Lab 9 – Introduction to NDE

Section 5, Group 5
Ethan Pickard, Isaac Pollard, Joseph Spewock, Lucas Tavares
11/28/2023

Introduction

The aerospace industry has become intertwined with the field of nondestructive evaluation in the past few years as safety requirements have been increased. Since this is the case, evaluating the safety of these complex parts has also become more complex. Thus, it is helpful for engineers to have exposure to the basics of the field of nondestructive evaluation. In this lab we go over three basic techniques that are used in the field of NDE, they are ultrasound, eddy current, and tap testing. In the ultrasonic section we attempt to find a circular flaw in a specimen that is submerged in water. For tap testing we are trying to see the differences in known defects while comparing the type of core they are mode out of. For the eddy current section of testing, we are testing to see the curves that are given for different metals and trying to get responses for small "cuts" in a plate.

Objective

The objective of this lab is to gain basic hands-on experience using multiple common types of NDE and to understand the theory behind why the techniques work to find the experimental flaws that were recorded in lab.

Hypothesis

We believe that throughout this lab we will produce the expected correlations, but that some of our data may be slightly off. This is likely due to minor errors caused by inexperience with the instruments and taking of measurements.

Variables

Table 1. List of variables

Symbol	Definition	Unit
f	frequency	kHz

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gain	gain	dB
T	thickness	millimeter
phase	Phase angle	degrees
D	Distance	inches
V	velocity	Cm/μsecond
Δt	Time of flight	seconds

Work assignments

For the in-lab parts of this lab we divided the work up equally between the four of us, we all did the UT simulation together. For the tap testing part of this lab Isaac contributed the most. When we did the eddy current lab, we brainstormed together what would be the best approach to get the best readings and Joseph took most of the readings. For the submerged ultrasound lab we all contributed very equally as there was a need to calculate flight distances, measure the flaw size, and use the oscilloscope.

For the lab report, Isaac did the methodology, procedure and apparatus section of the report. Joseph did the introduction, objective, hypothesis, list of variables, and data section of the lab report. Ethan contributed most to the analysis and Isaac, Lucas, and Joseph contributed final touches and formatting.

Methodology, Procedure, and Apparatus

Eddy current

For the eddy current evaluation, we were tasked with three different procedures, the first test involved analyzing an aluminum specimen to find cracks, starting from either face of the specimen. The second test used a slightly altered specimen, which was used to analyze cracks of larger thickness. The third consisted of using the eddy current apparatus to differentiate various metal specimens from each other given their varying conductivity.

The aluminum specimen, labelled BK1 was a thin rectangular bar which had cut into it three different thin slots of 2, 1.5, and 1 mm depth respectively. These slots were designed to mimic cracks in the specimen. The goal was to find these cracks using the eddy current toolkit provided. The toolkit consisted of the EC module attached to the current generating tip. This system was then attached to a laptop loaded with the required software to interpret and interface the various data being received. To ensure accurate test results, we began by performing a lift off calibration by first zeroing the graph and then adjusting the frequency and gain of the system appropriately using the laptop software, until we were able to record a reasonable image on the graph. This calibration took some time for our group, as it seemed the given frequency was not outputting readable results.

The actual test simply involved beginning a new recording on the system, sliding the EC tip along the specimen over a single crack, pausing, then restarting the recording and repeating the process until all three cracks were covered. The same procedure was used, except performed on the opposite side of the BK1 specimen. For this test, adjustments to the frequency were more substantial, as well as some shift of the gain being required. We consider this to be due to the permeation distance of the eddy currents having to be much further to record data deeper into the BK1 specimen. Test two involved specimen BK2, which had wider crack lengths with depths of 2, 1.6, 1.2 and .8 mm.

For the differentiation testing, we were given several samples of metal (Iron, Gold, Bronze, Copper, Ns, Ms, Aluminum) with the goal of graphing each samples response to EC. After re balancing the graph to zero while holding the EC tip in air, the procedure was to simply move the EC down onto each sample disk, contacting, then raising it and doing the same with the next sample. The test also included an aluminum sample similar to BK1, which had a very similar curve reported with it.

Tap Testing

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Tap testing involved using the acoustics of various voids and deformities to locate and classify various issues in a specimen. The materials for this test also included a computer, which was loaded with software which would translate tapping from the test onto a grid specified in size by the user and report the response via a color-coded data square. This data would be mapped in 3D by the software using the acoustic response to plot gradients of the varying depths of each defect. The other equipment was the tapping pen itself and a sample board which had specific deformity types labelled and spread across the board. We had four sections of the board which needed to be tested which included different sized honeycomb cores. With this board was a transparent grid sheet with .25” spacing, which could be used to quantify the grid maps of each tap test for the computer. The test began by allotting a matrix of squares around one of the four sets of defects, fully enclosing them, and tapping the grid squares with the pen to get a response. These individual grids can be later stitched together visually to form an entire map of the sample board.

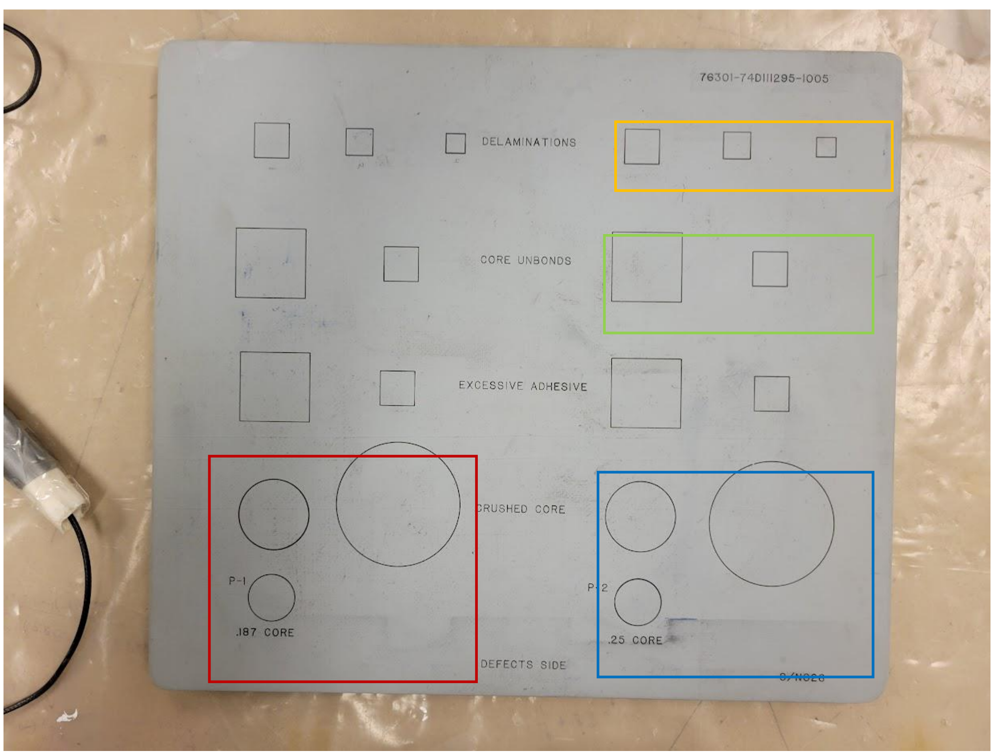

Figure 1. Sample board with marked testing areas. Red – Bottom Left, Yellow – Top Right, Green – Middle Right, Blue – Bottom Right

