Carburization detection

Russell NDE Systems is pleased to announce the development of a new Tool for the detection of Carburization, typically found in refinery and gas plant furnace tubes.

Definition:

Carburization is the absorption of carbon atoms into the granular structure of steel tubes used inside furnaces. Carburization makes the steel tubes harder, less ductile, and more prone to brittle failure.
Carburization can permeate through the steel tubes from either the inside or outside surface and because it is temperature sensitive it is usually worst on the hot side of the tubes.
The new probe can be scanned around the tube. It is low profile, and requires only 1.5” of clearance between the tube and the refractory liner. Scale on the tube should be removed if it is loose, but it has little effect on the technique so long as the scan is smooth.

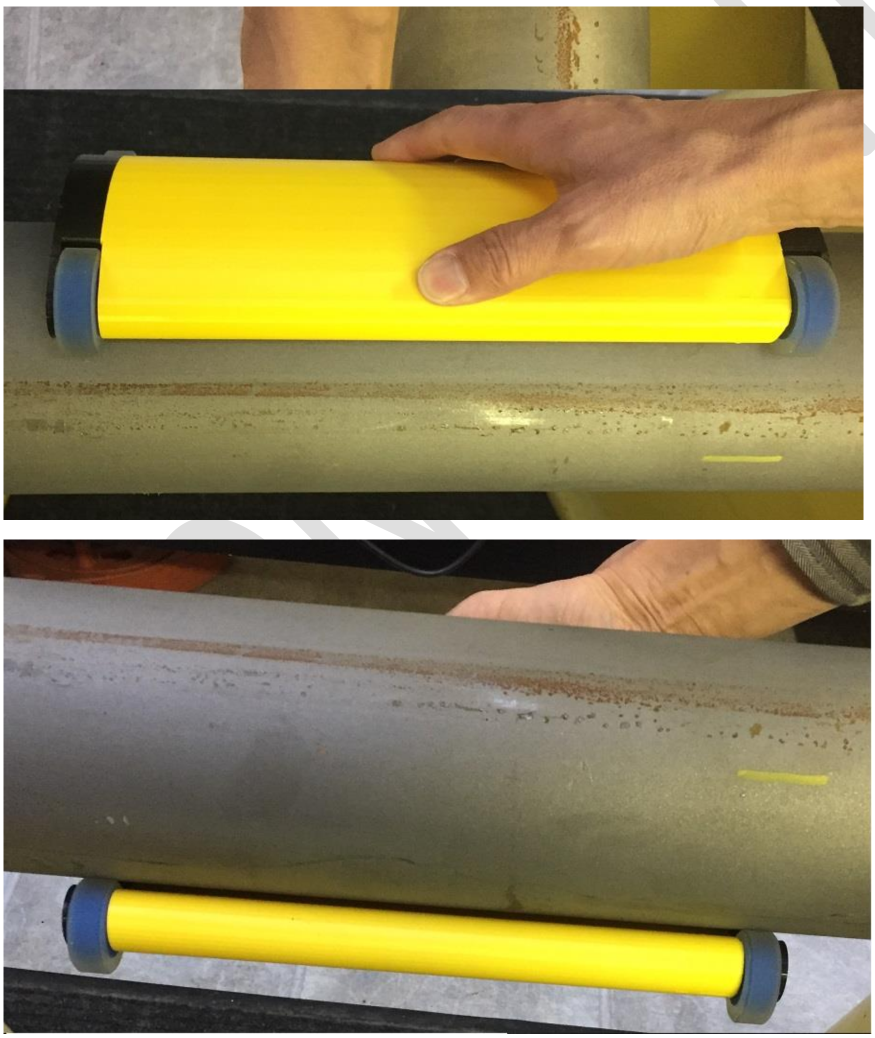


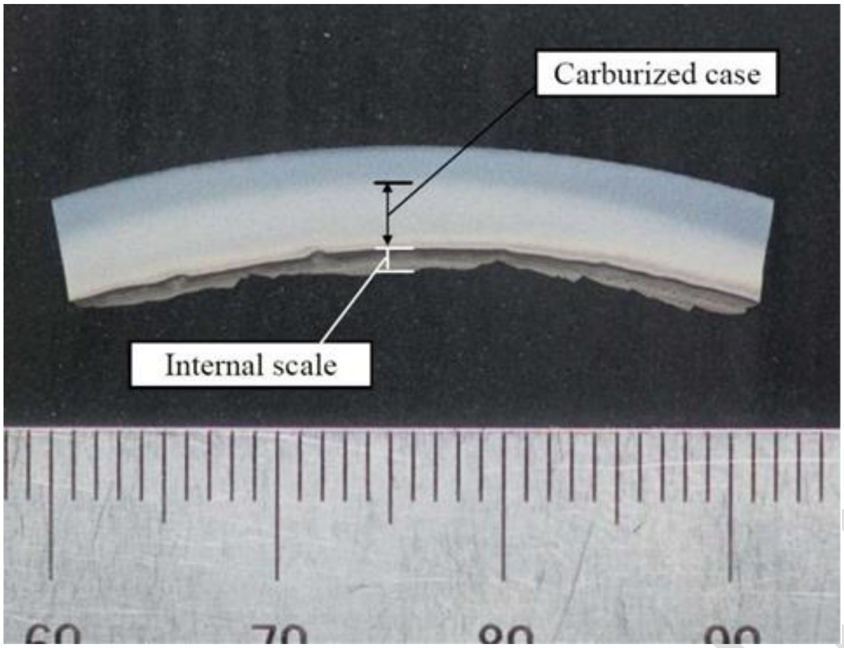
Fig-1: CIRC E-PIT probe on furnace tube

The probe, known as CIRC E-PIT, is light and portable and can be secured to the tube with a simple Velcro strap.

The internal coils send a signal into the tube surface which reflects from the inside surface and is affected by the amount of carburization within the wall.

The technique uses a non-contact eddy current, pitch-catch arrangement of coils at frequencies that are suitable to the application.

Typical furnace tube materials such as 5-chrome can be inspected at rapid speed, with minimal training.



In the tube pictured at left, the carburization has permeated from the inside of the tube which was in a “coker” service. The lighter area is carburized.

The coke build-up on the inside of the tube, on the hot side, further accelerates the permeation by providing a ready source of carbon, and making the tube locally hotter.

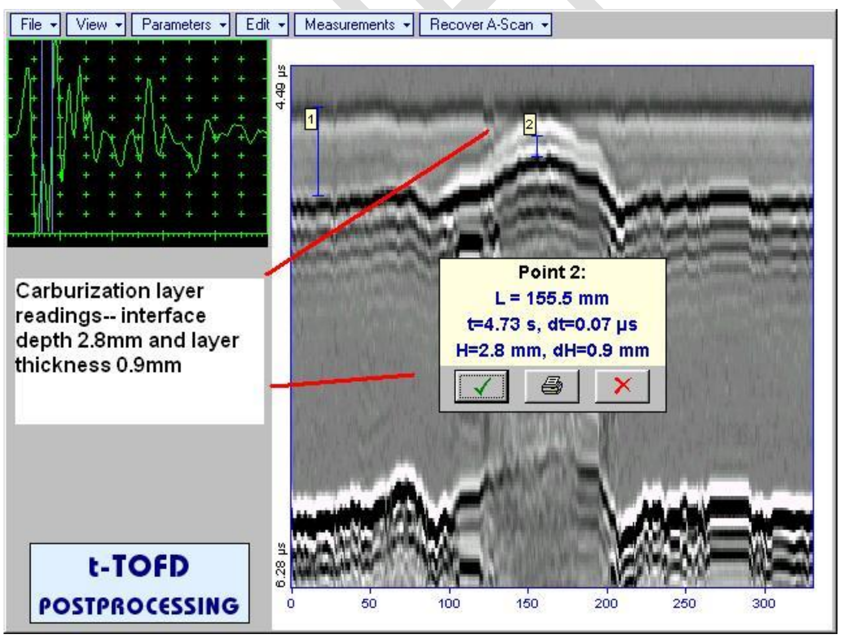
Fig-2: 5-Chrome tube with internal carburization (light area)

Fig-3: 5-Chrome tube with external carburization (light area)

The tube pictured above has been in a gas-fired furnace where the carburization (light area) has permeated the tube from the outside-in. In this case, the carbon atmosphere was created by the fuel that was firing the furnace. This tube shows carburization that has penetrated 100% through the wall on the hot side (centre of the photo), decreasing to 50% or less on the cold side.

The CIRC E-PIT probe connects to the Ferroscope 308 ET instrument and can operate in eddy current or RFT mode. The measurements taken by the probe as it is rotated around the pipe are similar to those obtained by the ultrasonic TOFD (time of flight diffraction) technique (which in our experience, works well for detecting the internal carburization case, but not as well for external carburization detection).

Fig-4: Ferroscope and lap-top computer used with CIRC E-PIT probe



The latest Ferroscope 308ET model pictured above with internal heat exchanger probes, and a lap-top running EasyLog Pro software.

The image on the left is a TOFD circ. scan of an internally carburized tube. The depth of carburization can be accurately measured with TOFD.

The data from the Ferroscope technique looks similar to a TOFD scan for ID carburization (see next page).

Fig-5: Time of flight diffraction (TOFD circ. scan signal) for internal carburization

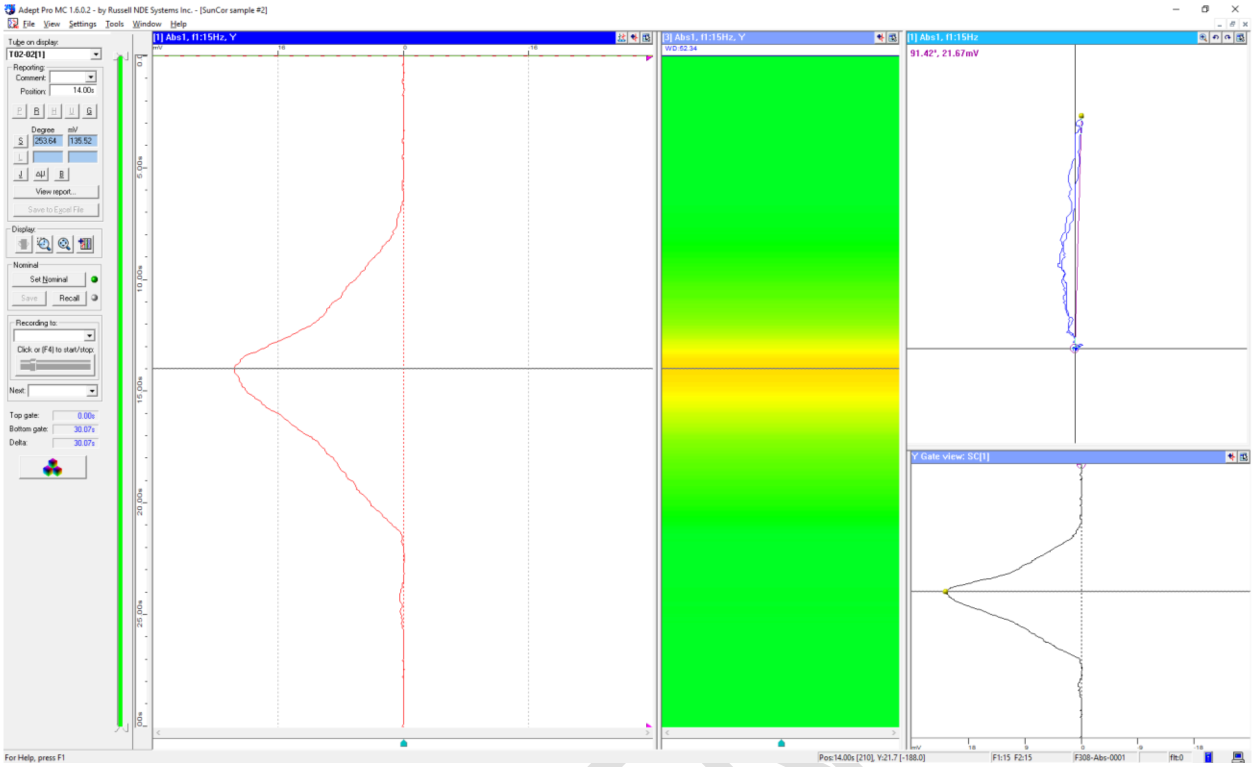


Fig-6: CIRC E-PIT scan of tube with 100% external carburization on hot side and 50% on cold side.

