GEORGIA INSTITUTE OF TECHNOLOGY

The George W. Woodruff
School of Mechanical Engineering

Ph.D. Qualifiers Exam - Fall Semester 2004

DESIGN
EXAM AREA

Assigned Number **(DO NOT SIGN YOUR NAME)**

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

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

DESIGN QUALIFIER

FALL 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

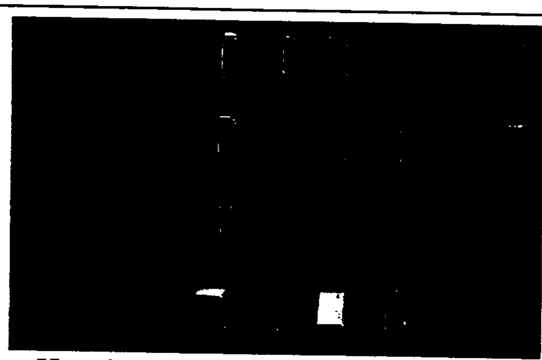
Please arrive half an hour before the scheduled time for the oral exam. During this period we will give you a question to think about. The scope of the oral exam is as follows:

* 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

Background

In a democracy, voting is the hallmark of citizen participation in government. During the 2000 Presidential elections, however, the fragility of that process became evident. The voting systems in Florida proved to be unacceptably unreliable, possibly disenfranchising thousands of citizens. Votes were under counted and over counted at a rate that left many people wondering about the validity of the overall voting process and the value of their individual vote.



Hanging chads… the source of much agony in the 2000 elections

Task

Assume that you are in charge of the design team responsible for developing the voting system for the State of Georgia with a targeted roll-out for the 2006 elections. Recent attempts at developing new, often computer-based voting systems have made it clear that developing such a system is an interesting design problem with many trade-offs. It is your task to identify these trade-offs and propose design alternatives that accommodate them.

The company would like to develop the system in such a way that it is sufficiently flexible that it can be used across all states of the Union. The system should accommodate not only national elections (president, senate, house), but also elections for state and local governments, school board and judicial elections. It should furthermore allow for up to 10 popular referenda.

An important aspect of developing a voting system is user-friendliness. The system should be usable by all citizens of voting age, regardless of their physical and mental abilities. Make sure to address this aspect in your design.

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.

Problem 2 – Analysis

One design being considered is to re-engineer the voting machines that use paper ballots that are being punched. As you may remember, hanging chads was a major issue and the redesign options are all focused on creating a cleaner punched ballot that has no hanging chads whatsoever. In Figure 1, a schematic of one possible redesign is given.

The user/voter has two options of operating the machine:

1- By pushing on top of the steel bolt (where it says "push" in Figure 1 below), which basically directly applies force to the bolt which punches the ballot using the "punch" at the bottom
2- By rotating the crank attached to a cam, which operates the cam causing the lever to pull down the bolt and punch the ballot. The cam is an eccentric cylinder with a radius of 3 cm. The distance from the center of the cylinder to the center of rotation of the cam is 1.5 cm. The lever is rotates around point B that is exactly in the middle of the lever.