Ultrasonic

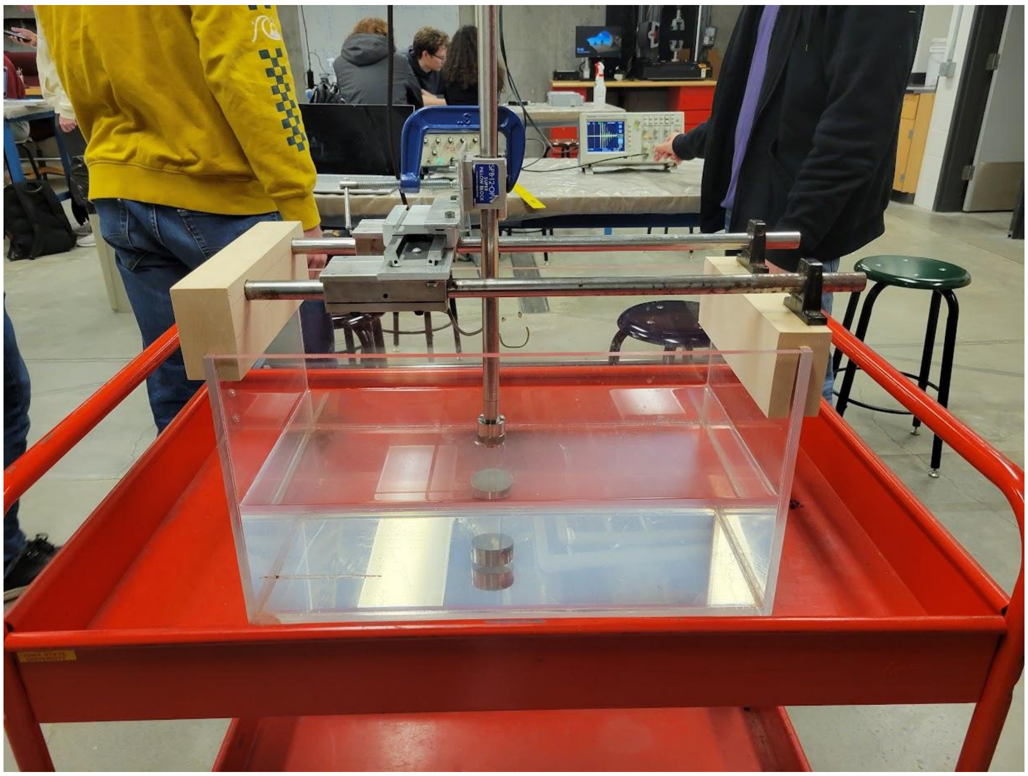

Figure 2. Photograph showing the ultrasound probe submerged in a tank

The example used for ultrasonic testing was to attempt to find a crack near the underside of a metal disk. The test involved a standard UT immersion setup which consisted of a specimen inside a large body of water, on top of which would rest the ultrasonic scanner, whose operating end was fully submerged inside the water and placed around 4.5” from the specimen. The UT device translates electric pulses into UT pulses which transmitted through the medium of water into the specimen. Since each medium has a different sound speed and path, this can be used to analyze the defects inside a specimen.

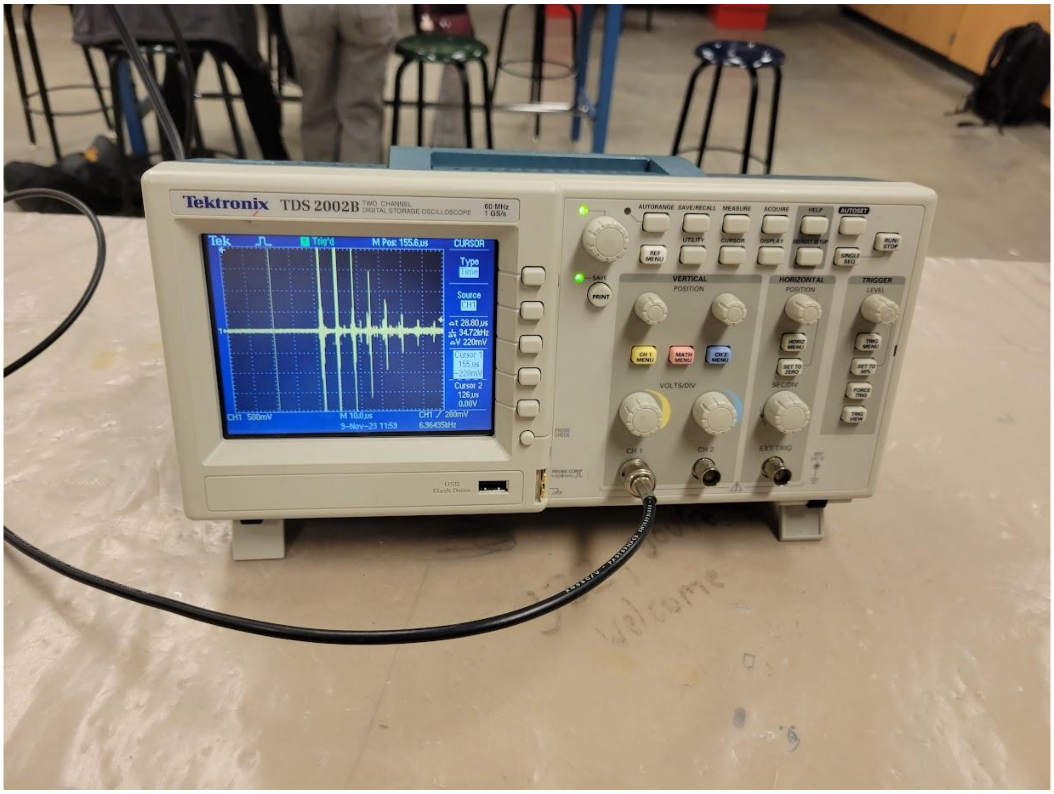

Figure 3. Oscilloscope reading for UT portion of lab

The scanner is hooked up to an oscilloscope which reads the pulses and echoes from the UT transmitter, the echoes are the reflections of each pulse against each varying medium. Each pulse and corresponding can be viewed on the oscilloscope as a wave of diminishing intensity. The process of finding defects with this method is to locate the pulse reflection for the front and back end of the specimen respectively, then analyzing the space between these echoes for another echo which represents the reflection of the pulse hitting the defect. This involves correctly setting up the graph of the scope as well as using the time of flight and travel distances to shift and zoom the graph into the correct area to find the defect echo. This is initially and primarily done using the relation D = .5*V*Delta_t to find the time between each reflection and adjusting the graph accordingly. Once the front and back-end echoes are determined, to find the defect, the UT module had to be translated across the disk specimen until the echo of the defect appeared on the calibrated scope.

