Case Study 3: Impact testing of low-temperature steels

Case specification

You are designing an apparatus to study the deformation of steel at low temperatures. Below about -20˚F, many steels become brittle, as a result, the ASME Boiler and Pressure Vessel Code imposes additional design requirements. One of these requirements is the use of low-temperature testing to prove that the steel in use retains sufficient impact resistance.

Your apparatus uses laser interferometry to measure deformation during the impact process. You and an undergraduate research assistant with no experience in the field will be running the experiment. Your apparatus is shown in Figures 1–3.

Laboratory

Your laboratory is in an older engineering building that used to house the campus' power plant. The room is about 20' by 20', with a 10' by 10' by 10' deep pit in the middle of the lab, in which you have placed your impact tester. The pit contains a floor drain, and access to the pit is controlled by a ladder bolted to the walls. There is a gas-fired hot water heater in one corner of the room. See Figure 1 for a schematic.

Sample stage

The sample stage is a hardened anvil immersed in a cold acetone bath at –78˚C (see Cooling, below). The steel sample, which is approximately 1 m by 1 m square and between 0.25 and 1 cm inch thick, lies flat on the stage. A hardened impact probe (see Impact probe, below) rests on the sample. A laser beam (see Interferometer, below) strikes the sample at a 45˚ angle, reflecting at an equal angle. See Figure 2.

Cooling

The apparatus is cooled to –78˚C by acetone from a dry ice-acetone bath. Cold acetone (1 gal/min) flows by the force of gravity from an open 100 gallon reservoir through standard plastic tubing. The acetone is sprayed through a nozzle into a tray surrounding the sample stage. The acetone level is adjusted so that the sample stage, but not the sample, is immersed in the liquid. Conduction through the sample stage indirectly cools the sample. Acetone is pumped back to the reservoir by a 1/2 hp centrifugal pump running on 480V power. See Figure 3.

Impact probe

The impact tester consists of a hardened beryllium probe mounted in a 6 inch pipe. The probe maintains constant contact with the sample. A normally-open detent (hold-back) mechanism suspends a 250kg depleted uranium weight in the pipe above the probe. An air cylinder actuated by 2500 psig of natural gas holds the detent closed. To fire the tester, the researcher presses a button located on the side of the coolant tray (the tray which contains the sample). The button momentarily interrupts power to a normally-open solenoid valve, which vents the natural gas pressure into the lab, releasing the air cylinder, which in turn releases the 250 kg weight to fall and strike the probe. After the impact, the weight is raised back into position using a pulley system powered by a 480V open squirrel-cage motor mounted on the pit floor. See Figure 2.

Interferometer

The laser interferometer uses a 4W (Class 4) infrared laser, which shines on the sample at the probe's impact point. The reflected beam is directed upwards and aligned with a mirror on the lab ceiling, which directs it through a doorway to an optical table in the neighboring laboratory. On the optical table, the frequency of the laser is doubled two times, and the four resulting beams are analyzed interferometrically by sensors on separate tables nearby.

Assignment

Before class on 11/26

Do the following before you arrive in class on 11/26:

1. Read the case description and the outline of the assignment.
2. Use the hazard checklist (provided as a Word .docx file on Blackboard) to identify the major sources of hazard in the experiment.
   Bring the checklist to class with you.
3. Read "How to do a What-If? analysis on an experiment" in preparation for the study you will do in class. Look over the example What-If? worksheet provided to familiarize yourself with the format.
4. ***Bring your laptop.*** You will not be able to complete the final project without your computer, as all necessary materials are distributed via Blackboard, including those which must be used in class.

In class on 11/26

We will briefly review how to do a What-If? analysis. Each group will then conduct an analysis on the experiment in the case study. The scope of the analysis will be the entire experiment, including procedures, materials, equipment, startup, disposal, and emergency situations. Please note the following:

- ***Complete at least 5 What-If questions*** over the course of the class period, analyzed to similar standards as the example. Use the entire class period for your analysis. If you have finished before the period is up, either revisit your analysis to refine it or do additional questions.
- ***Be exhaustive in considering causes and consequences***. Keep asking "what happens then?" and "what causes that" to follow the cause-and-effect chain as far as possible. The more comprehensive your work analyzing these factors, the better your results will be.
- ***Be creative in looking for recommended controls***; this is often a brainstorming process. Remember to look over your list of causes and consequences for additional ideas. Do not be afraid to come up with "silly" or "stupid" hazard controls—creative processes often thrive on "stupid" ideas, and one person's "stupid idea" can be the spark that prompts another person to innovate.

