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## ABSTRACT

High field pulsed magnets at the NHMFL use high strength conductors near their ultimate tensile strength. So stringent quality assurance of these conductors is critically important.

Here we present results of our nondestructive testing (NDT) of Glidcop AL-60 wires using Eddy current testing, ultrasonic testing and x-ray tomography (2D and 3D) methods. The advantages and disadvantages of each method are compared. We have successfully developed the capability for a long length eddy current wire inspection.

## EXPERIMENTAL

### 1. X-ray at Delphi Precision Imaging Inc.

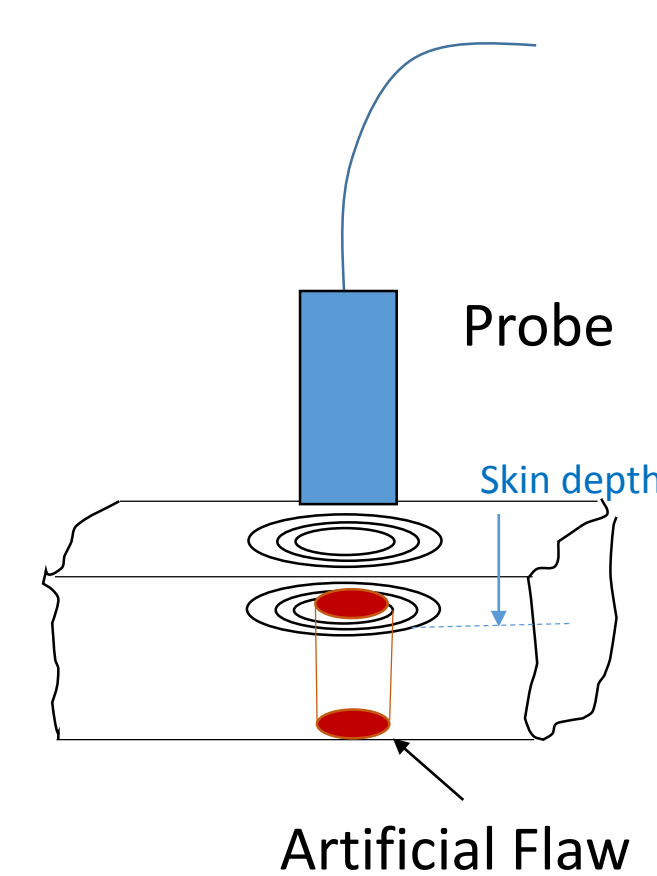


#### North Star X-5000 system

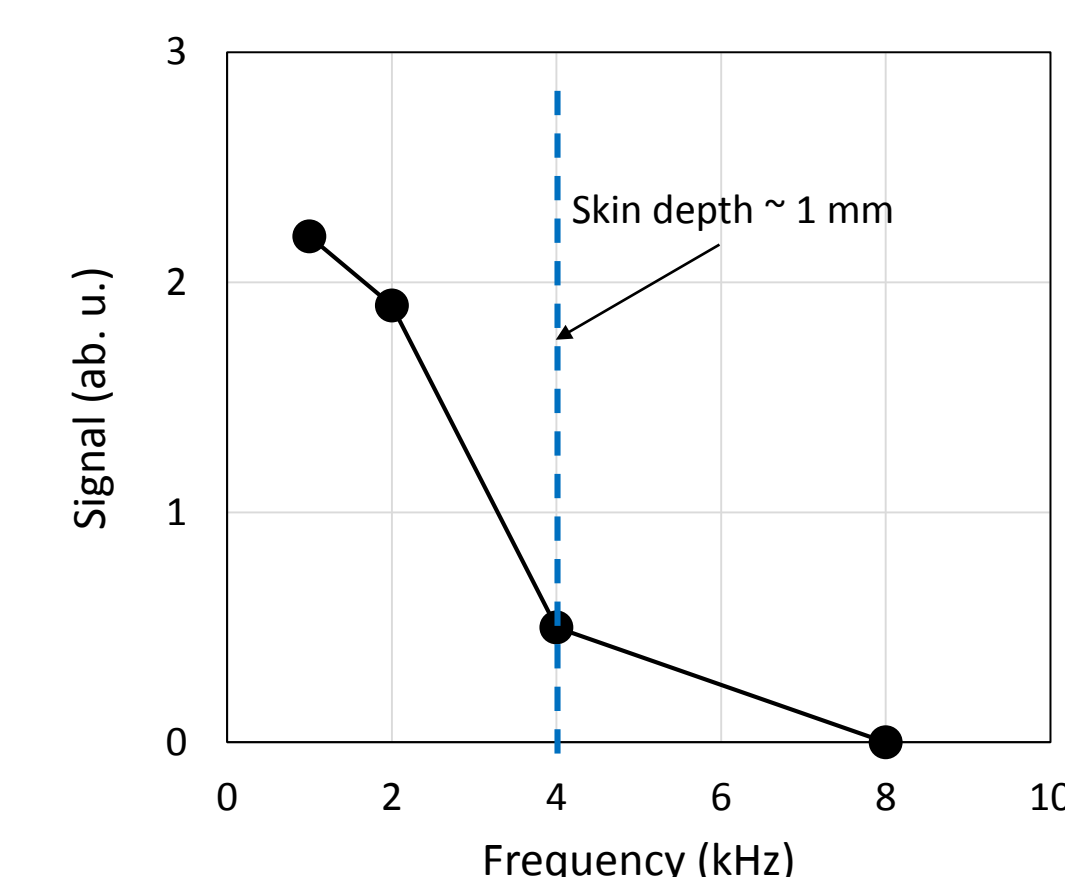
- 225 kV microfocus tube.
- 16"x16", 200 μm pixel detector.
- Resolution 13 – 28 μm.
- Both 2D and 3D (CT) scans.