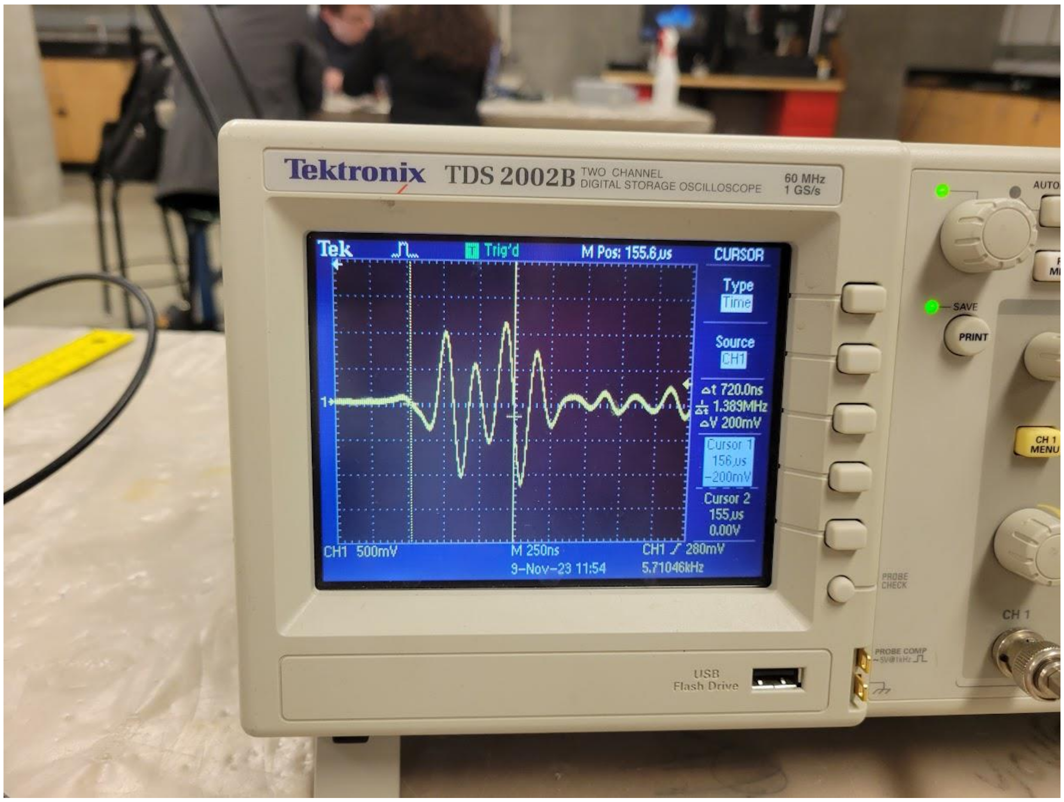

Figure 4. Oscilloscope reading of defect found

UT simulation

The UT simulation involved a virtual test using the same system as the ultrasonic system. This test, however, is done entirely by computer and is used to show the process involved in ultrasonic testing as well as many of the parameters involved. The software used is called UT S/N Sim, developed at ISU, it includes the most up-to-date methods for UT testing. The test involves finding FBH (Flat bottom hole) defects present at 2.5 and 3.5 cm depth inside a virtual Nickel block. The goal of the test also required that a signal-to-noise ratio of 4.5 be maintained for clarity. This ratio is determined as the ratio between the peak amplitudes of the defect signal versus the grain noise. The process for achieving this test involved the correct setting up of the experiment parameters in the software. Starting by setting the material type, material grain size, defect type and defect size as well as setting the inspection mode to longitudinal. Over several tests, we were to adjust the following settings to achieve good test results: Transducer type (circular, elliptical, rectangular (focused, unfocused)), transducer diameter, focal length, center frequency and bandwidth. All other parameters are to be kept the same. The focal length is the distance between the transducer and point at which the energy reaches a point. The center frequency would be the median frequency of the range specified. Bandwidth is the range of frequencies.

