Eddy Current Scanner (ECS)

Comprehensive User Guide

For Axle Bar & Stem Testing

Revision: January 2026

Contents

1 Introduction

Overview

The EddySonix Eddy Current Scanner (ECS), first launched in 2017 and continually enhanced, stands at the forefront of Non-Destructive Testing (NDT) technology. Designed for the precise measurement of Effective Case Depth (ECD) in axle bars, the ECS offers a modern, eco-friendly, and highly efficient alternative to traditional testing methods such as cut-checks and microhardness tests. It has become an industry benchmark, trusted by global leaders and local manufacturers alike.

Key Features and Technical Specifications

- **Unparalleled Precision**: Provides detailed case depth measurements using **multi-frequency signal processing** and **dynamic compensation algorithms**, ensuring high accuracy even with process variations.
- **Fast and Efficient**: Delivers results in under **30 seconds**, drastically reducing testing time compared to traditional methods.
- **Eco-Friendly and Sustainable**: Eliminates destructive testing, reduces material waste, and supports sustainable practices.
- **Advanced Hardware and Software**: Integrated Siemens PLC, servomotors, and a **dustproof IP65-certified rack** ensure durability and reliability.
- **Customizable Coils**: Specialized high-resolution coils with diameters from **27mm to 37mm** (expandable up to 100mm) accommodate axle bars of various sizes up to **1000mm in length** and **40mm in diameter**.
- **Health and Safety Compliance**: CE-certified, equipped with safety features such as **Omron light curtains** and emergency stop buttons.

Performance and Maintenance

- **Comprehensive Testing Capabilities**: Measures ECD at **up to 20 defined points**, providing a complete profile of the axle bar. Accuracy is validated with a **standard deviation (std) of 0.15mm** and a **maximum error of 0.3mm**.
- **Ease of Use**: Features an intuitive digital status screen, multi-frequency test options, and adjustable tailstock for fast part changes.
- **Rugged Mechanical Design**: Built with **aluminum construction**, **titanium centers**, and a robust coil housing for long-term industrial use.
- **Integrated Reporting**: Supports batch testing, traceability tools, and barcode printing to streamline quality control processes.

Summary

The EddySonix ECS is a versatile, high-performance, and environmentally conscious solution for axle bar testing. Equipped with state-of-the-art hardware and software, it ensures unmatched precision, safety, and reliability in industrial environments. Its fast testing cycles, adaptability to various part geometries, and advanced reporting tools make it the ideal choice for modern manufacturing operations.

In summary, the EddySonix Eddy Current Scanner is a versatile, accurate, and eco-friendly solution, equipped with advanced features to ensure precision, safety, and ease of use in industrial testing environments.

2 Reference Database Samples

Eddy Current testing, a "Relative Test" method, relies on comparing unknown parts with standard Reference or Database parts, which include both acceptable and unacceptable specimens. These standards are crucial for training and calibrating the equipment. For each type of axle bar, a specific "Part Program" is established, dependent on a well-curated collection of Database Samples. The creation of these samples, vital for the system's accuracy, involves careful manufacturing and inspection. The EddySonix Eddy Current Scanner measures Case Depth (ECD), Surface Hardness, and Run Out in axle bars, with its precision hinging on the quality of these reference samples.

2.1 Database Sample Creation for Case Depth (ECD)

This group is crucial for setting up part configurations, particularly for new types of axle bars, and is mandatory for initial database creation. To effectively measure ECD, it is essential to produce a series of Database (DB) samples that fall into five distinct categories:

- **Nominal:** A set of 16 samples, each consistently maintaining a uniform case depth across the entire sample.
- **Max-In:** A group of 6 parts, each positioned 0-0.3mm below the specified upper limit.
- **Min-In:** Another set of 6 samples, each 0-0.3mm above the lower limit.
- **Max-Out:** 6 samples, with each approximately 0.5mm above the upper limit.
- **Min-Out:** 6 samples, each about 0.5mm below the lower limit.
- **Raw:** A single sample for baseline comparison.

The "Nominal" category is particularly crucial, as these samples act as the primary calibration reference for the database, necessitating consistency in case depth without significant variations.

General Rules for ECD Samples:

When preparing DB samples for the EddySonix Scanner, follow these comprehensive guidelines:

- **Cast Code Consistency:** Select a singular cast code (heat number) for all DB samples to ensure uniformity in heat number or alloy.
- **Final Machining Stage:** All parts must be at the final stage of machining. They must have identical shapes to ensure the accuracy and reliability of ECD measurements.
- **Dimensional Uniformity:** Maintain identical dimensions, geometry, and CAD drawings across all parts.
- **Induction Hardening Process:** Use the same induction hardening machine and coil/station for the manufacturing of all samples.
- **Uniform Case Depth:** Ensure consistent case depth across all locations on each part, particularly for Nominal parts, where the ECD should be within the middle of the tolerance range.
- **Production Sequence:** Manufacture parts for each group in a single sequence to maintain consistency.
- **Documentation and Microhardness Checks:** Document the ECD values and perform microhardness cut-checks for a representative sample from each group. Additionally, record the induction machine parameters and cut-check values for Nominal parts for future reference.
- **Grouping and Labeling:** Methodically group and label parts to prevent mixing, ensuring they are protected from demagnetization or magnetic particle inspection.
- **Avoid Altering Surface Hardness:** Refrain from sandblasting the parts to preserve the surface hardness.

In emphasizing the criticality of crafting **Nominal** parts for the EddySonix Scanner's database, it's imperative to note the precision required in their production. If the induction hardening machine offers multiple spindles, it's essential to utilize only one spindle for all Nominal samples to guarantee uniformity in case depth. Consequently, in multi-spindle scenarios, insert a scrap axle part in the unused stations, focusing production solely on one, such as station 1 (coil 1). This ensures that Nominal parts exhibit consistent ECD (Effective Case Depth) throughout the axle bar. Adjustments to the feed and timing are pivotal, aiming for uniform ECD along the bar. Verification through cut-checks and microhardness testing after each adjustment is crucial to maintain this uniformity. After fine-tuning the induction parameters, produce 16 successive Nominal samples.

For other categories such as Max-In, Max-Out, Min-In, and Min-Out, adjusting the feed alone is adequate. While maintaining uniform ECD for these groups is beneficial, to streamline the process and minimize waste, a degree of variability in their ECD profiles is permissible.

Creating Mass Production Samples:

- After DB samples, prepare a series of "mass production" samples, selecting one from each production shift or different induction machine stations.
- Label approximately 10 to 20 parts from various production shifts and cast codes with temporary ECD information.

These steps are vital for the EddySonix system to be effectively calibrated and ready for measuring unknown parts from new production shifts and alloys.

2.2 Database Sample Creation for Surface Hardness Testing

Creating samples for Surface Hardness testing is optional and can be postponed to ease the initial project setup. If you decide to create these samples later, you may use various heat codes under more relaxed guidelines. The production process starts with the creation of Nominal parts, which are then reprocessed in the induction hardening machine at a significantly reduced power level with the water shower turned off. This approach reduces surface hardness while maintaining the Effective Case Depth (ECD) within acceptable limits. Alternatively, you can employ any suitable method to temper the samples and reduce their surface hardness. Manufacture and add these samples to the database whenever it suits your project timeline.

DB Samples for Surface Hardness:

1. **Nominal:** These are samples with optimal surface hardness across all locations, typically within the range of 58-59 HRC. A total of 20 samples is required.
2. **Low:** Samples with surface hardness ±1HRC near the tolerance band, for example, around 55-56 HRC, with 16 samples needed.
3. **Very Low:** These are samples with a surface hardness of around 52 HRC, requiring 10 samples.

General Guidelines for Surface Hardness Samples:

- **Diverse Cast Codes:** Select parts from varying cast codes. For instance, choose 5 samples from each cast code to ensure diversity.
- **Grouping and Labeling:** Organize the parts into clearly marked groups to avoid mixing.

- **Non-Demagnetization:** Ensure the samples are not demagnetized or subjected to Magnetic Particle Inspection. Store them in a safe environment, away from permanent magnets.

- **Measurement and Documentation:** Measure the Surface Hardness of all samples at three specified locations (excluding splines). Document these measurements in a table and ensure each part number corresponds with the appropriate row in the table.

2.3 Creation of Database Samples for RunOut Testing

The creation of Run Out samples is optional and can be deferred to streamline your initial setup tasks. You have the flexibility to add these samples to the database at a later time. It's worth noting that some car manufacturers, do not require this parameter to be measured. To manage various Run Out ranges, you can modify the offset at which the induction coil activates—either at the beginning at the first spline or at the end at the second spline.

DB Samples for Run Out:

- Nominal: N=6
- Max-In: N=6
- Min-In: N=6
- Max-Out: N=6
- Min-Out: N=6 (RunOut = 0mm)

These instructions are relevant for both ends of the spline. Adhere to these general guidelines:

- Choose parts from various cast codes, selecting five samples from each code.

- Clearly group and label the parts to prevent confusion and mixing.

- Store the parts in a magnet-free environment to avoid demagnetization or Magnetic Particle Inspection interference.

- Avoid sandblasting the parts, as this can alter surface hardness and impact RunOut measurement accuracy.

- Record the RunOut measurements for all samples in a detailed table, ensuring each part number corresponds to a specific row in the table.

- Conduct a cut check on one sample from each group to accurately measure RunOut.

2.4 Data Entry for ECD Samples

- Organize all ECD samples on a pallet, sorting them into five distinct groups: Nominal, Max-In, Min-In, Max-Out, and Min-Out. Ensure each group is clearly labeled.

- Allow the samples to reach room temperature. It is important to wait a few hours until the parts reach ambient temperature before scanning them. In general, after induction hardening, the core of the part remains hot for a long time, even if the surface seems cooler.

- When recording and entering data, do so in a single session for all parts to ensure consistent temperature conditions. All database samples should be scanned in one session to ensure they are all at the same temperature. Ensure that all parts have a stable and equal temperature. This is crucial as the database samples do not compensate for temperature fluctuations.

2.5 Cut-Check Procedure

- Perform a cut check, which entails measuring the microhardness at five designated points. Choose five representative samples from each group: Nominal, Min-In, Max-In, Min-Out, and Max-Out.
- Document the microhardness readings in a structured table, which will facilitate precise data entry into the system.

2.6 Labeling and Color Coding

Assign color codes to the samples using three different paint markers: Green, Blue, and Red. For each sample within its class, apply a sequential number starting from 1, continuing up to the total count in that class. Select one Nominal sample to serve as the Master Part and label it as 'Master'. This part should be stored carefully and used regularly for calibration purposes. For a visual representation of how to classify reference parts by color code and number, please refer to Table 1 and Figure 1.

Table 1. Color-Coded Classification of Database Samples.

Class	Database Group	Color Code	
Nominal	**A**	Green	Green
Max-In	**A**	Green	Red
Min-In	**A**	Green	Blue
Max-Out	**B**	Red	Red
Min-Out	**C**	Blue	Blue

Figure 1. Example of Grouping Reference Parts by Color-Code and Number.

2.7 Requirements for Creating a New Part Setup

Part Name:

The Part Name is instrumental for two main functions: it is utilized to create a folder bearing the part's name, and the same name is displayed on the main screen. To alter the Part Name, navigate to the **Part Definition** menu.

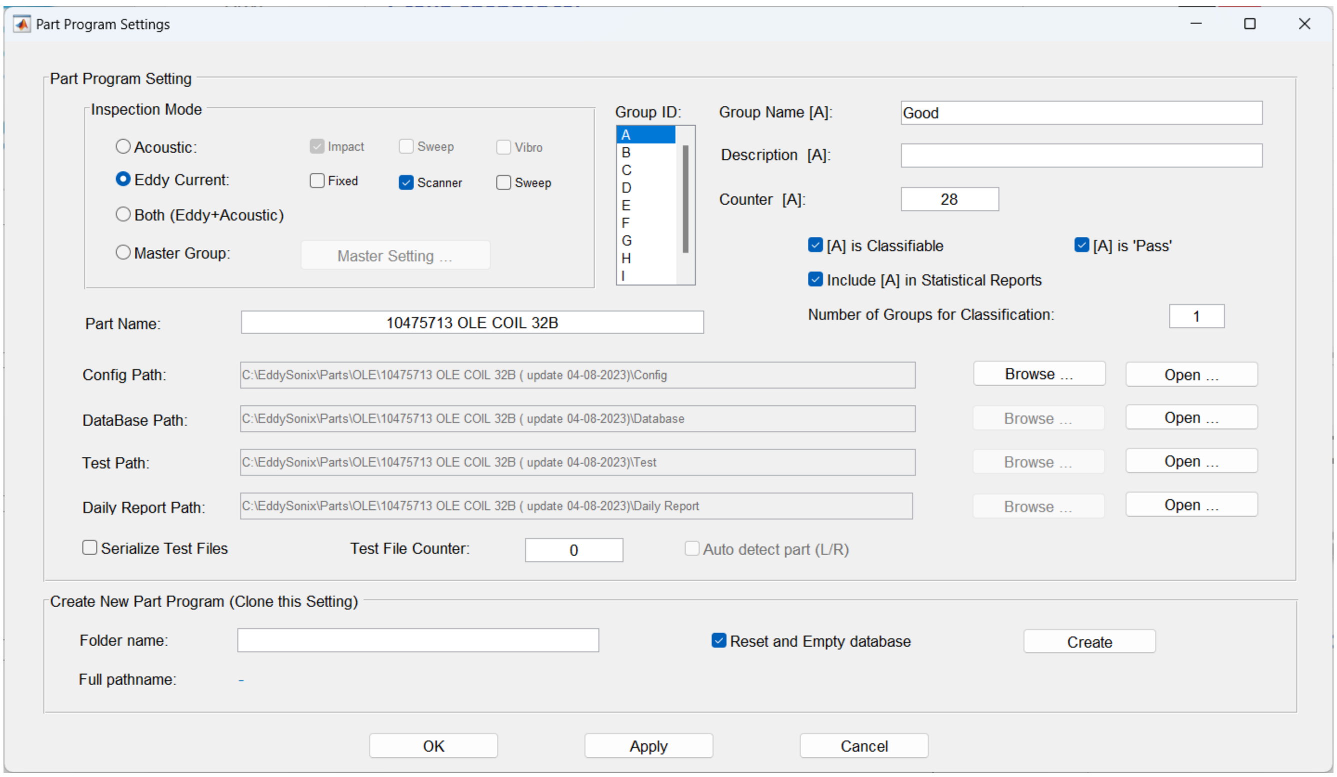


Figure 2. Part Definition Menu

Part Length (mm):

Part Length is the total length of the part from end to end (Figure 3).

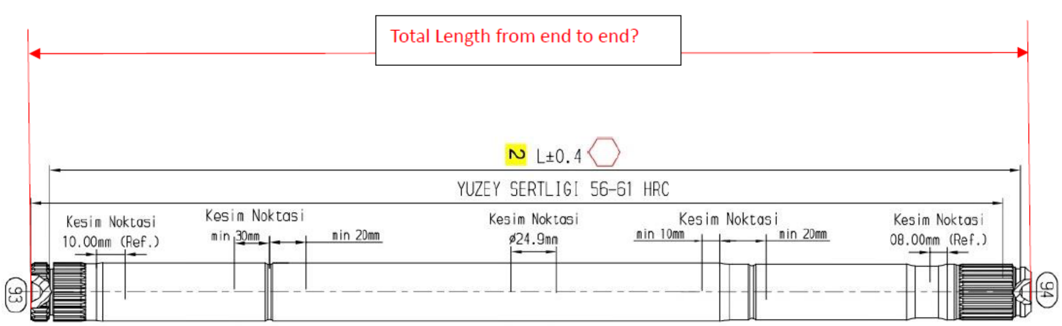


Figure 3. Illustration of an Axle Bar Indicating the Correct Measurement for Part Length, Measured from End to End.

Before proceeding with any other steps in the Part Setup process, it's important to first update the Part Length. To do this, navigate to the **Control I/O** menu. Within this menu, locate the **PLC Servo drive** section and select **Edit Parameters**. Here, ensure that the **Part Length** is entered accurately with the correct measurement. To finalize the update, press **Enter** and then click **OK**. It's crucial to avoid altering any other parameters in this menu (see Figure 4).

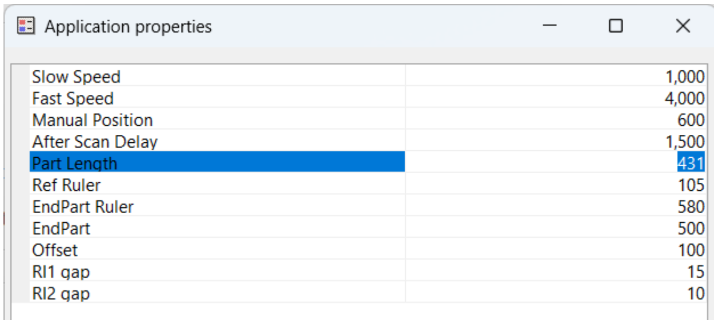


Figure 4. Menu Displaying Options for Defining Part Length and Additional PLC Settings.

In the software, the **Length** of an axle bar is defined from one end of the shaft to the other, encompassing the entire length of the axle. When specifying **Points** on the axle bar for inspection, their positions are determined relative to the starting end of the axle. This starting point is designated as zero in the software.

Points

Location of 5 Cut-check points (mm), Case Depth tolerance (min, max) at each point:

Point	**P1**	**P2**	**P3**	**P4**	**P5**
L (mm)					
Case Depth Min					
Case Depth Max					

Cut-check values of 5 samples:

Point	**P1**	**P2**	**P3**	**P4**	**P5**
Nominal					
Max-In					
Min-In					

Max-Out					
Min-Out					

2.8 Recording and Adding Samples to the Database

Before recording, ensure the parts have acclimatized to room temperature. To maintain consistent temperature conditions, all parts should be recorded and saved in a single session.

Important considerations:

- **Part Length:** Once the Database files are created, avoid changing the "Part Length" in the software parameters. Altering this value can render the Database invalid or cause it to malfunction.
- **Safekeeping of Axle Bar Samples:** It's essential to store the axle bar samples properly in a secure location, well away from any magnetic fields or magnets. This precaution is necessary to avoid magnetic hysteresis buildup in the samples, which could make it inappropriate for later training sessions.
- **Handling Samples After Scanning:** After completing a scan, promptly remove the sample from the Eddy Current scanner's fixture. Leaving a sample in the fixture for an extended period can result in residual magnetism accumulating at the beginning of the axle bar. It's key to remember that the scanner's coil is continuously active and emitting signals, even when not actively scanning a part.

3 Quick Software Setup

This chapter provides a quick guide on setting up a Part Setup for a new part. Chapter 0 will delve into these settings in more detail and offer a comprehensive review.

3.1 Testing an Axle bar

Let's start by assuming the Part Setup is already complete and trained. This approach will focus on scanning and testing axle bars, providing clarity on how the system functions post-setup. After the system has been trained with Database samples, it becomes capable of evaluating new, unidentified axle bars.

Testing Procedure:

1. The inspector places the axle bar in the fixture.
2. The 'Test' button is pressed to start the examination process.
3. The coil scans the axle bar, gauging the Case Depth at various points.
4. The Case Depth results are then displayed, typically within 30 seconds.

With the system trained using Database samples, it becomes capable of assessing new axle bars. The inspector secures the axle bar in the fixture, initiates the scan by pressing the Test button, and the system measures the Case Depth, presenting numerical results for different points along the axle bar within an average cycle time of 30 seconds.

Refer to Figure 5 and Figure 6 for examples of test results for two sample axle bars. These results include:

- Displayed Case Depth (ECD) at pre-determined points.

- Theta envelopes for each frequency, which are linked to ECD estimates and visible on the main screen.

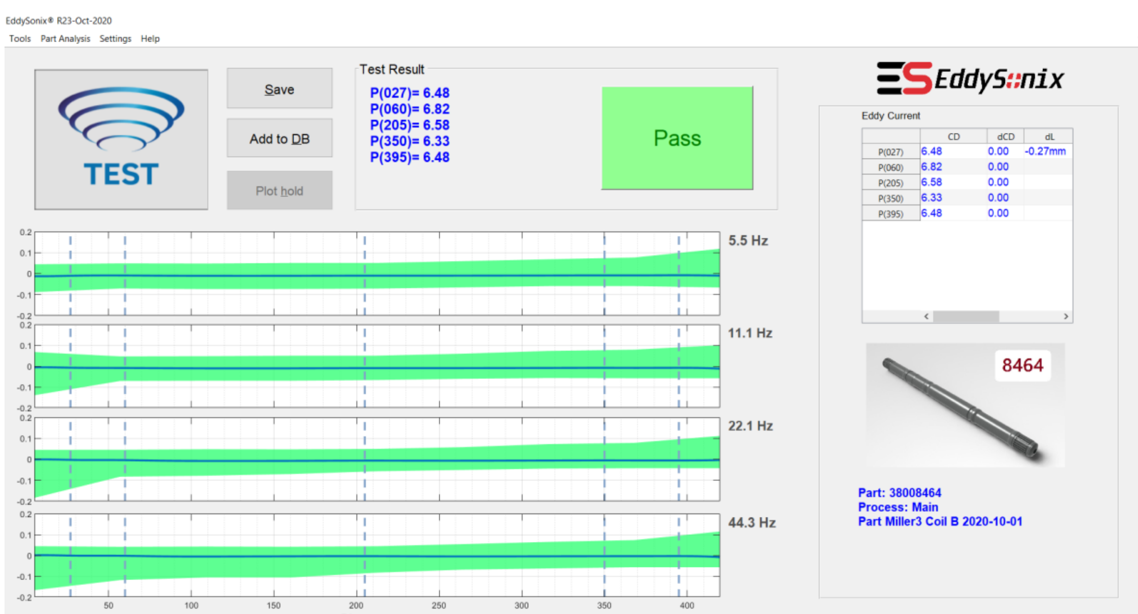


Figure 5. Main Screen of EddySonix Application Showing Test Results and ECD Envelopes for a Part Categorized as "Good".

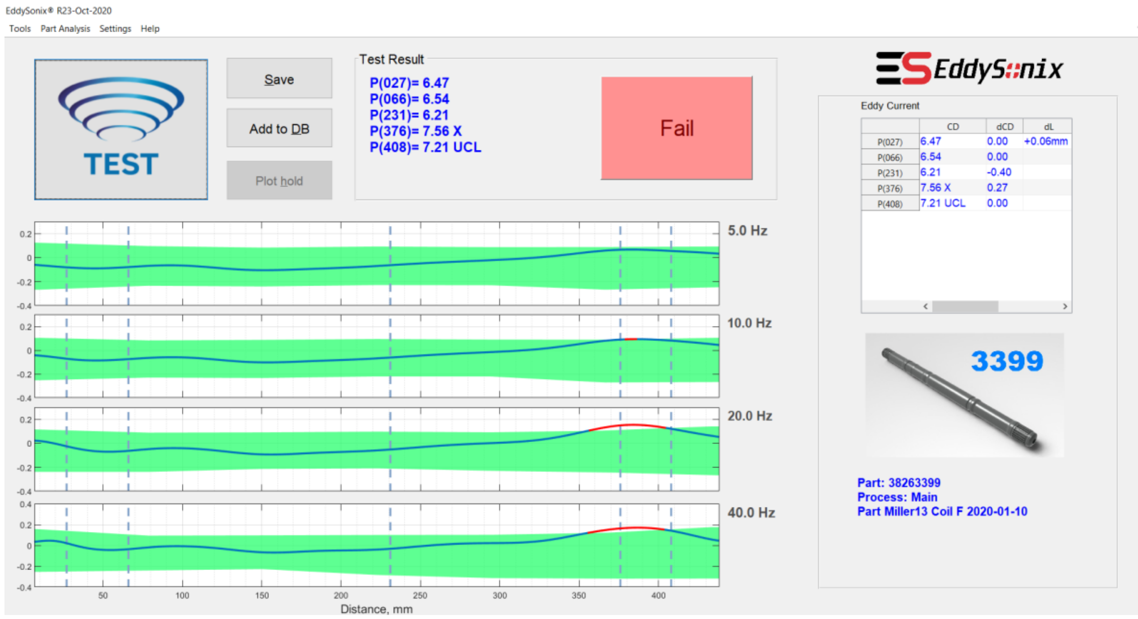


Figure 6. Test Results Displaying a Defective Axle Bar, Highlighting Excessive ECD Beyond the Limit at Point 4 (376mm).

3.2 Software Setup for a New Part

Starting the EddySonix Application:

The EddySonix application will automatically start when you turn on the computer. You can also manually open it from either of these paths, depending on your system setup: **D:\EddySonix\Program\EddySonix.exe** or **C:\EddySonix\Program\EddySonix.exe**.

Upon launching the application, two windows will appear:

- Main Screen
- Command Window

The appearance of the Main Screen is as follows (see Figure 7).

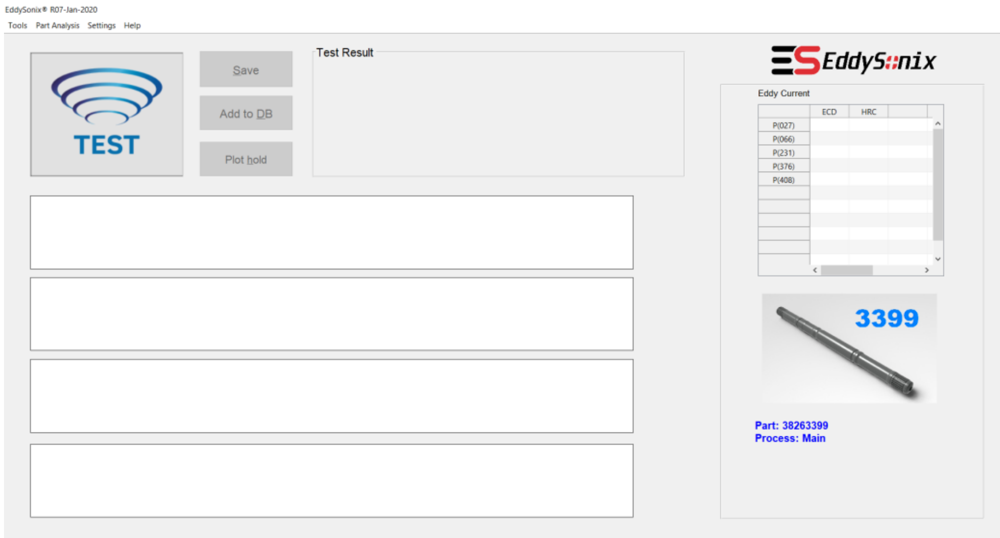


Figure 7. Main Screen of the EddySonix Application Following Startup.

The Command Window, appearing in the background as shown in the next figure, should remain open and not be closed (Figure 8).

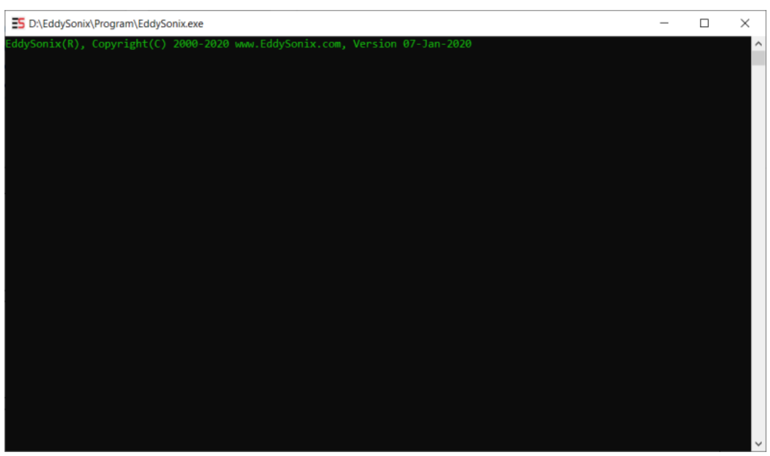


Figure 8. The Auxiliary Command Window in the Background.

Create a New Part Setup Template

To initiate a new Part Setup, the best practice is to clone an existing setup. This gives you a base template, which you can modify for the new part type. Here's how to do it:

1. Access the **Part Definition** menu (Ctrl+G) and go to the **Create New Part Setup (Clone this Setting)** pane. Input the desired Folder name in the edit box, but remember this cannot be altered later. Ensure to select the **Reset and Empty database** option (Figure 9).
2. After clicking **Create** and waiting for all files to generate, the new setup will become the active Part Setup. You can then adjust the **Part Name**, which by default is the same as the Folder name, in the **Part Setup Setting** pane. This name will be displayed on the main screen's right panel.

3. Finalize your settings by clicking 'OK'.

This cloning process is the recommended way to generate a foundational Part Setup, ensuring an efficient and accurate setup for new part types.

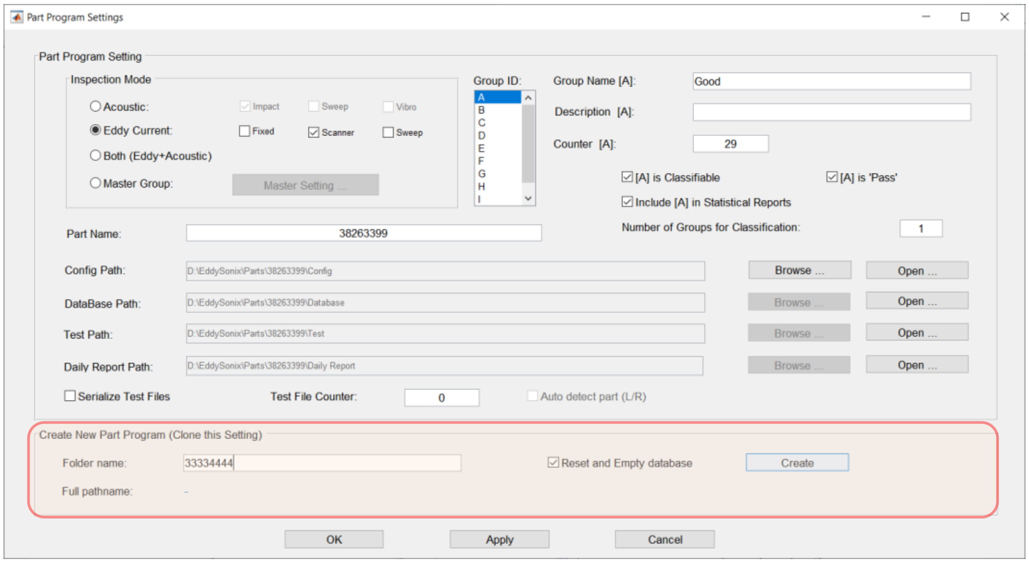


Figure 9. The Part Definition Menu, Showcasing the Pane for Creating a New Part Setup.

Note: To ensure the EddySonix application functions correctly, avoid using special characters such as @#$%^& in folder names. Although Windows supports these characters, the EddySonix app may encounter issues accessing subfolders with such names.

Assigning a Hotkey Number

When you exit the **Part Definition** menu, the **Part Selection** menu automatically opens (Figure 10). Here, you have the option to assign a Hotkey number to each part setup, with choices ranging from 1 to 99. This step is optional; you can simply press OK to close the menu if you don't wish to assign a Hotkey at this time. You can always return to this menu later to edit the Hotkey number or select the active Part Setup. After assigning a Hotkey and pressing OK, the main screen will display the currently selected Part Setup.

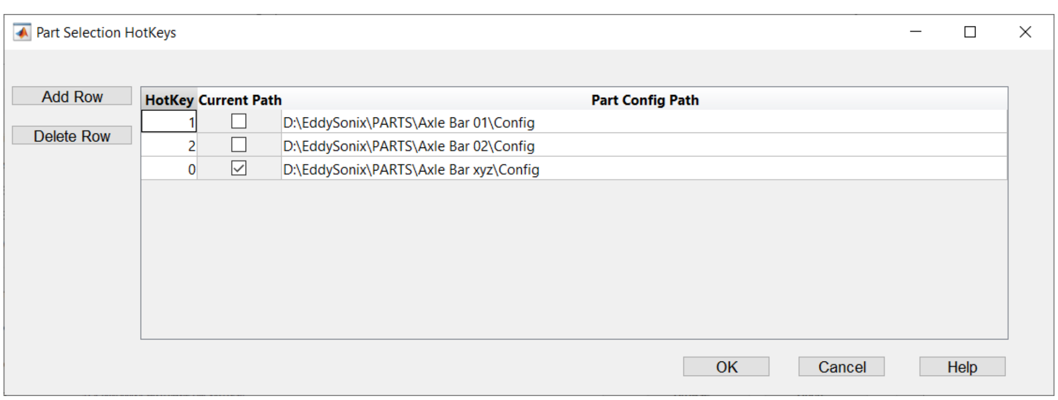


Figure 10. Option to Assign a Hotkey Number to Each Part Setup for Quick Access.

Changing the Part Image on the Main Screen

The image file for the part is located at **[Part Setup Folder]\FEM Results\PartImage.jpg**. You have the option to edit or replace this file as needed.

3.3 User Levels: Administrator and Operator

The EddySonix application includes two user levels to manage access and maintain security: **Administrator** and **Operator**.

Access Levels and Permissions

1. **Operator Level**:
    - This is the default mode when the application launches.
    - Operators can test parts and access basic menus.
    - Restricted menus and settings remain inaccessible.
2. **Administrator Level**:
    - Grants full access to all menus, advanced settings, and configuration tools.
    - Required for creating part programs, adjusting system parameters, and performing updates.

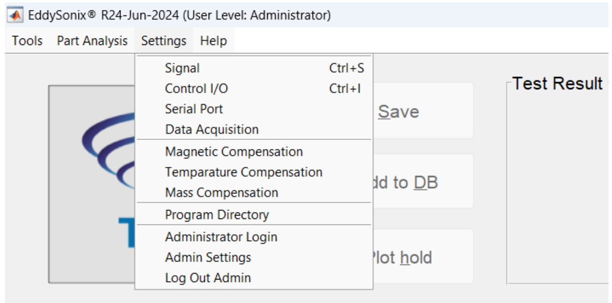
Switching Between User Levels

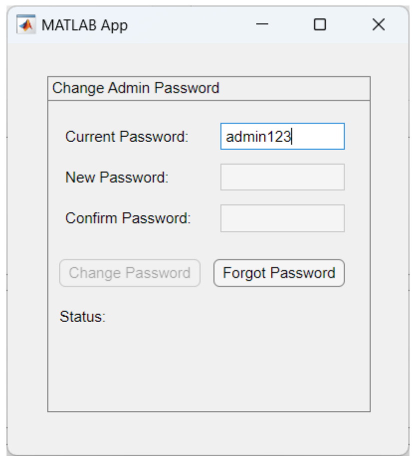
- **Switching to Administrator Mode**:
    - Log in directly using the Administrator password.
    - Alternatively, attempt to open a restricted menu; the system will prompt for the password.
- **Default Password**:
    - Initially set to **'admin123'**.
    - Change the password immediately through **Admin Settings** for security purposes.
- **Returning to Operator Mode**:
    - Log out as the Administrator to revert to Operator level access.

User Level Display

- The current **User Level** is displayed in the **top-left corner** of the main screen for easy identification.

Important Note: Always log out from Administrator mode after completing administrative tasks to ensure system security and proper user management.





3.4 Define Points for Case Depth Estimation

To set up points for Case Depth estimation, access the **Learn menu** and select the **Define Points** button in the **Case Depth** pane. This will open a table where you can:

- Edit the **Number of Points** to be checked on the Axle bar for Case Depth estimation, up to a maximum of 20 points.
- For each point, input the **Location**, Case Depth limits **CD Min**, and **CD Max** values. The positions of the inspection points on the axle bar are measured from the axle bar's initial end.
- Optionally, you can also define the **LCL** (Lower Control Limit) and **UCL** (Upper Control Limit) for each point. If you choose not to set these limits, leave them as NaN (Not a Number). Ensure that **LCL** is set higher than **CD Min** and **UCL** is set lower than **CD Max**.
- Optionally, you can define a **Label** for each point. This label will be displayed on the main screen and in the PDF report. Note: All labels must be filled out; otherwise, the application will revert to the previous version, showing only the points' locations.

LCL, acting as an alarm threshold, ought to be set higher than the **CD Min** value. A typical setting is approximately 0.15mm above the **CD Min**.

Similarly, **UCL** serves as an alarm threshold but is placed below the **CD Max** value. An example setting would be around 0.15mm less than the **CD Max**.

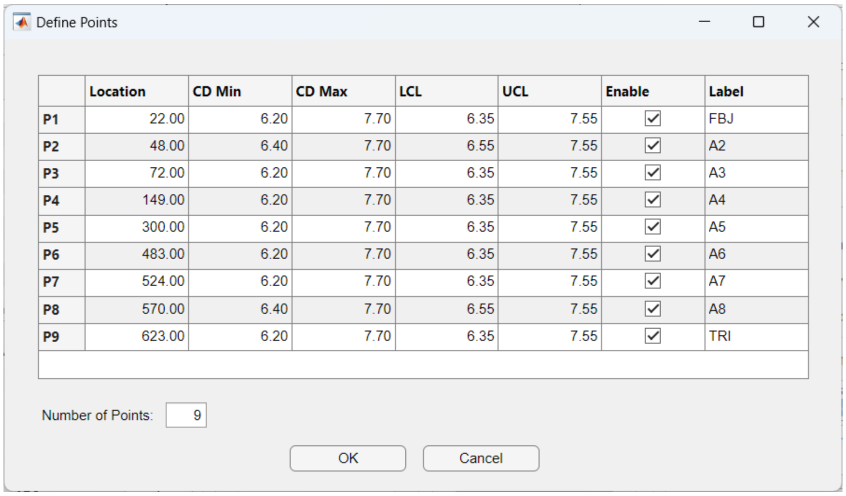


Figure 11. The Define Points Menu for Specifying the Number of Test Points, Their Locations, and ECD Limits.

3.5 Define Part Length

As previously detailed in Section 2.7, the **Part Length** is the total length of the axle bar, measured from one end to the other. In the software, this measurement spans the entire length of the axle. To update the **Part Length**, go to the **Control I/O** menu (see Figure 12). In this menu, find the **PLC Servo drive** section and choose the **Edit Parameters** option. Make sure to input the Part Length accurately. Once entered, press **Enter** to confirm and then **OK** to complete the update (see Figure 13). Be careful not to modify any other parameters in this menu.

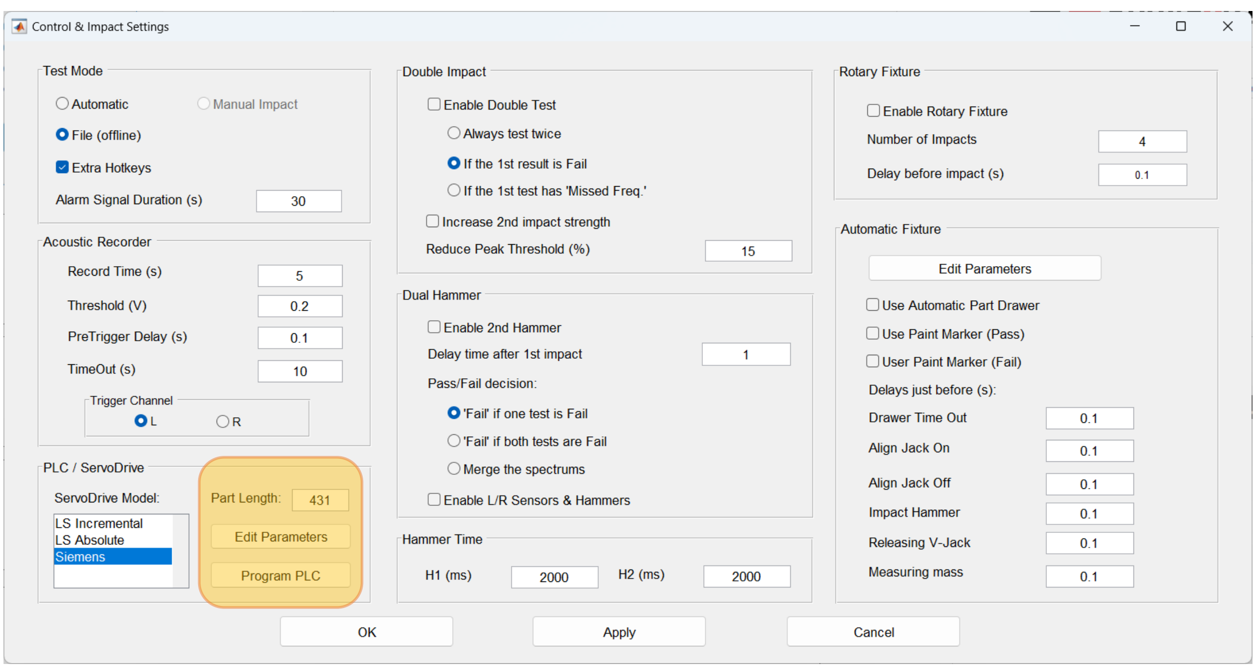


Figure 12. The Control I/O Menu for Setting PLC Parameters and Defining Part Length.

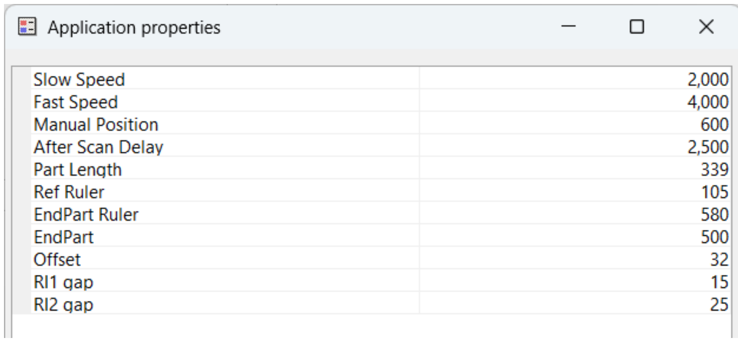


Figure 13. Menu Displaying Options for Defining Part Length and Additional PLC Settings.

Note: To be more user friendly, and avoid accidentally editing other PLC parameters, you can edit Part Length from the edit box on the main menu. However, the old, detailed menu to edit PLC parameters is still available.

- **Part Length Definition:** The Part Length refers to the axle bar's total length from one end to the other. While certain part drawings may specify the length as being from spline groove to groove, this measurement is not suitable for our settings. Instead, the Part Length should be directly measured from end to end using a measuring tape or a ruler.
- Do not edit other fields of the table.
- Make sure in the mechanical unit you have already adjusted the bottom tailstock center for this length.

Scan Speed

It is possible to change the scan speed:

- **Slow Speed** refers to the downward scan speed.
- **Fast Speed** refers to the upward movement (returning to Home position).

However, note that you cannot change the speed for existing Part Setups that are already configured and operational. In other words:

- For new databases, you can define the scan speed during setup.
- For existing databases, the speed is fixed once the database parts are saved.

Internal Reference – Parameter Relationships

- Coil travel distance: `Offset + Part_Length`
- Marker 1 trigger point: `RI1_gap`
- Marker 2 trigger point: `Offset + Part_Length – RI2_gap`
- Distance between markers: `Offset + Part_Length – RI2_gap – RI1_gap`

Then, navigate to the **PLC / ServoDrive** pane and click on **Program PLC**. Upon doing so, the following message will be displayed:

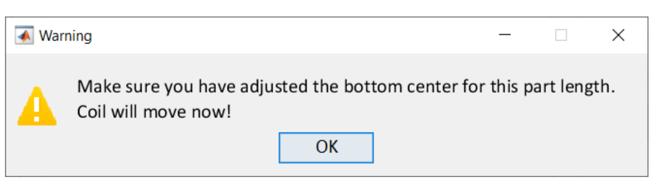


Figure 14. Warning Message Prompting Adjustment of Bottom Center Prior to PLC Programming.

Click **OK** to initiate PLC programming. Following this action, the coil will activate, moving to scan the new course after a 4-second delay.

To ensure consistent results, it's important to adopt a standard convention for positioning axle bars in the EddySonix fixture. This consistency is crucial, especially after scanning and saving the Master Part, as all subsequent parts must be placed in the fixture in the same orientation. We recommend always positioning the axle bars with the Fixed Joint spline facing upwards and the Tripod spline positioned at the bottom center. This orientation should be maintained for every part to guarantee accurate and repeatable measurements (Figure 15).

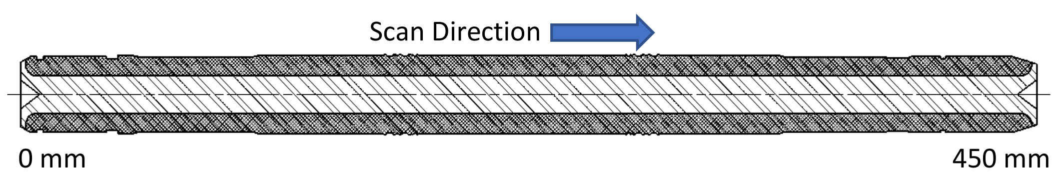


Figure 15. Axle Bar Orientation for Scanning, with Arrow Showing Direction of Scan and Fixed Joint Spline Positioned at the Starting Point as a Standard Convention.

If you are using an absolute servo drive, a specific menu will appear. In this menu, edit the **Part Length** and then click **Save & Program PLC** to apply the changes (Figure 16).

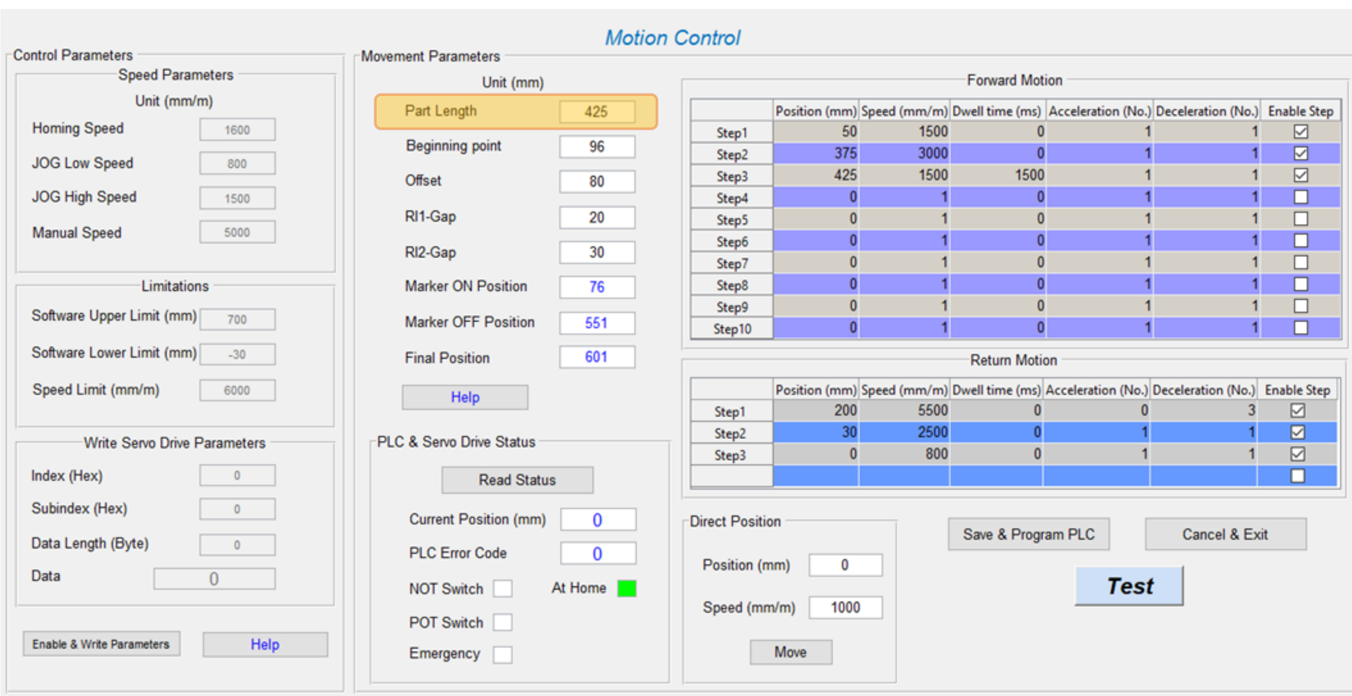


Figure 16. Setting Motion Parameters for Absolute Servo Drives.

3.6 Introducing Master Part and Empty Coil to the Database

Begin by selecting a Good Nominal part to serve as the Master part. This Master part is introduced to the database only once for the purpose of length alignment. Place the Master part into the fixture and press the **Test** button. Following a brief warmup period, the coil will scan the part and return to the **Home** position. If necessary, you can initiate a repeat scan by pressing the Test button again.

To save the Master part in the database:

- Press the **D** button to access the **Add to DB** menu (Figure 17).
- In the **Introduce Part** pane, mark the **Master Part** checkbox ☒, then click **Save**.

Tip for easy data entry without using a mouse (useful when wearing gloves):

- Press **D** to open the **Add to DB** menu.
- Use **M** or **E** to choose **Master** or **Empty Coil**, respectively.
- Hit **Enter** twice to save the information and exit the menu.

After saving, remove the Master part from the fixture. Then, press the **Test** button to scan the Empty coil. Open the **Add to DB** menu again by pressing **D**. In the **Introduce Part** pane, select **Empty Coil** and then click **Save** (Figure 18).

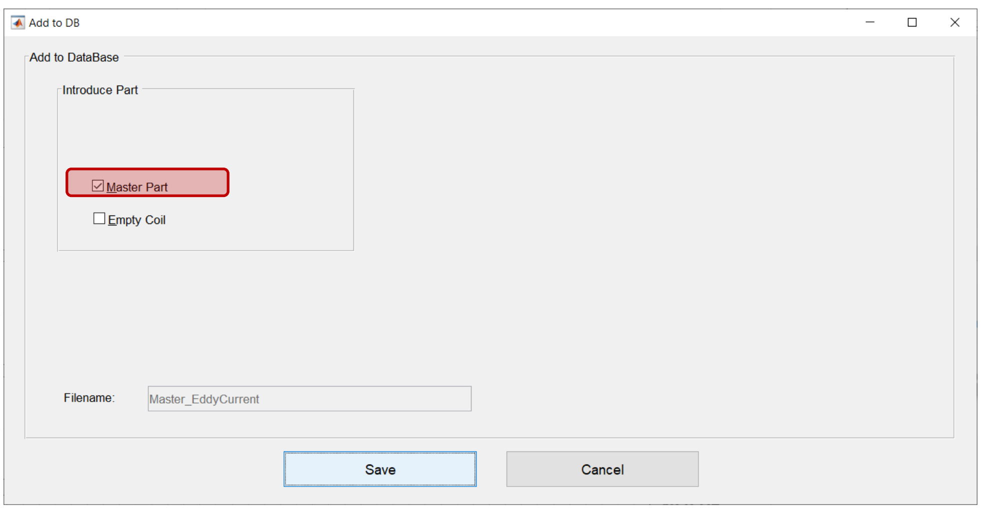


*Figure 17. **Add to DB** Menu for Introducing the **Master Part** to the Database.*

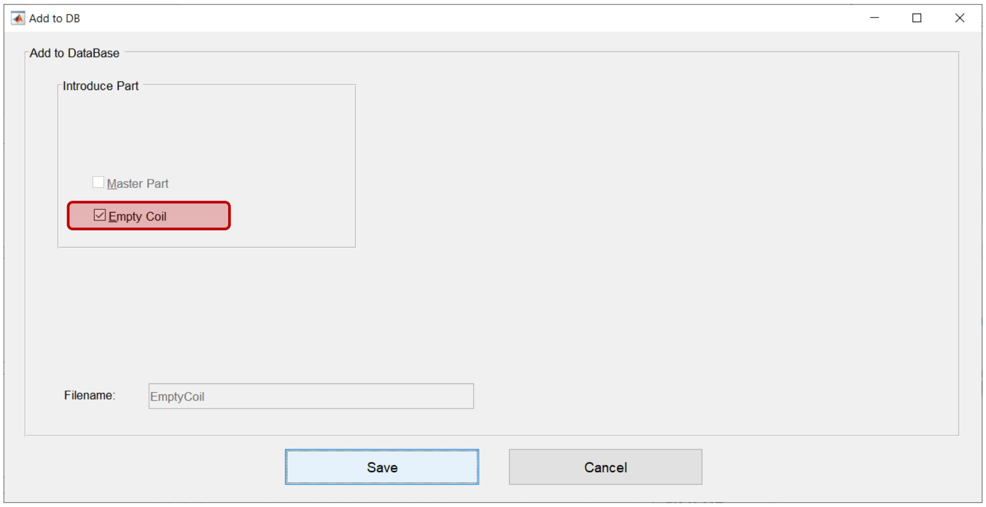


*Figure 18. **Add to DB** Menu for Adding the **Empty Coil** to the Database.*

3.7 Calibrating and Introducing Reference (DB) Parts

To calibrate the system using the **Empty Coil**, ensure there is no part in the fixture and then press the **Test** button. Following a brief warm-up period (Figure 19), an Empty Coil Calibration message will appear to confirm the calibration process (Figure 20).

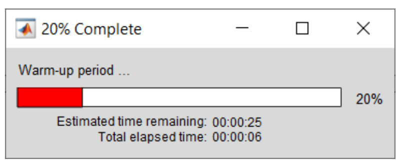


Figure 19. Progress Bar Indicating Warm-Up Waiting Period.

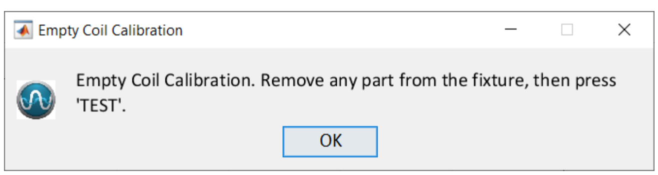


Figure 20. Message Box Indicating to Remove Axle Bar and Proceed with Empty Coil Scan.

When the calibration is successful, you'll see the following message: **"Calibration Completed Successfully."**

If a warning appears instead, check the following:

- Ensure that you have removed any part from the fixture.
- Verify that the correct coil associated with this part program is connected.

Once these checks are complete, you can proceed to scan and save the Reference Parts to the database. For traceability, it's important to label or mark the Reference Parts. Simply insert a part into the fixture and initiate the scan.

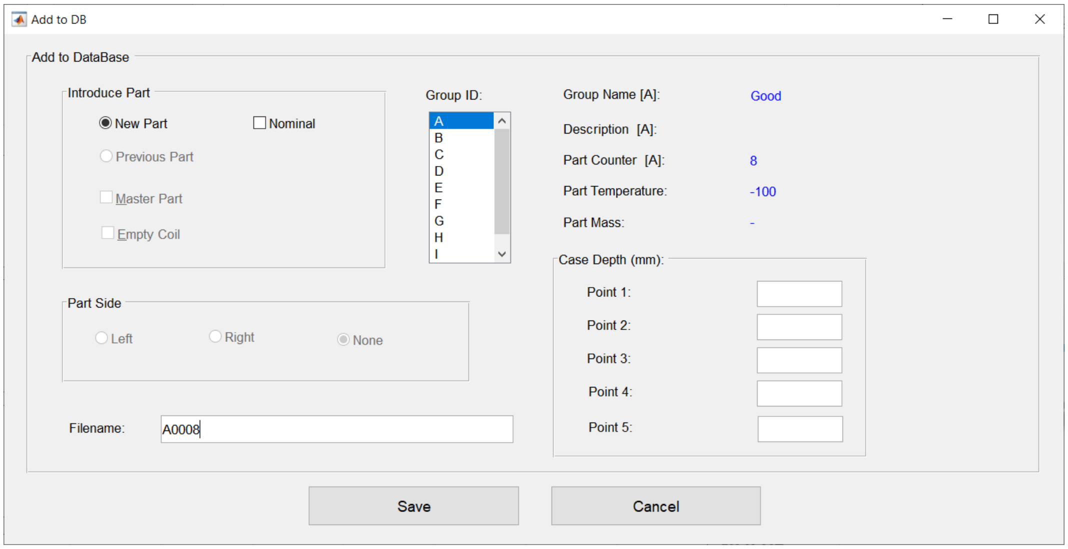


*Figure 21. **Add to DB** Menu for Saving Reference Parts to the Database, with Groups A, B, and C Designated for ECD Sample Storage.*

Once the scan is finished, follow these steps to save the scanned data into the database:

- To open the **Add to DB** menu, press **D**.
- Select a **Group ID** by pressing a key between **A** to **J**. Note that ECD samples should only be saved under groups **A**, **B**, and **C**.
- Hit Enter to modify the filename for comments, but avoid changing the first 5 characters.
- Double-press Enter to save and close the menu.

Remember, if you're wearing gloves, the keyboard is your primary tool; there's no need for a touch mouse.

A quick reminder about filenames: You may add a brief description in the **Filename** field, but do not alter the first 5 characters. For instance, a filename like **A0001 – Nominal 23** indicates a Good part; filenames beginning with **A** are classified as such. Ensure that all parts in Group **A** are Good and span the entire acceptance range. It's advisable to have 20 to 30 Good parts with these specifications:

- 14 **Nominal** (mid-range) in group **A** (A0001 – A0014)
- 6 **Max-in** (upper-limit) in group **A** (A0015 – A0020)
- 6 **Min-in** (lower-limit) in group **A** (A0021 – A0026)

There's no limit to the number of parts you can add to the database. Scan and save Max-Out samples in group B, and Min-Out samples in group C:

- 6 **Max-Out** in group **B** (B0001 – B0006)
- 6 **Min-Out** in group **C** (C0001 – C0006)

Figure 22 provides a screenshot of the File Explorer, displaying the arrangement of Database files within the Database folder.

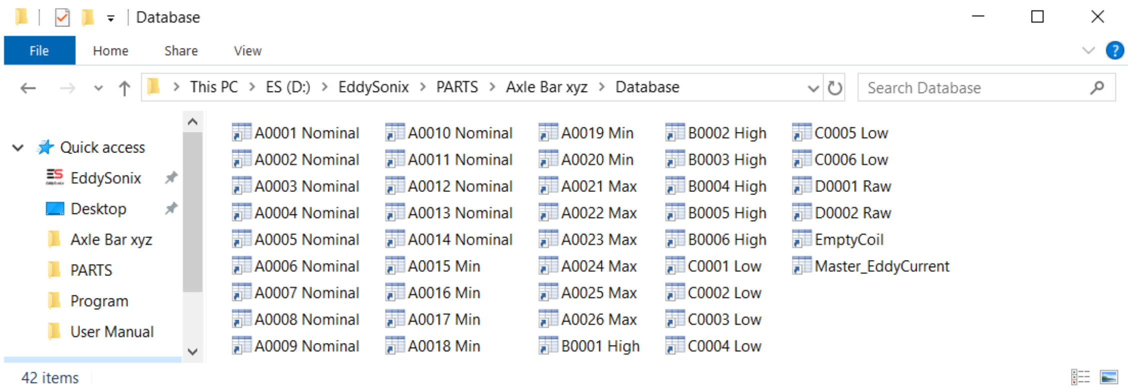


Figure 22. View of the Database Folder in File Explorer.

It's essential that all parts, including the Master and Reference parts, are at the same temperature when scanned. Therefore, ensure to scan all database parts in one continuous session. Avoid scanning parts immediately after induction hardening, and similarly, refrain from recording parts right after they have been brought in from a cold warehouse. All parts should be allowed to reach ambient temperature before scanning.

3.8 Editing Case Depths

Once the database is established, choose at least 5 samples for destructive testing, including Nominal, Max-In, Min-In, Max-Out, and Min-Out. Selecting a greater number of samples with known case depths will yield more accurate results.

To begin editing:

1. Navigate to the **Learn** menu and click on **Edit Case Depths** in the **Case Depth** pane.
2. Select at least five samples, including Nominal, Max-In, Max-Out, Min-In, and Min-Out, and input their respective Effective Case Depth (ECD) values. This step involves updating the ECD values for each reference point on these selected samples.

- Input data for at least 5 parts, ensuring inclusion of a Nominal, Max-Out, Min-Out, Max-In, and Min-In.

- The entered data should be based on microhardness measurements for accuracy.

- If 'NaN' (Not a Number) appears, it signifies the absence of a numerical value. To revert any changes, enter an alphabetic character to switch it back to 'NaN'.

In the **Nominal** column, ensure to only mark the Nominal samples with a checkmark. It's crucial to complete this step correctly; do not check any other types of parts, such as Max-In or Min-In.

