<u>Engineering Ethics Cases with Numerical Problems</u>

from an NSF & Bovay Fund sponsored workshop

August 14-18, 1995

Texas A&M University

Mechanical Engineering Case 5

How Far Should the Design Go?

<u>Authors</u>:

Alan Letton (aletton@acd.tusk.edu)

Jeff Layton (laytonj@sun.soe.clarkson.edu)

Daniel Yannitell (meyann@imr00.me.lsu.edu)

Michael Latcha (latcha@oakland.edu)

August Ryan Wilhelmsen

<u>Suggested Courses</u>:

Strength of Materials and

Mechanical Design

<u>Level</u>:

Sophomore, Junior, & Senior

I. Narrative

On May 5, 1989 Mr. Bill Brands, owner and CEO for Acme Industries, an asphalt manufacturer, was involved in an industrial accident, resulting in the loss of a worker's life. During routine plant maintenance, Mr. Brands decided to replace a motor that drives a pump through a flexible rubber coupling, presented in Figure 1 below.

The coupler was initially a part of the complete motor/pump assembly purchased from, and installed by, Lawhorn, Inc. On the morning of the accident, Lawhorn employee, Rebecca Flowers, was dispatched to the location of Acme Industries to install the new pump. After installation, the new motor was tested at a speed of 2500 rpm (the rated operating speed). Working with Ms. Flowers, was Mr. Brands, a plant technician (John Limbaugh), and the unit operator (Albert Gallway). Mr. Gallway observed that the new motor required 40% higher current and 40% more power than was observed during the operation of the older motor.

It was assumed that the higher power load on the motor was due to misalignment. The alignment was checked using a ruler, and appeared to be satisfactory. As a check on the system, the older motor was reinstalled and operated under similar conditions. The current and power were the same value as during the original installation.

Mr. Brands made the decision to disconnect the pump shaft from the coupler, assuming misalignment between the motor and the pump. To disconnect the pump shaft, a steel safety shield that covers the coupler section was removed. The new motor was reinstalled. The steel plate that connects the coupler to the pump shaft was left in place, attached to the coupler. Ms. Flowers returned to her truck to retrieve some equipment. While she was gone, Mr. Brands, instructed Albert to activate the motor, while he observed the coupler. The coupler quickly ruptured, flinging the metal plate into the worker's head, instantly killing him.

Instructor

To the instructor: this problem is designed for group discussion, analysis and technical development. Incidentally, this case is true--only the names have been changed.

II. Scenario 1

1. You have been asked as a forensic engineer hired by the family of the victim to prove that the design of the motor/coupler/pump system was unnecessarily dangerous. What information do you need to evaluate the design?

2. There are also other possible causes of the accident, such as the removal of the safety shield, poor safety practice of the company, improper maintenance of the system, etc. Are you obligated to investigate these possible causes of the accident? Should the client pay for this part of the investigation? How will you justify this to the client?

III. Scenario 2

1. You have been assigned as a forensic engineer, hired by Lawhorn, Inc., to prove that, while the design was adequate, Mr. Clifton was primarily responsible for the incident because of his improper and negligent operation. What information do you need regarding the operation, maintenance, safety procedures, and management policies of Acme? How will this affect your technical analysis?

IV. Technical Data on the Coupler

1. The coupler is made of a 2-ply nylon rubber composite, similar to automotive tires.

2. The dimensions of the coupler, and shaft are given in Figure 1. Notice that the coupler has an outside radius of 10 inches and a width of 6 inches.

3. The coupler is designed to tolerate some misalignment between the motor shaft and the pump shaft. The

specifications call for a maximum vertical misalignment of 0.5 inches between the two shafts.

4. The plate assembly at either end of the coupler weighs 10 lbs.

5. The motor is rated for horsepower not rotational speeds (the rated horsepower is approximately 100 Hp.). However, the nominal rotational speed was 2500 rpm, but the speed of the shaft at the time of the accident is not known.

6. The coupler is not pressurized because of the split needed to insert the metal plate.

7. The coupler is an off the shelf component bought by Lawhorn Inc. from a local rubber manufacturer.

V. Questions Regarding Ethics and Professionalism

There are several models of professional responsibility.

The first is the malpractice model. It is a minimalist model in which the professional is concerned only with meeting standards and requirements of the profession and any other laws or codes that apply to the given situation. This model is oriented toward finding fault when problems or accidents arise from someone's failure to meet a requirement.

The second, the reasonable care model, is somewhat more demanding. It is based on the idea that sometimes it is reasonable to expect a professional to consider factors not explicitly addressed in the regulations. Some of these factors for engineers are safety and quality, which usually cannot be formulated in quantifiable standards.

The third model is the good works model. In this model, the professional goes "above and beyond the call of duty" in his effort to complete the task. This involves taking time and consideration far above that which is required and even above that which might be reasonably expected.

1. Recall that the safety shield was removed from the assembly just prior to the accident. In addition, the pump shaft was also disconnected from the assembly. Is it *reasonable* to expect Lawhorn Inc. to have designed for the possibility that their product would be operated improperly? Are these disassembly steps *reasonable* expectations that the engineer should design against?

2. Assume that management is discouraging efforts to surpass the explicit requirements of a design in the interests of profit and advancement of the company. Create some arguments that show why assuming additional responsibility would be advantageous, even to the company.