Data

Tap Testing

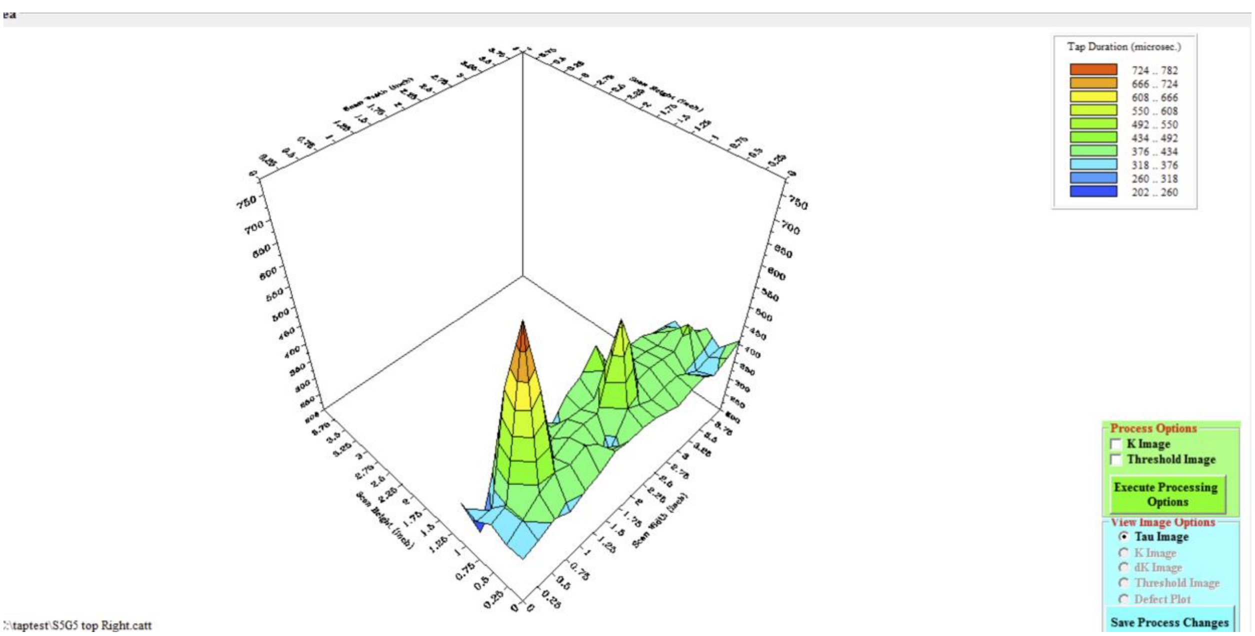

Figure 5. Processed data from Top right

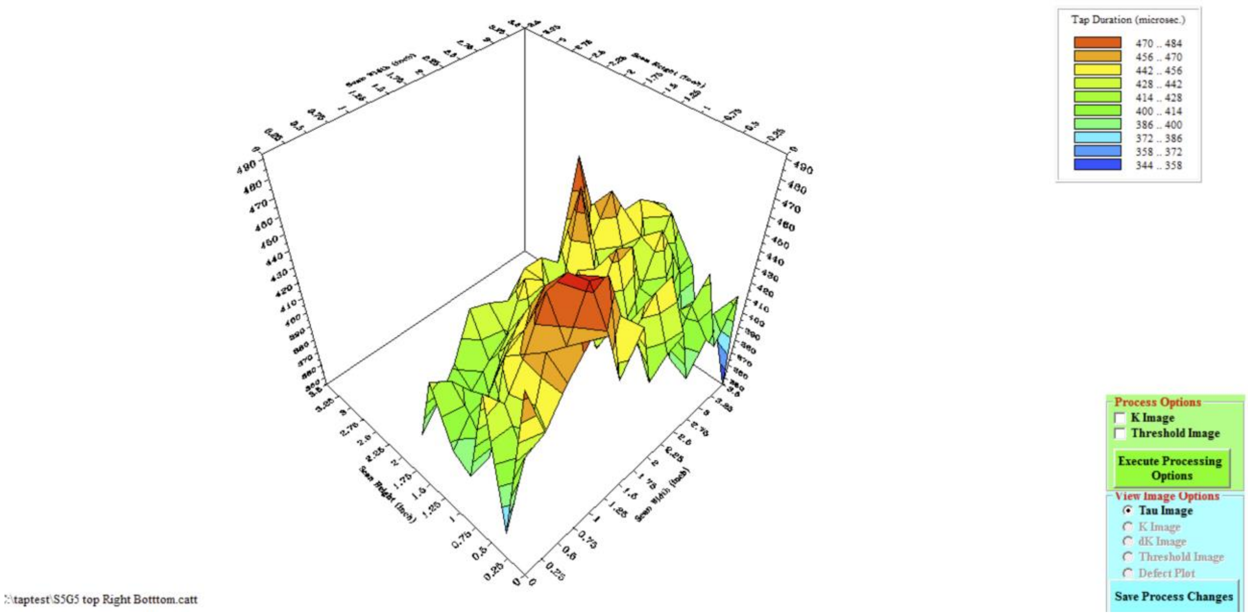

Figure 6. Processed data from Middle right

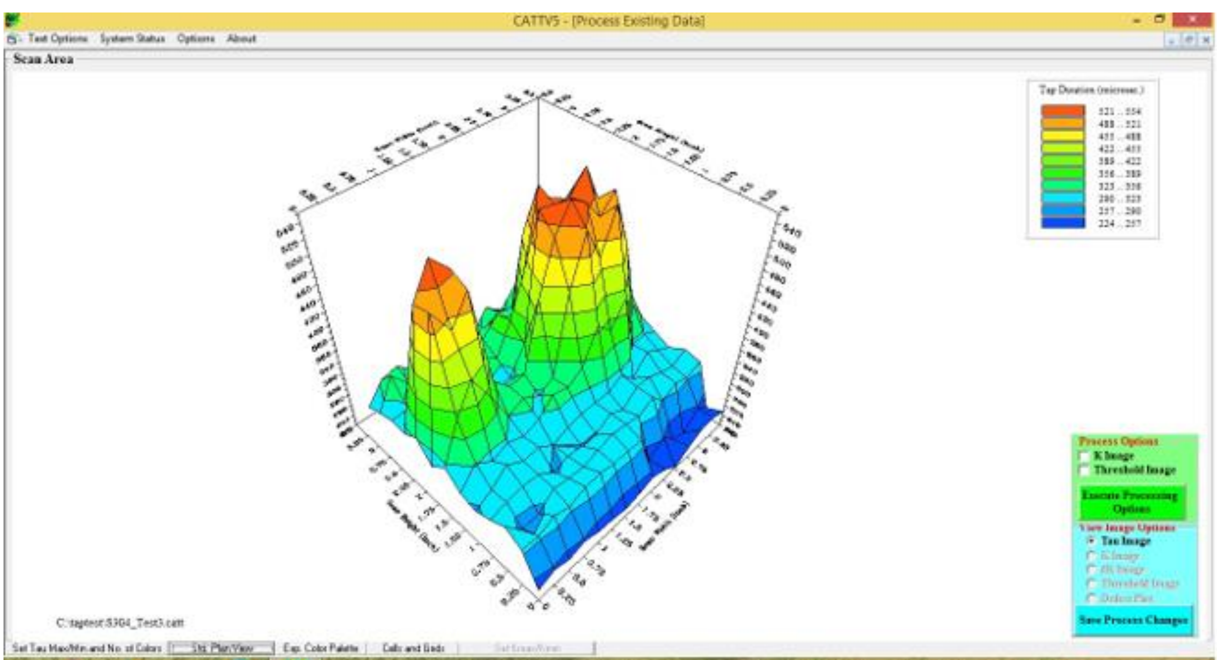

Figure 7. Processed data from Bottom right