Sample stage

### 2. Eddy current at NHMFL

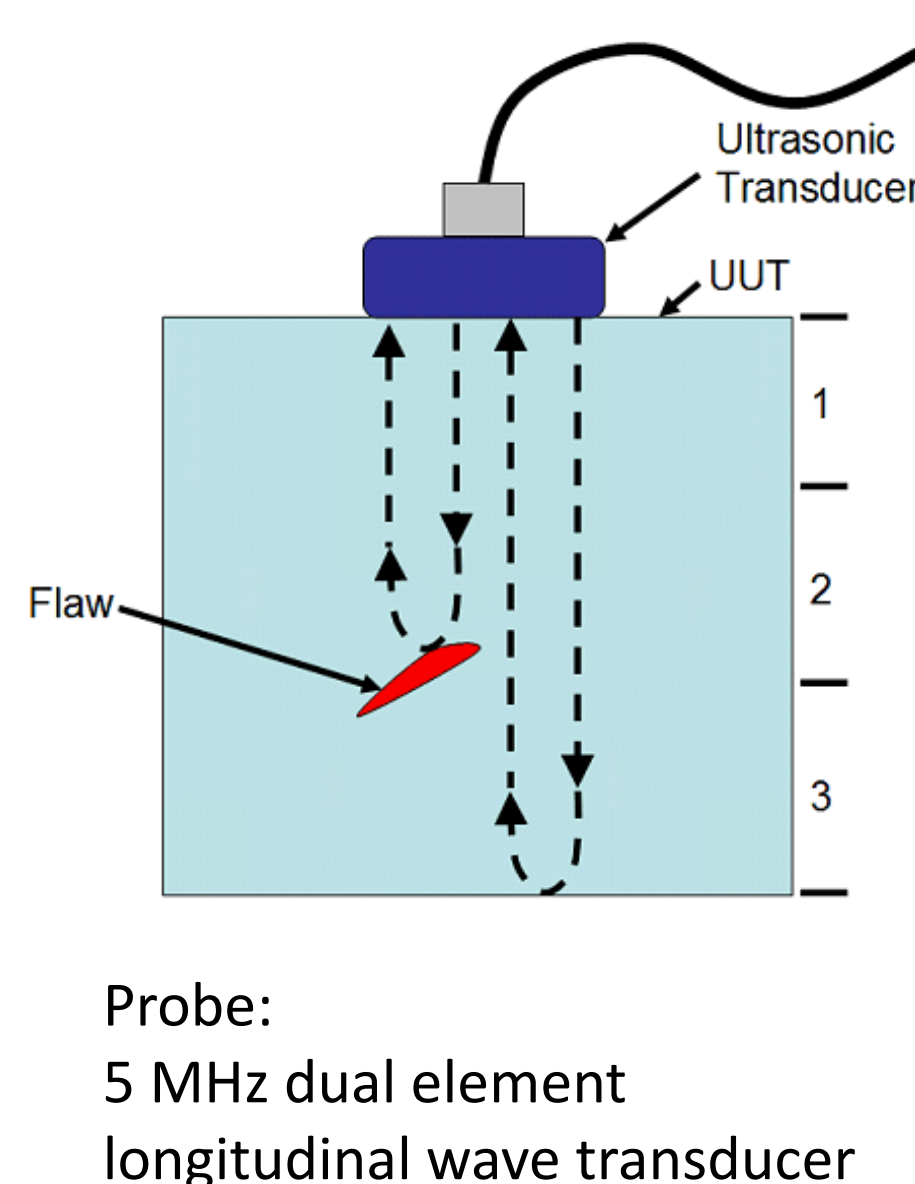
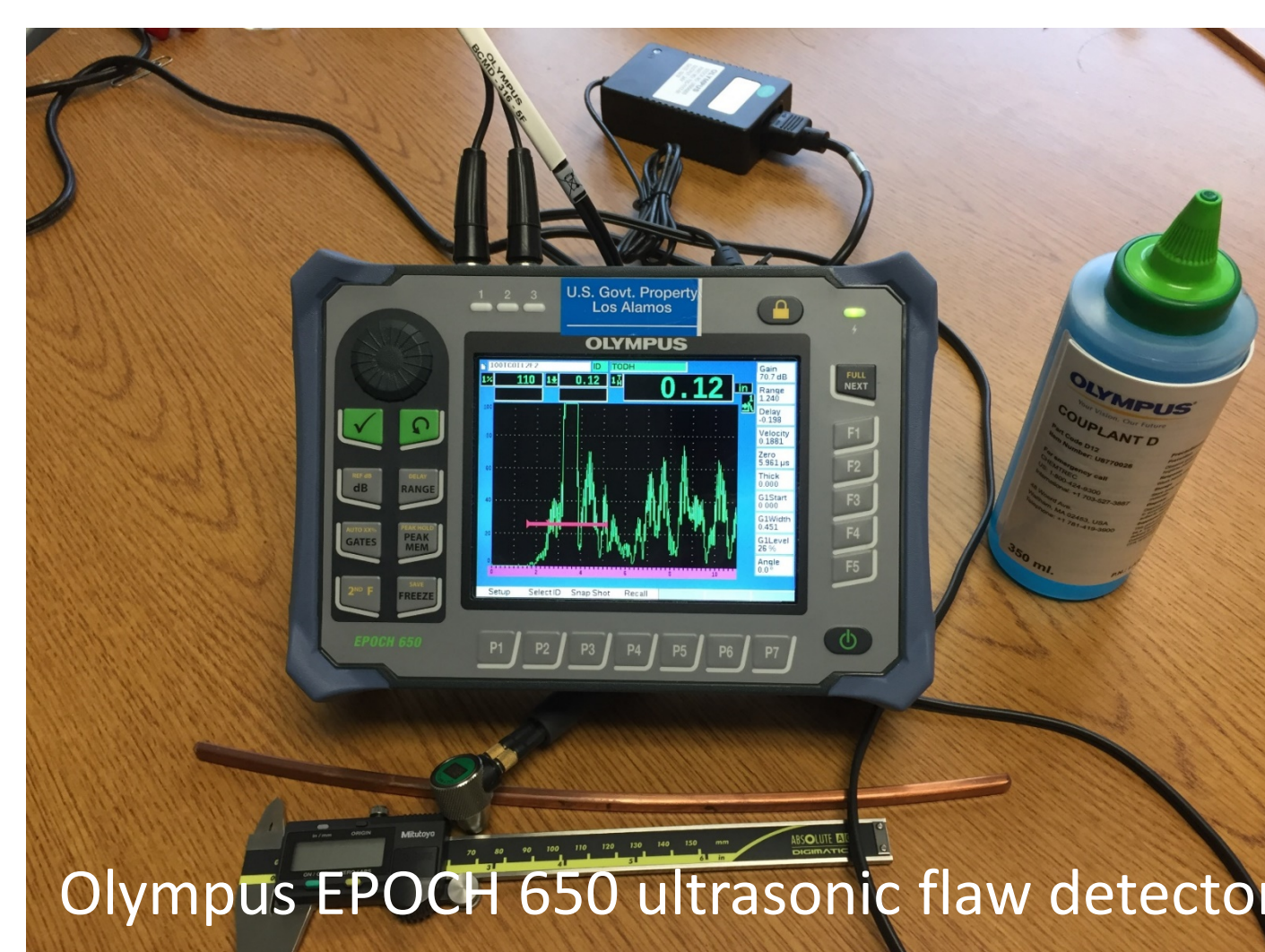