VI. Technical Solution (An Approach) - Scenario 1

Modeling:

As a first approximation in examining the failure of the coupler, it was modeled as a rigid bar attached at its base with a torsional spring as shown below in Figure 2. The other end of the bar is attached to the plate, which has a weight of 10 lbs. A simple relationship between the vertical deflection of the mass and the angle q can be derived

$d = l \sin q$ (1)

where d is the vertical deflection of the plate and q is the angle the bar makes with the shaft centerline. A relationship between the moments about the pivot point (torsional spring location) can also be derived

$$kq = W\, l \cos q \quad (2)$$

where k is the torsional spring constant, W is the weight of the plate, and l is the length of the rigid bar (6 inches). It is known that with the pump shaft disconnected the plate vertically deflected 0.5 inches (i.e. $d = 0.5$ inches) before the motor was activated. Therefore an equivalent spring constant can be found from Equations (1) and (2).

If we assume that the plate is undergoing some acceleration due to the rotational motion of the shaft (equal to the deflection times the rotational speed squared), then Equation (2) will change slightly to the following:

$$kq = m\, a\, l \cos q \quad (3)$$

where m is the mass of the plate, and a is the acceleration of the plate. Neglecting gravity, acceleration is $d\, w^2$. Equation (3) then becomes,

$$kq = m\, d\, w^2\, l \cos q \quad (3)$$

For a given angle q, the rotational speed w can be computed. Then the force in the rod can be derived from a free body diagram and an estimated stress in the rubber coupler can be computed (the coupler is 1/8 inch thick with a radius of 5 inches). Assuming that rubber has a failure stress of about 5400 psi, the Mathcad worksheet on the next page estimates the failure speed to approximately 2500 rpm.

$ft := 1L \qquad s := 1T \qquad g := 32.2 \cdot \frac{ft}{s^2} \qquad lb := 1M \cdot g$

$in := \frac{ft}{12} \qquad m := 60 \cdot s \qquad rad := \frac{in}{in} \qquad deg := \frac{\pi}{180} \cdot rad$

$rev := 2 \cdot \pi \cdot rad$

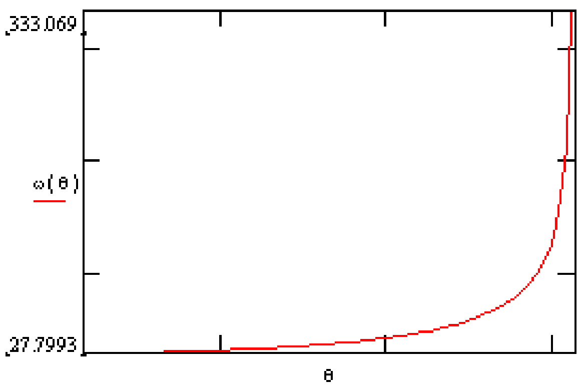
$W := 10 \cdot lb \qquad d_o := 0.5 \cdot in \qquad L := 6 \cdot in$

$\theta_o := asin\left(\frac{d_o}{L}\right) \qquad \theta_o = 0.083 \cdot rad \qquad \theta_o = 4.78 \cdot deg$

$k := \frac{W \cdot L \cdot cos(\theta_o)}{\theta_o} \qquad k = 716.664 \cdot in \cdot \frac{lb}{rad}$

$\omega(\theta) := \sqrt{\frac{k \cdot g \cdot \theta}{W \cdot L^2 \cdot sin(\theta) \cdot cos(\theta)}} \qquad \theta := \theta_o, \left(\theta_o + \frac{\pi}{200}\right) .. \frac{\pi}{2}$

$\omega_o := \omega\left(89 \cdot \frac{\pi}{180}\right)$



$\omega_o = 2.499 \cdot 10^3 \cdot \frac{rev}{m}$

$\omega_o = 261.676 \cdot \frac{rad}{s}$

$F := \frac{W}{g} \cdot \omega_o^2 \cdot L \cdot sin\left(89 \cdot \frac{\pi}{180}\right) \qquad F = 10631.05 \cdot lb$

$A := \pi \cdot 5 \cdot in \cdot \frac{1}{8} \cdot in \qquad A = 1.963 \cdot in^2$

$\sigma := \frac{F}{A} \qquad \sigma = 5.414 \cdot 10^3 \cdot \frac{lb}{in^2}$

$v := \omega_o \cdot L \qquad v = 130.838 \cdot \frac{ft}{s} \qquad T := \frac{1}{2} \cdot \frac{W}{g} \cdot v^2 \qquad T = 2.658 \cdot 10^3 \cdot ft \cdot lb$

VII. Solutions to Ethical Problems

1. The Code of Ethics of the American Society of Mechanical Engineers (ASME) requires engineers to "hold paramount the safety, health and welfare of the public in the performance of their professional duties." This requirement seems to involve more than the malpractice model of engineering professionalism. It seems to require that engineers not only avoid directly creating threats to public safety, health and welfare, but they go out of their way to prevent such problems. This seems to imply the reasonable care model, in terms of which engineers must

take a more proactive stance with regard to public safety, health and welfare than is implied in the malpractice model. Engineers must, according to the reasonable care model, take positive steps to prevent dangers to the public, even if this means going beyond quantifiable standards. By this standard, engineers should have attempted to come up with a design that would prevent or at least reduce the chances of an accident such as the one described in this case.

Of course, there are limits to the ability of engineers to design against misuse of equipment. These limits include not only cost, but also such factors as ease of manufacture and use. But, given the ASME code, it seems reasonable to expect engineers to have at least attempted to design features that could have protected against such accidents.

2. Engineers could have made several arguments to managers in favor of a higher level (reasonable care model) of professional responsibility. First, designing against such accidents could prevent lawsuits. Second, if lawsuits did occur, the manufacturer could use as part of its defense the claim that it had already gone beyond what was required in the area of safety and had a general policy of doing so. Third, engineers could argue that the higher safety standards of the company make its products more desirable to customers, and that its sales people could use safety as a selling factor. Fourth, engineers could argue that the higher safety standards might attract better engineers as employees. Fifth, the engineers could argue that the higher safety standards would generally improve the reputation or public image of the company.