Sample Calculations 1-6 relate to the Sample Calculations located on the back of the eddy current calculator slide rule.

Note: Remember to use the green slider card (inside the slide rule) for millimeters, and the blue slider for inches.

Sample Calculations 1 and 2 (on back of slide rule)

Purpose- to determine one standard depth of penetration (1δ) for a given material and test frequency. Flaw detection is best achieved at approximately 1δ or less.

Sample Calculation 3 (on back of slide rule)

Purpose- to determine test frequency that achieves 1δ at a specific depth.

Hint: If the goal of the test is to detect flaws down to a depth of (for this example, .060”). This formula provides the test frequency to achieve that goal.

Sample Calculation 4 (on back of slide rule)

Purpose- to determine the approximate thickness at which a given test frequency would produce a 90° separation angle between the thinning curve and lift-off line for a specific material and test frequency. This is the approximate thickness where thickness measurements can be made with minimal interference from liftoff. If you need to go thinner or thicker (to match the nominal material thickness), after you complete step “C” of the sample calculation, leave the red hairline where it is, and simply slide the slide card to the line up new nominal thickness with the 90° separation angle, and re-read the frequency under the red hairline.

Sample Calculation 5 (on back of slide rule)

This tutorial is very closely related to tutorial 5.

Purpose- to determine the test frequency that would produce a 90° separation angle between the thinning curve and lift-off line for an approximate given thickness of a specific material. Sample Calculations 4 and 5 are both related to measurement of part thickness.

Sample Calculation 6 (on back of slide rule)

Purpose- to determine the approximate test frequency that would produce a 180° separation angle between the thinning curve and lift-off line for a specific material and thickness. This allows user to measure conductivity or inspect for discontinuities throughout the complete depth of material, but with minimum interference from lift-off and thickness changes. Using this 180° separation angle will result in the effects of thickness changes and liftoff changes occurring in the same direction, allowing both effects to be simultaneously separated from conductivity-related changes. One note of caution about using a separation angle of 180° is that, since this puts the standard depth of penetration at over 1.8δ at the far surface of the test material, shallow far-side indications can occur beyond 180° measured from the lift-off line. If simply measuring material conductivity is the goal (for example, for material sorting) refer to Bonus Tutorial #1.

Bonus Tutorials

Bonus Tutorial #1

Purpose- Solely for making conductivity measurements (surface testing), while ignoring any variations in test part thickness.

Step 1: Determine test part nominal thickness.

For example, if test part thickness is .060”, divide this thickness by 3. So working with .060”, .060” divided by 3 = .020”.

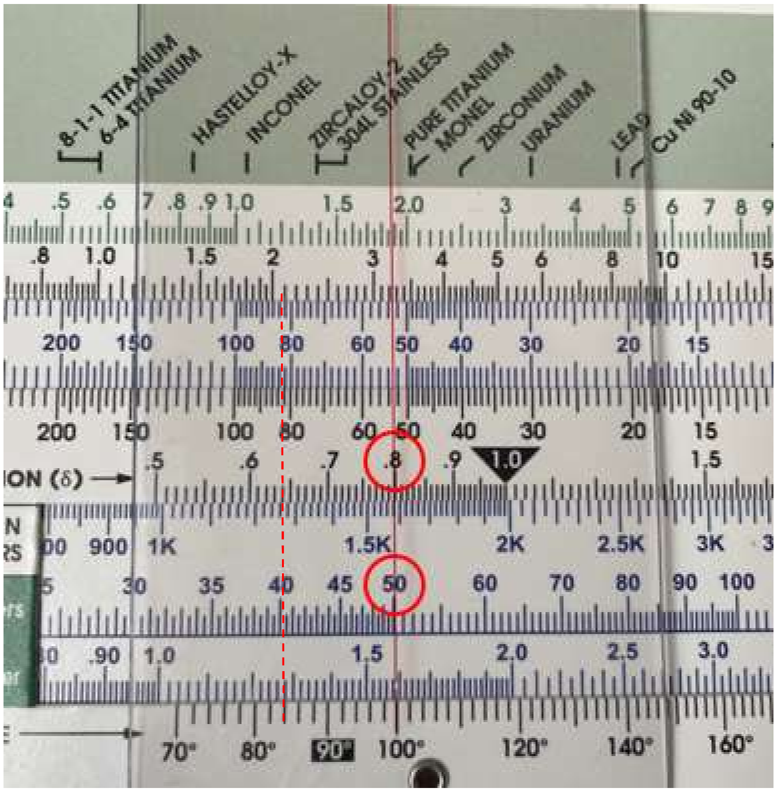
Step 2: Determine the test frequency to establish 1δ at 0.020” using Sample Calculation #3 (on the back of the slide rule) as a guide. The test frequency that produces 1δ at 1/3 of the total part thickness will produce 3δ within the test object. Since very few eddy currents will exist at the far test surface, thickness changes or far surface irregularities will not affect the conductivity reading.