Notes:

1) A scan of a tube with internal carburization would be similar to the above.
2) Frequencies between 10 and 80 Hz can be used, depending on tube properties
3) The amplitude of the signal, or the Y-component can be used to image the damage
4) The values of amplitude or "Y" can be used to calibrate the data

Research and development

During the months of December 2017 and January 2018, finite element modeling of the electromagnetic signal from tubes that had internal and external carburization were performed. The FEA models were supplemented with physical measurements made by the CIRC E-PIT probe, with good agreement; however, the number of samples available was small. We had:

1) Several 4" diameter x 0.237" wall thickness tube samples from a "coker furnace" with varying amounts of internal carburization, starting at 0% and reaching 60% maximum
2) One sample from a 4" diameter x 0.237" wall thickness from a CCR (Catalytic Cracking Regenerator), having external carburization to a depth of 50% for most of its circumference and 100% through wall on the hot side.
3) The photos of Nital etched tubes from these samples are shown on page-2
4) Several arrangements of coils, frequencies, drive voltages, scan speeds and lift-off distances were trialled empirically.

FEA Results

The following graphs show the expected signals from samples that have carburization at two depths: 25% and 50%. We have modelled the carburization as a local area that is scanned past with a detector coil. Perturbations in the EM field are modelled, and the carburized layer is modelled as "non-ferromagnetic", "weak ferromagnetic" and "strong ferromagnetic". Until we have a much larger sample, we are not sure which model is best; however, the "weak ferromagnetic" matched the field data quite well.

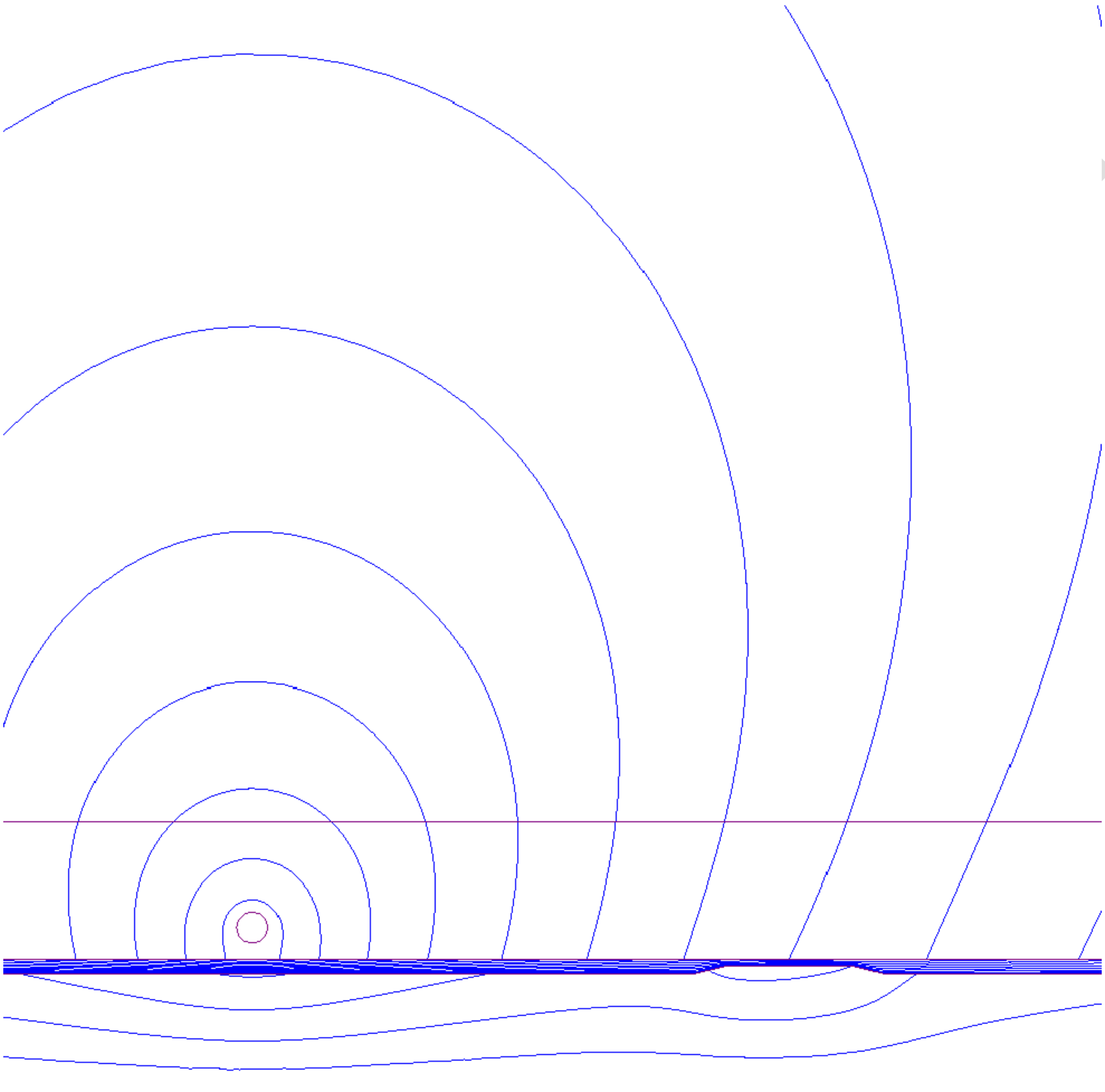


Fig-7: Magnetic field pattern for 50% ID carburization modeled as **non-ferromagnetic**

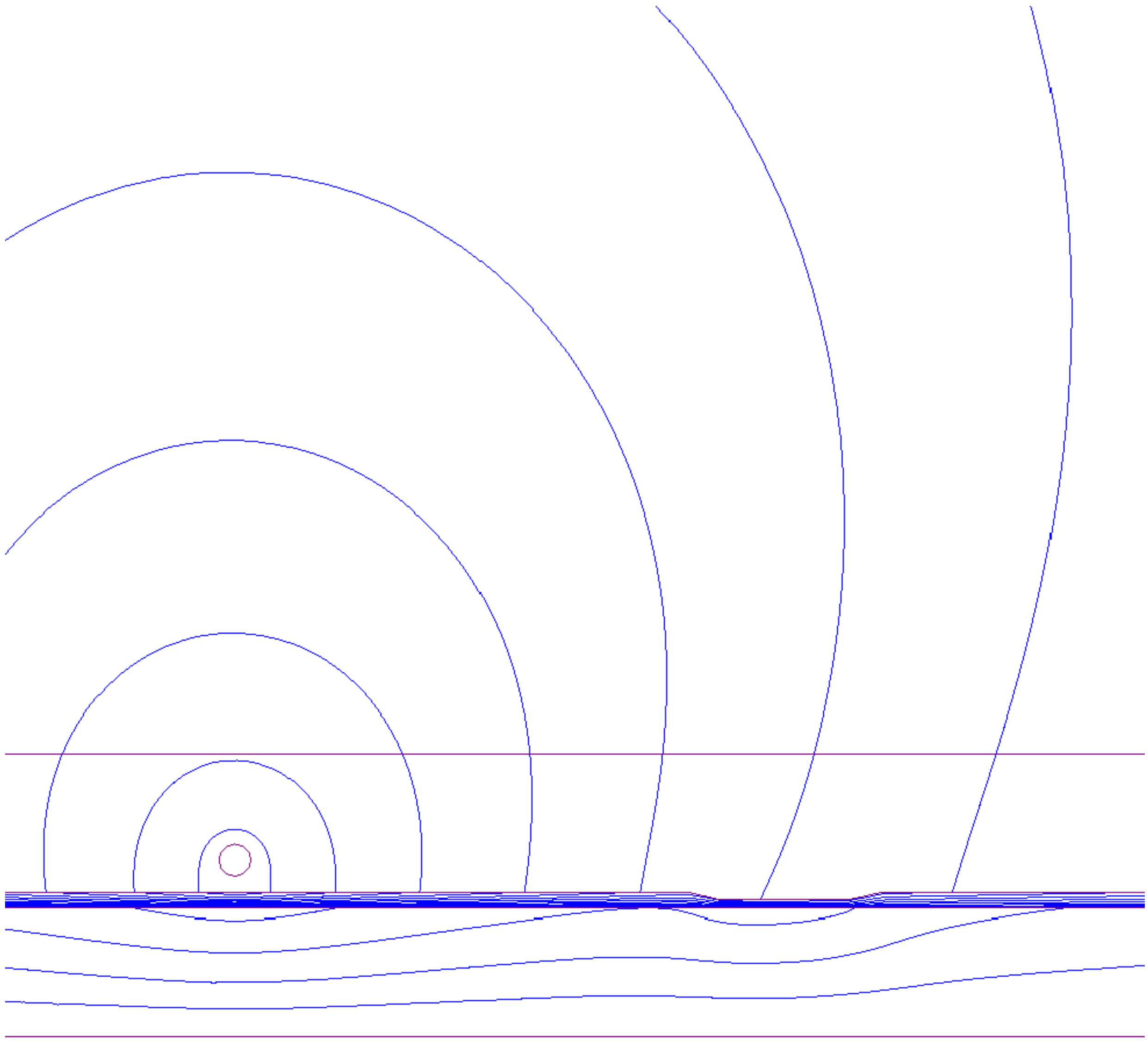


Fig-8: Magnetic field pattern for 50% OD carburization modeled as **non-ferromagnetic**