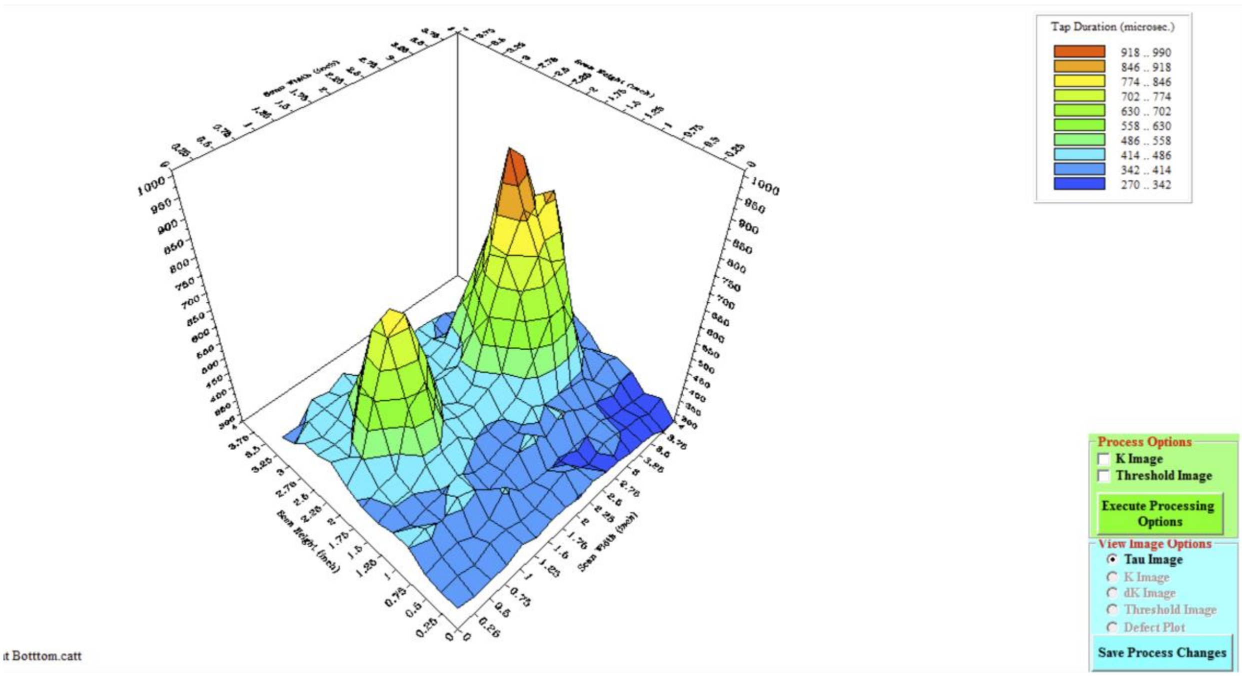

Figure 8. Processed data from Bottom left

UT Simulation

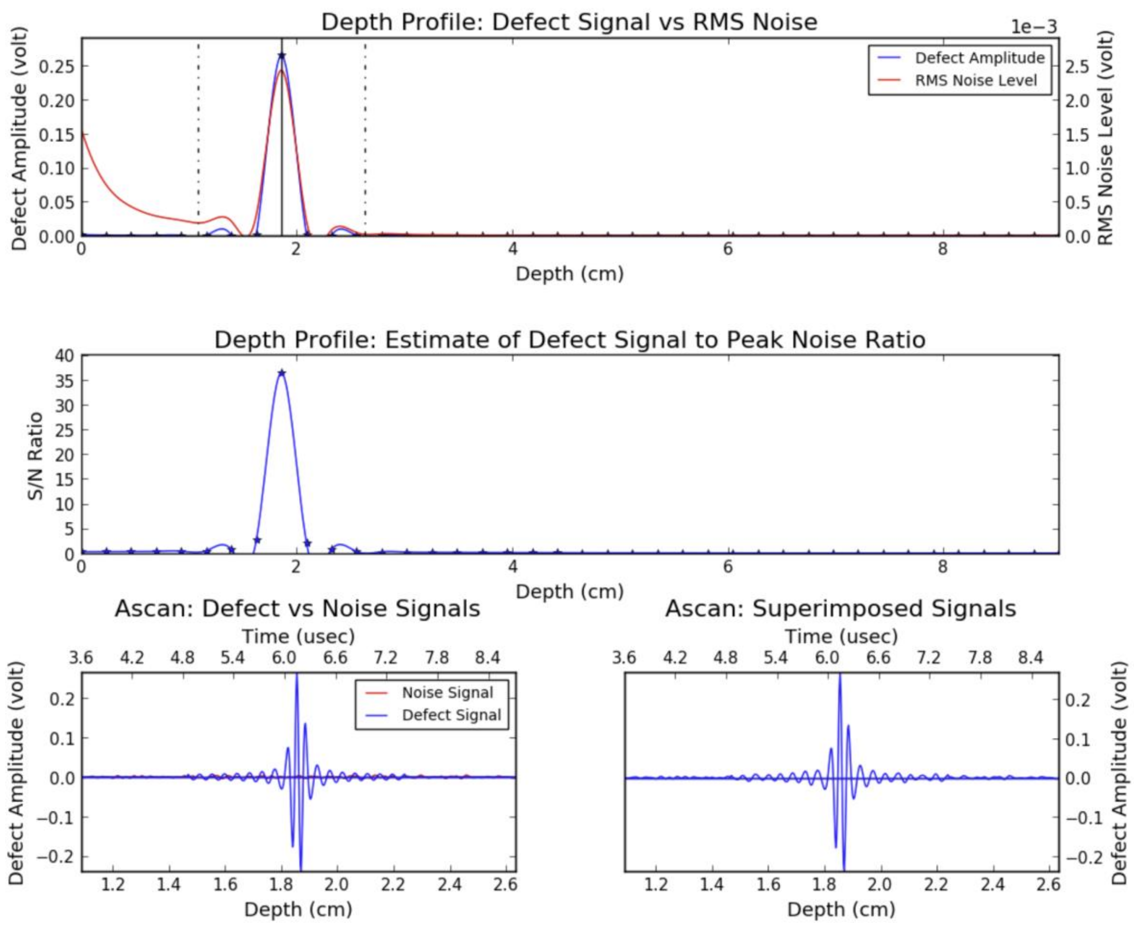

Figure 9. UT Simulation output

Eddy current

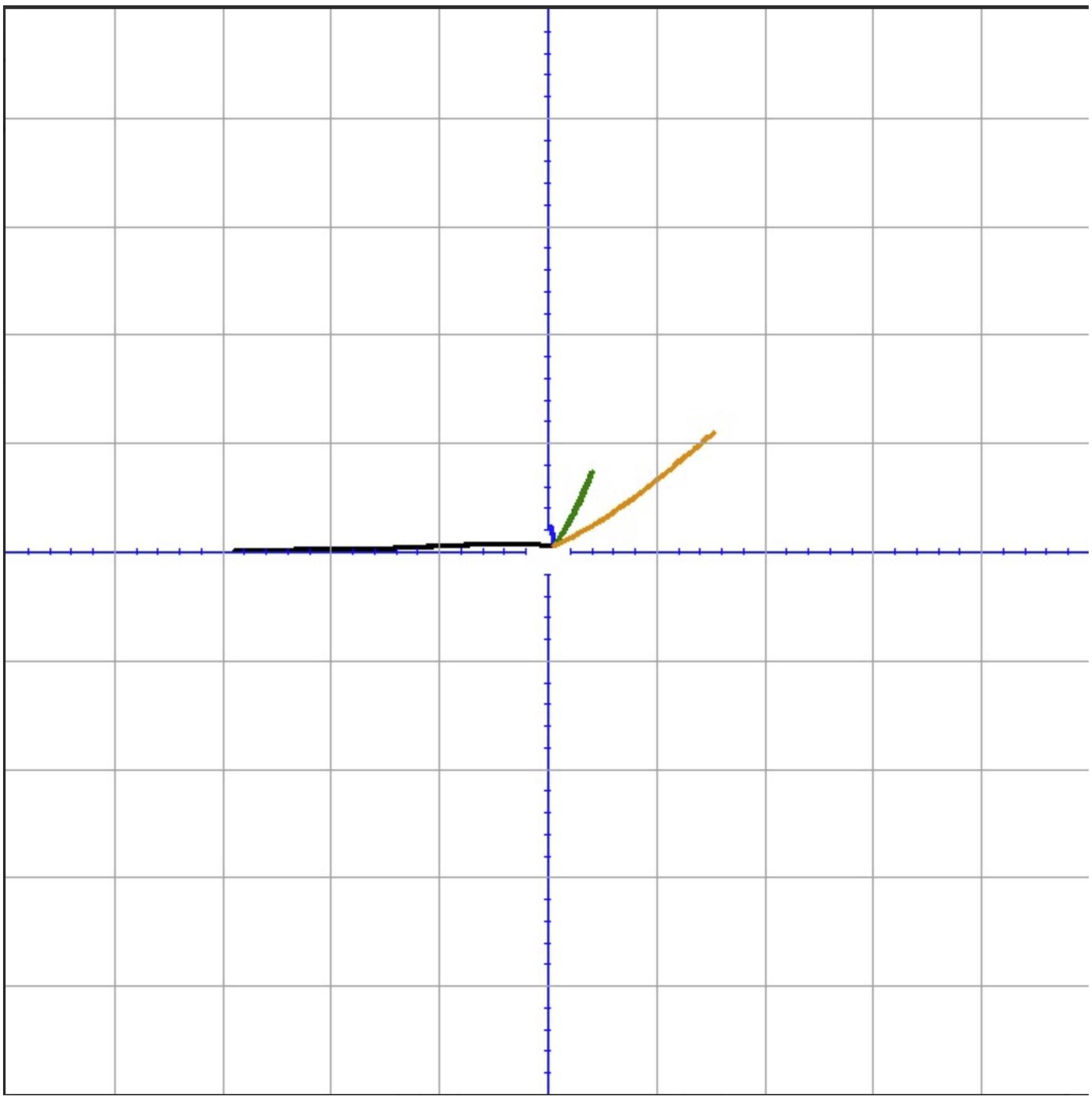

Figure 10. Eddy current reading of Fe(black), Au(green), Bz(blue), Cu(tan)

