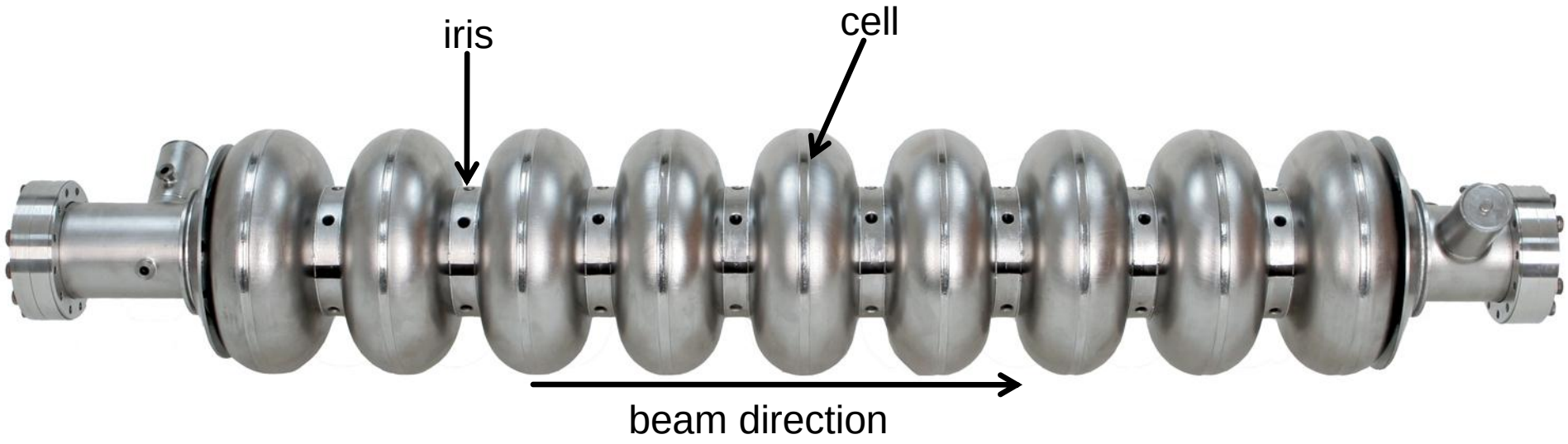
Optical Inspection of SRF Cavity Defects

Jared Sagendorf
Mentors: Matthias Liepe, Nicholas Valles
SRCCS 2010

SRF

A review of SRF

- Superconducting cavities made from purified niobium used to accelerate particles in accelerator machines
- Kept under superfluid helium at 1.8K or less
- RF (Ghz) EM fields build resonantly to produce high fields
- Exceptionally high Q-factors



Q-factor

- Where U = the energy stored in the field
- P_D = The power dissipated through wall losses

