GEORGIA INSTITUTE OF TECHNOLOGY

The George W. Woodruff
School of Mechanical Engineering

Ph.D. Qualifiers Exam - Fall Quarter 1998

Design
EXAM AREA

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Assigned Number (DO NOT SIGN YOUR NAME)

- **Please sign your name on the back of this page—**

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George W. Woodruff School of Mechanical Engineering
Georgia Institute of Technology

DESIGN QUALIFYING EXAM: WRITTEN

Fall 1998

Read the entire examination first. There are three questions. Attempt all three.

Problem 1 – Steam Engine Jet Connection

In Figure 1, you will see a two-stage Wheeler "steam jet apparatus". The Swedish engineer De Laval discovered that by a gradual widening of a tube in the direction of the flow and away from the input opening, the pressure of, e.g., steam will fall below the critical pressure and the speed will increase (you may remember this from your fluids or thermodynamics classes). In the old days (i.e., 1920s), the apparatus in Figure 1 was used to increase the speed of steam, almost by a factor of 3. A greater velocity of the steam is beneficial because it will suck more air in (with the steam) and it will result in higher energy for compression. Not surprisingly, a variety of these steam jets were made by different manufacturers - Wheeler being one of them.

As you may know, there is an old steam engine standing right in front of the Coon building. Let us assume that we want to bring it back in running order and equip it with the above shown Wheeler two stage steam jet apparatus. We found one of these steam jets in the basement of the Coon building, but it was disassembled and all the bolts are missing. The only information we could find was this old drawing (Figure 1) taken from an old Dutch book on "Piston Steam Engines", published in 1923. You are asked to help with the restoration and figure out the fasteners needed.

Your first task is to focus on the bolt-nut combination labeled "Situation 1" in Figure 1 which is used for clamping the nozzle part of the jet assembly to the lower (expansion) part of the jet. Six bolts are to be used, equally distributed over a bolt circle with a 200 mm diameter. In Figure 2, a close-up of one of the six bolts (and nuts) and the (round) flanges/members to be clamped is given.

A tensile load is induced on the bolt-nut combination by the pressure of 0.7 MPa in the steam jet. For simplicity, assume constant pressure acting on an area of 7,850 mm in the jet.

ISO grade 8.8, M20 bolts, with rolled thread and fine pitch, are being considered for the restoration in Figure 2. These bolts have a proof strength of 600 MPa and a tensile stress area of 272 mm^2. As you can see in Figure 2, a filler/gasket ring (made of copper) is used between the two flanges. The dimensions indicated in Figure 2 are as follows; L = 55 mm and L1 = L2 = 25 mm. The center of the bolt hole is 60 mm from the edge of the flanges. Clearly, Figure 2 is not drawn to scale, so do not derive any dimensions directly from the drawing.

Both flanges are made out of gray cast iron (E = 100 GPa). The modulus of elasticity is 119 GPa for the copper filler/gasket ring and 207 GPa for the steel bolt. Although not shown in Figure 2, assume a washer is used with a diameter D equal to 1.5 times the nominal diameter of the bolt. The threaded portion of the bolt in the grip is 15 mm.

Assume a joint constant of C = 0.20 for all questions.

a) What is the stiffness of the members?

b) Without considering any load or stress issues, is the spacing of the bolts appropriate? Why or why not?

c) Now assume that the pressure is increased to a constant value of 7 MPa. Suppose you are allowed to change the number of bolts. What would be the absolute theoretical minimum number of bolts we could use if we want a safety factor of 6.0 and a preload (F_i) of 75% of the proof load in each bolt?

d) Assume now that the pressure fluctuates between 0 and 7 MPa and that six M20, grade 8.8 bolts are used with a tensile stress area of 272 mm^2, endurance limit of 140 MPa, ultimate tensile strength of 900 MPa, yield strength of 720 MPa, and proof strength of 600 MPa. Using a recommended preload of 75% of the proof load, calculate the factor of safety for fatigue using the Goodman criterion.

e) Situation 2 (see Figure 1) highlights a different connection in the apparatus. Here, studs are used instead of bolts to connect the two parts/members. Give two good possible reasons why studs are preferred over bolts for this particular connection.

f) In general, why would you not recommend reusing the nuts for bolt-nut combination after, say, an overhaul has taken place for the steam jet?