Bonus Tutorial #2

Purpose- to determine F90 test frequency for flaw detection in thin plate. The F90 frequency will result in shallow near surface flaws and shallow far surface flaws being separated by approximately 90°, to optimize flaw detection.

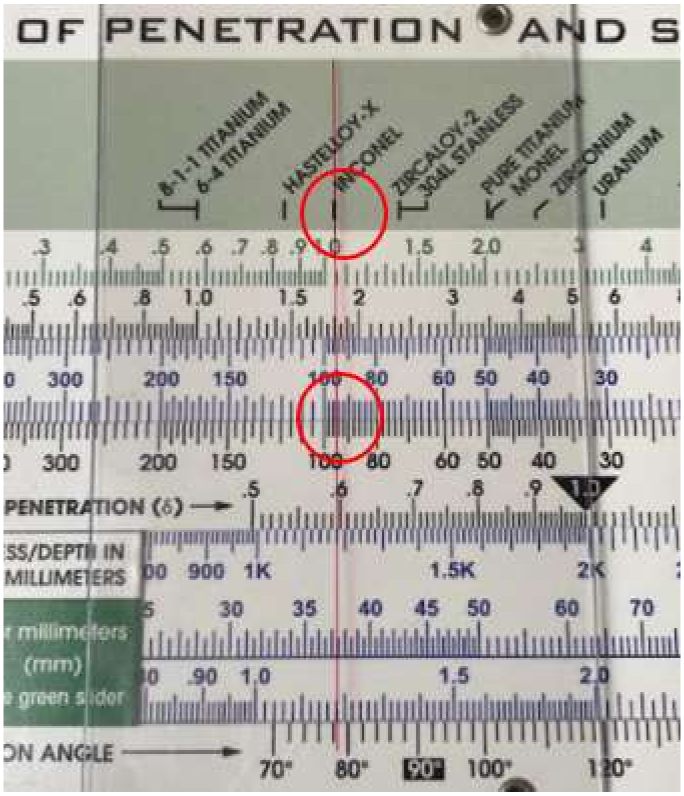
Step 1: Set part thickness to 0.8δ using slider.

Example, if the plate thickness was .050" (50 mils), you would match up 0.8δ on the SDP scale with 50 on the blue thickness slider as shown below:



Step 2: Select material conductivity or resistivity using red hairline.

Step 3: Read frequency under hairline. (If you use Inconel for an example, the F90 test frequency would be about 95 kHz).



Note: The 0.8δ factor is due to the following:

An acceptable compromise which gives both adequate sensitivity to subsurface flaws and adequate phase separation between near side and far side flaw signals is to use a frequency for which the thickness (t) = 0.8δ. At this frequency, the signal from a shallow far side flaw is close to 90° clockwise from the signal from a shallow near side flaw, so this frequency is termed f90. **By substituting t = 0.8δ** into the standard depth of penetration formula, the following formula is obtained:

F90 Frequency for Surface Testing (kHz)