$$Q \propto \frac{U}{P_D}$$

Q factor depends on temperature, but values on the order of 5×10^{10} are common

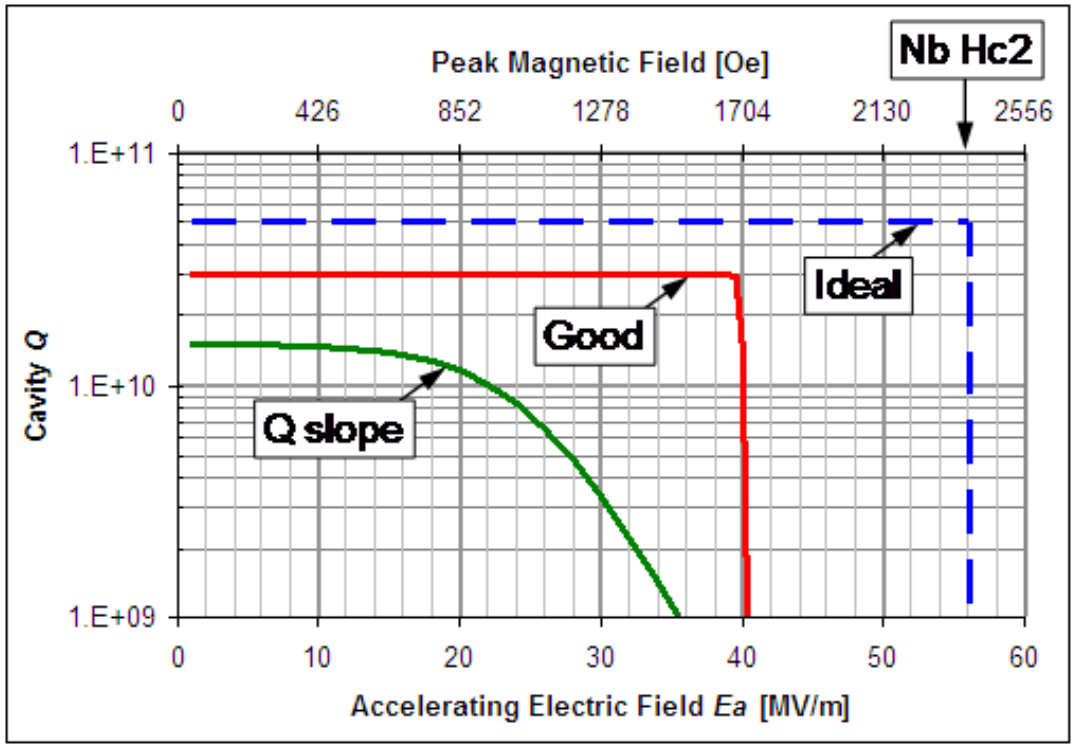
A 1Hz pendulum with a Q factor of this magnitude would swing for 1600 years!

- The higher your Q factor, the more efficient your cavity becomes

Q-slope

- A measure of a cavities performance is given by plotting Q vs. E_{acc}
- Causes of Q-slope are the subject of ongoing research

- Fabrication procedures developed to improve cavity performance:
  - High quality electron beam welding
  - Electropolishing using strong acids
  - High pressure rinsing and assembly in clean room
  - Vacuum bake at 120° for 48 hours

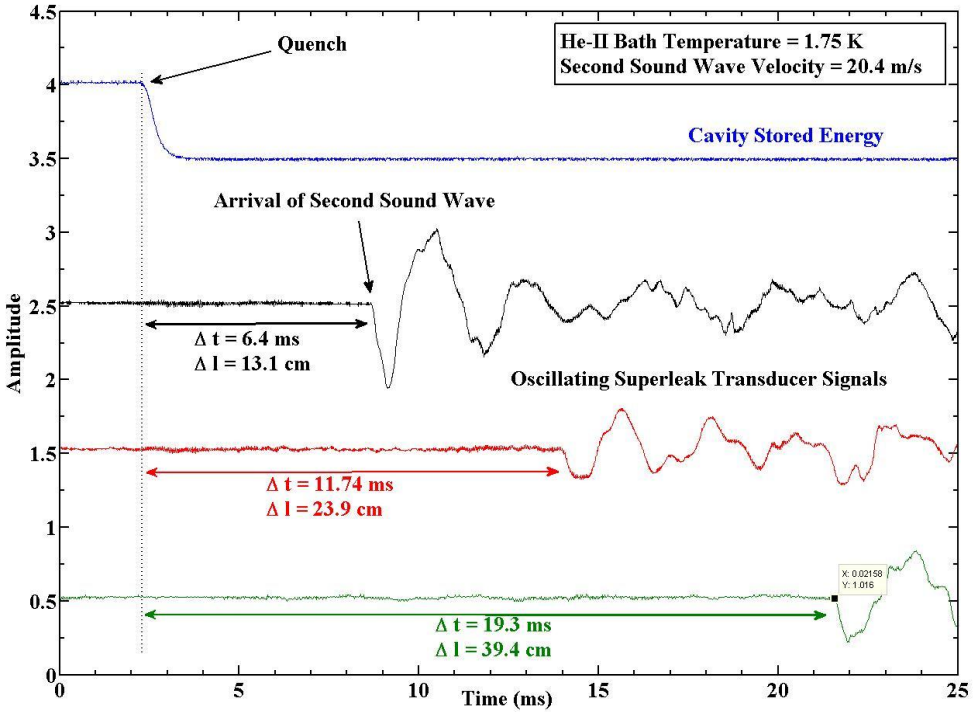


Quenching

- Quenching is the dissipation of energy due to localized heating and can lead to thermal breakdown of superconductivity
- That's bad