Useful Equations:

$C = k_{bolt}/(k_{bolt}+k_{members})$

$$F_m = \frac{k_m}{k_m + k_b} nP - F_i$$

$$F_b = \frac{k_b}{k_b + k_m} nP + F_i$$

Uncorrected Goodman Equation

$$\frac{\sigma_a}{\sigma_e} + \frac{\sigma_m}{\sigma_{ut}} = 1$$

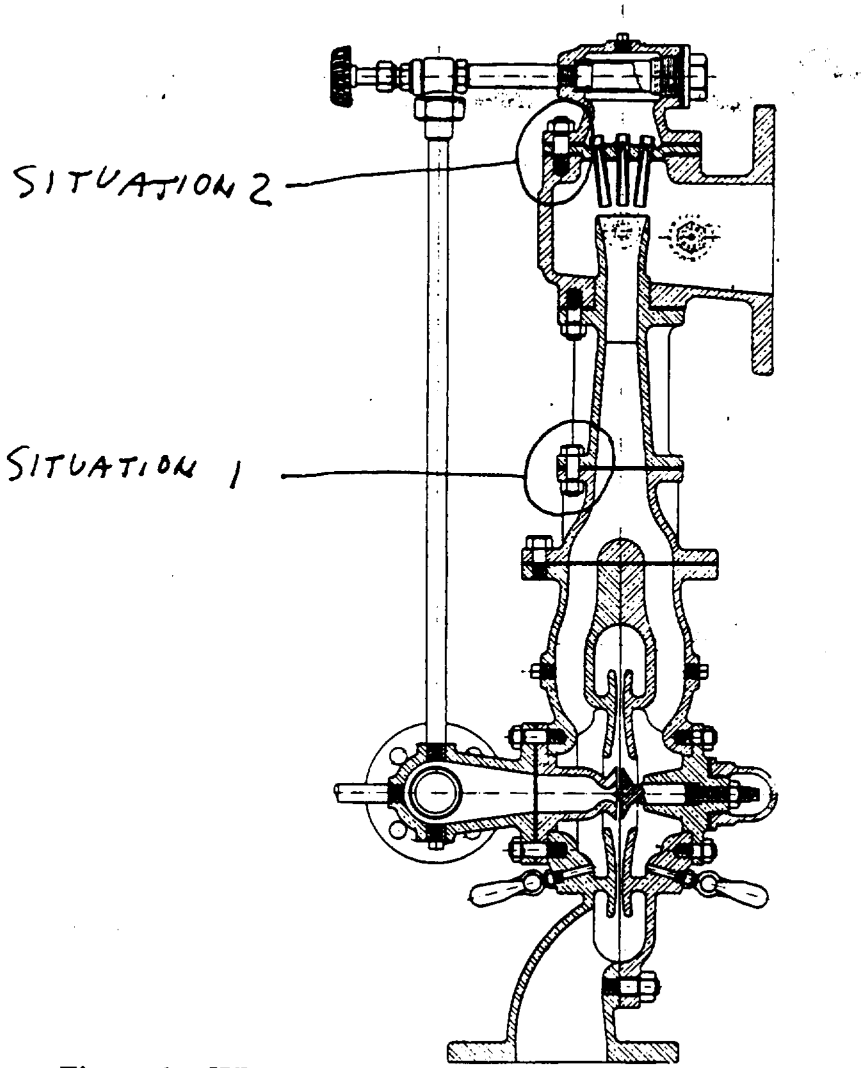

Figure 1 – Wheeler Two Stage Steam Jet Apparatus

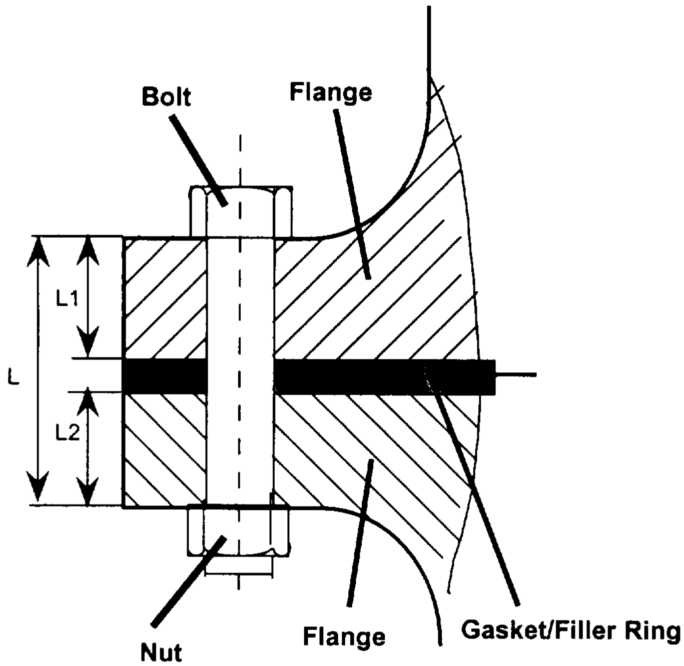

Figure 2 – Schematic of Flanges and Bolt-Nut Combination for Situation 1

Problem 2 – Mercedes Benz Valve Springs

In Figure 3, a cross-sectional drawing of the camshaft-valve assembly of a Mercedes Benz (MB) M118 engine is shown. This type of internal combustion engine was used in the late sixties and early seventies in the MB 250 series. The most powerful version of this engine was used in the 1972 Mercedes 250C automobiles. It provides a maximum 160 horsepower output at a speed of 5500 rpm.

Your task is to focus on the two valve return springs (labeled inner and outer spring in Figure 3). These helical compression springs ensure that the valve is being returned in its original (closing) position. The valve is opened by the camshaft pushing the rocker arm down, which in turn pushes the valve down.

The engine rotates at speeds between 500 and 7000 revolutions per minute, causing the valve to be opened and closed once every other revolution (the engine is a four-stroke engine).

The wire and mean coil diameter dimensions for the outer engaging spring are 4 mm and 30 mm, respectively. The wire and mean coil diameter dimensions for the inner engaging spring are 3 mm and 20 mm, respectively. Each spring has 10 active coils and 12 coils total because both springs are squared and ground. Both springs are made of shot-peened chrome vanadium wire with a modulus of rigidity of G = 79.3 GPa.

Spring equations:

$k = d^4 G / (8 D^3 N_a)$,

$\tau = K_S.(8 F D)/(\pi d^3)$,

$K_S = (2C+1) / (2C)$

$C = D/d$

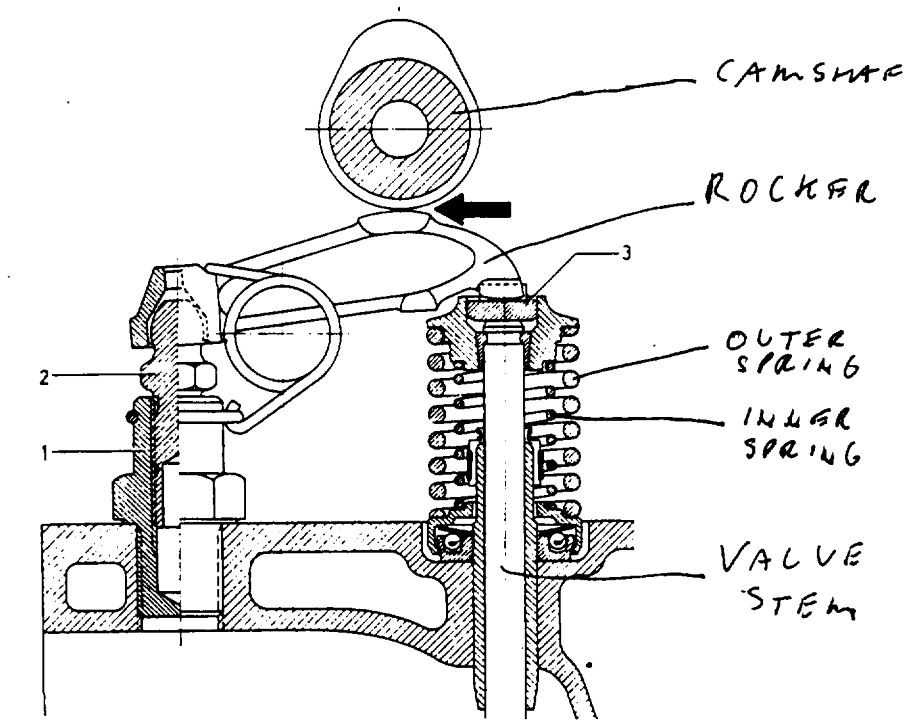

Figure 3 – Mercedes M118 Engine Camshaft-Valve Assembly

a) By inspection, which spring would be more prone to buckling and why?

b) Why should the inner and outer spring wires be wound alternately left hand and right hand?

c) Calculate the force required to move the valve 23 mm.

d) Besides monetary reasons, why would one rather use steel than aluminum or magnesium as spring material? Failure is not a reason.

e) If a designer would recommend two springs with the following dimensions:

Outer engaging spring: $d = 3$ mm, $D = 27$ mm, $N_{total} = 12$
Inner engaging spring: $d = 3$ mm, $D = 22$ mm, $N_{total} = 12$

Would this be a good recommendation? Why or why not?

Now, assume that a new design is considered with only one spring. The spring is supposed to travel a distance of 25 mm. When it is installed (and without any external load applied), the force on the spring is 200 N. The maximum force on the spring is 600 N when it is fully compressed and the valve is open. The wire diameter is 3 and the spring index C is 6.

f) What is the spring rate k?

g) The designer is considering to prescribe the length of the spring when fitted (but without any external load) to be 40 mm. Prove to the designer that a fitted length of 40 mm is not appropriate for this spring.

Problem 3 - Planetary Gear System

In Figure 4, a schematic of a planetary gear system is given. Gear 1 is called the sun wheel and it is fixed so that it cannot rotate. The rotation of the arm causes the planet gear 2 to rotate around the sun. This drives gear 3 which causes the so-called annulus gear to rotate. The annulus gear has an internal ring with teeth. The number of teeth on the sun wheel is 18, the number of teeth on the annulus is 90. There are three planet wheels. There are 40 teeth on gear wheel 2 that is engaged with the sun wheel.

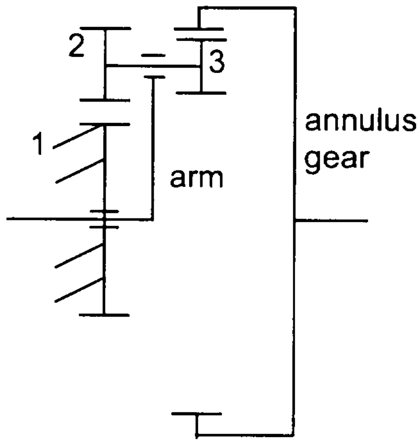

Figure not drawn to scale.

Figure 4 - Planetary gear system schematic

a) Given that all teeth have the same dimensions, what is the number of teeth on gear wheel 3 that is in contact with the annulus?

b) Assume that the planetary gear system is connected to a high-speed electric motor. Give at least two distinctly different ways of reducing the speed of the electric motor instead of this gear system.