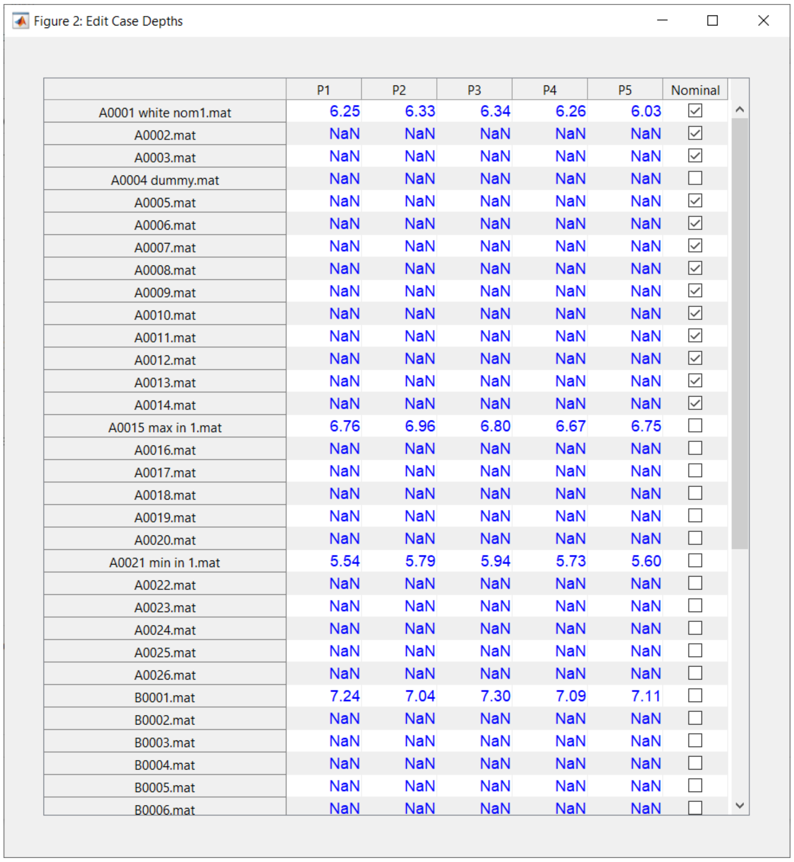


Figure 2: Edit Case Depths

	P1	P2	P3	P4	P5	Nominal
A0001 white nom1.mat	6.25	6.33	6.34	6.26	6.03	☑
A0002.mat	NaN	NaN	NaN	NaN	NaN	☑
A0003.mat	NaN	NaN	NaN	NaN	NaN	☑
A0004 dummy.mat	NaN	NaN	NaN	NaN	NaN	☐
A0005.mat	NaN	NaN	NaN	NaN	NaN	☑
A0006.mat	NaN	NaN	NaN	NaN	NaN	☑
A0007.mat	NaN	NaN	NaN	NaN	NaN	☑
A0008.mat	NaN	NaN	NaN	NaN	NaN	☑
A0009.mat	NaN	NaN	NaN	NaN	NaN	☑
A0010.mat	NaN	NaN	NaN	NaN	NaN	☑
A0011.mat	NaN	NaN	NaN	NaN	NaN	☑
A0012.mat	NaN	NaN	NaN	NaN	NaN	☑
A0013.mat	NaN	NaN	NaN	NaN	NaN	☑
A0014.mat	NaN	NaN	NaN	NaN	NaN	☑
A0015 max in 1.mat	6.76	6.96	6.80	6.67	6.75	☐
A0016.mat	NaN	NaN	NaN	NaN	NaN	☐
A0017.mat	NaN	NaN	NaN	NaN	NaN	☐
A0018.mat	NaN	NaN	NaN	NaN	NaN	☐
A0019.mat	NaN	NaN	NaN	NaN	NaN	☐
A0020.mat	NaN	NaN	NaN	NaN	NaN	☐
A0021 min in 1.mat	5.54	5.79	5.94	5.73	5.60	☐
A0022.mat	NaN	NaN	NaN	NaN	NaN	☐
A0023.mat	NaN	NaN	NaN	NaN	NaN	☐
A0024.mat	NaN	NaN	NaN	NaN	NaN	☐
A0025.mat	NaN	NaN	NaN	NaN	NaN	☐
A0026.mat	NaN	NaN	NaN	NaN	NaN	☐
B0001.mat	7.24	7.04	7.30	7.09	7.11	☐
B0002.mat	NaN	NaN	NaN	NaN	NaN	☐
B0003.mat	NaN	NaN	NaN	NaN	NaN	☐
B0004.mat	NaN	NaN	NaN	NaN	NaN	☐
B0005.mat	NaN	NaN	NaN	NaN	NaN	☐
B0006.mat	NaN	NaN	NaN	NaN	NaN	☐

Figure 23. Edit ECD Points Table for Entering Microhardness Data of at Least 5 Parts Required for Training.

3.9 Training the System

To initiate training, access the **Learn** menu and select **Solve & Train Models** (Figure 24). The primary objective of this training phase is to familiarize the system with the database as a model, thereby equipping it to accurately test new, unknown parts from mass production.

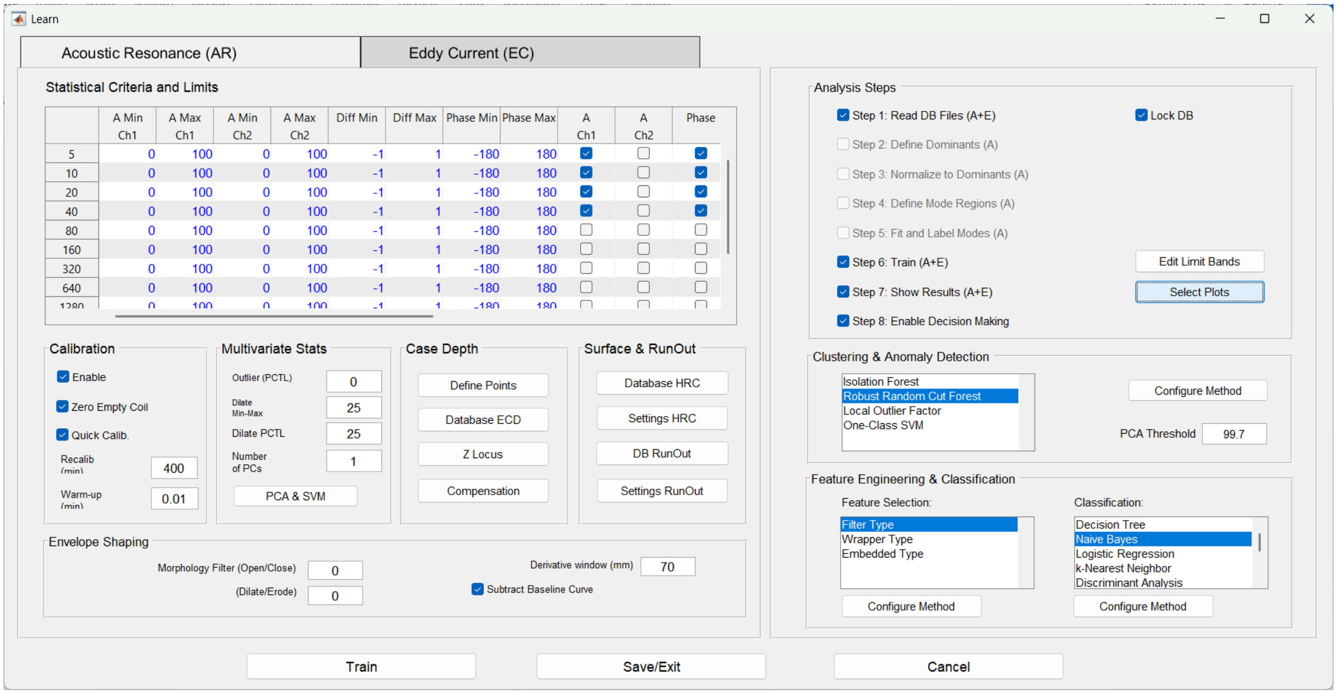


Figure 24. Display of the Learn Menu.

The progress bar shows the analysis steps:

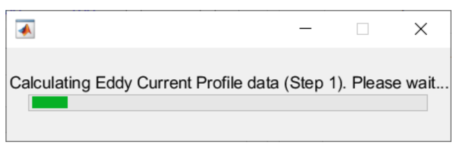


Figure 25. A progress bar will indicate the different steps involved in the training process.

As part of the training process, the **Profile Analysis** menu will automatically open, allowing you to review and modify the acceptance ranges (see Figure 26).

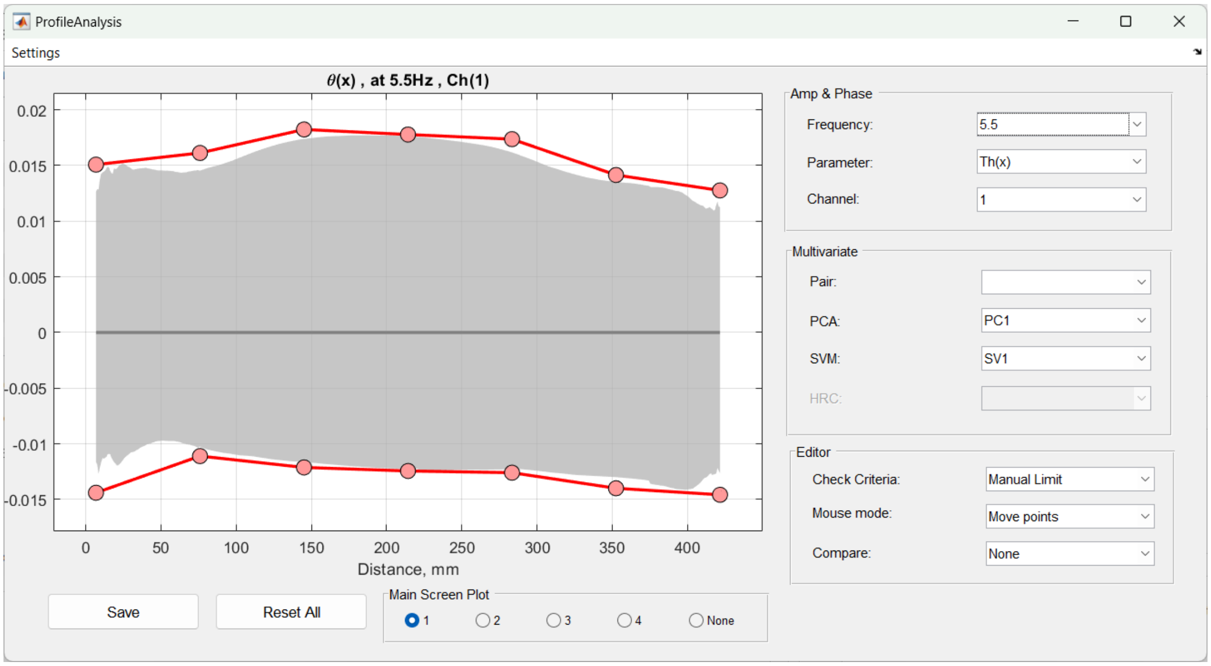


Figure 26. Profile editor menu. You can accept the default auto setting and close the menu.

By default, the suggested acceptance ranges in the **Profile Analysis** menu can be accepted as is, and the menu can simply be closed. However, when training the model for the first time for a new Part Setup, it's crucial to click **Reset All** to ensure the ranges are recalculated correctly.

- If the proposed ranges are not good, press the **Reset All** button to recalculate the ranges. Wait until the screen updates.

In the next phase, the training results and statistical outcomes (Step 7) are displayed sequentially. As each figure (window) opens, it will present the results one after another. Once you close a window, the next one will appear, showing the results for each frequency and criterion, until all the figures have been displayed.

- To bypass the opening of these figures, you can unselect **Step 7: Show Results** in the **Learn** menu.
- If you prefer to view only specific types of results, like envelopes or impedance planes, click on the **Select plots** button. Then, choose either **Fx Ranges** or **Trajectory** as per your requirement.

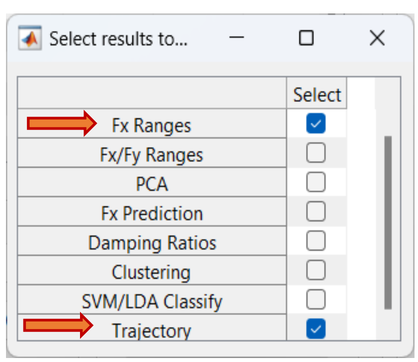


*Figure 27. Mark **Fx Ranges** to Display Envelopes, and/or **Trajectory** to View Impedance Planes at Defined Points.*

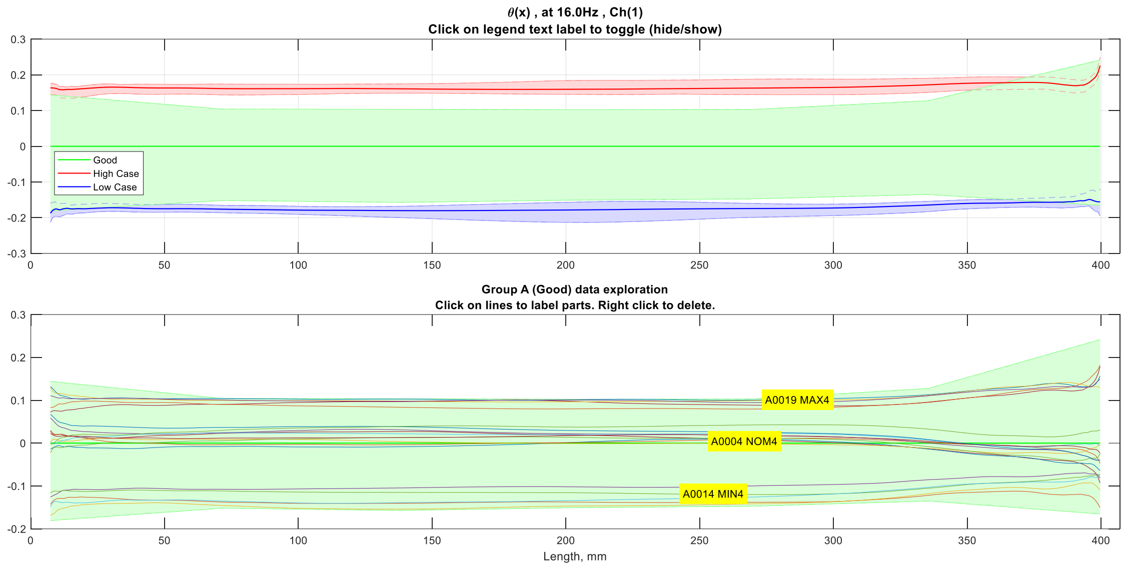


Figure 28. Database Visualization of Theta Envelopes at 16.0 Hz. The top section compares three groups: Good (Green) versus Bad (Blue and Red). The bottom section shows the database of 'Good' parts, which form the green limit band. Clicking on each line reveals the name of the corresponding part.

- The Green bands represent the "Accepted limits," which are set based on the "Good" parts introduced to the system's database. These include **Nominal**, **Max-In**, and **Min-In** reference samples.
- On the horizontal axis, the "Distance" along the part is measured in millimeters.
- The vertical axis displays the values of various criteria, such as **Theta**, **Amplitude**, or **Phase** at a specific Frequency, or any multivariate criteria that are derived from a combination of Amplitudes and Phases.

Close each window to progress to the next plot. If you wish to halt the sequence of plots, go to the **Interactive Tools** menu and select **Skip Plots**. This action stops the automatic opening of subsequent plot windows.

- ➢ Theta Envelopes $\theta_i(x)$ are the major parameters for Case Depth estimation. Low frequencies 5 to 20 Hz are used for Case Depth measurement.
- ➢ Examine the envelopes of all five groups meticulously. Should there be significant overlap between groups such as Max-Out and Max-In, perform a cut-check to confirm this observation. If it turns out to be true, remanufacturing the impacted group may be necessary. Typically, Max-In samples are found 0-0.3mm below the upper limit, while Max-Out samples tend to be 0.3-0.5mm above the upper limit.
- ➢ When training a database for the first time, it's important to review the graphs to confirm the validity of the samples and the accuracy of the settings. If you identify a sample that doesn't align with the others, you should exclude or remove that part from the database samples and also delete its corresponding file from the database.
- ➢ Once you've made the updates to the table (refer to Figure 23), it's necessary to retrain the database. During this training process, the "Profile Analysis" menu will appear. If you observe that the red limit bands don't align with the gray band, click on the "Reset All" button to recalibrate the limit bands (refer to **Error! Reference source not found.**).

If the **Trajectory** checkbox is selected in the **Select Plots** menu, the Z-Locus and case depth estimations at defined points are sequentially displayed. For a more comprehensive understanding of Theta curves and Z-Locus, please refer to Section 10.1. For instance, the impedance plane at a specific location, such as 230mm on the axle bar, is shown in Figure 29.

In this figure:

- Green dots represent **Good** parts from Group A.
- Red dots indicate parts with High Case Depth (**Max-Out**).
- Blue dots are for parts with Low Case Depth (**Min-Out**), all plotted at a specific cross-sectional point (e.g., 230mm) on the axle bar.

- Clicking on any dot will reveal the corresponding file name.

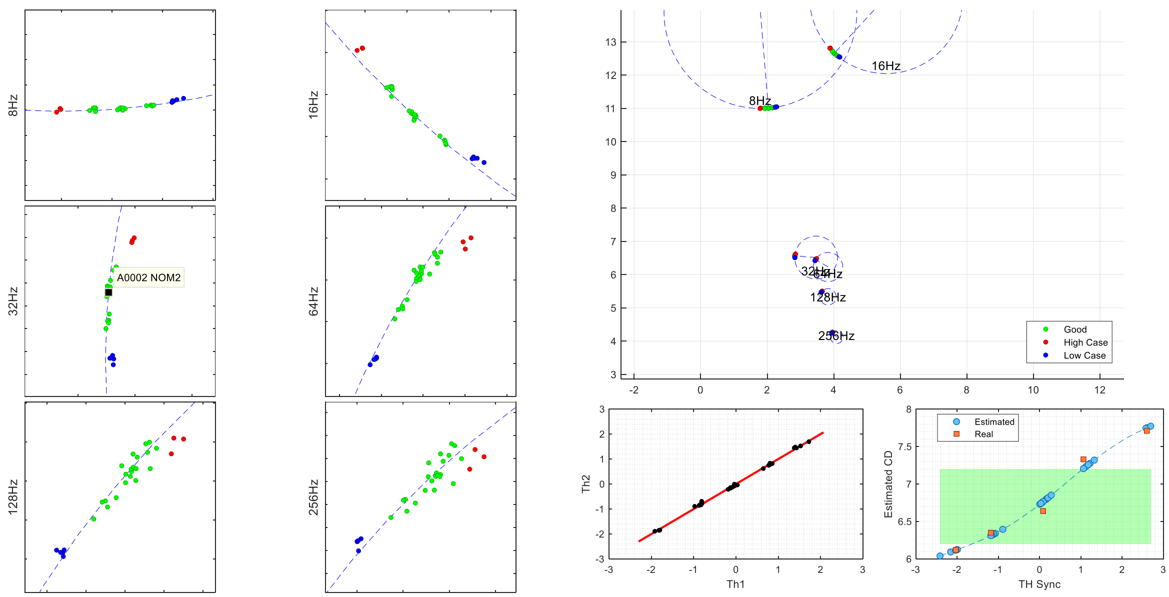


Figure 29. Visualization of Impedance (Z) Loci at Various Locations on the Axle Bar Post-Training.

A polynomial curve is used to establish the relationship between Θ (Theta) and ECD (Case Depth). To adjust the curve fit, select the **Interactive Tools** menu and then choose **Fit Options** CTRL+F (refer to Figure 30). For an in-depth explanation of the polynomial fit between Theta and ECD, please see Section 10.3.

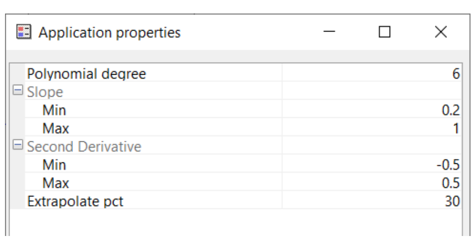


Figure 30. Adjusting Curve Fit Parameters.

If the **3rd Harmonic** option is enabled in the **Signal** menu, you have the ability to examine the 3rd harmonics at each point. However, by default, this option should be set to off.

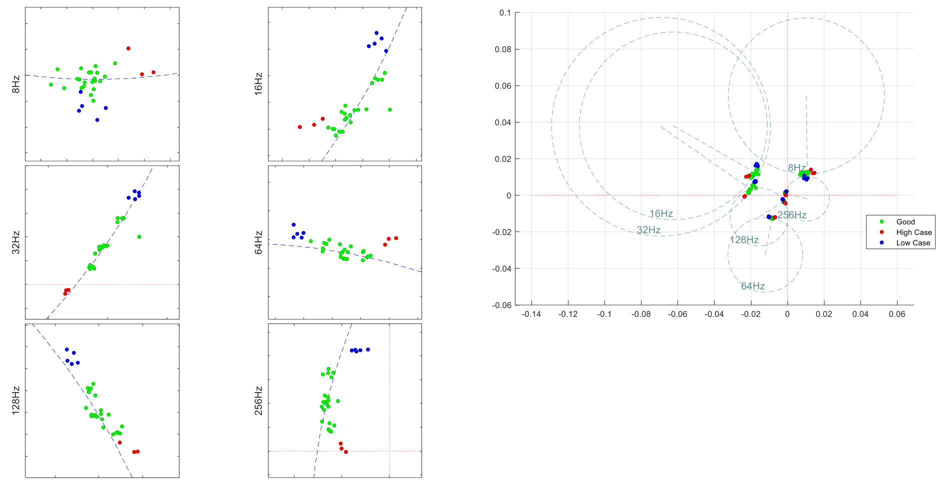


Figure 31. Display of 3rd Harmonics Loci at a Specific Location on the Axle Bar.

3.10 Testing

Following the completion of the training process, the system is now equipped to test unknown new parts. Below are some examples showcasing the results of these tests:

Example: Testing a Good Part (Nominal)

In this example, we conduct a test on a nominal part. Figure 32 displays the main screen with the test results. The Effective Case Depth (ECD) values at the five defined points are reported both on the top pane and in the right-side table.

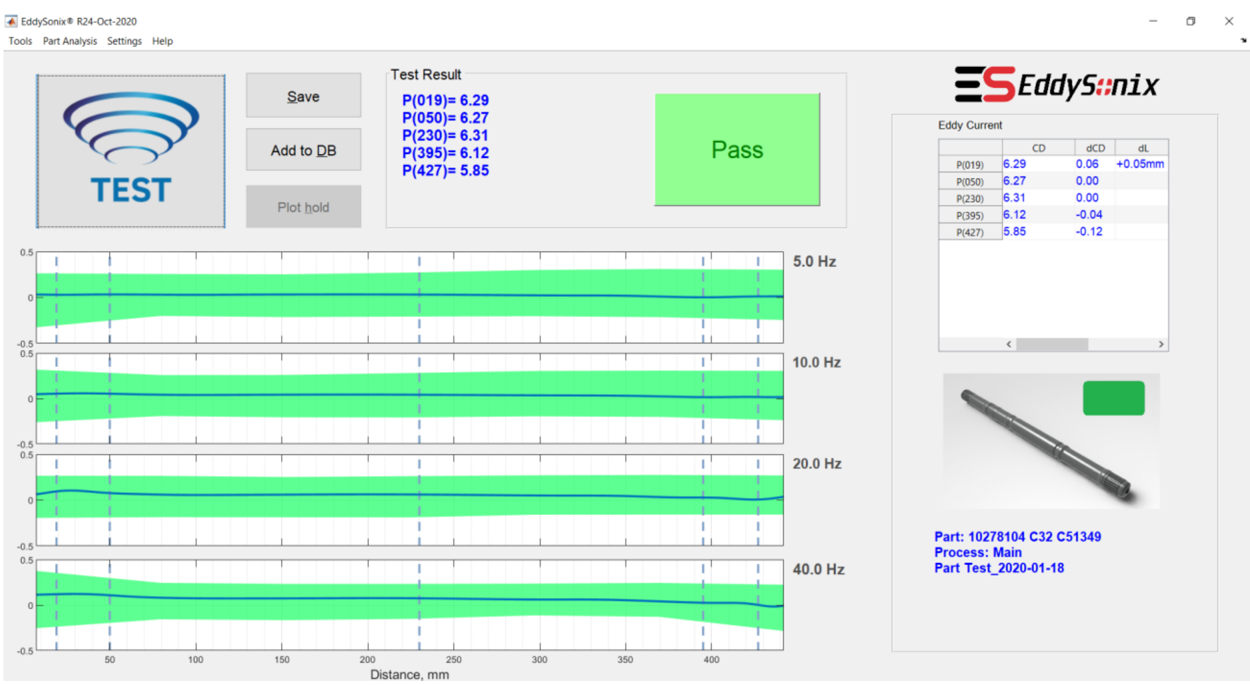


Figure 32. Display of Test Results for a "Good" Part, Showing Estimated ECDs at Five Points Along the Axle Bar.

For those interested in a more detailed view of the test results, pressing the 'R' or 'r' key provides additional information. Pressing 'r' (lowercase) displays envelopes that are partially out of the limit. However, pressing 'R' (uppercase) reveals all envelopes, encompassing both passing and rejected criteria, and includes a sequence of figures such as the envelopes and impedance planes.

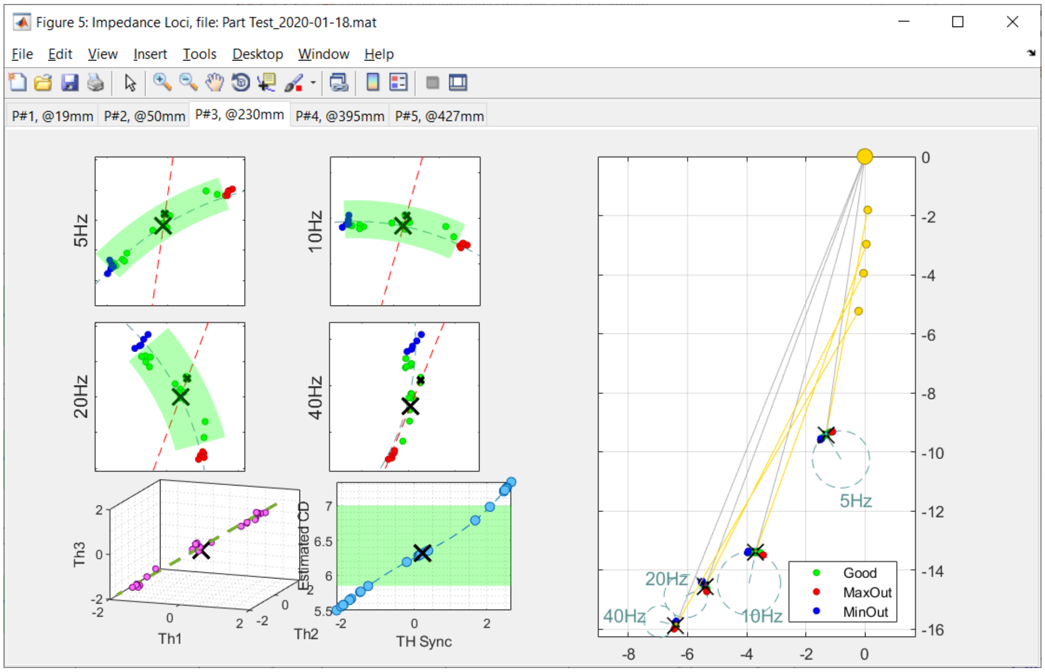


Figure 33. Detailed Test Results Accessible by Pressing 'R'. Use the Tabs Bar to View the Results for Each Defined Point.

Example: Bad Part (High Case Depth)

In this example, we examine the test results for a Max-Out part, indicative of a High Case Depth scenario (Figure 34).

Figure 34. Main Screen Displaying Test Results for a Max-Out Part with Deep Case at Various Locations.

For a more comprehensive view of the test results, press 'R' or 'r'. Then, utilize the Tab-bar to select and review the results for each specific point (Figure 35).

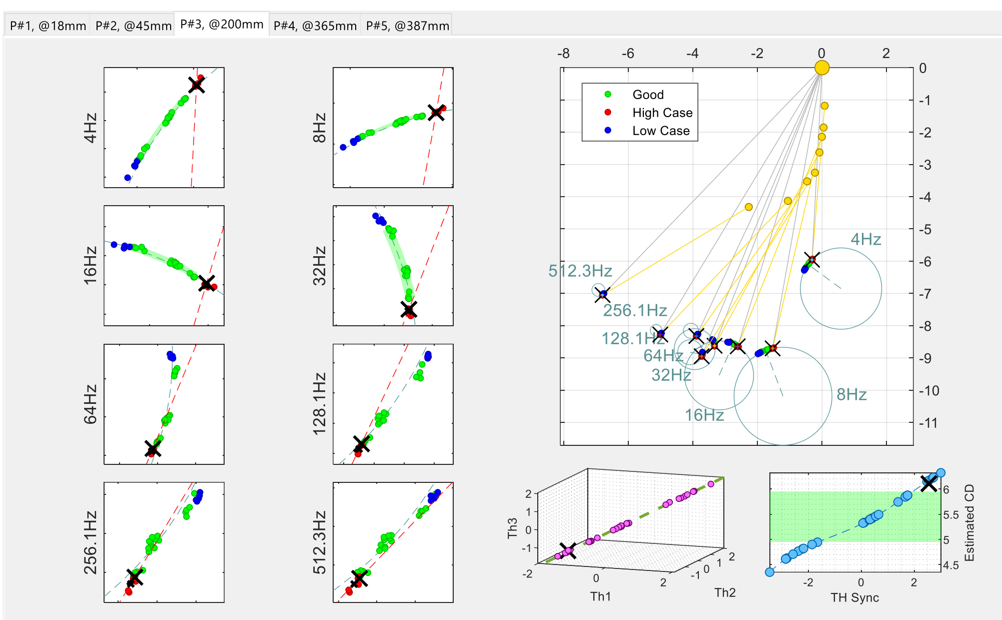


Figure 35. Display of the Impedance Plane for a Max-Out Sample at Point 3 (P3), Located 200mm Along the Axle Bar.

Example: Bad Part (Low Case Depth)

This example focuses on the test results for a part identified as having a Low Case Depth, typically referred to as a Min-Out part.

Figure 36. Figure: Main Screen Showing Test Results for a Min-Out Part with Low Case Depth at Various Points.

For Example 3, simply press 'R' or 'r' for detailed results, and then select the desired point from the Tab-bar.

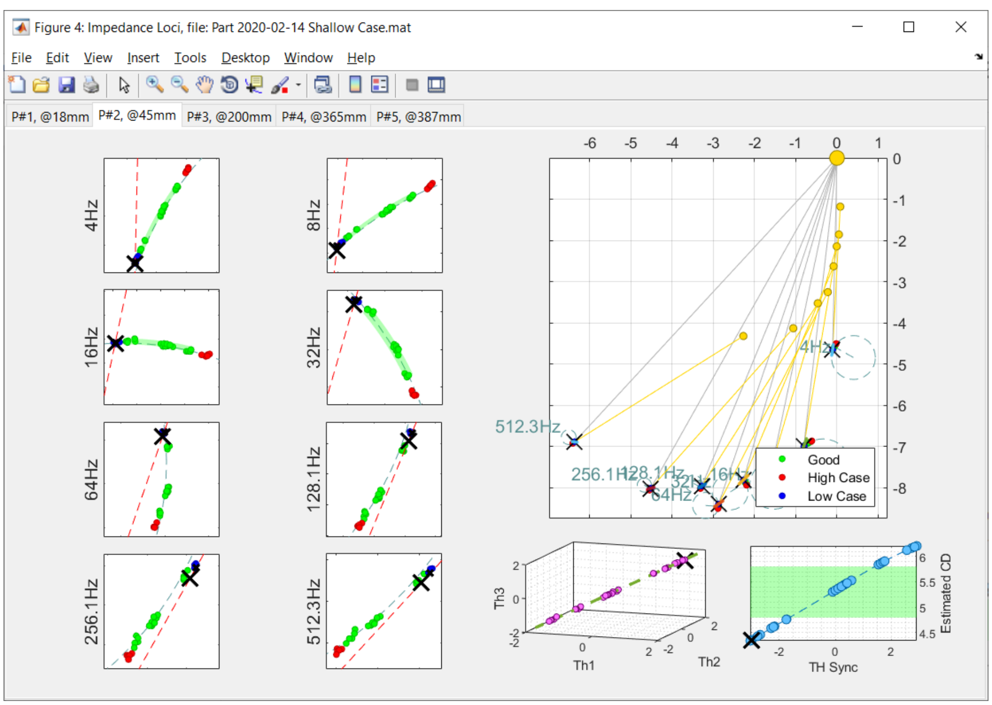


Figure 37. Display of the Impedance Plane for a Min-Out Sample at Point 2 (P2), Located 45mm Along the Axle Bar.

Example: LCL Alarm at P4 (350mm)

This example features an axle bar where the Effective Case Depth (ECD) falls below the Lower Control Limit (LCL) at Point 4 (P4), located at 350mm.

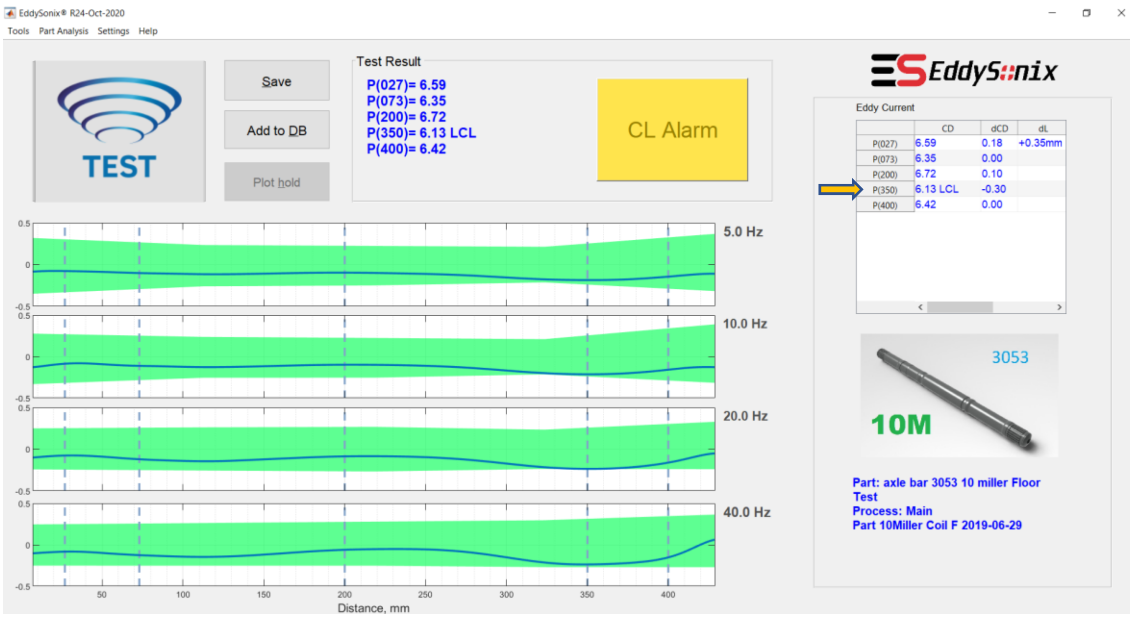


Figure 38. Illustration of Control Limits Set to Trigger Alarms for Points Approaching Tolerance Limits.

Example: Max Out at FBJ Spline (P1)

This case showcases a Max Out condition at the Fixed Ball Joint (FBJ) spline, identified at Point 1 (P1), located at 19mm. Figure 40 presents a 3D plot illustrating the theta responses across all frequencies, clearly depicting the increase in Effective Case Depth (ECD) at P1.

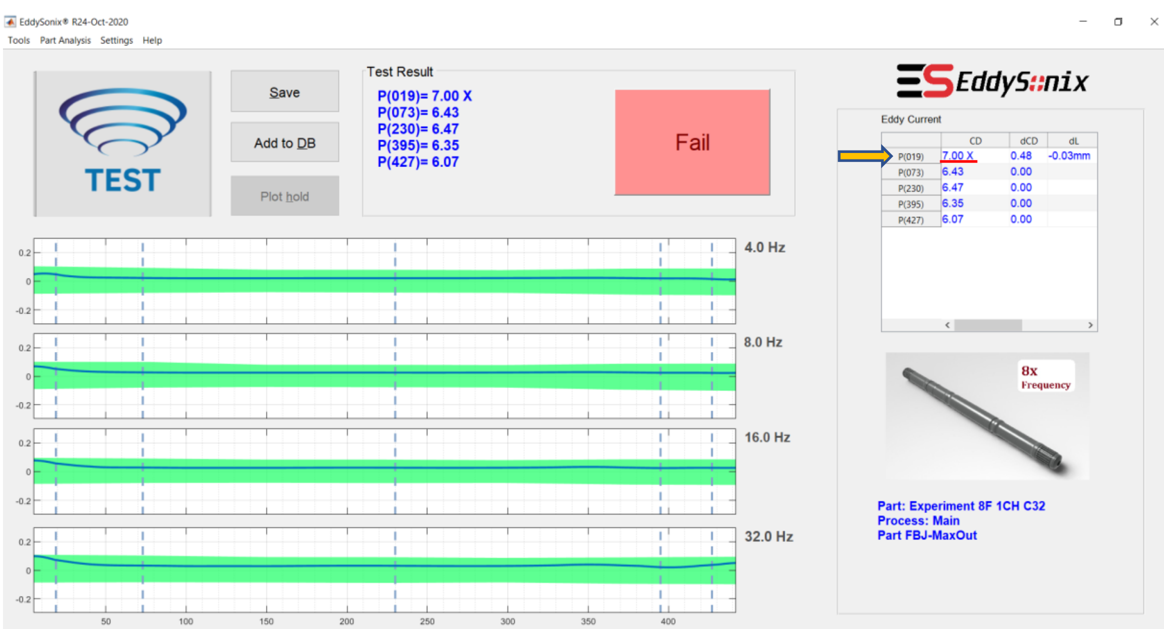


Figure 39. Accurate Estimation of ECD at Spline Ends Using Dynamic Compensation Algorithm.

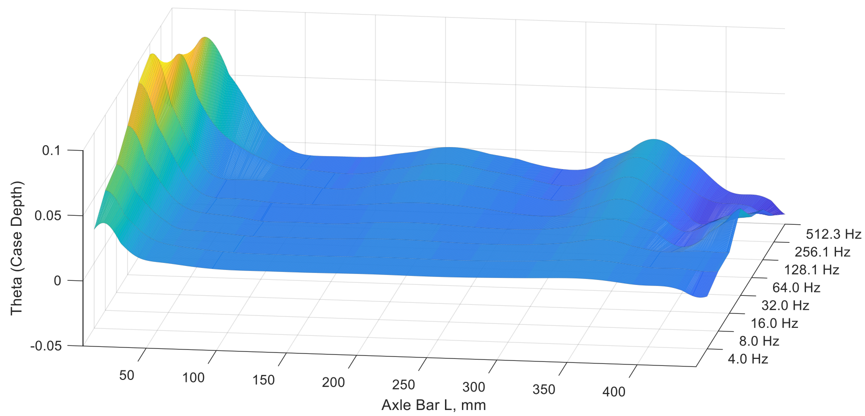


Figure 40. 3D Visualization of Theta (ECD) Response Across Frequencies (4 to 512 Hz) and Length, Highlighting ECD Rise at P1.

Example: Min Out at FBJ Spline (P1)

In this example, Point 1 (P1) at the Fixed Ball Joint (FBJ) spline, located at 19mm, is identified as a Min Out condition. Utilizing the Dynamic Compensation method, the system effectively identifies the decrease in Effective Case Depth (ECD) at this spline.

Figure 41. Display of Min Out Condition at FBJ Spline (P1), Highlighting the Decrease in ECD at 19mm, Detected Using Dynamic Compensation.

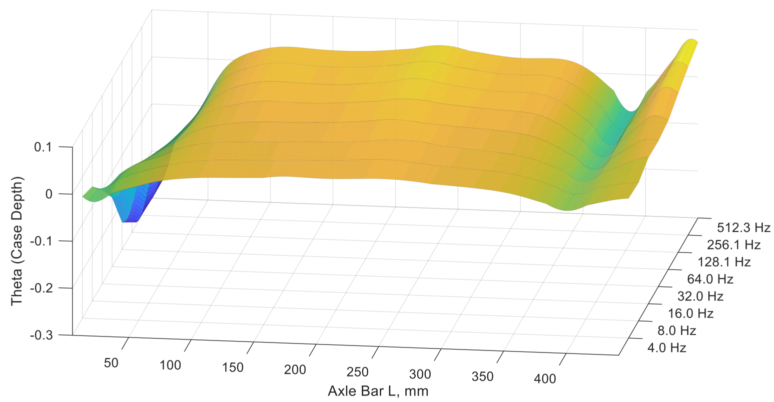


Figure 42. 3D Visualization of Theta (ECD) Response Across Frequencies (4 to 512 Hz) and Length, Showcasing ECD Fall at P1 Indicative of Min Out Condition.

3.11 Checklist to Update EddySonix Application

The EddySonix team provides regular updates to the application or supports customers in configuring Part Programs. Follow this checklist to successfully install and update the EddySonix application:

Step 1: Download Files

☐ Access the shared cloud and download the required files using your personal PC.

☐ Locate and download the **Program.zip** file to your local drive.

☐ Format a USB flash memory device and copy the **Program.zip** file to it.

Step 2: Copy Files to the EddySonix Machine

☐ Turn on the EddySonix machine and wait for the **autorun EddySonix application** to launch.

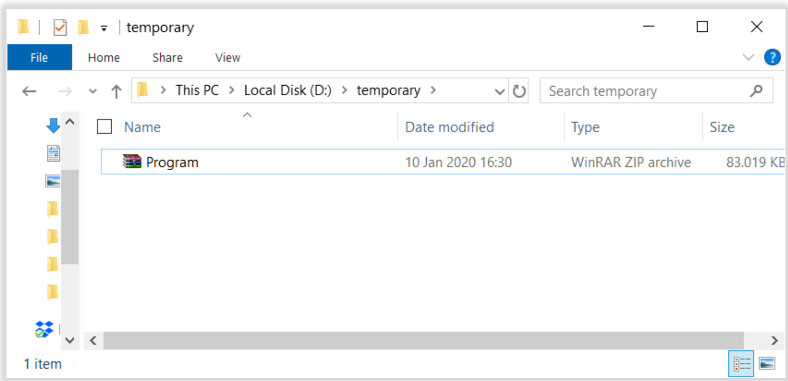
☐ Exit the EddySonix application.

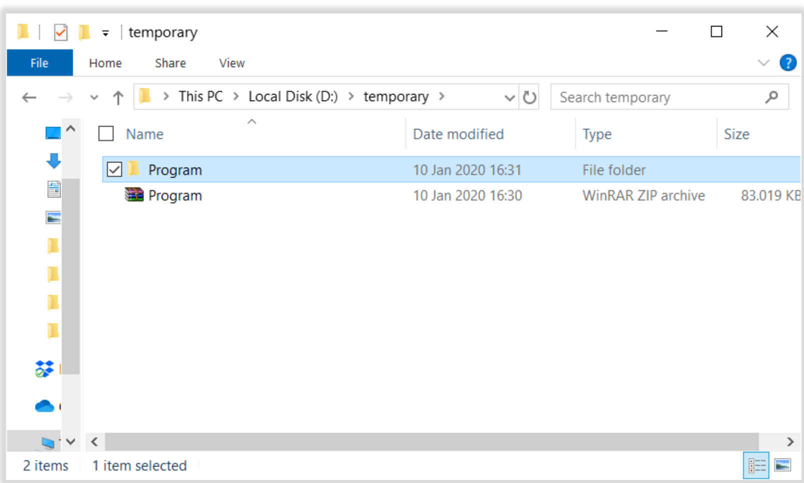
1. **Create a Temporary Folder**:
   - Use Windows File Explorer to create a **temporary folder** on the EddySonix machine.
   - Copy the **Program.zip** file from your USB flash memory to this folder.
2. **Extract Files**:
   - Unzip the **Program.zip** file into the temporary folder.
   - Open the extracted **Program** folder. You will see two files.
3. **Open Destination Folder**:
   - Navigate to the **D:\EddySonix\Program** folder using File Explorer.
4. **Copy and Replace Files**:

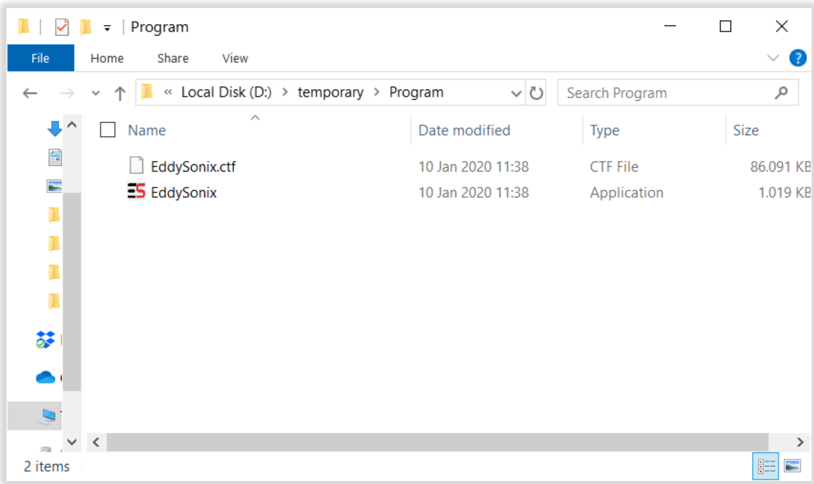
- Open both the temporary folder and the destination folder (D:\EddySonix\Program\) in separate windows.
- Select all files in the temporary folder (**Ctrl + A**) and copy them (**Ctrl + C**).
- Paste the files into the **D:\EddySonix\Program** folder.
- When prompted, select **"Replace the files in the destination"**.

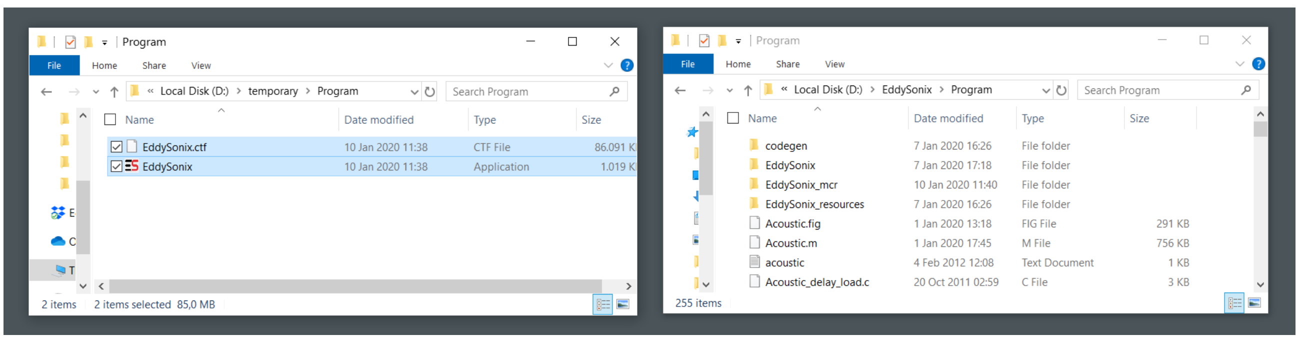
5. **Cleanup**:

   - Delete the temporary folder (D:\temporary).









Step 3: Run the Application

☐ Launch the updated application:

- Run **EddySonix.exe** from the path **D:\EddySonix\Program\EddySonix.exe**.
- Alternatively, restart the machine to allow the EddySonix application to run automatically.

☐ Wait approximately one minute for the installation and initial run of the updated application.

4 Part Setup and Configuration

4.1 Part Program Folder

The system allows for creating unlimited Part Programs for different types of parts. These programs are stored in: **D:\EddySonix\Parts**

For example: **D:\EddySonix\Parts\Axle Bar xyz**

Each Part Program folder contains the following subfolders:

1. **Config**
    - Stores settings specific to each part type or group.
    - Each part type has its own Config folder; there are no shared or general settings across parts.
2. **Database**
    - Contains records of Reference Parts.
    - Files for "Good" parts must begin with the letter A. Avoid using A for "Bad" parts, and do not use other starting letters (e.g., B, C) for "Good" parts.
    - Use Windows® File Explorer to delete files, but do not add or copy files into this folder manually.
    - Files can be renamed to include short descriptions.
3. **FEM Results**
    - Stores mode shape animations for Acoustic Resonant mode.
    - For Eddy Current mode, save a photo of the part as PartImage.jpg (resolution: 800x600, size <100 kB) to display on the main screen.
4. **Test**
    - Contains temporary files for tested parts.
    - Save parts into this folder by pressing the **Save** button or pressing the S key.
    - Filenames can be arbitrarily assigned or auto-serialized by the software.
5. **Daily Report**
    - Logs Pass/Fail test results.
    - Each day's log is saved in a separate file.
    - To view logs, open the **Daily Report** menu, select dates from the calendar, and generate a PDF report.

Warnings

1. Do not rename or delete subfolders after creating a new Part Program.
2. To delete or rename a Part Program:

- Remove it from the list of active groups in the software via the **Part Selection** menu (select and click **Delete Row**).
- Then, use File Explorer to rename or delete the Part Program.

4.2 Part Definition menu

Use the **Part Definition menu** to configure the initial settings for a new Part Program.

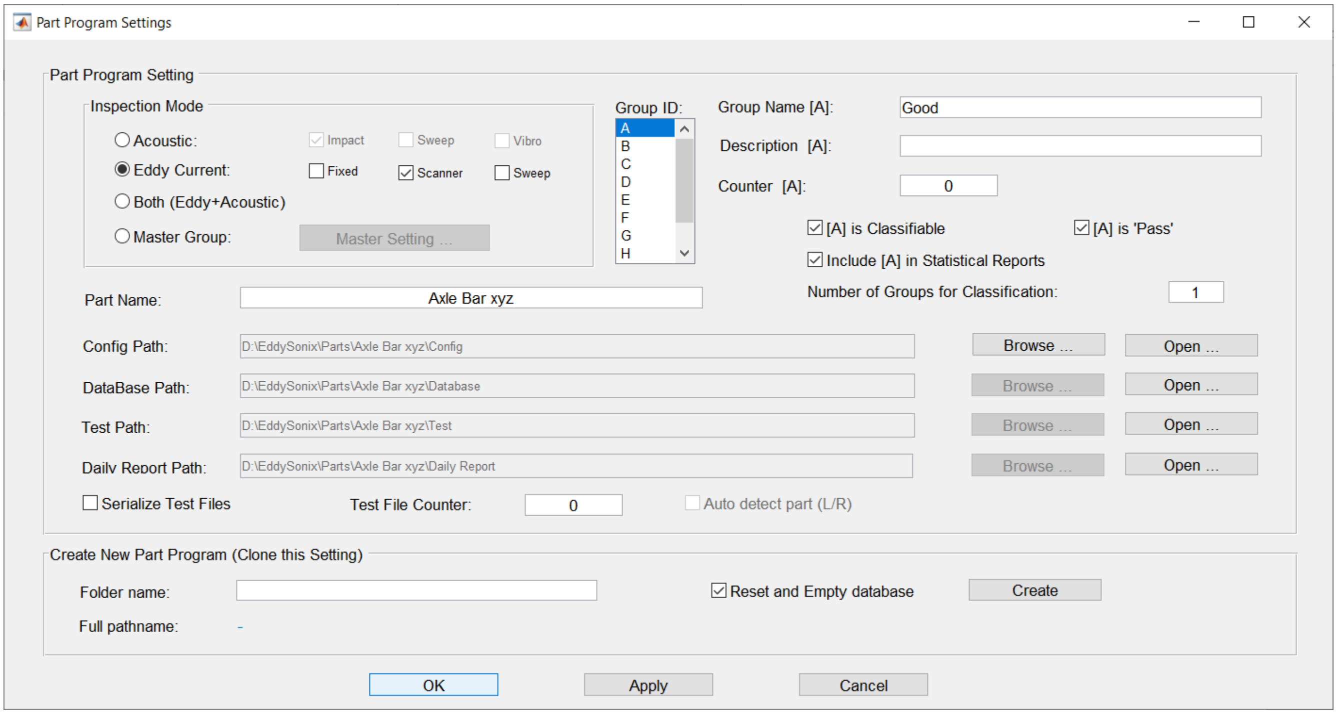


Figure 43. The first step to create a new Part Program

Steps to Create a New Part Program

1. **Open the Part Definition Menu**
   - Navigate to the **Part Definition menu** to begin setup.
2. **Set Config Path**
   - Click the **Browse...** button next to the **Config Path** field and select the new Config folder.
   - The remaining four paths will adjust automatically. Verify that all paths are correct.
3. **Edit Part Name**
   - Enter the desired name in the **Part Name** field. This name will appear on the main screen as the active Part Program.
4. **Reset Group ID Counters**
   - Select each Group ID (A, B, C, etc.) and reset their counters to 0.
5. **Configure Group IDs**

- Configure the following Groups and their labels:
    - **Group A**:
        - Label: **Good**
        - Settings:
          ☒ **Classifiable**
          ☒ **Pass**
          ☒ **Include in Statistical Reports**
    - **Group B**:
        - Label: **High Case**
        - Settings:
          ☒ **Classifiable**
          ☐ **Pass**
          ☒ **Include in Statistical Reports**
    - **Group C**:
        - Label: **Low Case**
        - Settings:
          ☒ **Classifiable**
          ☐ **Pass**
          ☒ **Include in Statistical Reports**
- **Groups D and E**: Reserved for **Surface Hardness** and **Runout** testing, respectively.

6. **SVM Classifier Configuration (if applicable)**
    - If the **SVM (Support Vector Machine)** classifier is activated:
        - Set **Number of Groups for Classification** to 2.
        - Ensure only **Groups B and C** are marked as **Classifiable**.
        - Leave other groups (D, E, etc.) unchecked. This ensures the SVM classifier focuses solely on **High Case** and **Low Case** groups.

4.3 Part Selection menu

The **Part Selection menu** opens automatically after closing the **Part Definition menu**. You can also access it anytime by navigating to the **Parts Analysis menu** and selecting **Part Selection (Ctrl + H)**.

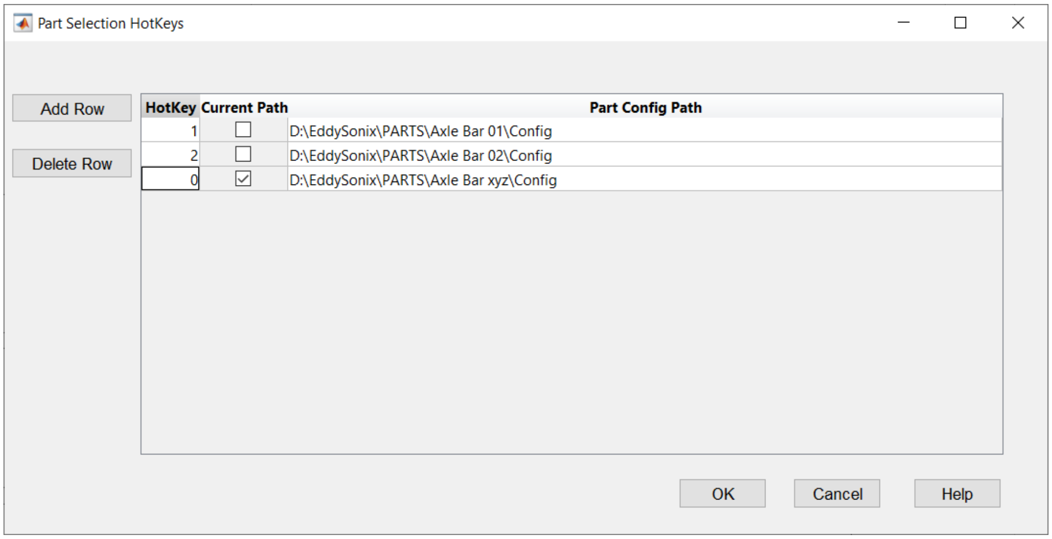


Figure 44. Selecting an already defined Part Program.

Overview

- The menu displays all available Part Programs.
- The **active Part Program** (Current Path) is marked with a check.
- You can define **Hot Key Numbers** for quick switching between Part Programs from the main screen (optional).

Using Hot Keys

1. **Single-Digit Hot Keys (1–9)**
    - Assign a Hot Key Number to a Part Program.
    - On the main screen, press the assigned number (1–9) to instantly switch to the corresponding Part Program.
2. **Two-Digit Hot Keys (10–99)**
    - Assign two-digit Hot Key Numbers.
    - To activate a Part Program:
        - Press 0 on the main screen.
        - Enter the two-digit Hot Key in the pop-up box.

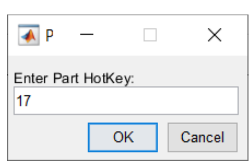


Figure 45. Two-digit hotkey menu

Editing the Part Program List

- **Delete Row:**
  - Removes a Part Program from the list but does not delete its associated files or folders.
  - Active Part Programs (checked) cannot be deleted.
- **Add Row:**
  - Adds a new Part Program to the list.
  - Use the Path Selector to select the **Config Path** for the new program.
  - Manually mark the new path as active (Current Path).

We recommend always keeping a backup of this file, as it might get corrupted or deleted:

`C:\EddySonix\Program\HotKeys.mat`

If any issue occurs, you can simply copy the backup file back into the same folder.

4.4 Control I/O menu

In **Eddy Current mode**, only the **Test Mode** and **PLC / Servo Drive** panels in the **Control I/O menu** are used.

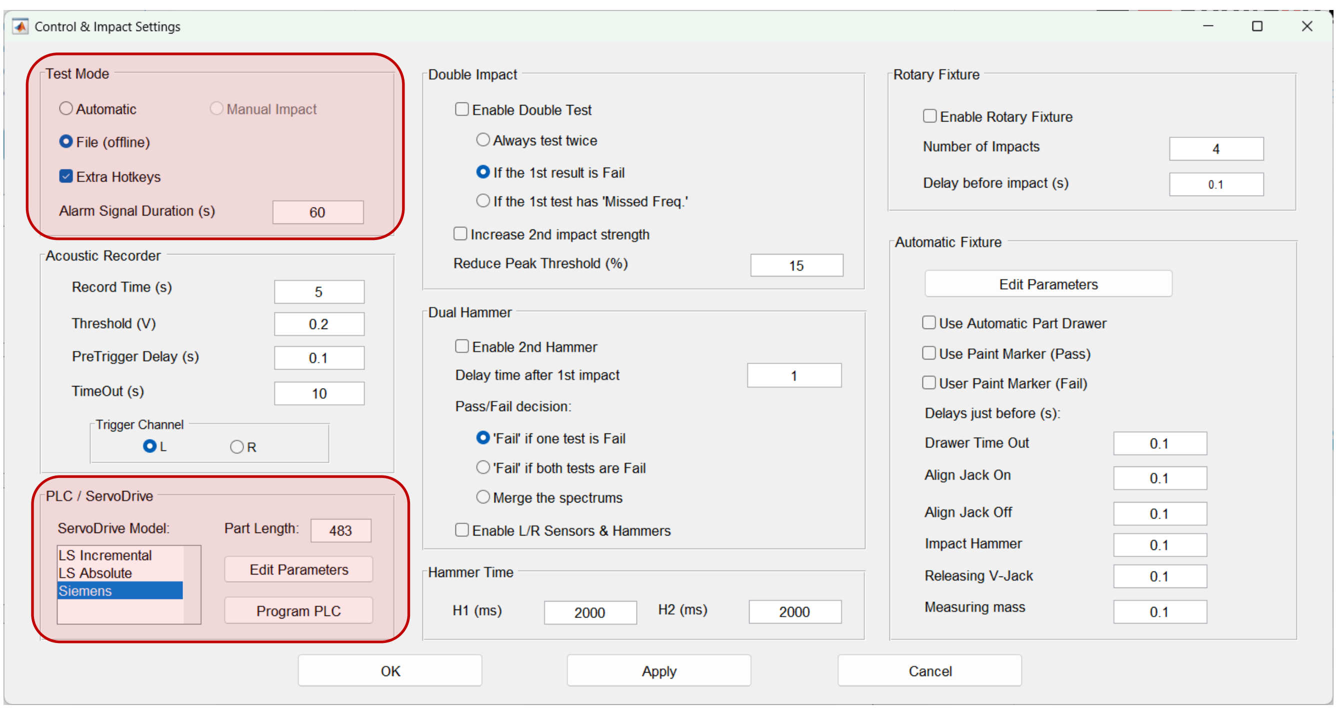


Figure 46. Control I/O menu to define Part length and program PLC

Test Mode Panel

Test Mode Selection:

- **Automatic**: Default mode for online part testing.
- **File (Offline)**: Test parts using files previously saved in the **Database** or **Test** folder.