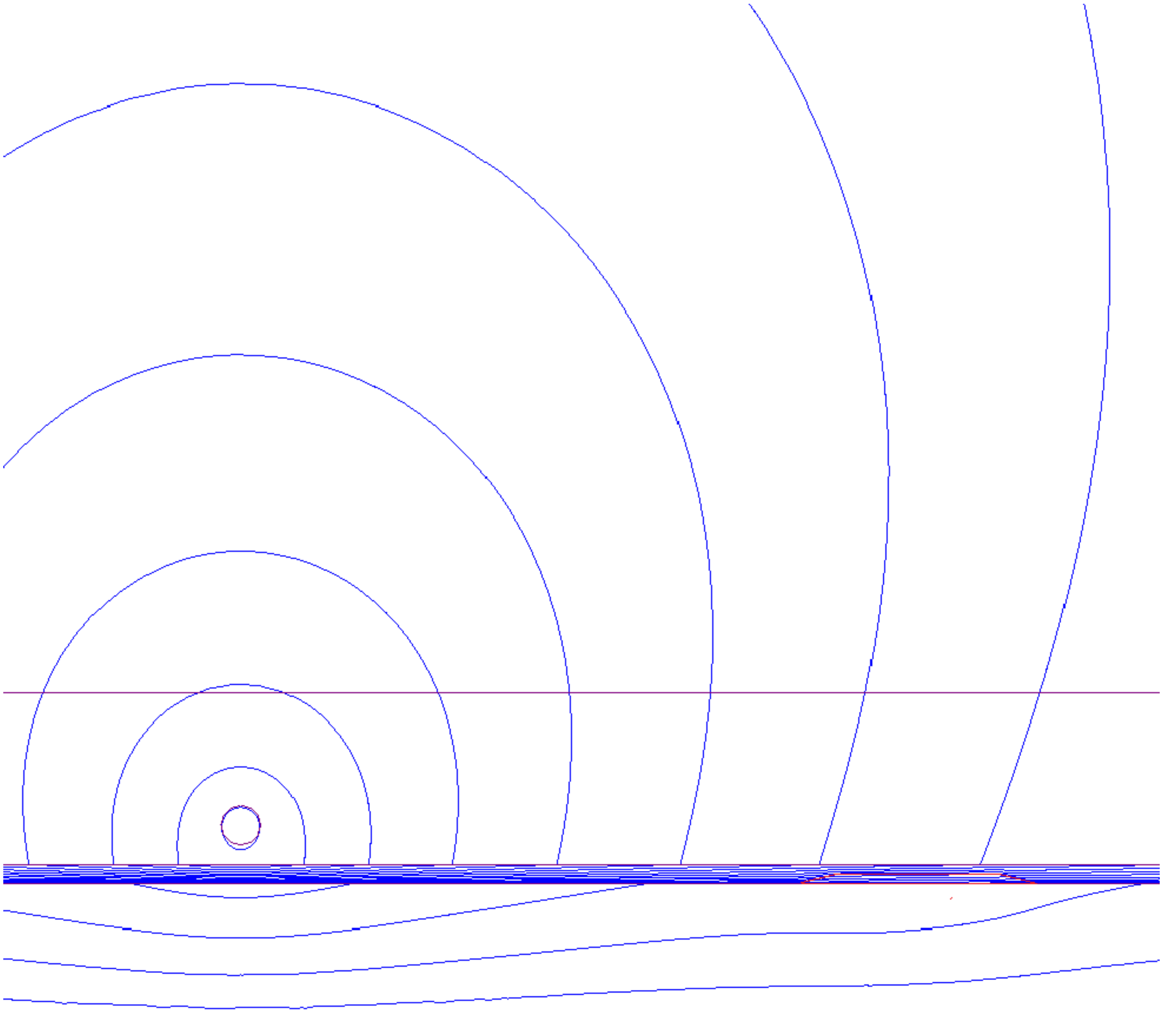


Fig-9: Magnetic field pattern for 50% ID carburization modeled as **weak ferromagnetic**

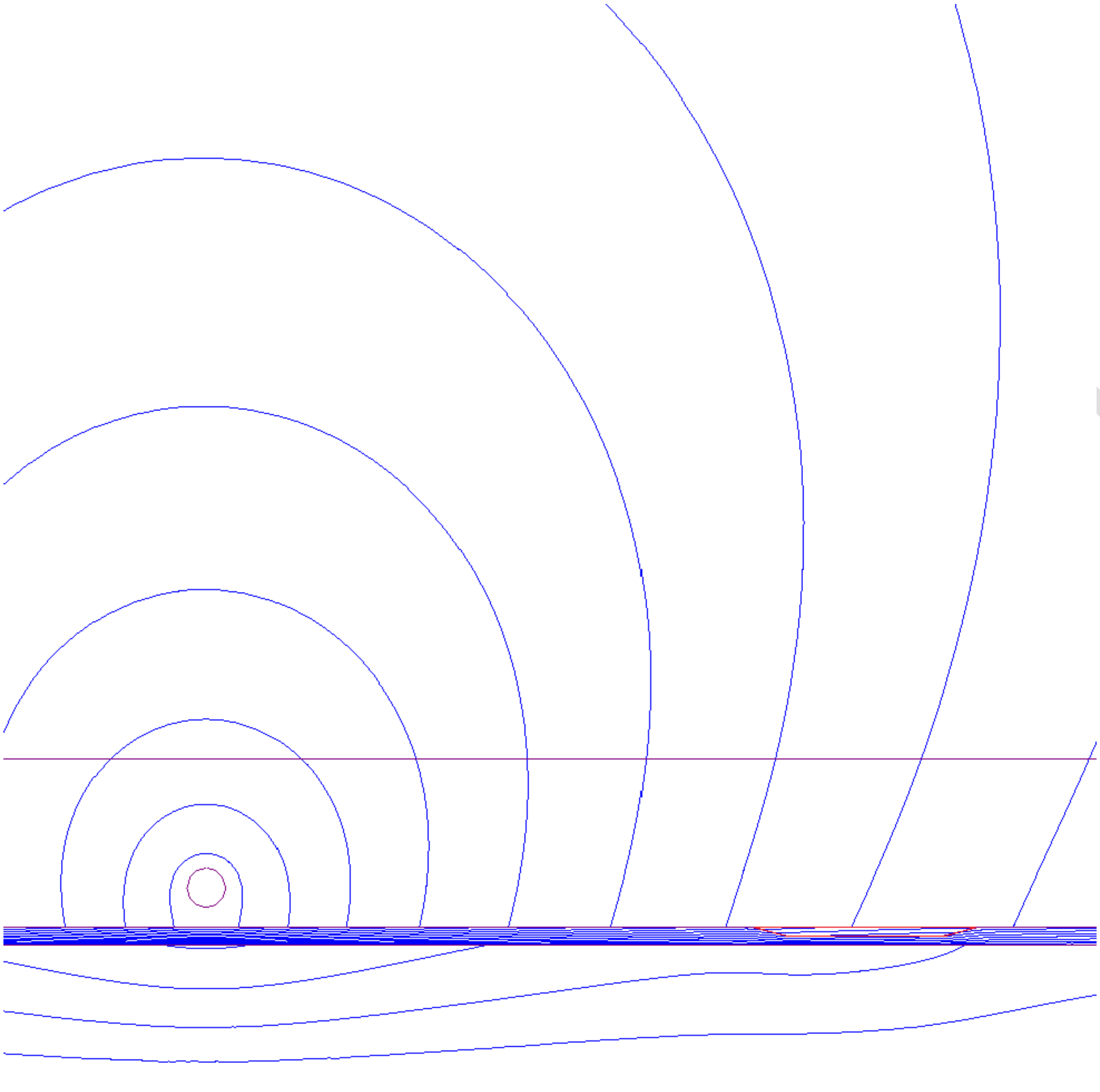


Fig-10: Magnetic field pattern for 50% OD carburization modeled as **weak ferromagnetic**

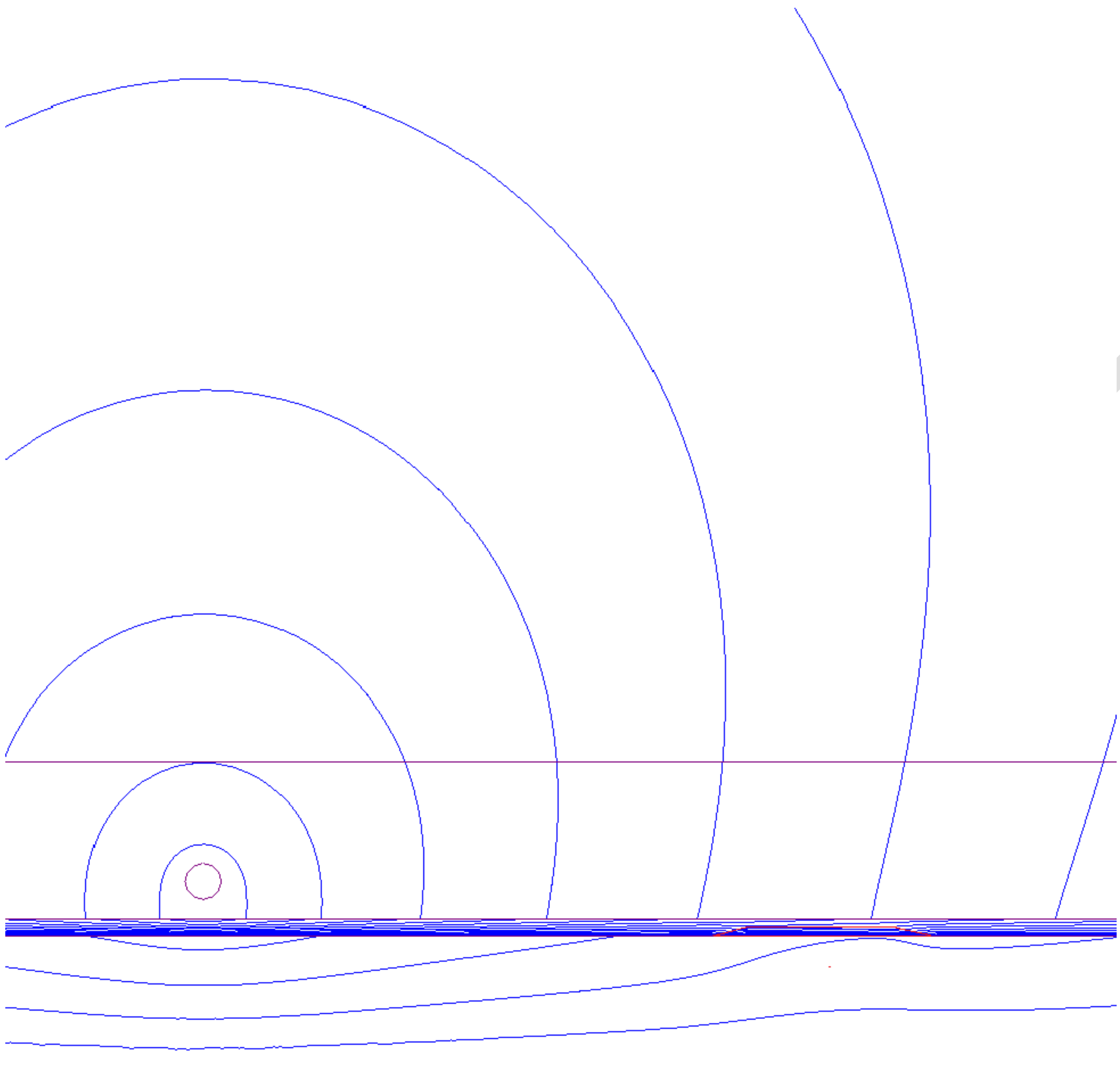


Fig-11: Magnetic field pattern for 50% ID carburization modeled as **strong ferromagnetic**