- The location of a quench is found using a system of oscillating superleak transducers (OST)

- Quenches are caused by microscopic defects on the surface of the cavity and are one of the major limiting factors of achieving theoretical field limits



Quenching

- Two classes of defects are believed to exist
  - Above the superheating field
    - Defects which cause field enhancements locally which bring the magnetic field above the H_{sh}
    - This causes the region to lose its superconductivity which produces heating and losses
    - These are often visible as pits or bumps in the surface
  - Below the superheating field
    - These are quenches which occur before the H_{sh} is reached
    - The reason for these quenches are unknown
    - Something in the region may be inhibiting superconductivity and producing heating
- Sometimes we find direct correlation between a defect and quench, sometimes we find none. The schools of thought are that defects must be the cause of quenches, or that there is no connection between quenches and surface defects. The truth must lie somewhere in-between…

Quenching

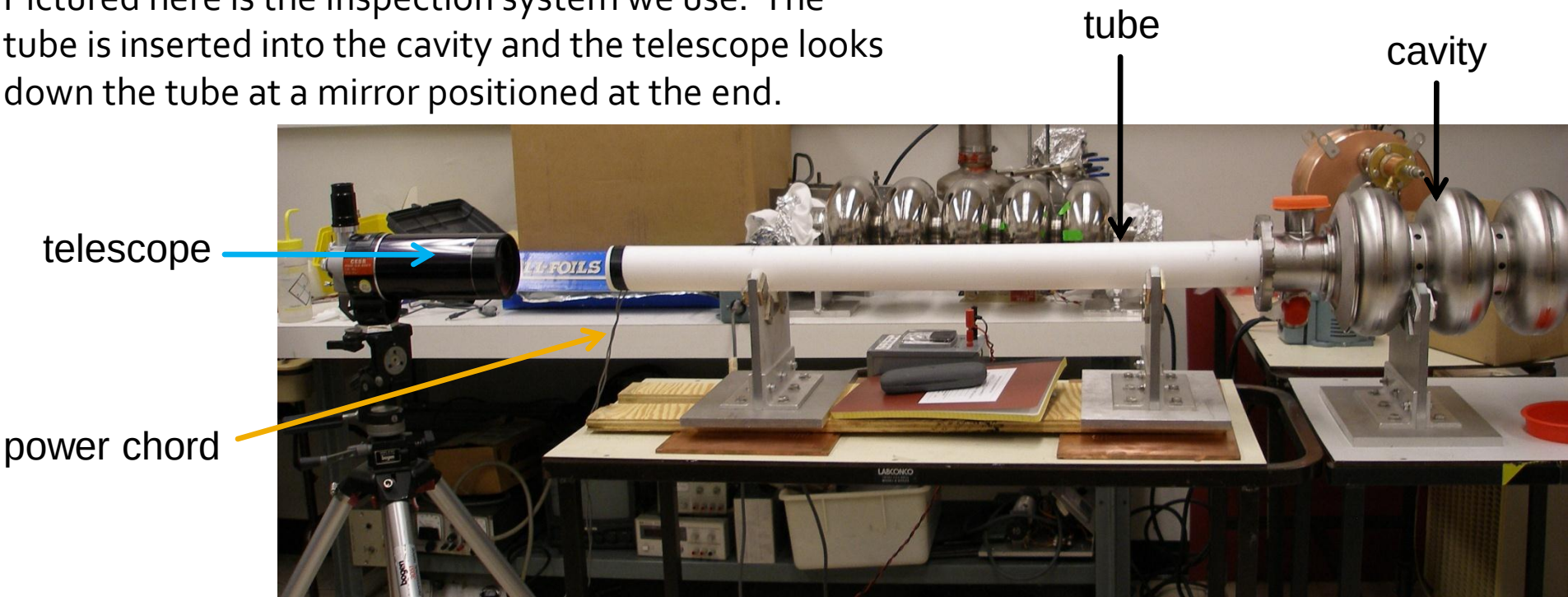
Here there are clearly pits in the cavity surface which correspond to a quench location