Enable Hotkeys:

- By default, this checkbox is **OFF**. When enabled, keyboard shortcuts become active:

Hotkey	**Action**
A	Switch to Automatic (Online) mode
C or X	Close all plot windows (keep main window)
D	Add part to Database
F	Switch to File (Offline) mode
H	Hold Plots (Toggle)
M	Manual Impact mode (Acoustic Resonant)
O	Open Test folder
Q	MECC Transfer for traceability
R	Plot all test results of the last part
r	Plot only failed test results of the last part
S	Save part to Test folder
W	Generate Daily/Log Report
Z	Plot raw signals

- When **Enable Hotkeys** is checked, you can adjust the **vertical zoom** on plot axes by clicking with the mouse.
- **Always Active Hotkeys**: Regardless of the checkbox status, the following shortcuts are always active: D, S, C, R, r.
- To view the full list of hotkeys, go to **Help → Keyboard Shortcuts**.

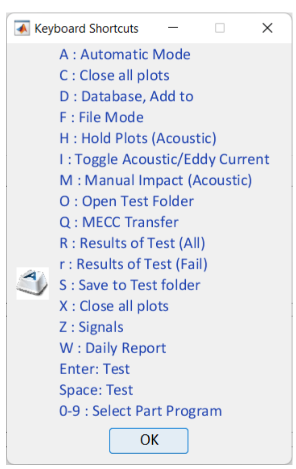


Figure 47. Keyboard shortcuts help

Alarm Signal Duration (s):

- Specifies how long test results and alarm signals (green/red) are displayed.
- Starting a new test clears the results and alarms from the previous test.

PLC / Servo Drive Panel

- **Edit Parameters**:
    - Only edit the **Part Length (mm)** when setting up a new part. Do not modify other parameters.
- **Program PLC**:
    - Programs the PLC with updated parameters.
    - Once programmed, the coil will move and scan the part.

Warning:
Ensure the **bottom center is adjusted** for the new part length **before programming the PLC**.

- When switching between Part Programs with different lengths, the software will automatically verify and update the PLC parameters.

4.5 Signal menu

In this menu you can define the excitation frequencies and their associated parameters. Normally the default settings are appropriate for setting up a new part program. If you want to change a setting, contact the EddySonix team for assistance.

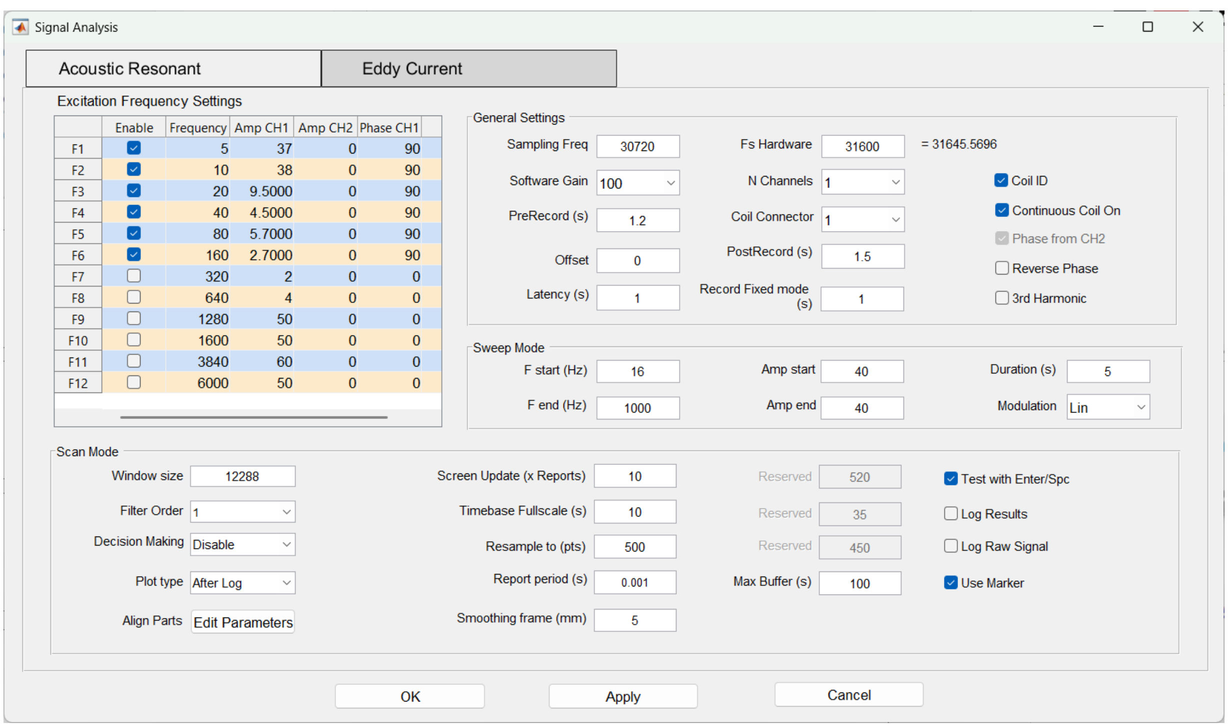
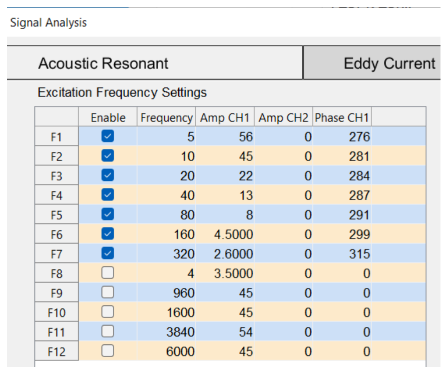


Figure 48. Signal Settings

Excitation Frequency Settings

Enable – You can activate multiple frequencies by checking the **Enable** field. The values of Frequency and Amplitude are editable.



	Enable	Frequency	Amp CH1	Amp CH2	Phase CH1
F1	☑	5	56	0	276
F2	☑	10	45	0	281
F3	☑	20	22	0	284
F4	☑	40	13	0	287
F5	☑	80	8	0	291
F6	☑	160	4.5000	0	299
F7	☑	320	2.6000	0	315
F8	☐	4	3.5000	0	0
F9	☐	960	45	0	0
F10	☐	1600	45	0	0
F11	☐	3840	54	0	0
F12	☐	6000	45	0	0

Figure 49. Define excitation frequencies and amplitudes.

Frequency – The value of Frequency should be an integer factor of Sampling Frequency. If you edit an arbitrary number, the software will automatically adjust it to the nearest factor, such that the Sampling Frequency is divisible by that number. For example, if you edit 27Hz, it will be modified to 25Hz to be divisible by Sampling Frequency (50'000 Hz).

If you change the frequencies, be sure to modify the **Window size** value in the **Scan Mode** pane. This value will be automatically adjusted to the selected frequencies. Just click on the edit box and hit Enter to be modified. The window size unit is "samples". For example, if the Sampling Frequency is 50'000Hz, and the Window size is 20'000, the window is 20'000/50'000 = 0.4sec. This value is the LCM (Least Common Multiple) of the periods of the excitation frequencies. Make sure that the proposed Window is less than 1 sec. If the value is too high, the selected frequencies do not have a small common multiplier. In this case, change the values of the frequencies and check the Window size again.

- Window of signal decomposition should contain at least "2 periods" of each excitation frequency. This is the minimum limit.
- The optimum value for the window size is approximately 0.4 or 0.5 s.
- Always check the decomposed signal (press "Z" after testing a part) to make sure it is clean, noise free, and unsaturated.
- After training the database, make sure the envelopes (Amp, Phase, Theta) are clean, noise free, and ripple free.

Amplitude – The Amplitude of each frequency can be adjusted separately. The final excitation signal is the sum of the selected sinewaves:

$$S(t) = \sum_i A_i \sin(2\pi F_i t)$$

Where *S(t)* is the excitation signal, '*i*' is the index for selected frequency, A_i is Amplitude, and F_i is Frequency.

After setting the above parameters, always scan a part and check the recorded signal by pressing the 'Z' hot key:

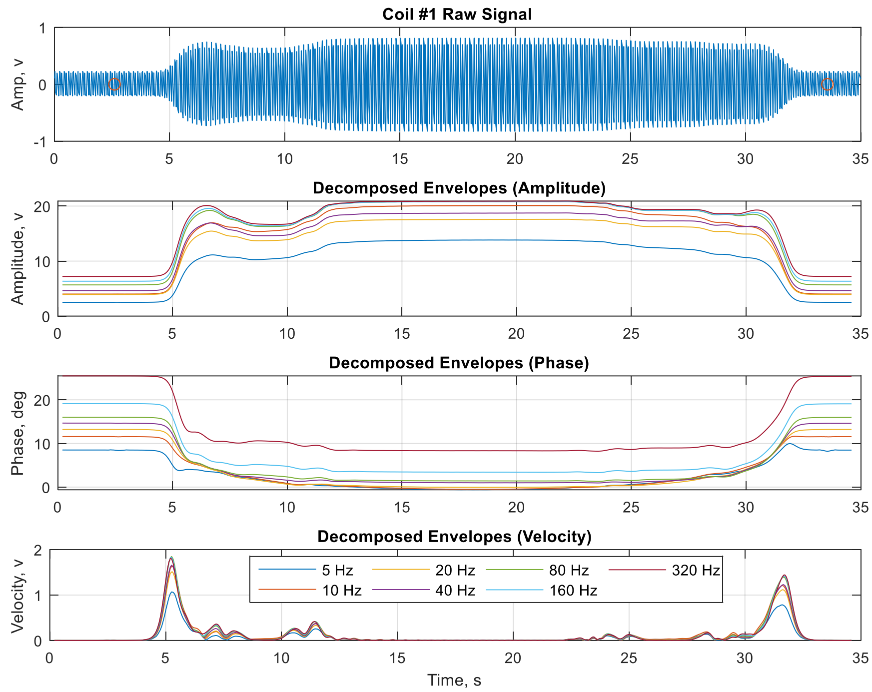


Figure 50. Check raw signals to make sure that the amplifier is not saturated.

You can zoom in to see the details. Use the mouse roller to zoom in or out quickly.

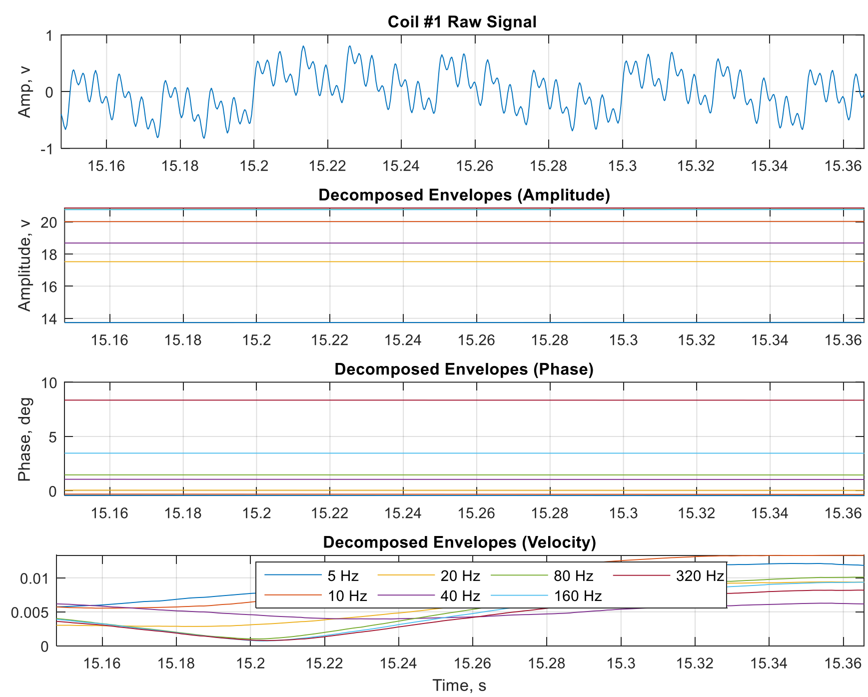


Figure 51. Zoom view of the raw signal. Make sure that the peaks are not saturated. Reduce excitation amplitudes if the peaks are saturated.

- Check that the recorded signal is not saturated and noisy.
- Check that the Amplitudes of the decomposed frequencies are in good proportion.

Cross Over Frequency F_C –At this frequency, all parts (shallow to deep) have almost equal Amplitude, and only phase is sensitive to case depth. As a rule of thumb, the relation between F_C and nominal Case Depth (CD) is:

$$\sqrt{F_C}.CD = 19$$

For example, if the nominal Case Depth is 6.3mm, then F_C=9.1Hz.

If you test a part with Case Depth higher than nominal, then:

- Amplitude decreases for frequencies less than F_C
- Amplitude does not change at F_C
- Amplitude increases for frequencies higher than F_C
- Phase always increases at all frequencies

If you test a part with Case Depth lower than nominal, then:

- Amplitude increases for frequencies less than F_C
- Amplitude does not change at F_C
- Amplitude reduces for frequencies higher than F_C
- Phase always decreases at all frequencies

Align Parts

At the start of Database creation, we scan a part and save it as the Master. This Master is only used to align all future parts so that they have the same length and share the same zero point. For normal axle bars with two ends, the software detects both edges, then shifts the first edge to the Zero position and stretches the other end until its length matches the Master. In this process, the new virtual part may become slightly shorter or longer (up to ±2 mm), but it is adjusted to the exact Master length with 0.1 mm accuracy.

This alignment is critical. Only after this step can we overlap all Database envelope signals and build the Impedance Plane Loci (Z-Locus). Even a 1 mm random edge shift makes it impossible to check the splines or the zones near each end. This happens because the raw eddy current signals (Amplitude and Phase) change very quickly near the edges. That's why alignment and synchronization with the Master part are essential.

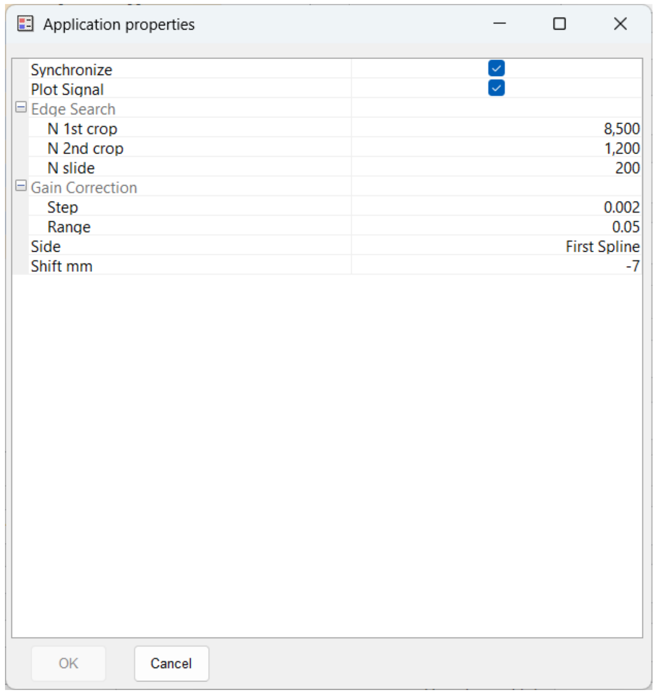


Figure 52. Align Part settings

4.6 Learn Menu (Overview)

The Learn menu is where you can define and adjust various criteria for evaluation. Whenever you modify any settings or are training for a new Part Setup for the first time, access the **Learn** menu and select **Solve & Train Models**.

To begin, navigate to the **Case Depth** pane. Here, you'll find four key buttons: **Define Points**, **Database ECD**, **Z Locus**, and **Compensation**. Each of these requires parameter adjustments.

- **Define Points:** For detailed instructions, refer to sections **Error! Reference source not found.** and 3.4
- **Database ECD:** See section **Error! Reference source not found.** for guidance.
- **Z Locus:** See section
- **Compensation:** See section **Error! Reference source not found.**

Ensure to review and adjust these settings carefully as they are critical for the accurate functioning of the system.

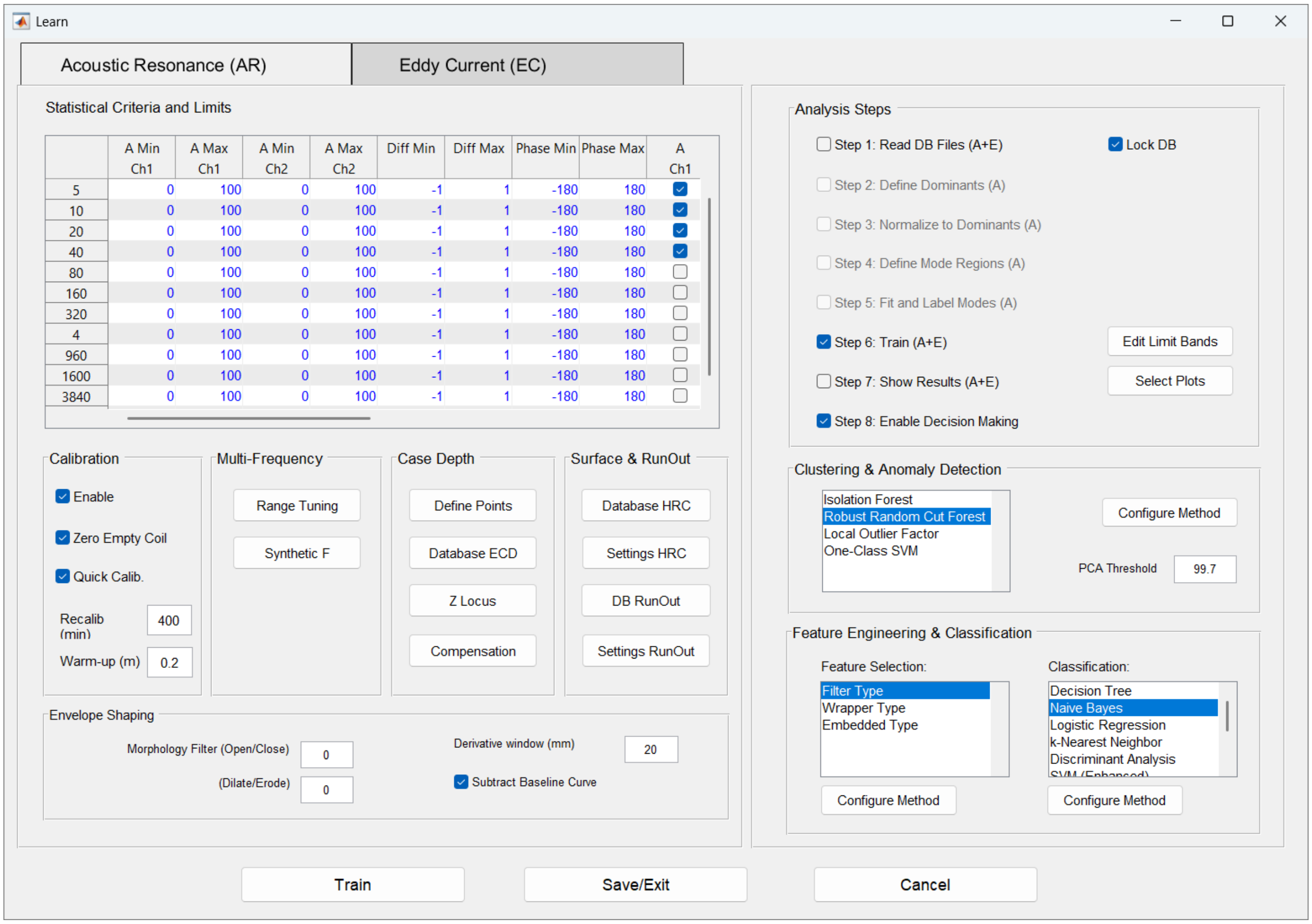


Figure 53. Learn Menu

4.7 Coil ID

Each coil has a unique ID that is recognized by the program. The system performs two checks:

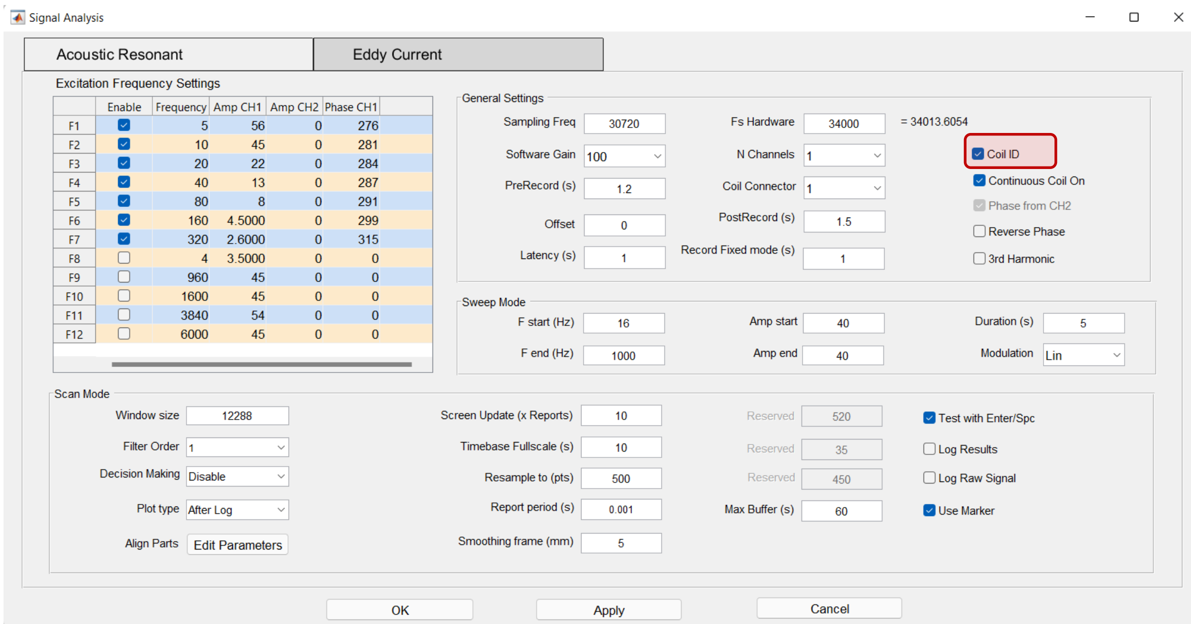
1. Whether the coil is properly connected to the device.
2. Whether the coil matches the selected Part Program

Examples of coils IDs:

Coil ID	Name / Label
C20220206213522	32A
C20220206213659	32B
C20220206213746	37A
C20220206013601	37B
C20220206013709	27A
C20220206213616	27B

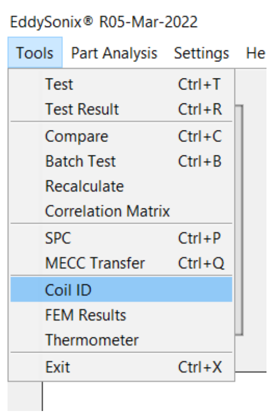
Activating Coil ID Recognition

1. Open the **Signal menu**.
2. Check the **Coil ID** option to enable the feature.

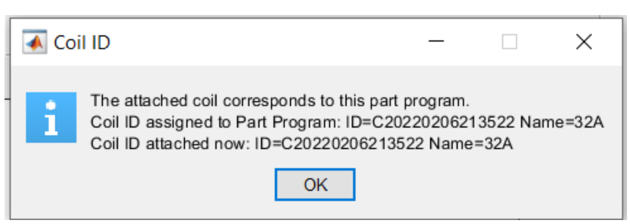


Accessing Coil ID Information

- Navigate to **Tools → Coil ID** to view details about the connected coil.

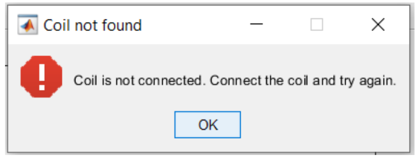


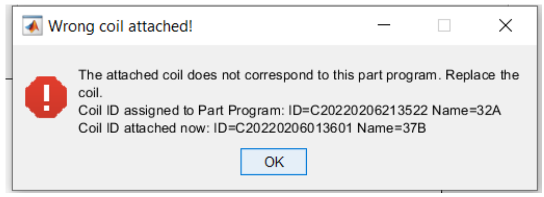
Example message:



Error Messages

If the coil ID is incorrect during testing, the program will display one of the following error messages:





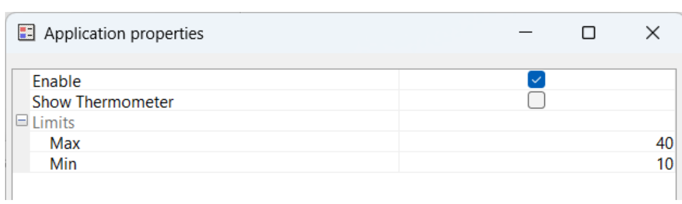
The machine checks the coil when you change the program and press the Test button. So, after selecting a new program, the coil is not immediately checked — the check only happens when you start the test. This gives you time to replace the coil before pressing Test.

We recommend updating the Part Name to include the Coil Number. This way, after changing the program, you'll clearly know which coil to use. Remember, the coil isn't checked until you press the Test button.

4.8 Enabling the Ambient Temperature Sensor

The system measures ambient temperature and saves it in each test file. Temperature readings can be displayed on the main interface. Set upper and lower temperature limits; the system alerts if these are breached, indicating unsuitable operating conditions. Configure temperature settings as follows:

1. Go to "Temperature Compensation" in the menu.
2. In the "Eddy Current" section, select "Settings."
3. Use "Edit" to modify temperature parameters:



4.9 Servo drive Motion Control

The **servo drive motion control** feature enables programming the absolute servo drives for **variable speed** during the scanning process.

- **Speed Adjustment**: The servo drive can move slower at critical areas, such as splines or other predefined points, to ensure precise measurements.
- **Efficiency**: The drive accelerates at mid-sections of the axle part, where high precision is less critical, optimizing the overall scanning process.

Benefits:

- **Faster Test Times**: By adjusting the speed dynamically, the testing process is completed more efficiently.

- **Reduced Data Size**: Minimizing the scanning time at non-critical areas results in smaller raw data files, streamlining data handling and analysis.

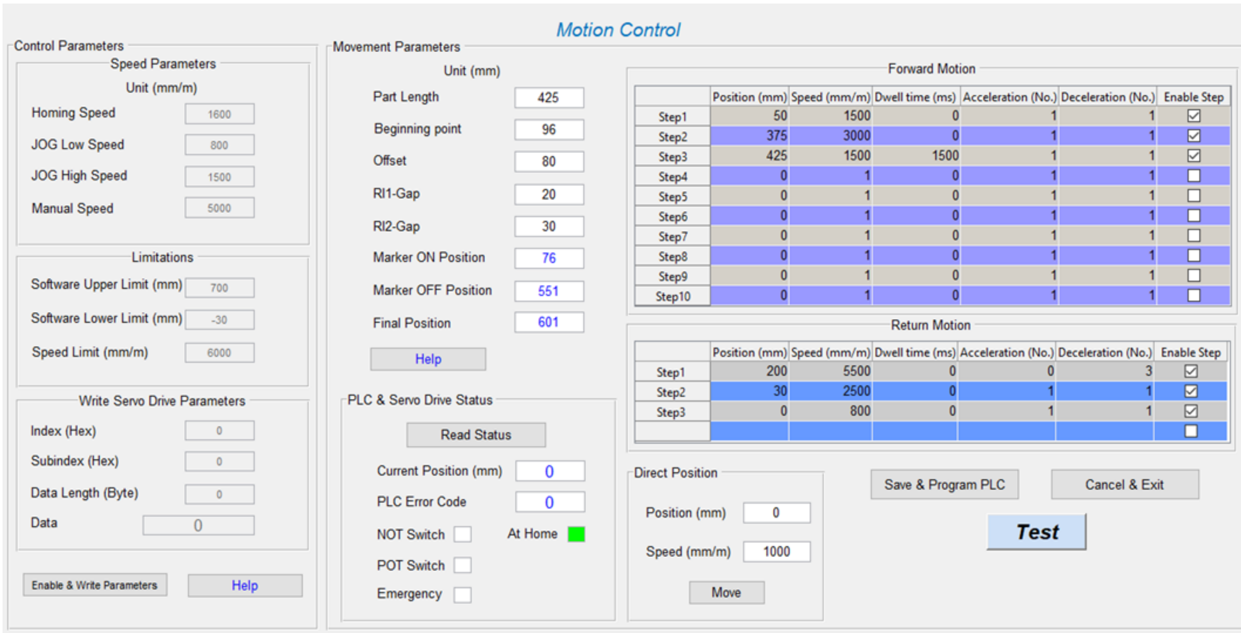


Figure 54. Motion Control menu for servomotors.

Servo Drive Motion Control Pane Descriptions

Forward Motion

- **Step Control**: Define up to **10 steps** for scanning the axle bar.
- **Custom Parameters**: Configure position, speed, hold time, acceleration, and deceleration for each step.
- **Example Usage**: For long parts, increase scanning speed in the middle section (no diameter variation) to optimize cycle time, and reduce speed at splines for enhanced precision.

Return Motion

- Define up to **3 steps** for the return motion to the "Home" position.

Direct Position

- Designed for **study and debugging**, allowing direct movement of the coil to a specified position at a defined speed.

Movement Parameters

- **Key Adjustment**: Modify only the "Part Length" field for each part type.
- **Caution**: Avoid changing other fields.
- **Help Button**: Use the "Help" button to display detailed descriptions of each parameter for guidance.

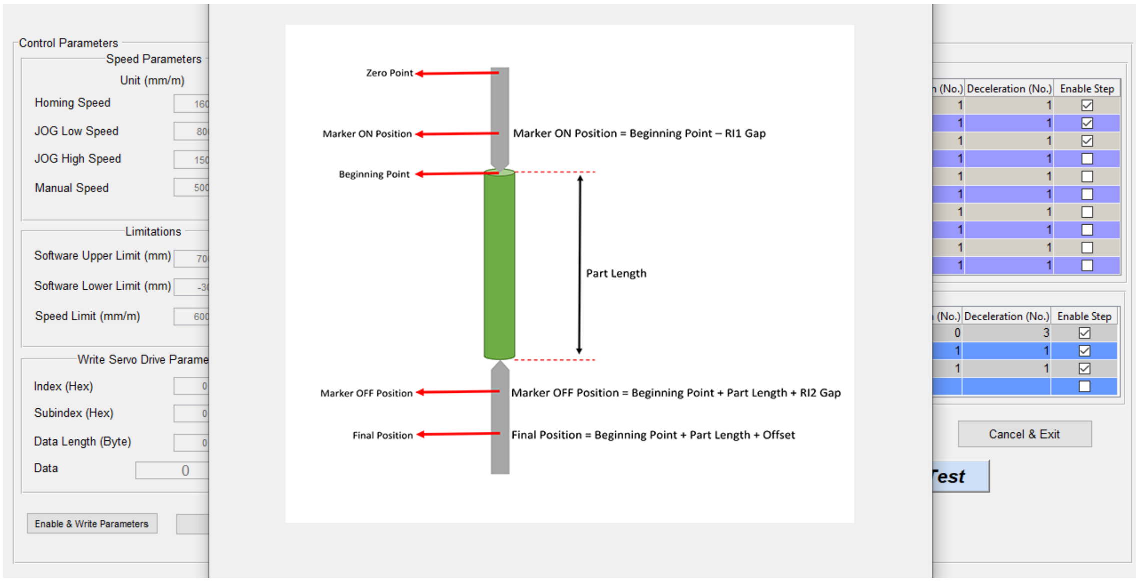


Figure 55. Press the "Help" button to show the description of "Movement Parameters".

PLC & Servo Drive Status

This panel allows you to monitor the operational status of the **PLC** and **Servo Drive**.

- **Status Monitoring**: Provides a quick overview of system functionality.
- **Read Status**: Press the **"Read Status"** button to display detailed information, including any **Servo Drive alarms** and **error codes**.

Use this feature to diagnose and troubleshoot any issues promptly.

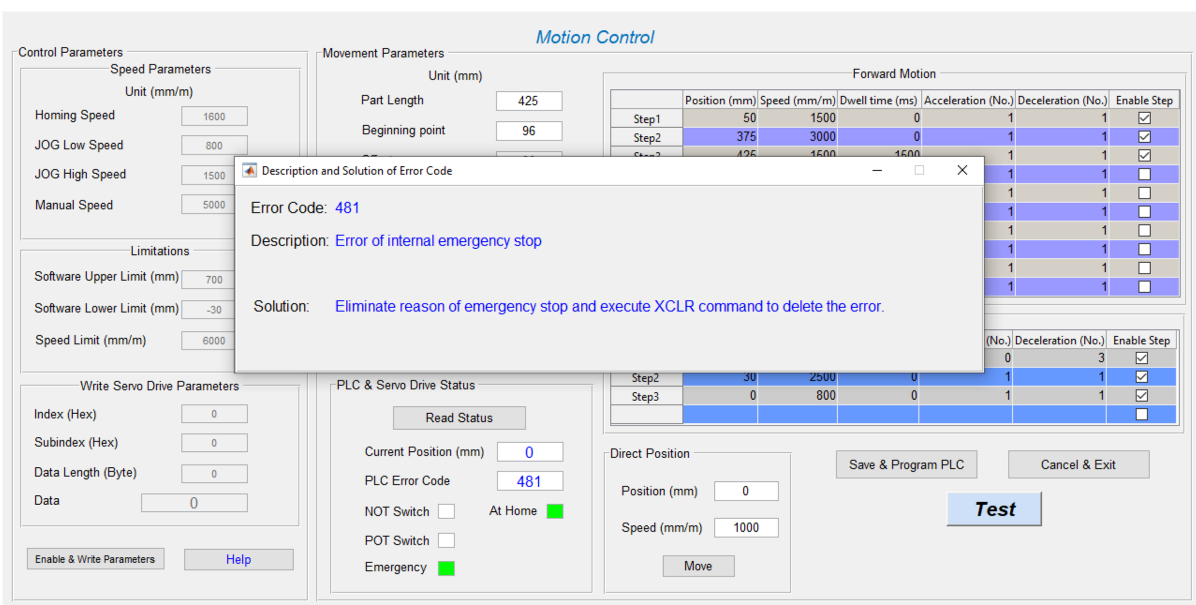


Figure 56. Press the "Read Status" button for a more detailed status of an error and the troubleshooting procedure.

Control Parameters

This section allows you to configure fundamental **servomotor parameters**, such as:

- **Speed Limits**: Set the maximum and minimum speed of the servo drive for controlled motion.
- **Position Limits**: Define the allowable range of motion for the servo.

Note: Changes made to these parameters are global and will apply to all part programs. Adjust with caution to ensure compatibility across all parts.

5 Compensation and Case Depth Estimation

In this menu, you can choose frequencies to be used for Case Depth measurement and adjust their specific parameters. It's important to remember that after making any changes in this menu, you should click **OK** to close this menu, and then click on **Solve & Train Models** to ensure the training is updated with the new settings.

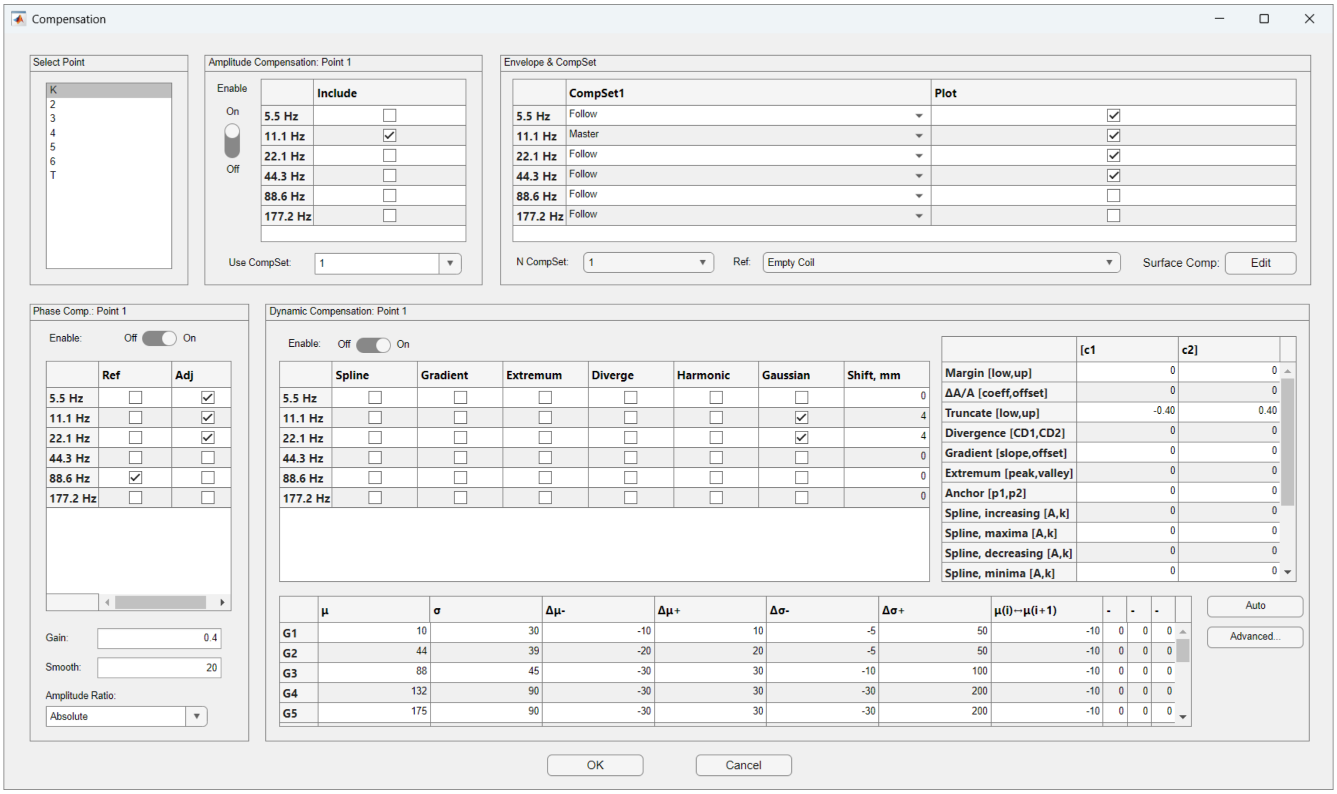


Figure 57. Compensation Menu

To start, go to the **Envelopes** pane and allocate a compensation method for each frequency range. The default settings should be as follows:

- Low Frequencies (5.5 and 11.1 Hz): Set to **Independent Intersection**
- Medium Frequencies (22.1 and 44.3 Hz): **Set to Dependent on F (Intersect)**
- High Frequencies (88.6 and 177.2 Hz): Set to **None**

For those interested in a deeper understanding, here's an insight into frequency selection based on angle α:

Frequencies where the angle α falls between 60° and 120° are typically chosen as Independent. The optimal frequency in this category is known as the Cross-Over Frequency, characterized by an angle α of exactly 90°. At the Cross-Over Frequency, all parts, from shallow to deep, exhibit equal amplitude, making the phase the primary sensitive indicator of case depth.

In our specific example (see Figure 58), the cross-over frequency is approximately 8 Hz. The closest frequencies to this value are 5.5 Hz and 11.1 Hz, chosen due to the sufficiently wide angle α. Therefore, we categorize both 5.5 Hz and 11.1 Hz as **Independent** frequencies.

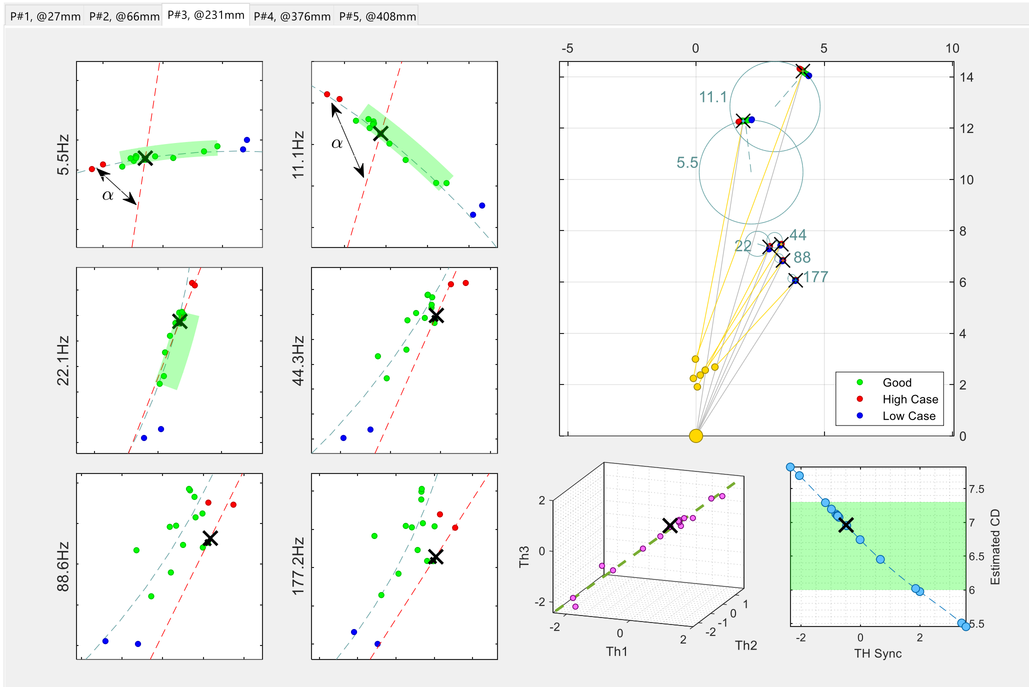


Figure 58. Check impedance plane to choose independent frequencies for static compensation.

Navigate to the **Envelopes** pane and set the first two frequencies as **Independent** frequencies.

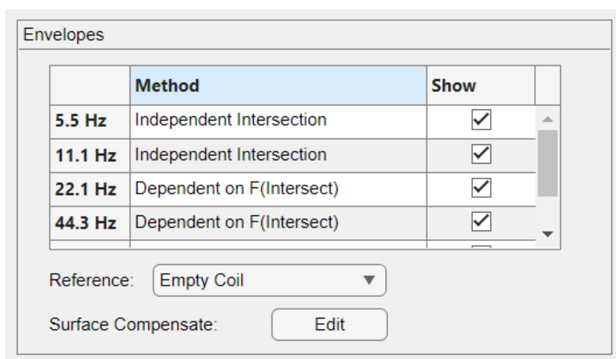


Figure 59. Select Independent frequencies from the Envelopes pane.

From the **Envelopes** pane, proceed to select **Reference** option from the list box (see Figure 60). Your choices are typically between **Empty Coil** and **Absolute Zero**. The default setting is **Absolute Zero** for coils equipped with a ferrite concentrator, while for older coils without a concentrator, set it to **Empty Coil**. For the most effective setup, consider reaching out to the EddySonix team for their expert recommendation.

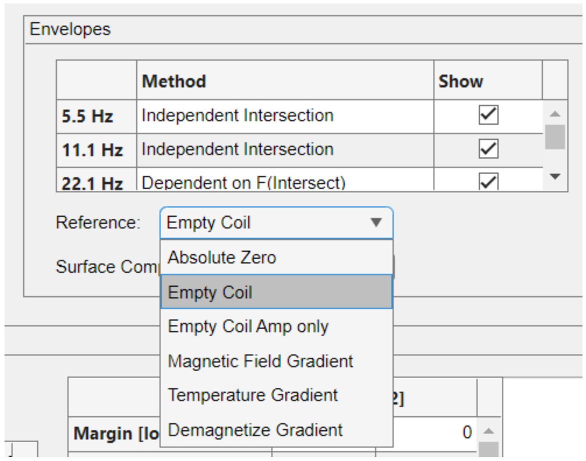


*Figure 60. Select **Reference** method for compensation.*

5.1 Amplitude Compensation

Navigate to the **Select Point** pane and individually select each point. Then, on the right-side pane under **Amplitude Compensation**, ensure that frequencies F1, F2, and F3 are selected; however, note that not all these frequencies need to be selected simultaneously. You can choose any combination of these frequencies according to your requirements. Ensure the **Enable** switch is turned **On**. This adjustment should be applied for all points as indicated (see Figure 61).

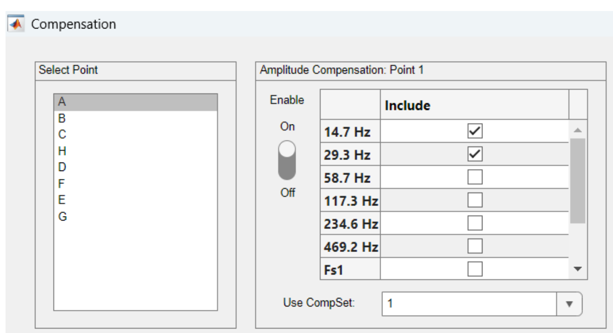


Figure 61. Selection of Frequencies (F1, F2, F3) for Amplitude Compensation at Each Point (e.g., P1, ..., P9).

5.2 Phase Compensation

Phase Compensation is used to reduce surface-related phase effects by normalizing selected frequencies against a defined reference frequency.
It operates **per inspection point** and is configured independently for each point.

After selecting a point, Phase Compensation parameters apply only to that point.

Enable
Turns Phase Compensation on or off for the selected point.

Ref (Reference Frequency)
One or more frequencies can be selected as reference.
The reference should typically be a **high frequency (about 80–200 Hz)** where surface effects dominate, so that the normalization and surface-effect reduction work reliably.

Adjust (Adjusted Frequencies)
Frequencies checked in the *Adjust* column will be corrected using the reference frequency.
Unchecked frequencies are not modified.

Gain
Weighting factor applied to the phase correction.

- Gain = 1 → full correction
- Gain = 0 → no effect (equivalent to disabled)

Smooth
Defines the smoothing window applied to the phase residue.
Smoothing is applied after weighting and before subtraction.

Processing logic
For each selected *Adjust* frequency:

1. The reference phase is subtracted from the frequency phase
2. The residue is multiplied by *Gain*
3. The result is smoothed
4. The processed residue is subtracted from the original phase

This reduces surface-related phase variations while preserving bulk material response.

Amplitude Ratio
Additional scaling applied to the phase correction.
Available modes:

- Relative
- Absolute
- None

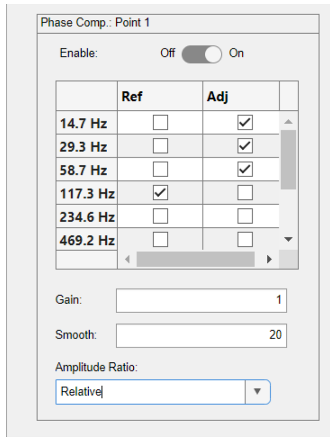


Figure 62. Configurations for Phase Compensation.

5.3 Dynamic Compensation

The purpose of Dynamic Compensation is to improve local resolution of the Theta envelopes, especially at critical regions such as splines, grooves, diameter transitions, or other locations where the Effective Case Depth (ECD) changes abruptly along the shaft.

During scanning, the moving coil inherently behaves like a **moving average**. This causes natural smoothing of the signal, which can blur or attenuate sharp local changes in case depth. As a result, true local peaks (positive or negative) in the ECD envelope may appear weakened or partially suppressed.
Dynamic Compensation counteracts this effect by applying a **deconvolution-type correction**, effectively reversing the smoothing introduced by the scanning motion and restoring sharper envelope features closer to their true physical shape.

Figure 63 shows the Dynamic Compensation pane. Dynamic Compensation is configured **per inspection point**. To modify the settings for a given point, the point must first be selected. Compensation can then be enabled or disabled individually for that point.

The pane contains:

- **Point-specific settings**, including the *Enable* option and a checkbox table for selecting frequencies and compensation methods.
- **Global parameters**, defined in the tables on the right and bottom of the pane, which apply to all points.

For initial database setup of a new part, it is recommended to **disable Dynamic Compensation for all points**. After initial training, Dynamic Compensation can be selectively enabled for specific points based on observations during testing or mass production. When configuring this menu for the first time, press the **Auto** button to calculate the default coefficients in the bottom table.

The recommended compensation method is **Gaussian**. In the left table, each row corresponds to a frequency and each column to a compensation method. Dynamic Compensation should typically be applied only to **low and medium frequencies**, up to approximately **40 Hz**. For each point where Dynamic Compensation is required, the left table must be configured **individually for that point**.

The right-side table usually does not require modification. For advanced users, the main parameters are described below:

- **Truncate [low, up]**
  Default: [-0.3, 0.3] mm
  This defines the maximum allowed correction applied to the ECD. For example, if the calculated correction is +0.34 mm while the upper limit is 0.3 mm, the correction is clipped to +0.3 mm before being applied.

- **Gaussian [Npeak]**
  Default: 10 for a 400 mm axle bar
  This parameter defines the number of Gaussian functions used to model each Theta envelope. For longer parts, this value should be increased proportionally (e.g., ~17 for a 700 mm shaft). If modified, the **Auto** button must be pressed again.

- **Gaussian [Gain]**
  Typical range: 0.1 – 1 (default: 0.3)
  This gain controls the strength of the dynamic correction applied to the envelope. It should be adjusted by comparing EddySonix results with cut-check data from production parts.

- **Gaussian Final [Gain]**
  Default: 1
  This is a final scaling factor applied to the computed correction before updating the ECD value.

- **Other Parameters**
  Parameters related to Morphology and Convolution Kernels are pre-optimized and should not be modified. These are intended to be set only by EddySonix.

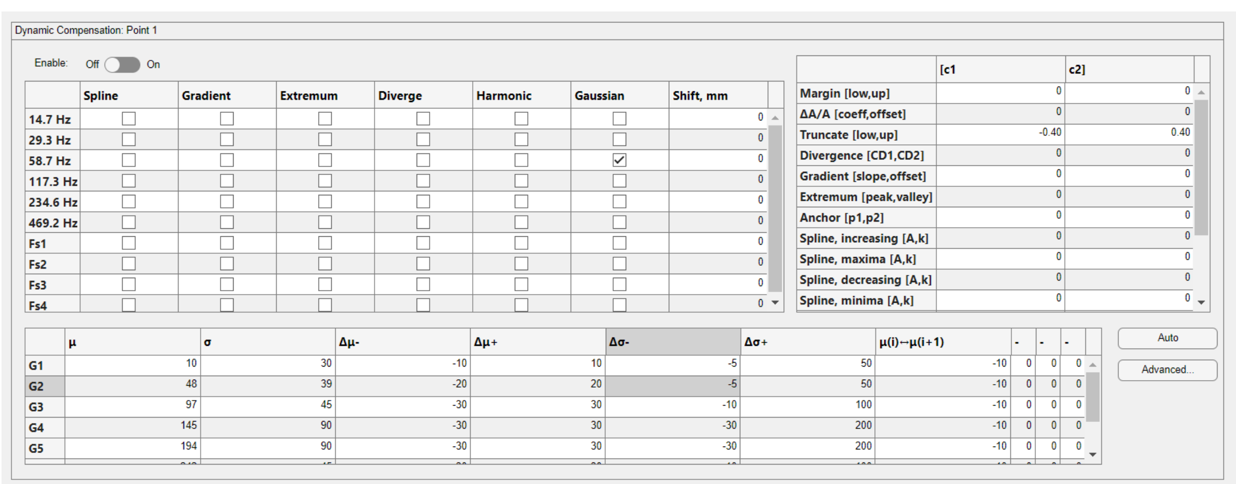


Figure 63. Dynamic Compensation Pane

5.4 Advanced Compensation (Extreme / Out-of-Range Conditions)

Advanced Compensation is a rule-based safety mechanism used when numerical Effective Case Depth (ECD) estimation is not valid or may be misleading.

It is not a learning or compensation algorithm and does not require training.
Instead, it evaluates selected raw signal criteria against user-defined thresholds and, when triggered, suppresses the numeric ECD output and replaces it with a short text label.

This mechanism is intended for extreme or untrained conditions such as raw (non-hardened) parts with ECD ≈ 0, extremely shallow hardened layers (ECD below the trained range), or localized regions where standard ECD estimation fails while neighboring points remain nominal.

When an Advanced Compensation rule is triggered at a given inspection point, the numeric ECD value is intentionally not reported.
Instead, the ECD output is suppressed and replaced by a short user-defined text label (for example: *Raw*, *VeryLow*, *NoCase*).
This ensures clear and unambiguous reporting in situations where a numeric ECD value would be physically incorrect or outside the valid model range.

Typical use cases for Advanced Compensation include raw (non-hardened) parts with ECD equal to zero, parts with extremely shallow case depth that are hardened but below the trained range, and localized conditions where standard ECD estimation becomes unreliable while neighboring points remain nominal.
In these situations, Advanced Compensation acts as a safety layer to prevent misleading numeric ECD results.

Advanced Compensation operates by evaluating selected raw signal features (such as amplitude, phase difference, or envelope derivatives) at each inspection point and comparing them against user-defined thresholds.
If one or more rules are satisfied, numeric ECD reporting is suppressed for that point and replaced by a predefined text label.

Advanced Compensation should be used only when numerical ECD estimation is no longer reliable, such as for raw or insufficiently hardened parts, extremely shallow case depth outside the trained range, or localized conditions where the trained model cannot represent the physical behavior.
It is intended as a safety and reporting mechanism, not as a replacement for normal training or compensation.

Advanced Compensation Configuration Workflow

Advanced Compensation is configured per inspection point from the **Compensation** menu.
The workflow consists of selecting the inspection point, defining one or more raw-signal rules, and assigning a text label that will replace the numeric ECD result when the rule is triggered.

Configuration steps:

1. Select the desired inspection point (e.g. Point G).
2. Open the **Compensation** menu.
3. Press the **Advanced…** button in the Dynamic Compensation pane.
4. Enable one or more Advanced Compensation rules for the selected point.
5. Define thresholds based on observed raw-signal envelopes.
6. Assign a short text label (maximum 10 characters) to be reported when triggered.

Defining Rules and Thresholds

Each Advanced Compensation rule evaluates raw signal features at the selected inspection point and compares them against user-defined thresholds.

Typical inputs include:

- Phase difference between two frequencies
- Amplitude ratio between two frequencies
- Raw amplitude envelope at a single frequency
- Derivative of amplitude along the part length

Thresholds are defined manually based on observed signal behavior from known reference parts.

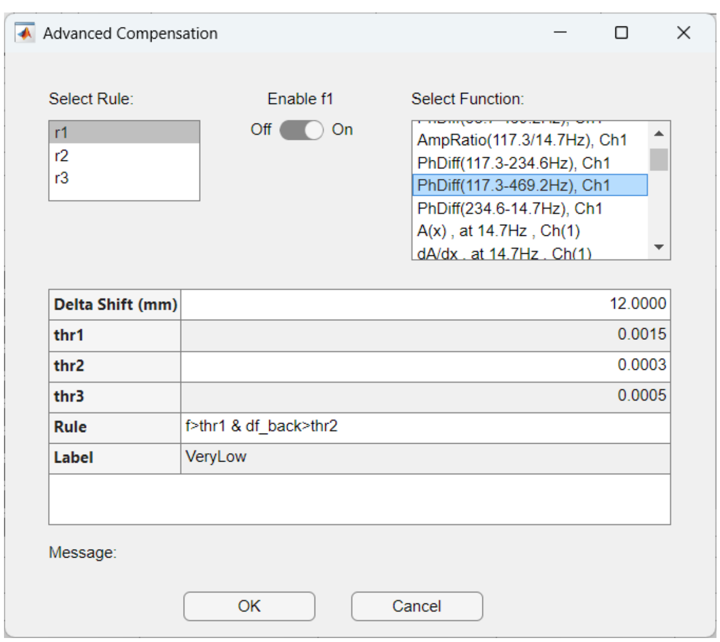
A practical guideline for threshold selection is:

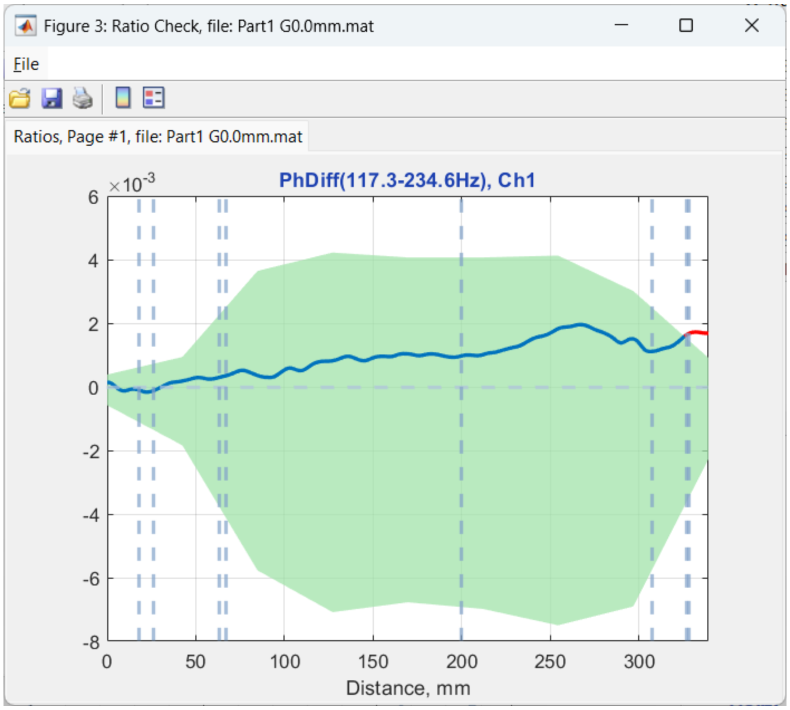
- Observe the raw signal value for a known extreme case (e.g. raw or very low ECD part)
- Observe the maximum value of the trained envelope
- Place the threshold between these values to ensure rejection of extreme parts while preserving valid measurements

Rules can combine multiple conditions using logical operators:

- AND (&)
- OR (|)
- Parentheses for grouping

When a rule evaluates to **true**, the numeric ECD output is suppressed and replaced by the assigned text label.





Delta Shift and Delta Terms (df_back, df_forw)

Delta Shift defines how far (in mm) the software looks **before** and **after** the current inspection point to compute local changes of the selected function **f**.

Let the current point position be **x** and the Delta Shift be **Δ** (mm). Then:

- **f** = f(x)
- **df_back** = f(x) − f(x − Δ)
- **df_forw** = f(x + Δ) − f(x)

So:

- **df_back > 0** means **f increased** from (x−Δ) to x.
- **df_forw < 0** means **f decreased** from x to (x+Δ) (useful to detect a "peak").

Notes

- Δ is in **mm** along the axle length.

If x−Δ or x+Δ falls outside the available range, the software uses the nearest valid data point (or disables that delta term for that evaluation, depending on implementation).

Rule Syntax Limitation

The rule expression must use **only** the predefined variables
f, thr1, thr2, thr3, df_back, df_forw together with logical operators (> < >= <= == & | ( )).
Any other variable name, function, or expression will be rejected and will result in a **syntax error**.

Guidelines for Threshold Selection

Advanced Compensation thresholds are **not derived automatically** and must be defined manually by the user based on signal behavior.

A practical and reliable method is:

- Display the relevant raw-signal envelope (amplitude, phase difference, ratio, etc.)
- Compare **normal parts** (within trained ECD range) against **extreme parts** (raw or very low ECD)
- Identify:
  - **b** = maximum value reached by normal parts (upper green limit)
  - **a** = value reached by extreme or raw parts (red curve)

A recommended rule-of-thumb threshold is:

Threshold = b + 0.7 × (a − b)

This places the threshold safely above normal variation while ensuring all extreme conditions are detected.

Thresholds should:

- Reject all raw or extreme parts
- Avoid triggering on valid hardened parts
- Be validated using multiple reference samples

Result Behavior and Reporting

When Advanced Compensation is active, the system evaluates all enabled rules independently at each inspection point during testing.