In class on 12/3

We will have a short lecture on Inherently Safer Design. Each group will then conduct an Inherently Safer Design brainstorming session. Please note the following:

- ***Please come up with as many improvements as possible*** in the time allotted—***at least 12 reasonable ideas*** for inherently safer improvements to this case should be practical.

- ***Consider all six principles*** of Inherently Safer Design.
- ***Consider materials used, use modalities and procedures, location, support equipment, and the skill level of the experimenters.***

After the Inherently Safer Design brainstorming session, we will play the role of "management," that is, the principal investigator. Imagine you are the principal investigator for this experiment, and that your students have presented you with these safety recommendations and these ideas for an inherently safer experimental design. ***Decide the following***:

- Which "What-If?" recommendations will you accept and implement? Why? Acceptable recommendations are usually effective at reducing risk, implementable, and economical.
- Which Inherently Safer Design ideas are promising? Why? The best ISD ideas eliminate or reduce risk, while at the same time reducing cost or making the process easier or more successful.

At the presentation (held during Final Exam period 12/13/13 0900-1200, in the usual classroom)

The final assignment consists of three elements:

1. Each student must submit the certificate from the myLearning research assistant qualifier course. The link to the qualifier is on Blackboard; myLearning will email you the certificate when you complete the exam. Note the following:
    1.1. You have only three chances to complete the exam. It is not recommended to repeatedly open and close the course to verify that it works, as you will be locked out. If this happens, email me with an explanation, and I will instruct myLearning to reset your course. In any event, looking at the exam questions in advance is pointless as the questions on the exam are randomized.
    1.2. If you have trouble accessing myLearning, try a) logging in from the 'hopkins' network, and b) logging into myLearning first through my.johnshopkins.edu and then using the link on Blackboard. The course is available only through the link, not through the general myLearning course catalog. If you still cannot get into the course, please inform me.
2. Each group must submit a report, described below. Submit reports through Blackboard; only one student from each group need submit the report. Remember to put all students' names on the report, though.
3. Each group must create and deliver a presentation, described below. Only one student should do the presenting; others should attend to answer questions.

Report

The report is due at 0900 on 12/13; no late assignments will be accepted unless Blackboard is not working the morning of 12/13. Submit the report through Blackboard. There is no upper or lower page limit on the report; it should be as long as necessary to include the required information and no longer. Include the following information:

1. Title page:
    1.1. Title.
    1.2. Group members.
    1.3. Course number, semester, and section.

2. Hazard summary: A bulleted-list summary of the principal hazards present in the experiment, including the type of hazard and its main source. (E.g., pressure from compressed gases and pressurized equipment.)
3. What-If? analysis: Describe, in short paragraph form (3-5 sentences), each recommendation you made during the What-If? analysis. (If you have a great number of recommendations, you may limit yourselves to the top 8.) Explain how the recommendation acts to reduce risk. Justify, in a sentence or two, why you chose to accept or reject the recommendation.
4. Inherently Safer Design: Describe, in short paragraph form, each of your promising ideas for making the experiment inherently safer. For the three you considered most promising, explain your choices in terms of practicality and risk reduction.
5. Appendices: include your hazard checklist, your What-If? analysis worksheets, and your complete list of inherently safer design ideas (including the "impractical" ones). Use the Word templates provided on Blackboard for the checklist and worksheet; do not submit scanned copies of in-class notes. Legible scanned figures are acceptable, if figures are needed for your report.

Presentation

Each group has an assigned 15 minute period for their presentation. The entire group must be present for the presentation, as the entire group is expected to contribute to answering questions. Attendance at other groups' presentations is not permitted; please do not enter the examination room until invited by an instructor. The presentation should take 7-9 minutes; the remaining time will be consumed with questions. You may use the chalkboard during the presentation, but the computer projector will be unavailable. Include the following information:

1. The top three risks you found in your "What-If?" analysis, along with recommendations made to reduce those risks and your reasons for accepting or rejecting the recommendations.
2. The three most practical ideas you had to make the experiment inherently safer, along with justification for your choices.

Grading

See the Rubric for grading standards for this assignment.

Auxiliary materials

The folder "Course Content/Final Exam" contains supplementary information, including

- The figures referenced above.
- The hazard checklist. (Word format)
- A blank "What-If?" analysis worksheet. (Word format)
- A primer on conducting "What If?" analyses.
- Rubric for grading of the report and presentation.