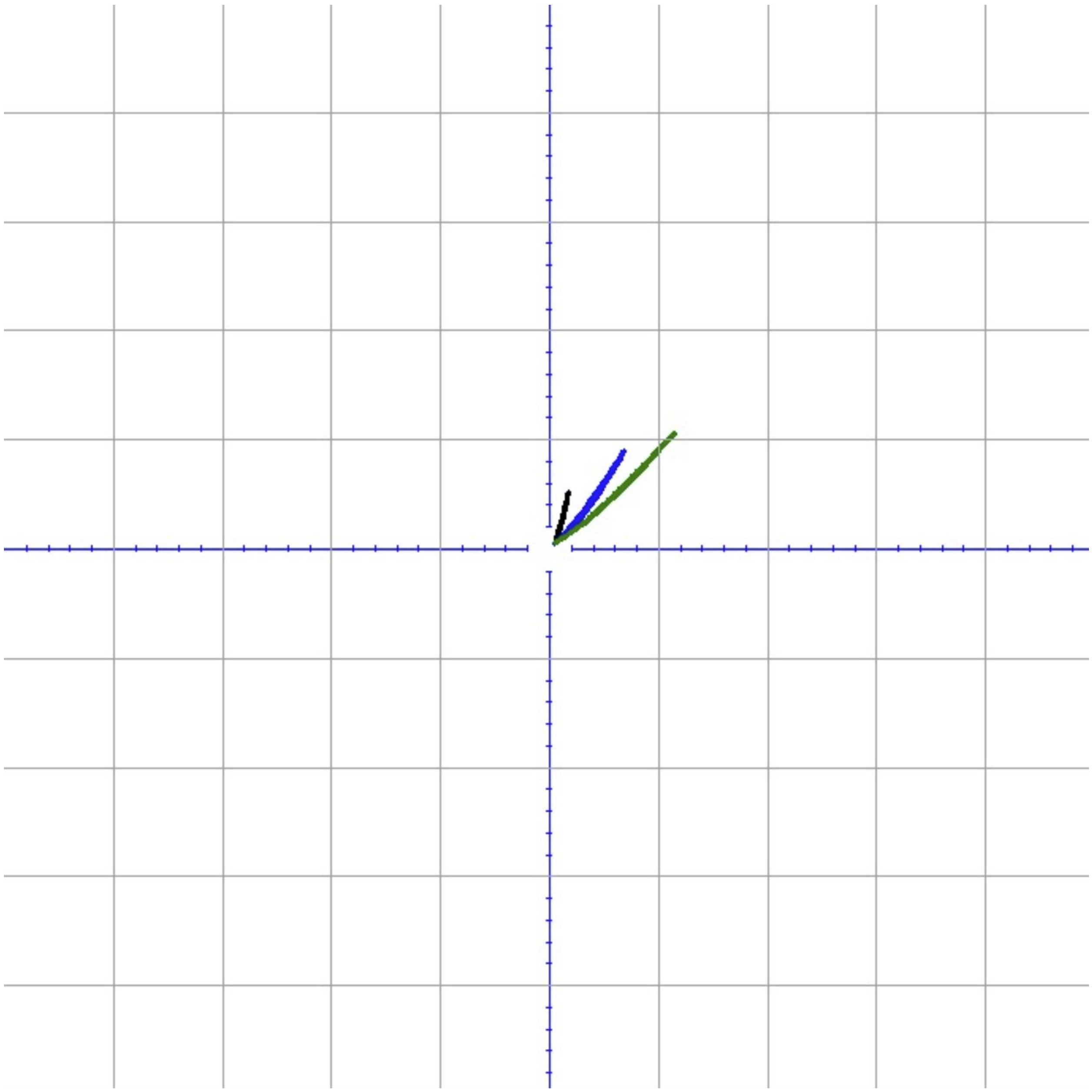

Figure 11. Eddy current reading of Ns(black), Ms(blue), Al(green)

