The Official Titanium Pro Series ICT Test Report

The Innovators in Probe Technology

Spring Probe Function in In-Circuit Test

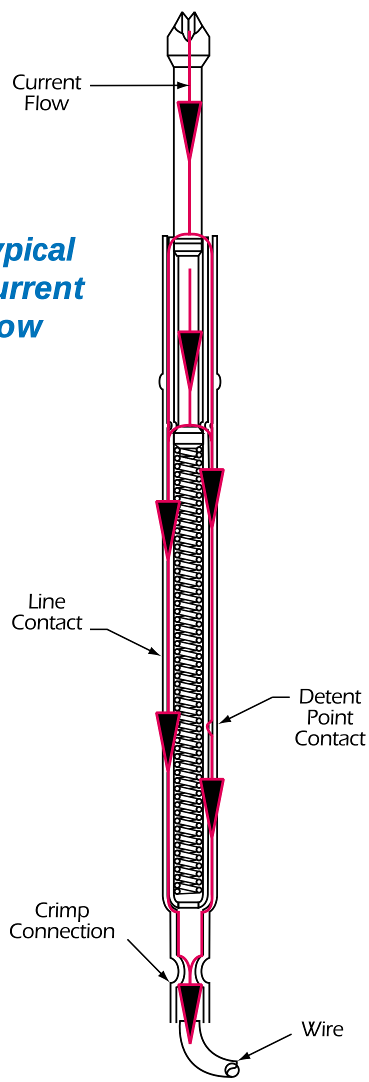
Spring Contact Probes are compliant components that provide an electrical contact path between a test point on a PCB and the automated test equipment (ATE). Probes are installed in a fixture, a customized interface between the PCB and ATE. Probes allow multiple test points with varying heights and configurations to be accessed simultaneously as the PCB contacts the test fixture and the probes compress. Circuit path integrity is critical for accurate testing. The performance of the probe is vital. It is the physical connection to the PCB test point and the only part of the system that is mechanically dynamic and electrically indispensable.

The primary current path of a probe is from the plunger to the barrel and then to the receptacle. The current then transfers from the receptacle wire termination through the fixture wiring to the tester. Accurate current transfer within the probe is dependent on the physical contact of the probe's components. They must contact each other in a repeatable fashion.

Mechanical obstructions can cause poor electrical functioning of the probe and even cause complete electrical failure. If the plunger does not contact the barrel, the current must flow through the relatively high resistance spring, causing elevated resistance readings and false opens.

This phenomenon occurs in two ways. First, when the plunger is compressed on the spring in such a manner that the plunger does not contact the barrel (centering) and second, when contaminants become trapped inside the barrel and insulate the plunger from the barrel. The resistance of the probe will also vary from actuation to actuation, in relation to the plunger/barrel contact point and cleanliness of this point. Variations in resistance will occur when small amounts of contamination are trapped between the plunger and barrel or when the plunger or barrel plating is worn to the degree that the base material is exposed and oxidized.

Typical Current Flow



Introduction

The original ICT probe design was created to address the probe-related challenges of In-Circuit Testing. The introduction of the ICT Probe Series was the first fundamentally new probe technology in over 30 years, benefiting test personnel by surpassing performance levels obtained from the previous industry standard probe designs. The Titanium Pro ICT Series continues the revolution of high performance probe design by refining the ICT concept to achieve an even greater performance threshold. Previously unattainable results are realized through a stronger, more robust design and new plating options that are more equipped to handle and excel in the typical rigors of today's In-Circuit Test environment. This report documents the extensive internal testing program for the Ti-Pro ICT Series. The test results validate our claim that test personnel will realize significant fixture performance gains using the Ti-Pro ICT Probe Series.

The Innovators in Probe Technology

Probe Design and Performance

Historically, probe design has focused on biasing techniques to ensure internal contact between the plunger and barrel, attempting to prevent elevated resistance and large variations in resistance. This performance aspect is important because relatively small variation in resistance, voltage, and current must be measured on the PCB by the test equipment. If the variation in the probe's resistance is greater than the allowable signal variation being measured, the test equipment will reject the PCB. This false open causes a good board to be rejected.