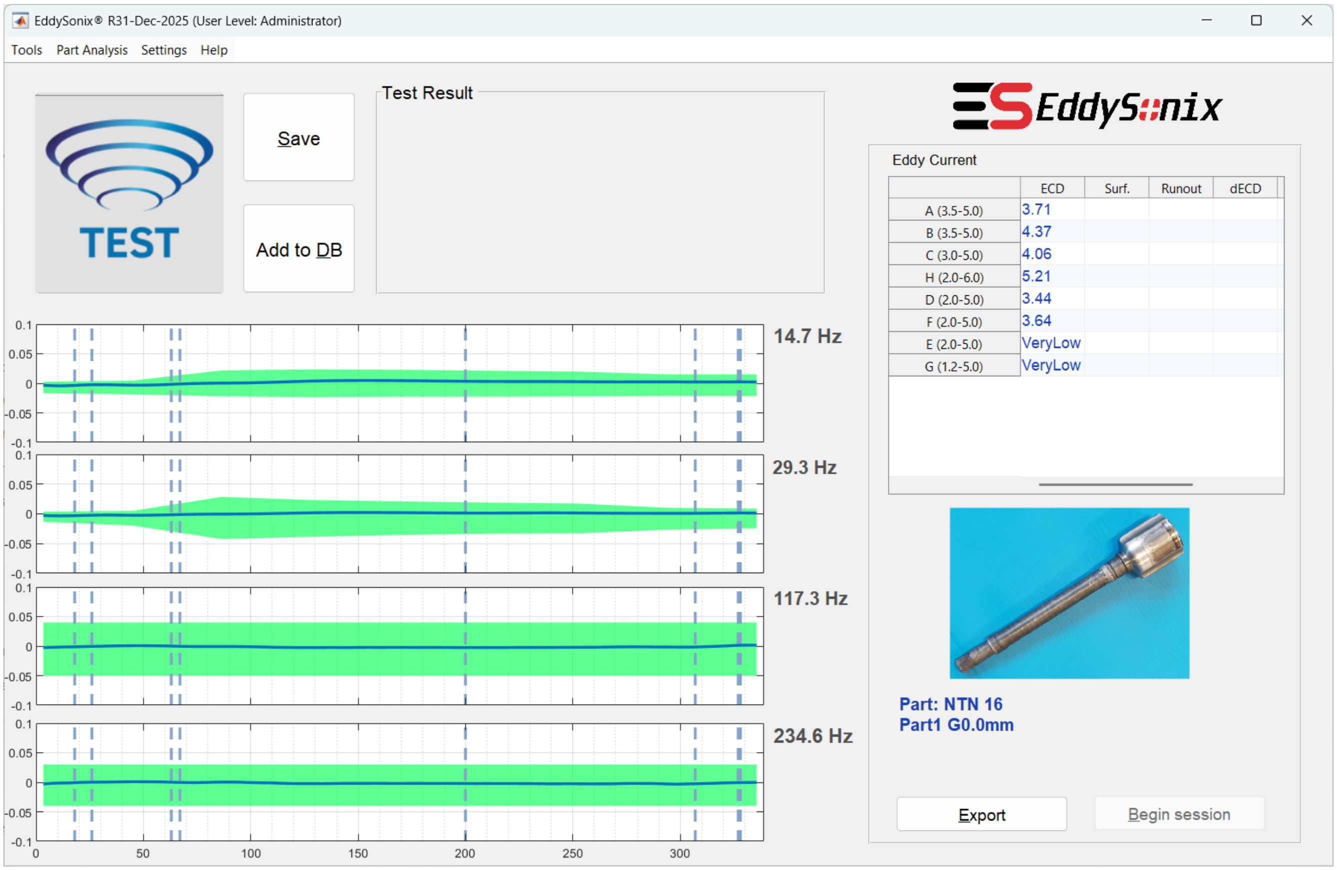
If **no rule is triggered**, the system behaves normally:

- A numeric Effective Case Depth (ECD) value is calculated
- The value is reported in tables, plots, and exports

If **any Advanced Compensation rule is triggered** at a point:

- Numeric ECD estimation for that point is suppressed
- No extrapolated or misleading value is reported
- The ECD field is replaced by the user-defined text label (e.g. *Raw*, *VeryLow*)
- Other points on the same part remain unaffected

This ensures that extreme or non-physical conditions are reported explicitly, without influencing valid ECD results at neighboring points.



Advanced Compensation should be configured only after reviewing several known bad parts. When multiple rules are enabled for the same inspection point, the last enabled rule that evaluates true is applied, suppressing numeric ECD reporting and replacing it with its label. This feature does not modify the training database, limit bands, or any normal compensation settings.

5.5 Synthetic Frequencies (FS) – Extended Input for Compensation

In some axle bars with shallow case depth (e.g., Nominal = 4mm), the Z-locus trajectory from Max-Out to Min-Out parts becomes nearly parallel to the amplitude vector that originates from the origin. In such cases, phase variation is minimal, and the compensation algorithm becomes ineffective, since the Z-locus does not rotate enough between groups.

To improve this, a new interface has been added to define **Synthetic Frequencies (FS)**. A synthetic frequency is not a real excitation signal, but a virtual point on the impedance plane, computed by combining the amplitude and phase of existing frequencies.

The goal is to create new vectors with better orientation in the complex plane, increasing the angle between the Z-locus (Max to Min) and the amplitude vector. This helps improve the accuracy of compensation and case depth estimation.

Users can define the amplitude and phase of each synthetic frequency using mathematical expressions. Examples:

- `Amp_FS1 = (Amp_F1 + Amp_F3) / 2`

- `Amp_FS2 = sqrt(Amp_F1^2 + Amp_F2^2)`
- `Ph_FS1 = (Ph_F1 + Ph_F3) / 2`

Once defined, these synthetic frequencies are added to the signal list and can be used in envelope plots, Z-locus visualization, and training. They behave like regular frequencies but are computed after scanning, based on recorded signal data.

This feature allows better control over the Z-locus geometry and makes the compensation algorithm usable in cases where phase rotation is weak and amplitude is the dominant changing factor.

To define synthetic frequencies: Open the **"Learn"** menu, and from the **"Multi-Frequency"** pane, click on the **"Synthetic F"** button. This opens the menu to define Synthetic Frequencies.

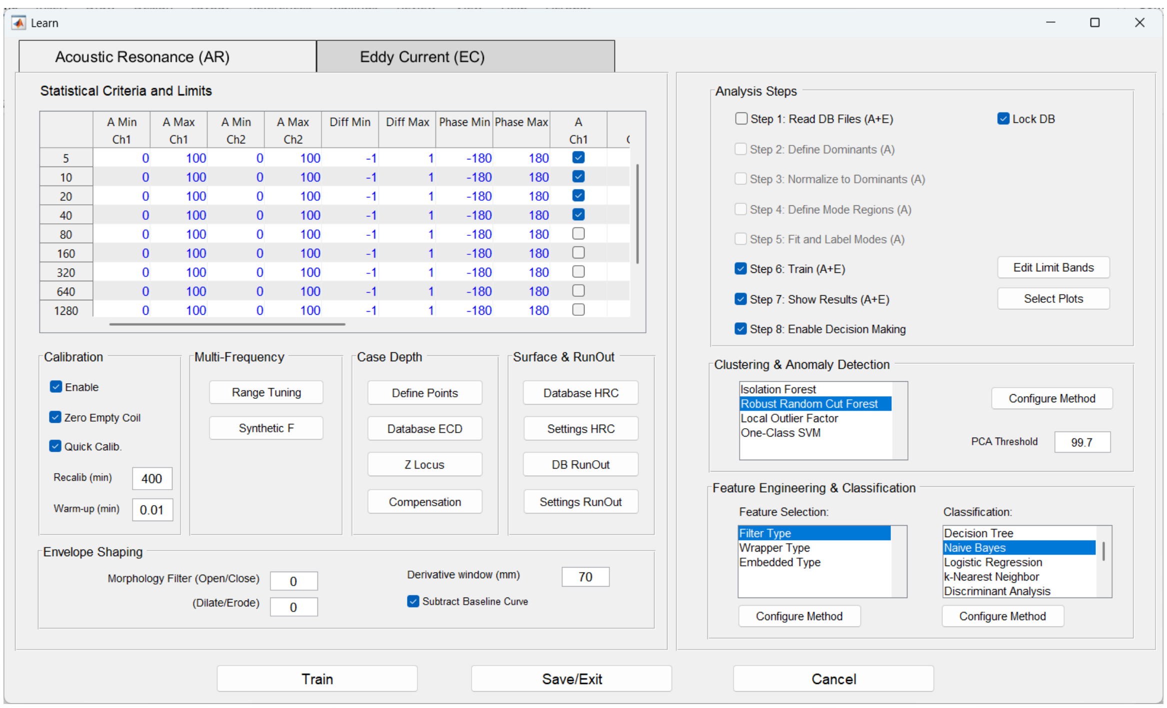


Figure 64. Accessing the Synthetic Frequency Editor from the Multi-Frequency Pane

After opening the **Synthetic Frequencies** menu, you can define up to **10 virtual frequencies (Fs1 to Fs10)**. For each Fs, define both the **synthetic amplitude** and **synthetic phase** using mathematical expressions.

You can use the following variables:

- `a(i)   : Absolute amplitude of real frequency` *Fi*
- `ae(i)  : Amplitude relative to empty coil voltage`
- `p(i)   : Absolute phase of real frequency` *Fi*
- `pe(i)  : Phase relative to empty coil`

Each synthetic frequency consists of:

- `As → Synthetic amplitude`
- `Ps → Synthetic phase`

Example Definitions:

- `As = sqrt((0.8 * a(2))^2 + (0.2 * a(1))^2)`
  `(Root sum of weighted squared amplitudes from F2 and F1)`
- `Ps = 0.5 * pe(2) + 0.5 * pe(5) + a(6)/a(4) - 1`
  `(Combination of phase and amplitude ratios)`

You can define multiple synthetic frequencies to extend the input space used in compensation and case depth analysis, especially when standard frequencies provide limited phase variation.

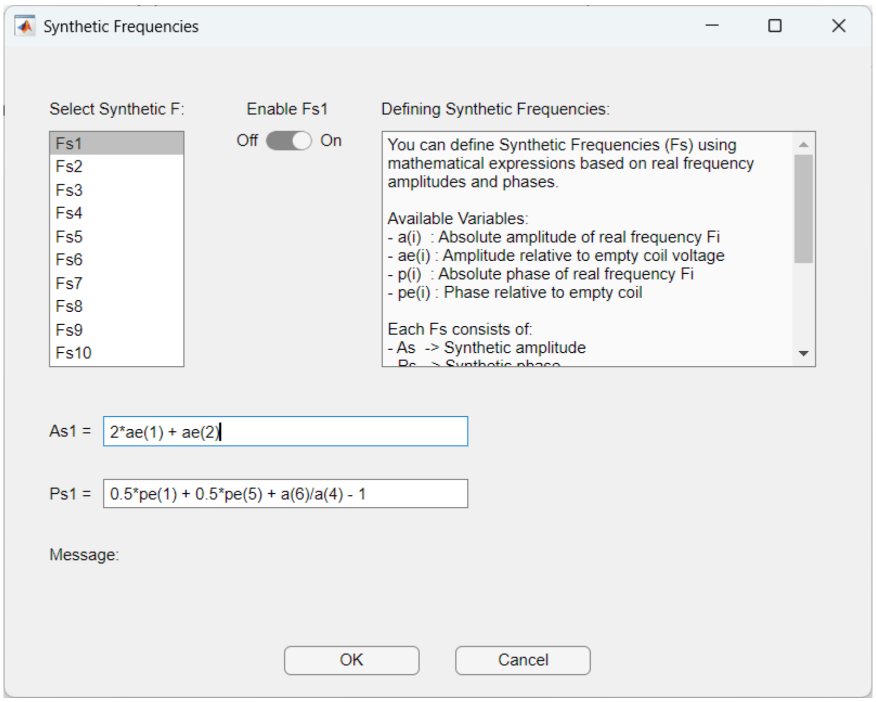


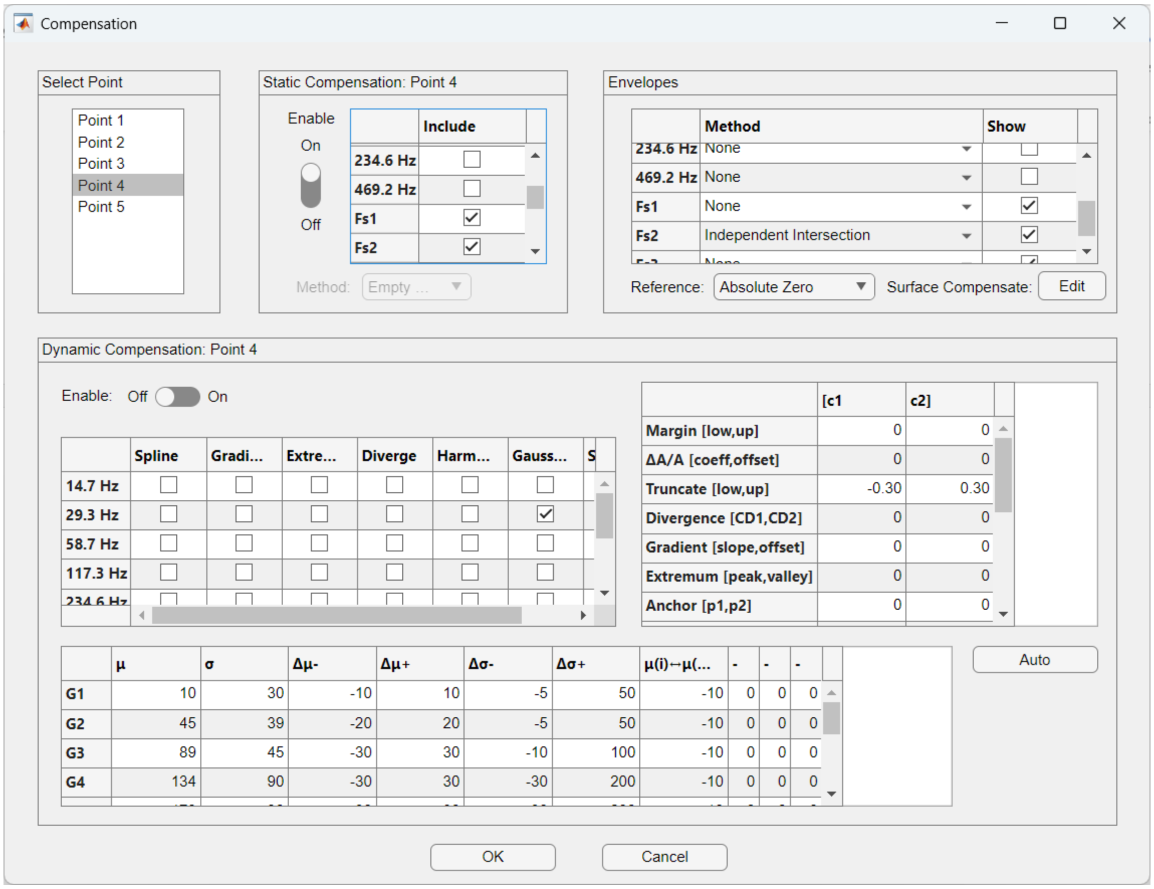
Figure 65. User Interface for Defining Synthetic Frequencies (Fs1–Fs10)

After defining the synthetic frequencies, open the **"Compensation"** menu. You will see the list of defined **Fsyn** (e.g., Fs1, Fs2) added to the list of real frequencies.

These synthetic frequencies can now be used like any normal frequency:

- Select them in the **Static Compensation** section by checking the "Include" box.
- Assign compensation methods (e.g., *Independent Intersection*) in the **Envelopes** section.
- View and compare their envelopes along with real frequencies.

This allows full integration of synthetic frequencies into the compensation process, enabling finer control and improved ECD estimation when traditional frequencies show limited separation.



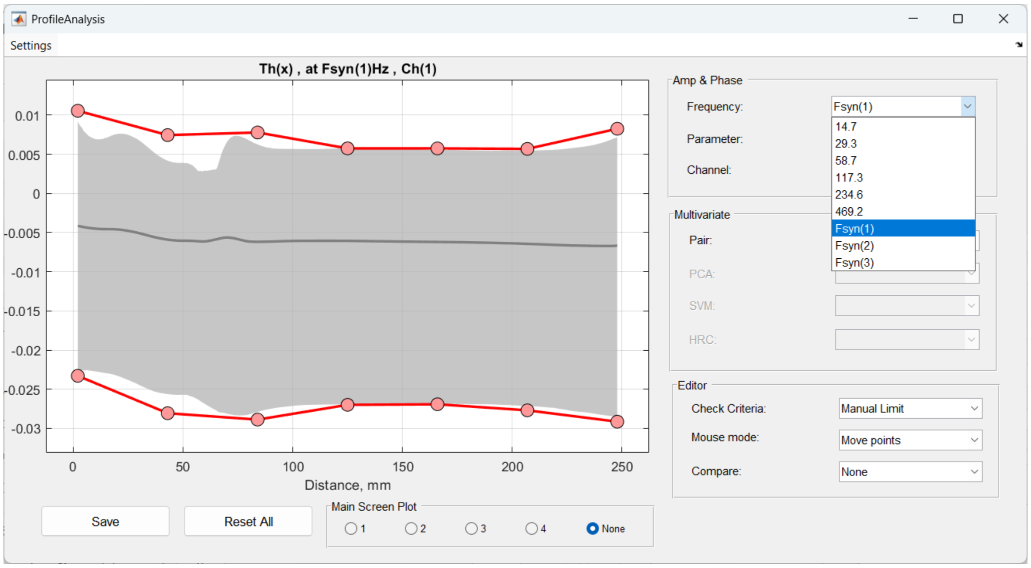
After defining synthetic frequencies and including them in compensation, go to the **"Learn"** menu and click **"Train"**. This will open the **"Profile"** menu for envelope analysis.

In this menu, **Fsyn entries (e.g., Fsyn(1), Fsyn(2), etc.) are fully integrated** into the frequency selection dropdown. You can analyze their Theta, Amplitude, or Phase envelopes just like real frequencies.

Use the options under:

- **Frequency** – to select any real or synthetic frequency
- **Parameter** – to choose between Th(x), A(x), or Ph(x)
- **Editor** – to set acceptance limits manually or automatically

These envelopes can be used to fine-tune limit bands and validate the effectiveness of synthetic frequencies in separating part groups.



After training is completed, proceed to **Step 7: Show Results**. In the **Z-Plane** view (under *Criteria Type*), you will see the synthetic frequencies (e.g., **Fsyn(1), Fsyn(2), Fsyn(3)**) added at the end of the plot sequence, after the real frequencies.

These plots display the Z-locus for the selected point (e.g., Point 4: 140 mm), comparing parts from all groups. The synthetic frequencies often exhibit **improved separation** between part groups and **better alignment of the Max–Nominal–Min trajectory**, enhancing discrimination where real frequencies show weak rotation.

This confirms that the synthetic frequencies are fully integrated and can contribute effectively to case depth estimation and decision boundaries.

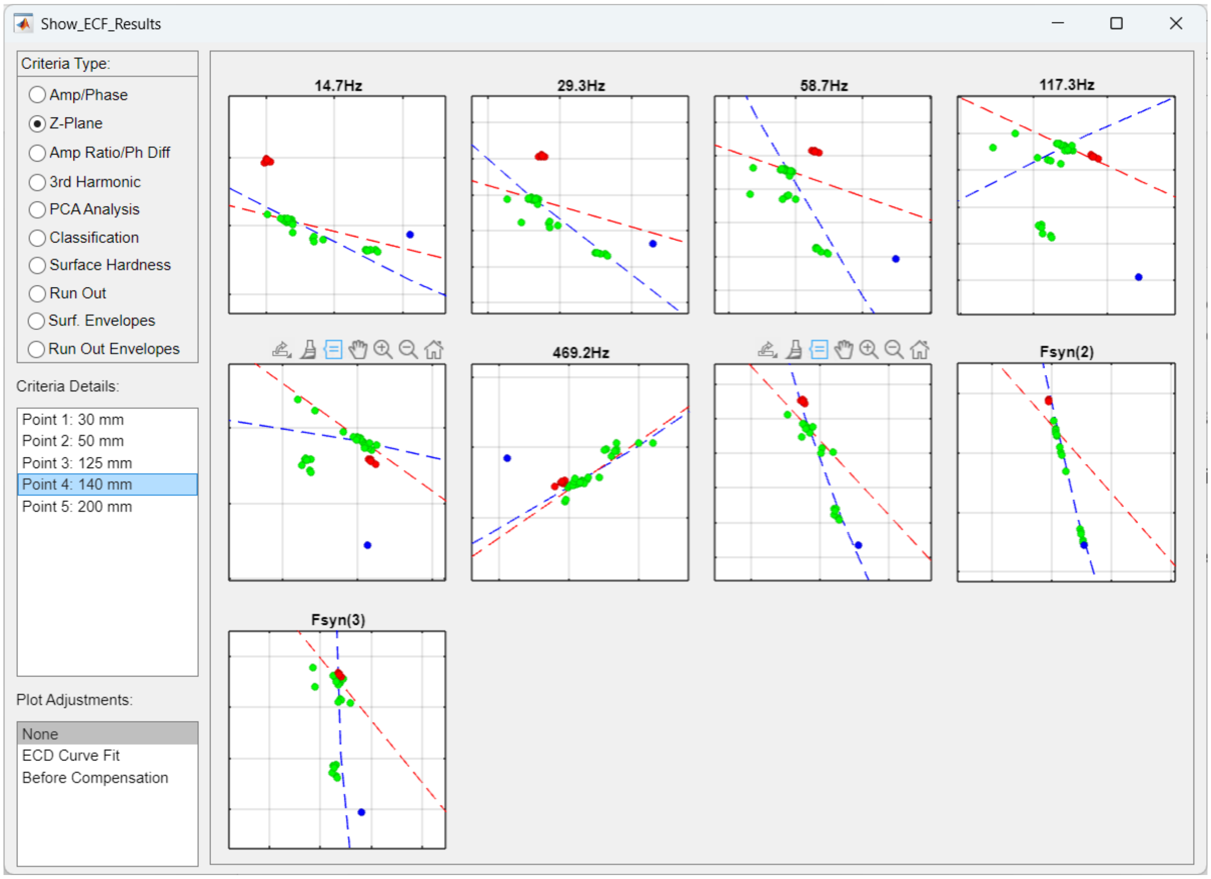
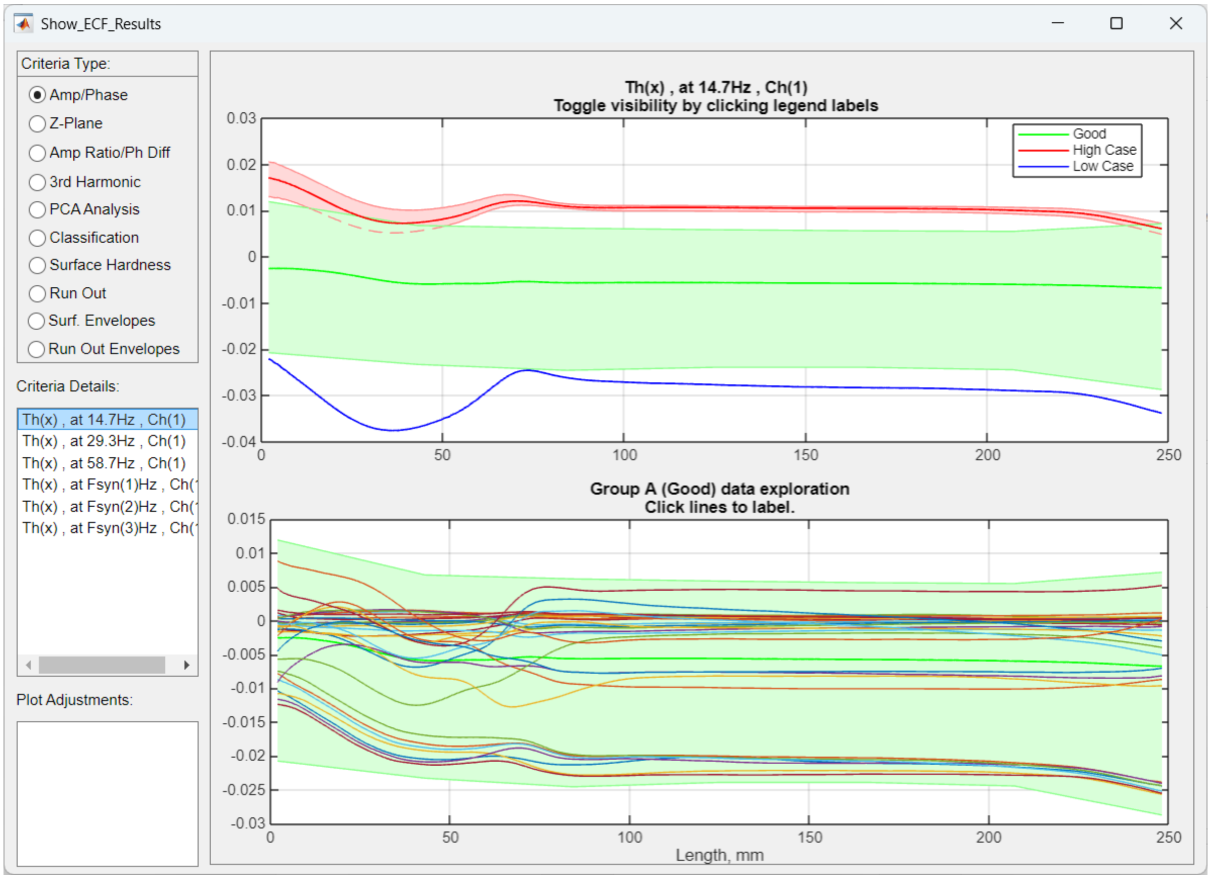


Figure 66. Z-Plane Plot Showing Improved Separation Using Synthetic Frequencies



5.6 Using Compensation Sets (CompSets) for Variable Case Depth Profiles

In Eddy Current case depth (ECD) inspection, parts such as **stems** or **axle bars** often have regions with different case depth specifications along their length. For example, the first 100 mm of a stem may require compensation tailored to a **deep case (e.g., 5 mm)**, while the remaining section may correspond to a **shallow case (e.g., 3 mm)**. In such cases, a single compensation strategy is insufficient. The **CompSet** feature allows users to define **multiple compensation sets**, each with its own selection of **master frequencies**. During inspection, different CompSets can be assigned to different length intervals of the part, enabling precise and adaptive compensation across varying ECD profiles.

Configuring Compensation Sets

To begin using CompSets for adaptive compensation, first open the **Learn** menu and then select the **Compensation** menu. At the top-right of the Compensation window, set the total number of **CompSets** (from 1 to 4) according to the number of distinct ECD regions you expect in your part.

Once the number of CompSets is defined, the **CompSet table** will update dynamically to show one column per set. For each frequency, you can assign a role in each set:

- Set the frequency to **Master** for the primary frequency used in compensation for that set.
- Set it to **Follow** if it should inherit compensation from the Master frequency.

- Or set it to **Off** if it should be excluded from compensation in that set.

This setup allows you to define multiple compensation strategies tailored to different zones of the part.

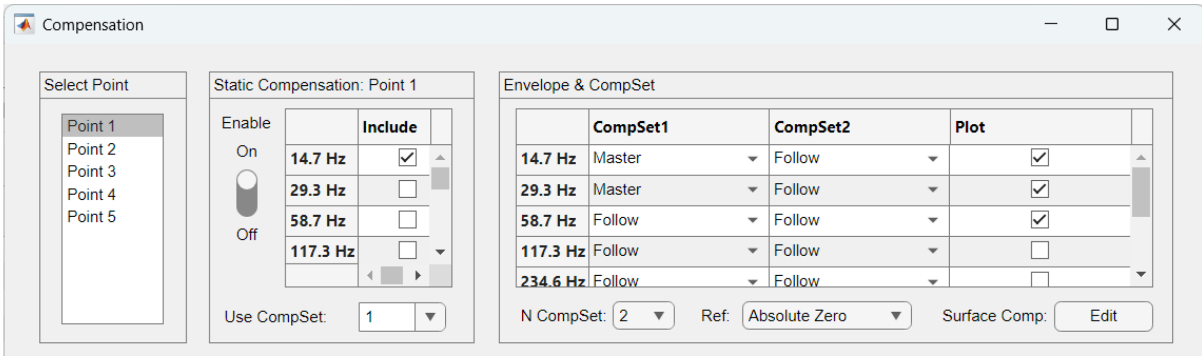


Figure 67. Compensation Set Table with Master, Follow, and Off Assignments per Frequency

Assigning Compensation Sets to Points

Once you've defined the CompSets, you can assign a compensation strategy to each inspection point. On the **left side** of the Compensation window:

1. Select a **Point** from the list (e.g., Point 1, Point 2, etc.).
2. In the **Static Compensation** panel for that point, use the dropdown menu labeled **"Use CompSet"** to choose which compensation set (e.g., CompSet 1, 2...) to apply.

This allows each point along the scan length to use a different compensation strategy—ideal for parts where ECD (case depth) varies along the profile, such as stems or axle bars. For instance, the first 100 mm of a part might use a deep-case compensation (CompSet1), while the remaining length uses shallow-case compensation (CompSet2).

This flexible configuration ensures accurate compensation tailored to the actual ECD profile of each zone.

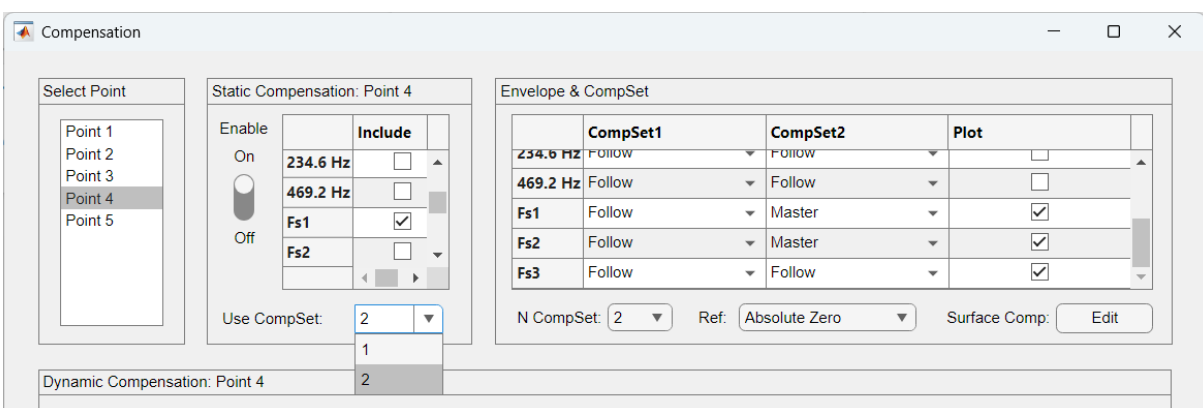


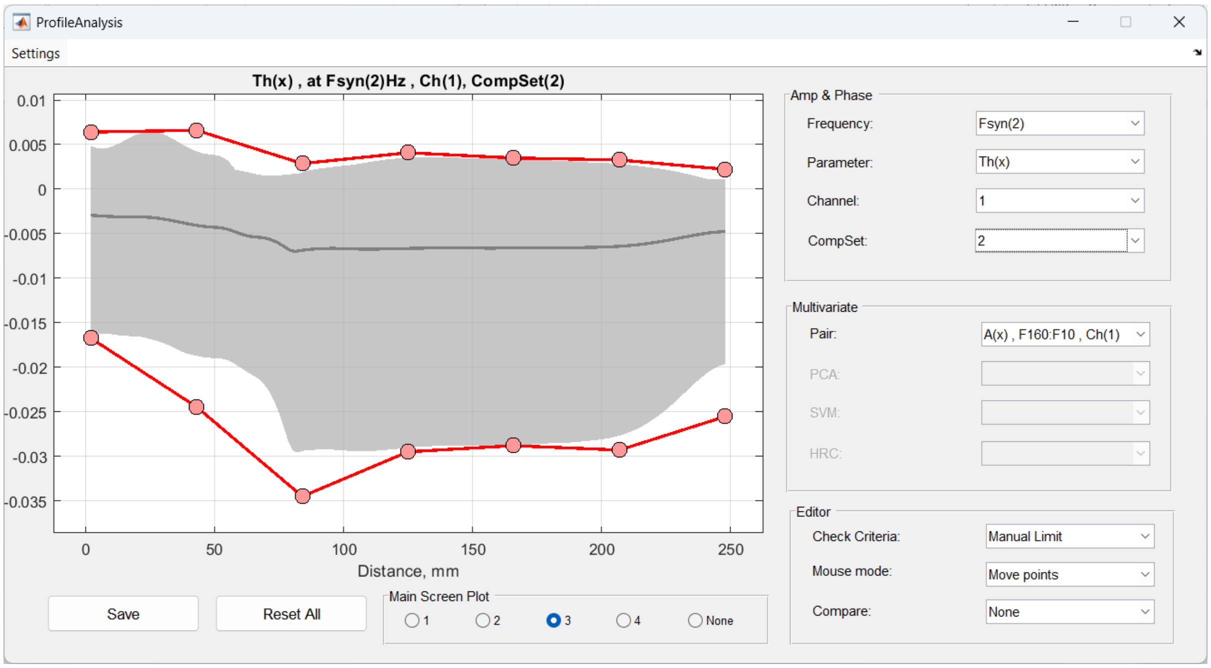
Figure 68. Assigning Compensation Set to Individual Points Along the Scan

Selecting CompSet for Envelope Checking

After configuring the Compensation settings and pressing **OK**, click **Train** in the Learn menu. This opens the **Edit Limit Bands** window.

During training, envelopes (e.g., Theta, Amplitude, Phase) are computed for each frequency and for each defined CompSet, since compensation depends on the Master frequencies assigned per set.

In the **Edit Limit Bands** window, the **CompSet** dropdown lets you choose which CompSet version of the envelope to use for testing. This allows each limit check to refer to the envelope compensated using the appropriate strategy for that region.

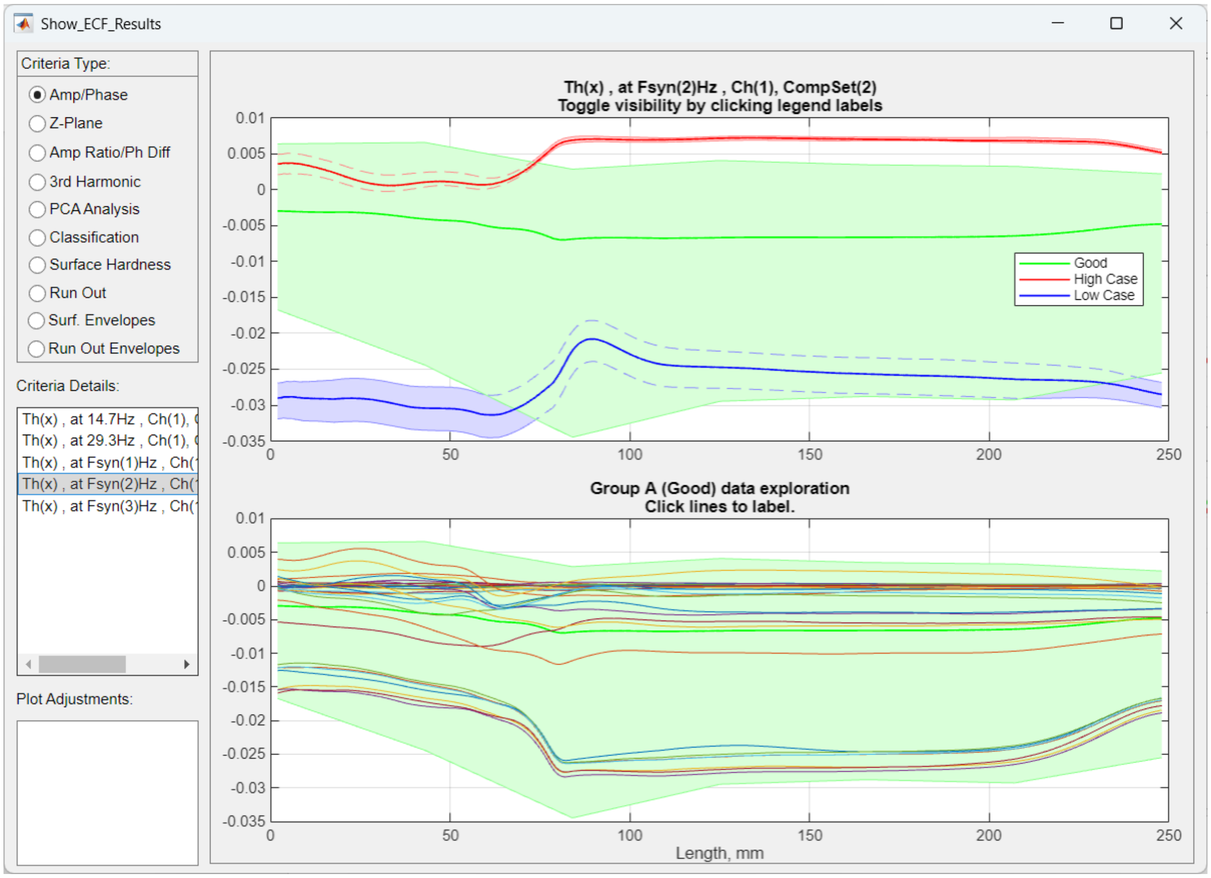


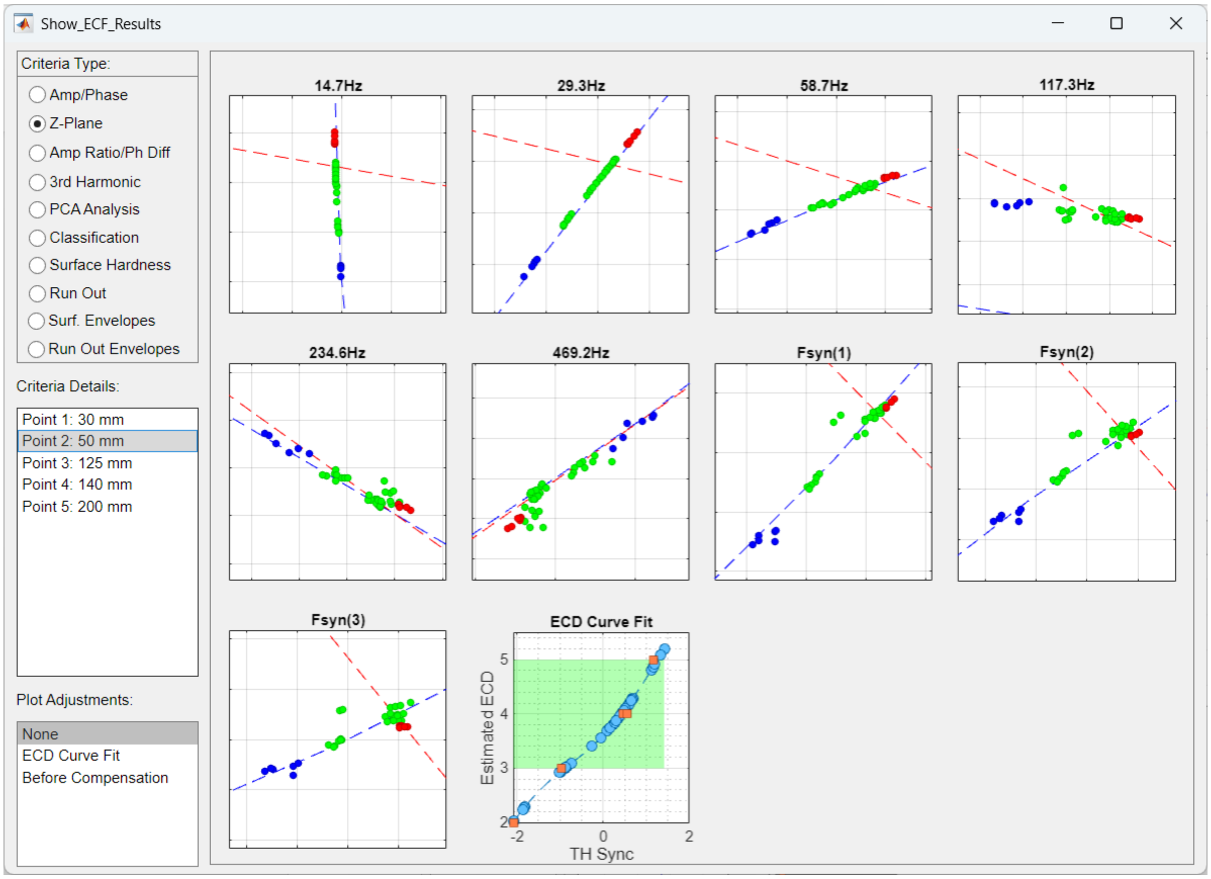
Training Results with CompSet (Step 7)

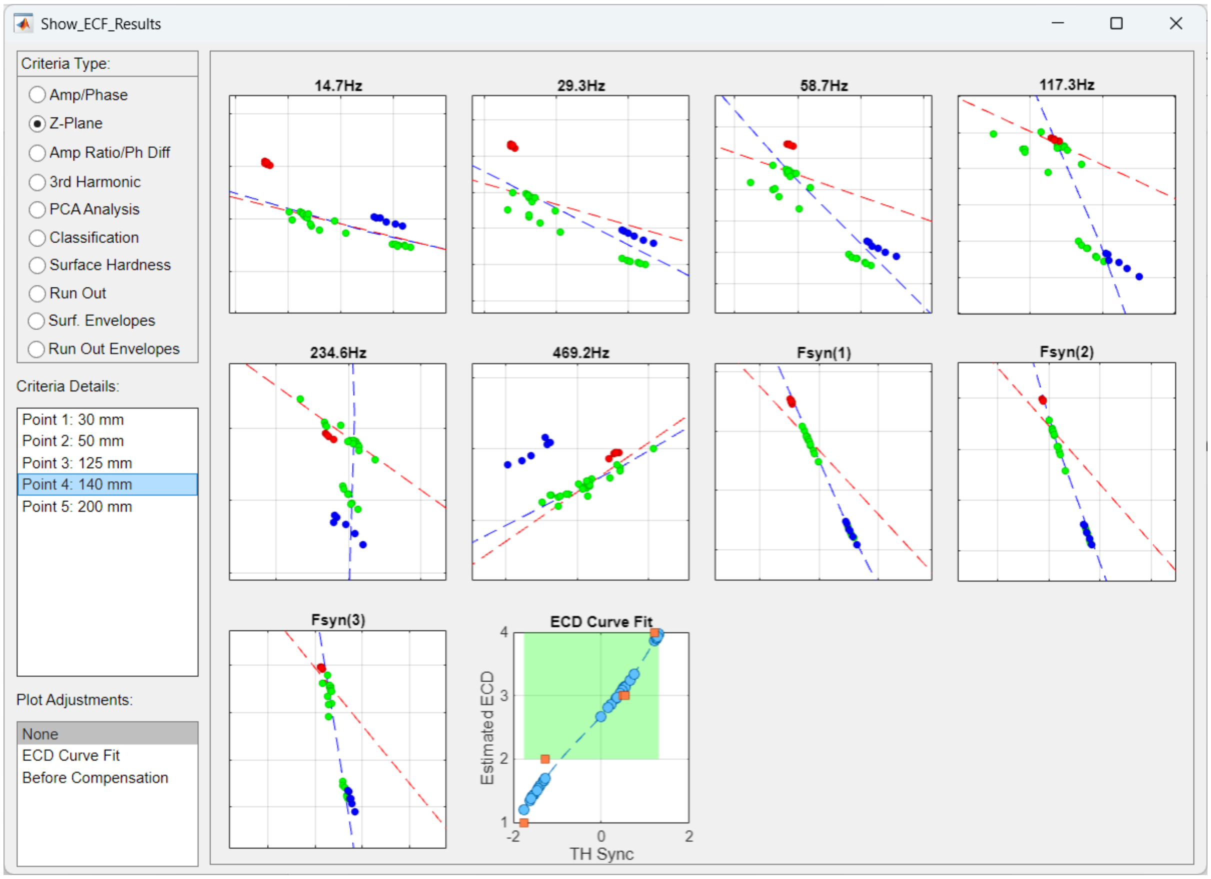
The training results show how the selected CompSet affects both envelope and Z-Plane analysis. For example:

- The first plot shows the envelope of Th(x) at Fsyn(2) using **CompSet 2**, visualizing the margin band for classification.
- The second plot shows the Z-Plane for **Point 2**, which uses **CompSet 1**, where 14.7 Hz and 29.3 Hz are set as master frequencies. The Z-Locus here is well-defined and satisfies all selection criteria:
    1. The data points from all groups (Good, High, Low) are clearly separated.
    2. The Z-Locus lies along a straight line.
    3. The angle between the Z-Locus and the compensation line is wide enough to allow reliable compensation.

- The third plot evaluates **Point 4**, which requires a different compensation strategy due to a shallower case depth. Here, **CompSet 2** is used with synthetic frequencies. Fsyn(2) provides the best Z-Locus alignment and is suitable for case depth estimation and compensation.




Show_ECF_Results
Criteria Type:
Amp/Phase
Z-Plane
Amp Ratio/Ph Diff
3rd Harmonic
PCA Analysis
Classification
Surface Hardness
Run Out
Surf. Envelopes
Run Out Envelopes
Criteria Details:
Point 1: 30 mm
Point 2: 50 mm
Point 3: 125 mm
Point 4: 140 mm
Point 5: 200 mm
Plot Adjustments:
None
ECD Curve Fit
Before Compensation
14.7Hz
29.3Hz
58.7Hz
117.3Hz
234.6Hz
469.2Hz
Fsyn(1)
Fsyn(2)
Fsyn(3)
ECD Curve Fit
Estimated ECD
TH Sync



5.7 Statistical Criteria and Limits table

Check the following columns:

- **A. Ch1** – Check all excitation frequencies. You can then exclude a frequency from the Profile menu.
- **Phase** – Check all excitation frequencies. You can then exclude a frequency from the Profile menu.
- **PCA** – Check frequencies that you want to be included in the PCA (Principal Components Analysis).
- **Classify** – Check frequencies that you want to be included in the SVM Classification
- **Ratio** – Check frequencies that you want to be included in the pair test. After checking a frequency, a popup menu opens to select the pair. For Example, after checking F5 (5Hz), you can select 6 criteria:

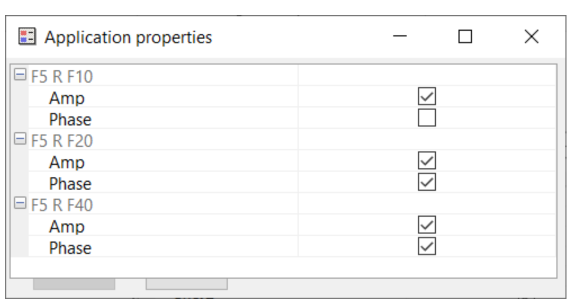


Figure 69. Activating multivariate (Pair) criteria

- **F5 R F10**, Amp = A_5/A_{10}
- **F5 R F10**, Phase = $\varphi_5 - \varphi_{10}$

A good criterion: Select the amplitude ratio of a frequency lower than F_C and the other higher than F_C. This feature can better highlight the defect.

Calibration pane

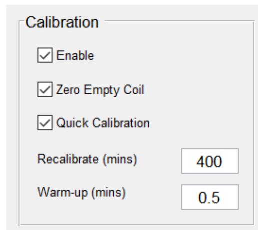


Figure 70. Calibration pane in Learn menu

Make sure the 3 parameters are checked:

☒ Enable

☒ Zero Empty Coil

☒ Quick Calibration

Warm-up (minutes) – When you turn on the machine, we recommend warming up for about 15 minutes. The coil turns on when you start a test and stays on afterwards. But when you open a menu, or switch between groups the coil turns off.

Recalibrate (minutes) – Define a timer to recalibrate empty coil. A timeout of 45 to 60 minutes is recommended. The goal of calibration is to compensate for temperature variations.

5.8 Multivariate Statistics pane

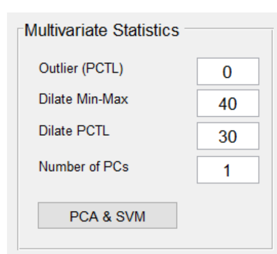


Figure 71. PCA and SVM settings in Learn menu

Number of PCs – Define number of PCs (Principal Components) to be checked. A value between 1 to 3 is recommended. You can further enable/disable a PC from **Profile Analysis** menu.

Dilate Min-Max – You can extend the accepted tolerance range by this percentage value. If you enter zero, the range sticks to the min and max parts in the Database. Depending on the statistical distribution of the reference parts, you can increase the range by 10% up to maximum 50%.

Outlier Percentile – The software checks the statistical distribution of Reference Parts in Group A, and can cancel outliers. Normally, this value should be zero if you are sure that the parts in group 'A' are Good and in the acceptance range. For example, if you assign Outlier Percentile = 2%, then the samples are sorted, and 1% from top and 1% from bottom will be removed.

Dilate PCTL (Percentile) – The above operation (Outlier Percentile) will shrink the range anyway, so adjust the Dilate Percentile to about 20 to 30% to correct the range.

The combination of the three operations (Dilate Min-Max, Outlier Percentile, Dilate Percentile) will remove outliers, but if there is no outlier in the distribution then no samples will be removed.

The abovementioned 3 operations are applied on envelope criteria: Theta, Amplitude, Phase, Pairs, PCA, and SVM. Similarly, press **Edit** button to individually set these parameters for PCA and SVM Classification:

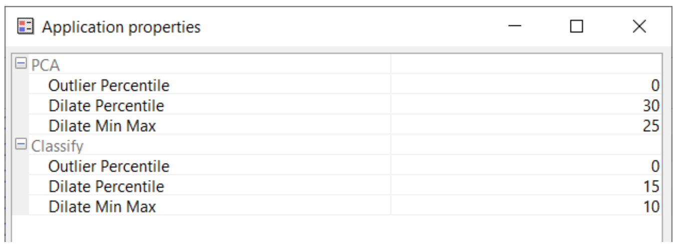


Figure 72. More detailed PCA and SVM settings

5.9 Classification (Good-Bad) pane

Only SVM classifier is used for Eddy Current Scanner. Other types of classifiers are used for Acoustic Resonant application. Press Classify params button to adjust SVM parameters.

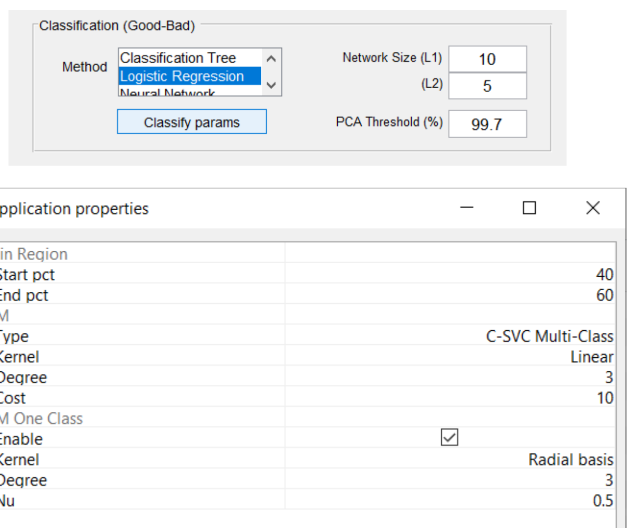


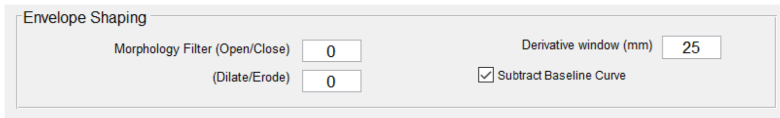
Figure 73. SVM parameters

Train Region – Adjust which section of part is used for training. In the above example, start=40% and end=60% means that 20% middle section of the parts are selected for classification.

SVM – Set parameters of SVM classifier. Depending on the number of groups defined as Bad and classifiable in the Group Setting menu, separate SVMs are trained. For example, if you define group B as High Case Depth, and group C as Low Case Depth, then two SVMs are trained to separate groups A from B, and A from C.

SVM One Class – If checked, the One Class SVM is trained. This classifier doesn't need Bad groups. It models only Group A to train.

Envelope Shaping pane



Morphology Filter (mm) – This operation is applied on the acceptance limit ranges to horizontally smooth and expand the upper and lower limits. The two operations Close/Open and Dilate/Erode will extend the green band.

Derivative window (mm) – This operation calculates the derivatives of Amplitudes and Phases. The width of operator $\partial/\partial x$ can be defined. We preset the value to 25mm, depending on the resolution and frequency selection you can reduce the value.

☒**Subtract Baseline Curve** – Always check this field to subtract the baseline. The baseline is calculated by ensemble averaging of envelopes of "Good" reference parts in Group A. After the baseline is subtracted, the green band will be centered to zero. The baseline will be subtracted from all parts tested thereafter. This will allow a better visualization of the results.

Analysis Steps pane

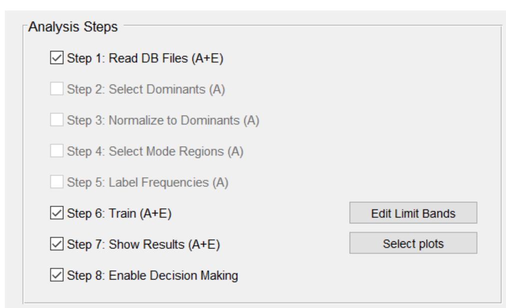


Figure 74. Analysis Steps in Learn menu

By default, all steps (1, 6, 7, 8) should be checked.

☒ **Step 1: Read DB Files** – This step sequentially opens the database files, calculates again the Amplitudes and Phases from the raw signal, and saves the results in one file Config\GroupsDB_S1E. This step is time consuming, so check Step 1 in the following conditions when you:

- Construct a new database
- Delete some files from the database
- Modify some parameters in the Signal Analysis menu.

☒ **Step 6: Train** – This step calculates the acceptance limits for all criteria. Repeat Step 6 when you modify these setting in the Learn menu:

- Executing Step 1: Read DB Files
- Check/Uncheck a parameter from Limits and Statistical Criteria table
- Statistical / Calibration pane: change Outlier Percentile, Dilate Min-Max, Dilate Percentile, Edit menu
- Profile Analysis: change any parameter

5.10 Edit Limit Bands

This menu automatically opens after Step 6, or you can also click Edit Limit Bands button to open it. In this menu you can manually modify the limit ranges and compare them with Bad parts.

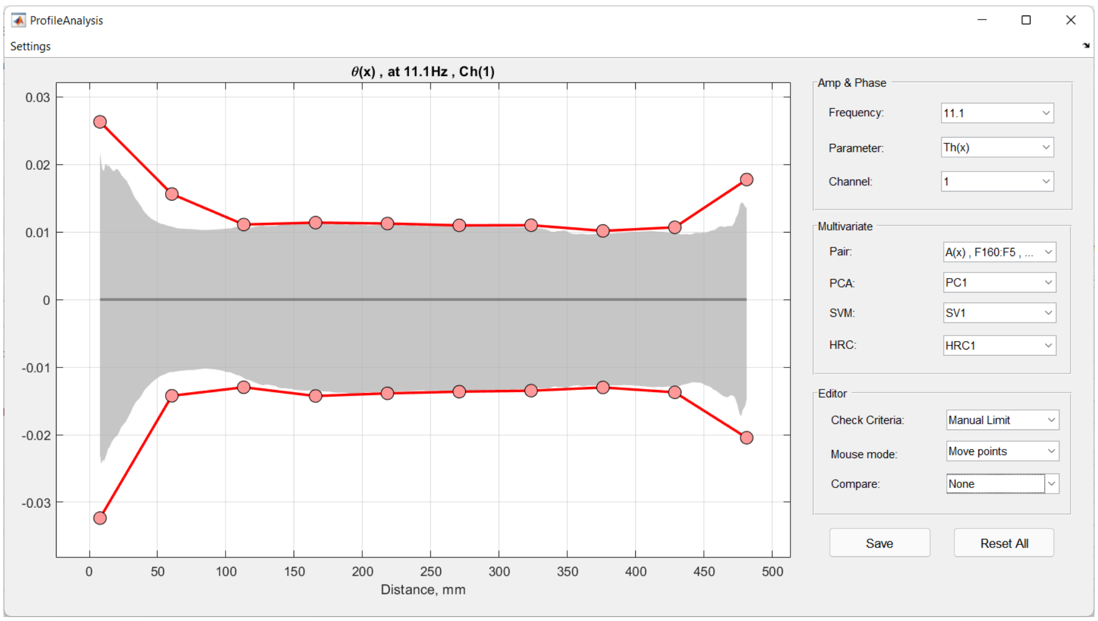
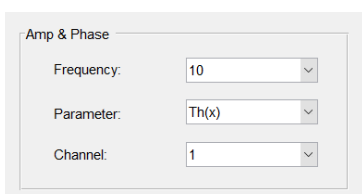


Figure 75. Profile editor to edit limits and activate criteria

- The Gray band shows the acceptance limits calculated in Step 6 during Training.
- The two Red lines with knots are the Manual limits. You can drag the knots to modify the acceptance limits.

Description of panes on the right:

Amp & Phase – You can select the criterion to view. This pane selects base criteria: Amps, Phases, and Derivatives

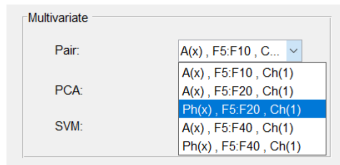


- Frequency – Select a frequency e.g.: 5, 10, 20, or 40Hz

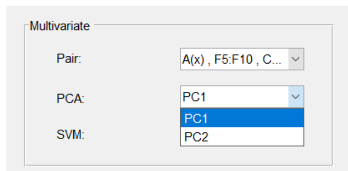
- Parameter – Select Th(x), A(x), Ph(x) or their derivatives
- Channel – Select coil channel

Multivariate – Select multivariate parameters to view.

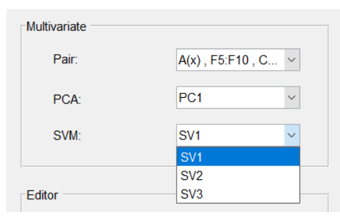
Pair – Based on the pairs defined in Learn menu, you can select and view a criterion



PCA – Based on the Number of PCs set in Learn menu, you can select and view a criterion



SVM – Based on the number of groups (Bad Parts set as Classifiable), you can select and view a criterion.

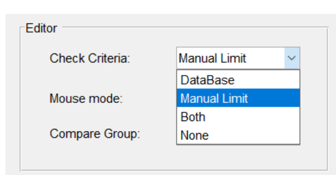


In this example:

- SV1 is the classification between Group A (Good) and B (High Case Depth). The classifier maximizes the distance between the two groups.
- SV2 is the classification between Group A and C (Low Case Depth).
- SV3 is trained using only Group A (One Class SVM).