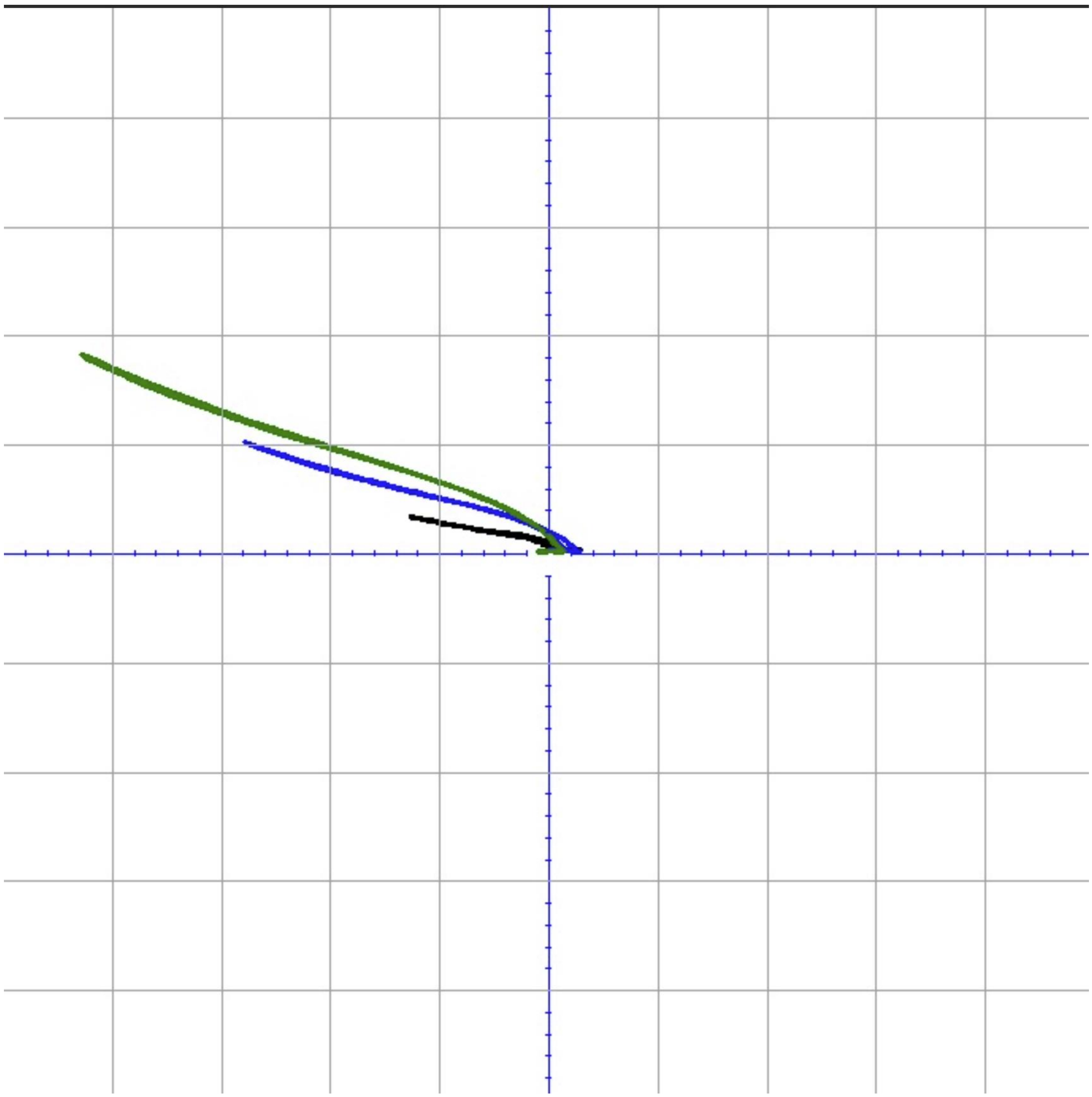

Figure 12. Eddy current reading of top of first sample

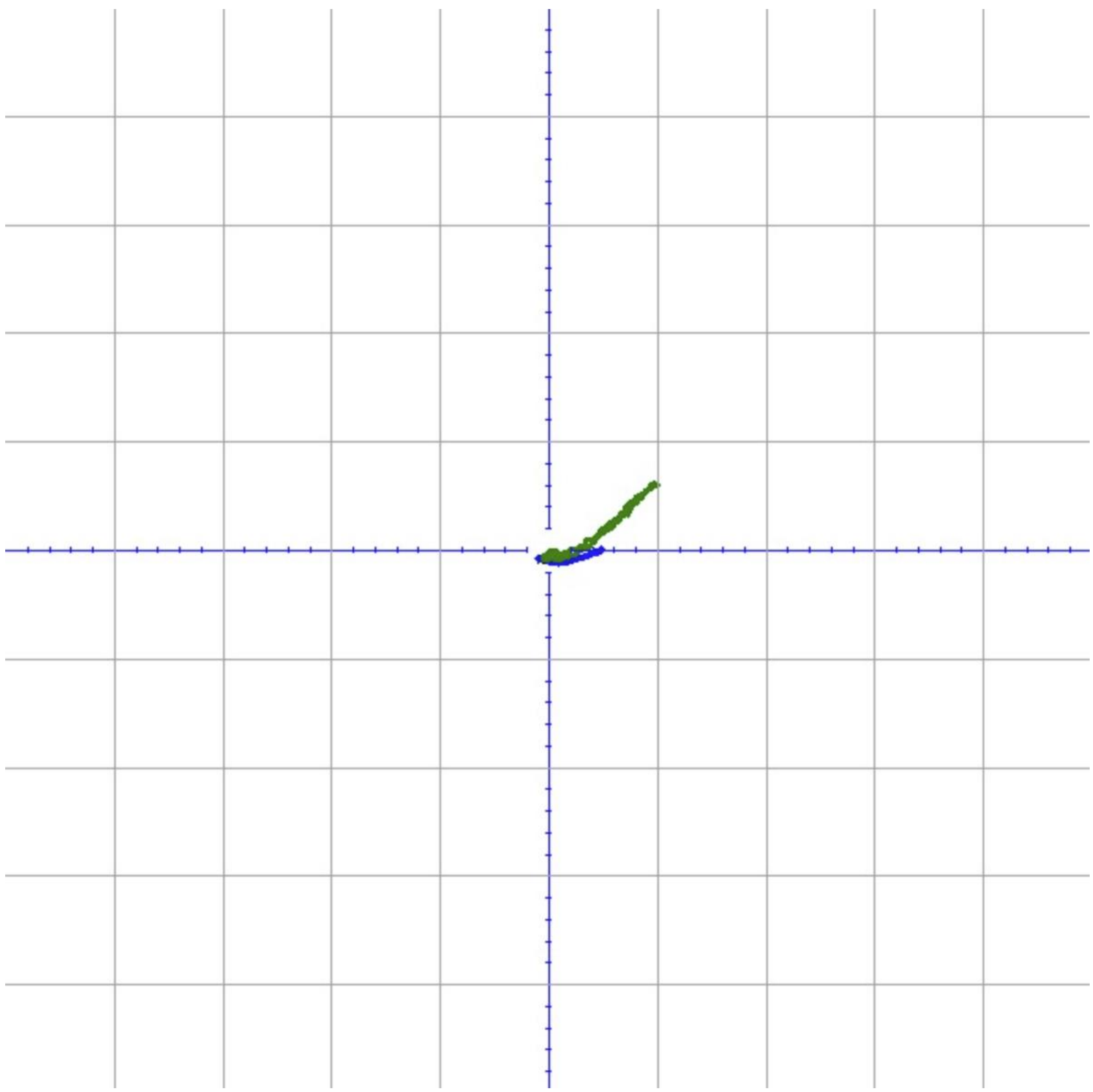

Figure 13. Eddy current reading of bottom of first sample

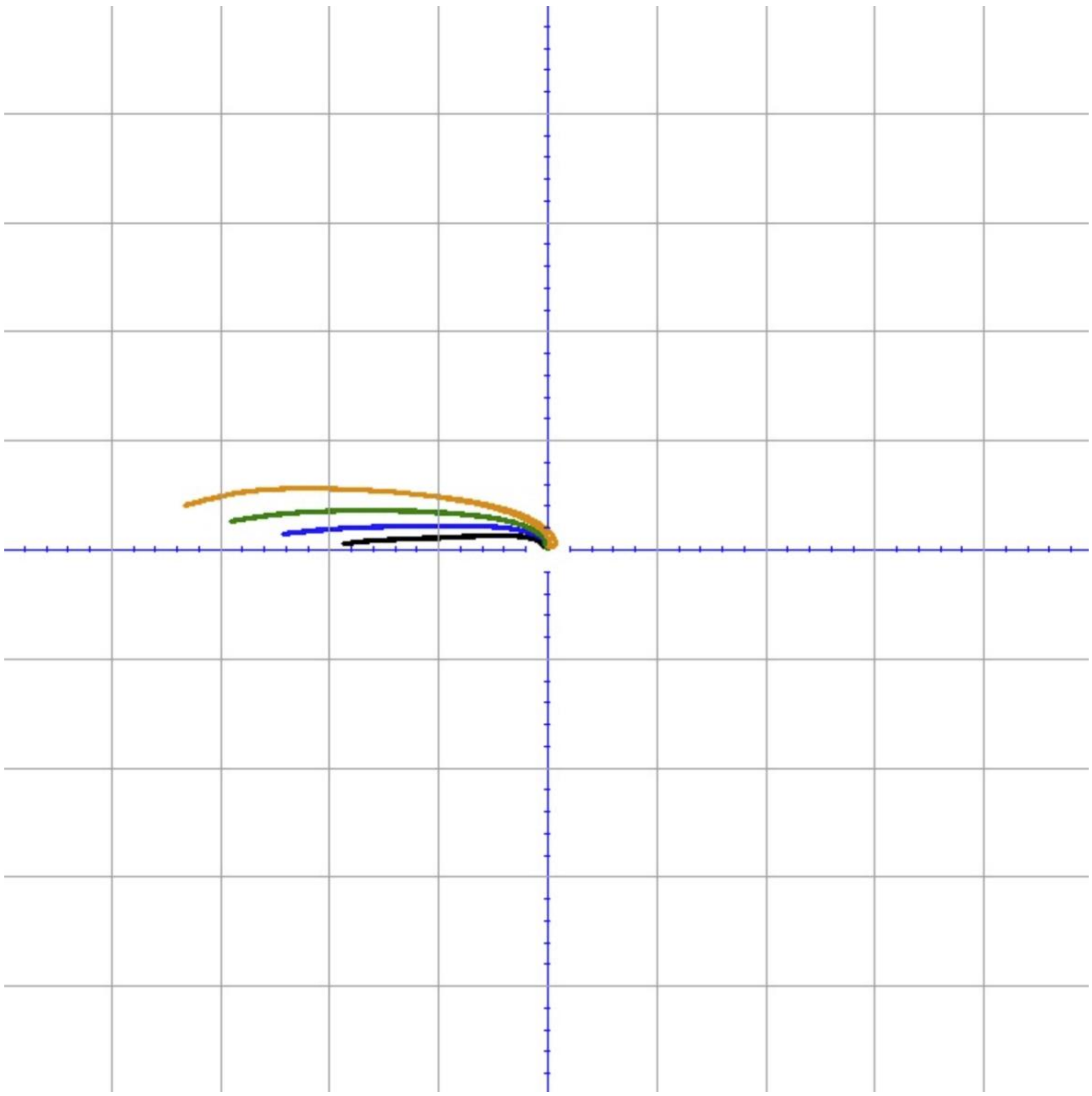

Figure 14. Eddy current reading of top of second sample

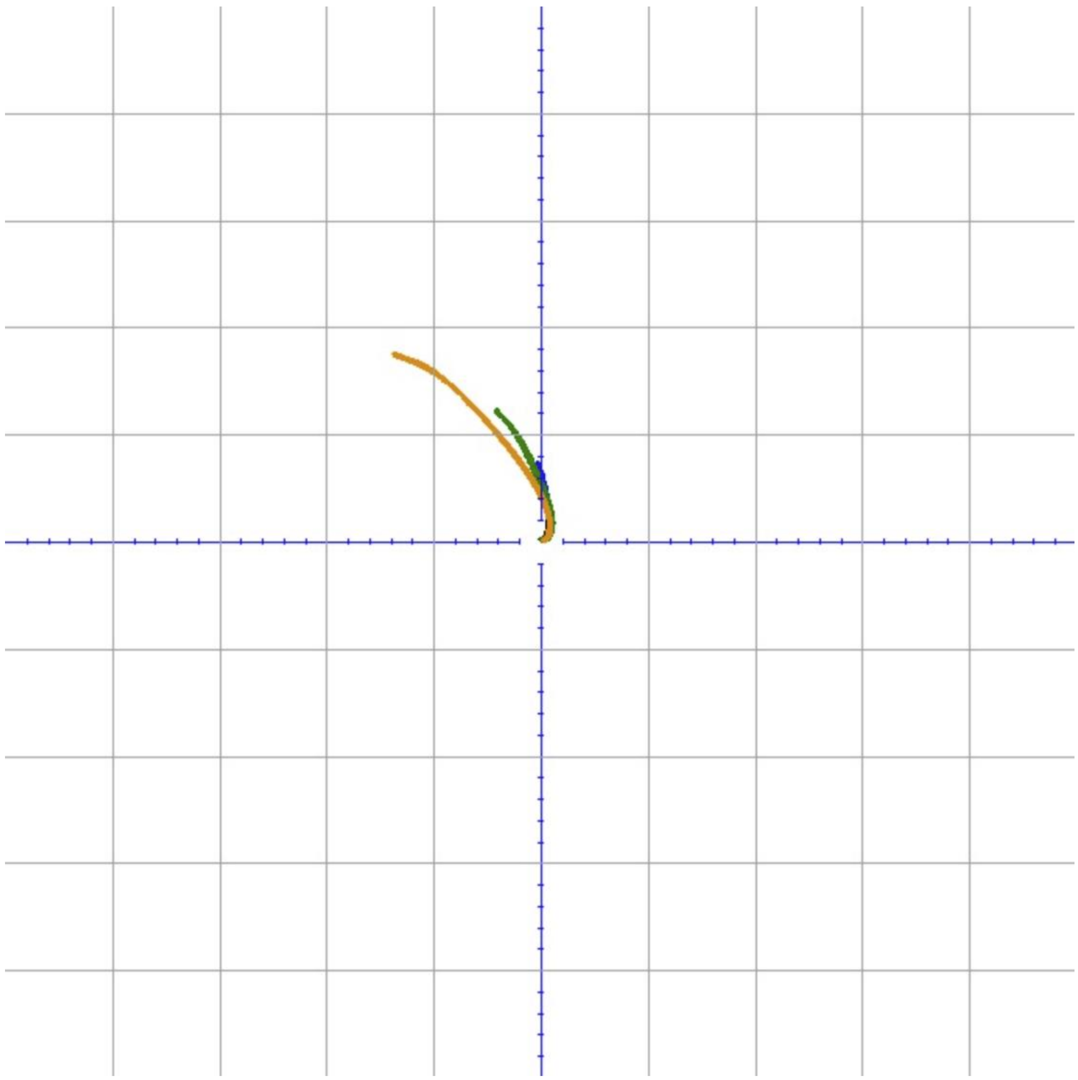

Figure 15. Eddy current reading of bottom of second sample

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Ultrasonic

Table 2. Measured sized flaw from ultrasonic test

	Reading 1 (mm)	Reading 2 (mm)	Reading 3 (mm)
Edge1	140	140	140
Center	136	137	136
Edge2	132	130	132

Analysis

1. After the tap testing of sample one was completed, the computer system was able to generate a graph of the results. Looking at the graph for sample one, you notice that the test picked up two defects and maybe a very small third defect. Moving onto the second test, the graph shows two defects. This is kind of hard to tell because of all the extra noise in the data but you can make out two separate defects. The third and fourth samples both had very similar results and picked up two defects. In the little bit of variation from the graphs generated from samples 3 and 4, you notice that the time duration is different, and this is because of the core size.

2. The results that were produced from the tap testing were made by a preset ¼ inch tap spacing. This spacing was great for detecting the bigger defects, but the smaller defects like the one in sample one was hard to pick up on. If the spacing was increased to ½ inch, the small defects would be most likely impossible to see and I'm sure that it would make even the bigger defects difficult to read on the graphs.

3. To answer this question, let's look at this equation: $k = \frac{\pi^2 M}{T^2}$. In this equation, k represents stiffness and T represents time. From this we notice that as time increases, stiffness decreases. This makes since with the results because the first test should have a larger tapping time duration due to lower stiffness.

4. The liftoff calibration that we routinely performed in the lab was used to visualize how much we as a group needed to alter the gain, phase angle, and frequency. This was done so that we would get a suitable curve that would fit in our window, and it would make it much easier to identify defects in materials.

5. To identify the "cracks" as they got deeper in the material, we increased the frequency of the probe, and this successfully helped us identify the known deformities. In this case this would be used in the tests where we were attempting to read the cracks from the bottom of the specimen. For this we not only increased the frequency, but also increased the gain. The reason this works is because in an eddy current probe, as frequency increases the depth of penetration also increases, but you lose resolution in the process.

6. To solve for the water path, z_1, the focal length equation can be used: $F = Z_1 + \frac{V_2}{V_1} Z_2$. Here F is 8, $\frac{V_2}{V_1}$ is 4.054, and Z_2 is 0.9. Plugging these values in and solving for Z_1, you get a water path is 4.3 inches, which is close to the assumed 4.5.

