-stress-concentration-diagram.pdf
4) No hint other than the Goodman equations are shown in problem 4. Don't expect too many questions to be this easy.
5) Spherical ball bearing – sounds like Hertzian contact. Fatigue is most affected by tensile loads and shear loads – compression loads are generally less of a concern for fatigue. Are there any tensile stresses created by Hertzian contact? Where is the shear stress the greatest for this loading?
6) No hints provided. Review strength of materials if you have difficulty whit this – don't be surprised to see similar questions on the final.
7) Lawn mowers typically have a single reciprocating piston that as it moves back/forth it results in alternating forces. Use your knowledge about magnification factor (MF) to answer this question.