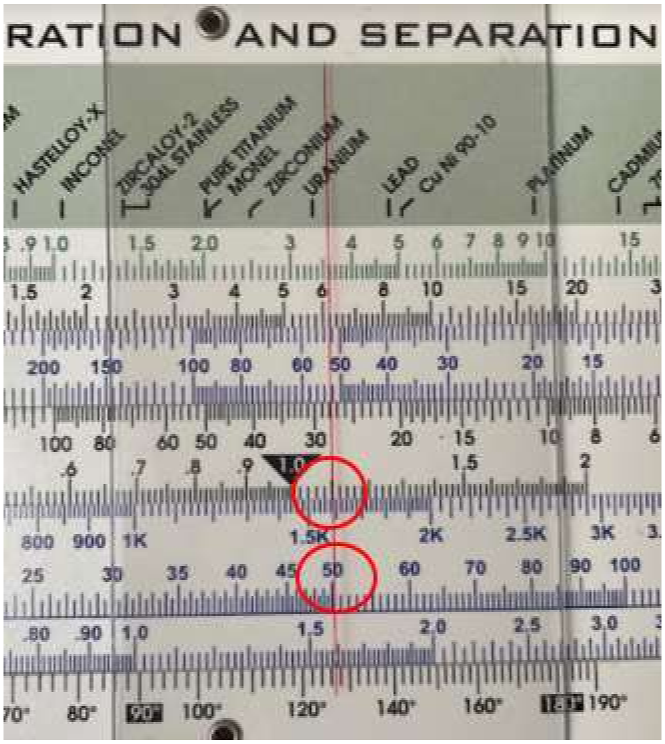
$$\mathrm{F90}_{\mathrm{kHz}} = \frac{1.6\rho}{{t_{mm}}^2} \qquad \mathrm{F90}_{\mathrm{kHz}} = \frac{.0025\rho}{{t_{in}}^2}$$

Bonus Tutorial #3

Purpose- to determine F90 test frequency for flaw detection in tubing. The F90 frequency will result in shallow near surface flaws and shallow far surface flaws being separated by approximately 90°, to optimize flaw detection.

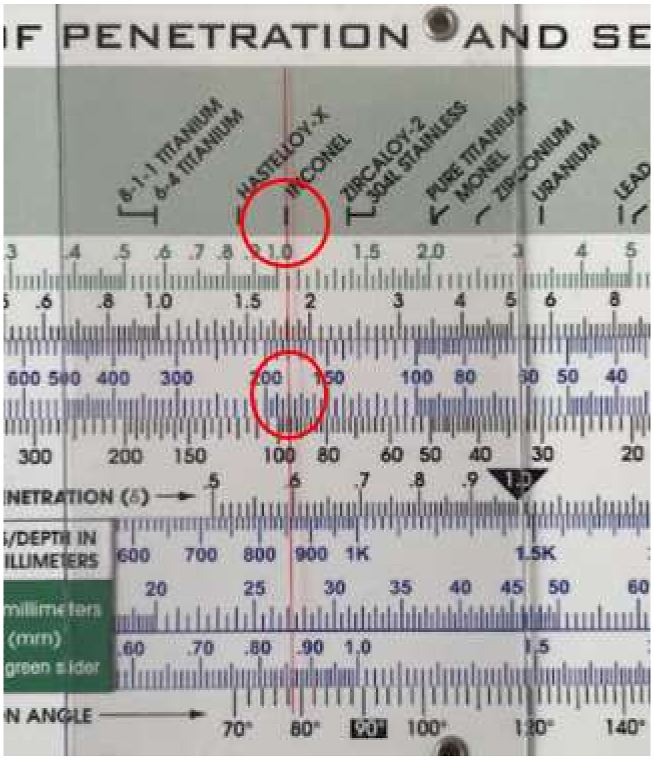
Step 1: Set part thickness to 1.1δ using slider.

Example, if the plate thickness was .050” (50 mils), you would match up 1.1δ on the SDP scale with 50 on the blue thickness slider as shown below:



Step 2: Select material conductivity or resistivity using red hairline.