Probes:  
 500 Hz – 40 kHz internal  
 50 kHz - 100 kHz surface  
 100 kHz – 500 kHz encircle surface

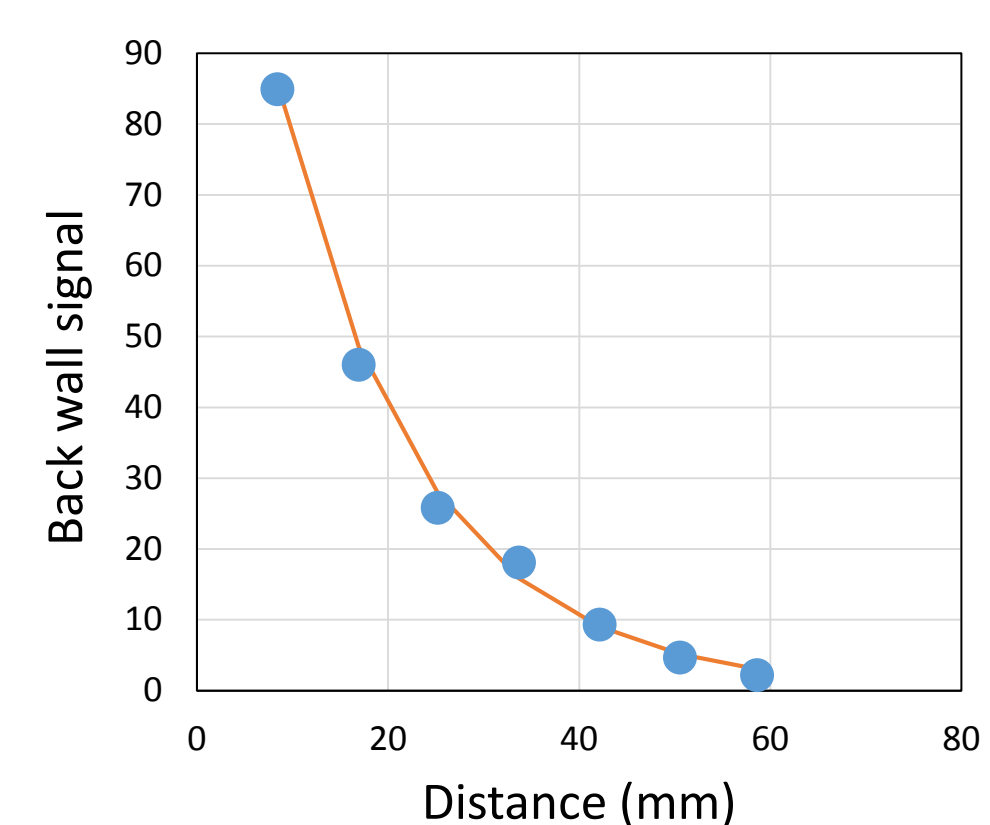


Frequency response of a hole 1 mm from surface. Skin effect prevents detection of deep defects.