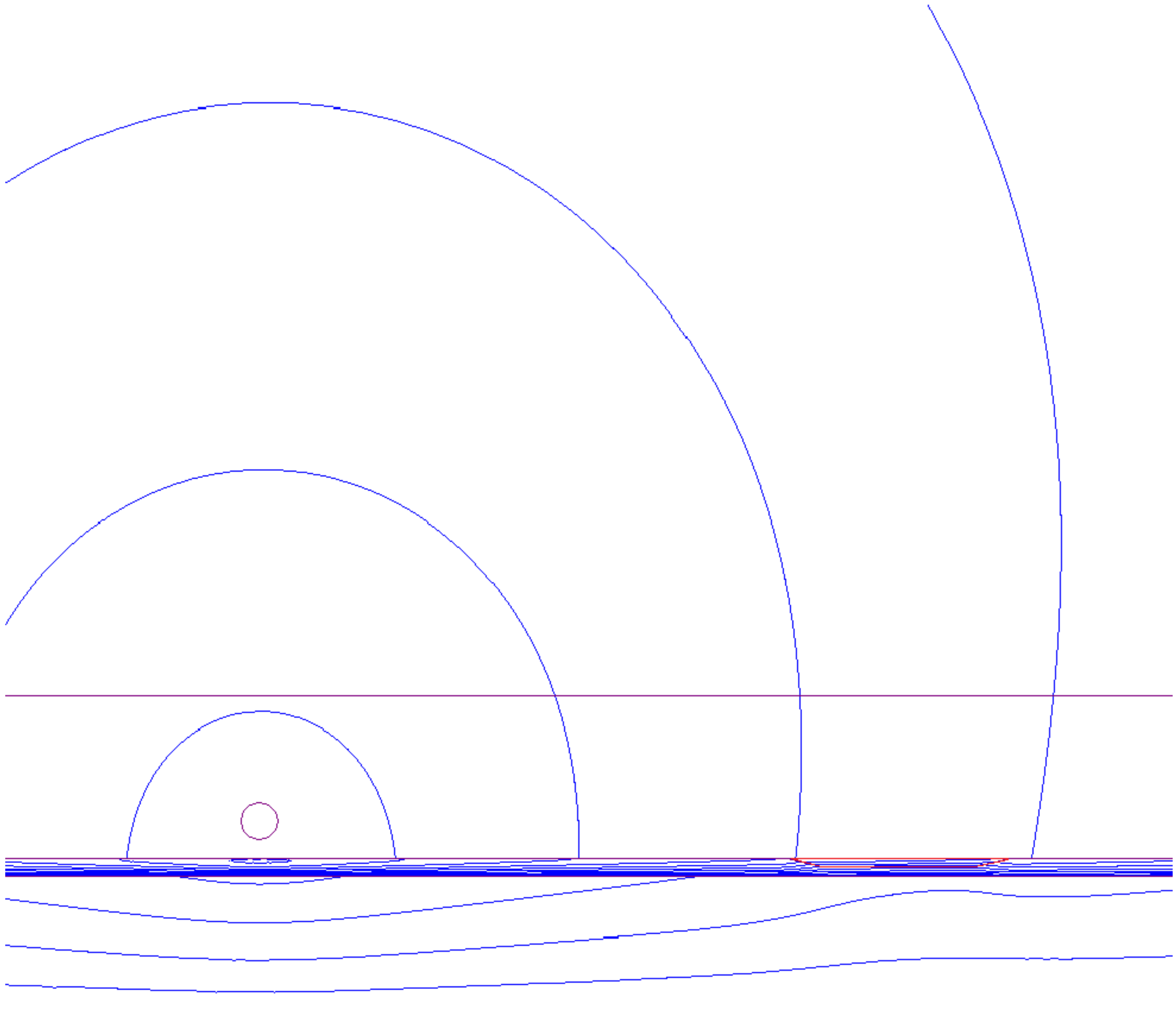


Fig-12: Magnetic field pattern for 50% OD carburization modeled as **strong ferromagnetic**

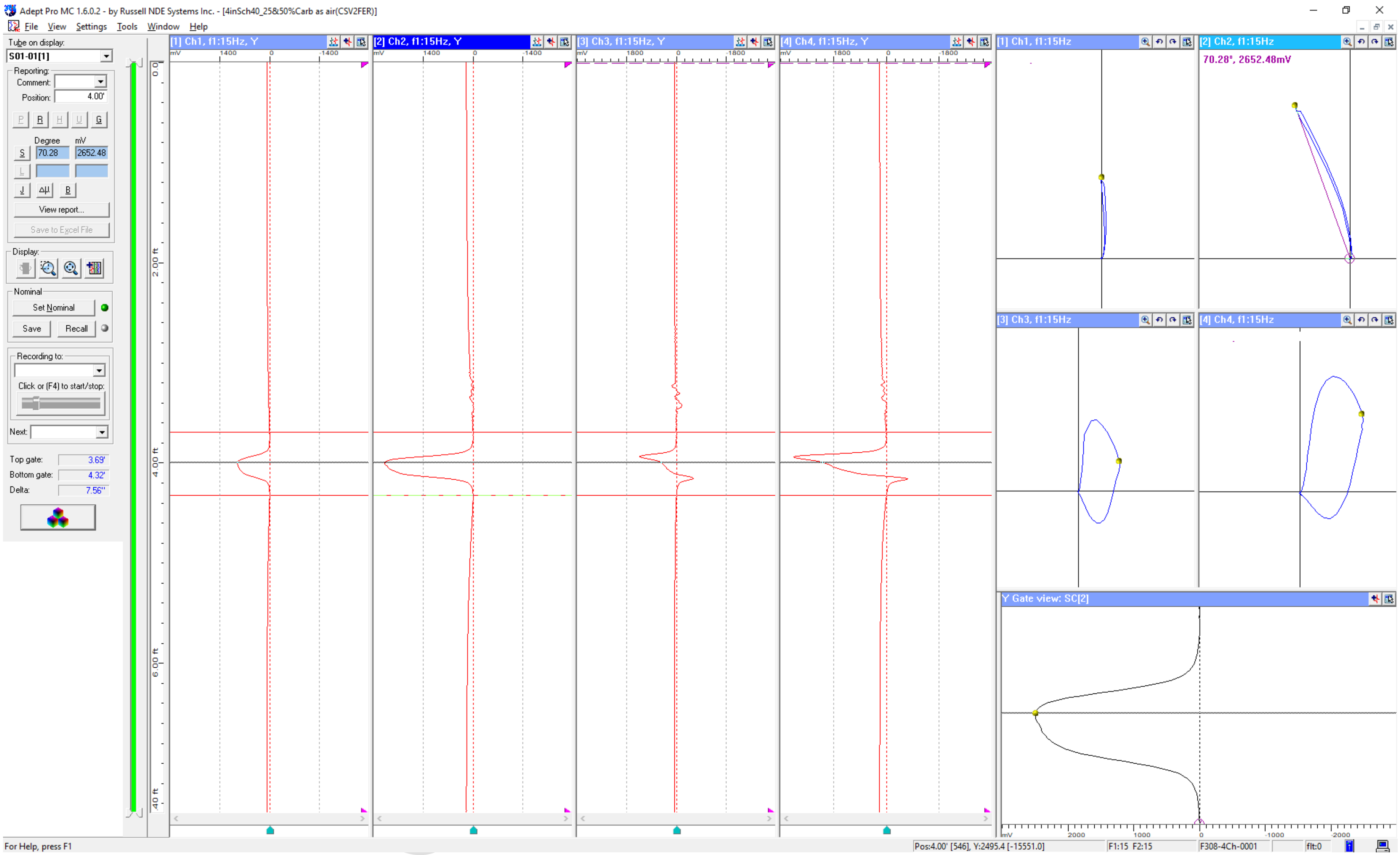


Fig-13: ID and OD carburization modeled as non-ferromagnetic material

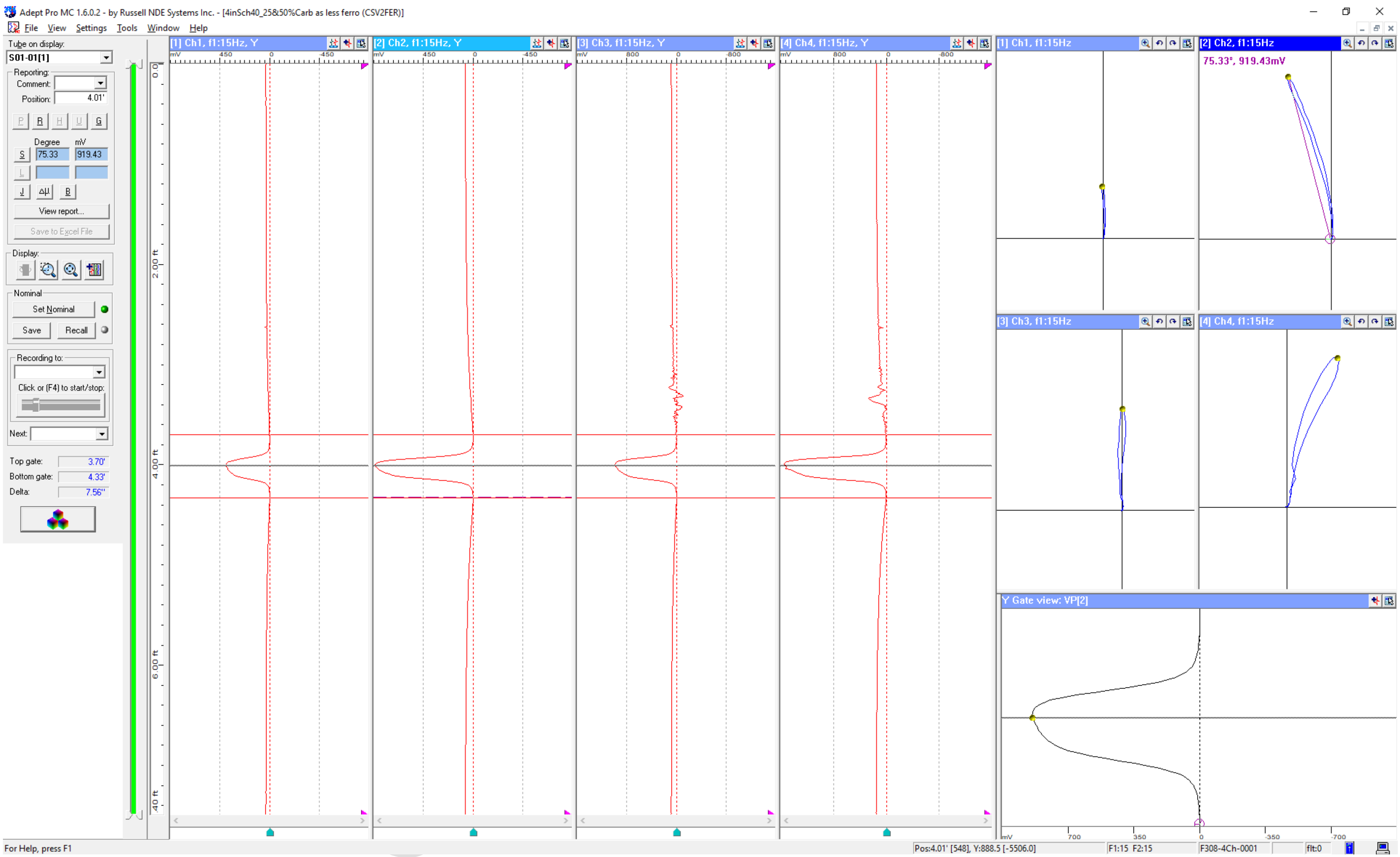


Fig-14: ID and OD carburization modeled as ferromagnetic material weaker than base tube