Here is an image of quench location with no visible defects

Optical Inspection System

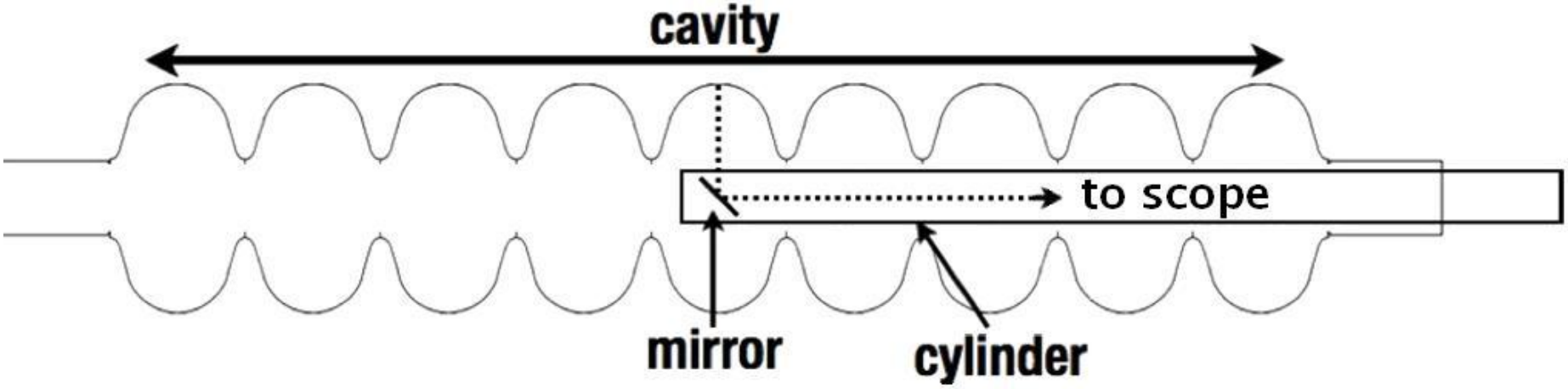
- When a quench location has been identified, we proceed to visually inspect the area where the quench occurred for surface defects

Pictured here is the inspection system we use. The tube is inserted into the cavity and the telescope looks down the tube at a mirror positioned at the end.