7. From examining page 17 of the lecture slides and from the data used in our experimentation, we have a recorded end-to-end flaw size average of (8*2 + 10)/3 = 8.67 mm. Page 17 shows a diagram of the flaw signal as it is recorded end-to-end. From this diagram, it would appear the flaw signal echoes several times as it diminishes to zero, these extraneous echoes are what appear to cause the apparent increase in flaw size reported, as the echoes near the end are not actually from the original flaw but are possibly from grain noise echoes. Keeping this in mind, a 50% estimation would give us a new average flaw diameter of (5 + 4*2)/3 = 4.33 mm. This estimation falls very close to the given diameter of 5 mm; however, it might be more beneficial when conduction NDE to overestimate possible defects.

8. In the realm of ultrasonic simulation to meet the Signal-to-Noise Ratio (SNR) requirement, the size of the transducer diameter emerges as the most influential parameter, significantly affecting beam field dimensions, coverage, and sensitivity during inspection. A larger diameter impacts the extent of specimen coverage, crucial for overall inspection efficacy. Following closely, the center frequency plays a pivotal role in balancing penetration depth and sensitivity to smaller defects. The interplay between these parameters is intricate, with focal length and water path contributing contextually. Systematic simulation runs, iteratively adjusting parameters while keeping others constant, provide insights into their individual impacts and facilities the identification of optimal combinations aligned with SNR requirements for specific inspection scenarios.

9. In terms of environmental effects, one should always consider the temperature fluctuations that happen yearly and how this may affect the tank that is stored underground. Another thing that we

would consider is the sealant that would be used to seal the tank. This is because after the sealant is placed on it, it may no longer be possible to use various techniques on the tank such as Ultrasound or eddy current. However, before the sealant is put on, we would suggest using ultrasound to see if there are any cracks or deformities in the tank. To avoid using a submersion medium, EC testing could also be attempted at regular intervals to check for defects.

Conclusion

The field of Non-Destructive Evaluation is one of the most crucial and useful for all engineering applications, as it most fundamentally allows a complex and often comprehensive analysis of a given material or part to be conducted without using up the material in the process, leaving it undamaged and ready for use. This presents an effective means for significantly reducing the cost of manufacturing, as well as allowing for more satisfactory levels of quality control, which increases safety and reliability. In this lab, our group was able to conduct our own set of NDE tests from a variety of sample systems which are commonly applied to NDE in the field. Among the tests which included use of electromagnetics, acoustics and ultrasonics, the UT immersion testing is considered to be one of the most common forms of NDE. This is due to its wide range of applications to a variety of materials and situations. Having foundational knowledge of UT immersion is obviously a solid advantage in any engineering field.