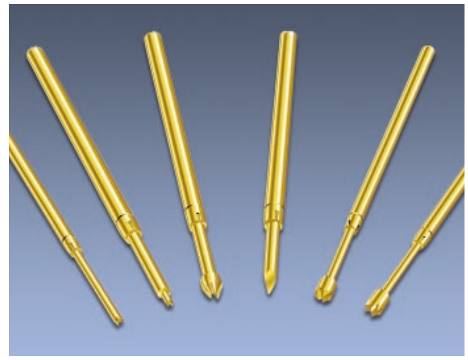
In addition to electrical performance, pointing accuracy and durability are crucial aspects of probe performance. Correct registration of the fixture to the target is essential for successful contact. The inherent accuracy of the probe plays a considerable role in the total accuracy of the system and has implications for probe life. Poor fixture to target registration can cause increased sideload forces on the probe, prematurely wearing components and increasing stress on the spring. Specifically, the plunger to barrel contact surface plating will wear quicker and plunger tips and edges can prematurely wear or otherwise be compromised.

Durability is the probe's capacity to resist contaminated environments by functioning properly in a consistent manner. Contamination can take the form of flux residues and particulate matter from the board production processes or the environment. Contamination can work its way into the internal portion of the probe, creating an insulating effect by lining the plunger and barrel contact points. The probe then suffers from variable or very high resistance. In addition, the internal contamination trapped in the spring cavity becomes an abrasive grit that wears the internal platings of the probe and barrel, and causes premature spring failure.

The inherent flaws of conventional probe designs arise from tradeoffs taken to improve one performance aspect to the detriment of another. These designs incorporate some form of internal biasing mechanism to ensure electrical contact. Biasing mechanisms force the plunger tail to one side of the barrel by use of a bias ball with a bias cut plunger tail, a bias cut plunger tail only, or a biased spring design. Forcing the plunger tail to one side tilts the plunger within the barrel, creating the worst case geometry for pointing accuracy. In addition, by forcing the plunger to one side, biasing opens a larger gap between the plunger and barrel at the barrel top allowing contamination easier entry into the internal portion of the probe. In bias designs, pointing accuracy and durability are sacrificed for electrical performance.

The ICT design features a barrel modification process that machines the barrel top into four bifurcated beams of precise length and profile. The beams are then formed to perfect center by a special manufacturing process that provides a compliant pressure fit between the beams and plunger resulting in a zero working clearance between the plunger and barrel. This seemingly simple innovation, adapted and refined from proven pin and socket connection technology, is exceedingly effective at providing substantial performance gains.

ICT Design



The ICT design is the first fundamental new probe technology offered since biasing was first introduced. This new design addresses the three primary aspects of performance important for In-Circuit Testing: electrical resistance, pointing accuracy, and durability.

In contrast to bias designs that have only one small and highly variable contact point, the bifurcated beams provide full radial contact (360°) to the plunger shaft, providing the most stable current path possible. This enlarged contact area never changes as the probe is compressed. It is always the plunger shaft to barrel beams, which results in the lowest, most consistent resistance of any probe.

Since the four bifurcated beams are formed to perfect center, the plunger shaft is positioned in axial and radial alignment with the barrel providing the best possible pointing accuracy. In contrast, bias designs intentionally force the plunger off axis to achieve acceptable electrical performance.

The Titanium Pro Advantage

The Titanium Pro ICT Series features an improved plunger design and a corresponding new beam design. During the manufacturing process, the bifurcated beams are customized for each plunger, eliminating any manufacturing tolerance between the plunger's outside diameter and the inside diameter of the beams. In the new design, the retained length of the plunger is reduced by .100" (2.54mm), allowing for a longer spring. Thus, higher forces are obtainable while eliminating the tendency for premature mechanical failure, specifically when over stroking occurs.

The Ti-Pro ICT Probes feature our new G2 proprietary barrel material and plating. Our G2 barrel was designed to increase the friction force between the inside of the receptacle and the outside of the barrel. In essence, it has a "less slick" fit. The Ti-Pro Series probes are less likely to "walk out" during test and have an extraction force – 25% greater than probes manufactured with an unplated surface on the outside of the barrel.

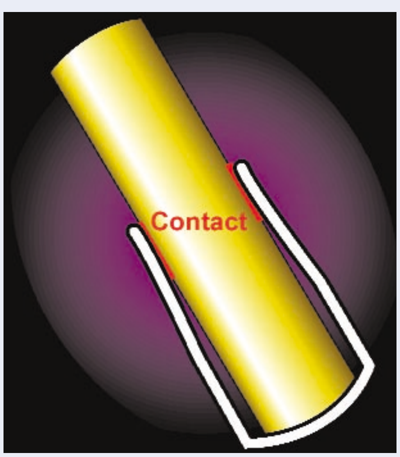
The Ti-Pro Series probes also feature our new revolutionary plunger plating, with a plating hardness of 400 knoop, **over TWICE as hard as the standard cobalt gold** (180 knoop) commonly used on probes. As with all platings, it is the additives of the plating bath that determine the hardness of the electro-deposit. Through detailed design experiments, we believe we have developed the hardest electro-deposited gold obtainable. As a result, the Tri-Pro ICT Series is less susceptible to wear from side loading and is more equipped to withstand the harshness of today's In-Circuit Test environments.