Step 3: Read test frequency under hairline. (If you use Inconel for an example, the F90 test frequency would be about 180 kHz).



Note: The 1.1δ factor is due to the following:

The normal operating frequency should be the frequency which gives a f90 separation between the signals from a shallow inside surface flaw and a shallow outside surface flaw. However, because of the difference in configuration between surface testing and tube testing, this frequency is that at which the tube wall thickness equals approximately **1.1 standard depths of penetration**. **By substituting t = 1.1δ** into the standard depth of penetration formula, the following formula is obtained:

F90 Frequency for Tube Testing (kHz)

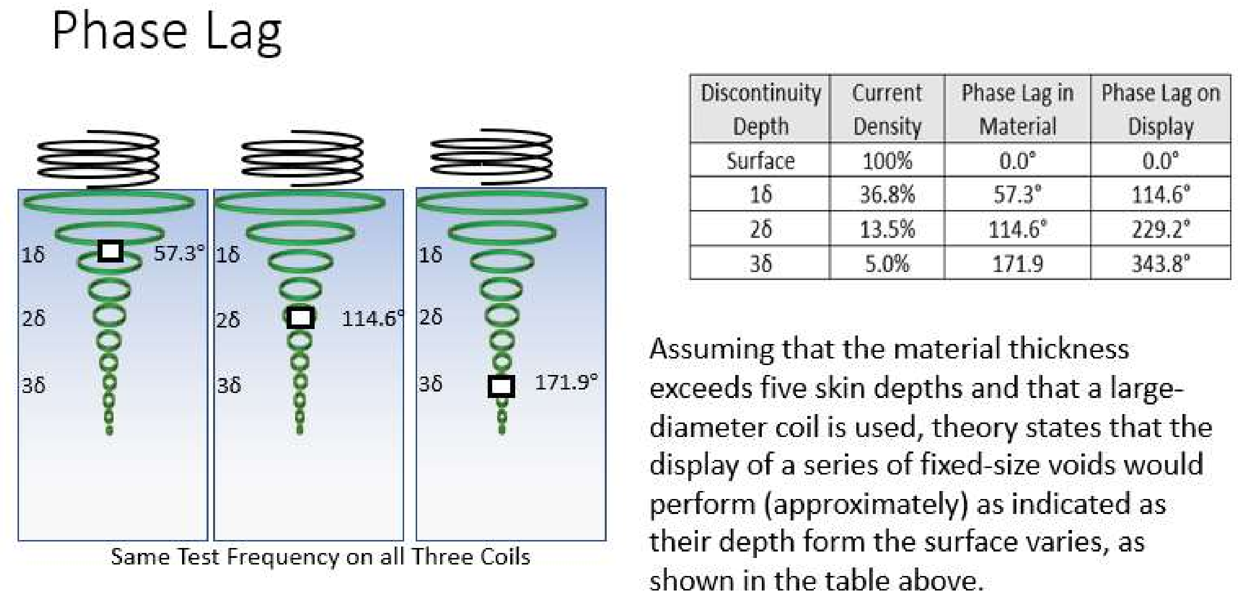
$$F90_{kHz} = \frac{3\rho}{t_{mm}^{\ 2}} \qquad F90_{kHz} = \frac{0.00465\rho}{t_{in}^{\ 2}}$$

Bonus Tutorial #4

Whereas Bonus Tutorials 2 and 3 helped determine the approximate F90 test frequencies for plate and tubing respectively, this tutorial will help determine the approximate test frequency that will place shallow far surface flaws in the range of approximately 170°.

A few notes regarding phase lag.

Eddy Current events that happen around 1δ display signals at approximately 114°, while eddy current events that happen around 2δ display signals at approximately 229°. If the goal of the test is to keep near surface flaws and far surface flaws displaying between 0°-180°, the prime test frequency (roughly 2F90) should be limited to around 1.6δ occurring at the nominal tube wall thickness.