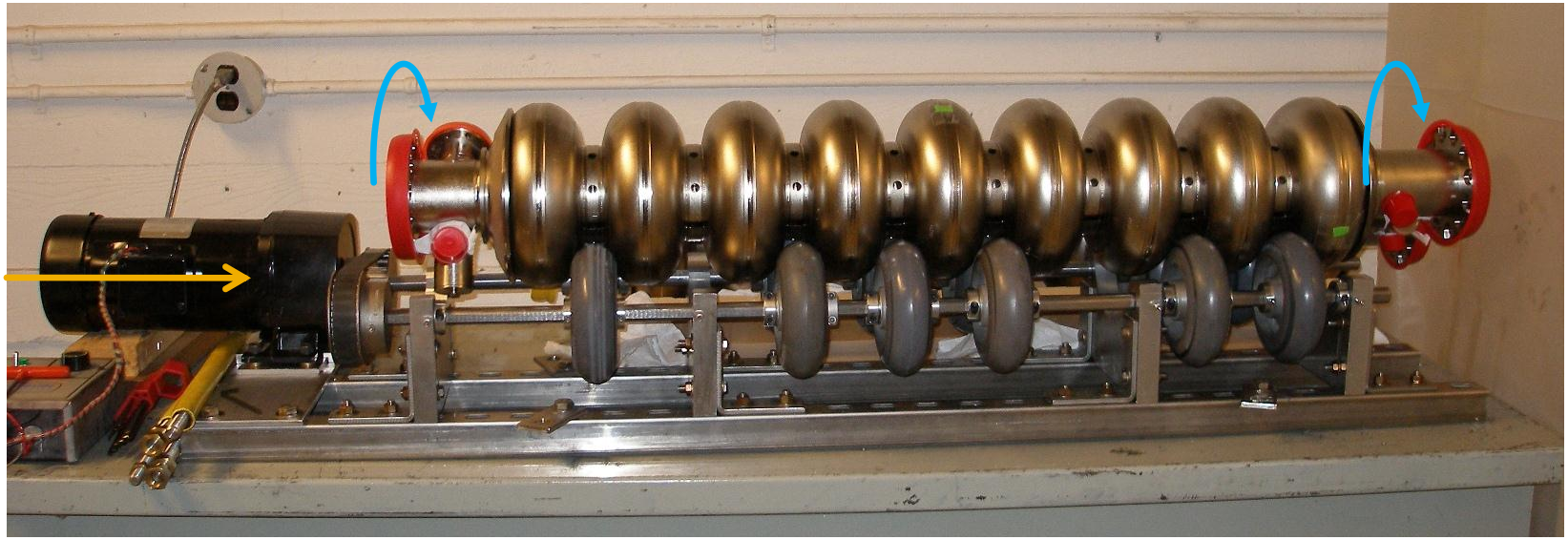
Optical Inspection System

- A light source at the end of the cylinder illuminates the inside of the cavity
- Light reflects off the surface of cavity and into telescope where image is magnified
- A special adapter is fitted to telescope to take photographs
- Focus is maintained at the telescope



Tumbling

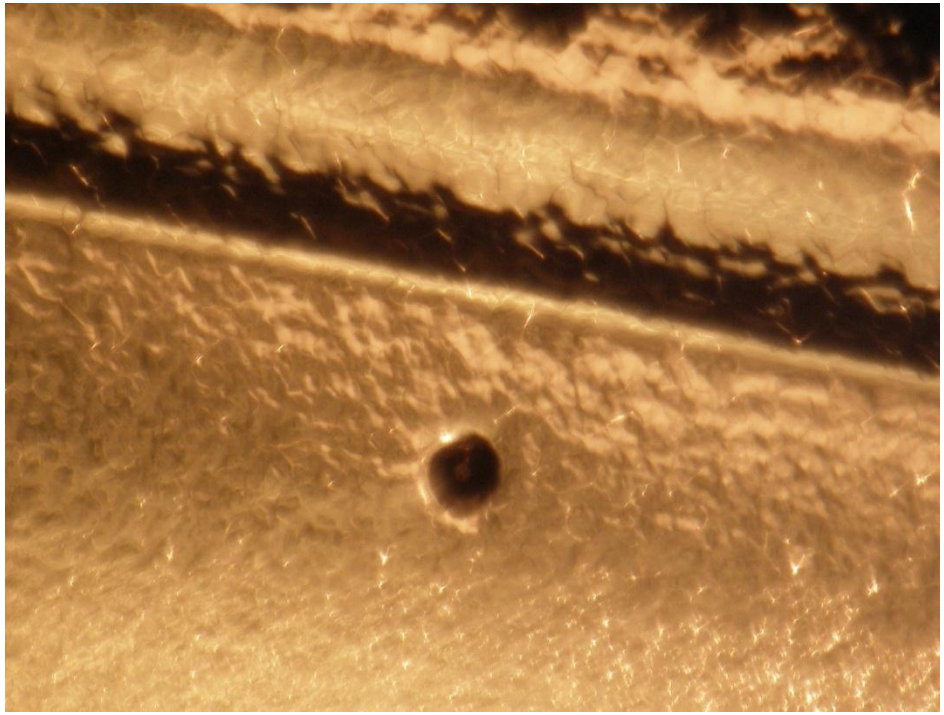
- Defects can be removed by the process of "tumbling"
- The cavity is rotated for several days with ceramic pellets and water in the cell to be repaired