Editor – From this pane you can adjust upper/lower limits for each criterion

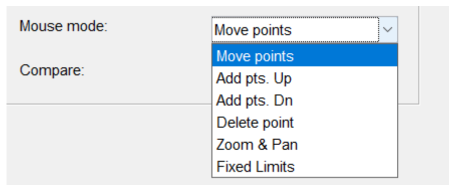
- Check Criteria – After selecting the criterion (from one of the above panes), you can select the acceptance ranges:



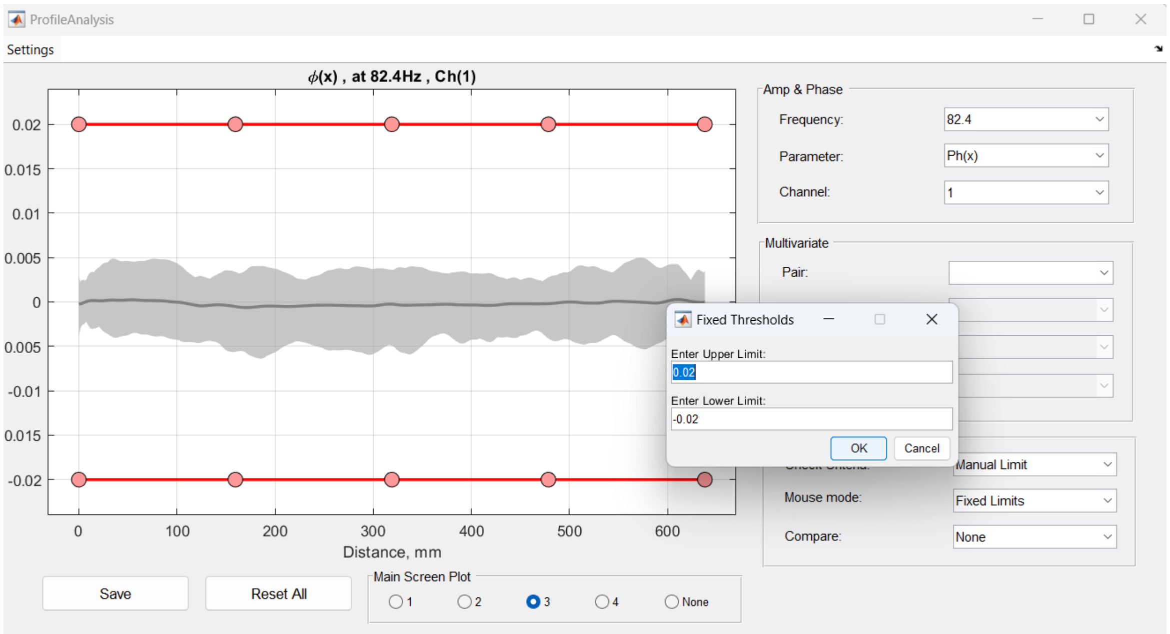
- DataBase – The ranges are defined by Database after training (Step 6). Manual limits are disabled. If you select this option, the DB band turns into Green, and the Manual lines turns into Gray.

- Manual Limit – The ranges are defined by Manual Limits. Database ranges are ignored. If you select this option, the DB band turns into Gray, and the Manual lines with adjustable knots turns into Red.
- Both – Both Database band and Manual limits are considered. At each section the minimum tolerance is considered as the acceptance range.
- None – The Criterion is disabled and is not checked during the test.

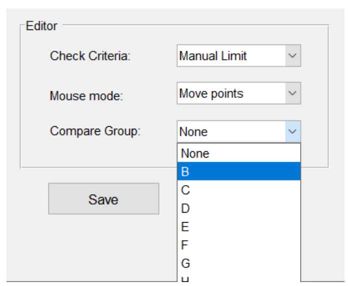
Mouse mode – Use to adjust manual limits



- Move points – Click on a knot and move it to extend or shrink the range
- Add pts. Up – Click to insert a new knot on the upper line in order to better refine the upper limit
- Add pts. Dn – Click to insert a new knot on the lower line
- Delete point – Click on a knot to remove it
- Zoom & Pan – Left button for Pan, Right button for Zoom. Hold the left button and move the mouse to pan. Hold the right button and move up for vertical Zoom In, down for vertical Zoom Out, right for horizontal Zoom In, and left for horizontal Zoom Out.
- Fixed Limits – This option allows for the manual entry of upper and lower limit bands. It is particularly useful for setting phase limits at high frequencies, such as 80 Hz and 160 Hz, which correspond to surface hardness indicators. This manual entry method is advantageous when the acceptance range needs significant expansion, which may be cumbersome to achieve through mouse dragging alone. An example dialog box below illustrates how limit bands can be directly entered.

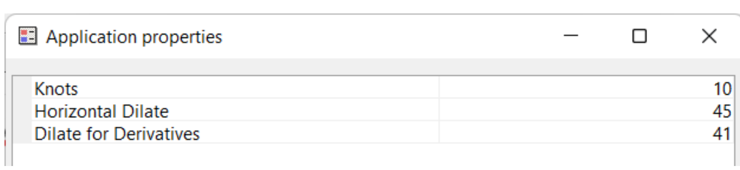


Compare Group



Select a Bad Group (B or C) to compare the ranges and margins. This tool helps better adjust the manual limits. You can increase the acceptance limits but avoid overlapping with the Bad parts.

Default Manual menu



From the **Settings** menu, open the **Default Manual** menu to adjust the default manual parameters. To apply the changes press **Reset All** button. Notice that **Reset All** will recalculate the tolerance bands.

Example – View Phase at 10Hz, switch to Database limits, compare with group B

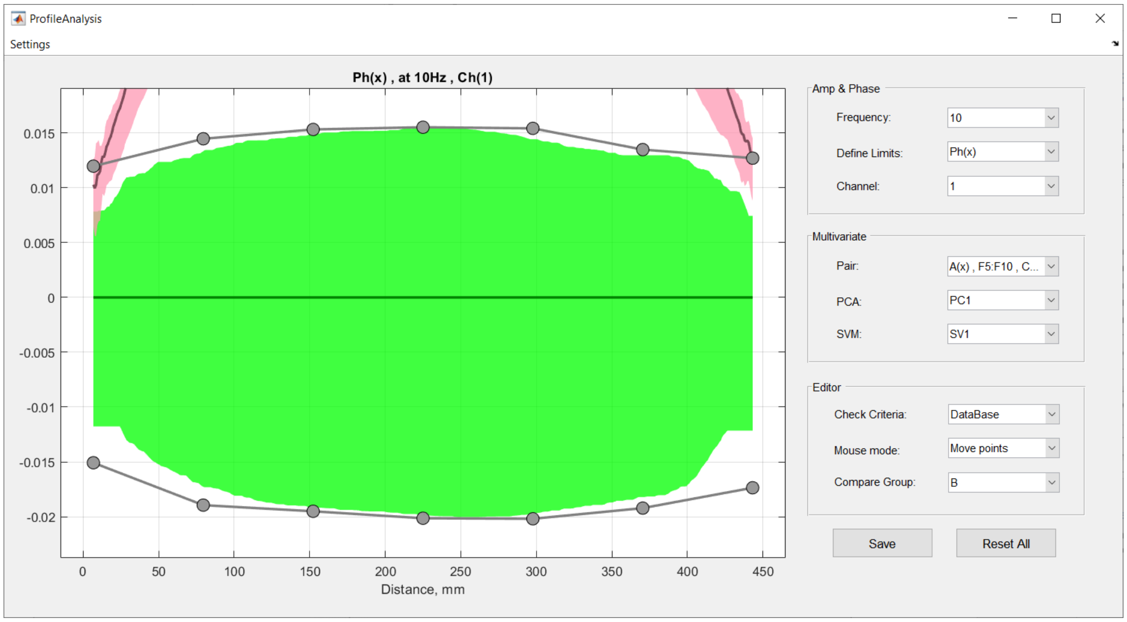


Figure 76. Profile menu. Controlling criteria Phase at 10Hz, comparing with Group B (Deep case)

Close the Profile Analysis menu to complete the training.

5.11 Step 7: Show Results

Click **Select Plots** button in front of the Step 7 to select which results to show.

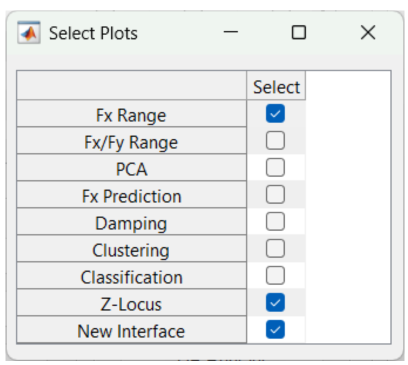


Figure 77. Select parameters to show the Learn results.

- Fx Ranges: Show Theta, Amplitude and Phase envelopes
- Fx/Fy Ranges: Show Ratios
- PCA: Show PCA results
- SVM/LDA Classify: Show SVM results
- Freq. Prediction, Damping Ratios, and Clustering are not used in Eddy Current mode.
- Trajectory: Show Impedance Loci

The selections will be saved for later use.

The figures are sequentially opened. Close a figure to open the next figure.

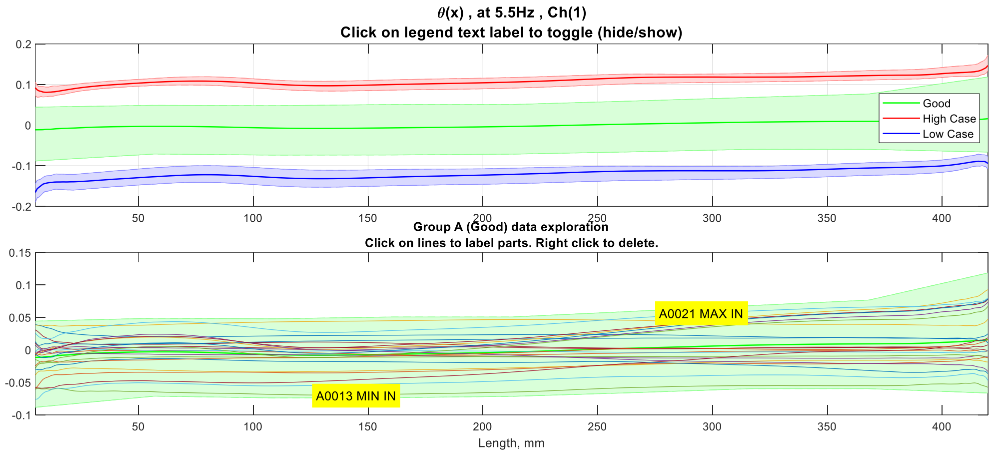


Figure 78. Envelopes of Theta at 5Hz. Top: Three groups of Good (Green), Max-Out (Red), and Min-Out (Blue). Bottom: Database of Good parts in Group "A" and the "Green" limit band. Click on each line to see part name.

Each figure has two sections:

- The top plot shows all Groups: Acceptance band in Green, in comparison with other Bad groups. You can click on a legend to hide/show it.
- The bottom plot shows the Acceptance band, as well as all sample parts in the database. Click on a line to show the part filename. Right click on the yellow name to hide it.

This tool can help find outliers in the database and remove them. If a part (line) is too far away from other lines, it is suspect that it is not a good part. Click on the line to see the file name, then find the part and perform destructive testing on the part. If the part is Good keep the file, otherwise delete the file and train again (Steps 1, 6, 7).

You can skip the sequence by selecting **Interactive Tools** > **Skip Plots** menu, or simply use hot key Ctrl+C.

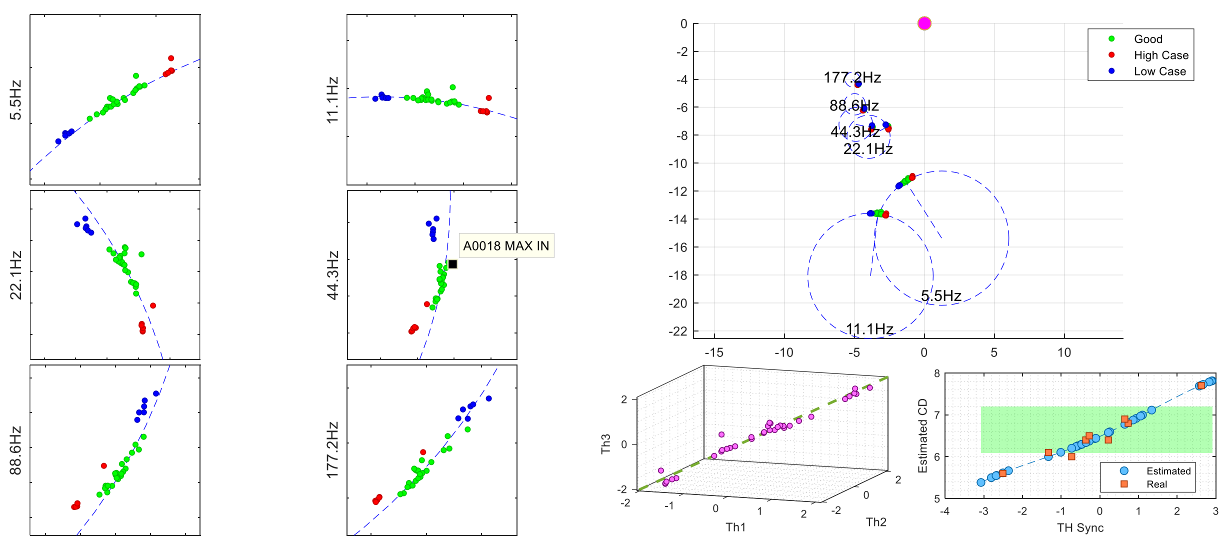


Figure 79. Impedance planes. Check that there is no outlier sample in database. Check that the polynomial fit between Case Depth and Theta is monotonic.

If the **"New Interface"** option in **"Select Plots"** is enabled, you can view, inspect, and analyze all features and trained results in a more advanced interface (see Figure 80).

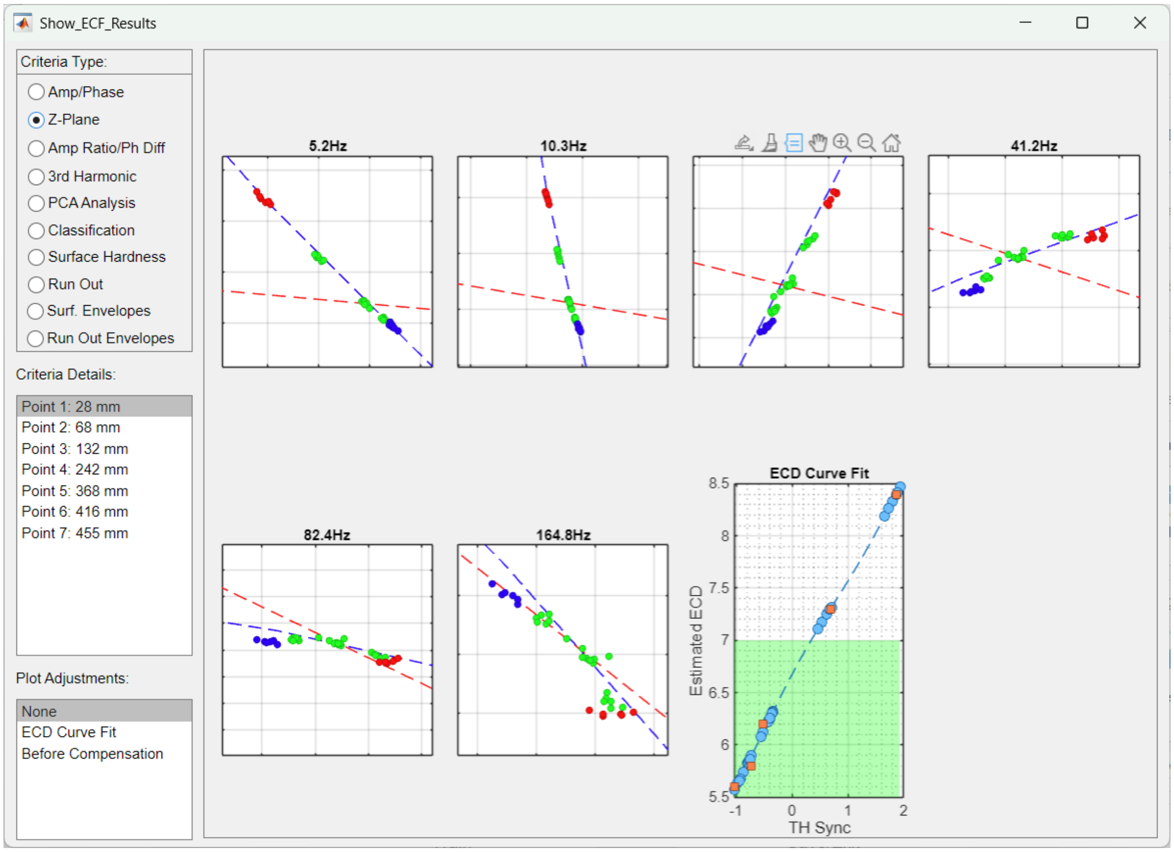


Figure 80. Advanced Interface for Inspecting and Analyzing Trained Results.

5.12 Lock DB Option

Once the database has been trained, it is automatically locked to safeguard against unintended file additions. However, there may be instances where you need to both add new files to the database and view test results. To facilitate this, you will need to unlock the database. Please proceed with the following instructions to successfully unlock your database.

1. Navigate to the "Learn" menu.
2. In the "Analysis Steps" pane, deselect the "Lock DB" option.
3. Click on "Only Save & Exit" to finalize the changes.

6 Testing, Results, and Reporting Workflow

6.1 Test

After completing training (Steps 1, 6, and 7), ensure that **Step 8: ☑ Enable Decision Making** is checked in the **Learn menu**. The system is now ready to test new parts.

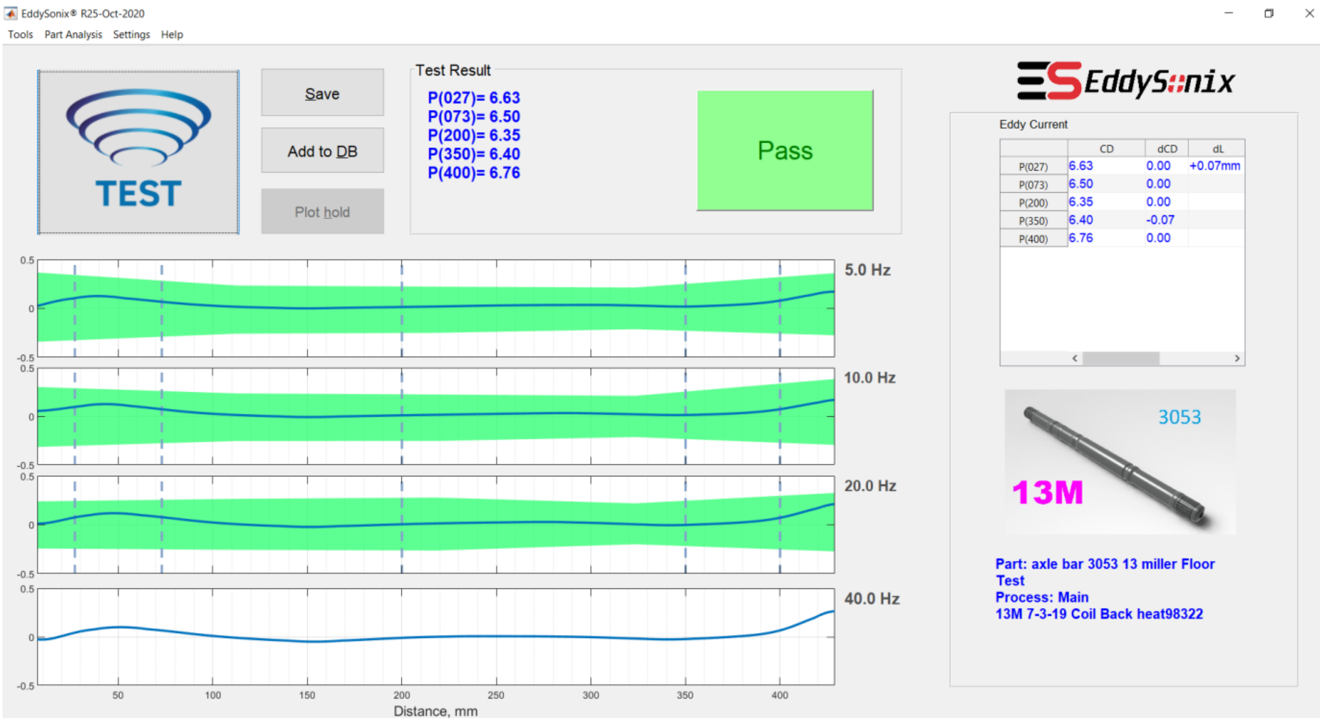


Figure 81. Testing an unknown axle bar

Adjusting the Vertical Scale

- During testing, click on any plot to adjust the vertical scale.
- A popup menu will appear to set the **min** and **max** limits for the y-axis.
- The adjusted values are saved for future testing.
- This function is available when **Enable Hotkeys** is activated (**Control/Impact menu → Test Mode pane → Enable Hotkeys**).

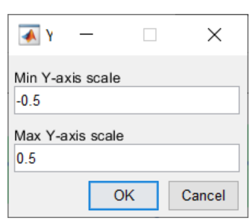


Figure 82. Click on each graph to adjust Y-axis zoom view

Hotkey Results Display

- Press **'r'** to display **rejected criteria**.

- Press **'R'** to display **all criteria**.

Test Results Examples

The following are examples of test result visualizations:

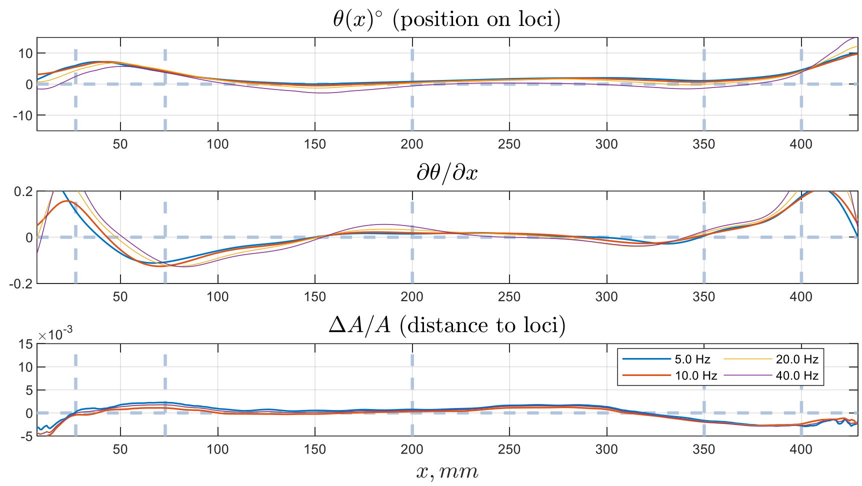


Figure 83. Intermediate results help understand part's behavior

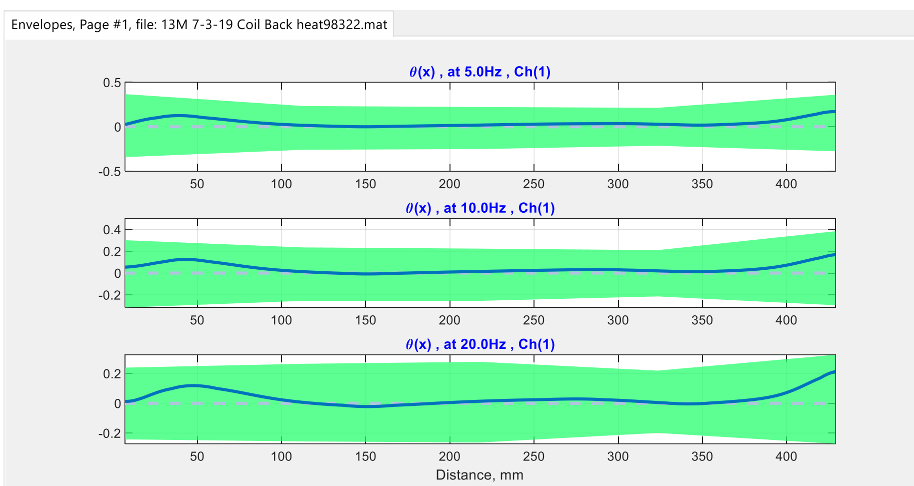


Figure 84. Envelopes results

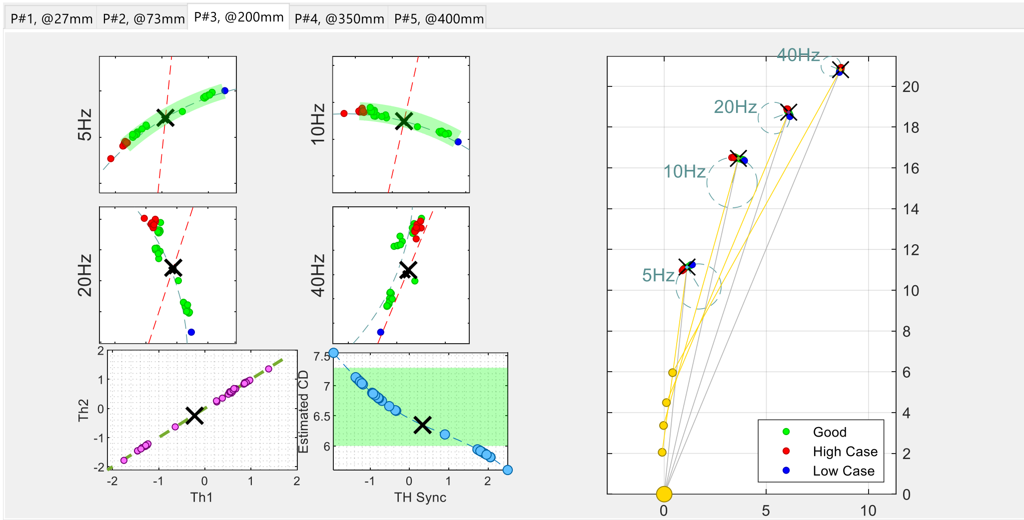


Figure 85. Impedance plane results

Use the **'C'** or **'X'** key to close any open figure

Customizing Display Settings

To set what is displayed when pressing the **'R'** key:

1. Open the **Locus Z menu**.
2. Configure the following options:

- **Plot Results**:
  - Envelopes
  - Impedance Loci
  - Harmonic3 Loci
- **Theta Axis**: Adjust y-axis limits in envelope plots.
- **Debug**: Enable other intermediate plots for deeper analysis.
- **Log Tests**: Save all test data in the **Daily Report folder**. (Note: Ensure sufficient disk space, as filenames are timestamped.)

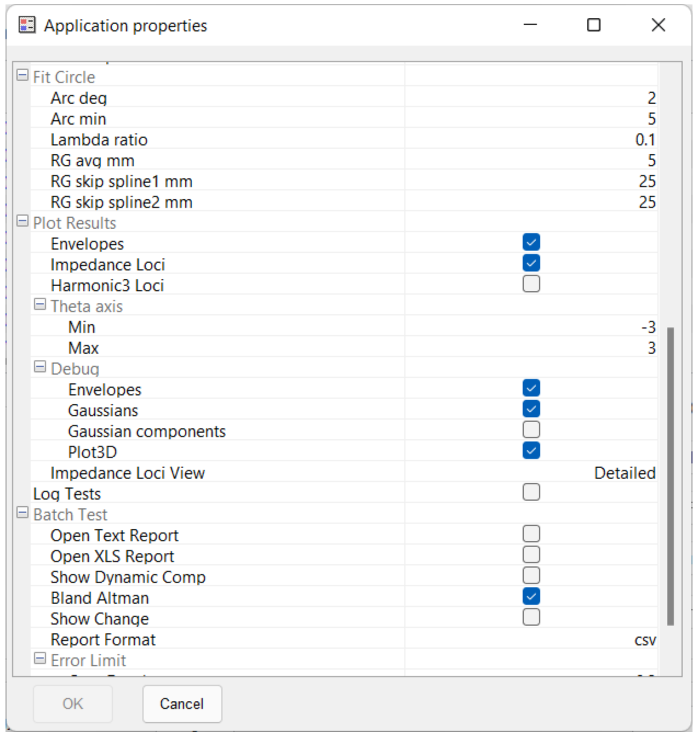


Figure 86. Select the detailed results to display

Raw Signal Visualization

- Press **'Z'** to display raw signals, which help adjust excitation amplitudes.
- *Important*: Once the database is created, avoid changing parameters in the **Signals menu**, especially **excitation frequency and amplitude**.

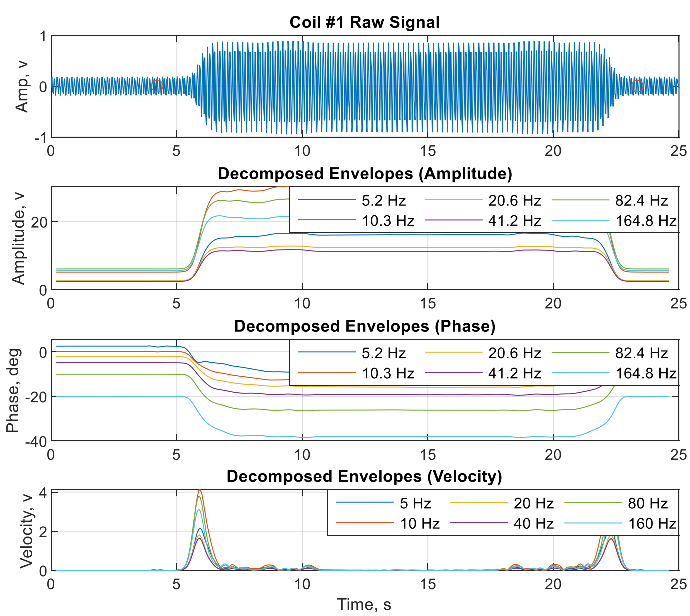


Figure 87. Raw signal and its decomposed components.

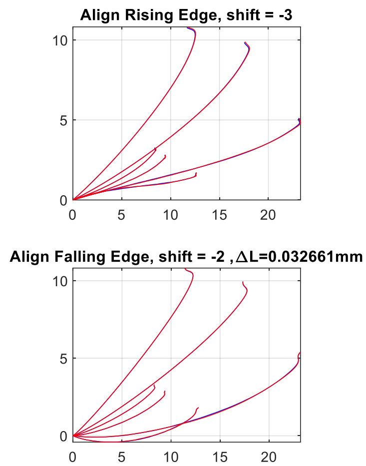


Figure 88. Spline ends alignment

6.2 Compare

The **Compare** tool allows you to analyze and compare the results of multiple tests on a single graph.

Steps to Compare Test Results

1. **Save Test Files**:
    - After testing, save the part files in the **Test folder**.
2. **Open the Compare Tool**:
    - Navigate to **Tools → Compare**.
    - A file selection menu will appear.
3. **Select Files to Compare**:
    - Use **Ctrl + Left Click** to select multiple files.
    - Click **Open** to load the files for comparison.

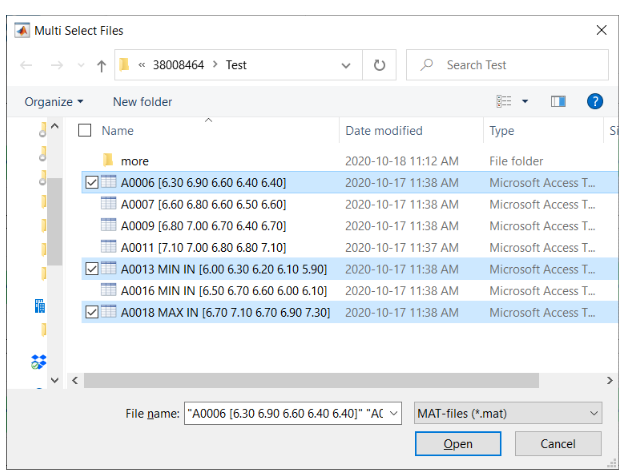


Figure 89. Select multiple files to compare their results.

Example of some plots:

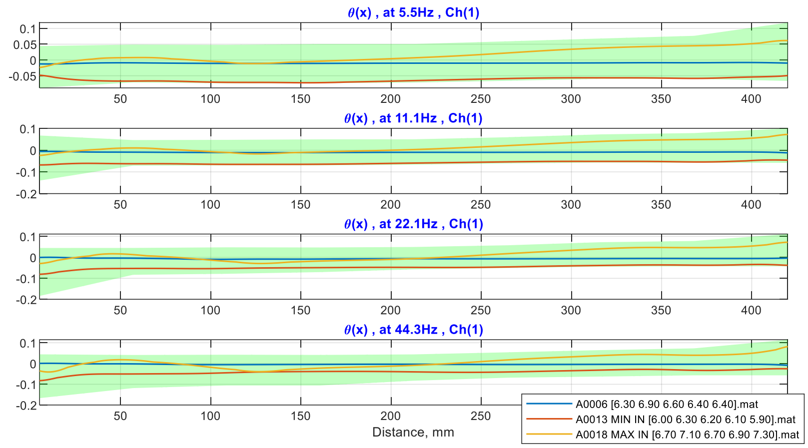


Figure 90. Comparing envelopes of selected parts

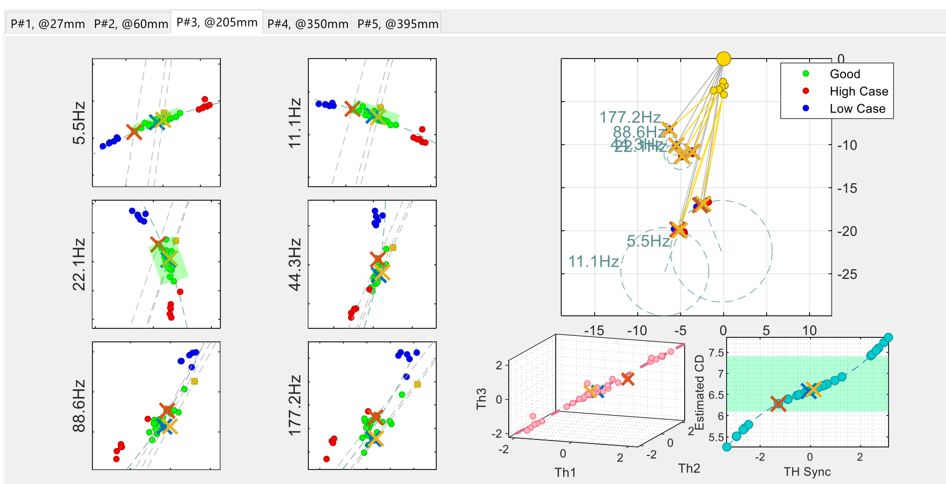


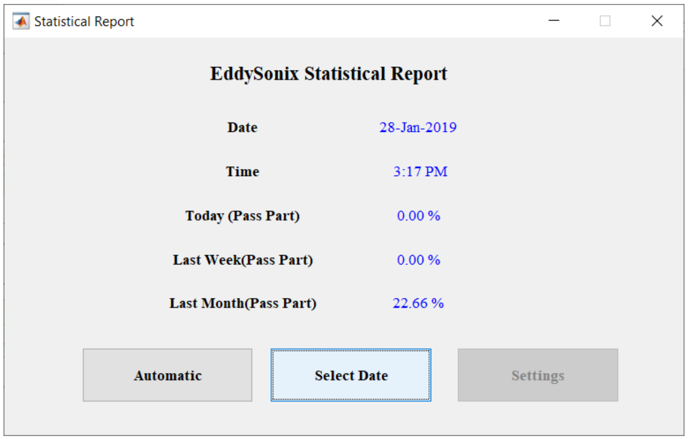
Figure 91. Comparing Impedances of selected parts

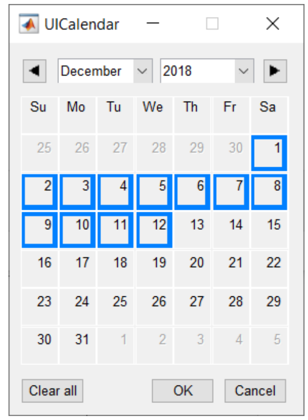
6.3 Daily Report

The **Daily Report** feature allows you to view and analyze test result records.

Steps to Generate a Daily Report

1. Navigate to **Tools → Daily Report**.
2. Select the desired dates from the calendar.
3. A PDF file is generated, displaying the following:
    - Percentage of **Pass/Fail** results.
    - Histograms for detailed analysis.





6.4 Impedance Planes and Case Depth Estimation

Sample parts with varying Case Depths form distinct orbits in the Eddy Current Impedance Plane. The figure below illustrates an example of impedance loci for different frequencies.

Example: Impedance Loci of Parts with Different ECDs

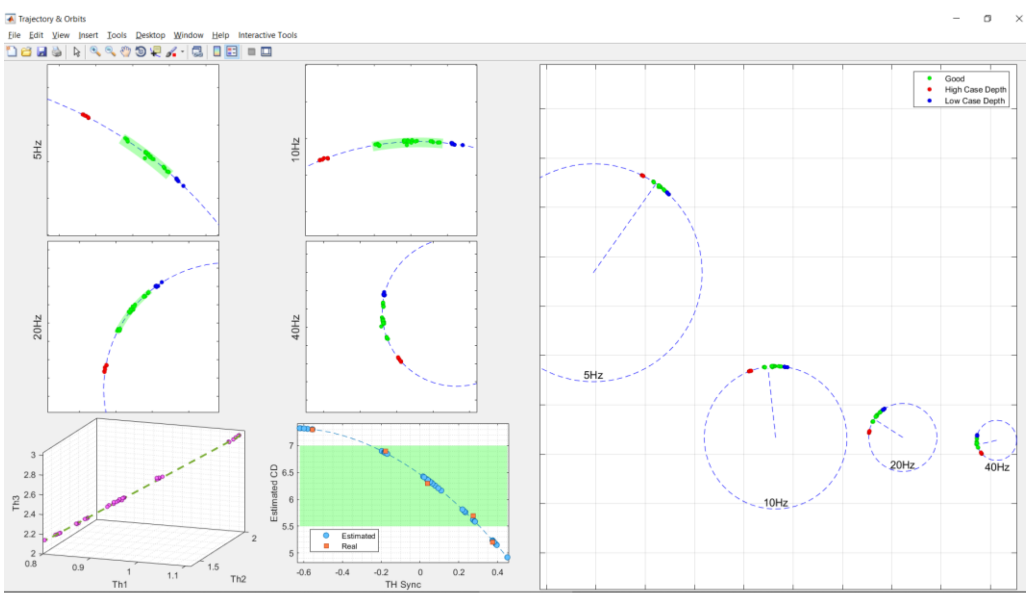


Figure 92. Impedance loci of parts with varying Effective Case Depths (ECD).

In this example, the following parts from one lot were selected:

Cases	Result	N	CD (mm)
Low Case	NOK	5	5.2
Min	Good	5	5.7
Nominal	Good	15	6.3
Max	Good	5	6.9
High Case	NOK	5	7.3

- In Figure 92, each dot (small circle) represents the impedance (**Real, Imaginary**) of an axle bar at a specific location (e.g., L = 225mm).
- The impedance of all parts—Good or Bad—at each frequency forms arc loci.
- Each sample can be characterized by its **radius** and **angle Theta** (Th1, Th2, Th3, Th4).

6.5 Report Generation and Barcode Printing

Generate Reports

The Eddy Current Scanner automatically creates detailed test reports after each scan. These reports include:

- Case depth results for multiple points along the axle bar.
- Pass/Fail decisions with corresponding limits for quick evaluation.

Reports can be automatically transferred to a pre-configured network path, ensuring seamless traceability and accessibility.

YOUR LOGO HERE

Test Report

Part: 10455642 OLE COIL 37A

Scan Date: 29-Jan-2024, 13:16:22

Report Generated on: 20-Nov-2024, 09:16:44

Final Decision: PASS

Case Depth Results:

Label (Location)	Result (mm)	Min	Max
(22 mm)	6.76	6.20	7.70
(48 mm)	7.17	6.40	7.70
(72 mm)	7.04	6.20	7.70
(149 mm)	6.88	6.20	7.70
(300 mm)	7.11	6.20	7.70
(483 mm)	7.12	6.20	7.70
(524 mm)	7.13	6.20	7.70
(570 mm)	7.16	6.40	7.70
(623 mm)	6.77	6.20	7.70

Figure 93. Example of a test report in PDF format

Barcode Printing for Traceability

Barcode printing provides a quick and reliable method for traceability:

- A unique serial number barcode is generated for each tested part.
- Attach the printed barcode to the part for future reference, allowing efficient tracking across production lines or quality audits.

Seamless Integration

The system supports Zebra ZD410 barcode printers, enabling:

- Printing of 1D and 2D (QR-code) labels.

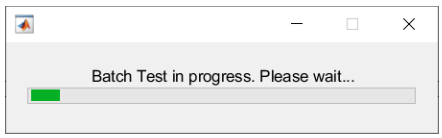
- Easy configuration of network paths and barcode settings through the software's Settings menu.

Note: Press the 'P' key to generate a PDF report and the 'Q' key to print a barcode after completing the test.

6.6 Batch Test

The **Batch Test** tool allows you to analyze multiple files offline, all saved within a folder, and generate a comprehensive statistical report. To use this tool, go to the **Tools menu**, and select **Batch Test (CTRL + B)**.

Important Note: If you make changes in the **Learn menu**, ensure you run **Tools → Recalculate** before initiating a Batch Test.



File Preparation

Files saved during testing can be used for statistical analysis. If microhardness cut-check values for the files are available, these values should be included in the filenames for detailed analysis. Use the following filename format:

- Add the five cut-check values to the filename, separated by spaces or commas, and enclosed in brackets. For example:
  - Part17 [5.01 5.43 5.68 5.72 5.71].mat
  - Part18 [5.01, 5.43, 5.68, 5.72, 5.71].mat

For parts with known cut-check values, the software will generate a detailed statistical report.

- Correlation Coefficient
- RMSE (Root Mean Square Error) $RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N} e_i^2}$
- Mean Error (Average of all Errors) $ME = \frac{1}{n}\sum_{i=1}^{N} e_i$

Where e_i is the Case Depth difference between Microhardness and Eddy Current for part i.

Sample Collection

To obtain meaningful statistical data, use a minimum of **30 samples**. These samples should:

- Be collected from daily production.
- Represent a **normal distribution** by including randomly selected parts, not just problematic ones.

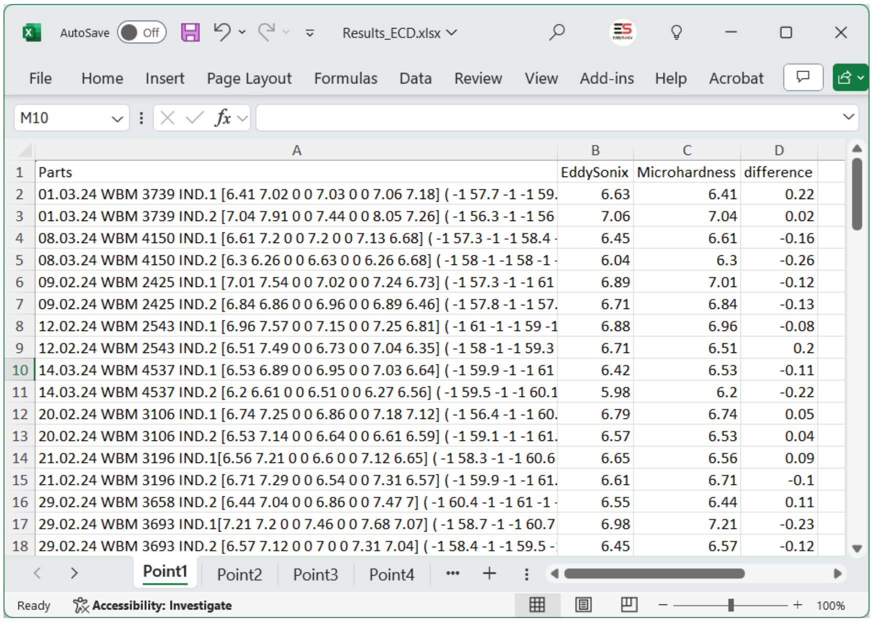
Reports

The Batch Test generates the following outputs:

Excel File:

- Compares EddySonix results with microhardness data.

- Each sheet corresponds to a test point (e.g., P1: Sheet1, P2: Sheet2).
- The file is saved in the **\Test\results.xlsx** location.



	Parts	EddySonix	Microhardness	difference
2	01.03.24 WBM 3739 IND.1 [6.41 7.02 0 0 7.03 0 0 7.06 7.18] (-1 57.7 -1 -1 59.	6.63	6.41	0.22
3	01.03.24 WBM 3739 IND.2 [7.04 7.91 0 0 7.44 0 0 8.05 7.26] (-1 56.3 -1 -1 56	7.06	7.04	0.02
4	08.03.24 WBM 4150 IND.1 [6.61 7.2 0 0 7.2 0 0 7.13 6.68] (-1 57.3 -1 -1 58.4 -	6.45	6.61	-0.16
5	08.03.24 WBM 4150 IND.2 [6.3 6.26 0 0 6.63 0 0 6.26 6.68] (-1 58 -1 -1 58 -1 -	6.04	6.3	-0.26
6	09.02.24 WBM 2425 IND.1 [7.01 7.54 0 0 7.02 0 0 7.24 6.73] (-1 57.3 -1 -1 61	6.89	7.01	-0.12
7	09.02.24 WBM 2425 IND.2 [6.84 6.86 0 0 6.96 0 0 6.89 6.46] (-1 57.8 -1 -1 57.	6.71	6.84	-0.13
8	12.02.24 WBM 2543 IND.1 [6.96 7.57 0 0 7.15 0 0 7.25 6.81] (-1 61 -1 -1 59 -1	6.88	6.96	-0.08
9	12.02.24 WBM 2543 IND.2 [6.51 7.49 0 0 6.73 0 0 7.04 6.35] (-1 58 -1 -1 59.3	6.71	6.51	0.2
10	14.03.24 WBM 4537 IND.1 [6.53 6.89 0 0 6.95 0 0 7.03 6.64] (-1 59.9 -1 -1 61	6.42	6.53	-0.11
11	14.03.24 WBM 4537 IND.2 [6.2 6.61 0 0 6.51 0 0 6.27 6.56] (-1 59.5 -1 -1 60.1	5.98	6.2	-0.22
12	20.02.24 WBM 3106 IND.1 [6.74 7.25 0 0 6.86 0 0 7.18 7.12] (-1 56.4 -1 -1 60.	6.79	6.74	0.05
13	20.02.24 WBM 3106 IND.2 [6.53 7.14 0 0 6.64 0 0 6.61 6.59] (-1 59.1 -1 -1 61.	6.57	6.53	0.04
14	21.02.24 WBM 3196 IND.1[6.56 7.21 0 0 6.6 0 0 7.12 6.65] (-1 58.3 -1 -1 60.6	6.65	6.56	0.09
15	21.02.24 WBM 3196 IND.2 [6.71 7.29 0 0 6.54 0 0 7.31 6.57] (-1 59.9 -1 -1 61.	6.61	6.71	-0.1
16	29.02.24 WBM 3658 IND.2 [6.44 7.04 0 0 6.86 0 0 7.47 7] (-1 60.4 -1 -1 61 -1 -	6.55	6.44	0.11
17	29.02.24 WBM 3693 IND.1[7.21 7.2 0 0 7.46 0 0 7.68 7.07] (-1 58.7 -1 -1 60.7	6.98	7.21	-0.23
18	29.02.24 WBM 3693 IND.2 [6.57 7.12 0 0 7 0 0 7.31 7.04] (-1 58.4 -1 -1 59.5 -	6.45	6.57	-0.12

Scatter Plot Microhardness vs. EddySonix

- Blue dot: error is less than 0.3mm
- Red dot: error is more than 0.3mm

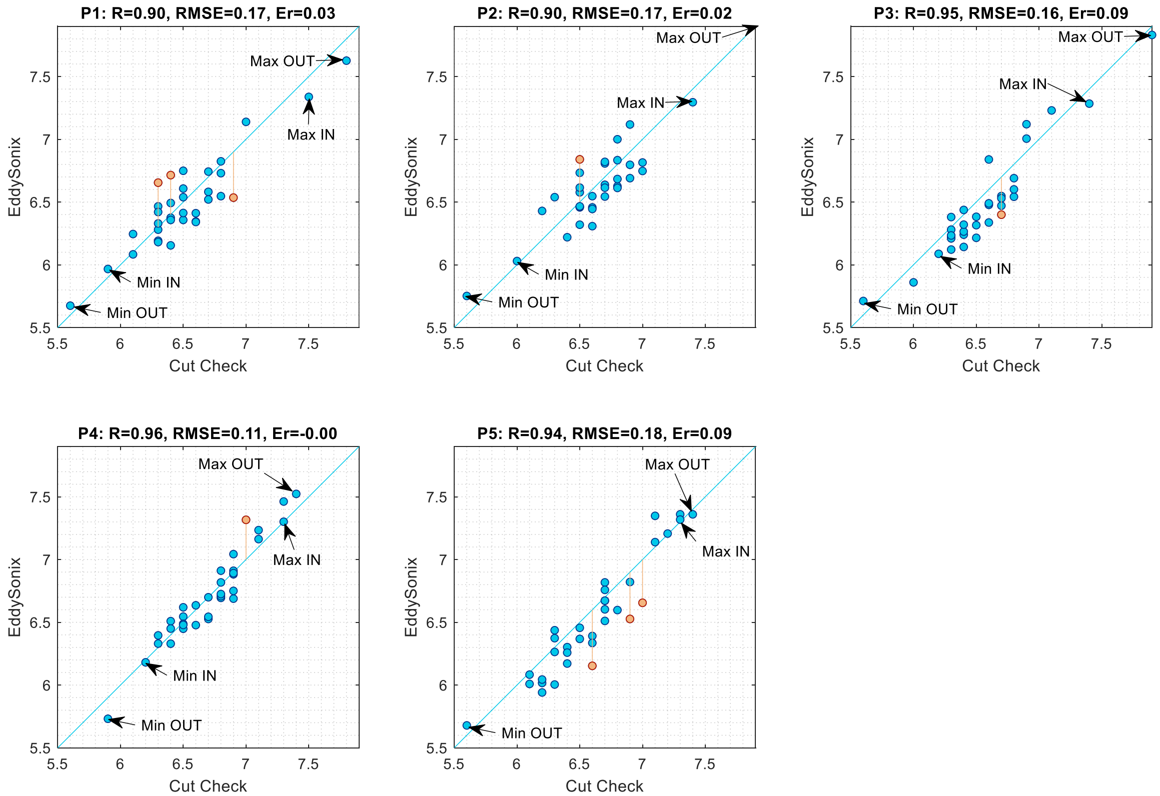


Figure 94. Scatter plot of Microhardness vs. EddySonix ECD estimation at 5 locations on axle bar.

Bland-Altman Report for Each Point (P1, …, P5)

The **Bland-Altman analysis tool** provides a detailed comparison of two ECD (Effective Case Depth) data sets obtained from **Microhardness** and **EddySonix** tests. This analysis includes a Bland-Altman plot and a correlation scatter plot, offering insight into the agreement and accuracy of the measurements.

How to Enable Bland-Altman Reports

To generate the Bland-Altman report during a **Batch Test**:

1. Open the **Learn menu**.
2. Navigate to **Z Locus → Batch Test**.
3. Check the option ☑ **Bland-Altman**.

This statistical information is reported on the correlation plot:

n	**number of data points used**
SSE	sum of squared error
RMSE	root mean squared error
R	Pearson Correlation Coefficient
p	Pearson correlation p-value
rho	Spearman rho correlation value and p-value
y	slope and intercept equation

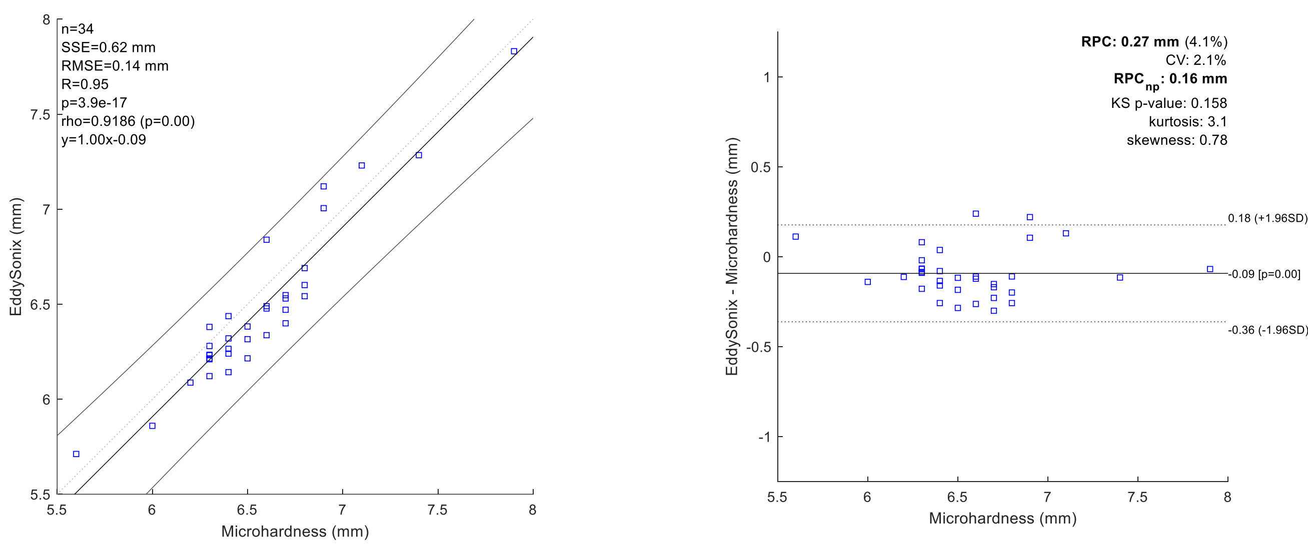
Confidence Interval Lines are shown on correlation plots.

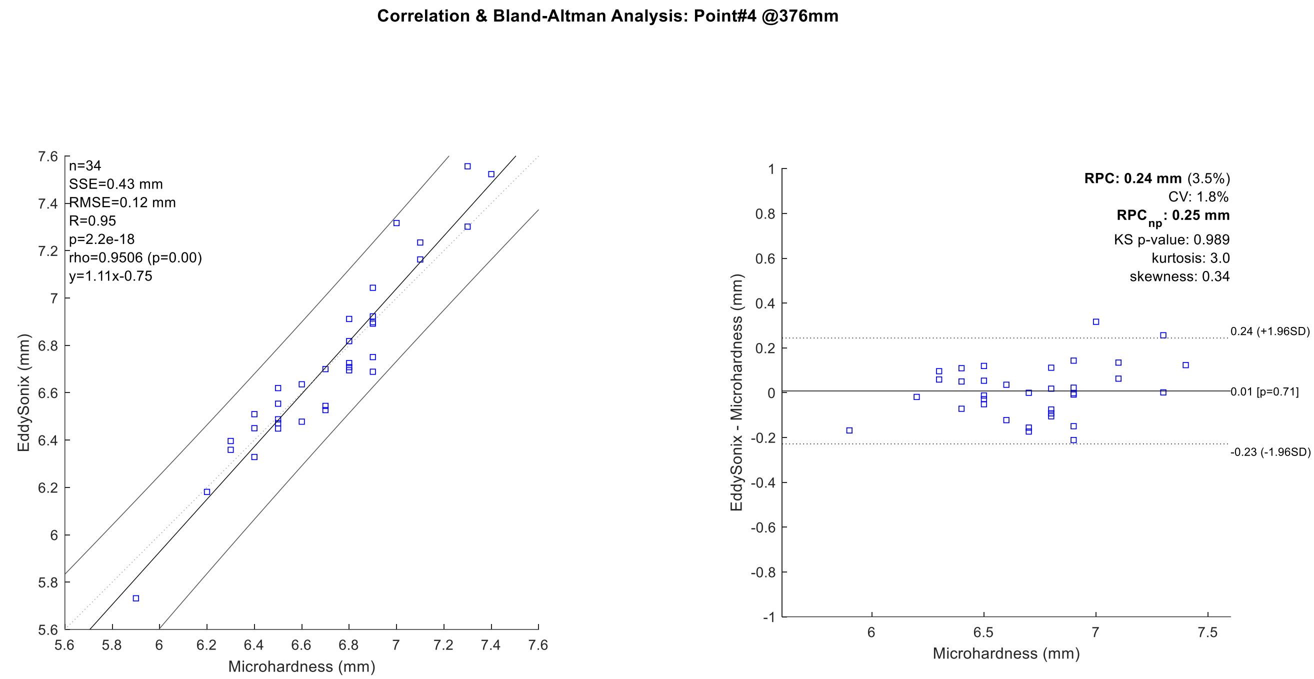
This statistical information is reported on the Bland-Altman plot:

RPC	reproducibility coefficient and % of values, also known as "limits of agreement"
CV	coefficient of variation (SD of mean values in %)
RPC_{np}	RPC estimate based on IQR (non-parametric statistics) where RPCnp = 1.45*IQR ~ RPC (if distribution of differences is normal).
KS	Kolmogorov-Smirnov test that difference-data is Gaussian
kurtosis	Kurtosis test that difference-data is Gaussian
skewness	skewness test results
IQR	interquartile range

Note: Gaussian distribution is tested using the Kolmogorov-Smirnov test. If the data seems to violate the assumption of distribution type, a warning message is generated.

Correlation & Bland-Altman Analysis: Point#3 @231mm





You can define Batch Test settings from **Learn** → **Z Locus** menu:

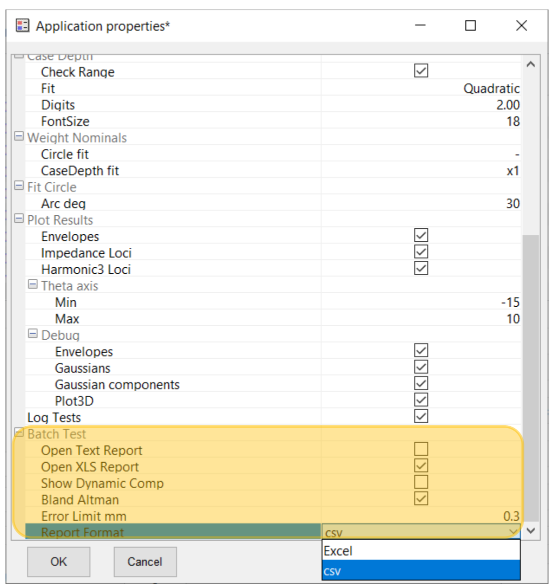


Figure 95. In this menu, specify the reports you want to create.

6.7 Batch Test – Preparation for Fine Tuning After Initial Training

One of the important applications of the **Batch Test** feature is to support **fine tuning of a Part Setup** after its initial training.

When a new Part Setup is created, it is typically trained using a limited set of reference parts, including **Nominal, Max-In, Max-Out, Min-In, and Min-Out** samples. This provides a baseline for testing new parts from production, covering different lots, heats, or process variations.

However, due to natural variability in production, the initial training may not ensure high accuracy at every **defined Point** along the part. To improve reliability and precision, **additional evaluation** is required before any fine tuning is performed.

Preparation Steps:

1. **Sample Collection**
   Gather **30 to 50 parts** from actual production over several weeks. These should represent a wide range of normal process variations.

2. **Scanning and Saving**
   Each part is scanned using the existing Part Setup and saved in the **Test folder**.

3. **Cut-Check and File Labeling**
   Each scanned part is **cut-checked** using microhardness measurement. The cut-check values are then appended to the corresponding filenames.

4. **Running Batch Test**
   With all test files prepared, the **Batch Test** is executed on the Test folder. This produces:
   - A full **statistical report**
   - **Error and correlation analysis** at each defined Point

These results allow the user to evaluate how well the trained model performs under real production conditions. This analysis forms the basis for the **next step: fine tuning**, which will be explained in the following section.

⚠️ **Important Note:**
The **Batch Test is a reporting tool only**. It does **not apply corrections**, modify case depth values, or update the database automatically.
It is **not a self-learning or self-correcting** process.

Fine Tuning – Step 1: Outlier Detection and Data Integrity Check

Before adjusting any parameters, the first step in fine tuning is to **identify and verify outlier data** in the Batch Test results.

Outliers may indicate **errors in data entry** or **issues during cut-check testing**. Addressing these issues is critical before making any tuning decisions.

Common Issues to Check:

1. **Data Entry Mistakes**
   - Check if any point shows a value **too far from the trend**. This may be due to a **typing or formatting error** when concatenating the cut-check values to the filename.
   - Verify the values carefully against original lab records.

2. **Point Order Errors**

- Ensure that the **sequence of cut-check values** in each filename **matches the defined Points** in the system.
- A common mistake is swapping values for two adjacent points.

3. **Missing Data Handling**
   - If a cut-check value is missing for a Point, insert a **zero or negative number** as a placeholder.
   - The total number of values must always match the number of defined Points, otherwise the system will not align the data correctly.
4. **Cut-Check Test Errors**
   - Some deviations may come from **errors in microhardness testing**.
   - It is strongly recommended to **store the cut samples in labeled bags** for several months, so you can recheck any suspicious measurements later.

This step ensures that the Batch Test results are based on **accurate and consistent data**, which is essential before proceeding to any parameter adjustment.

Fine Tuning – Step 2: Correcting Systematic Errors (Bias / Offset)

Once the data integrity is confirmed, the next step is to check for **systematic errors**, also called **bias** or **offset**, at each defined Point.

These errors are visible in the **correlation and error plots** generated by the Batch Test. A high **Er. (mean error)** value indicates that the prediction at that point consistently deviates from the cut-check values.