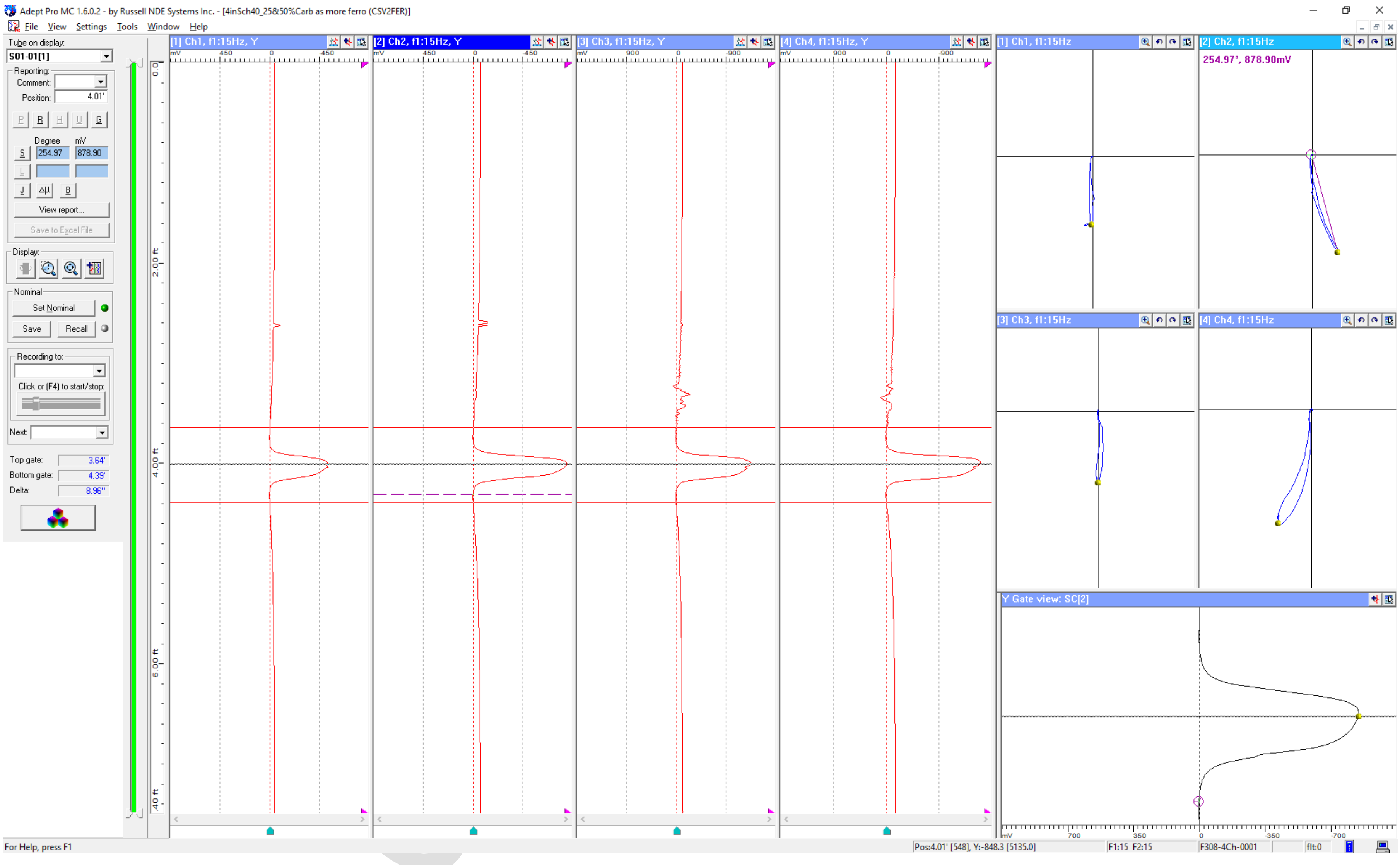


Fig-15: ID and OD carburization modeled as ferromagnetic material stronger than base tube

FEA for carburization in ∅4” sch 40 (0.237”)

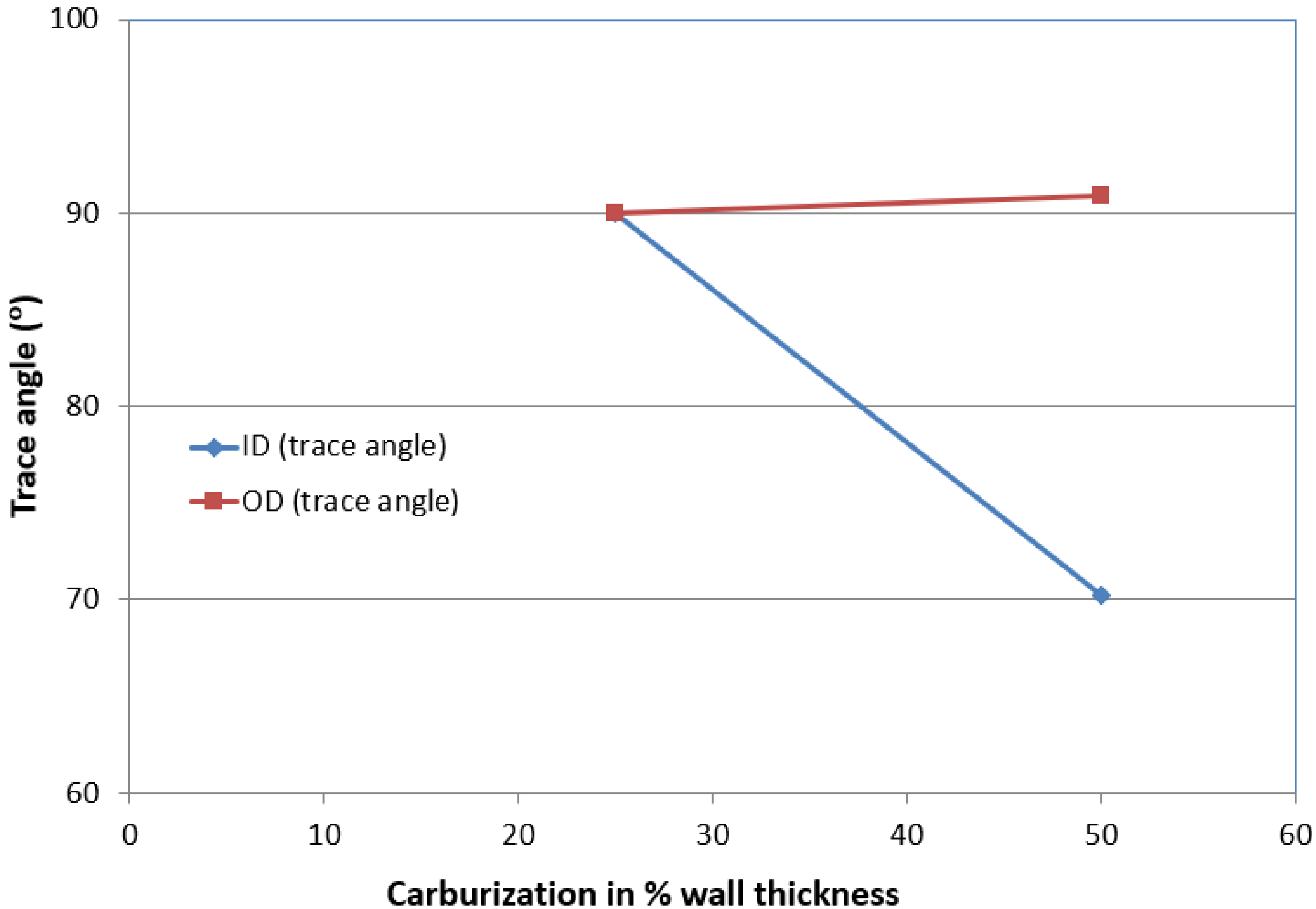


Fig-16: Trace angle for ID and OD carburization modeled as **non-ferromagnetic**

FEA for carburization in ∅4" sch 40 (0.237")

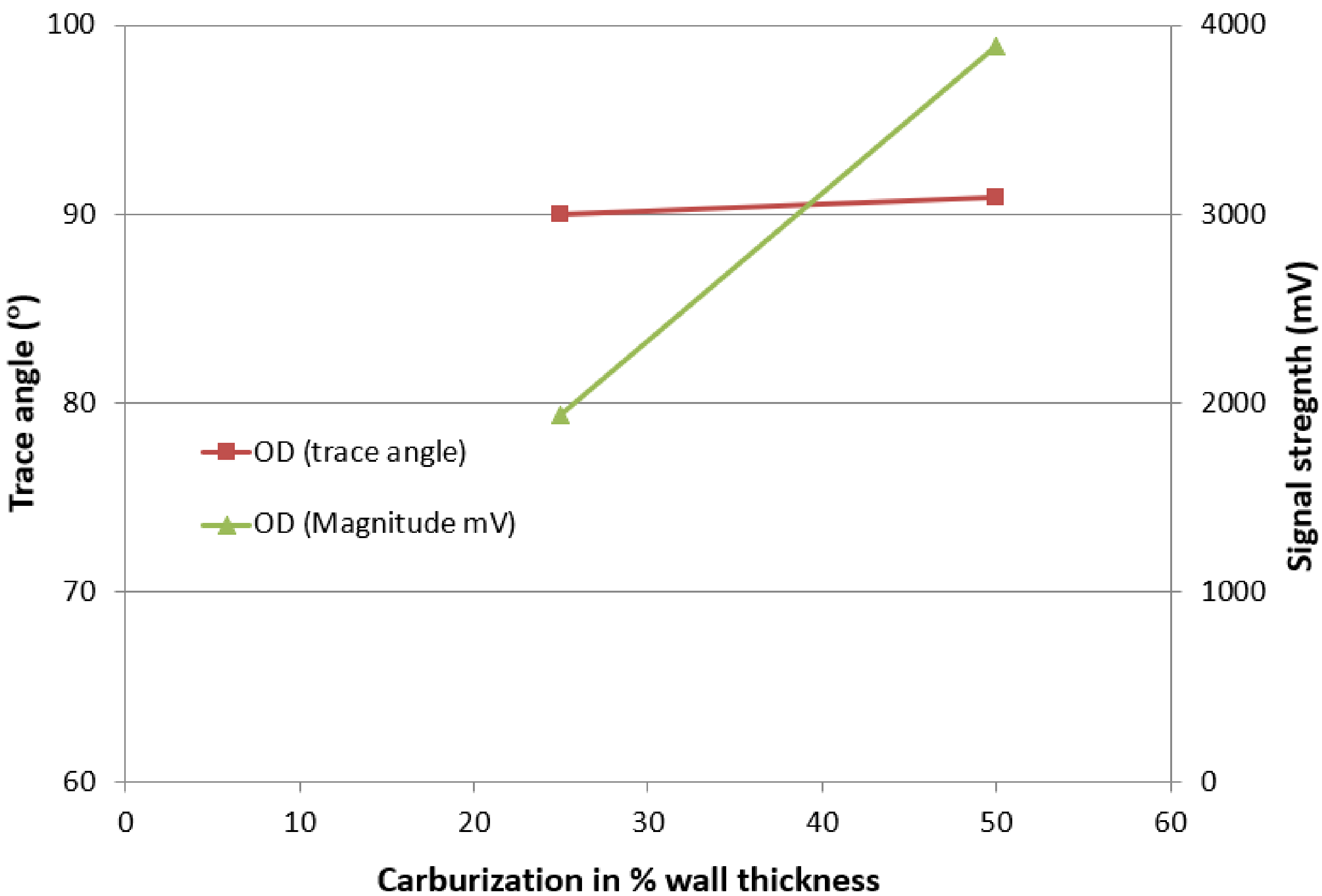


Fig-17: Trace angle and signal strength for OD carburization modeled as **non-ferromagnetic**

FEA for carburization in ∅4” sch 40 (0.237”)