Phase Lag

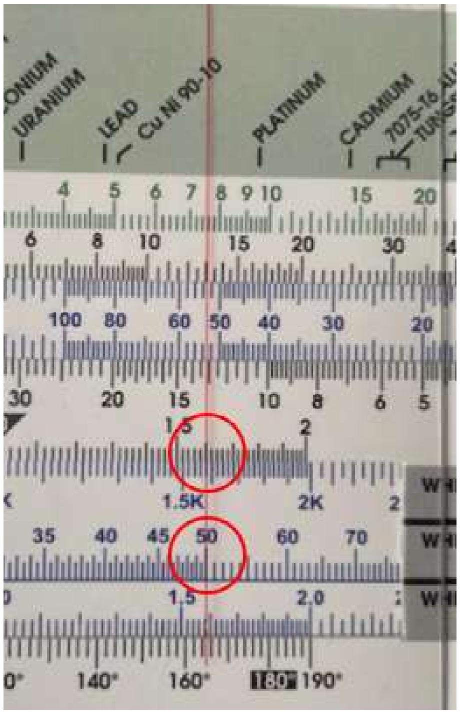
Same Test Frequency on all Three Coils

Discontinuity Depth	Current Density	Phase Lag in Material	Phase Lag on Display
Surface	100%	0.0°	0.0°
1δ	36.8%	57.3°	114.6°
2δ	13.5%	114.6°	229.2°
3δ	5.0%	171.9	343.8°

Assuming that the material thickness exceeds five skin depths and that a large-diameter coil is used, theory states that the display of a series of fixed-size voids would perform (approximately) as indicated as their depth form the surface varies, as shown in the table above.

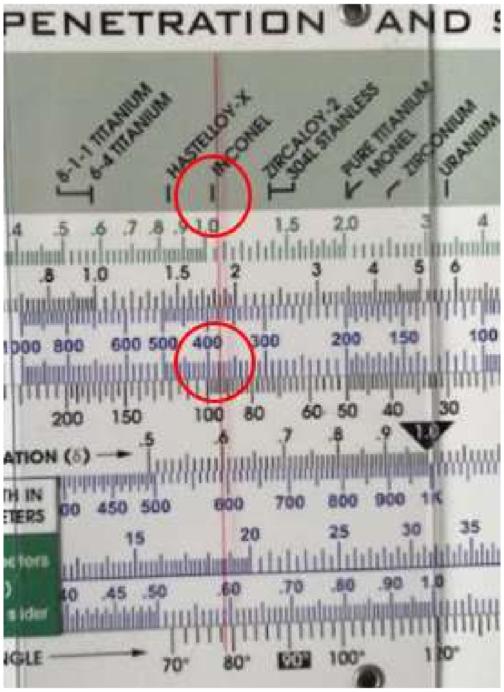
This tutorial will establish far surface flaws occurring around 170°. Once you learn how to perform this exercise, you can adjust the frequency to set a shallow far side flaw to something less than or greater than approximately 170° by adjusting desired %δ to match the tube wall thickness on the slide rule.

Step 1. Using the slider, line up the tube wall thickness with 1.6δ (for this example we will use .050” (50 mils) for the wall thickness).



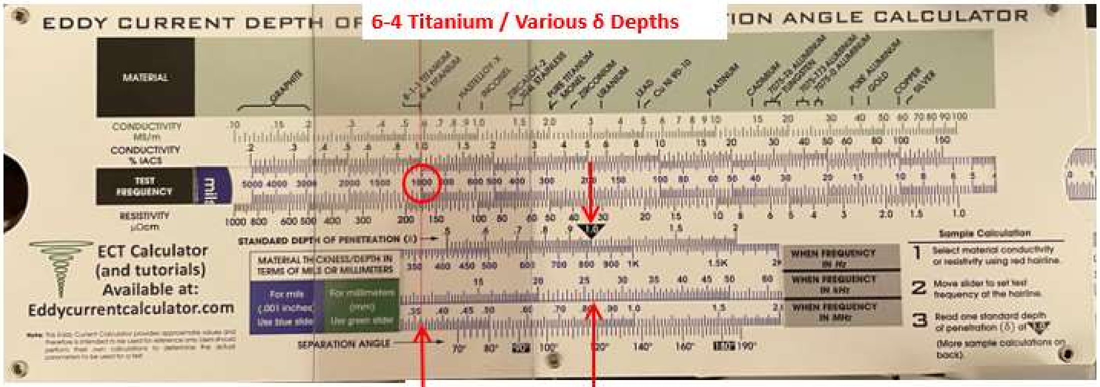
Step 2. Move hairline to material σ or ρ.