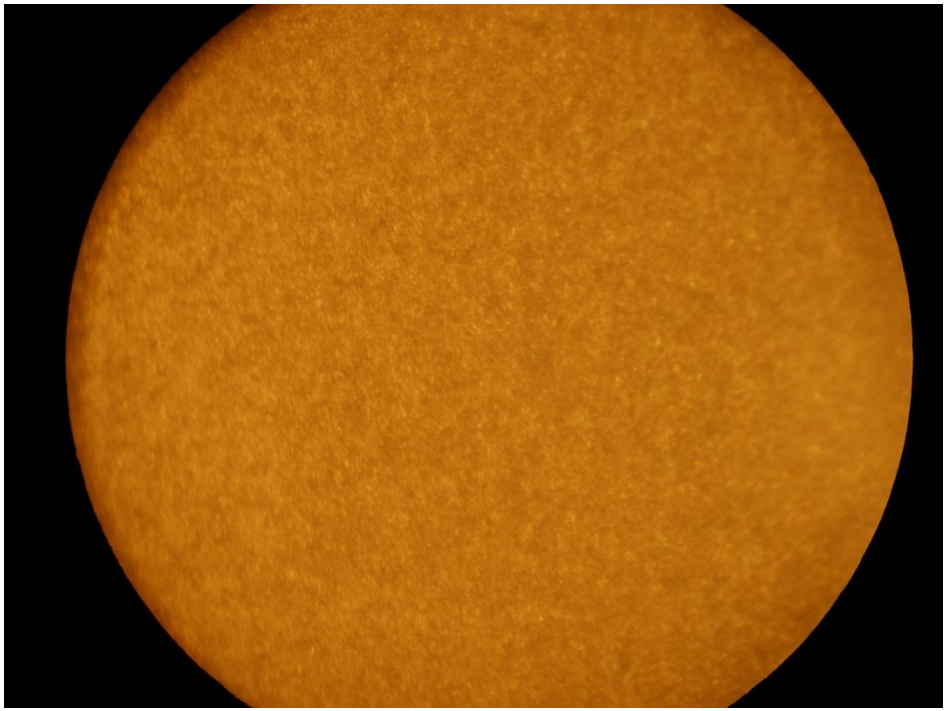
- This process removes roughly 15μm of surface per day polishing the cavity
- After tumbling the cavity is re-inspected to determine if further tumbling is required

Tumbling

Before Tumbling



Same location after 3rd tumble (high magnification)

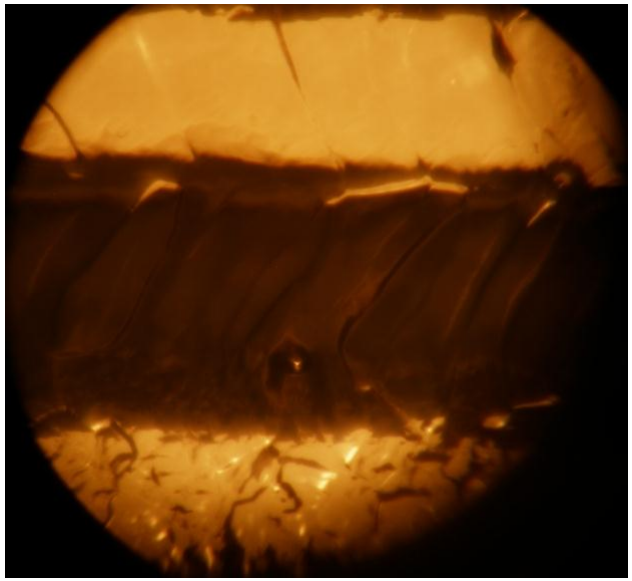


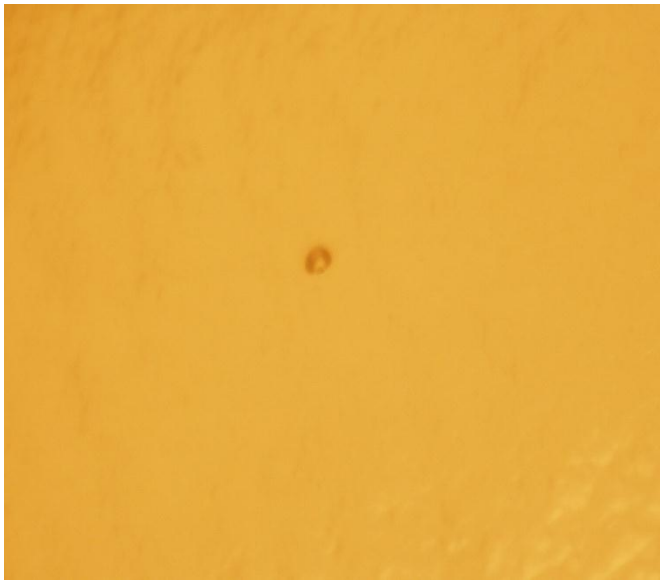
Tumbling can repair defects and eliminate quenches