Correction Procedure:

1. **Identify the Error**
   - Look at the **Er.** value for each Point in the Batch Test report.
   - If Er. is not close to zero, a systematic offset exists.
2. **Adjust the Database Value**
   - Open the Part Setup and locate the ECD value in the database for the affected Point.
   - **Add the Er. value** to the current ECD to correct the bias.
3. **Targeted Adjustment (Optional)**
   - Analyze whether the error comes mostly from:
     - The **Max region** (above Nominal)
     - The **Min region** (below Nominal)
     - Or the entire range

- Use this insight to apply more focused adjustments if needed.

4. **Retrain the Point**
   - After editing the ECD, **retrain the Part Setup**:
     - Ensure **Step 1 (Use Database)** and **Step 6 (Update Settings)** are both checked.
     - Train only the affected Point.
5. **Re-run Batch Test**
   - Run the Batch Test again to check if the correction has reduced the **Er.** value.
   - **Note:** This step does **not** aim to improve the correlation (**R**). The goal is to bring **Er. close to zero**, which also helps reduce **RMSE**.
   - A low Er. means the offset (bias) has been corrected.

🔍 **Tip:** Work **one Point at a time**. Complete adjustments for Point 1 before moving to Point 2, and so on. This avoids confusion and isolates changes clearly.

Fine Tuning – Step 3: Frequency Adjustment for High RMSE

After correcting the systematic error (Er.), if **RMSE remains high** or **some parts still show large errors** (e.g., > 0.5 mm), the issue may be due to **inadequate frequency selection** for that specific Point.

Procedure:

1. **Identify the Problem Point and Affected Parts**
   - Focus on the Point(s) with high RMSE or where a few parts still deviate significantly.
2. **Try a Different Frequency**
   - In the **Compensation** menu:
     - Select the correct **Master frequency**.
     - In the **Amplitude Compensation** pane, check **one or multiple frequency channels** that better model the ECD for that Point (e.g., switch from F1 to F2 or use both).
3. **Retrain and Test**
   - Only check **Step 6 (Update Settings)**.
   - Train the Point and run **Batch Test** again to see if the error is reduced.

Fine Tuning – Step 4: Phase Compensation Adjustment

If frequency selection alone does not reduce the error, the next step is to tune the **Phase Compensation**, which is the second stage of compensation.

Procedure:

1. **Enable Phase Compensation**
   - In the **Compensation** menu, ensure **Phase Compensation is turned ON** for the target Point.
2. **Select Reference Frequency**
   - The **Ref frequency** must be high (e.g., above 100 Hz).
   - Try increasing it to **200 Hz or higher** if needed for better sensitivity.
3. **Select Adjusted Frequencies**
   - In the second column of the Phase Compensation pane, **check the Adj. frequencies** you want to use.
4. **Tune the Gain**
   - The default gain is **0.5**.
   - Adjust it between **0.1 and 1.0** to see its effect.
   - Higher gain increases the effect of correction.
5. **Retrain and Test**
   - Train using only **Step 6**, and re-run the Batch Test.
   - Evaluate if the error has improved for the previously affected parts.

Fine Tuning – Step 5: Dynamic Compensation for Local Peak or Valley Errors

If some parts still show **local peaks or valleys** in the ECD curve that are not well modeled, you may need to activate the **third level of compensation: Dynamic Compensation**. This step increases **sensitivity and resolution** at specific Points by enhancing localized features in the signal.

Procedure:

1. **Open Dynamic Compensation Pane**
   - Click **Auto** to recalculate the coefficients based on the current part length.
2. **Select the Target Point**
   - Use the **"Select Point"** menu to choose the specific Point with local error.
   - Turn on **"Enable"** for that Point.
3. **Configure Gaussian Frequencies**
   - Use only the **"Gaussian"** column.
   - Select **one or two frequencies** for enhancement — these should be **one level higher** than those used in Amplitude Compensation.

- Example: If F1 and F2 are used in Amp Compensation, then use **F2 and F3** for Dynamic Compensation.

4. **Enable Z Locus Display**
   - In the **"Z Locus"** menu, make sure the **Gaussian components are checked (enabled)** to visualize their effect.

5. **Test and Visualize the Result**
   - Test a sample part.
   - Press **'R'** to refresh the view and observe the effect of Dynamic Compensation.
   - Enhanced peaks or valleys should become more visible.

6. **Adjust the Gain**
   - In the Dynamic Compensation panel, adjust the **Gain** to control the strength of peak enhancement.
   - Tune the gain to improve modeling while avoiding overfitting.

Fine Tuning – Step 6: Switching to Synthetic Frequencies or Compensation Sets

If, after applying all previous techniques, **significant errors still remain** for certain parts or Points, it may indicate a **limitation in the input signal space** or a **mismatch between compensation strategy and the case depth profile**.

In such cases, two advanced solutions are available:

- **Synthetic Frequencies**
  When the existing frequencies do not provide enough variation (especially in shallow-case regions), synthetic frequencies can be created by mathematically combining existing signal data. This extends the input space and can reshape the Z-Locus for better separation and accuracy.

- **Compensation Sets (CompSets)**
  If the case depth varies significantly along the part, a single compensation model may not be sufficient. CompSets allow assigning different compensation strategies to different Points, making the model adaptive to local variations.

These advanced tools should only be used **after all other corrections fail**. They provide **a new level of flexibility and modeling capability**, helping to overcome signal geometry or process variation challenges.

📘 **Refer to chapters:**

- *Synthetic Frequencies – Section 5.4*
- *Compensation Sets – Section 5.6*
  for detailed instructions on how to configure and apply these tools.

6.8 External Export – MECC format

The **Transfer** feature enables seamless traceability by sending test results to a network path and printing a barcode for each part.

Steps to Transfer Results and Print Barcode

1. **Initiate the Transfer**:
    - After each test, press the **"Q"** key to open the **MECC dialog box**.
    - Press the **"Transfer"** button.
2. **Attach the Barcode**:
    - A barcode with a unique serial number is generated and printed.
    - Attach the barcode to the tested part for tracking and future reference.
3. **Send Results to Network**:
    - Test results are saved in a **CSV file** and automatically transferred to the configured network path.

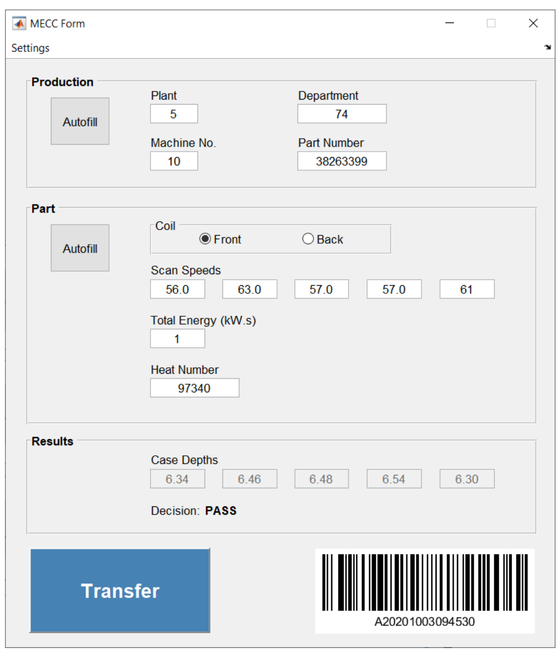


Figure 96. Transferring test results and printing a barcode.

Settings for Traceability

- **Define Network Path and Barcode Type**:
    - Open the **Settings menu** to configure the network path for CSV storage and select the type of barcode (1D or 2D).

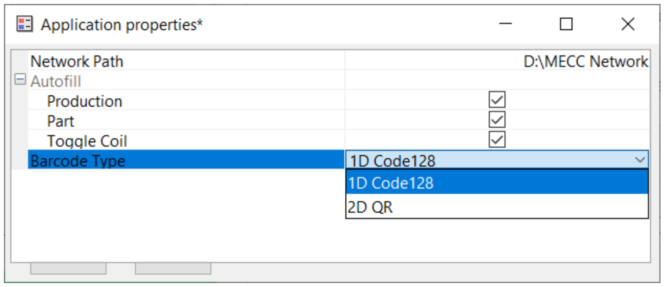


Figure 97. Settings for traceability

Supported Printers

- EddySonix supports Zebra printers using ZPL (Zebra Programming Language), specifically the **Zebra ZD410** model.
- Both **1D barcodes** and **2D (QR-code)** labels can be printed.

Figure 98. Connecting a Zebra ZD410 printer to the EddySonix machine.

CSV File Format

The CSV file generated includes essential test data, formatted for easy integration with traceability systems. Ensure that the configured path has sufficient storage space to handle the file generation.

#	Description	Example
1	Plant	5
2	Department	74
3	Machine number	#10
4	Part number	38263399
5	Coil (B / F)	B
6	Scan speed 1	56.0
7	Scan speed 1	63.0
8	Scan speed 1	57.0
9	Scan speed 1	57.0
10	Scan speed 1	61.0
11	Total Energy	1

12	Heat number	97370
13	ECD 1 • Pass: 6.65 • Reject: 7.47 X • Upper Limit Alarm: 7.30 UCL • Lower Limit Alarm: 5.70 LCL	6.65
14	ECD 2	
15	ECD 3	
16	ECD 4	
17	ECD 5	
18	Test mode • Offline: using saved files • Online: really scan a part	Online
19	Test result • PASS • PASS CL ALARM • FAIL	PASS
20	Time stamp	09/23/2020 3:46:53 PM
21	Machine tag	SD803193X01

6.9 External Export – SESAME format

The SESAME external export provides automatic generation of structured result files for traceability, quality tracking, and integration with external MES / quality systems.

When enabled, the export is performed automatically after each successful test and saved to a user-defined network or local folder.

This export format is rule-based, deterministic, and independent of operator actions once configured.

It generates the required file in a **single export folder** (example: C:\EddySonix\Exports\) so SESAME can access it easily.

Required files and folder setup

Export folder

Create (or ask IT to create) this folder on the machine PC:

- C:\EddySonix\Exports\

This folder will contain the exported SESAME files.

Excel mapping files (must be copied once)

Copy these **two Excel files** into:

- C:\EddySonix\Program\

Files:

- EDDYSONIX Geographical Breakdown SESAME.xlsx
- EDDYSONIX Product Breakdown SESAME.xlsx

Important:

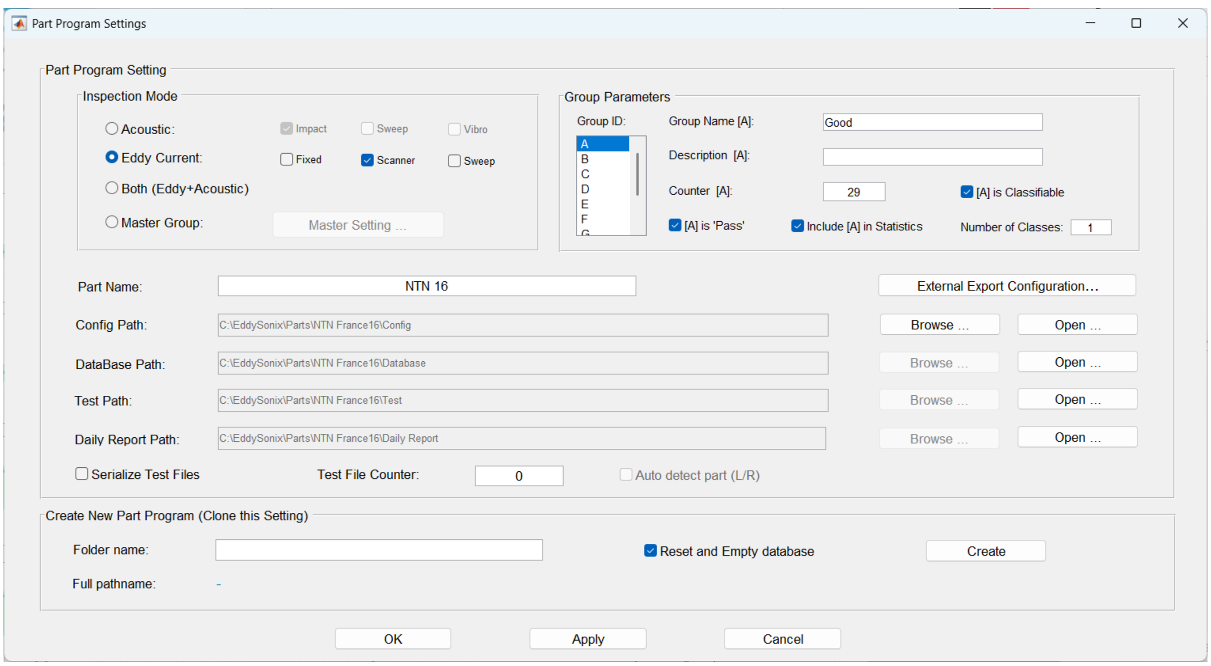
- Keep the filenames exactly the same.
- Do not rename the files.
- Do not move them into a Part Program folder.

External Export Configuration (one time per Part Program)

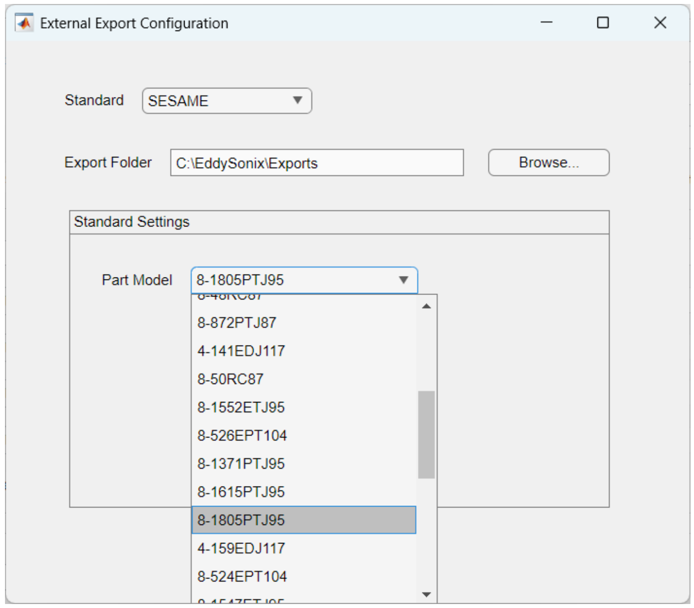
Open the Part Program Settings

1. Open the **Part Program Settings** window (Part Definition menu).
2. In this window, locate and click the **External Export Configuration…** button (see the Part Definition screenshot in this document).

Important:
The export configuration is **stored per Part Program**.
You must configure **External Export Configuration** separately for **each Part Program** that will use SESAME export.



Open “External Export Configuration…”



Select the Standard

In the "External Export Configuration" window:

1. Set **Standard** to:
   - **SESAME**

Select the Export Folder

1. In **Export Folder**, set:
   - C:\EddySonix\Exports\
2. You can use **Browse...** to select it.

Note:

- The folder must exist.
- If the folder does not exist, export will be blocked and an error message will be shown.

Select the Part Model (SESAME)

In the **Standard Settings** panel:

1. Use **Part Model** dropdown to select the correct code (example: 8-1805PTJ95).
2. Click **OK**.

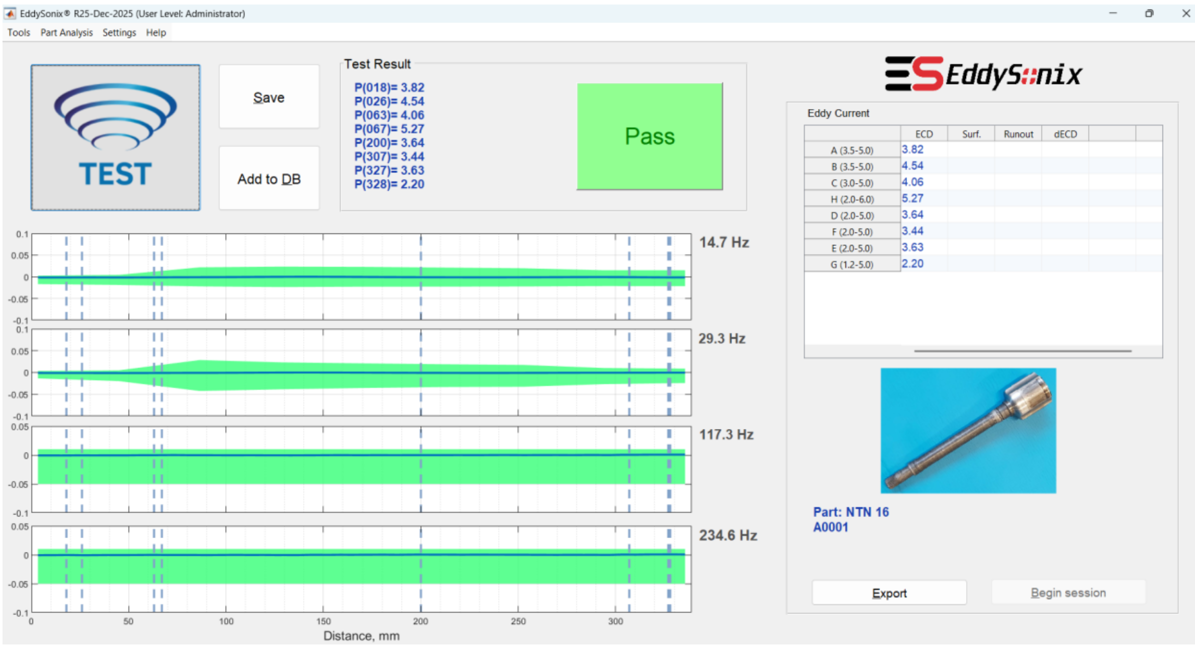
Result:

- The Part Program now stores the SESAME product information for export.

How to export after a test

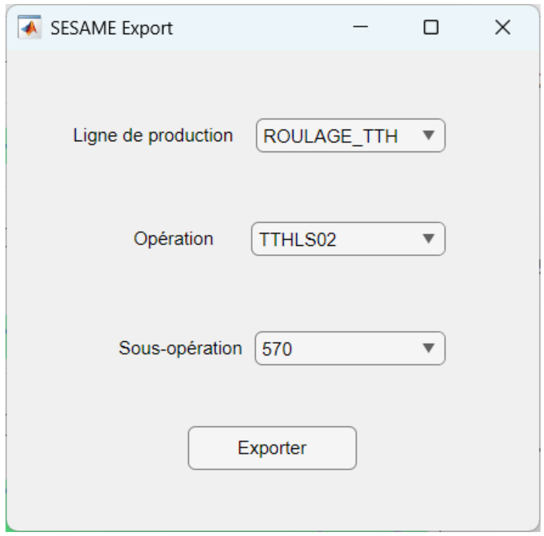
Perform a valid test

1. Test a part normally.
2. If the test is valid, the Export button will be enabled.



Use Export button

1. On the main screen, click **Export**.
2. The **SESAME Export** dialog opens.
3. Select:
    - **Ligne de production**
    - **Opération**
    - **Sous-opération**
4. Click **Exporter**.



Result:

- A SESAME file is created inside:
    - C:\EddySonix\Exports\

Output files and naming

Where the files are saved

All SESAME exports are saved in:

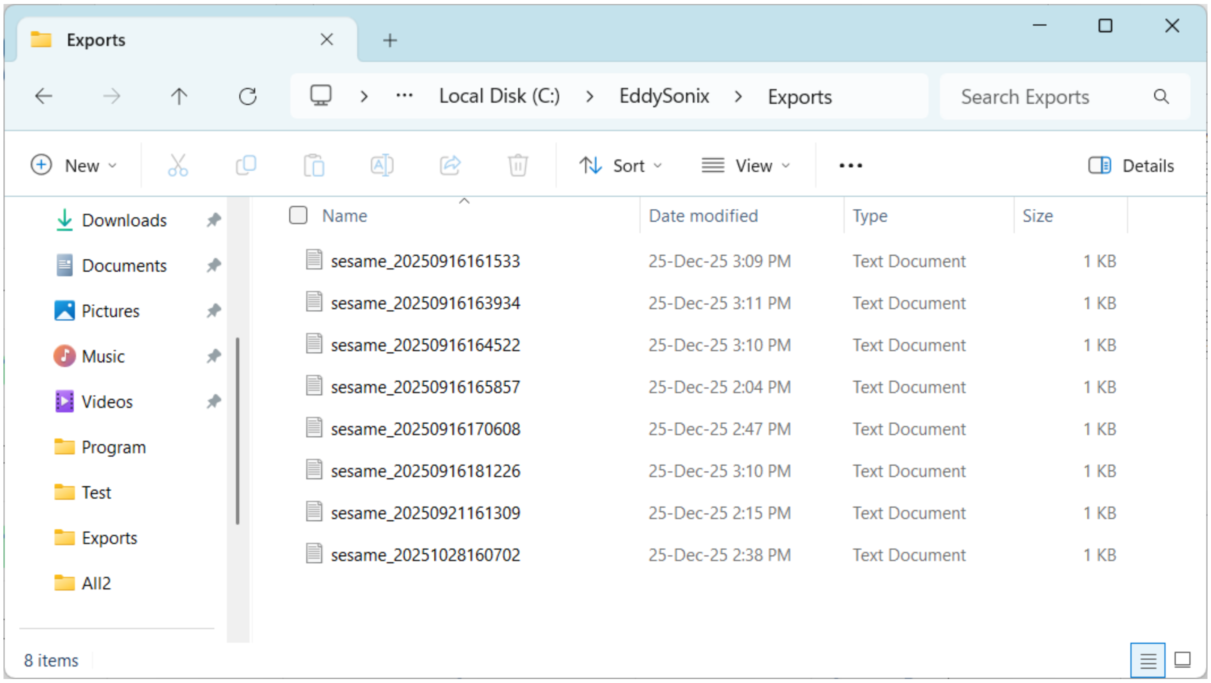
- C:\EddySonix\Exports\

File naming

Files are saved with a timestamp based on the **scan time** (the real test time), not the export time.

Example:

- sesame_YYYYMMDDhhmmss.txt (or equivalent naming used in your build)



Common issues and quick checks

Export button disabled

Possible reasons:

- No valid test has been completed.

SESAME export configuration missing

If Part Program is not configured:

- Open **Part Program Settings**
- Click **External Export Configuration…**
- Set **Standard = SESAME**
- Set **Export Folder**
- Select **Part Model**
- Click **OK**

Excel mapping files missing

If export dialog cannot load required data:

- Confirm both XLSX files exist in:
  - C:\EddySonix\Program\

Recommended workflow

1. Copy the two SESAME XLSX files to C:\EddySonix\Program\ (once).
2. Configure each Part Program one time via **External Export Configuration…**
3. After each valid test, use **Export** to generate SESAME file(s).

7 Surface Hardness Testing

7.1 Build a database

For Surface Hardness analysis, reference samples are stored in the same database folder and are identifiable by filenames starting with the letter 'D'. To ensure consistency and organization, save these reference samples in Group D. Preparation of the samples follows the guidelines detailed in section 2.2.

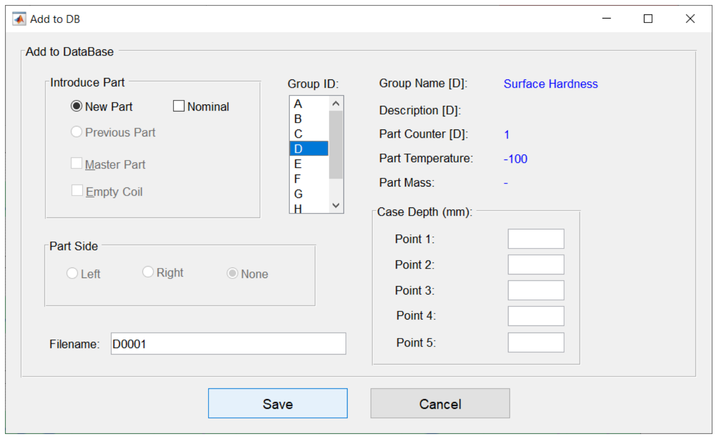


Figure 99. Dialog box to add Surface Hardness reference samples to the database.

Upon initiating the database creation for Surface Hardness testing, refer to Figure 99, which illustrates the dialog box for adding Surface Hardness reference samples to the database. It is crucial that both 'Good' and 'Defective' samples for Surface Hardness are categorized under Group D to maintain uniformity in training data. Importantly, samples from Groups A, B, and C are excluded from Surface Hardness training to prevent data contamination.

To configure Group D parameters, access the **Part Definition** (Ctrl+G) menu, then assign the following settings to Group D as shown in Figure 100:

- Group Name [D]: Surface Hardness
- Ensure the following options are unchecked:
- ☐ [D] is Classifiable
- ☐ [D] is Pass
- ☐ Include [D] in Statistical Reports

Next, proceed to scan and store both 'Good' and 'Bad' reference samples within Group D.

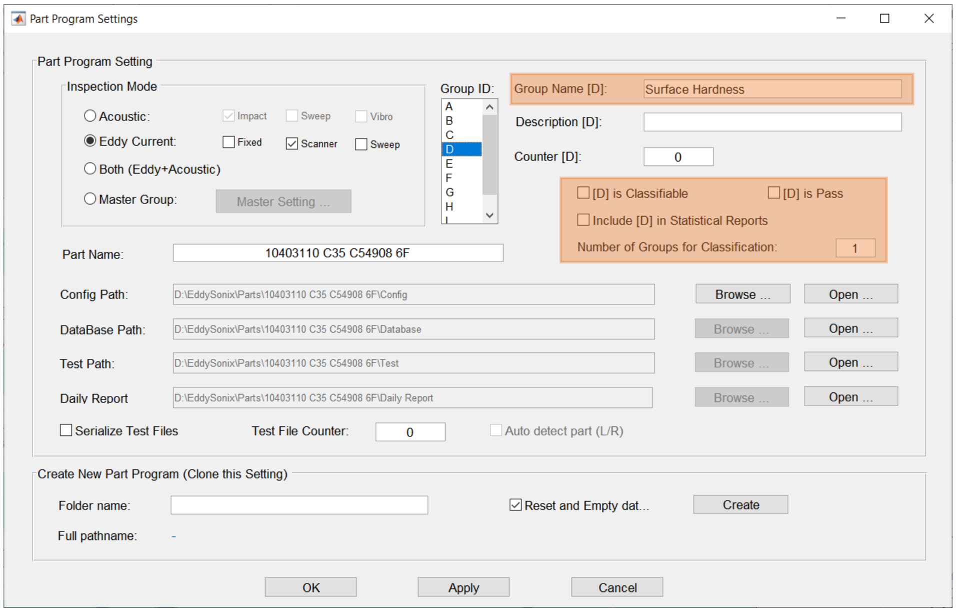


Figure 100. Set group D as indicated. Uncheck the three checkboxes.

For Surface Hardness values adjustment:

1. Navigate to the Learn menu.
2. Click on the **Database HRC** button to modify the Surface Hardness values for the reference parts.
3. For good samples, ensure to check ☒ the Nominal checkbox.
4. Input the known Surface Hardness values for the parts at specific points.

See Figure 101 for an example of the table used to edit Surface Hardness values in the database.

This systematic approach ensures that Surface Hardness training data is accurately categorized and readily accessible for analysis and training purposes.

Figure 2: Edit Surface Hardness

	P1	P2	P3	P4	P5	P6	P7	P8	Nominal
D D09063 MAXRUNOUT1 (6.4 ...	NaN	56.70	NaN	NaN	NaN	NaN	NaN	NaN	☐
D HRC NOK2 (-1 53.6 -1 53...	NaN	53.60	NaN	NaN	NaN	NaN	NaN	NaN	☐
D0001 HRC NOK2	NaN	53.60	NaN	54.10	NaN	54.40	NaN	NaN	☐
D0002 HRC NOK3	NaN	NaN	NaN	54.70	NaN	NaN	NaN	NaN	☐
D0003 HRC 75B	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	☐
D0004 HRC 70C	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	☐
D0005 HRC 68C	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	☐
D0006 HRC 68A	NaN	55.80	NaN	NaN	NaN	54.10	NaN	NaN	☐
D0007 HRC 72C	NaN	54.40	NaN	53.50	NaN	53.50	NaN	NaN	☐
D0008 HRC 68B	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	☐
D0009 HRC 75A	NaN	52.30	NaN	51.10	NaN	51.60	NaN	NaN	☐
D0010 HRC 70A	NaN	55.00	NaN	54.50	NaN	54.50	NaN	NaN	☐
D0011 HRC 70B	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	☐
D0012 HRC 72A	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	☐
D0013 HRC 72B	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	☐
D0014 HRC 75C	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	☐
D0015 NOM10(58.1 57.4 58....	NaN	58.10	NaN	58.00	NaN	58.10	NaN	NaN	☑
D0016 NOM11(56.9 56.1 56....	NaN	56.90	NaN	57.10	NaN	57.00	NaN	NaN	☑
D0017 NOM RO6(57.2 58.0 5...	NaN	57.00	NaN	58.00	NaN	57.20	NaN	NaN	☑
D0018 NOM RO2(57.2 58.2 5...	NaN	57.00	NaN	58.20	NaN	58.20	NaN	NaN	☑
D0019 SERI1(58.1 58.0 57....	NaN	58.10	NaN	58.00	NaN	57.60	NaN	NaN	☑
D0020 SERI2(58.3 58.4 57....	NaN	NaN	NaN	58.40	NaN	57.30	NaN	NaN	☑
D0021 HRC 180B	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	☐
D0022 HRC180 C	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	☐
D0023 HRC180 A	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	☐
D0024 HRC160 A	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	☐
D0025 HRC160 B	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	☐
D0026 HRC160 C	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	☐
D0027 D09190 SERI A	NaN	58.50	NaN	58.80	NaN	58.40	NaN	NaN	☑
D0028 D09190 SERI B	NaN	58.60	NaN	58.70	NaN	58.60	NaN	NaN	☑
D0029 D09190 SERI C	NaN	58.70	NaN	58.60	NaN	58.80	NaN	NaN	☑

Figure 101. Table for editing the surface hardness values in the database

7.2 Configuring Surface Hardness Parameters

To configure the Surface Hardness settings in the software, open the **Learn** menu and proceed to the **Surface & Runout** section, then click on the **Settings HRC** button to open the configuration dialog box for Surface Hardness, as illustrated in Figure 102.

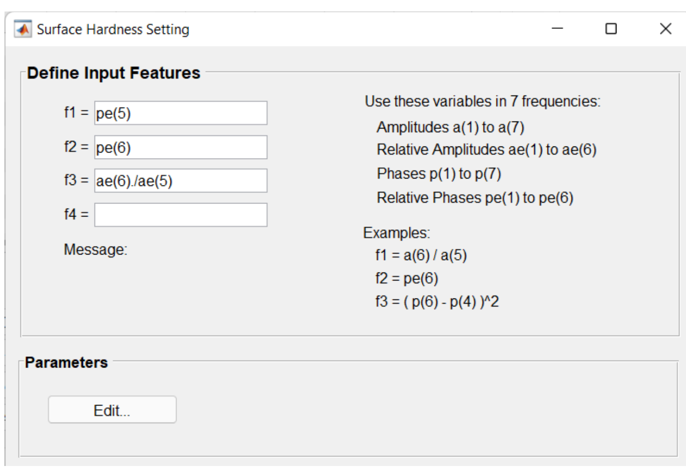


Figure 102. Dialog box for Surface Hardness parameters.

Defining Input Features: Within the Define Input Features area, establish the functions that are most indicative of Surface Hardness. You have the flexibility to define functions f1 to f4 according to your specific requirements. By default, we recommend setting:

- f1 = pe(5)
- f2 = pe(6)
- f3 = ae(6)/ae(5)

These functions are chosen for their sensitivity to variations in Surface Hardness.

Note: Use only two high frequencies, approximately 80Hz and 160Hz, for surface hardness measurement. In the formulas, pe(5) refers to the Relative Phase at the 5th frequency (80Hz), and ae(6)/ae(5) is the ratio of Relative Amplitudes from the 6th to the 5th frequency (160Hz to 80Hz). Be aware that in some Part Setups, 80Hz and 160Hz might be the 4th and 5th frequencies, requiring the formula adjustment to: pe(4), and ae(5)/ae(6).

Fine-Tuning Tolerance Limits: After defining the input features, proceed to the **Parameters** section and click the **Edit** button to fine-tune additional settings:

- **Enable HRC Test:** Ensure this box is checked (☒) to activate Surface Hardness testing.
- **Range HRC:** Input the acceptable range for Surface Hardness, specifying both the minimum and maximum limits.
- **Clip HRC:** This function ensures any estimated Surface Hardness values exceeding the specified range are adjusted to the nearest boundary. For instance, a prediction of 45 HRC, with a set minimum of 48 HRC, will be clipped to the minimum value and reported as 48 HRC.

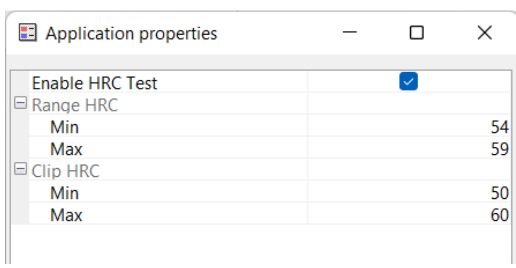


Figure 103. Configuring Surface Hardness limits and activation in the HRC test settings.

7.3 Training the Model

After setting up the Surface Hardness parameters, proceed to train the model:

1. Revisit the **Learn** menu, ensuring the following steps in the Analysis Steps pane are active:
   - ☒ Step 1: Read DB Files
   - ☒ Step 6: Train
   - ☒ Step 7: Show Results
   - ☒ Step 8: Enable Decision Making
2. Click the **Train** button and await the display of statistical results, which will appear for each defined point sequentially. Closing a result window will automatically bring up the next set of results.

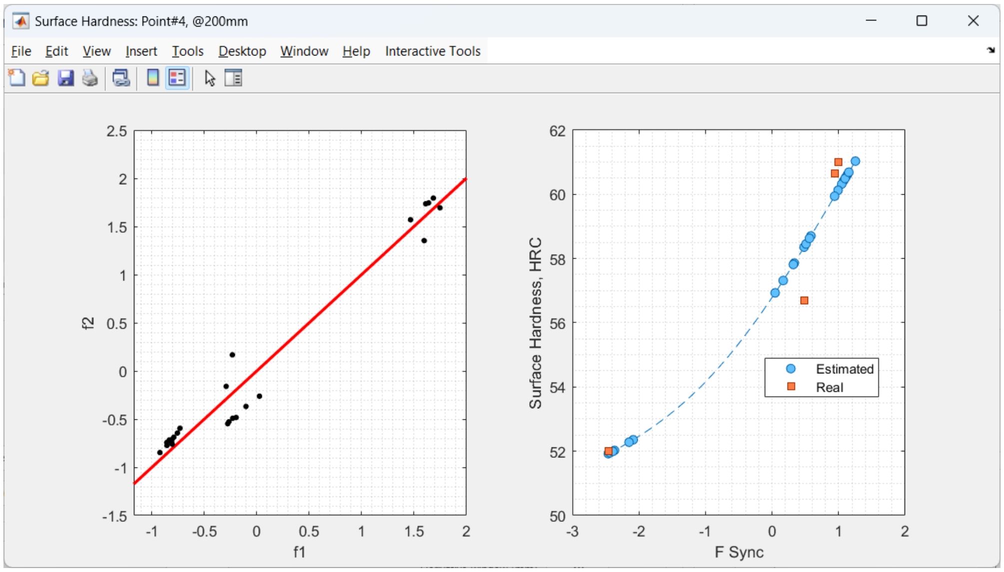


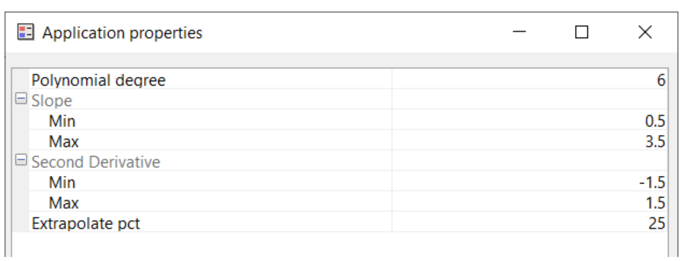
Figure 104. Sequential display of Surface Hardness training results for each point on the axle bar. Navigate through the results by closing the current figure to view the next.

The training results include diagrams illustrating the interplay between defined functions and Surface Hardness. The left diagram shows the scatter between functions f1 and f2, which combine into a unified function *F_Sync*. The right diagram plots Surface Hardness against *F_Sync*, highlighting a nonlinear relationship modeled by a polynomial function. Each data point represents a specific axle bar sample, identifiable by clicking on the dots.

To adjust the polynomial function's parameters for accurately modeling the relationship at each point:

- Access the parameter settings by pressing 'Ctrl+F' or by navigating through the **Interactive Tools** menu to **Fit Options**.

Remember, these parameters require individual adjustments for each defined point along the axle bar.



Application properties

Polynomial degree	6
Slope	
Min	0.5
Max	3.5
Second Derivative	
Min	-1.5
Max	1.5
Extrapolate pct	25

Figure 105. Adjusting Polynomial Fit Parameters for Surface Hardness Analysis.

This menu and the adjustment of polynomial parameters implement a constrained polynomial fit, ensuring the relationship between Surface Hardness and *F_Sync* remains monotone with bounded slope and curvature to prevent atypical slopes.

7.4 Testing and Results Interpretation

This section outlines the process for testing parts and interpreting their Surface Hardness values, which are determined at specific points and expressed in HRC units.

Figure 106. Demonstrates Surface Hardness testing results for a part randomly selected from mass production, showcasing the estimations at predefined points.

Figure 107. Displays the results for a part identified to have low Surface Hardness, highlighting the tool's sensitivity and accuracy.

For an in-depth examination of these results:

Figure 108. Provides a method to access a detailed analysis by pressing the "R" key. Here, the test results for each part are pinpointed with a black cross "X," offering a granular view of the data collected during testing.

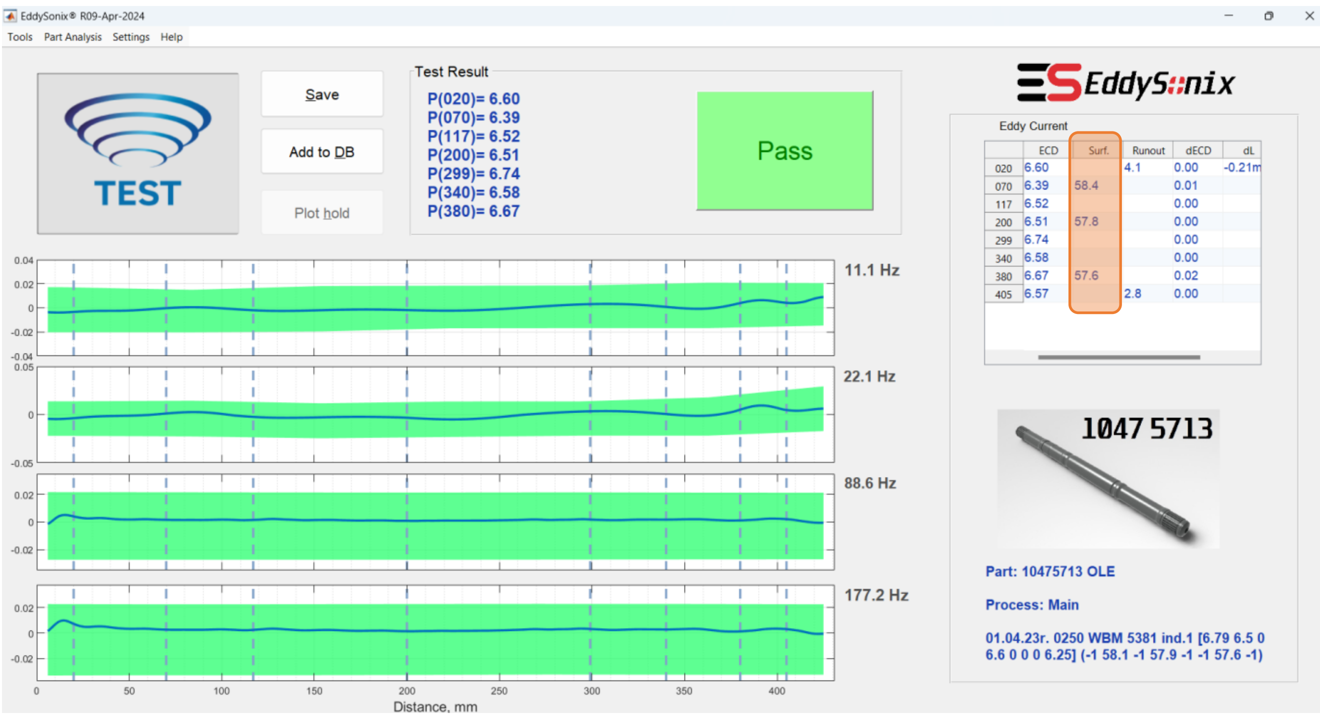


Figure 106. Test results displaying Surface Hardness estimations for a randomly selected part from mass production.

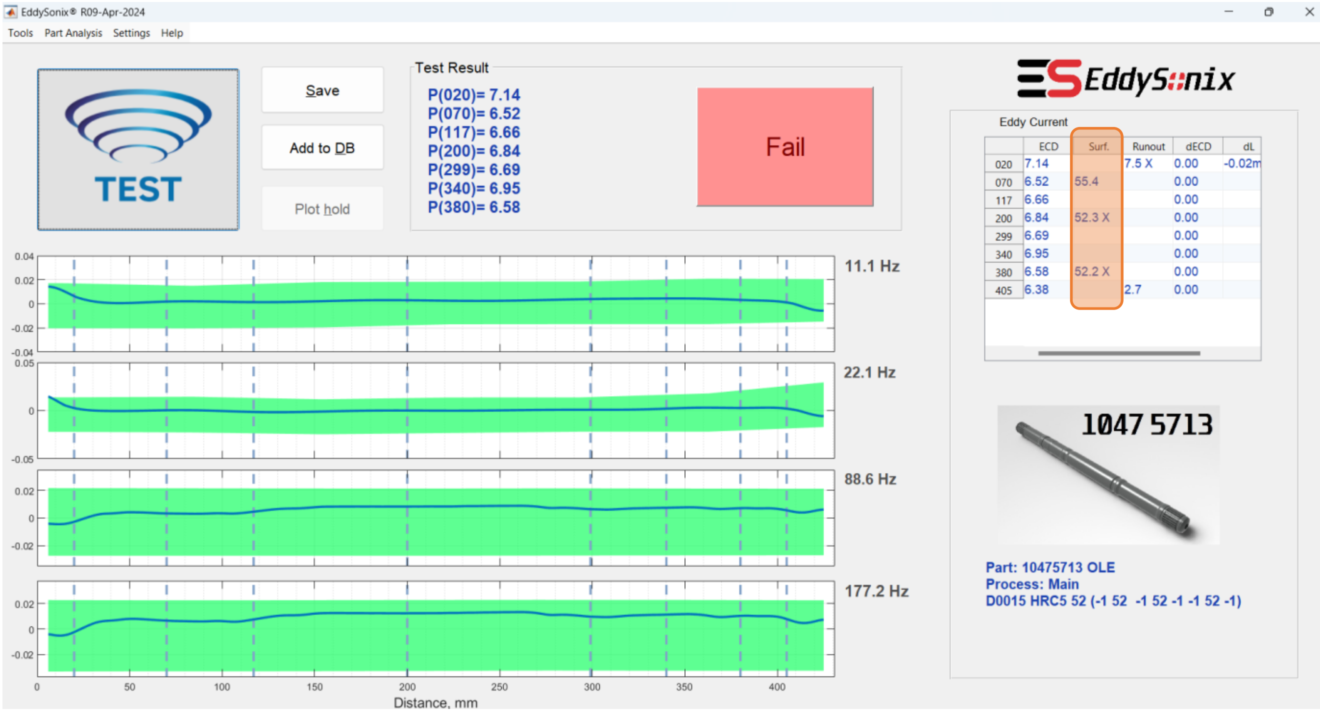


Figure 107. Test outcome for a part exhibiting low Surface Hardness.

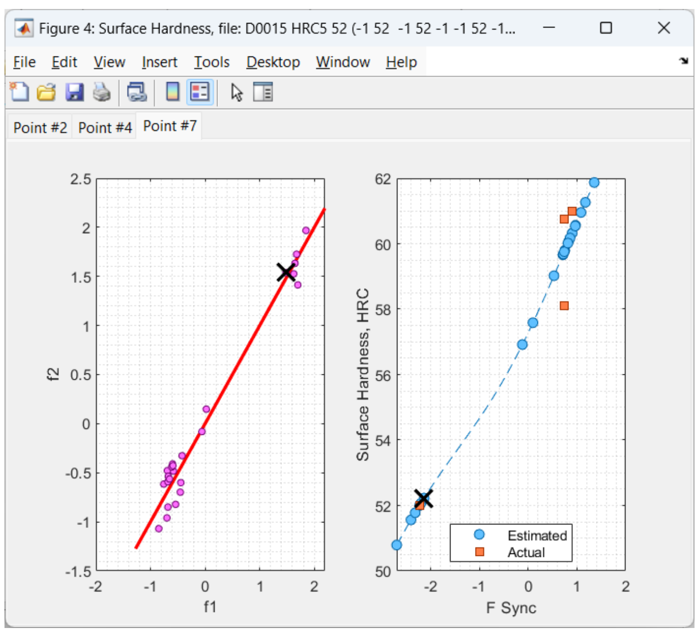


Figure 108. Detailed results viewable by pressing the "R" key. The test outcomes for the part are marked with a black cross "X".

7.5 Optional: Full-Length Surface Hardness Envelopes

This section offers an optional method to evaluate surface hardness features along the full length of a part. Users can activate this detailed analysis as needed through the **Profile Analysis** menu:

1. Begin in the **Learn** menu.
2. Select **Edit Limit Bands**.
3. In the **Multivariate** pane, use the **HRC** dropdown menu to pick the features (e.g., HRC1, HRC2, ...) for which you want to analyze the envelope.
4. Move to the **Editor** pane. Within the **Check Criteria** dropdown, choose **Manual Limit**.
5. In the same pane, select **Fixed Limits** from the **Mouse Mode** dropdown.
6. Set your upper and lower limits to adjust the acceptance range.
7. Click **Save**, then close the **Profile Analysis** menu.
8. Conclude by pressing **Train** in the **Learn** menu for the analysis to take effect.

This feature, while optional, allows for an extensive evaluation of surface hardness across a part's entire length, enhancing quality control processes.

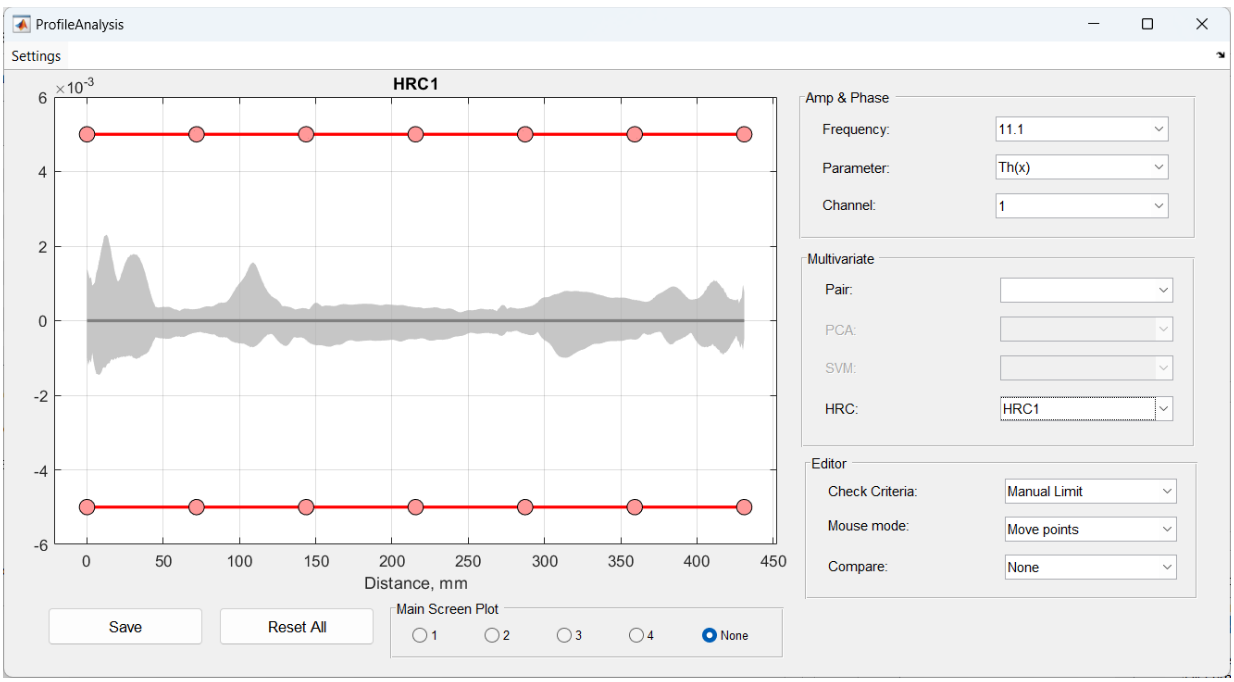


Figure 109. The Profile Analysis menu showcases the settings for enabling full-length surface hardness envelope analysis.

Upon completion of training, with Step 7 (Show Results) activated, the software will display plots of the chosen HRC envelopes. This includes viewing envelopes of individual parts in the database (Group D) alongside the acceptance limits set in the Profile Analysis menu. Clicking on any envelope plot reveals the part's filename.

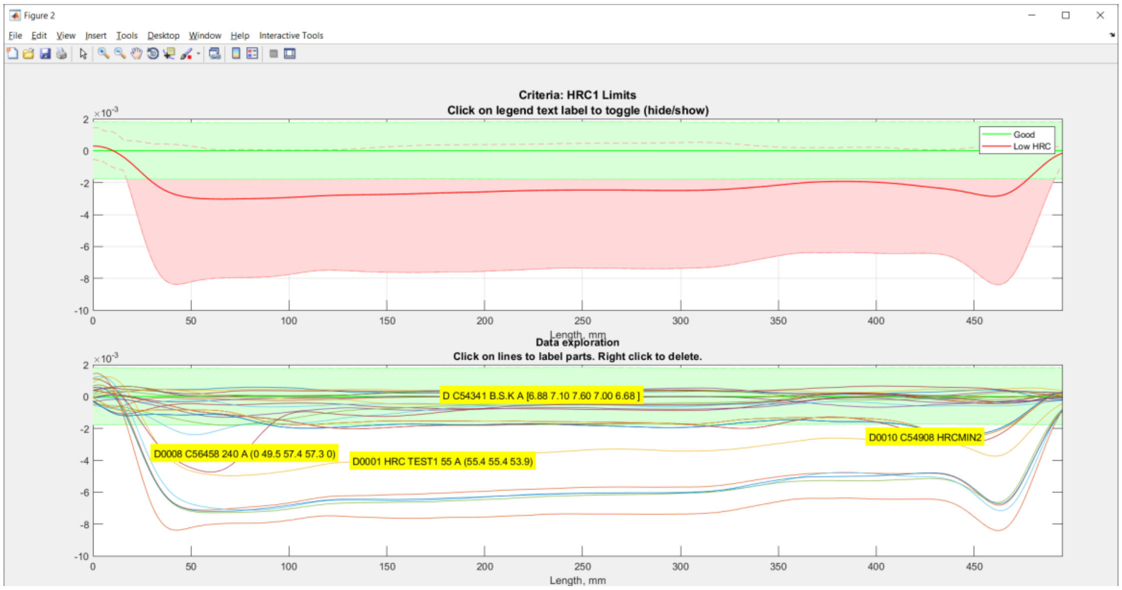


Figure 110. Example of HRC envelope plots with clickable functionality to identify part filenames.

After conducting a test, you can view the HRC test results by pressing either the "R" or "r" key, which will display the HRC envelopes. Below are examples illustrating various outcomes:

- **Example 1:** Displays a part with very low surface hardness, ranging approximately between 50-52 HRC, indicating significant deviations from desired hardness levels. (Figure 111)
- **Example 2:** Showcases a good part with an optimal surface hardness level, situated in the desirable range of 57-59 HRC, reflecting high-quality material properties. (Figure 112)
- **Example 3:** Highlights a part with locally low surface hardness, pointing out areas on the part that fall short of the hardness requirements, potentially indicating uneven material treatment or localized defects. (Figure 113)
- **Example 4:** Illustrates a part at the limit low end of HRC acceptance, with hardness values around 55-56 HRC, signaling a need for close monitoring or adjustment in the production process to ensure quality standards are met. (Figure 114)

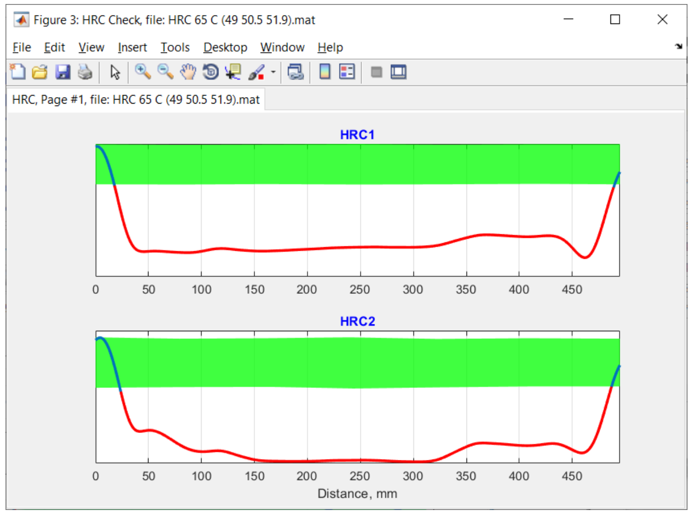


Figure 111. Part with Very Low Surface Hardness (50-52 HRC).

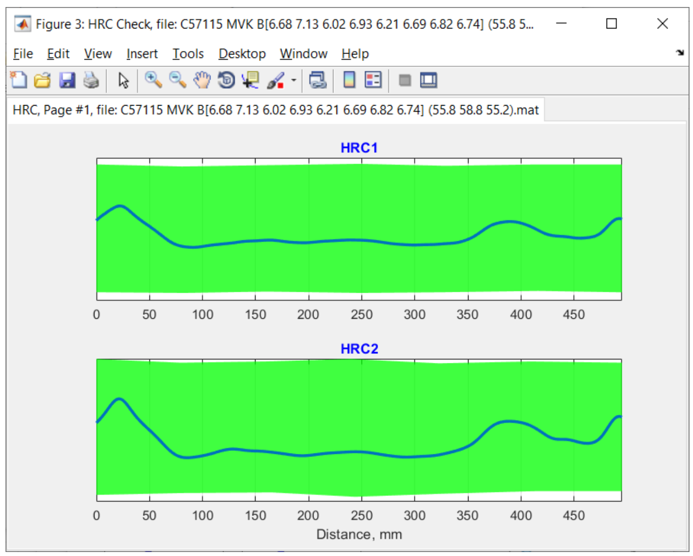


Figure 112. Good Part Demonstrating Optimal Surface Hardness (57-59 HRC).

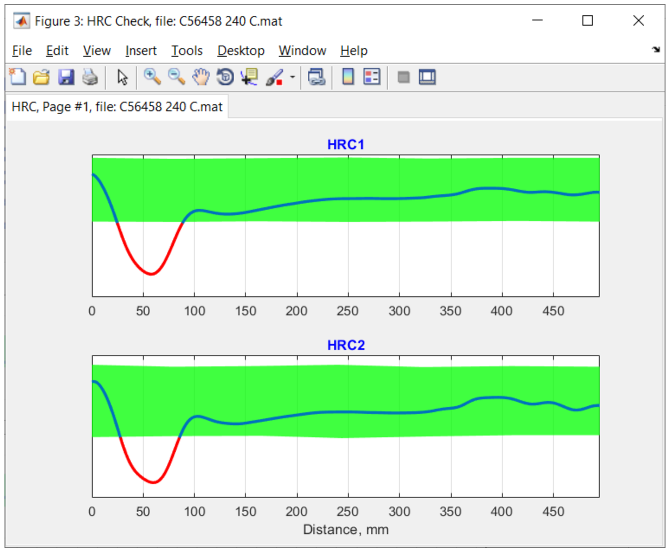


Figure 113. Part Exhibiting Locally Low Surface Hardness.

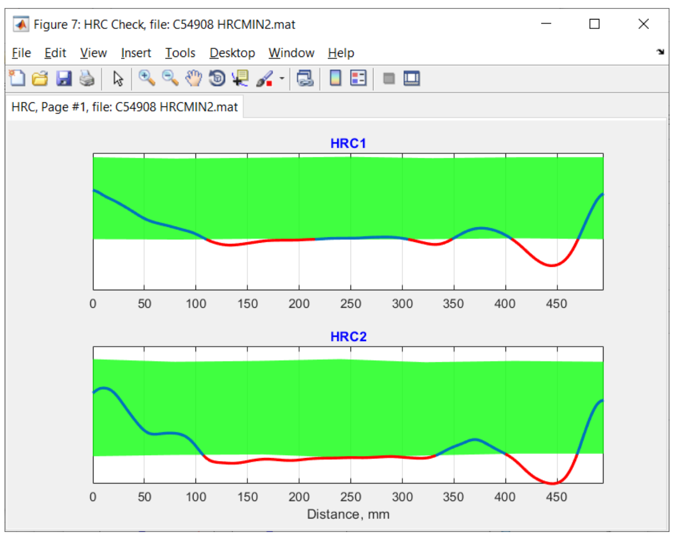


Figure 114. Part at the Lower Limit of HRC Acceptance (55-56 HRC).

8 Run Out Testing

8.1 Database Preparation

The first step in setting up the Runout measurement database is to manufacture reference samples under the following conditions (applicable to both spline ends):

Required Reference Samples

- **Nominal**: N = 10
- **Max-In**: N = 6
- **Min-In**: N = 6
- **Max-Out**: N = 6
- **Min-Out**: N = 6

Measurement Instructions

1. Measure the **Runout** of all samples using **etching** and document the results in a table.
2. Perform a **cut-check measurement** on one sample from each group.
3. **Do not**:
    - Demagnetize or use Magnetic Particle Inspection (MPI) on the samples.
    - Sandblast the parts, as this affects surface hardness and introduces errors in Runout measurements.
4. Store the samples in a **safe box**, away from permanent magnets.

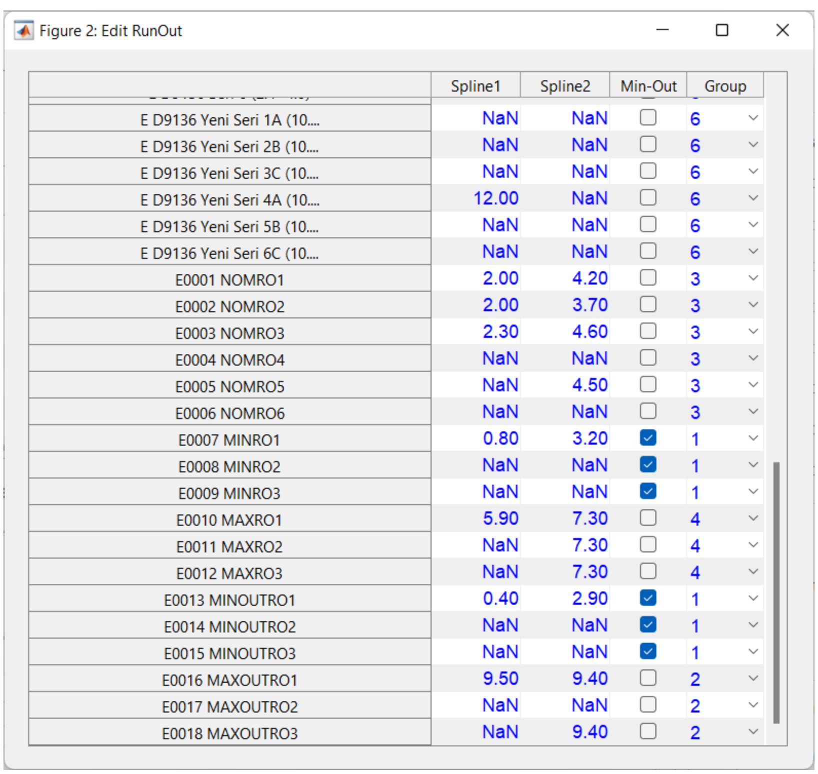
Database Construction in EddySonix Application

Steps to Create Runout Database

1. **Scan and Save Files**:
    - Scan the reference samples using the EddySonix machine.
    - Save the scanned files in **Group E** using the **Add to DB** function.
2. **Access Database Runout Menu**:
    - Open the **Learn menu**.
    - Navigate to the **Surface & Runout pane** and click **Database Runout**.
3. **Select Reference Baseline**:
    - Check ☒ the **Min-Out checkbox** for Min-Out or Min-In samples.
    - These checked samples will construct the **reference baseline**.
4. **Edit Runout Values**:

- Assign measured Runout values to at least the following:
  - 3 Nominal samples.
  - 1 Max-Out sample.
  - 1 Min-Out sample.
  - 1 Max-In sample.
  - 1 Min-In sample.

