ME 103 — Experimentation and Measurements
Spring 2026 — George Anwar

HW4

Due: Monday, March 30th at 11:59 pm

- This homework will cover the sensor design and applications.
- In all of the questions, **show your work**, not just the final answer. Unless we explicitly state otherwise, you may expect full credit only if you explain your work succinctly, but clearly and convincingly. For coding questions, attach a screenshot of your code and output.
- Present your answers with **a suitable number of significant figures** for each question. Show your work, including a mathematical formula or the MATLAB or Python code you wrote, before reaching the result. You may need to install the Signal Processing Toolbox if using MATLAB.
- Throughout this assignment, neglect systematic (bias) errors. Also, assume a normal distribution for the underlying distribution (population) if necessary.
- If you have a confirmed disability that precludes you from complying fully with these instructions or with any other parameter associated with this problem set, please alert us immediately about reasonable accommodations afforded to you by the DSP Office on campus.
- **Start early. Some of the material is prerequisite material not covered in lecture; you are responsible for finding resources to understand it.**

Deliverables

Submit a PDF of your homework to the **Gradescope assignment** entitled "{Your Name} HW4". You **must** typeset your homework in LaTeX (submit PDF format, not .doc/.docx format) . Mac Preview, PDF Expert, and FoxIt PDF Reader, among others, have tools to let you sign a PDF file. We want to make *extra clear* the consequences of cheating.

0 Honor Code

I will adhere to the Berkeley Honor Code: specifically, as a member of the UC Berkeley community, I act with honesty, integrity, and respect for others. Failure to comply with these guidelines can be considered an academic integrity violation. Please email Professor Anwar ganwar@berkeley.edu if you have any questions!

- **List all collaborators. If you worked alone, then you must explicitly state so. Read the following statement and sign below if you agree**:

  "I certify that all solutions in this document are entirely my own and that I have not looked at anyone else's solution. I have given credit to all external sources I consulted."

  Signature : ______________________ *Date* : ______________________

  While discussions are encouraged, *everything* in your solution must be your (and only your) creation. Furthermore, all external material (i.e., *anything* outside lectures and assigned readings, including figures and pictures) should be cited properly. We wish to remind you that consequences of academic misconduct are *particularly severe*!

- Violation of the Code of Conduct will result in a **zero** on this assignment and may also result in disciplinary action.

1 Measuring Strains up to Fracture [50 pts]

Engineers very often need to test material samples under tension until they fracture. Measurements of the extension of the sample as well as the applied load are taken periodically as the load is ramped up, from the time when no stress is applied until the moment of fracture. From these force–displacement data, together with knowledge of the dimensions of the sample, material parameters including Young's modulus, yield strength, ultimate tensile strength, and failure strength and strain can be determined.

Tensile testing machines (e.g. the Instron machines in Hesse Hall) measure load with load cells that are mounted in line with the applied load and convert the applied force into an electrical signal that can be recorded using a DAC and logging software such as LabVIEW. Load cells are often made from a block of material with known stiffness to which a strain gauge is attached, although there are other types of strain gauge.

Meanwhile, there are several available ways of measuring the extension or strain of the material being tested. These include:

- **Clamping an extensometer to the gage section of the dogbone**: this device incorporates an LVDT to measure the changing separation of two points on the gage section. However, an extensometer cannot easily be used if material will be tested to large strains or to fracture, since the displacement of the LVDT is limited and the kinetic energy released at the moment of fracture could damage the extensometer. A video (from ME 108) showing tensile testing using an extensometer is found under this homework folder.
- **Mounting (gluing) an electrical resistance strain gauge directly to the test specimen**. This method can provide an accurate measure of strain at a specific location in the material, though strains are typically limited to about 3–5% because the metal resistive film inside the strain gauge has finite ductility and will eventually fracture, at which point the resistance would become effectively infinite. Specialized strain gauges are available that can go up to $\sim 20\%$ strain or even larger. However, a further challenge with using strain gauges for testing ductile materials to failure is that the plastic deformation that precedes fracture usually involves necking, which occurs at a random location along the gauge length. Therefore there is no way of predetermining whether the strains measured by a single strain gauge will be at the location of necking or elsewhere.
- **There is a rotary encoder attached to the motor that drives the leadscrew that pulls the jaws of the Instron apart**. This encoder provides data on the relative displacement of the machine's jaws and therefore can be used to estimate the extension of the test specimen. However, the Instron frame, the sample-mounting jaws, and the load transmission mechanism are themselves not perfectly stiff, so the displacement measured at the motor also includes a component of displacement due to distortion of the machine and will overestimate elongation of the specimen.
- **Digital image correlation (DIC)**, where a video is taken of the test specimen during loading, with fine dot patterns having been drawn or printed onto the surface of the test specimen. Software1 is then used to track the motion of the dots and extract a 2D map of strains over time. DIC is a very versatile technique, although accuracy is harder to quantify at present, and extensive data processing generally has to be done after the test is complete.

Your challenge in this part of the homework is to conceptualize and describe a design for a new strain measurement technique that addresses the limitations of the above methods. This is intended to be an interesting challenge, and there is no right or wrong answer here, so let your creativity flow and don't be afraid to put unconventional ideas down on paper if you can explain why you think they're worth considering.