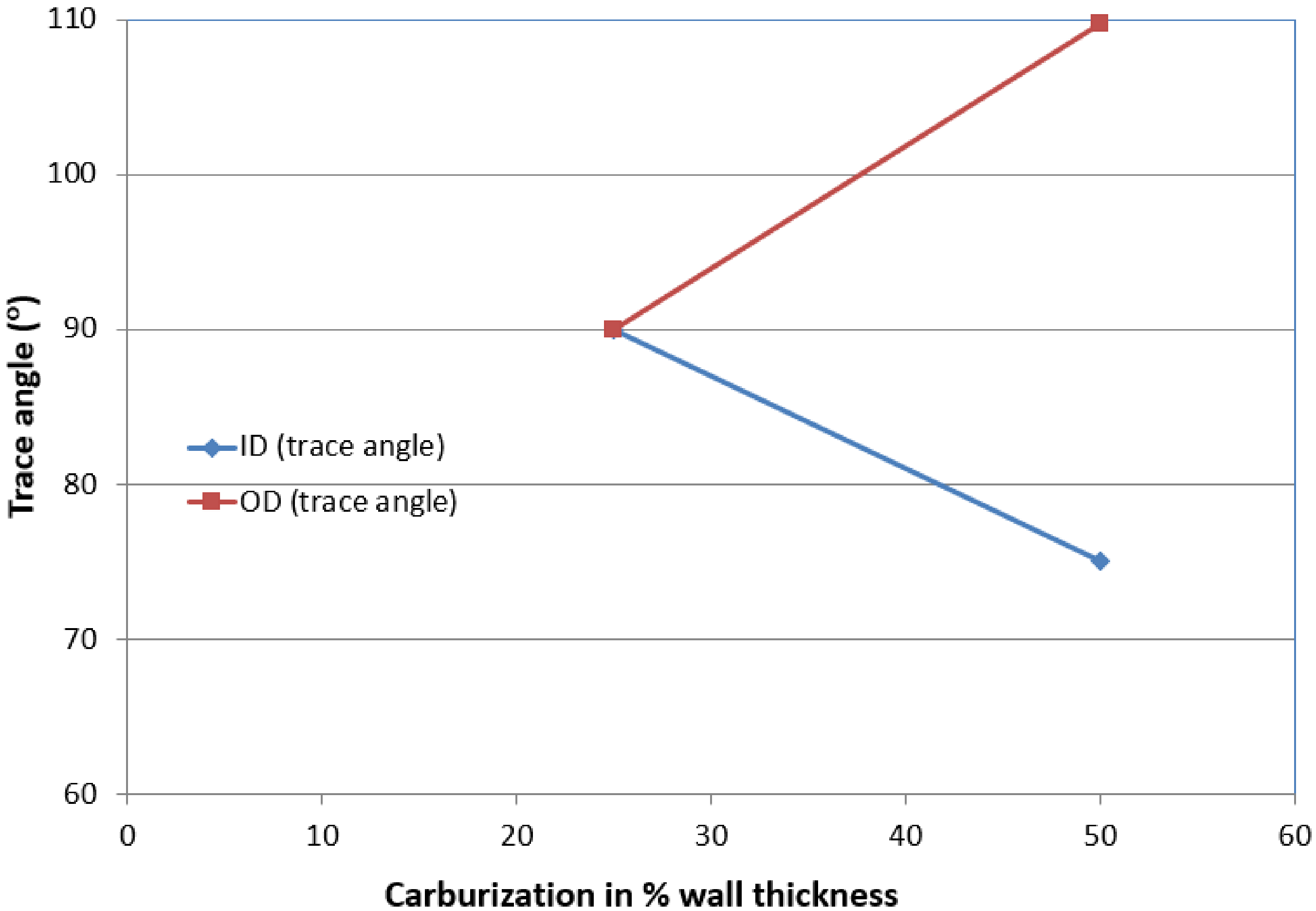


Fig-18: Trace angle for ID and OD carburization modeled as **weak ferromagnetic**

FEA for carburization in ∅4” sch 40 (0.237”)

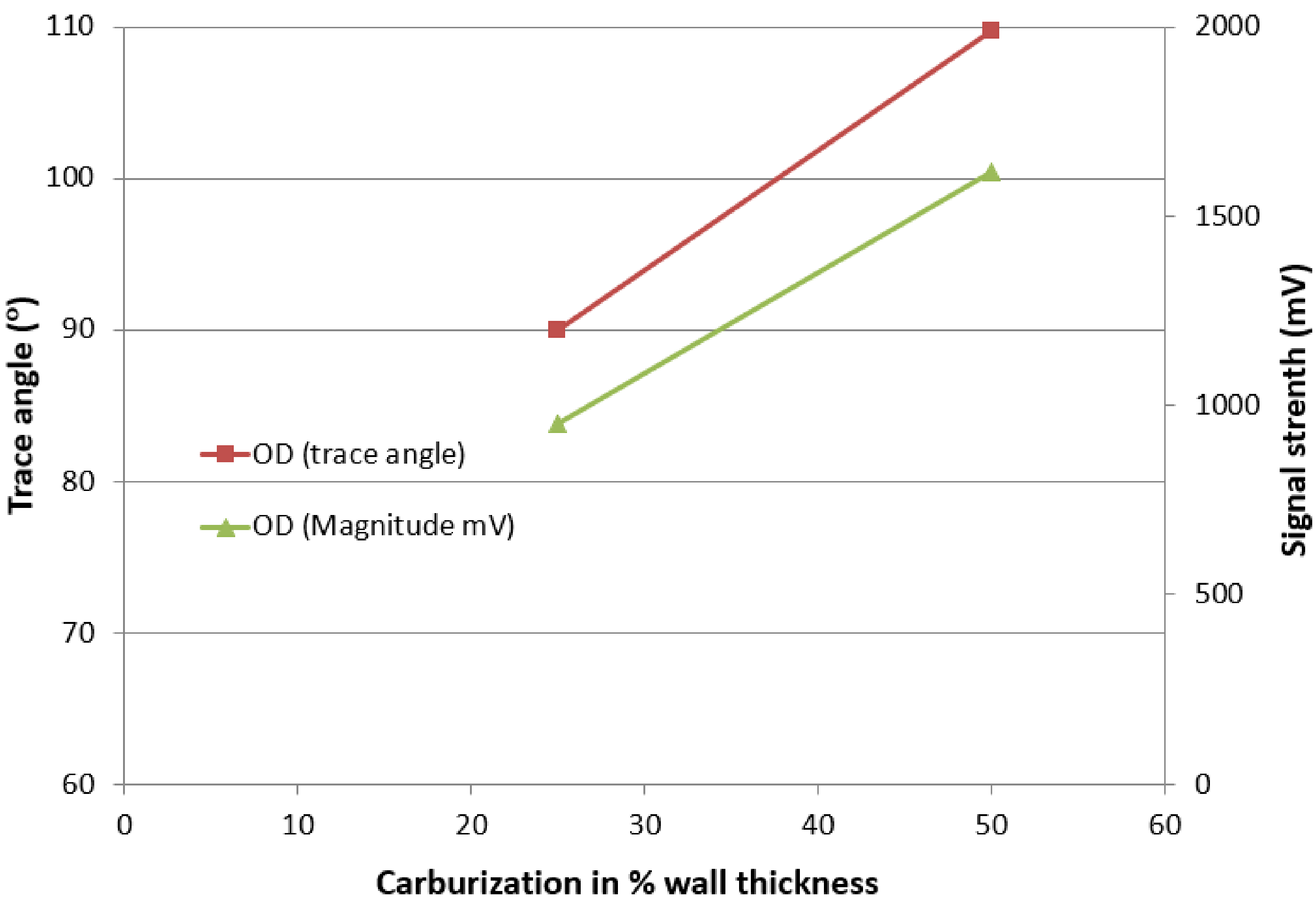


Fig-19: Trace angle and signal strength for OD carburization modeled as **weak ferromagnetic**

FEA for carburization in ∅4" sch 40 (0.237")

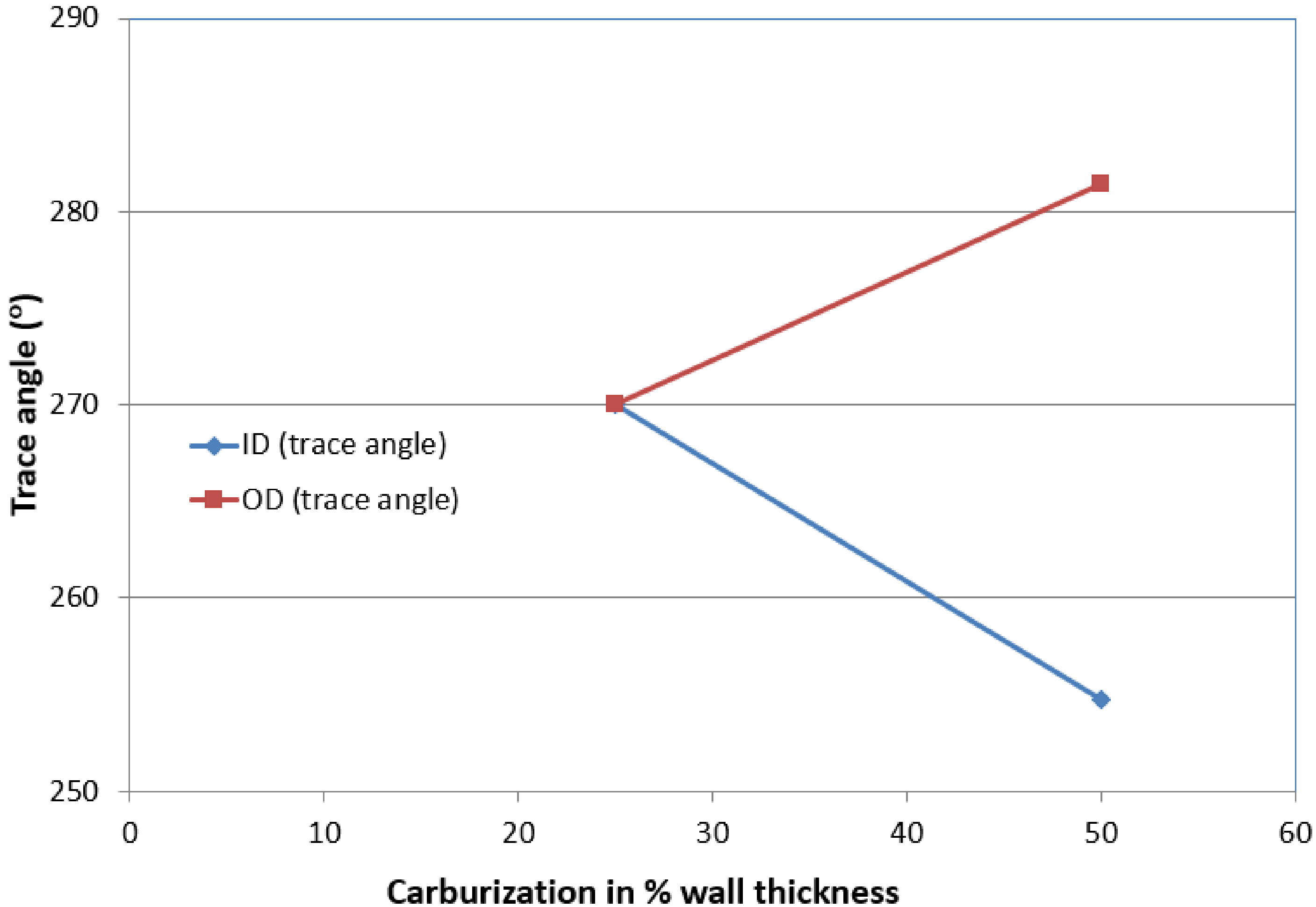


Fig-20: Trace angle for ID and OD carburization modeled as **strong ferromagnetic**

FEA for carburization in ∅4" sch 40 (0.237")