### 3. Ultrasonic at NHMFL



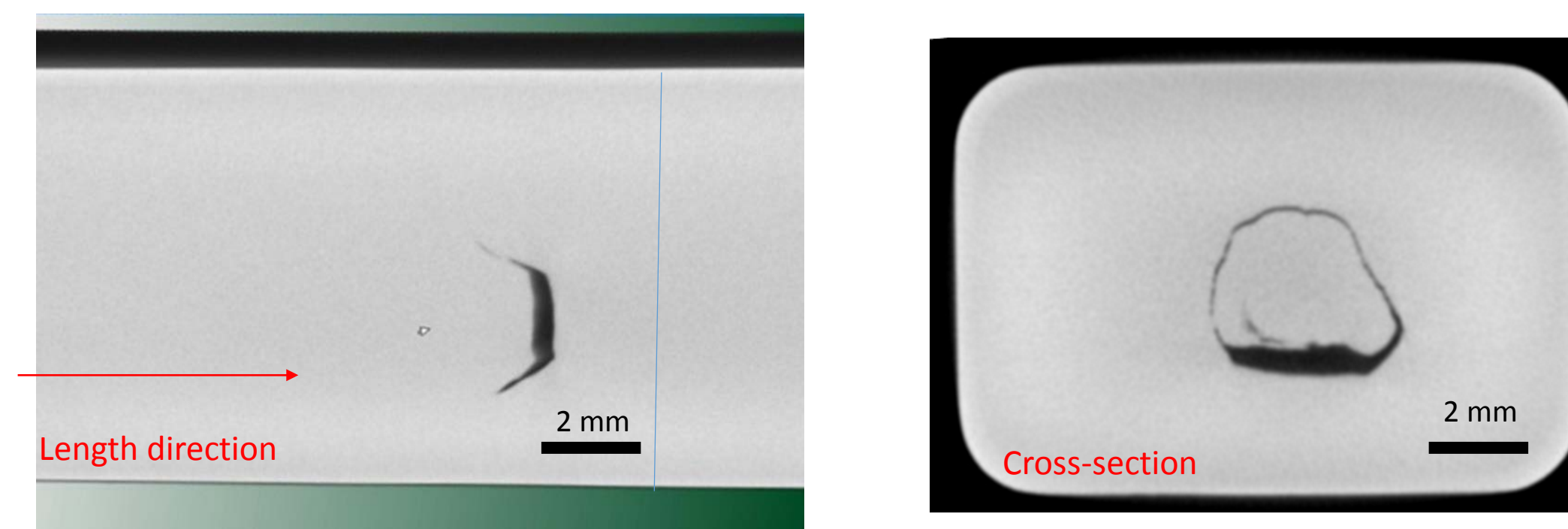
Probe:  
 5 MHz dual element longitudinal wave transducer



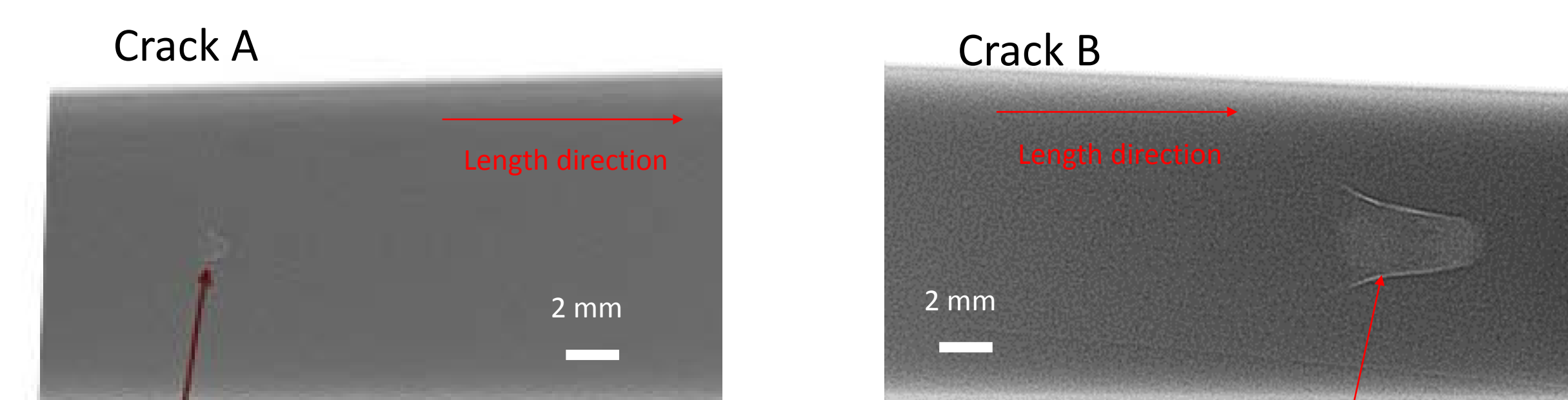
Ultrasonic attenuation limits the detection sensitivity. Characteristic attenuation length is ~ 14 mm.