Step 3. Read test frequency under hairline. If you use Inconel for this example, the frequency would be around 380 kHz.

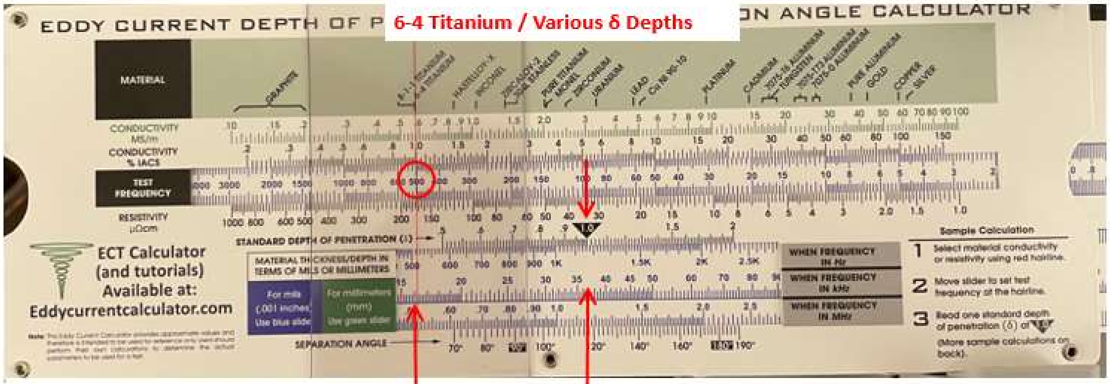


Bonus Tutorial #5

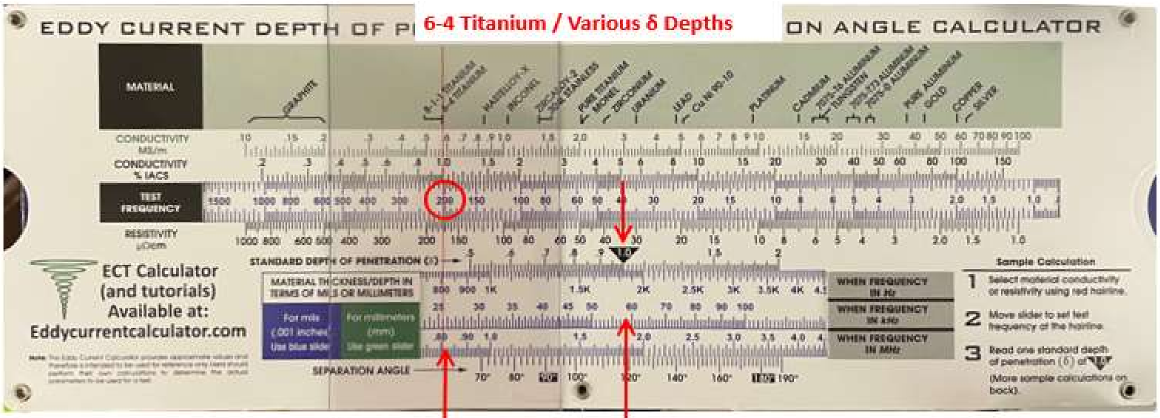
This tutorial shows how to determine what depth 1δ occurs at for different test frequencies in the same material (6-4 Titanium).