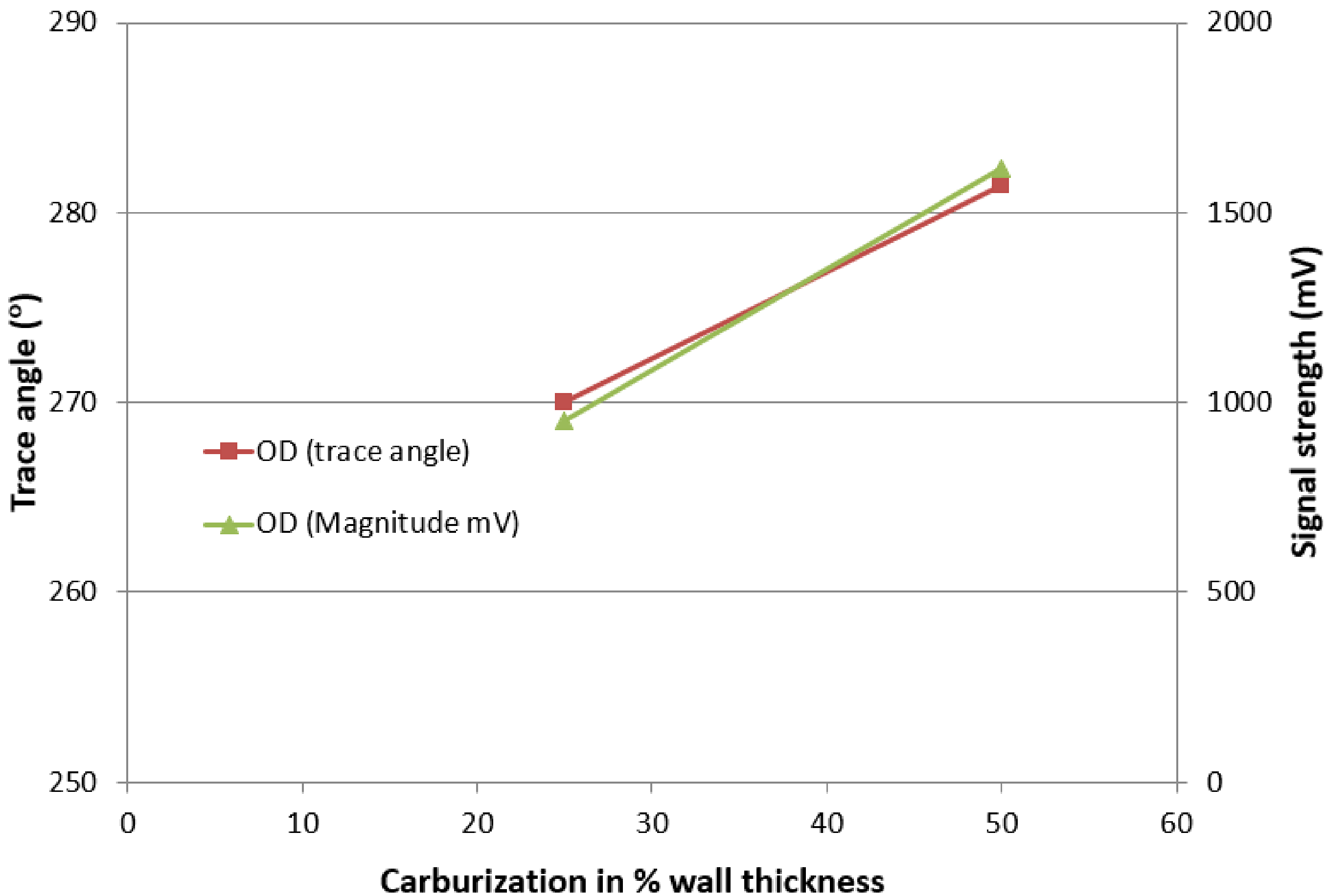


Fig-21: Trace angle and signal strength for OD carburization modeled as **strong ferromagnetic**

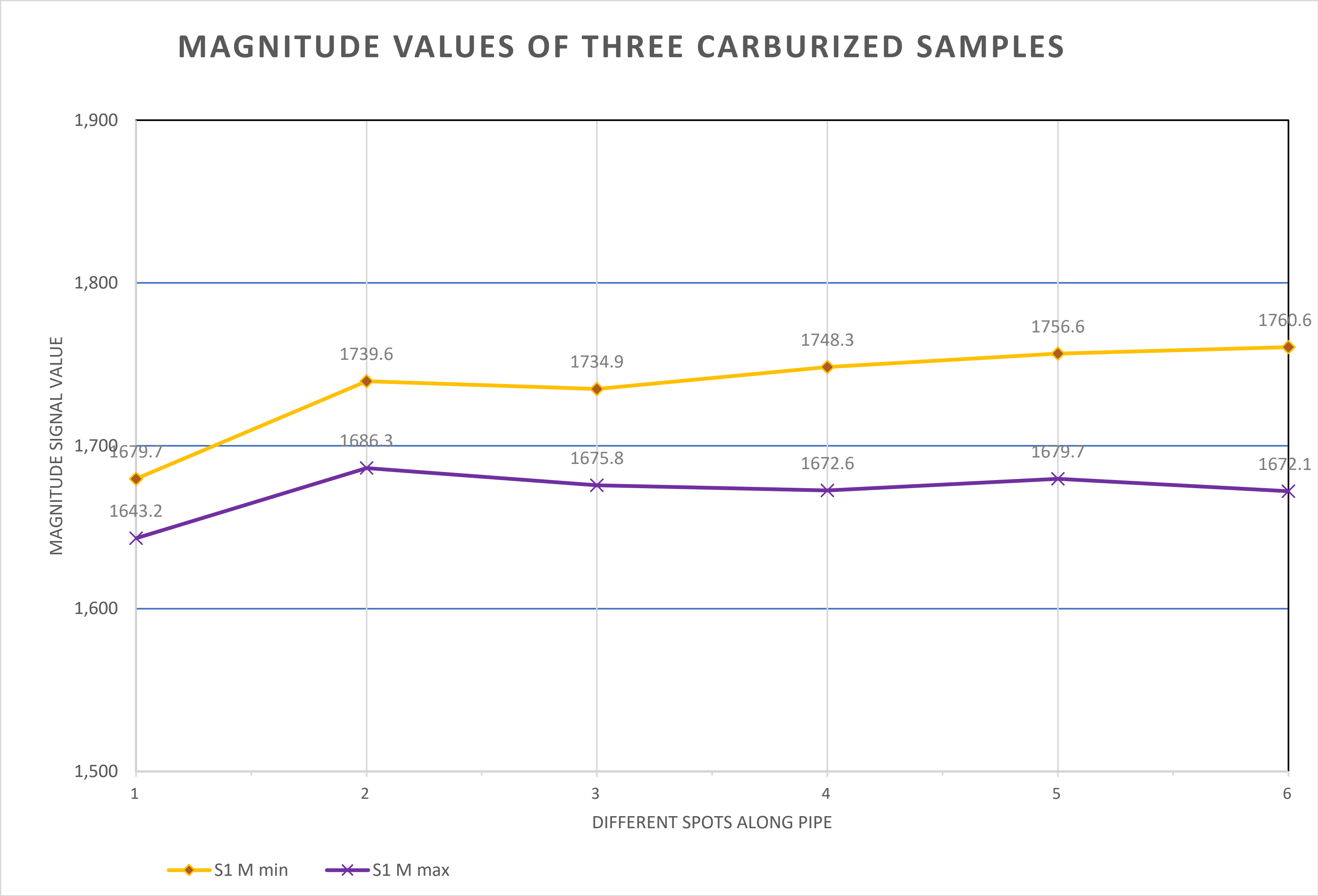


Fig-22: Magnitude values taken on internal carburized sample#1 at 300mm intervals
Min=Cold side minimum value, Max=Hot side maximum value, arbitrary amplitude units

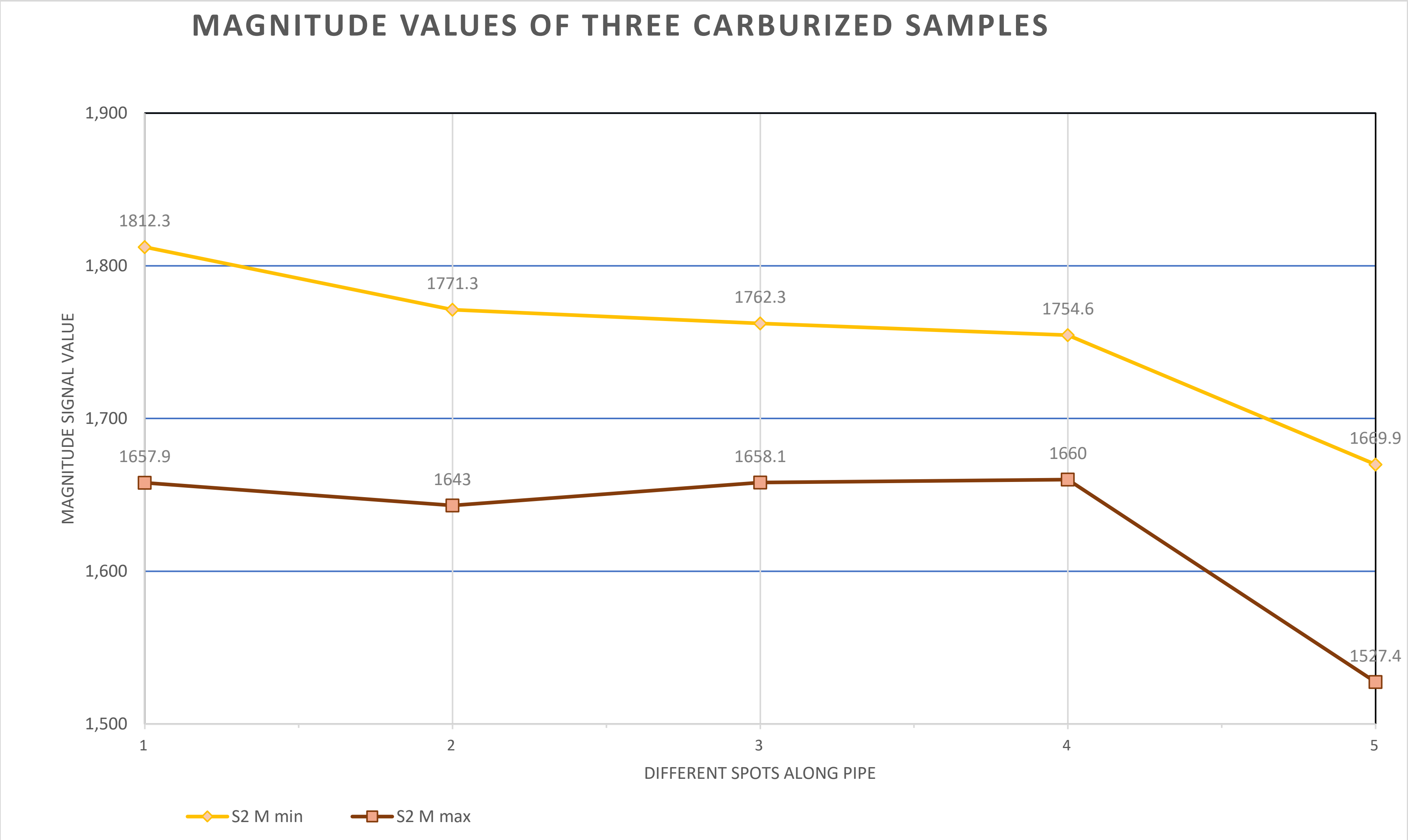


Fig-23: Magnitude values taken on internal carburized sample#2 at 300mm intervals
Min=Cold side minimum value, Max=Hot side maximum value, arbitrary amplitude units