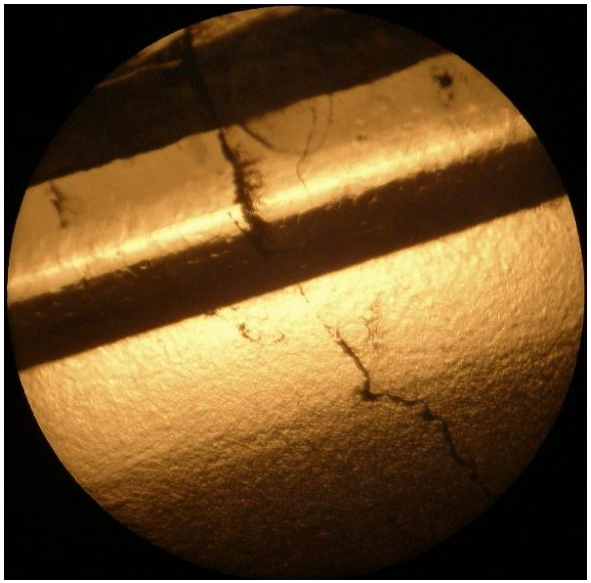
Project Details

Main Goals

- Inspect cavities and identify + photograph surface defects
  - This will be an ongoing part of my project, several photographs I've taken shown below





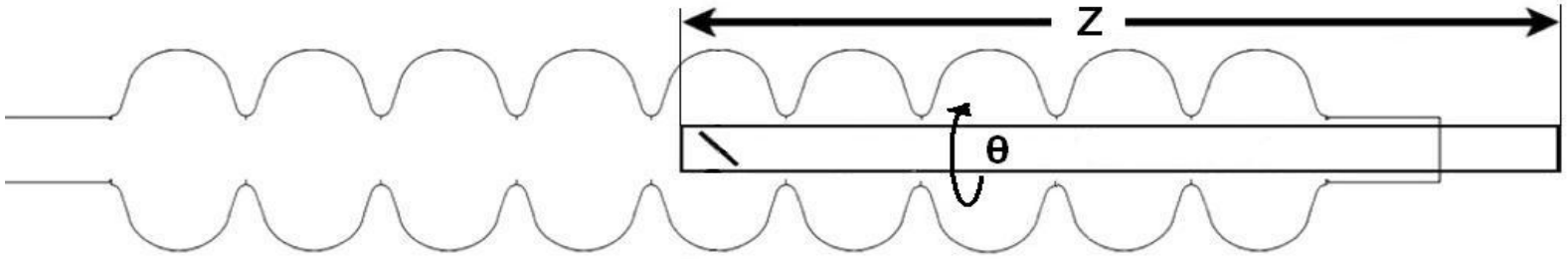


- Using images like these I will identify common characteristics of "bad" defects based on shape, size, location etc…

Project Details

Main Goals (continued)

- Improve the existing inspection system
  - Currently the system has some major limitations, some improvements I plan to make are:
  - Set up a permanent inspection station with mounts for tubing
  - Create a coordinate system to accurately record the position of defects and quickly locate known defects for further examination
  - Re-design mirror and light source housing to allow mirror tilt to be adjusted & easier access to change light bulb



A polar coordinate system to measure distance into the cavity along the horizontal axis and the angle at we are rotated from a reference point

Project Details

Main Goals (continued)

- Implement a data storage system to organize cavity data
  - Build a database to store information about individual cavities, especially defect data including:
    - Location
    - Size
    - Date imaged
  - This will be implemented in Access and include SQL queries
- Map the defect locations and quench locations
  - Using a matlab program, we will take the measured location of defects and plot them against quench locations obtained from OST data to see visually the correlation on the surface of the cavity