These new design features make the Ti-Pro Series by far the most robust in-circuit test probe. The compliant fit between the plunger and barrel, the gentle wiping of the plunger shaft during deflection, and the harder gold plating vastly reduce wear commonly seen as a black surface on the shaft of the plunger, resulting in longer probe life. The longer spring volume, corresponding higher spring forces, and absence of grit in the internal portion of the probe all contribute to increasing mechanical spring life.

The Ti-Pro ICT design offers In-Circuit Test performance potential not possible with conventional designs. The results of our comparative test program demonstrate and document the performance capabilities the Titanium Pro ICT Series Probes compared to conventional technology.

Test Program

The complete test program included exhaustive laboratory testing of IDI Ti-Pro ICT probes against top In-Circuit Test product offerings from the various primary probe vendors. Tests were designed to address the most relevant performance criteria, mimicking the variety of conditions found in typical installations. The various electrical, pointing accuracy, and durability tests are described here with documented results and stated conclusions in the final section.

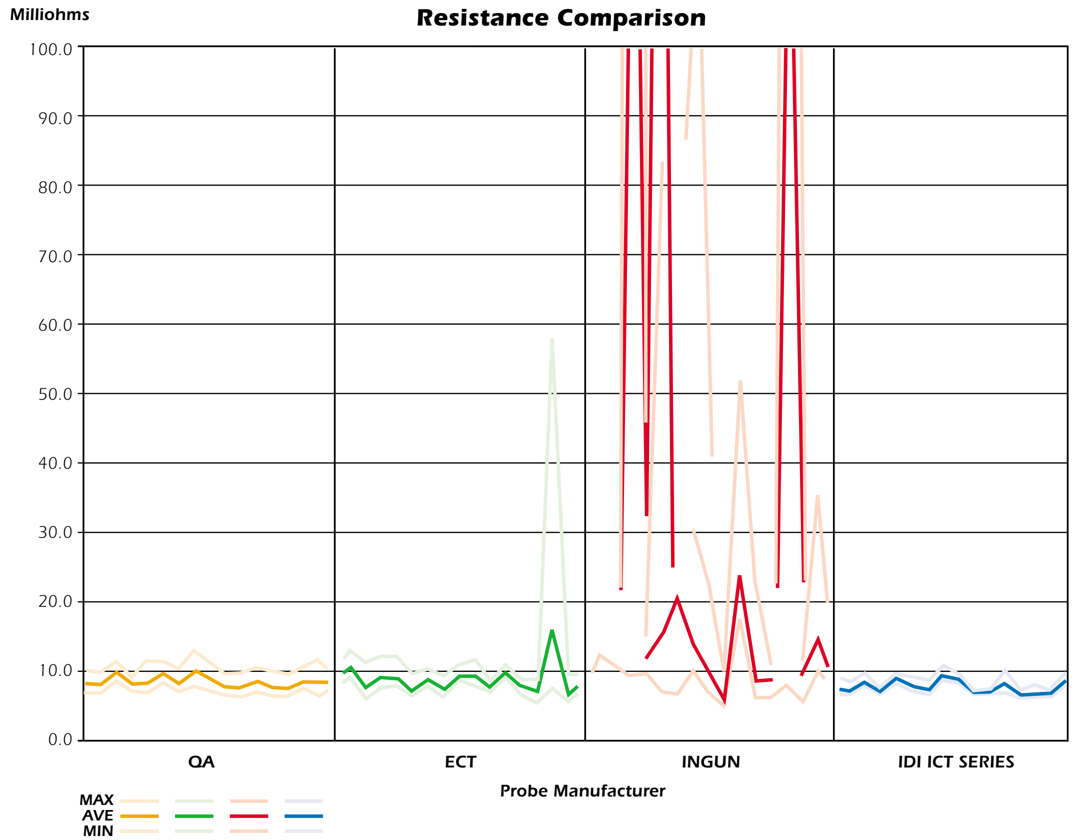


The zero working clearance between the plunger and barrel closes the pathway for contamination to enter the internal portion of the probe. This has a dramatic impact on long-term electrical performance and durability of probes in contaminated environments. The beams apply a light force to the plunger shaft, wiping contamination from the shaft as the plunger is stroked.