Here, the red hairline is positioned at 6-4 Titanium, and the blue slide is moved to set 1000 kHz at the hairline.
In this slide card position, you can see that 1δ occurs at approximately 26 mils (.026") in the material (at 1000 kHz)

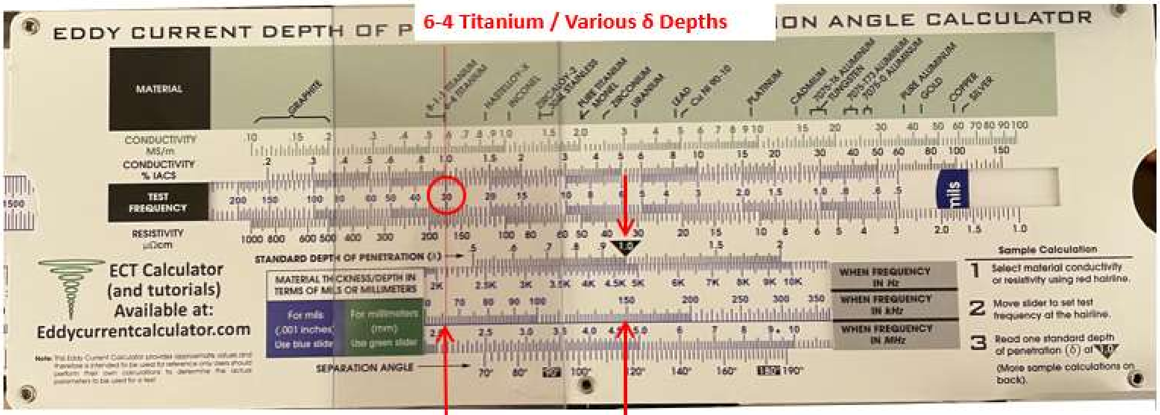


Here, the red hairline is positioned at 6-4 Titanium, and the blue slide is moved to set 500 kHz at the hairline.
In this slide card position, you can see that 1δ occurs at approximately 37 mils (.037") in the material (at 500 kHz)



6-4 Titanium / Various δ Depths

Here, the red hairline is positioned at 6-4 Titanium, and the blue slide was moved to set 200 kHz at the hairline. In this slide card position, you can see that 1δ occurs at approximately 59 mils (.059") in the material (at 200 kHz)



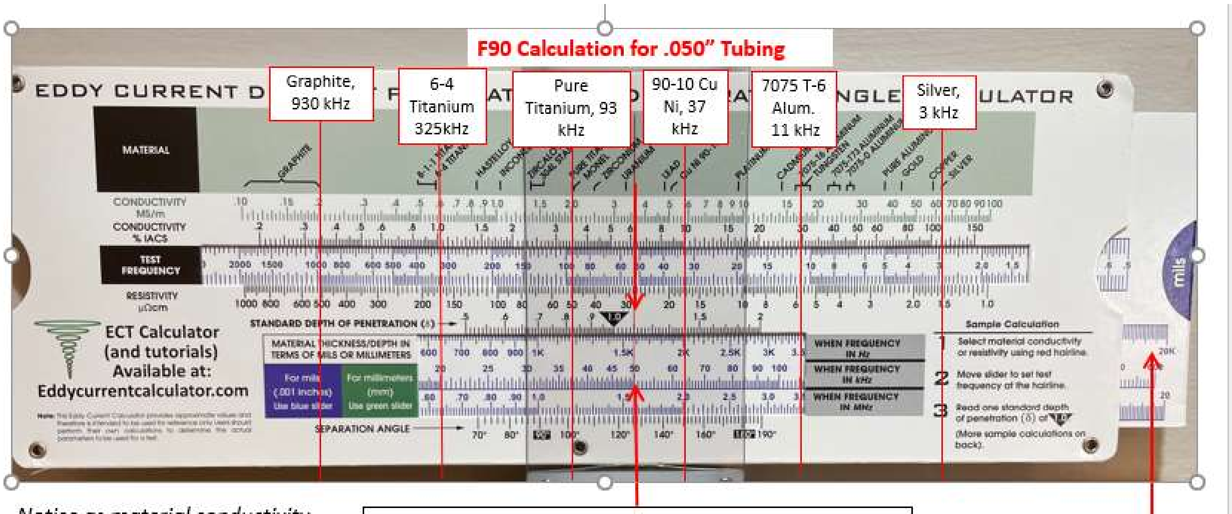
6-4 Titanium / Various δ Depths

Here, the red hairline is positioned at 6-4 Titanium, and the blue slide card was moved to set 30 kHz at the hairline. In this slide card position, you can see that 1δ occurs at approximately 150 mils (.150") in the material (at 30 kHz)