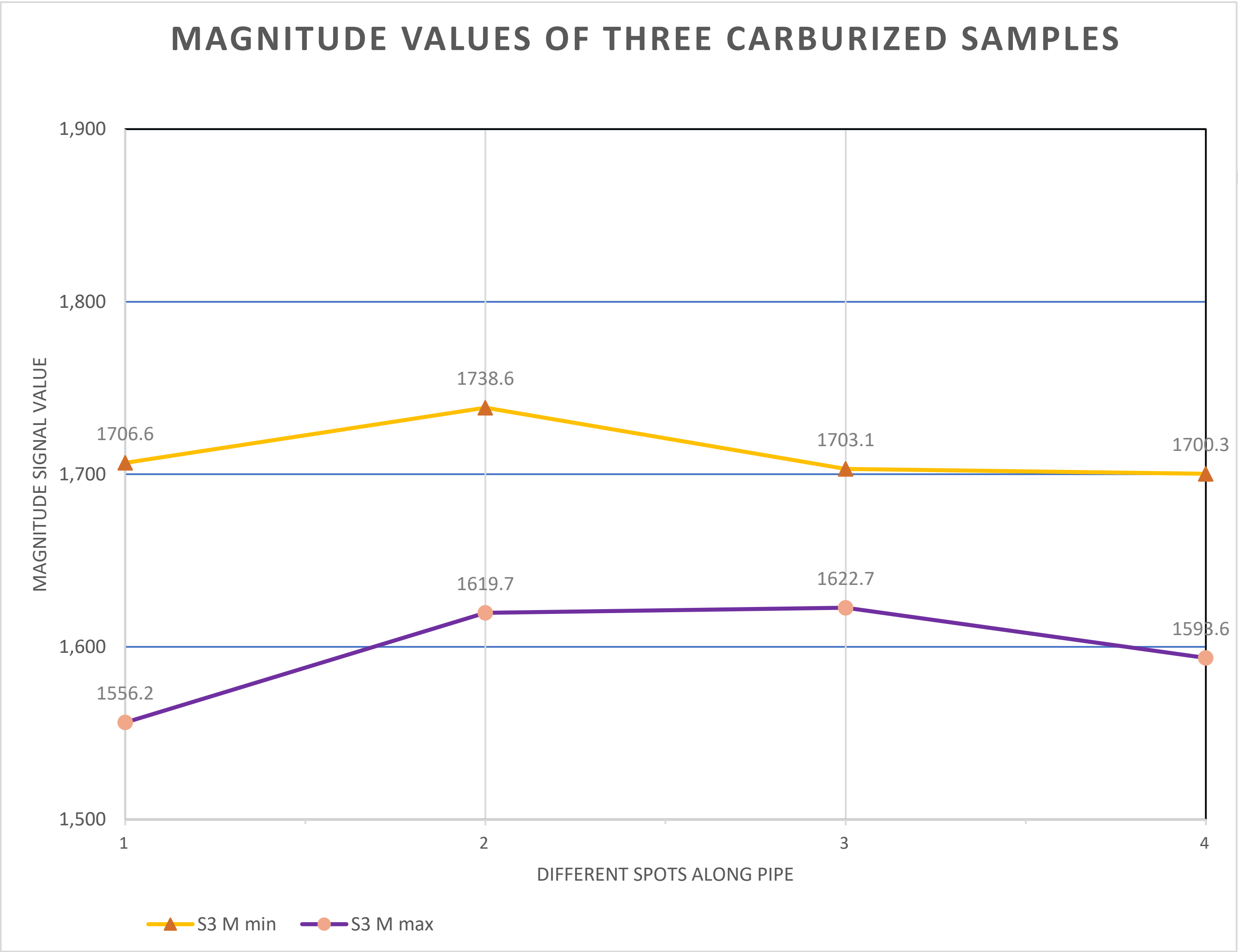
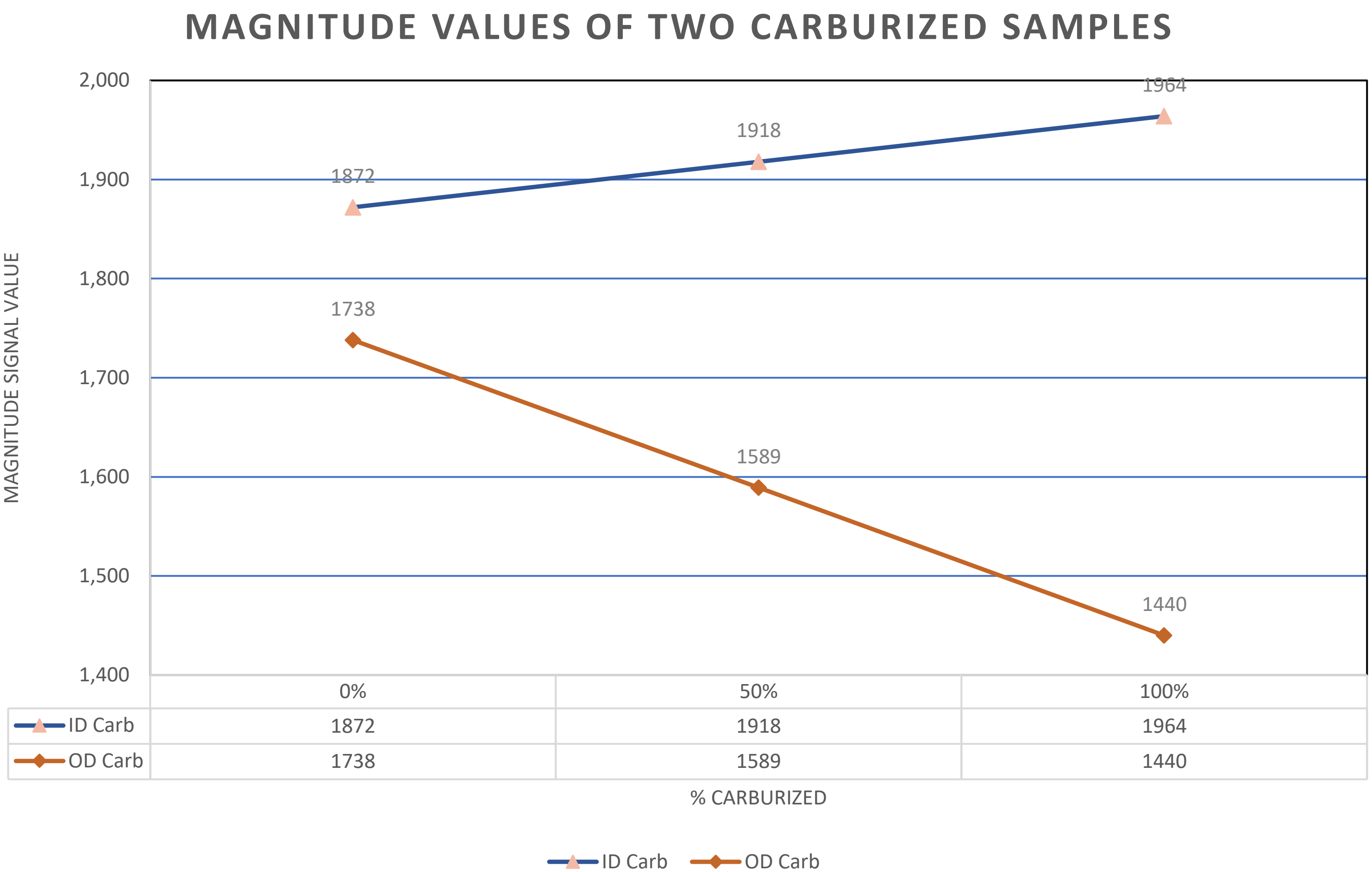
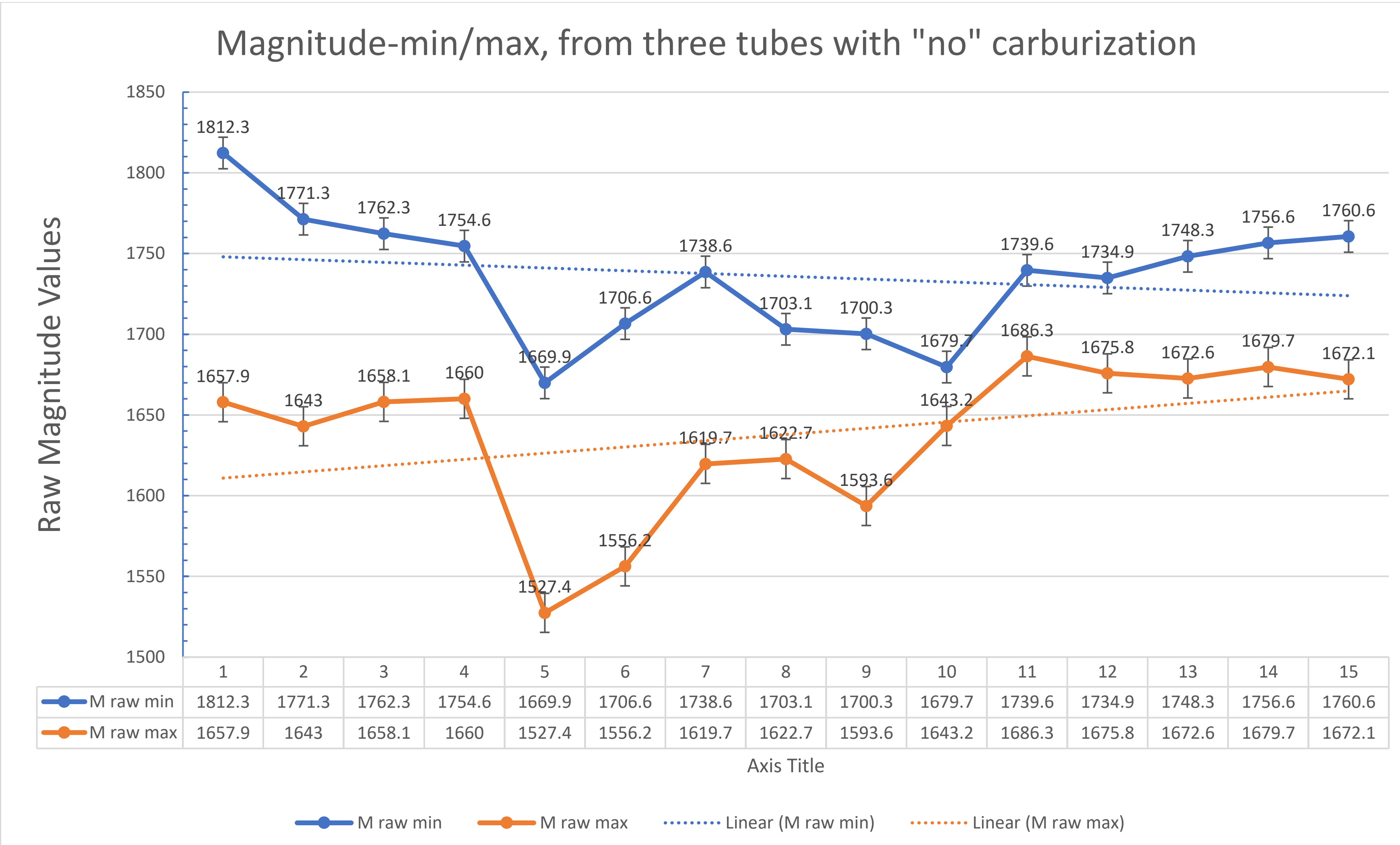


Fig-24: Magnitude values taken on internal carburized sample#3 at 300mm intervals
Min=Cold side minimum value, Max=Hot side maximum value, arbitrary amplitude units



	0%	50%	100%
ID Carb	1872	1918	1964
OD Carb	1738	1589	1440

Fig-25: Values measured from the "cold (min) and hot (max) sides" of three tube samples which had 0% carburization on the cold side and carburization up to 50% deep on the hot side. This illustrates the variations that are due to material properties of the tubes (i.e. the cold side readings should all represent 0% carburization, so the spread in EM values is due to other properties of the tube)



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
M raw min	1812.3	1771.3	1762.3	1754.6	1669.9	1706.6	1738.6	1703.1	1700.3	1679.7	1739.6	1734.9	1748.3	1756.6	1760.6
M raw max	1657.9	1643	1658.1	1660	1527.4	1556.2	1619.7	1622.7	1593.6	1643.2	1686.3	1675.8	1672.6	1679.7	1672.1

Fig-26: values of Magnitude (arbitrary) from a sample with ID carburization that varied from 0% on the cold side to 50% on the hot side, and one with OD carburization from 50% (cold side) to 100% (hot side). Note 0% for OD carb and 100% for ID carb are calculated, not actually measured.

Conclusions from Empirical tests

1) On all three sample tubes with internal carburization, there are clear differences in signal magnitude values between hot and cold sides
2) Cold side values on all samples range from 1669 to 1812
3) Hot side values on all samples range from 1527 to 1686.3
4) Field testing should include a "young tube" with a very short time in the furnace. This should be measured and the lowest magnitude value recorded as 0% carburized.
5) A field operator should use two other sample tubes from the same furnace (or at least the same tube size, wall thickness and material, with different operating hours and known amounts of carburization. From these known values a calibration curve can be constructed.
6) Note: because the tube wall is subject to small material property and thickness variations, the accuracy of carburization depth prediction will be affected. In most electromagnetic measurements, the accuracy expected is +/- 15%, for these reasons.