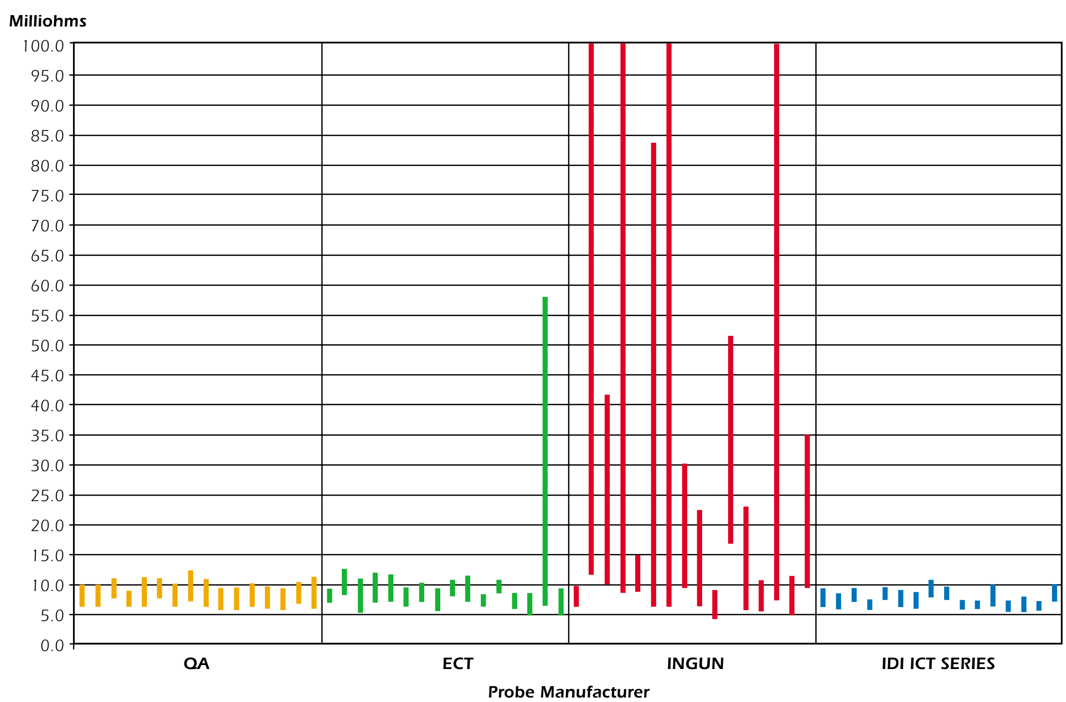
Electrical Characteristics

Tests measuring average probe resistance (Graph 1) and resistance variation per probe (Graph 2) over 200k cycles were conducted. As shown on Graph 1, the average resistance of the Ti-Pro ICT probes is less than the competitor probes. The Ti-Pro ICT probes will more likely remain within the allowable tolerance range when measuring sensitive components during In-Circuit Test, over the lifetime of the probe. Graph 2 uses the same test data, but demonstrates the total resistance variation of each probe over 200k test cycles. The smaller the spread of resistance values, the more consistent the resistance. The ICT probes exhibit a tight range of resistance compared with competitor probes resulting from the constant circuit path through the probe.

Graph 1 – Minimum, Average, and Maximum Resistance
100 mil center, .250" travel probes over 200,000 cycles



Graph 2 – Minimum, Average, and Maximum Resistance Variation
100 mil center, .250" travel probes over 200,000 cycles



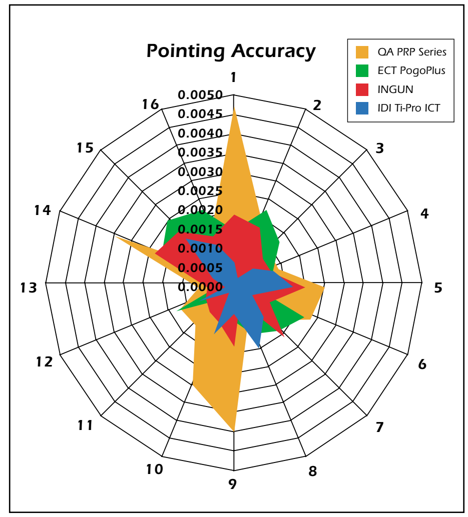
Pointing Accuracy

Pointing accuracy was determined by measuring sixteen pieces of each probe series before and after 200,000 cycles. The cumulative effects of test usage are thus factored into this measurement, giving a truer picture of the probes' typical pointing accuracy. Probes were placed in a 3-wheel concentricity gage, then rotated to measure the plunger tips' maximum distance from center by an optical comparator. The test setup is shown in Figure 1. The value produced by this measurement, total indicator runout (TIR), is halved and expressed as pointing accuracy, or deviation from true center.