### A. Internal chevron cracks

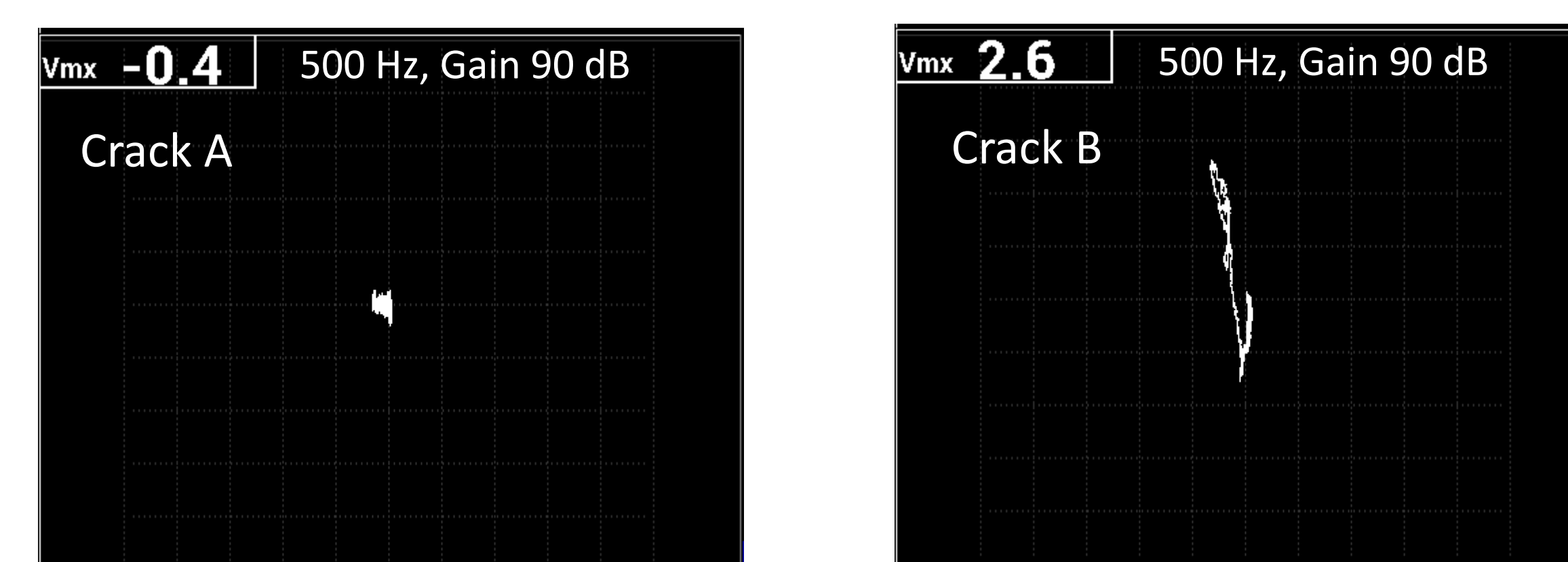
Central bursts or 'chevron' cracks occur in cold drawn wire when lubrication is inadequate, or the drawing die geometry is not optimized. They cannot be seen by visual inspection. We found chevron cracks in Glidcop AL60 wires.



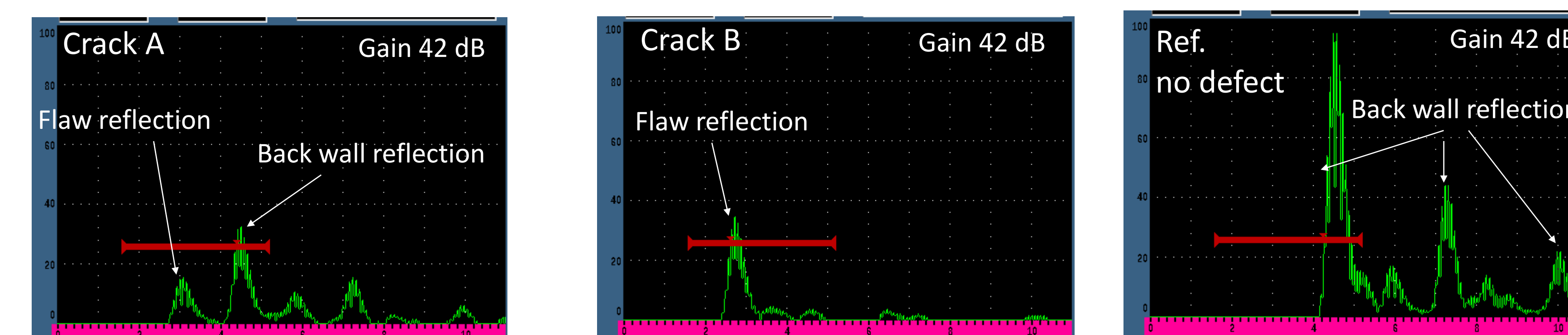
**X-ray CT scan:** a chevron crack in a 12.3 x 8.4 mm² AL60 wire