Note that as test frequency was decreased, 1δ occurs at increasingly deeper locations within the material whereas the highest frequency (1000 kHz) produced 1δ at a much shallower depth.

Bonus Tutorial #6

This tutorial shows how calculate the F90 frequency for tubing made from various materials, all having a wall thickness of .050”.



F90 Calculation for .050” Tubing

Graphite, 930 kHz

6-4 Titanium 325kHz

Pure Titanium, 93 kHz

90-10 Cu Ni, 37 kHz

7075 T-6 Alum. 11 kHz

Silver, 3 kHz

Notice as material conductivity increases, lower inspection frequencies are used.

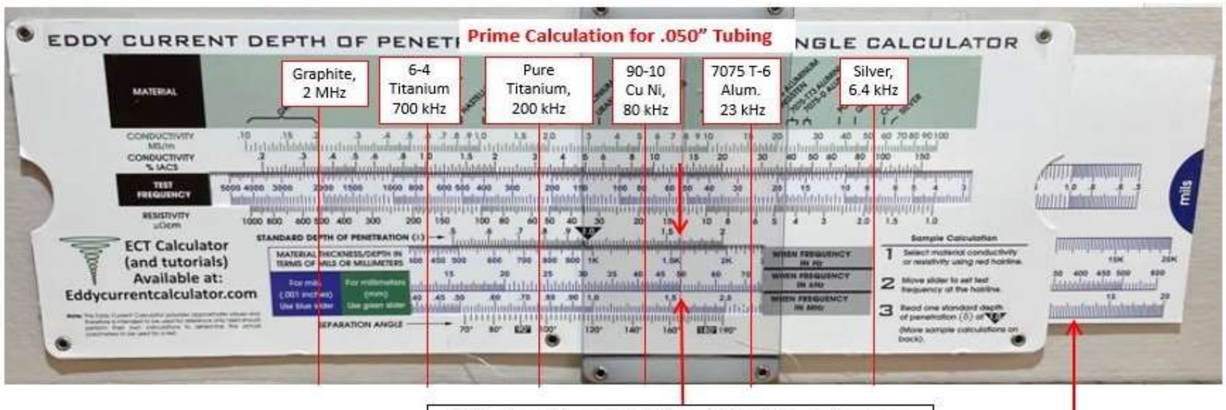
$$F90_{Hz} = \frac{4.65\rho}{t_{in}^{2}}$$

With the slide card in this position (50 mils lined up with 1.1δ), the F90 Frequency for tubing for all non-ferrous materials with a wall thickness of .050” can be read along the Frequency Scale by moving the red hairline to desired material.

Slide Card (Blue for Mils)

Bonus Tutorial #7

This tutorial shows how to calculate the prime frequency for tubing made from various materials, all having a wall thickness of .050”.



Prime Calculation for .050” Tubing

Graphite, 2 MHz

6-4 Titanium 700 kHz

Pure Titanium, 200 kHz

90-10 Cu Ni, 80 kHz

7075 T-6 Alum. 23 kHz

Silver, 6.4 kHz

Higher frequencies used for prime frequency results in more phase spread for depth sizing.

$$F_{\substack{prime\\Hz}} = \frac{10\rho}{t^{2}}$$

With the slide card in this position (50 mils lined up with 1.6δ), the prime Frequency for tubing for all non-ferrous materials with a wall thickness of .050” can be read along the Frequency Scale by moving the red hairline to desired material.

Slide Card (Blue for Mils)