5. **Define Color Groups (Optional)**:
   - Assign color codes for visualization:
     - **1 (Green)**: Nominal parts.
     - **2 (Red)**: Max-Out parts.
     - **3 (Blue)**: Min-Out parts.
     - **4**: Max-In parts.
     - **5**: Min-In parts.
     - **6 to 8**: Mass production samples.
   - These colors enhance data visualization during the analysis phase.



	Spline1	Spline2	Min-Out	Group
E D9136 Yeni Seri 1A (10....	NaN	NaN	☐	6
E D9136 Yeni Seri 2B (10....	NaN	NaN	☐	6
E D9136 Yeni Seri 3C (10....	NaN	NaN	☐	6
E D9136 Yeni Seri 4A (10....	12.00	NaN	☐	6
E D9136 Yeni Seri 5B (10....	NaN	NaN	☐	6
E D9136 Yeni Seri 6C (10....	NaN	NaN	☐	6
E0001 NOMRO1	2.00	4.20	☐	3
E0002 NOMRO2	2.00	3.70	☐	3
E0003 NOMRO3	2.30	4.60	☐	3
E0004 NOMRO4	NaN	NaN	☐	3
E0005 NOMRO5	NaN	4.50	☐	3
E0006 NOMRO6	NaN	NaN	☐	3
E0007 MINRO1	0.80	3.20	☑	1
E0008 MINRO2	NaN	NaN	☑	1
E0009 MINRO3	NaN	NaN	☑	1
E0010 MAXRO1	5.90	7.30	☐	4
E0011 MAXRO2	NaN	7.30	☐	4
E0012 MAXRO3	NaN	7.30	☐	4
E0013 MINOUTRO1	0.40	2.90	☑	1
E0014 MINOUTRO2	NaN	NaN	☑	1
E0015 MINOUTRO3	NaN	NaN	☑	1
E0016 MAXOUTRO1	9.50	9.40	☐	2
E0017 MAXOUTRO2	NaN	NaN	☐	2
E0018 MAXOUTRO3	NaN	9.40	☐	2

Figure 115. An example of database setup for Runout measurement.

8.2 Parameter Setting

To configure settings for Runout measurement:

1. Open the **Learn menu**.
2. Navigate to the **Surface & Runout pane**.
3. Click the **Settings Runout** button to access and adjust the parameters.

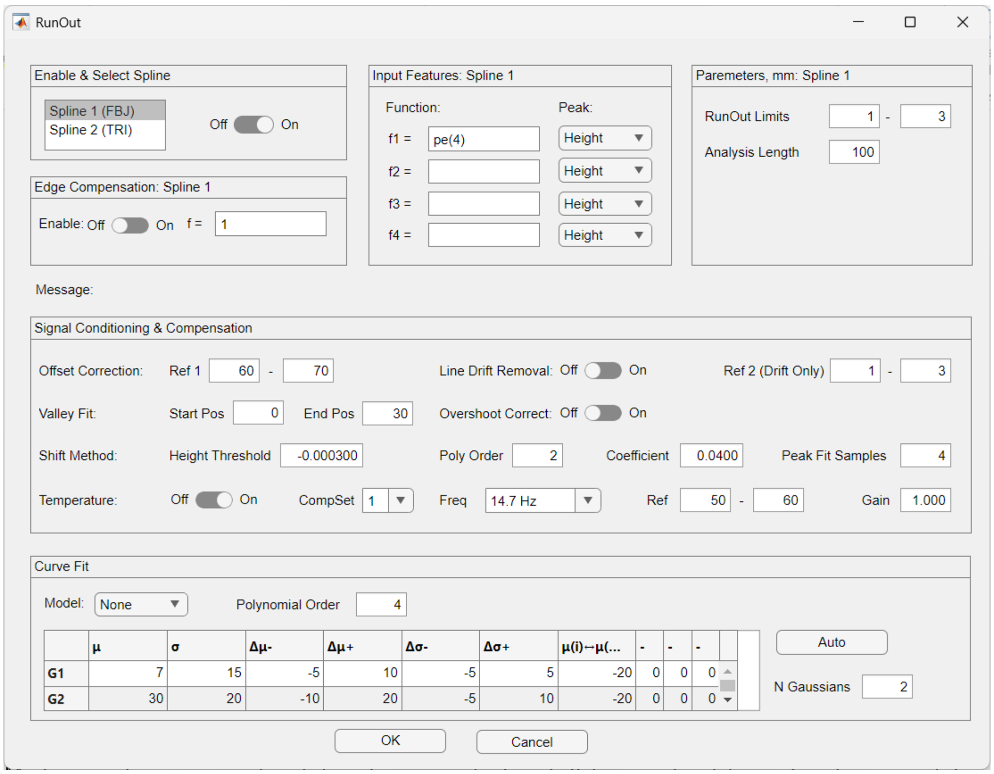


Figure 116. Runout setting menu

Description of Parameters in the Runout Settings Pane

Most parameters are pre-set and do not require adjustment. Below is a breakdown of each pane and its functionality:

Enable & Select Spline

Spline Selection:

- Begin by selecting the spline to configure: **Spline 1 (FBJ)** or **Spline 2 (TRI)**.
- This allows you to set up parameters for each spline **independently**.

Test Enable:

- For each selected spline, use the **On/Off toggle** to enable or disable RunOut testing.
- This flexibility allows you to configure RunOut analysis for **only one spline** or **both splines**, depending on the application requirements.

💡 Note: All subsequent parameter settings (Input Features, Signal Conditioning, Curve Fit, etc.) are specific to the currently selected spline.

Input Features: Spline-Specific Signal Definition

Function f1 – f4:

- You can define up to **four signal functions** (f1 through f4) per spline to extract features relevant for **RunOut measurement**.
- Each function computes a specific signal characteristic, such as:
  - **Phase** at a defined frequency — particularly effective in the **100 to 200 Hz** range.
  - **Amplitude ratio** between two frequencies.

Default Configuration:

- The default setup generally provides sufficient results.
- However, for optimized and robust **RunOut measurement**, especially with complex geometries or tighter tolerances, we **strongly recommend consulting the EddySonix team** for guidance on choosing the best signal function(s) and frequency parameters for your part.

🔧 *Tip:* Proper function selection can significantly impact measurement precision and repeatability. Let our experts help fine-tune your setup for best performance.

Parameters (mm)

- **Runout Limits**:
  - Set the **Min** and **Max tolerances** for each spline based on part specifications.
- **Analysis Length**:
  - Defines the length on either side of the axle bar used for analysis.
  - **Default Setting**: No modification needed.

Surface Compensation:

- Length used to cancel the effect of surface hardness variations.
- **Default Setting**: No modification needed.

Signal Conditioning & Compensation

This section contains all preprocessing tools used to stabilize the envelope signal and extract the most meaningful feature (either **height** or **horizontal shift**) from the valley of the envelope. These tools enhance accuracy by correcting for offset, drift, temperature effects, and more.

Offset Correction

- **Ref1 [Start – End]:**
  Always active. Defines the reference region on the envelope (in mm) used to calculate the mean

baseline offset. This mean is subtracted from the entire signal, bringing the signal to zero baseline. Useful to remove static vertical shift caused by probe or system drift.

Line Drift Removal

- **Switch:** On/Off toggle
- **Ref 2 (Drift Only) [Start – End]:**
  When enabled, two reference regions (Ref 1 and Ref 2) are used to fit a linear drift line. This drift is then removed across the full envelope, which is helpful if the signal baseline isn't constant but trends gradually across the part length.

💡 Use **Ref 2** only when a noticeable drift is visible across the signal range.

Valley Fit

- **Start Pos / End Pos (mm):**
  Defines the search window (in mm) within which the valley (negative peak) is detected. This region must be carefully selected to include the valley and exclude noise or edge effects.

Shift Method – Height Threshold

- **Height Threshold:**
  Applies only when the **Peak** setting is Shift. This defines the minimal valley amplitude required to accept the peak shift (horizontal position) as a valid feature.

Overshoot Correct

- **Switch:** On/Off
  Used only when **Peak** is set to Height. If the envelope has a post-valley overshoot (positive bump), this option switches from simple "valley-to-zero" height to "valley-to-peak" height.
  Helps avoid false readings in profiles with rebound or overshoot behavior.

Temperature Compensation

- **Switch:** On/Off
- **CompSet / Freq / Ref [Start – End]:**
  Measures the average value in the specified position range from the selected compensation dataset and frequency.
  A correction factor is applied to normalize for temperature-dependent drift in eddy current signals.
- **Gain:**
  Adjusts the strength of the compensation.
  - Gain = 1.0: Full compensation (default)
  - Gain = 0.0: No compensation
  - Gain < 1.0: Partial correction

Curve Fit

- These define the constraints for fitting Gaussian curves.
- **Default Setting**: No modification needed.
- **N Gaussian**:
  - Number of Gaussians used to model feature signals.
  - **Default Setting**: Set to 2.

Saving Changes

1. After adjusting the parameters, click **OK** to close the Runout menu and return to the Learn menu.
2. Press the **"Only Save & Exit"** button to save your changes.

8.3 Train

To test unknown parts, a model must first be trained using the database and the defined parameters.

Steps for Training

1. Open the **Learn menu**.
2. Click **Solve & Train Models** to initiate the training process.

Training Process

- The system displays **intermediate** and **final results** step by step during the training process.
- **Intermediate Results**:
  - Provide insights into the relationship between features and Runout.
  - Help identify areas where parameters can be adjusted to strengthen the correlation between features and Runout.
- Close each figure to proceed to the next step in the training process.

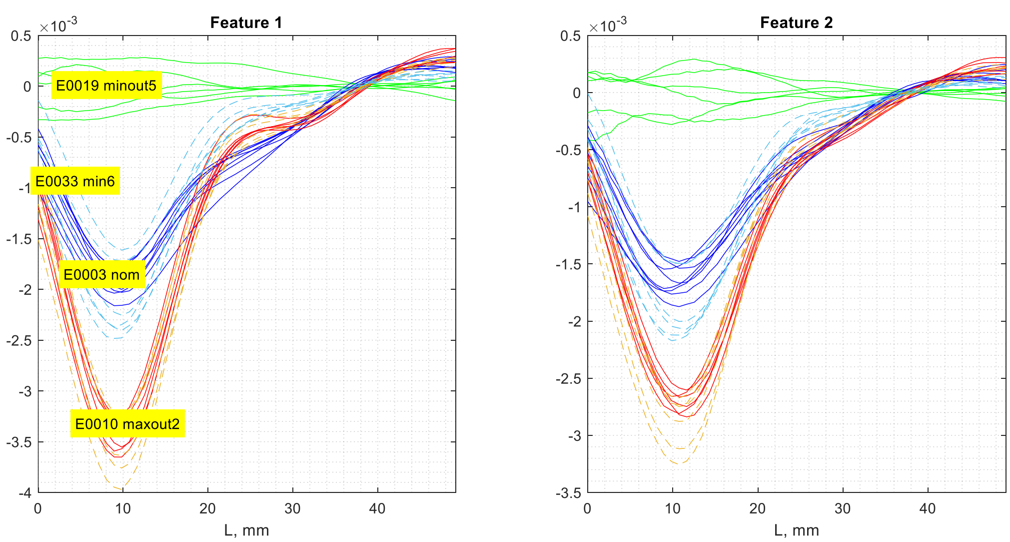


Figure 117. Results of Features for Spline 1 (FBJ) defined in Runout Setting. You can click on each graph to show / hide the file name.

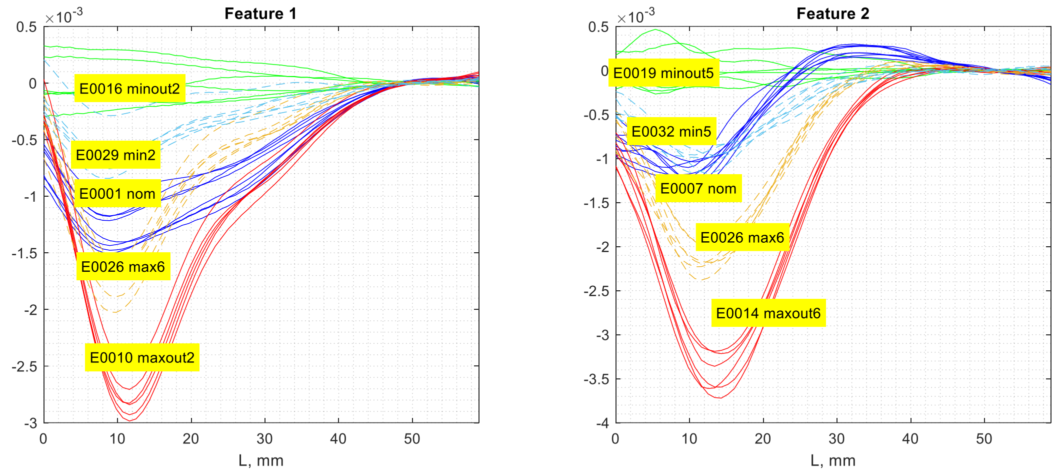


Figure 118. Results of Features for Spline 2 (TRIPOD) defined in Runout Setting.

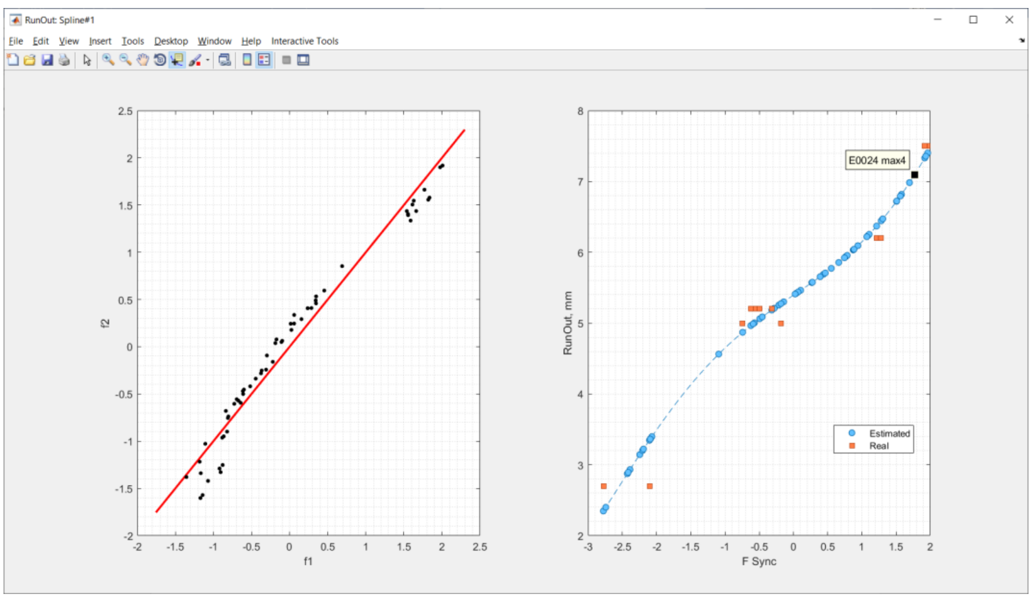
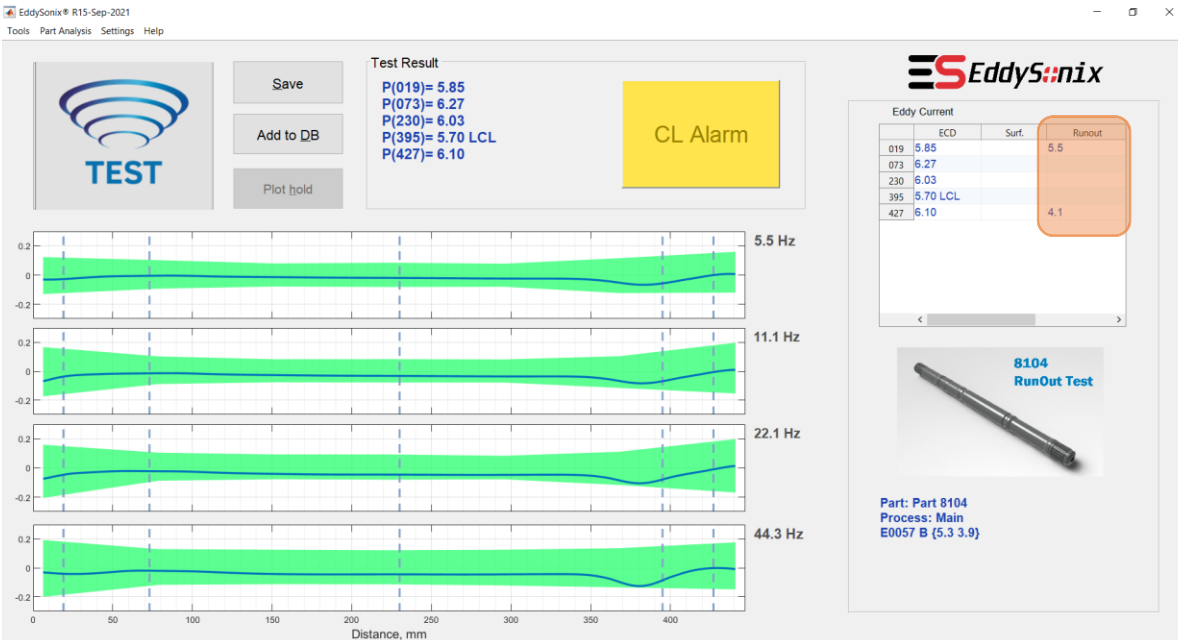


Figure 119. Left: Feature-to-Feature scatter plot. The red line (F-Sync) merges all features into one unified variable. Right: Runout vs. Feature (F-Sync) diagram. The blue circles represent all the samples in the DB, the red rectangles represent the samples whose Runout values are defined in the DB. You can click on each dot to display the corresponding file name.

8.4 Test a part

After completing the testing process, the **Runout results** are displayed in the **right panel table**.

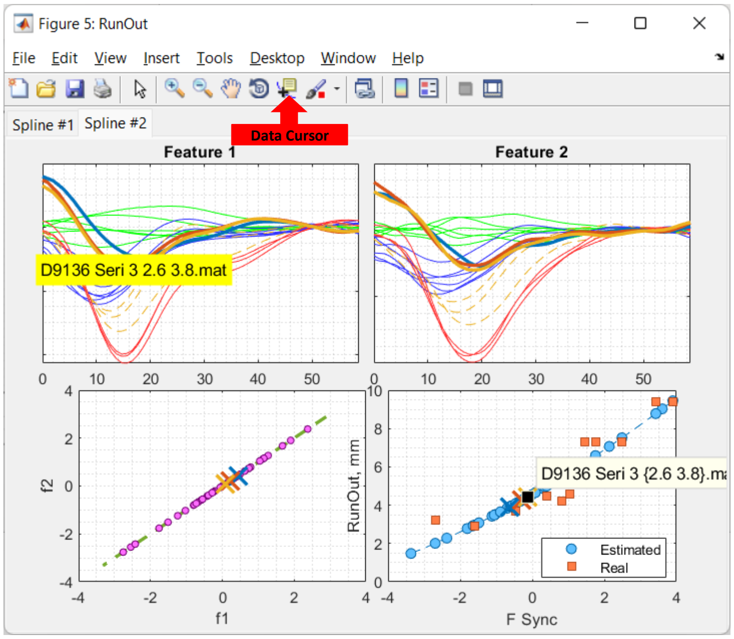


8.5 Compare

This tool allows you to visually compare data across multiple test files.

Example: Comparing Files

1. Select up to multiple files to compare.
2. The tool generates plots for selected data points.
3. **Interactive Feature**:
    - Click on any data point in the plot to display the corresponding filename for easier identification.

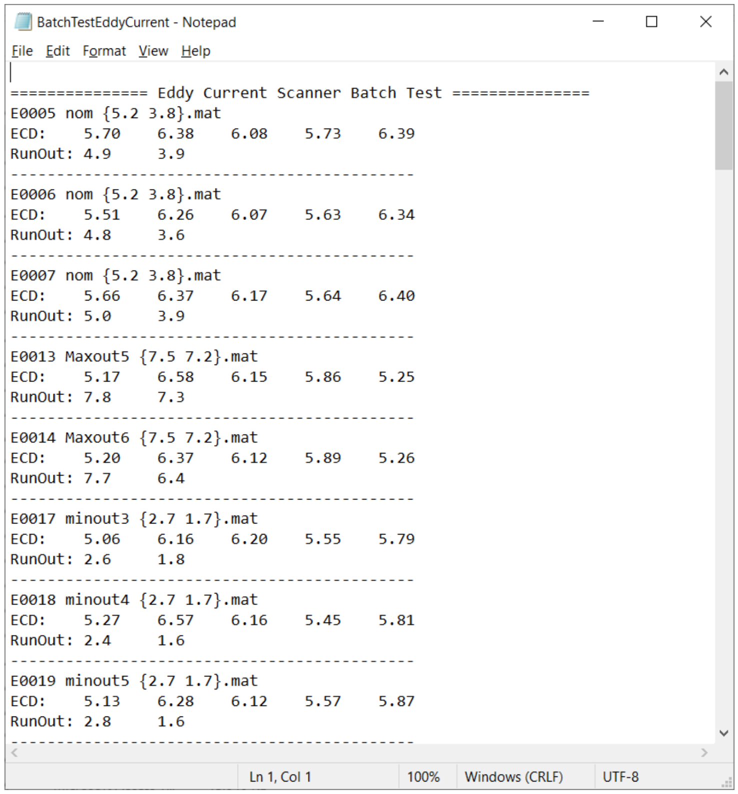


- Click on each line (upper plots) to show filename. Make sure Data Cursor icon is OFF.
- Click on each point (lower plots) to show filename. Make sure Data Cursor icon is ON.

8.6 Batch Test

Similar to Case Depth and Surface Hardness analyses, you can run Batch Test to test offline all the files in Test folder and generate statistical report. From the **Tools** menu, select **Batch Test (CTRL+B)**.

Batch test results are saved in ..**\Test\BatchTestEddyCurrent.txt**



```
BatchTestEddyCurrent - Notepad
File Edit Format View Help

=============== Eddy Current Scanner Batch Test ===============
E0005 nom {5.2 3.8}.mat
ECD:     5.70    6.38    6.08    5.73    6.39
RunOut: 4.9     3.9
--------------------------------------------
E0006 nom {5.2 3.8}.mat
ECD:     5.51    6.26    6.07    5.63    6.34
RunOut: 4.8     3.6
--------------------------------------------
E0007 nom {5.2 3.8}.mat
ECD:     5.66    6.37    6.17    5.64    6.40
RunOut: 5.0     3.9
--------------------------------------------
E0013 Maxout5 {7.5 7.2}.mat
ECD:     5.17    6.58    6.15    5.86    5.25
RunOut: 7.8     7.3
--------------------------------------------
E0014 Maxout6 {7.5 7.2}.mat
ECD:     5.20    6.37    6.12    5.89    5.26
RunOut: 7.7     6.4
--------------------------------------------
E0017 minout3 {2.7 1.7}.mat
ECD:     5.06    6.16    6.20    5.55    5.79
RunOut: 2.6     1.8
--------------------------------------------
E0018 minout4 {2.7 1.7}.mat
ECD:     5.27    6.57    6.16    5.45    5.81
RunOut: 2.4     1.6
--------------------------------------------
E0019 minout5 {2.7 1.7}.mat
ECD:     5.13    6.28    6.12    5.57    5.87
RunOut: 2.8     1.6
--------------------------------------------
Ln 1, Col 1    100%    Windows (CRLF)    UTF-8
```

Figure 120. Batch Test results of all files in Test folder

File Naming and Data Editing for Runout

To include **Runout measurements** or other test data for a part, follow these guidelines for renaming files and editing data fields.

File Renaming Rules

1. **Runout Data**:
   - Add the measured **Runout values** inside braces { } in the filename.
   - The number of elements must always be **two** (for **Spline 1** and **Spline 2**).
2. **Case Depth (ECD) Data**:
   - Include **Case Depth values** inside square brackets [ ].
   - The number of elements must match the number of points defined in the Part Program.
   - If the number of elements is incorrect, the file will be ignored.
3. **Surface Hardness (HRC) Data**:
   - Add **HRC values** inside parentheses ( ).
   - The number of elements must match the number of points defined in the Part Program.
   - If the number of elements is incorrect, the file will be ignored.

General Guidelines

- **Order of Data**: The order of ECD, HRC, or Runout data is **not important**.
- **Unknown Data**: If a value for any point is unknown, enter 0 or a negative value like -1. Avoid entering text or leaving the value blank.
- **Separators**: Use a **space** or a **comma** to separate numbers. For decimal values, it is recommended to use a **dot** (e.g., 6.5), though commas are also acceptable.

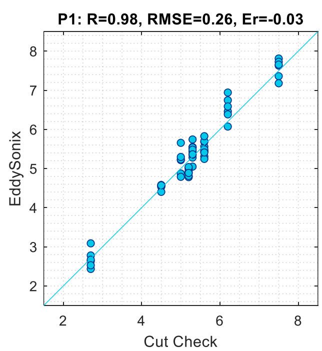
Example Filenames

1. A file with all three types of data:
   Part17 [6.1 6.5 6.8] (58.0 59.5 60.0) {0.3 0.4}.mat
2. A file with unknown Runout for Spline 2:
   Part18 [5.9 6.4 6.7] (58.0 59.0 59.5) {0.2 -1}.mat

Examples: These are valid filenames:

- E0001 NOMRO1 {2.3 4.7} [6.55 6.99 6.58 6.96 6.35 6.80 7.07 6.75] (0 58.1 0 57.4 0 58 0 0)
- E0001 NOMRO1 [6.55 6.99 6.58 6.96 6.35 6.80 7.07 6.75] {2.3 4.7}
- E0001 NOMRO1 {2,3 4,7}
- E0001 NOMRO1 [0 6.99 6.58 6.96 6.35 6.80 7.07 -1] (0 58.1 0 57.4 0 58 0 0) {-1 4.7}

For those parts with known Runout values, a statistical report is also generated. The information for each point includes:



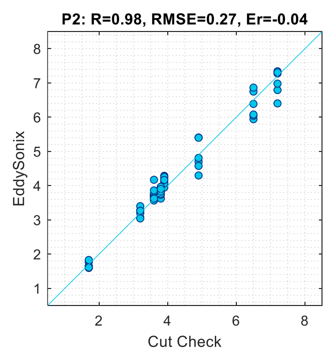
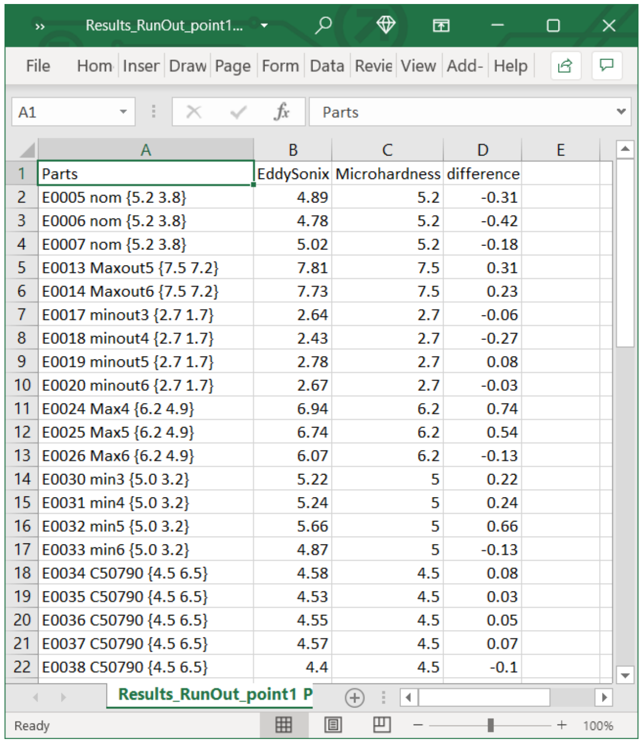


Figure 121. Batch Test result of parts with known Runout. Left: Spline 1, Right: Spline 2.

To get a meaningful statistical information, at least 30 samples is recommended. Collect the samples from daily production, and in order to have a normal distribution, randomly add parts to the Test folder.

The detailed test results are also saved in Excel file for each spline:



	A	B	C	D	E
1	Parts	EddySonix	Microhardness	difference	
2	E0005 nom {5.2 3.8}	4.89	5.2	-0.31	
3	E0006 nom {5.2 3.8}	4.78	5.2	-0.42	
4	E0007 nom {5.2 3.8}	5.02	5.2	-0.18	
5	E0013 Maxout5 {7.5 7.2}	7.81	7.5	0.31	
6	E0014 Maxout6 {7.5 7.2}	7.73	7.5	0.23	
7	E0017 minout3 {2.7 1.7}	2.64	2.7	-0.06	
8	E0018 minout4 {2.7 1.7}	2.43	2.7	-0.27	
9	E0019 minout5 {2.7 1.7}	2.78	2.7	0.08	
10	E0020 minout6 {2.7 1.7}	2.67	2.7	-0.03	
11	E0024 Max4 {6.2 4.9}	6.94	6.2	0.74	
12	E0025 Max5 {6.2 4.9}	6.74	6.2	0.54	
13	E0026 Max6 {6.2 4.9}	6.07	6.2	-0.13	
14	E0030 min3 {5.0 3.2}	5.22	5	0.22	
15	E0031 min4 {5.0 3.2}	5.24	5	0.24	
16	E0032 min5 {5.0 3.2}	5.66	5	0.66	
17	E0033 min6 {5.0 3.2}	4.87	5	-0.13	
18	E0034 C50790 {4.5 6.5}	4.58	4.5	0.08	
19	E0035 C50790 {4.5 6.5}	4.53	4.5	0.03	
20	E0036 C50790 {4.5 6.5}	4.55	4.5	0.05	
21	E0037 C50790 {4.5 6.5}	4.57	4.5	0.07	
22	E0038 C50790 {4.5 6.5}	4.4	4.5	-0.1	

Figure 122. Excel report of Batch Test

You may choose to report the Bland-Altman results for detailed statistical analysis. The report is generated on two separate pages for each spline.

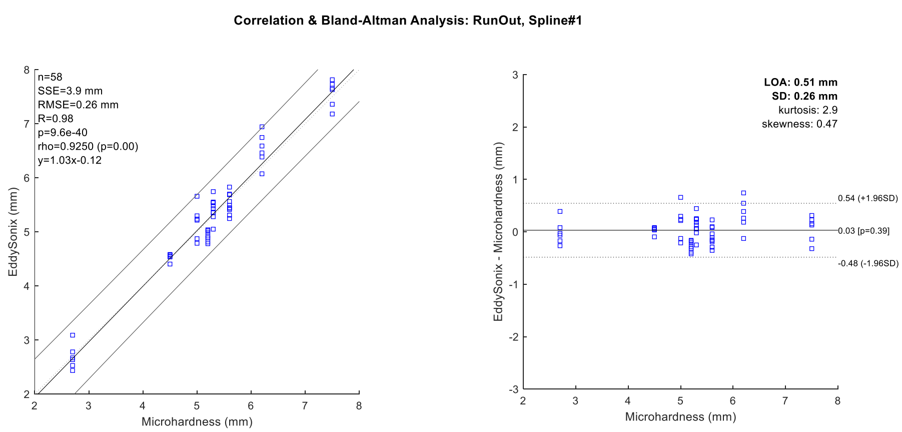


Figure 123. Bland-Altman Report

9 Service and Maintenance

This concise guide provides essential instructions for maintaining and troubleshooting your EddySonix equipment, ensuring its optimal performance and reliability. Our goal is to equip you with the necessary knowledge for efficient maintenance, helping to prolong the life and enhance the functionality of your EddySonix devices.

9.1 Lubricating the Ball Screw, Rail, and Wagon Procedure

1. **Safety Check:** Power off the machine and engage lockout to prevent accidental operation.
2. **Access:** Open the back door of the mechanical unit. Ensure there's at least 800mm of clearance behind the machine for accessibility.
3. **Cleaning:** Use a cloth or brush to remove dirt and old lubricant from the ball screw, rail, and wagon.
4. **Lubricant Selection:** Use the manufacturer-specified grease for high-precision components.
5. **Lubrication Application:**
    - **Ball Screw:** Apply grease evenly along the shaft, concentrating on the ball bearing grooves. Use a grease fitting if available.
    - **Rail and Wagon:** Evenly distribute grease along the rail.
6. **Excess Removal:** Wipe away any extra grease to avoid debris build-up.
7. **Reassemble:** Close the back door of the unit.
8. **Test Run:** Perform a test to confirm smooth operation.
9. **Documentation:** Record the maintenance date and the lubricant type used.
10. **Maintenance Frequency:** Adhere to EddySonix's recommended lubrication schedule: every 3 months for heavy use and every 6 months for lighter use.

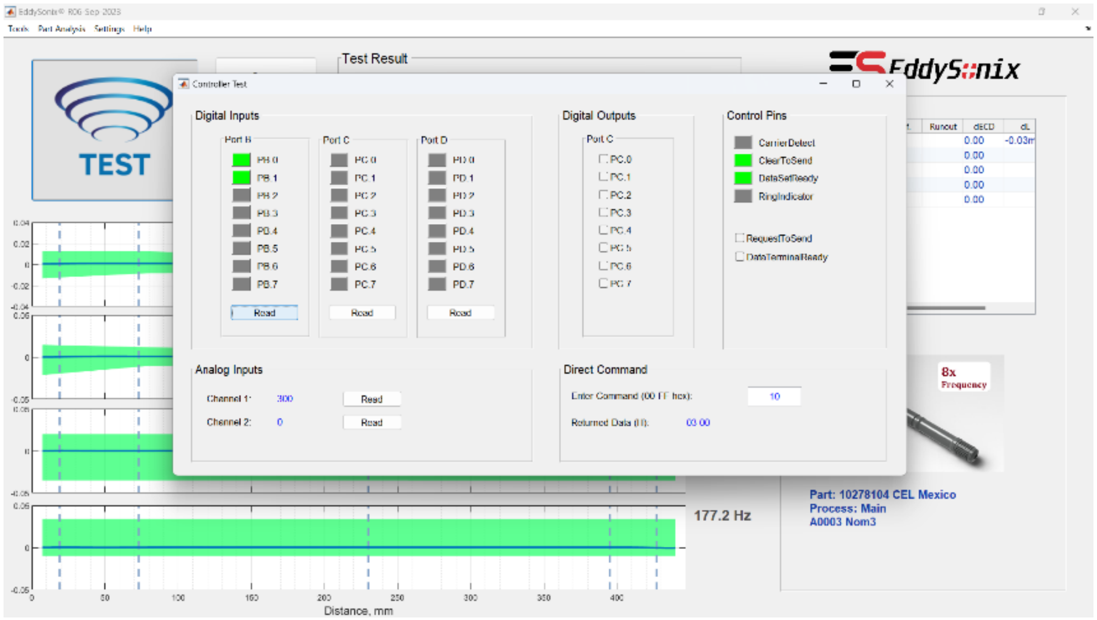
9.2 PC and User Interface

- **System Overview:** The system utilizes a standard PC running Windows 11, complete with a familiar interface including a monitor, keyboard, and mouse.
- **Diagnostics Software:** Siemens and NI diagnostics tools are integrated and accessible through their respective software applications.
- **IT Support:** GKN plant IT departments are equipped to diagnose and repair the PC component as required.

9.3 Input / Output Functionality Checks

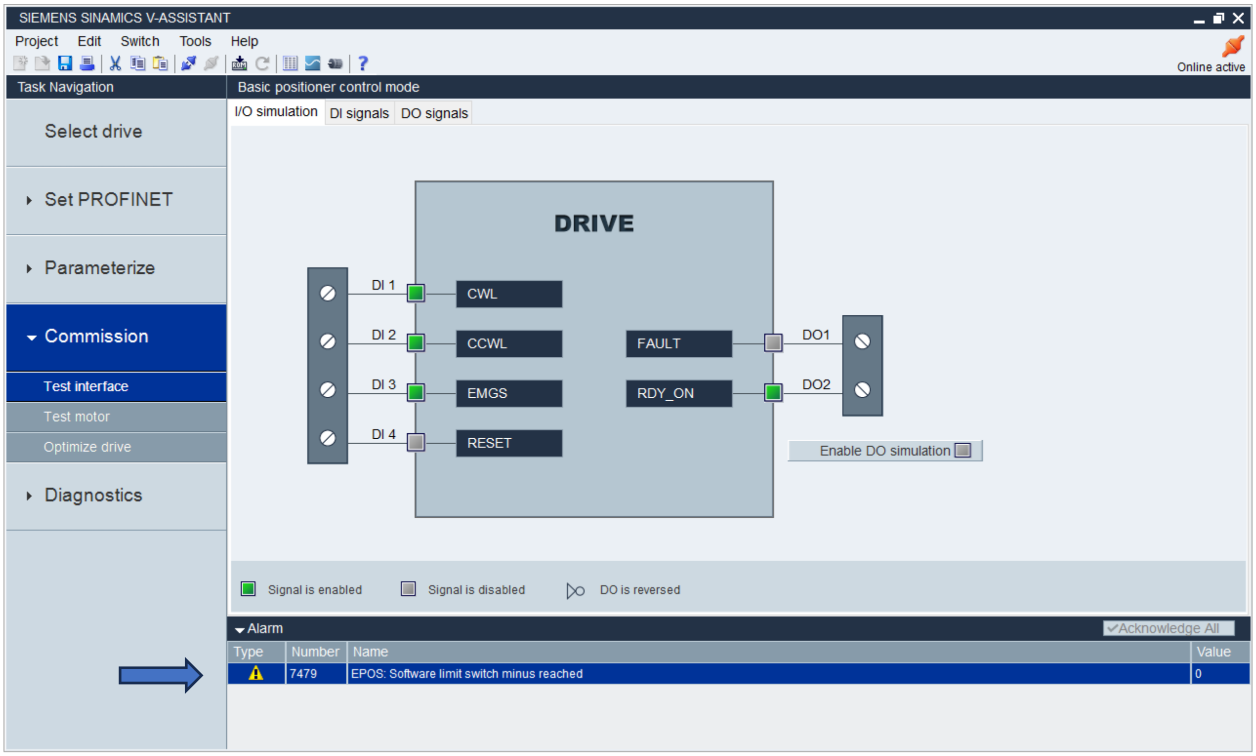
- **Embedded Tools:** The EddySonix app contains various tools for troubleshooting both analog and digital components.
- **Status Monitoring:** This software can assess the status of all input and output connections, identifying and guiding the resolution of issues.

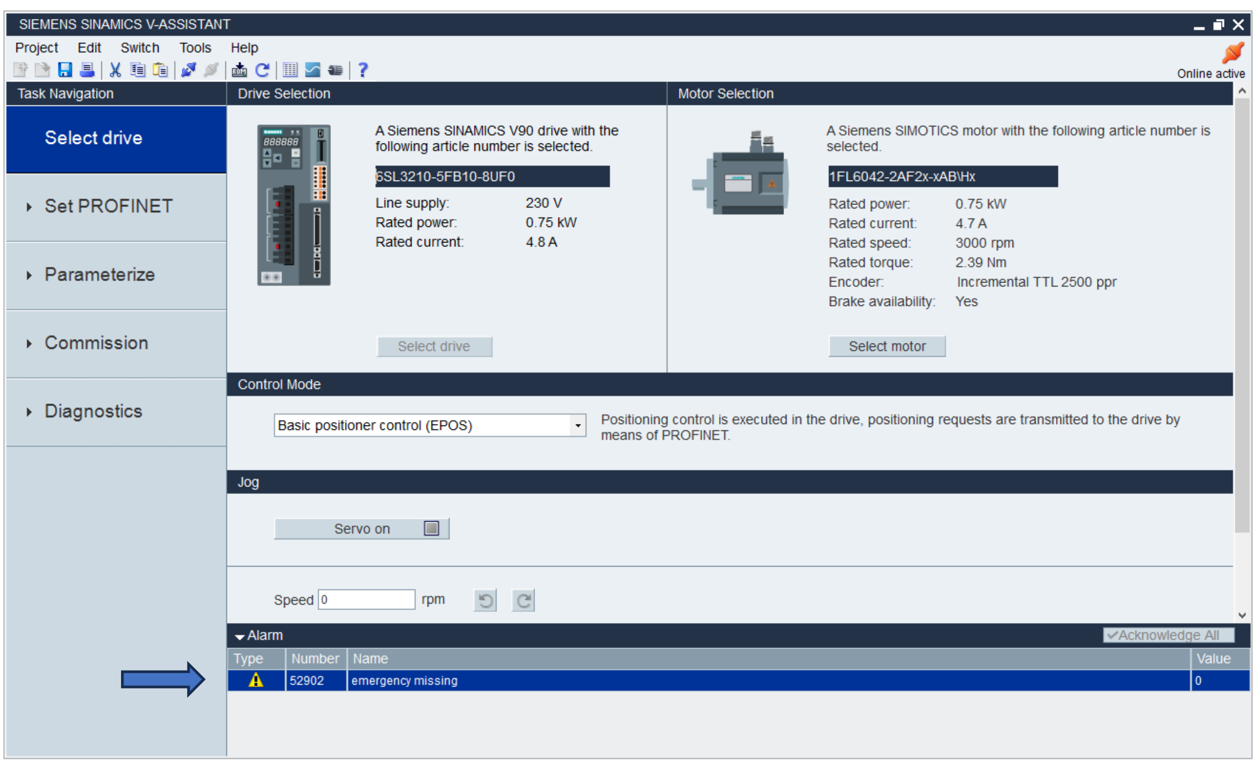
- **Controller Connection:** The EddySonix app connects to the controller unit via the serial port. If this connection is disrupted, access the serial port menu to test and evaluate the input and output port status.

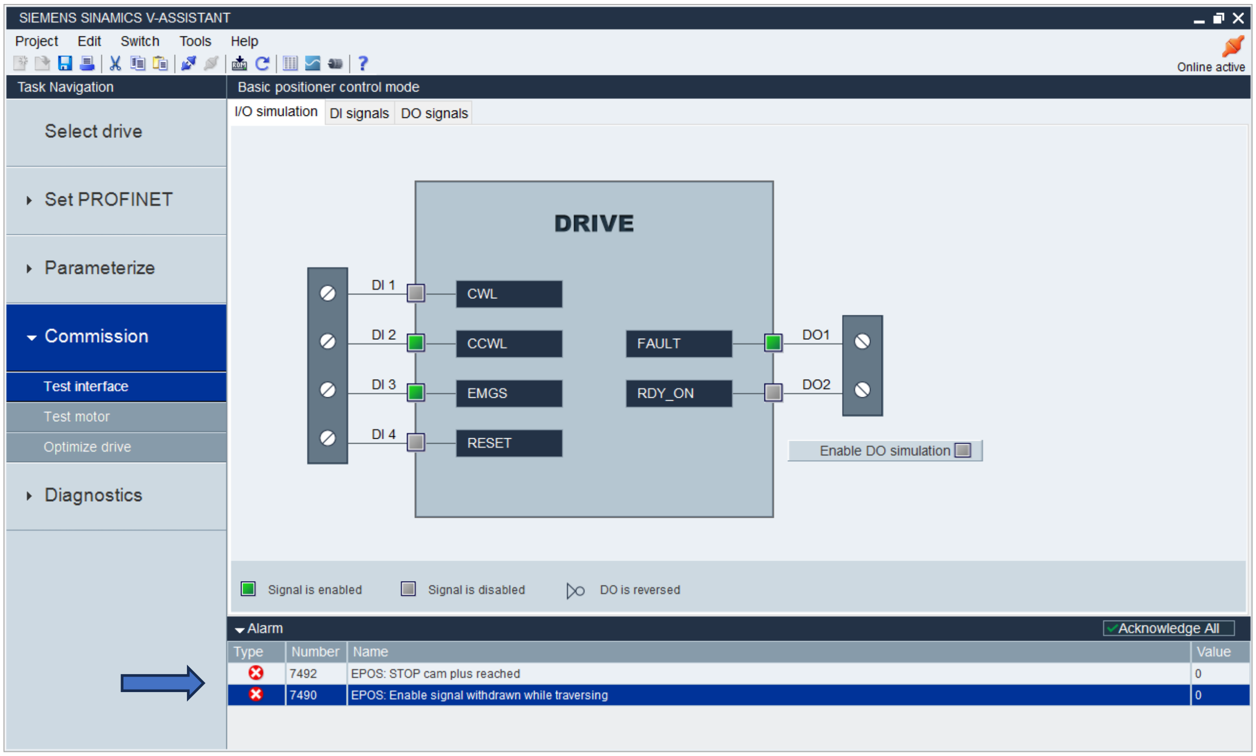


9.4 Siemens Servo Drive Troubleshooting

- **Routine Checks:** Under normal conditions, running the Siemens V-Assistant program is not required.
- **Fault Identification:** Use this program for system troubleshooting only. It will display error types, codes, and descriptions in case of alarms or faults.
- **Preparation:** Before running the application, ensure the servo drive is connected to the PC using a USB cable.

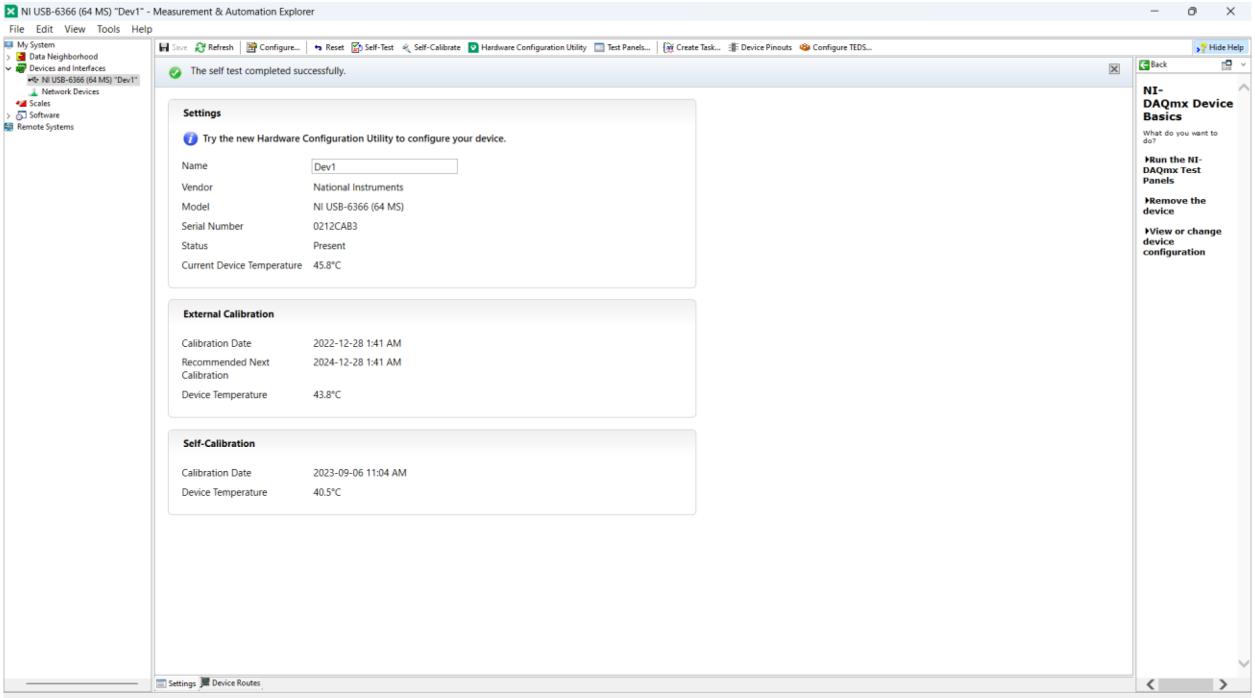

SIEMENS SINAMICS V-ASSISTANT
Project Edit Switch Tools Help
Online active
Task Navigation
Basic positioner control mode
Select drive
Set PROFINET
Parameterize
Commission
Test interface
Test motor
Optimize drive
Diagnostics
I/O simulation
DI signals
DO signals
DRIVE
DI 1
DI 2
DI 3
DI 4
CWL
CCWL
EMGS
RESET
FAULT
RDY_ON
DO1
DO2
Enable DO simulation
Signal is enabled
Signal is disabled
DO is reversed
Alarm
Acknowledge All
Type Number Name Value
7479 EPOS: Software limit switch minus reached 0

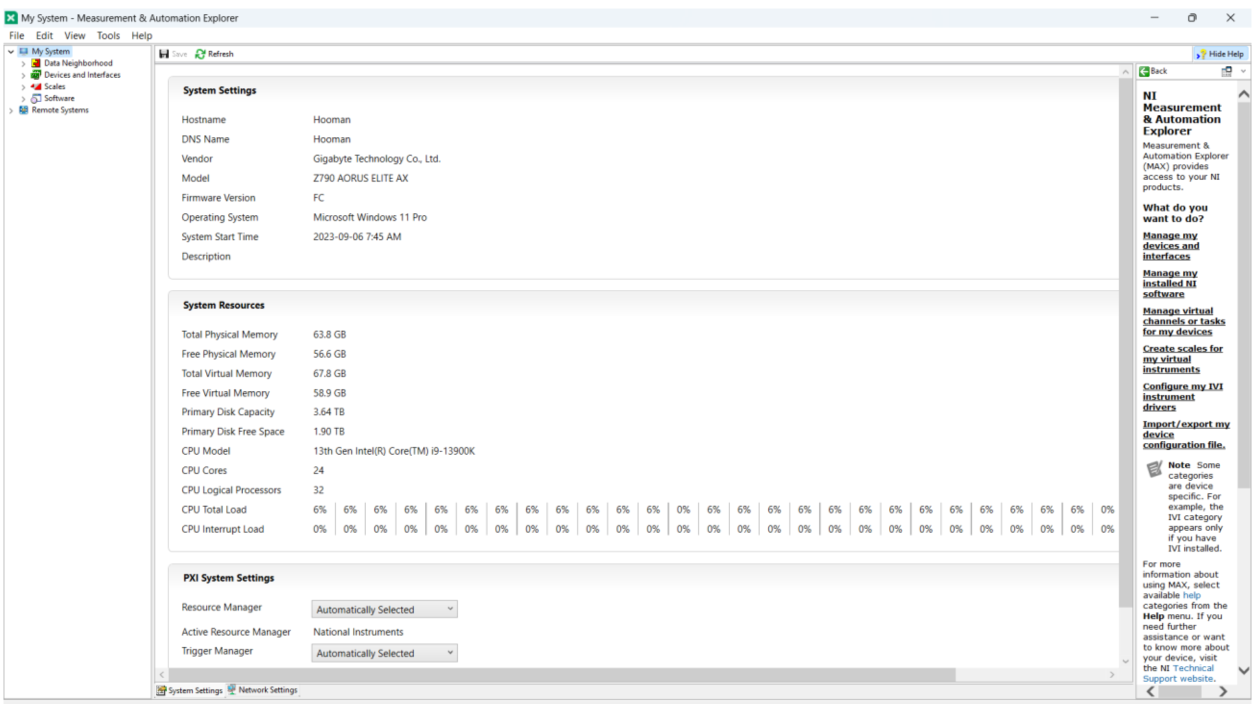

SIEMENS SINAMICS V-ASSISTANT
Project Edit Switch Tools Help
Online active
Task Navigation
Drive Selection
Motor Selection
Select drive
Set PROFINET
Parameterize
Commission
Diagnostics
A Siemens SINAMICS V90 drive with the following article number is selected.
6SL3210-5FB10-8UF0
Line supply: 230 V
Rated power: 0.75 kW
Rated current: 4.8 A
Select drive
A Siemens SIMOTICS motor with the following article number is selected.
1FL6042-2AF2x-xAB\Hx
Rated power: 0.75 kW
Rated current: 4.7 A
Rated speed: 3000 rpm
Rated torque: 2.39 Nm
Encoder: Incremental TTL 2500 ppr
Brake availability: Yes
Select motor
Control Mode
Basic positioner control (EPOS)
Positioning control is executed in the drive, positioning requests are transmitted to the drive by means of PROFINET.
Jog
Servo on
Speed 0 rpm
Alarm
Acknowledge All
Type Number Name Value
52902 emergency missing 0



9.5 NI (National Instruments) Self-Test and Calibration

- **Standard Procedure:** Calibration of this board is typically not required unless an issue arises in preceding steps.
- **Operational Steps:**
  - Power on the system and exit the EddySonix app.
  - Launch the NI Device Monitor and ensure the device is identified as "Dev1".
  - Execute the "Self-Test" to confirm basic I/O functionality of system devices.
- **Cautionary Notes for Self-Calibration:**
  - **Typically Unnecessary:** This self-calibration task is generally not required. We do not recommend performing it as it can lead to incorrect calibration if not executed properly.
  - **Mandatory Remote Supervision:** If this task is deemed necessary, it must be conducted under the strict remote supervision of the EddySonix team to ensure proper procedure and accuracy.
  - **Disconnect AC Input Signals:** Before considering "Self-Calibration," all Analog input signals should be disconnected or disabled to prevent miscalibration.
  - **Attention to Analog Output Channels:** Be aware that analog output channels may vary during self-calibration. Disconnect these channels beforehand to avoid any potential for calibration errors.


NI USB-6366 (64 MS) "Dev1" - Measurement & Automation Explorer
File Edit View Tools Help
My System
Data Neighborhood
Devices and Interfaces
NI USB-6366 (64 MS) "Dev1"
Network Devices
Scales
Software
Remote Systems
Save Refresh Configure... Reset Self-Test Self-Calibrate Hardware Configuration Utility Test Panels... Create Task... Device Pinouts Configure TEDS...
Hide Help
The self test completed successfully.
Settings
Try the new Hardware Configuration Utility to configure your device.
Name Dev1
Vendor National Instruments
Model NI USB-6366 (64 MS)
Serial Number 0212CAB3
Status Present
Current Device Temperature 45.8°C
External Calibration
Calibration Date 2022-12-28 1:41 AM
Recommended Next Calibration 2024-12-28 1:41 AM
Device Temperature 43.8°C
Self-Calibration
Calibration Date 2023-09-06 11:04 AM
Device Temperature 40.5°C
Settings Device Routes
Back
NI-DAQmx Device Basics
What do you want to do?
Run the NI-DAQmx Test Panels
Remove the device
View or change device configuration


My System - Measurement & Automation Explorer
File Edit View Tools Help
My System
Data Neighborhood
Devices and Interfaces
Scales
Software
Remote Systems
Save Refresh
Hide Help
System Settings
Hostname Hooman
DNS Name Hooman
Vendor Gigabyte Technology Co., Ltd.
Model Z790 AORUS ELITE AX
Firmware Version FC
Operating System Microsoft Windows 11 Pro
System Start Time 2023-09-06 7:45 AM
Description
System Resources
Total Physical Memory 63.8 GB
Free Physical Memory 56.6 GB
Total Virtual Memory 67.8 GB
Free Virtual Memory 58.9 GB
Primary Disk Capacity 3.64 TB
Primary Disk Free Space 1.90 TB
CPU Model 13th Gen Intel(R) Core(TM) i9-13900K
CPU Cores 24
CPU Logical Processors 32
CPU Total Load
CPU Interrupt Load
PXI System Settings
Resource Manager Automatically Selected
Active Resource Manager National Instruments
Trigger Manager Automatically Selected
System Settings Network Settings
Back
NI Measurement & Automation Explorer
Measurement & Automation Explorer (MAX) provides access to your NI products.
What do you want to do?
Manage my devices and interfaces
Manage my installed NI software
Manage virtual channels or tasks for my devices
Create scales for my virtual instruments
Configure my IVI instrument drivers
Import/export my device configuration file.
Note Some categories are device specific. For example, the IVI category appears only if you have IVI installed.
For more information about using MAX, select available help categories from the Help menu. If you need further assistance or want to know more about your device, visit the NI Technical Support website.

10 Appendices

10.1 Installation Guide

Upon the arrival of the crates, securely store them in your designated area. The EddySonix team will be responsible for unpacking, setting up, and providing training during their visit. It is essential for both the customer and EddySonix team to collaboratively ensure a well-coordinated installation and setup process.

Prior to installation:

- Prepare the sample parts for database creation and testing, adhering to the specifications outlined in the EddySonix User Manual. Ensure these samples are stored securely in a location away from magnets and areas with high electromagnetic noise.

- Arrange the designated space and ensure the necessary conditions for machine installation are met, following the guidelines in this manual.

Crates

The machine is shipped in two crates:

- Hardware rack (L x W x H) = 2100mm x 1080mm x 1100mm, Weight = 370kg
- Mechanical unit (L x W x H) = 2050 mm x 900mm x 1070mm, Weight = 420kg

Figure 124. EddySonix packaging in two crates

Installation Space Required

To prepare for the installation of the device, please ensure the following conditions are met in the designated space:

- Room: Provide a clean, laboratory-standard environment.

- Power Outlet: Ensure availability of a power outlet compatible with 115V AC, 60Hz, single-phase power supply (specifically for US and Mexico).

- Ground Connection: Have a ground connection available in the installation area.

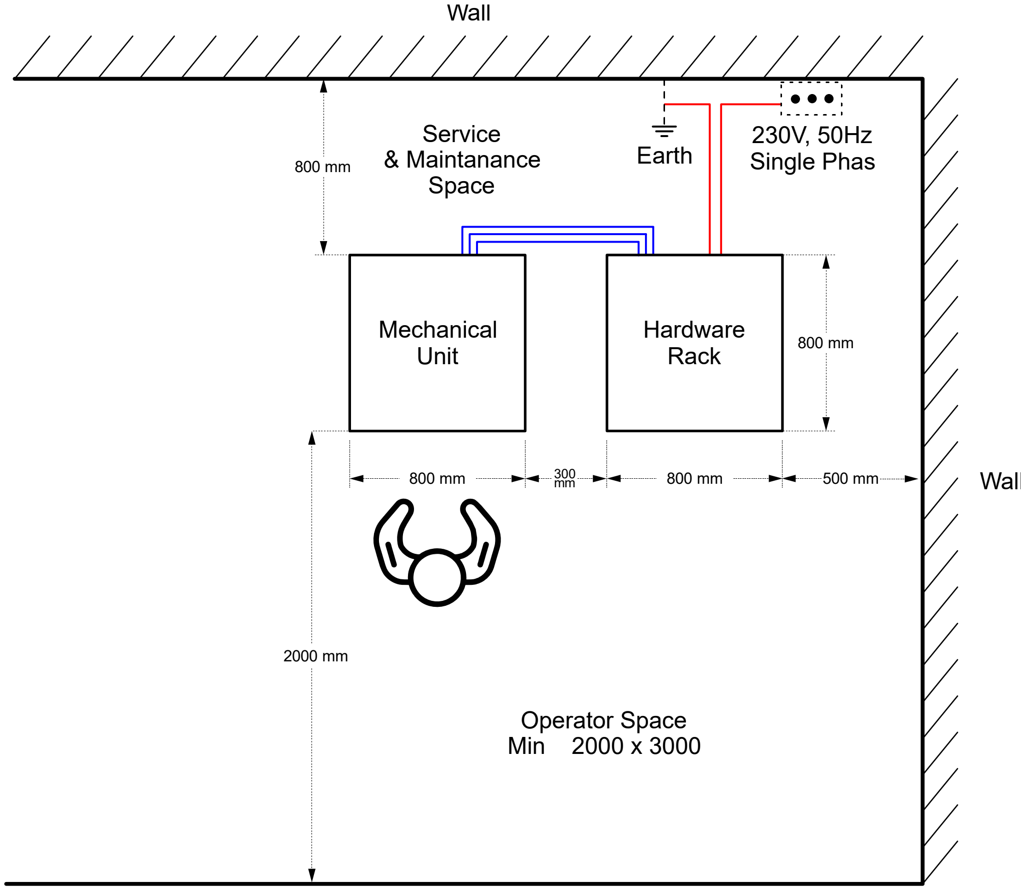


Figure 125. Top View of System Layout. Note: For US and Mexico installations, the mains power requirement is 115VAC, 60Hz. (The depicted outlet indicates 230VAC, 50Hz, which is not applicable for these regions.)