**X-ray 2D scan** also revealed a small crack (A) and large crack (B).

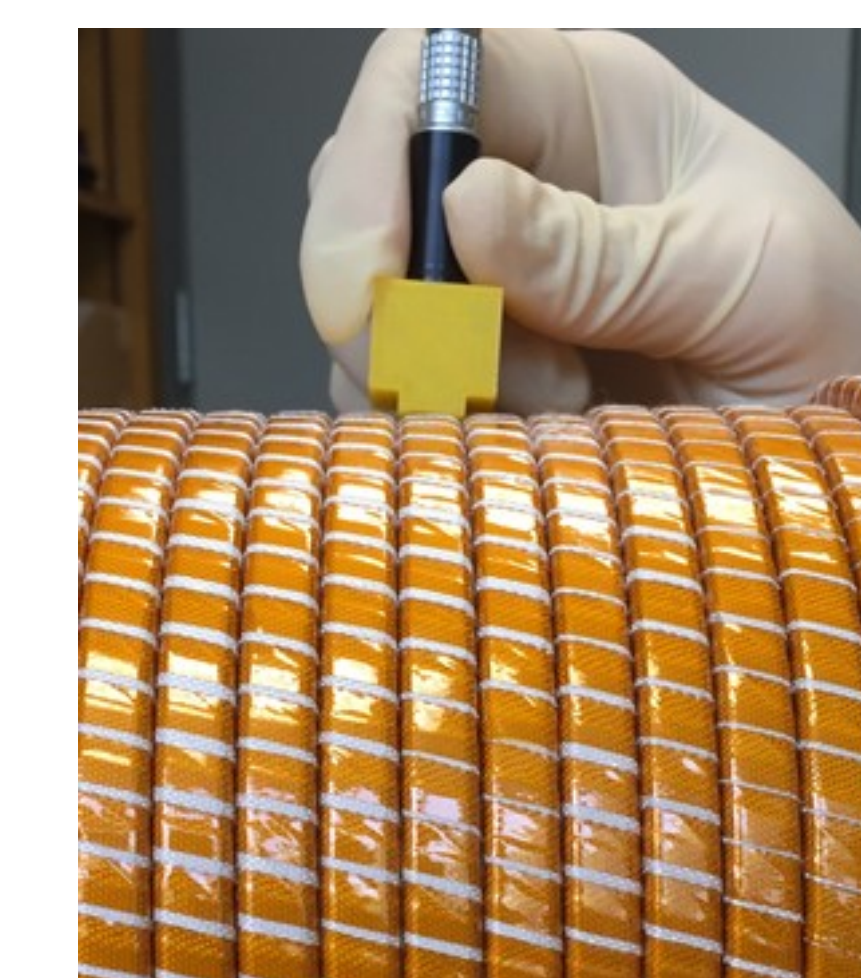


**Eddy current:** at  $f_{min}$  of 500 Hz (skin depth ~ 3 mm), only the large crack B was detected.

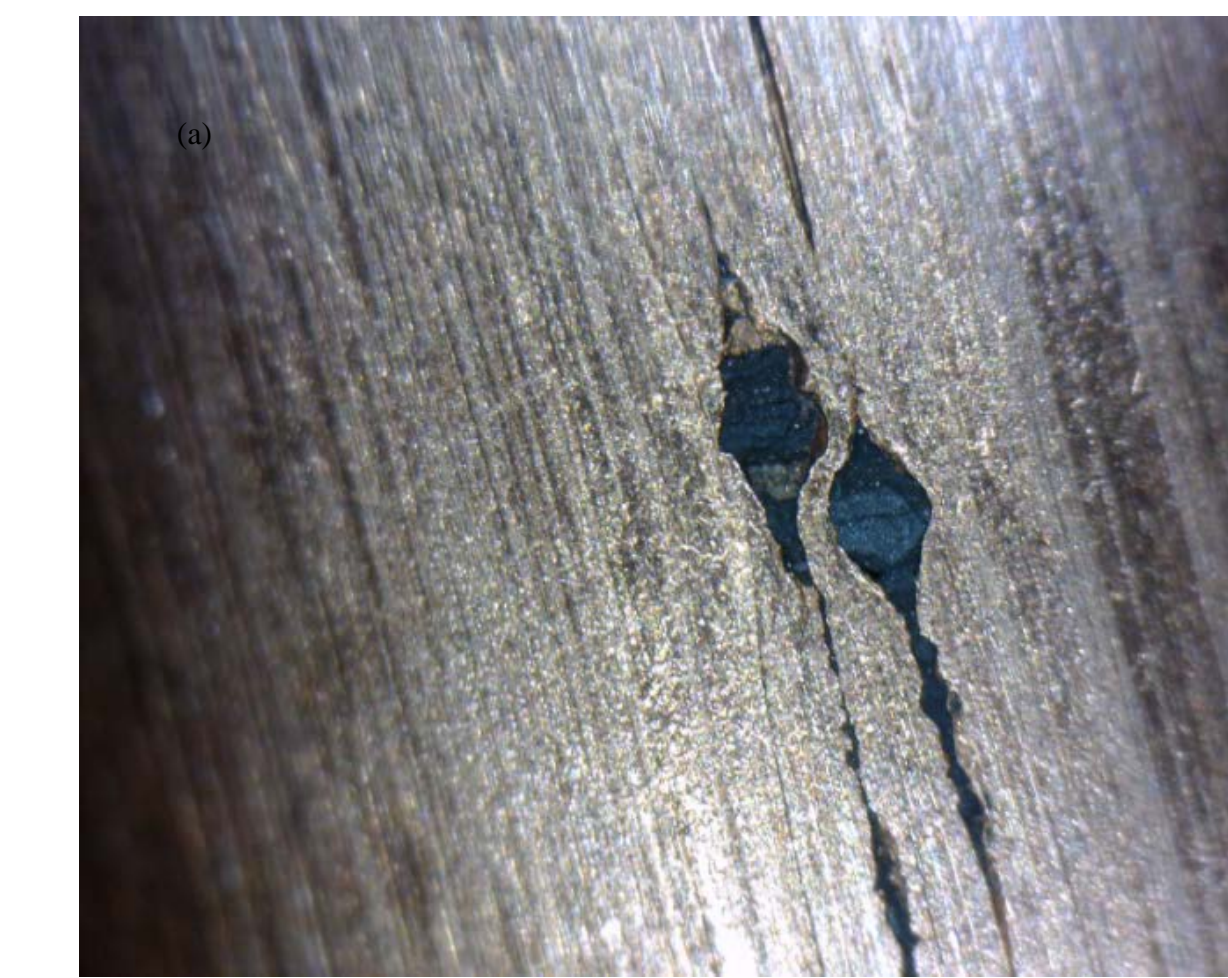


**Ultrasonic:** detected both defects by reflection signal as well reduction in back wall reflections

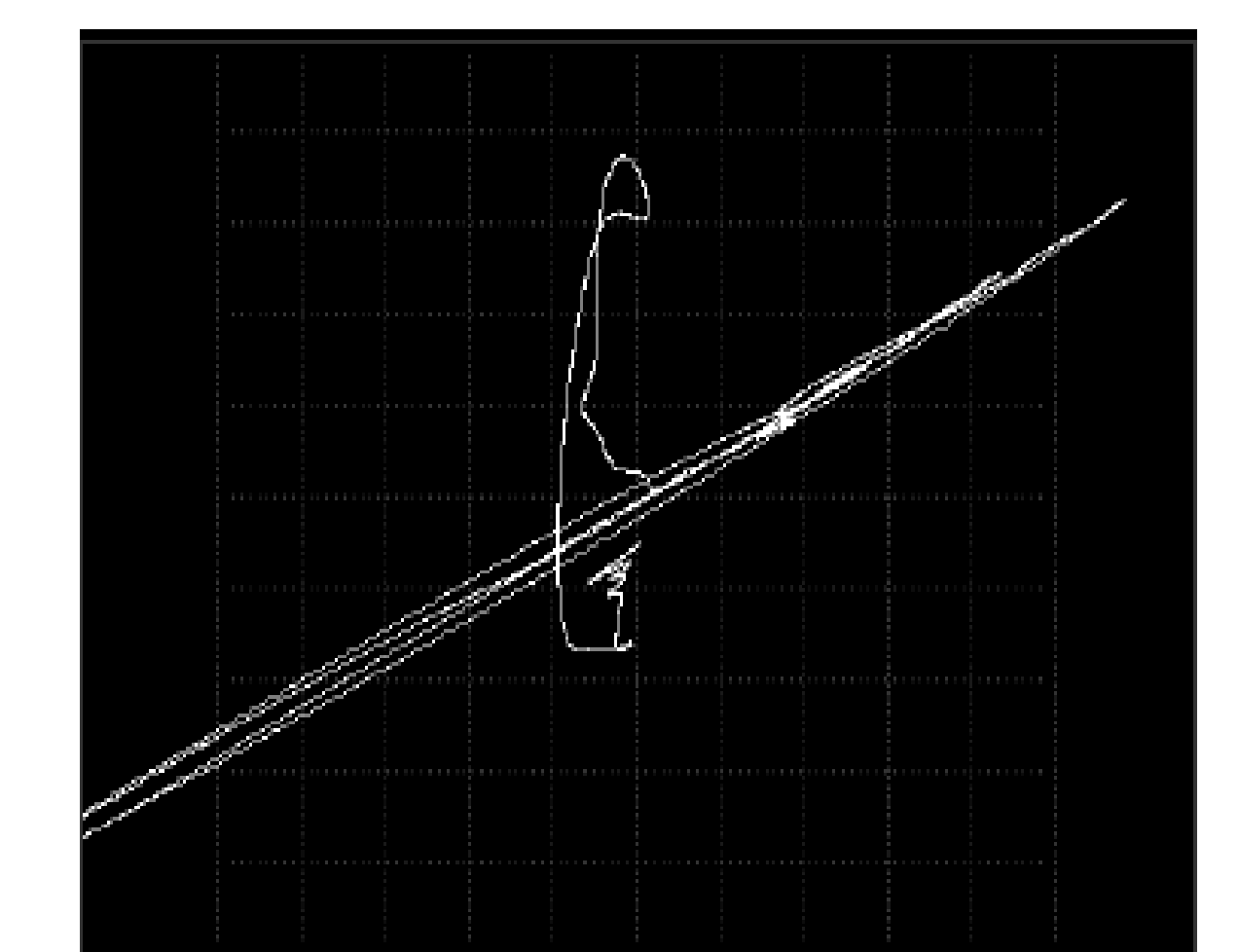
### B. Surface cracks and inclusions



Eddy current inspection during winding of insulated conductor

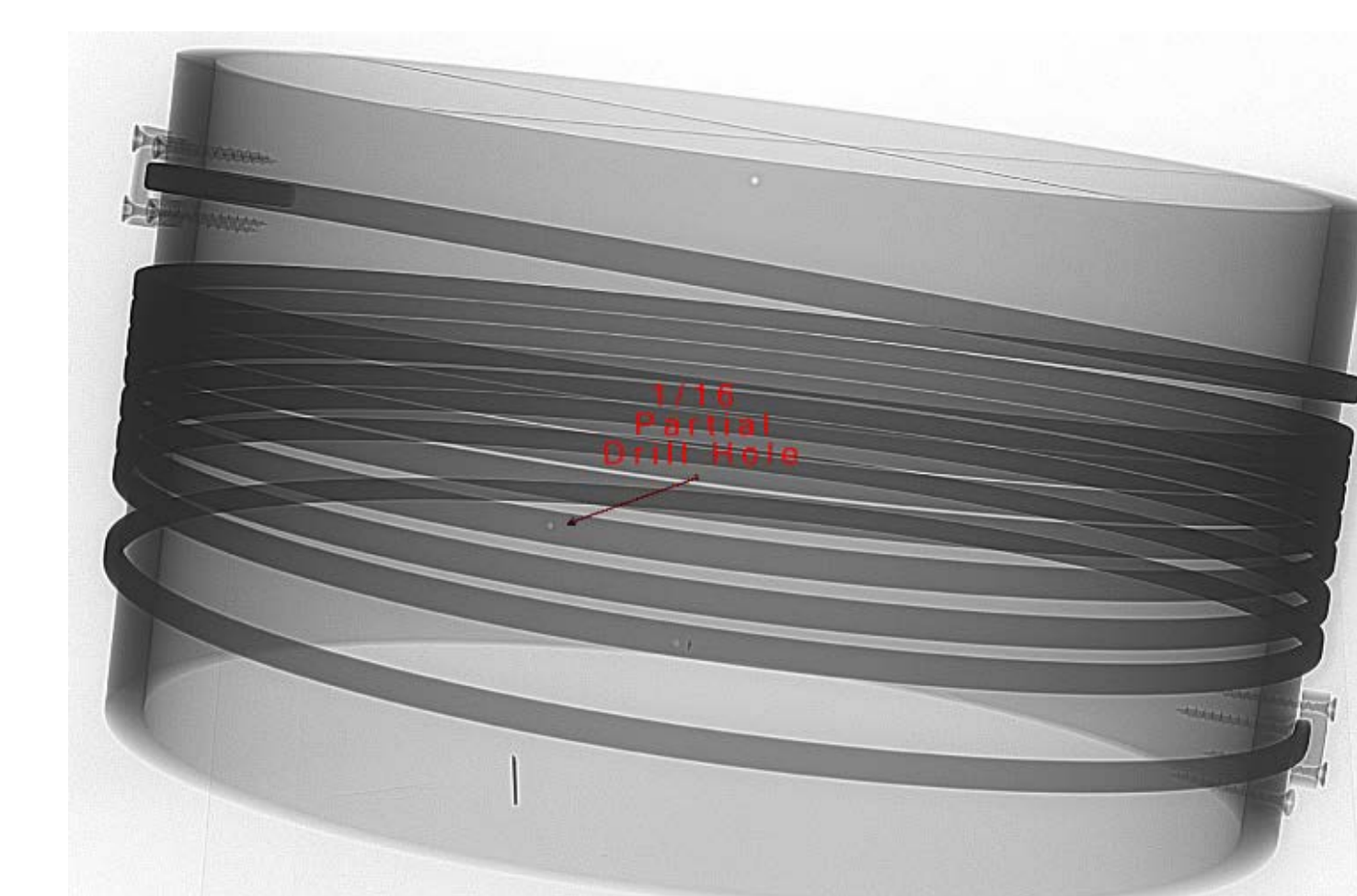


Ferromagnetic surface inclusions



Eddy current signal from surface inclusions

### C. Long length inspections



Pilot project: X-ray 2D scan of a coil of a few meters long AL60.



Long length eddy current testing capability for AL60 wires and precursors are developed. This picture shows surface inspection of 0.54" diameter long-length AL60 precursor wire has been developed.

## SUMMARY

We have been developing NDT methods for quality assurance of high strength conductors for pulsed magnets. Eddy current, ultrasonic and x-ray (2D and 3D) inspection were used on Glidcop AL-60 wires. Chevron cracks were found in Glidcop AL60 wires by all three NDT methods. In addition, surface inclusions were found on finished wires as well as on an AL60 precursor. We have developed a long length eddy current wire inspection capability.

## ACKNOWLEDGEMENT

We thank Mr. Daniel Bone of Delphi Precision Imaging Inc. for performing x-ray 2D and CT scans on our conductors. Thanks also go to Mr. William (Chuck) Edie of Olympus NDT for carrying out some experiments with eddy current inspection. Mr. Justin Deterding and Mr. Donald Richardson of the NHMFL are acknowledged for assistance in eddy current inspections of long wires. This work was supported by the U.S. National Science Foundation under Grant No. DMR-1644779 and the State of Florida.