The requirements are:

- The method should work with a dogbone of the same initial dimensions as shown in the ME 108 tensile testing video linked from the homework folder i.e. a dogbone cut from a sheet of material, with a gauge section having length 57.2 mm, width 12.8 mm, and thickness 6.4 mm. Techniques that are more generally applicable to different test geometries are welcome, but not required.

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- Should be capable of measuring strains up to at least 50%.
- Should withstand sudden fracture of the test specimen without being damaged – or, if some damage to a measurement component is inevitable but the cost of replacing the component is reasonably small (i.e. if you think the sensor could be disposable), include an estimate of the cost of each tensile test.
- Should be able to determine strain at five or more equally spaced locations along the gauge length of the dogbone test specimen simultaneously.
- You can attach items or mark the test specimen in any way you think necessary, though any modifications should not significantly affect the strain measured.
- Should ultimately result in the data being digitally logged in a computer.
- Should be able to yield data that can be read off by the user from the computer in real time if necessary (not rely on post-processing of data).
- Should be capable of detecting strain rates of up to 10%/second while ensuring that the difference between the last logged value of strain and the instantaneous true value of strain is never greater than 0.0001 or finer.
- Should be capable, in principle, of achieving an accuracy of ±1% in strain.

(a) [18 pts] Brainstorm at least three different measurement approaches that you think you could use to meet the criteria above.

You may need to think of ways of incorporating or combining existing sensors or techniques in new ways, or use a completely novel sensing approach. Show your concepts with labelled sketches and a couple of sentences of explanation.

One direction to consider is whether electrical resistance strain gages could be used in some way that allowed them to sense much larger strains than if they are directly bonded to the sample.

Another might be to think about contact-free approaches involving light interacting with the specimen in different ways.

Solution: TODO

(b) [26 pts] Choose one of your ideas and develop it further, showing a detailed drawing that is as quantitative as you can be. The drawing can be done by hand or computer but should indicate the specifics of how your technique will work (e.g. dimensional values for objects attached to the test specimen, quantitative specifications for any electrical circuitry used to obtain the data, such as resistors, bridges, and ADCs). Include information on how your technique will be calibrated across the full range of 0–50% strain.

Solution: TODO

(c) [6 pts] Make estimates of the resolution and accuracy of your technique.

Solution: TODO

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2 Temperature Sensing for Heat Treatment [50 pts]

In this part of the homework, you will design a temperature sensing technique for characterizing different methods of quenching and tempering an alloy steel.

In quenching, the material is heated to typically 850–950°C, e.g. in an oven, and then plunged into cold water, oil, or ootentially some other fluid, to conduct away the heat from the metal and rapidly cool it. This quenching process 'freezes' in place a certain microstructure, consisting predominantly of martensite, which is very hard but brittle. The cooling rate is a critical parameter as it determines how much martensite is in the material once it has cooled. Cooling rates as high as 1000°C/second may occur during quenching, although the value depends strongly on the fluid into which the component is immersed, the geometry of the component being quenched, and the location within the component (the surface will cool more rapidly than the center).

In tempering, some of the brittleness is relieved by re-heating the material to 300–600°C, holding the temperature for a period of time to allow iron carbide precipitates to form, which add toughness, and then cooling more slowly in air.

The rate of cooling during quenching is a very important parameter in predicting final microstructure, hardness, and toughness of the material, so it would be desirable to measure how the temperature of the material changes as a function of time during quenching. From these data, cooling rates could be determined and related to measurements of the material's resulting mechanical properties.

(a) [13 pts] Select and describe a suitable technique for measuring temperatures inside a 1-inch-diameter alloy steel bar during quenching.

Specifications for the technique are:

- Capable of measuring temperatures from room temperature up to 950°C.
- Capable of measuring cooling rates up to 1000°C/s while maintaining an error between the last logged temperature and the instantaneous current temperature of not more than 1.0°C.
- The 1 inch-diameter steel bar can be modified as you see fit, to enable the technique to be applied.
- At minimum, the cooling rate at the center of the bar should be directly measured; if you think it is desirable to measure temperatures elsewhere as well, then describe how that would be accomplished.
- The measurements should be logged digitally into a computer for later interpretation.

Solution: TODO

(b) [13 pts] Explain why you have chosen this temperature sensing method rather than other available techniques. Base your answer on specific attributes of your chosen technique such as measurable temperature range, response speed, ability to withstand the harsh environment of the quenching process, and any other relevant factors.

Solution: TODO

(c) [24 pts] Describe the specifics of your measurement technique, using a detailed sketch to illustrate the setup. Include:

- The specifications/type of sensor chosen.
- The design and settings of the electronic interface between the sensor and the computer.
- How you would calibrate your system across the temperature range of interest.
- How you will address the rapid thermal contractions that occur when a material is quenched to avoid damage to the sensor or inaccurate measurements.

Again, this task is intended to be open-ended and to give you a chance to practice your engineering skills by applying your knowledge to a design problem with several constraints.

Solution: TODO

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