Unpacking Process

To begin unpacking, use a cordless drill/screwdriver to remove the screws.

Start by opening the top side of the crate:

Figure 126. Unscrew the top of the box.

Proceed to open the four sides: Left, Right, Front, and Back:

Figure 127. Open the four sides of the crates.

Next, remove the blue plastic covers:

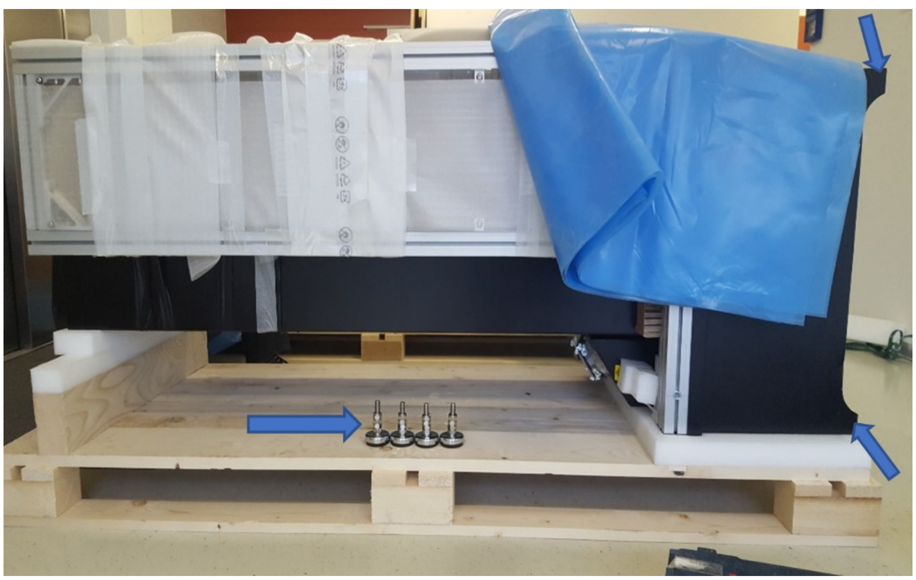


Figure 128. Remove the plastic sealing cover, followed by attaching the 4 Leveling Foot Mount Pads to the Mechanical Unit.

Attaching the 4 Leveling Foot Mount Pads to the Mechanical Unit.

Positioning the Device Upright

Ensure the device is positioned upright at this stage. This task requires the presence of two physically capable individuals. Gently and cautiously rotate the device into a vertical position.

⚠ Caution: The units are heavy. Adhere to the instructions meticulously when rotating them.

- Avoid gripping the Safety Light Curtains. Instead, hold the mechanical unit from the back and bottom.

Moving the Device with a Forklift

Utilize a forklift to relocate the machine to the laboratory.

⚠ Safety Reminder: Be vigilant about cables while transporting the units with a pallet transporter. Ensure that cables do not become entangled or trapped under the wheels or bases.

Installation Procedure

The mechanical unit contains various accessory packs and boxes. Gently remove the fasteners and adhesive tapes.

⚠ Caution: Avoid using a cutter to open the adhesive bands to prevent damaging the cables.

Installing the Servomotor

- The coil housing is held in place with a cable tie. Refrain from cutting or opening this cable tie, as it prevents the coil housing from sliding.

- Position the servomotor atop the unit and secure it with screws, ensuring the cables face backward.

- After securing the servomotor, cut and remove the cable tie to release the coil housing.

⚠ Important: Do not connect the device to the mains power at this stage.

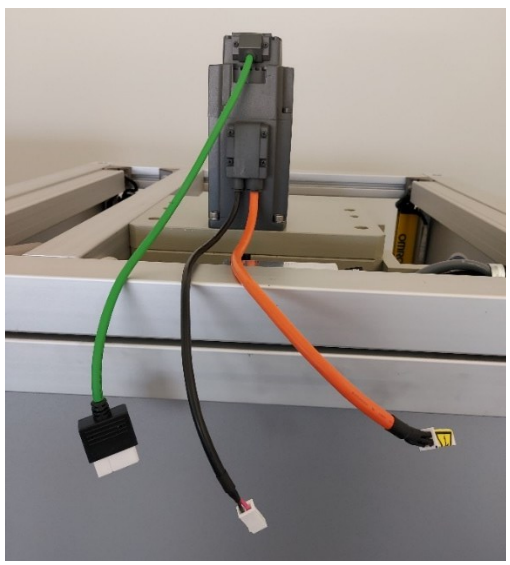


Figure 129. Position the servo motor and securely fasten the screws.

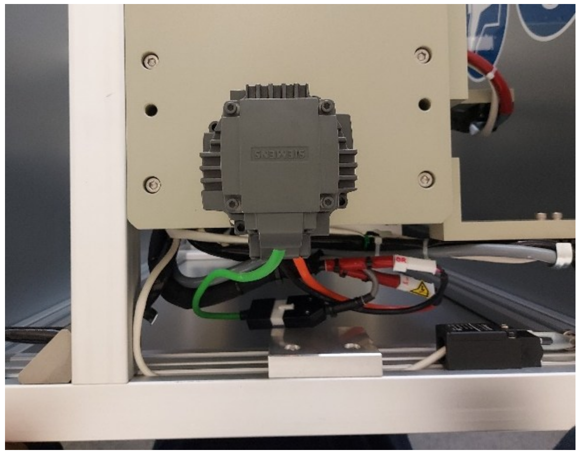


Figure 130. Connect all three coil connectors. Utilize the markings on the connectors to determine the correct orientation for connection.

Connect the machine's ground cable (yellow-green) to the laboratory's grounding point. Following this, establish connections between the mechanical unit and the electrical rack by linking the respective cables.

Figure 131. Front view of the system.

Figure 132. Rear view of the system. Three main cables connect the rack to the mechanical unit.

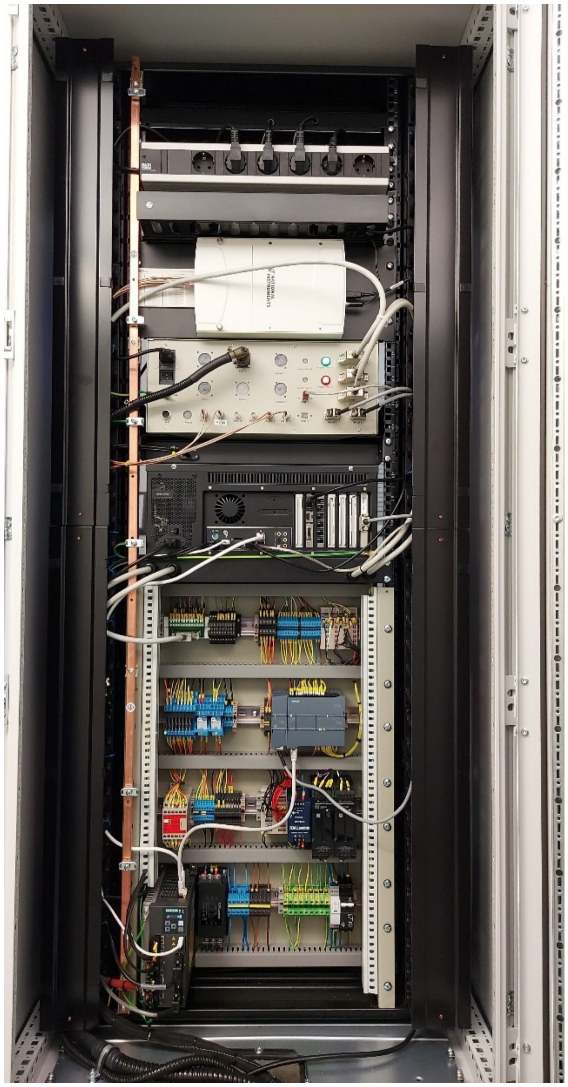


Figure 133. Backside view of the open hardware and electrical rack, showcasing the organized layout of components, including the power distribution, data acquisition system, and PLC modules for seamless integration and efficient operation.

- Ensure the back door of the mechanical unit is securely closed.

- Verify that the back door of the rack is also closed.

- Confirm that the lockout switch is set to the OFF position.

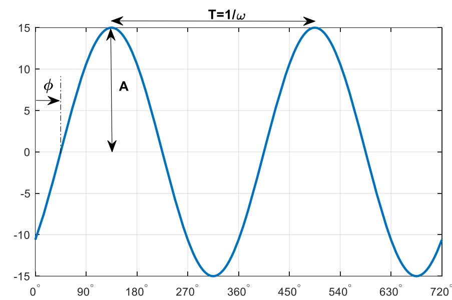
After completing these checks, proceed to connect the power cable to the mains power supply.

10.2 Understanding Eddy Current Theory and Impedance Plane in Case Depth Measurement

1. **Sinusoidal Signals:**

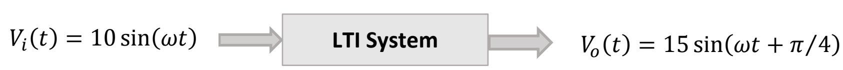
    - **Definition:** A sinusoidal signal is represented as $x(t) = A\sin(\omega t + \varphi) = A\sin(2\pi f t + \varphi)$, where A is amplitude, ω is frequency in radians per second, and ϕ is phase in radians.

- **Characteristics:** These signals are fundamental in physics and essential across all engineering fields. They maintain their waveform when combined with another sine wave of the same frequency, regardless of phase and magnitude differences.



2. **Linear Time-Invariant (LTI) Systems:**

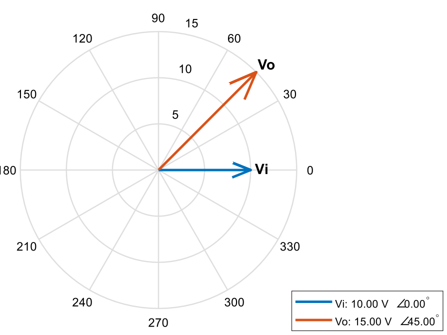
- **Response to Sinusoidal Input:** When a sine wave is input into a linear system at a certain frequency, the system responds at the same frequency with a specific magnitude and phase angle.

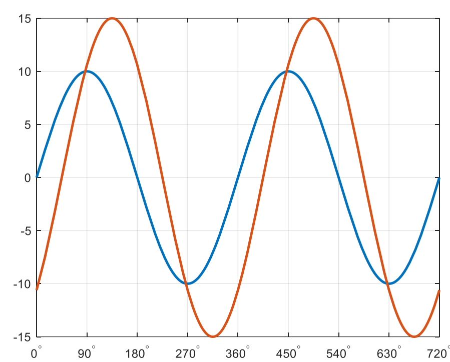


3. **Phasor Repr**

- **Concept:** Sinusoidal functions can be depicted as phasors, which are vectors in a complex plane.

- **Components:** Phasors represent amplitude and phase in polar coordinates, but do not include frequency as it remains constant.



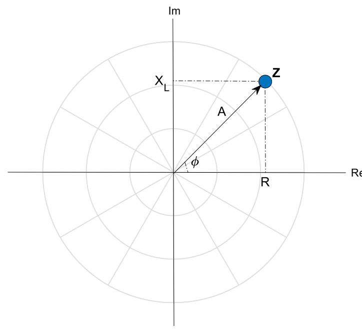


4. **Impedance in Eddy Current Testing:**

- **Eddy Current Testing:** Involves injecting a current signal into a coil and reading the response from a secondary coil.

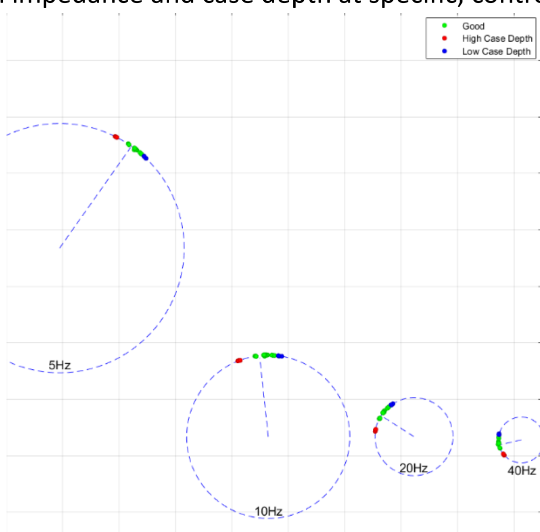
- **Impedance Definition:** Represented as *Z=V/I*, indicating the properties like structure and hardness of the sample part.

- **Representation:** The part's impedance is shown using a phasor diagram (amplitude and phase) or with Resistance (R) and Inductance (XL) in Cartesian coordinates.

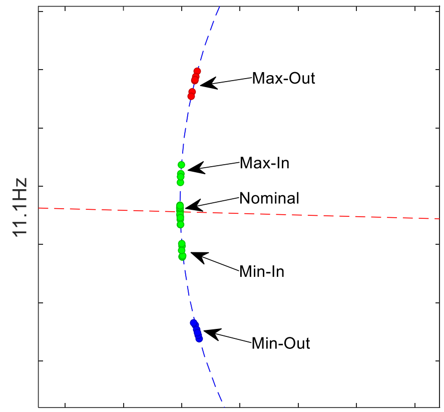


5. Impedance Locus in Eddy Current Testing at Specific Frequencies

- **Focused Frequency Testing:** EddySonix conducts eddy current testing at select frequencies, specifically 5Hz, 10Hz, and 20Hz for Case Depth measurement.
- **Impedance Plane Observation:** When examining axle bars with different case depths (ranging from shallow to deep) at these fixed frequencies, a distinctive pattern is observed on the impedance plane.
- **Arc Formation on Impedance Graph:** At each of these frequencies, plotting the impedance values for axle bars with varying case depths reveals that the data points form an arc.
- **Pattern Consistency:** This arc, representing a segment of a circle, is consistently observed across the tested frequencies.
- **Interpretation Significance:** This pattern, unique to EddySonix's findings, offers valuable insights into the relationship between impedance and case depth at specific, controlled frequencies.



The following figure presents a detailed impedance locus graph at a frequency of 11.1 Hz, illustrating the variation in impedance for different axle bar samples. Each dot on the graph represents an individual part, with a total of 40 samples depicted. The distribution is as follows: 16 dots for 'Nominal' samples, indicating standard case depths, and 6 dots each for 'Max-Out' (deep case depth), 'Max-In', 'Min-In', and 'Min-Out' (shallow case depth) samples. This visualization provides an insightful representation of how impedance varies with case depth at a fixed frequency, highlighting the precise and consistent measurement capabilities of the EddySonix system.



Additional Insights on the Impedance Locus

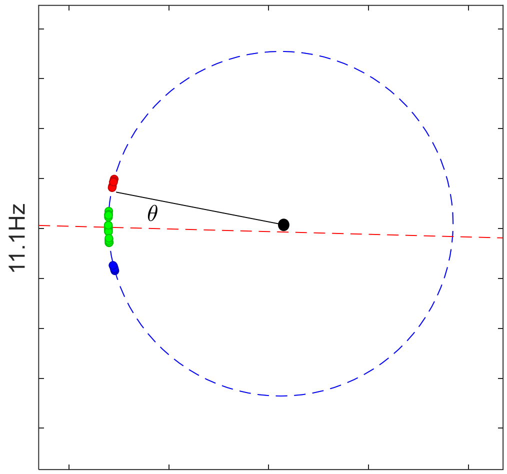
This Impedance plane is specifically related to spline 2 of the axle bar. It's important to note that for each location along the axle bar, we generate a separate impedance locus. Therefore, we calculate an individual impedance plane for every millimeter along the shaft. For instance, if the length of the axle bar is 500mm, we perform the scanning process to calculate 500 different impedance planes. This comprehensive approach allows for a detailed analysis of the axle bar, providing a deeper understanding of the impedance characteristics at various points along its length.

Understanding the Theta Angle in Eddy Current Testing

The concept of the Theta Angle emerges from the observation that the impedance locus forms an arc. To analyze this arc, we fit a circle over the sample points. By setting our zero reference at the center of this circle, each sample point on the locus can be uniquely represented by its angular position, or Theta Angle, on this circle. It's crucial to note that all points share an equal radius on this fitted circle.

For a more accurate and standardized comparison, we normalize all samples against the 'Nominal' samples. This means we adjust the data so that the mean Theta Angle of the Nominal samples is set to zero degrees. Consequently, samples categorized as 'Max' (indicating a deeper case depth) display a positive Theta Angle, while 'Min' samples (with a shallower case depth) exhibit a negative Theta Angle.

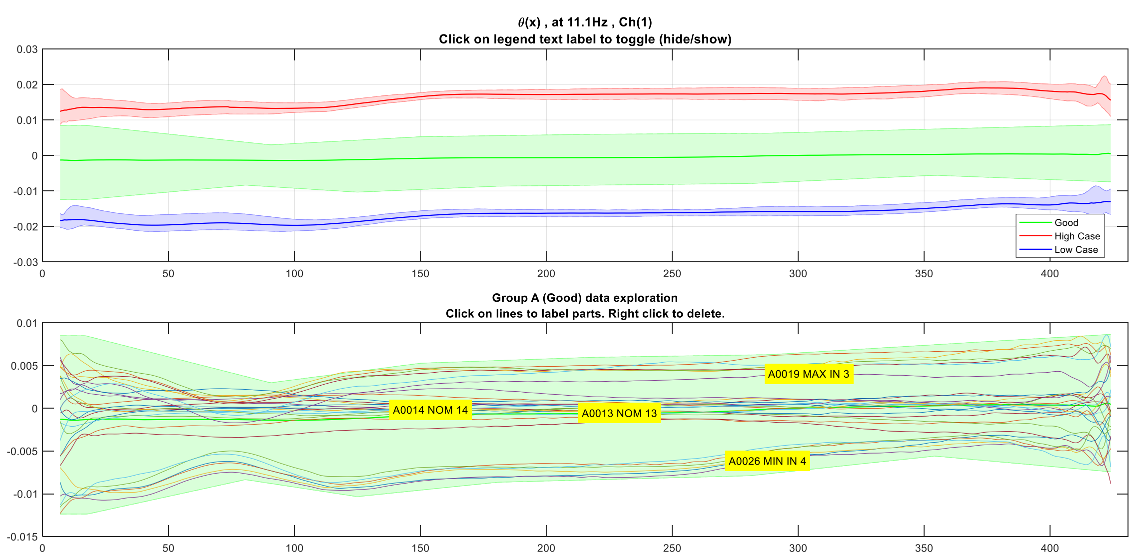
The next figure visually demonstrates this concept, showcasing how each category of parts – Max-Out, Max-In, Min-In, and Min-Out – is positioned in relation to the Nominal samples on the circle, thereby illustrating their respective Theta Angles.



Advantages of Normalizing to Nominals in Impedance Analysis: Creating the Theta Envelope

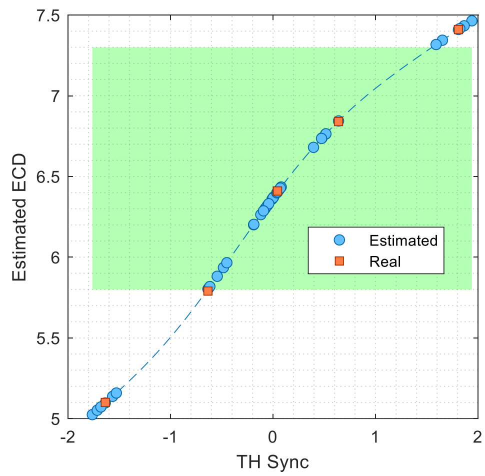
An additional benefit of normalizing our impedance data to Nominal samples, or 'Zeroing to Nominals,' is our ability to create what we call the 'Theta Envelope' for each axle bar. By aligning all individual impedance points to the Nominal standard, we effectively concatenate these points along the axle bar. This process results in a continuous envelope or curve, known as the Theta Envelope, which represents the comprehensive impedance characteristics along the entire length of the axle bar. The Theta Envelope simplifies the overall analysis and provides a more coherent and complete understanding of the axle bar's condition. This unified approach enhances our capability to detect subtle variations and anomalies in impedance, enabling more precise and accurate assessments of each part's integrity and quality.

The following figure will illustrate the Theta Envelopes of the 40 sample parts we previously discussed. It's important to note that this envelope is closely related to the 'Case Depth' envelope along the axle bar, providing a visual correlation. However, it's crucial to understand that this is an indicative visualization; the exact case depth will be calculated in a subsequent step, allowing for a precise and quantifiable measurement of each part's characteristics.



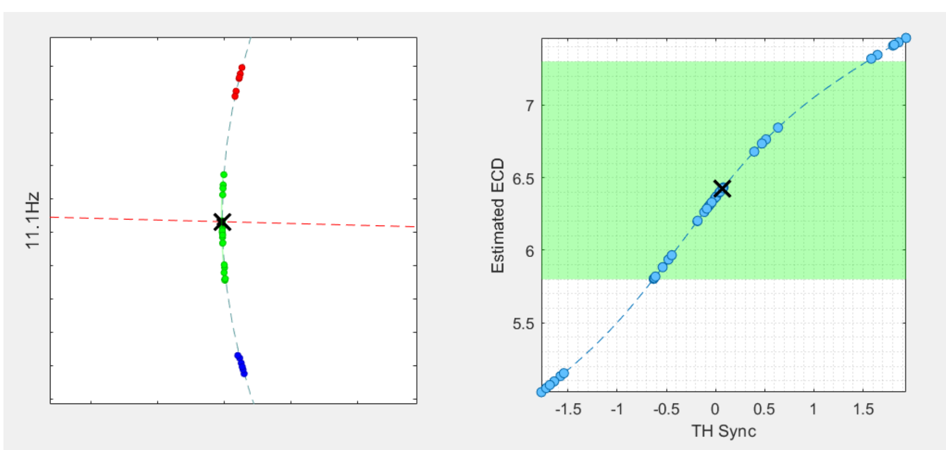
Precise Measurement of Case Depth Using Theta Angles

The 'Theta Envelope' is primarily a visual tool. For precise case depth measurements at each point on the axle bar, we analyze individual Impedance Planes at specific locations. Here, 'Theta Angles' are calculated for selected frequencies, such as 5 and 10 Hz, and combined into a single measure called 'Sync Theta'. We then apply a polynomial fit to correlate Sync Theta with Case Depth, creating a function that accurately maps these variables. The next figure shows this curve fit, demonstrating the exact relationship between Case Depth and Theta.



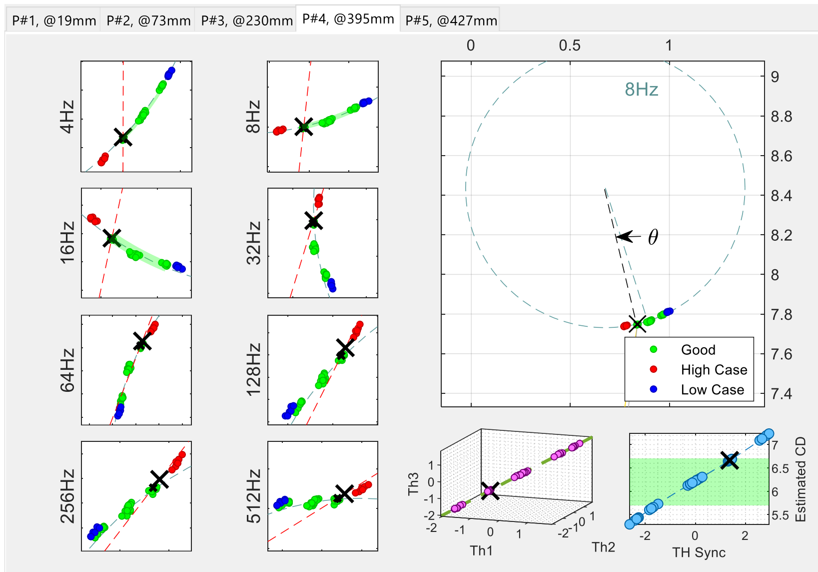
Testing Process for New Unknown Parts

To assess a new, unknown part, we first examine its impedance loci. We then measure its Theta angle at the specific points of interest. Using the previously established polynomial function, we apply these Theta measurements to accurately determine the part's Case Depth. This approach ensures precise and reliable analysis. The following figure provides an example of this process applied to spline 2 of a part.



10.3 Curve Fitting between TH_SYNC (Θ) and Case Depth (CD)

When we test a part, we calculate theta (θ) envelopes at each frequency. As an example, the following figure shows the test results of a Max-In part at Point P#4 395mm. On the right side we zoon in the impedance locus at 8 Hz. The impedance locus of all parts (Min to Max CD) is assumed to lie on a circular arc. We define theta (θ) as the angle between the baseline (center of data) and the angle of the part tested. Its unit is in radians.

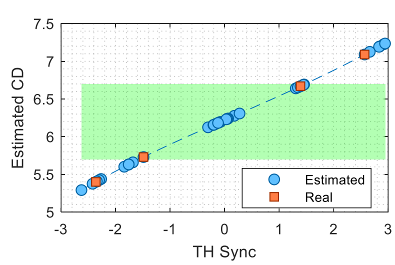


Similarly, we calculate theta for each frequency. So, for each frequency F_i we have theta θ_i. We merge the selected theta (those selected in Compensation menu) into one unified theta called TH_SYNC (Θ). In the above figure, the right – bottom graph (3D) shows the merging of Th1, Th2, and Th3 into one unified THETA (Green line).

Θ has a direct relationship with Case Depth. In most cases it is even proportional (linear relationship), so a simple line fit (1st order polynomial) can relate Θ to CD. In the above figure, the right – bottom graph shows the relation between Θ and CD, which is almost linear for this example. For a linear relationship we can express Estimated Case Depth as:

$$CD = a_1\Theta + a_0$$

The coefficients a_i are found during training (Learn menu, Solve & Train Models). A line is fitted to only points whose Case Depth are defines through Database Cut-Checks menu. These points are shown in Red Squares in the following figure:

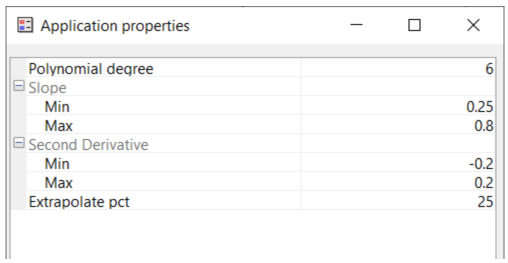


After training is complete, we test an unknown part, calculate Θ, knowing a_i coefficients, we estimate CD (Case Depth) using the above equation.

However, in some cases, the relationship between Θ and CD is not purely linear. Therefore, we allow the choice of a polynomial up to order 8:

$$CD = \sum_{i=0}^{N} a_i \Theta^i$$

To manage the high degree of freedom in such a curve, we need to impose constraints. We define the maximum and minimum slope, and even the maximum and minimum curvature (2nd derivative, or slope of the slope):



This ensures that the physical requirements are met, particularly when extrapolating the equation. For example, the curve must be monotonic (e.g., always increasing). To achieve this, we constrain the slope to always have the same sign (e.g., always positive). This means that if Θ increases, then CD also increases.

Note: The minimum and maximum values of the Slope should remain positive.

10.4 Harmonic Analysis

Suppose that we have a "Linear" circuit or system:

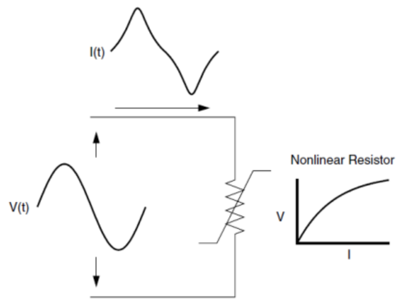
- If we excite the input with a sine wave $\sin \omega t$, then the output will be sine wave with the same frequency $A.\sin(\omega t + \varphi)$.
- If we double the amplitude of excitation to $2.\sin(\omega t)$, then the output will be doubled as well to $2A.\sin(\omega t + \varphi)$

In our Eddy Current system, we apply a sine wave current to the excitation coil $I = \sin \omega t$, and measure the axle bar response from the pickup coil $V = A.\sin(\omega t + \varphi)$. The decomposition algorithm assumes that the input and output frequencies ω are equal. So, the algorithm calculates the Amplitude A and Phase φ. We assume that the system is linear.

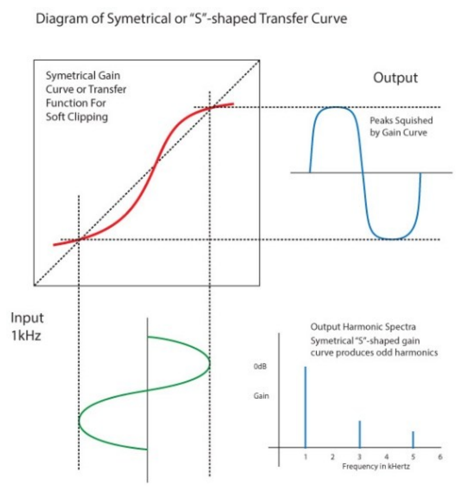
In the same way, we can apply superposition of two sine waves $I = \sin \omega_1 t + \sin \omega_2 t$, and measure the output $V = A_1 \sin(\omega_1 t + \varphi_1) + A_2 \sin(\omega_2 t + \varphi_2)$. Note that the two frequencies ω_1 and ω_2 are independent and each can be arbitrarily chosen. For example, $\omega_1 = 4.0, and\ \omega_2 = 13.0$. The decomposition algorithm will calculate Amplitudes A_1 and A_2, and Phases ϕ_1 and ϕ_2, knowing that the frequencies are ω_1 and ω_2. The two frequencies do not interfere with each other, and we say they are orthogonal.

We can extend the problem to multiple frequencies and excite the coil with $\omega_1, \omega_2, \dots, \omega_N$ where the frequencies are totally independent and can be chosen arbitrarily.

Step 2: Now suppose that we have a "Nonlinear" circuit or system, in which the change of the output is not proportional to the change of the input. In other words, the impedance changes when the voltage applied across it is changed. For such loads or impedances, the plot between, voltage across them and the current through them, do not come out to be a straight line.

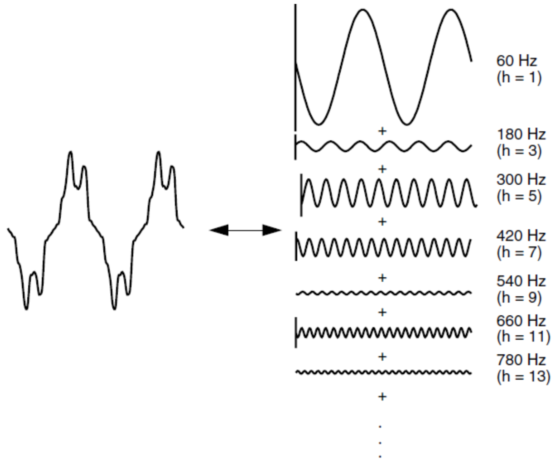


Now if we excite the input with a sine wave $\sin \omega t$, then the output will be distorted, which means that the shape is not sinusoidal. The output is still periodic with period ω, but the shape is not sine wave.



If a voltage/current signal is not sinusoidal, but is periodic, it can be represented as a sum of desired frequency (ω) sinusoid and multiples of desired frequency sinusoids (2ω, 3ω, 4ω, etc.) according to Fourier. These are termed as Harmonics.

Any periodic distorted waveform can be expressed as sum of pure sine waves, in which the frequency of each sinusoid is an integer multiple of the fundamental frequency. The sum of sinusoids is referred to a Fourier series. When both the positive and negative half cycles of a waveform have identical shapes, the Fourier series contains only odd harmonics.



In eddy current testing, the nonlinearity results from a hysteresis of the magnetization curve of the test part. In the following figure, H is applied magnetic field to the part which is proportional to the excitation current, and B is magnetic induction which is proportional to the output pickup.

Note that hardened layer and soft layer have different hysteresis (nonlinear) patterns. Harmonic analysis of eddy current signals can describe the shape of the magnetic hysteresis loop. Higher harmonics of the testing frequency reflect the structural constitution and magnetic properties better than the first harmonic. The harmonic analysis of eddy current signals could be employed efficiently for the determination of case depth of steel parts due to different magnetic properties of hardened layer (martensite structure) and core of the sample (ferrite-pearlite structure).

In our Eddy Current system, we apply a sine wave current to the excitation coil $I = \sin \omega t$, and measure the axle bar response from the pickup coil. But this time, we assume that the response is distorted due to the hysteresis loop, so we calculate odd harmonics (only H3 and H5) amplitudes and phases as well:

$$V = A_1 \sin(\omega t + \varphi_1) + A_3 \sin(3\omega t + \varphi_3) + A_5 \sin(5\omega t + \varphi_5)$$

The decomposition algorithm assumes that the signal consists of three frequencies ω, 3ω, and 5ω. Then calculates three amplitudes A_1, A_3, A_5, and three phases ϕ_1, ϕ_3, ϕ_5.

We can extend the problem to multi-frequency excitation, and for each frequency we can independently calculate amplitudes and phases for fundamental frequency, 3rd harmonic, and 5th harmonic.

For example, if we excite the coil by a set of these frequencies: 4Hz, 13Hz, 15Hz, then we calculate the response at these frequencies:

4, 13, 15, 12, 39, 45, 20, 65, 75 Hz

Where the blue are fundamental frequencies, green the 3rd harmonics, and red the 5th harmonics.

In practice the amplitudes of 3rd and 5th harmonics are much smaller (between 1/100 and 1/1000) than fundamental frequency.

There is some interesting academic research, but it has not studied the effects of changes in cast code and temperature. We perform the tests to better integrate the harmonic data into our model.

10.5 A Guide to Statistical Analysis

Correlation Coefficient

Definition

Correlation coefficients are used to measure the strength of the relationship between predicted and actual data. Values always range between -1.0 (strong negative relationship) and +1.0 (strong positive relationship). Values close to zero imply weak or no linear relationship.

Scatter Plot

Before performing correlation analysis, we should visually look at the data. A scatterplot is a graph of one variable vs. another variable. It gets an idea about how the two variable covary.

Linear Relationship

Pearson correlation is a measure of the linear relationship between variables. In simple terms, it answers the question, Can I draw a line graph to represent the data?

Small correlation values do not necessarily mean that no relationship exists between the variables. The variables may have a nonlinear relationship. To check for nonlinear relationships graphically, scatterplots should always be examined.

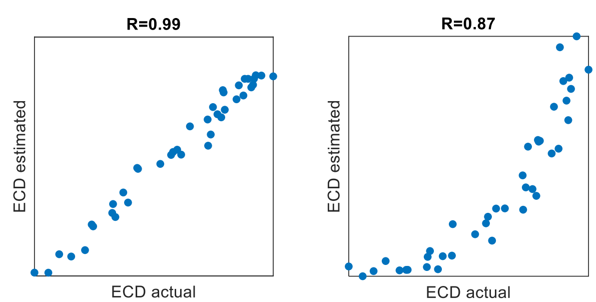


Figure 134. Left: Linear relationship shows high R; Right: Nonlinear relationship shows less R

Data Distribution and Outliers

In a Pearson correlation analysis, both variables are assumed to be normally distributed. The empirical distribution of the data (the histogram) should be bell-shaped and resemble the normal distribution. This might be difficult to see if the sample size is small.

When both variables are normally distributed use Pearson's correlation coefficient, otherwise use Spearman's correlation coefficient. Spearman's correlation coefficient is more robust to outliers than is Pearson's correlation coefficient.

The Pearson correlation coefficient is very sensitive to extreme (outlier) data values. A single value that is very different from the other values in a data set can greatly change the value of the coefficient. You should try to identify the cause of any extreme value. Correct any data entry or measurement errors. Consider removing data values that are associated with abnormal, one-time events (special causes). Then, repeat the analysis.

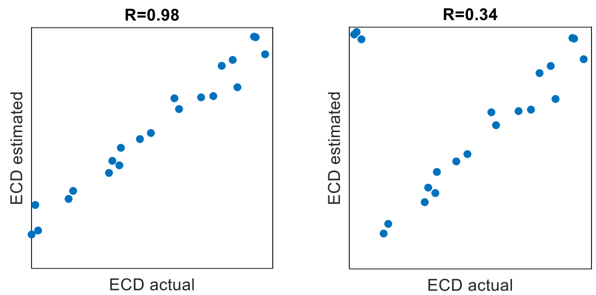


Figure 135. Left: High correlation variables. Right: Adding few outliers can considerably reduce correlation.

Conversely, a few outliers can greatly increase correlation, while originally there is little correlation between the two variables.

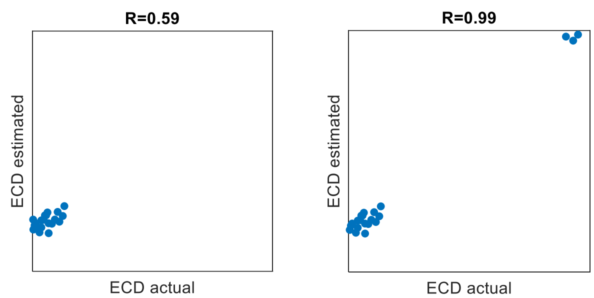


Figure 136. Left: Low correlation between variables. Right: adding few outliers misleads to high correlation.

Range of variability

Notice for Range of variability: The sample set must cover the range of data changes. If we collect samples from a small variation range, we will get a small correlation. In simple words, 10% of the data should be in group of [Max-Out, Max-In, Min-Out, Min-In]. Otherwise, ignore interpreting R for this point.

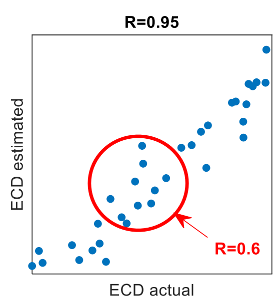


Figure 137. The whole data has strong correlation, but if we view the data inside the red circle in isolation, the correlation is low.

Sample Size

Correlations obtained with small samples are unreliable. The larger the sample, the more stable the correlation coefficient. The minimum sample size to run Pearson's correlation coefficient is recommended to be 30 data points.

Significance test

Quantifying a relationship between two variables using the correlation coefficient only tells half the story, because it measures the strength of a relationship in samples only. If we obtained a different sample, we would obtain different r values, and therefore potentially different conclusions.

We perform a hypothesis test of the "significance of the correlation coefficient" to decide whether the linear relationship in the sample data is strong enough. To determine whether the correlation between variables is significant, compare the p-value to your significance level. If this probability is lower than the conventional 5% ($P<0.05$) the correlation coefficient is called statistically significant.

Hence, smaller the p-value more confident is the prediction. This has nothing to do with the value of the correlation coefficient.

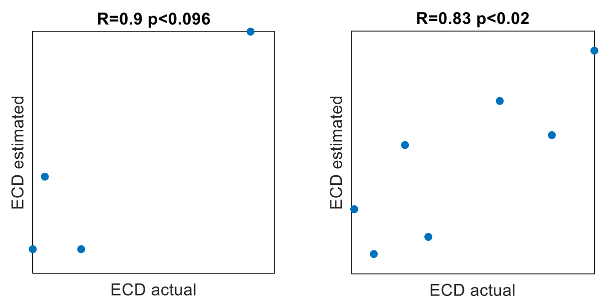


Figure 138. Left: p-value=0.1 so less confidence on R. Right: p-value=0.02 so high confidence on R

Bland-Altman Analysis

Definition

Bland-Altman analysis is a simple and accurate way to quantify agreement between two measurement methods S_1 = *Microhardness* and S_2 = *EddySonix*. It plots the difference between the two measurements $S_1 - S_2$ on the Y axis, and the average of the two measurements $(S_1 + S_2)/2$ on the X axis.

One of the outputs is **95% Limits of Agreement (LOA)** which describe the range for 95% of difference points, or 95% of future measurement pairs (Microhardness, EddySonix). The LOA include both systematic (bias) and random error (precision), and provide a useful measure for comparing the likely differences between results measured by two methods. When one of the methods is a reference method, the limits of agreement can be used as a measure of the total error of a measurement procedure.

Then the mean and standard deviation of the differences are calculated. For easier interpretation, three lines are also shown:

- **Bias** – which is mean of the differences $S_1 - S_2$. It is represented by a central horizontal line on the plot.
- **95% Limits of Agreement (LOA)** – which is calculated as mean ± 1.96 standard deviation of $S_1 - S_2$. They are represented by horizontal lines above and below the central horizontal line.

The Limits of Agreement describe the range for 95% of difference points, or 95% of future measurement pairs. The LOA include both systematic (bias) and random error (precision), and provide a useful measure for comparing the likely differences between results measured by two methods. When one of the methods is a reference method, the limits of agreement can be used as a measure of the total error of a measurement procedure.

As a quantifiable measure, bias and limits of the agreement give information about the utility of the new measurement method.

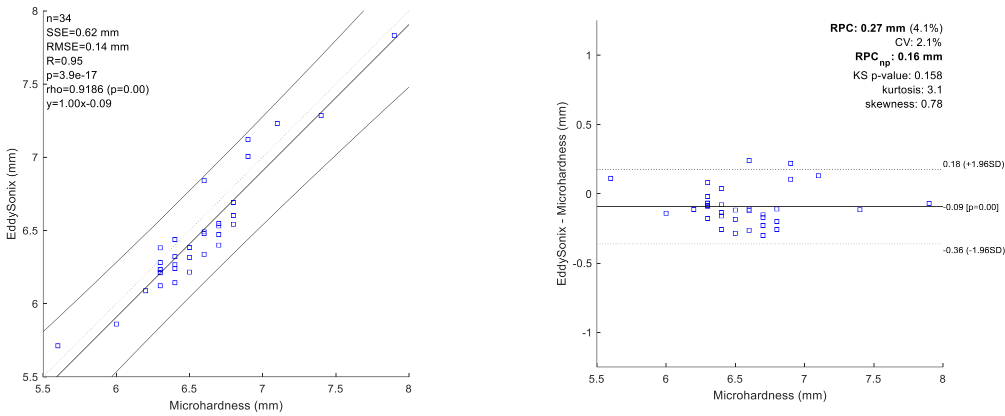


*Figure 139. **Left:** Correlation analysis and scatter plot of data measured by two methods: Microhardness as reference and EddySonix as the new device. **Right:** Bland-Altman plot. The solid line shows the mean of the differences between the two measurements; the dashed lines show the upper (mean + 1.96 SD) and lower limits (mean – 1.96 SD) of the interval of agreement. Here, the limits of agreement are -0.36 and 0.18 mm, indicating that 95% of the differences between these two measurements are within this range. The negative bias -0.09 indicates that EddySonix on average provides less ECD than microhardness, while if the bias would be positive, EddySonix would provide higher ECD estimation than microhardness.*

Interpretation

Despite its simplicity, Bland-Altman is often not properly interpreted. The following information can be derived visually from the diagram:

- Whether one measuring method in principle measures higher or lower than the other (bias or systematic error)
- How much the deviation fluctuates (standard deviation)
- Whether there are outliers
- Whether the deviation of the methods or the spread of the deviations depends on the level of the values.
- Check the presence of proportional bias.

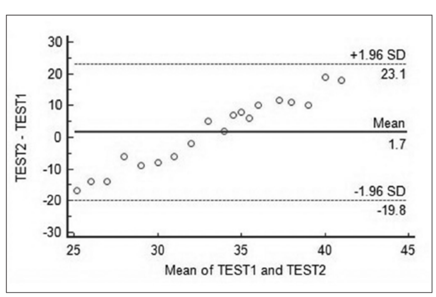


Figure 140. Example of a Bland–Altman plot showing proportional bias.

Advantages

Correlation analysis alone may lead to incorrect results in comparison of two measurement methods. The Bland-Altman analysis is a complementary, simple, and accurate way to quantify agreement between two variables.

Correlation is best used when both variables are normally distributed. This might be difficult to see if the sample size is small. The Pearson correlation coefficient is very sensitive to extreme (outlier) data values. This is while Bland-Altman does not assume the variables are normally distributed, and is robust against outliers. It only assumes that the difference errors are normally distributed.

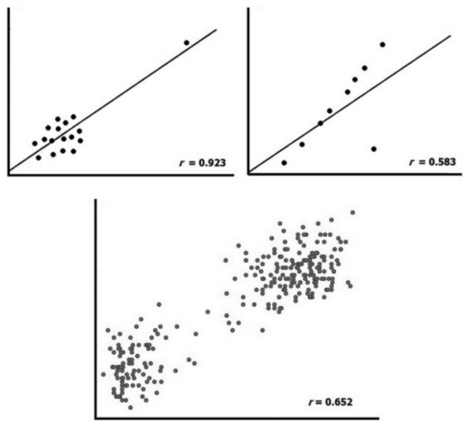


Figure 141. Examples of misleading correlations

Limitations

One of the problems in the Bland-Altman analysis is the need to meet the assumption of normal distribution for the differences. The measurement variables themselves need not to be normally distributed, but their differences should.

The data may be tested against the normal distribution using classical methods such as the Shapiro-Wilk test or Kolmogorov-Smirnov test. Visual evaluation of the histogram plot may not be adequate.

Another problem arises from the sample size. Studies comparing methods of measurements should be adequately sized to conclude that the effects are universally valid.

Agreement between two methods

We want to know by how much the new method is likely to differ from the old; if this is not enough to cause problems then we can replace the old method by the new or use the two interchangeably. This is called determining the agreement between methods.

Only an experienced specialist in the same field, can decide whether the bias and LOA are acceptable or not. An important problem is to assess how narrow the limits of agreement need to be before two techniques can be considered interchangeable.

So, how big a difference would be acceptable is a matter of specialist in the same field judgment. The specialist must first define the maximum tolerable LOA. Then if the differences within mean ± 1.96 SD are acceptable, the two methods may be used interchangeably.

Regression Analysis

If two variables are highly correlated, it is then feasible to predict the value of one from the value of the other. In simple linear regression, the value of one variable x is used to predict the value of the other variable y by means of a simple mathematical function $\hat{y} = a + bx$, which quantifies the straight-line relationship between the two variables.

Where a and b are two constants denoting the intercept of the line on the Y-axis (y-intercept) and the gradient (slope) of the line, respectively.

In addition to Bland-Altman analysis, it is recommended to perform regression analysis to compare two methods of measurements. The Bland-Altman analysis may bring proportional bias, so regression analysis can be used to calibrate one measurement against another.

Root Mean Square Error (RMSE)

RMSE is a measure of accuracy, and is the most frequently used measure of the differences between values predicted by a model or an estimator and the actual values.

To compute RMSE, calculate the residuals (difference between prediction and actual) for each data point, then calculate the root mean square of the residuals. RMSE is always non-negative. The smaller an RMSE value, the closer predicted and actual values are. RMSE has the same unit of the actual data. In our application, the unit is mm.

In RMSE calculation, since the errors are squared before they are averaged, it gives a relatively high weight to large errors. This means the RMSE should be more useful when large errors are particularly undesirable.

Sensitivity and Specificity

Sensitivity measures the proportion of "PASS" that are correctly identified.

Specificity measures the proportion of "FAIL" that are correctly identified. In NDT we expect high Specificity.

We can calculate Sensitivity and Specificity for each point on axle bar separately.

		Microhardness	
		Pass	**Fail**
EddySonix	**Pass**	True Positive (TP)	False Positive (FP)
	Fail	False Negative (FN)	True Negative (TN)

$$Sensitivity = \frac{TP}{TP + FN}$$

$$Specificity = \frac{TN}{TN + FP}$$

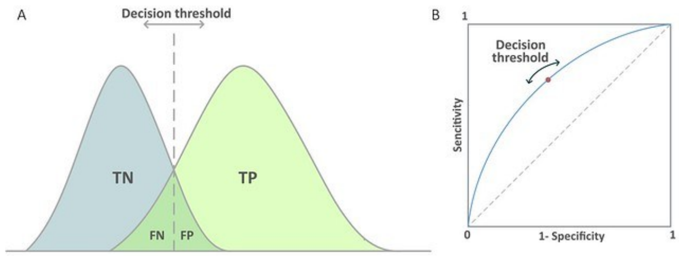
Example:

		Microhardness	
		Pass	**Fail**
EddySonix	**Pass**	TP=50	FP=1
	Fail	FN=3	TN=40

$$Sensitivity = \frac{TP}{TP + FN} = \frac{50}{50 + 3} = 94.3\%$$

$$Specificity = \frac{TN}{TN + FP} = \frac{40}{40 + 1} = 97.6\%$$

Note that we can move the Cutoff threshold value. But this is a tradeoff between Specificity and Sensitivity.

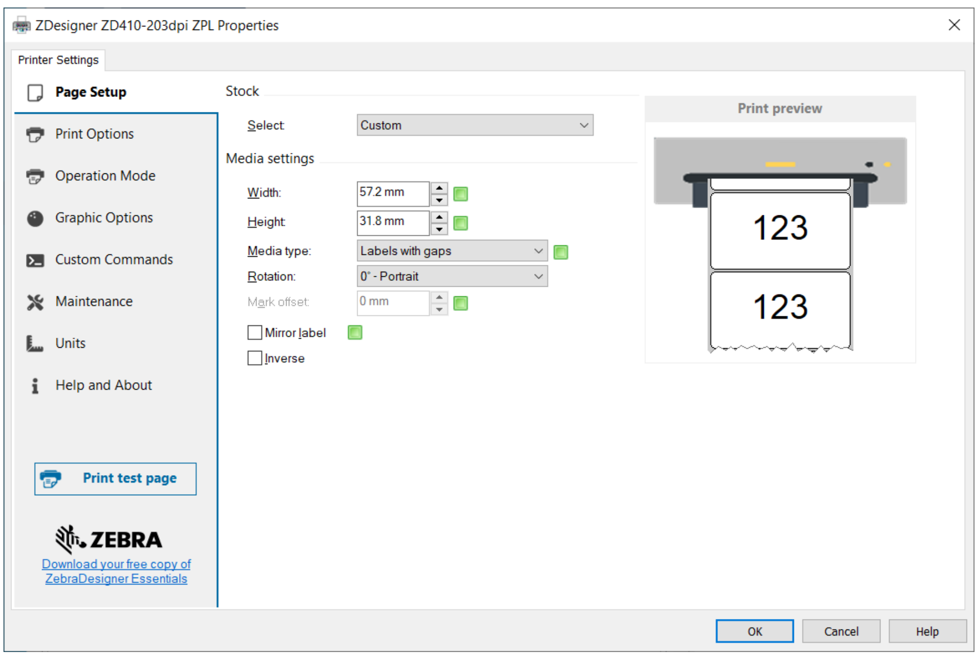


10.6 Install Zebra ZD410 printer driver

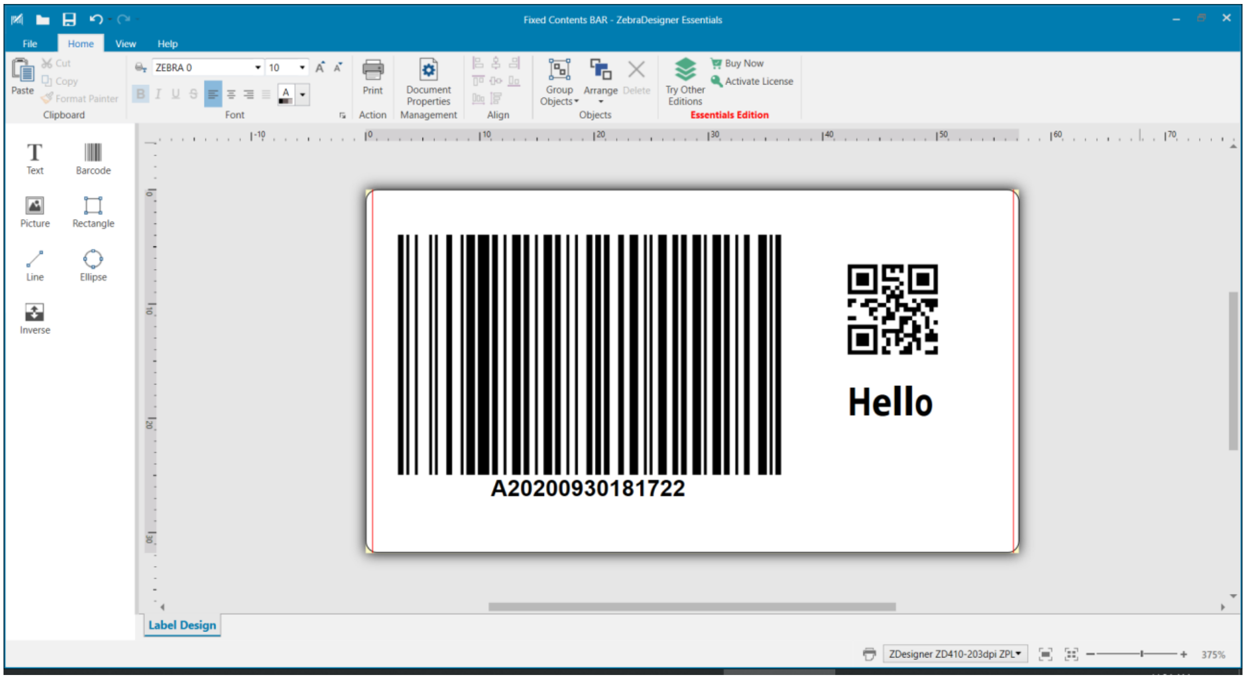
Download the printer driver and application from the link below:

https://www.zebra.com/us/en/support-downloads/printers/desktop/zd410.html

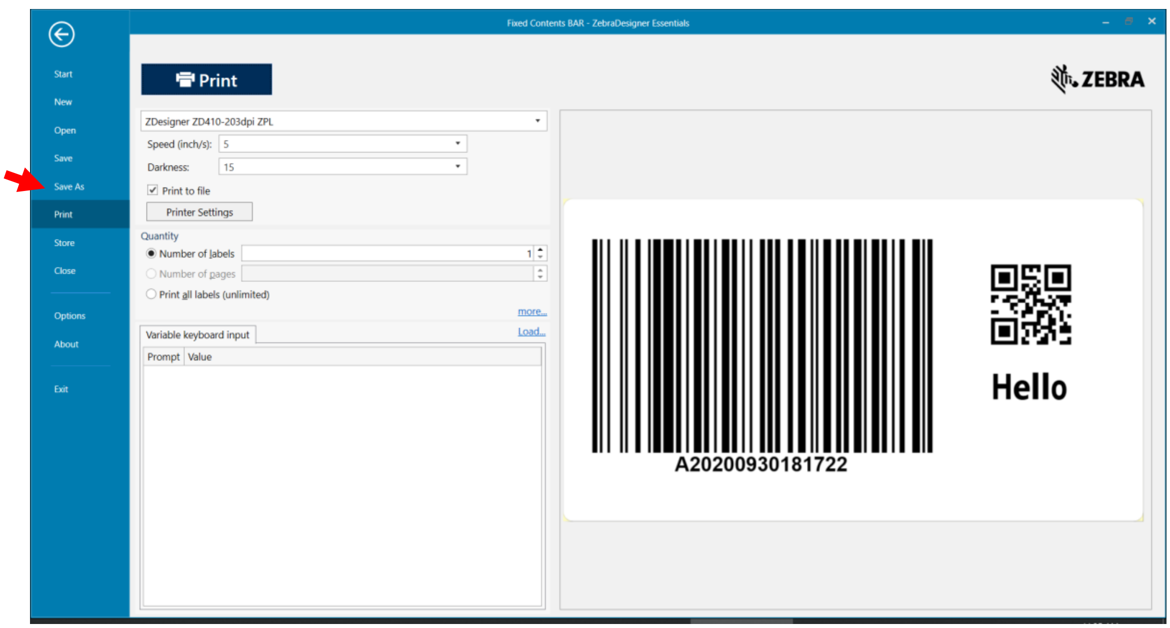
Open printer properties and define label width and height:



Optionally, you can design your own label by installing ZebraDesigner Essentials (free version).



Then print to file



Save as **template.prn** or **templateQR.prn** and copy it in folder **D:\EddySonix\Program**.

The saved file is ZPL command. Open the file and replace the 14-digit timestamp characters with one asterisk character "*" (see Figure 142 and Figure 143).

```
^PON
^PMN
^LH0,0
^JMA
^PR5,5
~SD15
^JUS
^LRN
^CI27
^PA0,1,1,0
^XZ
^XA
^MMT
^PW448
^LL254
^LS0
^BY2,3,168^FT18,200^BCN,,Y,N
^FH\^FD>:A>520200930181722^FS
^FT332,124^BQN,2,3
^FH\^FDLA,A20200930181722^FS
^FT332,158^A0N,28,28^FH\^CI28^FDHello ^FS^CI27
^PQ1,0,1,Y
^XZ
```

Figure 142. Original ZPL command

```
^PON
^PMN
^LH0,0
^JMA
^PR5,5
~SD15
^JUS
^LRN
^CI27
^PA0,1,1,0
^XZ
^XA
^MMT
^PW448
^LL254
^LS0
^BY2,3,168^FT18,200^BCN,,Y,N
^FH\^FD>:A>5*^FS
^FT332,124^BQN,2,3
^FH\^FDLA,A20200930181722^FS
^FT332,158^A0N,28,28^FH\^CI28^FDHello ^FS^CI27
^PQ1,0,1,Y
^XZ
```

Figure 143. Modified ZPL command for EddySonix application. Replace 14-digit timestamp with one asterisk "" character.*

Save the file for EddySonix application.

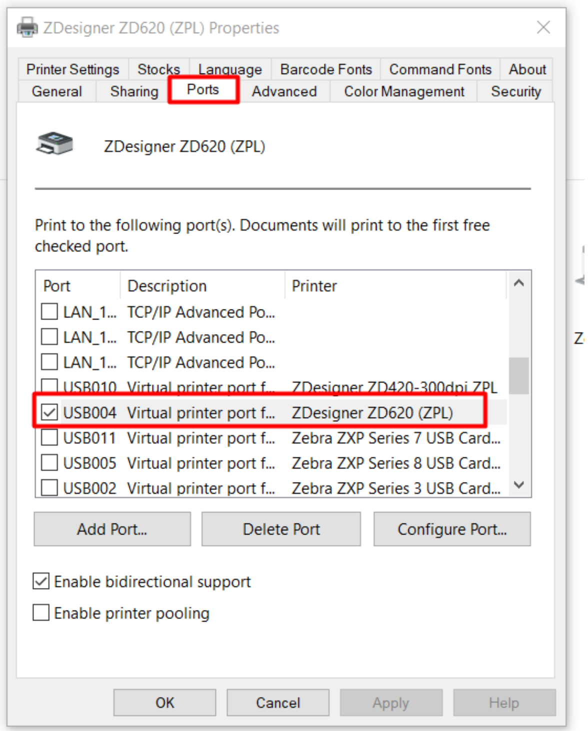
Install a Generic Text Printer

This section explains how to print a ZPL file using a text editor and the Windows Generic Text Driver Printer. To print a file that contains ZPL command (the extension of the file is not important as long as it is possible to open the file with a text editor, it can be .txt, .zpl, .prn..), you can use the Generic Text Printer Driver provided by Windows.

After installing the printer using Windows driver, you can use this feature by installing a second instance of the same printer on the same port where the standard printer is already installed by following these steps:

Check which port your computer is using to communicate with the printer:

1. Open the **Windows** > **Control Panel** > **Devices and Printers**.
2. Right-click on the required **printer**.
3. Select the **Ports** tab and check for the selected port.



Proceed with the installation of the second instance of the printer by using the Generic Text Driver.

EC Declaration of Conformity

(Original EC Declaration of Conformity)

We,	EddySonix Chemin des Taborneires 4 CH-1350 Orbe
hereby declare that the	
product	**Eddy Current Scanner**
type	**ECS-04**
serial number	**ECS-202112**
satisfies all the essential requirements of the following Directives:	**2006/42/EC (Machinery Directive)** **2014/30/EU (EMC Directive)** **and their amendments**
Person authorised to compile the technical file in accordance with Annex VII A of Directive 2006/42/EC:	**Hooman Dejnabadi** **Chemin des Taborneires 4** **CH-1350 Orbe**
Harmonised standards applied:	**EN ISO 12100:2010,** **EN ISO 13849-1:2015, EN 60204-1:2018, EN ISO 13855:2010**
Other technical standards and specifications applied:	**None**

Orbe, 10.01.2022

Dejnabadi

Hooman Dejnabadi, Director