Graph 3 is a radar plot of each probe's pointing accuracy depicted as a data point located a distance from the graph's center (true center). The data points are connected and color filled to illustrate the scatter of strikes typical for each probe type. Graph 4 overlays the results for comparison and displays the before cycling and after 200,000 cycles.

It is seen that the Ti-Pro ICT Series displays the tightest scatter pattern of any probe type. Consequently, the Ti-Pro ICT probe is more likely to hit targets on center resulting in highly reliable contact and overall fixture performance. The likelihood of glancing off, misalignment or completely missing targets is substantially diminished resulting in improved yields.

Graph 4 – Combined Pointing Accuracy 100 mil Center, .250" Travel Probes



Graph 3 – Individual Pointing Accuracy

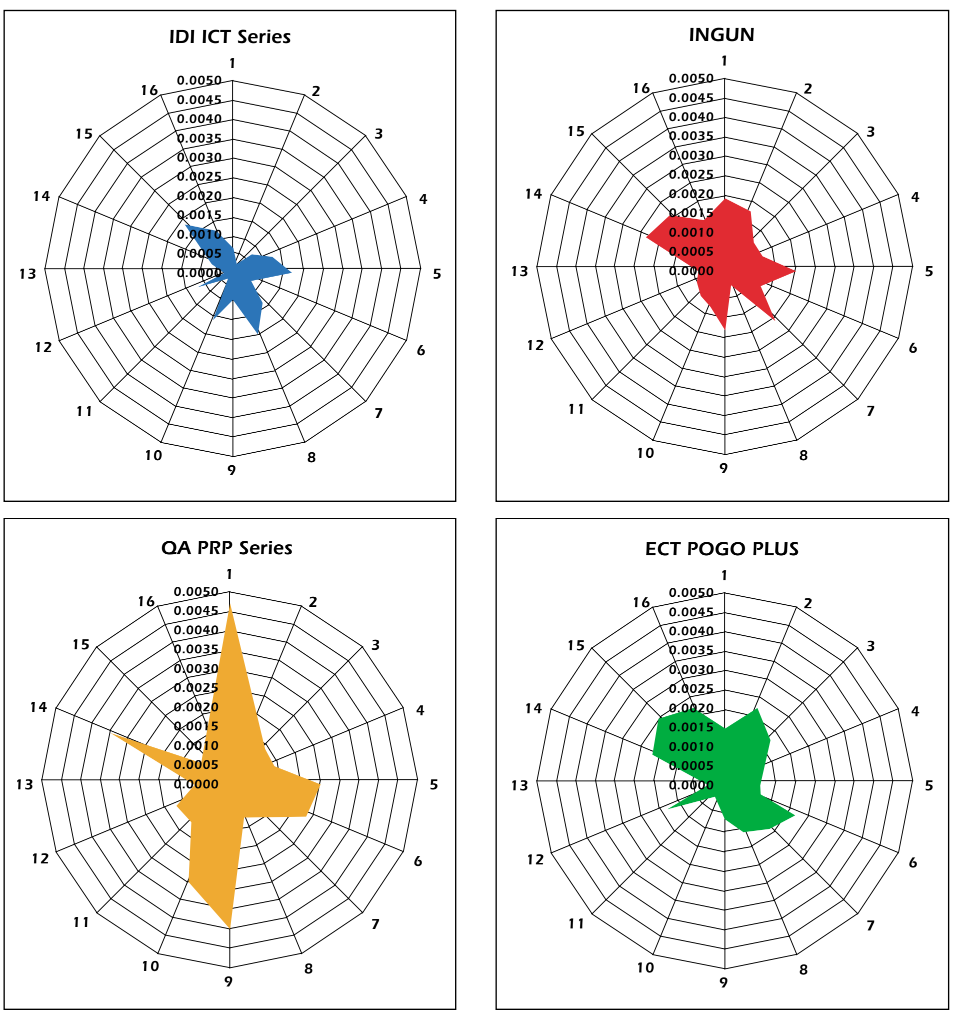
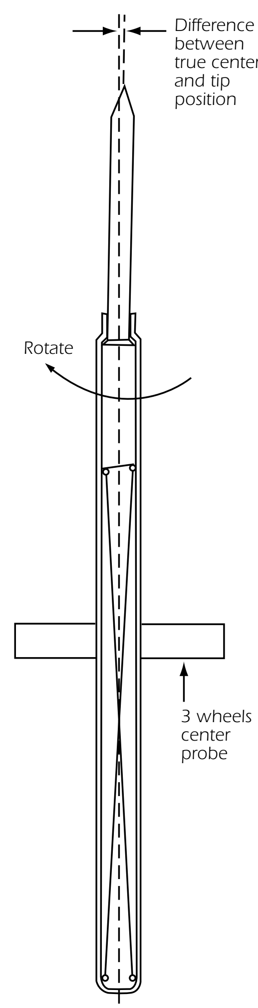


