Lab 1: Getting Ready for Manufacturing Quality Control

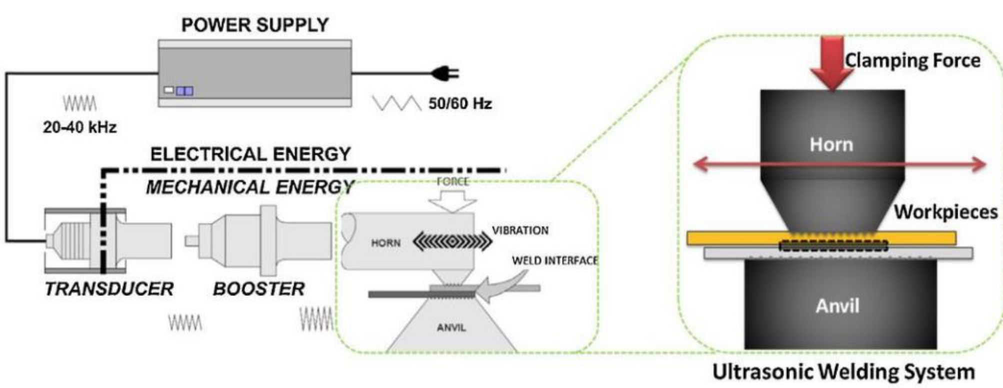
Assigned: September 29, 2023 Due: October 20, 2023

Lab objectives

(1) Understand the process of ultrasonic metal welding, and sensors used to sense the welding online for quality monitoring purpose.
(2) Perform preliminary data analysis including visualization, exploration, frequency analysis, and hypothesis testing.
(3) Practice data science thinking in a real-world manufacturing/engineering setting.

Introduction

Ultrasonic metal welding is a solid-state joining process that is well suited for battery tab joining in electric vehicle manufacturing. A typical ultrasonic welding system is displayed in the figure below. During each welding cycle, the transducer transforms electrical energy into high-frequency mechanical vibration. This mechanical vibration is transferred to a welding tip through an acoustically tuned horn. A metallurgical bonding between thin metal sheets clamped under pressure is created with oscillating shears generated by high-frequency vibration.



Ultrasonic metal welding can produce good quality welds when the welding conditions are optimal. However, an abnormal process condition can cause poor welds even with optimal parameter settings. For example, workpiece and tool surface conditions strongly affect weld quality. Vanishing oil, stamping fluid, cutting fluid, and other oil-based fluids are reported in the assembly line of battery packs as possible sources of contamination. The presence of oil contaminations will lead to poor weld quality. Unfortunately, such abnormal process conditions may not be easily detected before a welding cycle. Online process monitoring with sensing signals is a common approach in ultrasonic welding of automotive lithium-ion batteries. The potential quality of the weld could be determined by the features extracted from the online process signals.

In this lab, we will develop a prototype online monitoring algorithm to detect abnormal process conditions utilizing features generated from sensing signals. The abnormal process conditions will be simulated by applying Tap Magic ProTap Cutting Fluid at the interface between the workpieces. Besides, the effect of the workpiece dimension is also studied in this experiment.

Data collection

The data we analyze in this lab is collected from ultrasonic metal welding of copper sheets. The welding process is performed on 360 samples, each containing time series of five different sensing signals. Two variables, surface condition and the dimension of copper sheet, are varied in this dataset to study the effect of these factors on the quality of copper sheet welding.

The online monitoring sensor signals are connected to a data acquisition device (DAQ), processed by a computer through MATLAB, and then saved into a csv file. Five sensors are mounted on the ultrasonic metal welding machine for the monitoring purpose: acoustic emission (AE) sensor, displacement signal of actuator, power signal from controller, sound signal from microphone, and clamping pressure from the pressure regulator. Details on the design of experiments and sensing signals are provided as follows.

(1) Samples
- Use copper sheets for both top and bottom layers.
- Three different levels of surface condition
  a. Clean
  b. Level 1
  c. Level 2
- Four dimensions of sheets: Fixed width of 25mm and various length of 50mm, 60mm, 70mm, and 80mm.
- The thickness of sheets: 0.008”
- 30 repetitions for each (surface condition, copper sheet dimension) combination. The total number of samples is therefore 30x3x4=360.

(2) Sensors
- Sampling rate: 20kHz
- Each csv file has 6 columns of data for a duration of 2 seconds.
  a. 1st column = time (sec)
  b. 2nd column = AE sensor signal
  c. 3rd column = Displacement signal from the actuator
  d. 4th column = Power signal from the controller
  e. 5th column = Sound signal from the microphone
  f. 6th column = Clamping pressure from the pressure regulator

Data analysis and lab report

A Python template is provided to assist you with the data analysis.

(1) Influence of workpiece dimensions.
   i. Use data collected from dataset with “Clean” samples to visualize the influence of workpiece dimensions. Specifically, plot the power signals with the same dimension in one figure. You will need to generate 4 plots for 4 workpiece dimensions. (10 points)
   ii. What differences can you tell from the plots? No quantitative measures are needed. (10 points)

(2) Influence of surface contamination.
   i. Use data collected from dataset with “50mm workpiece” to visualize the influence of surface contamination. Specifically, plot the power signal with the same surface condition in one figure. You will need to generate 3 plots for 3 contamination levels. (10 points)
   ii. What differences can you tell from the plots? No quantitative measures are needed. (10 points)

(3) Frequency analysis.
   i. Perform Fast Fourier Transform (FFT) for all AE and microphone signals. (10 points)
   ii. Record the peak frequency around 20 kHz (f) and the corresponding power value (P). (10 points)
   iii. Calculate the mean and standard deviation of f and P for each combination of workpiece dimension and surface contamination level. You will need to calculate 4 × 3 = 12 numbers for both f and P. (10 points)
   iv. Plot box plots for f and P against the condition combinations. (10 points)

(4) Statistical hypothesis testing.
   i. Using data from “Clean” samples with varied workpiece dimensions, carry out t-test to examine if f and P are significantly different between workpiece dimensions. (10 points)
   ii. Using data from samples produced with the “50mm workpiece” but different sample surface conditions, carry out t-test to examine if f and P are significantly different between sample surface conditions. (10 points)