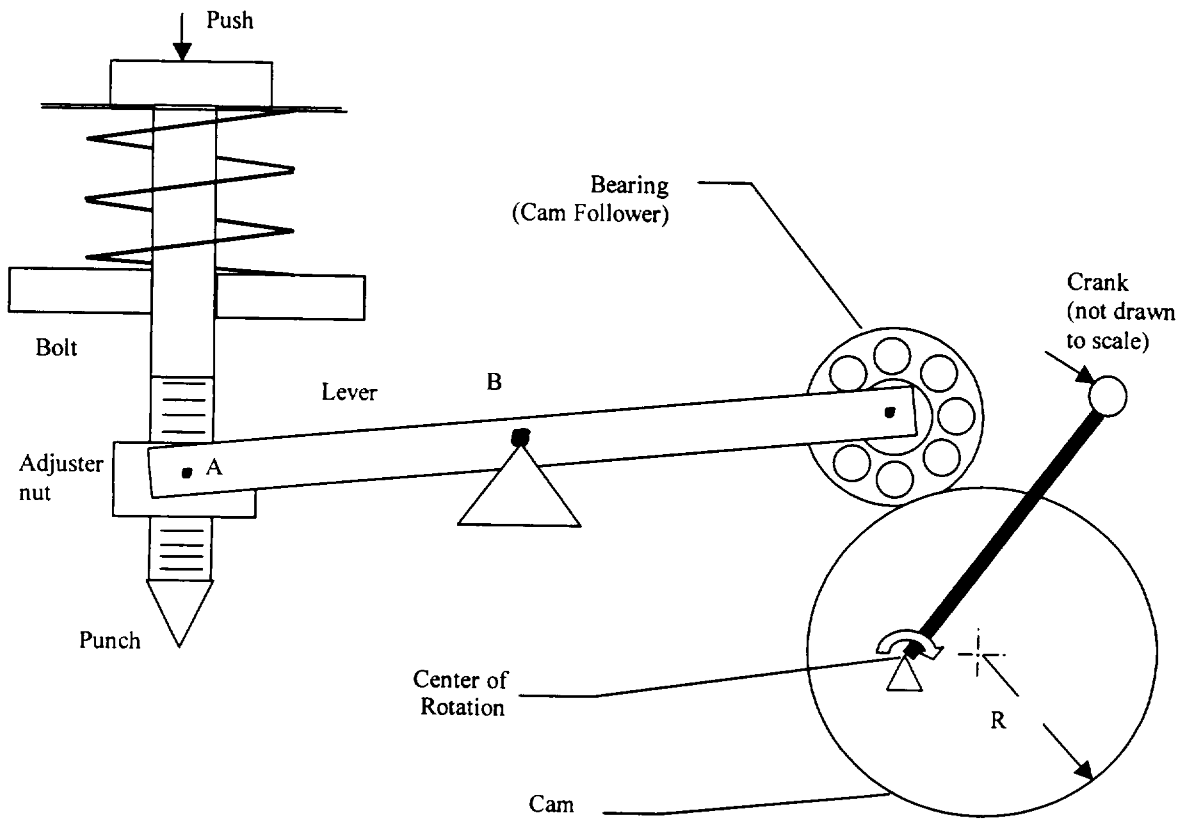


Figure 1 - Voting Machine Mechanism Schematic (<u>not drawn to scale</u>)

A single row deep-groove ball bearing with 10 mm bore and 30 mm outer diameter is used as a cam follower (labeled "Bearing" in Figure 2).

A helical compression spring is used to pull back the bolt (and punch) from the ballot. The spring has squared and ground ends and has a 3.5 mm wire diameter. Assume that the spring material is hard drawn steel wire with a modulus of rigidity of 79.3 GPa and an ultimate tensile strength of 965 Mpa. The spring has a free length of 10 cm, a 1 cm coil pitch, and a mean coil diameter of 4 cm.

a) Of the two user/voting options given above, explain which option do you think would work best and why?

b) Calculate the solid length of the spring?

c) If we assumed for the moment that the spring has 10 active coils, calculate the spring rate and the difference between the minimum and maximum force exerted by the spring if we operated the voting machine (and spring) using the crank only.

d) Some experiments are being done on a prototype and in Figure 3 a plot of the deflection curve of the spring is shown. Explain what is happening in Figure 2 and why the curve changes at points A, B, and C.

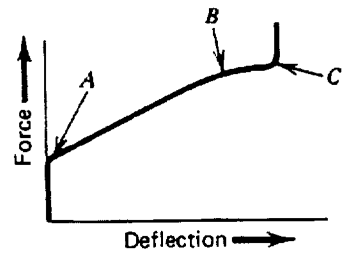


Figure 3 – Loaded Spring and Force-Deflection Curve

e) Instead of a straight compression spring, a conical shaped spring like shown in Figure 4 is used. Assume that the number of coils remains the same and that D_{top} = 3 cm and D_{bottom} = 5 cm. If the load remains the same, will you have to increase or can you decrease the wire diameter of this new spring if you want to have the same factor of safety against failure through (static) yielding? Explain why.

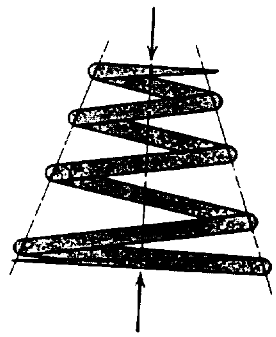


Figure 4 – Conical Spring

f) If the force on the bearing is 500 N and the bearing's basic load rating is 5.07 kN, how may votes can be cast based on the L_{10} life of the bearing? Assume no slip between the cam and bearing.

g) Assume we use a new spring with a spring constant k of approximately 50 N/cm, can you derive a value for the stiffness constant or joint constant C for this bolted joint connection? What does this value of C indicate about the load taken by the bolt?

<u>Some spring equations:</u>

$k = d^4 G / (8D^3 Na)$, $\tau_{max} = Ks\,[(8\,F_{max}\,D)/(\pi\,d^3)]$, $C = D/d$, $K_s = (2C + 1) / 2C$, $S_{sy} = 0.56\,S_{ut}$