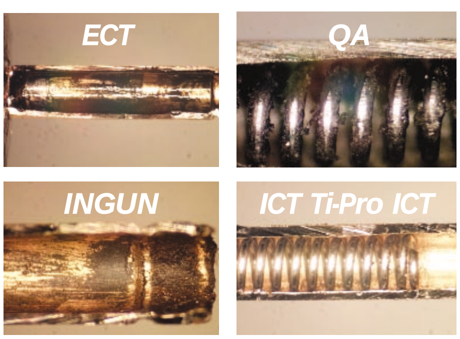
Figure 1 – TIR Setup



Durability

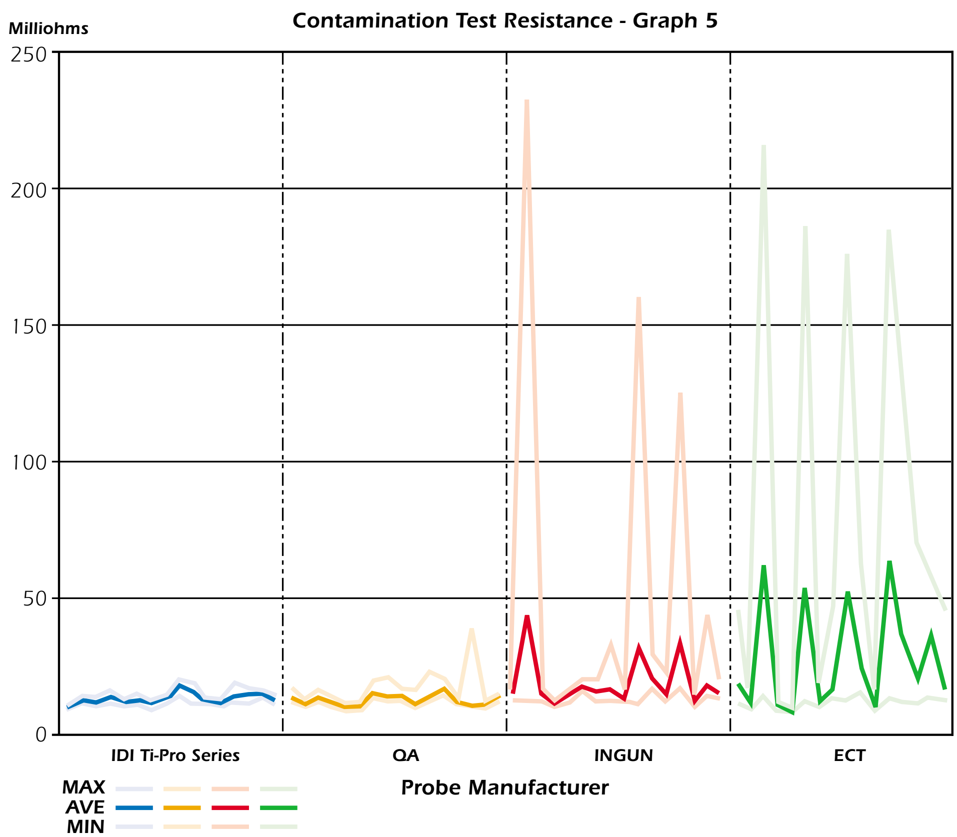
The durability test consisted of an electrical test similar to that performed for electrical characterization. The fixture receptacle holes were drilled with a 2.5° angle from vertical to induce side-load. In addition, contamination was applied directly to the probes at intervals throughout the test. The contamination consisted of solder flux; steel, plastic and aluminum filings; various grades of abrasive compounds; and ordinary dirt.

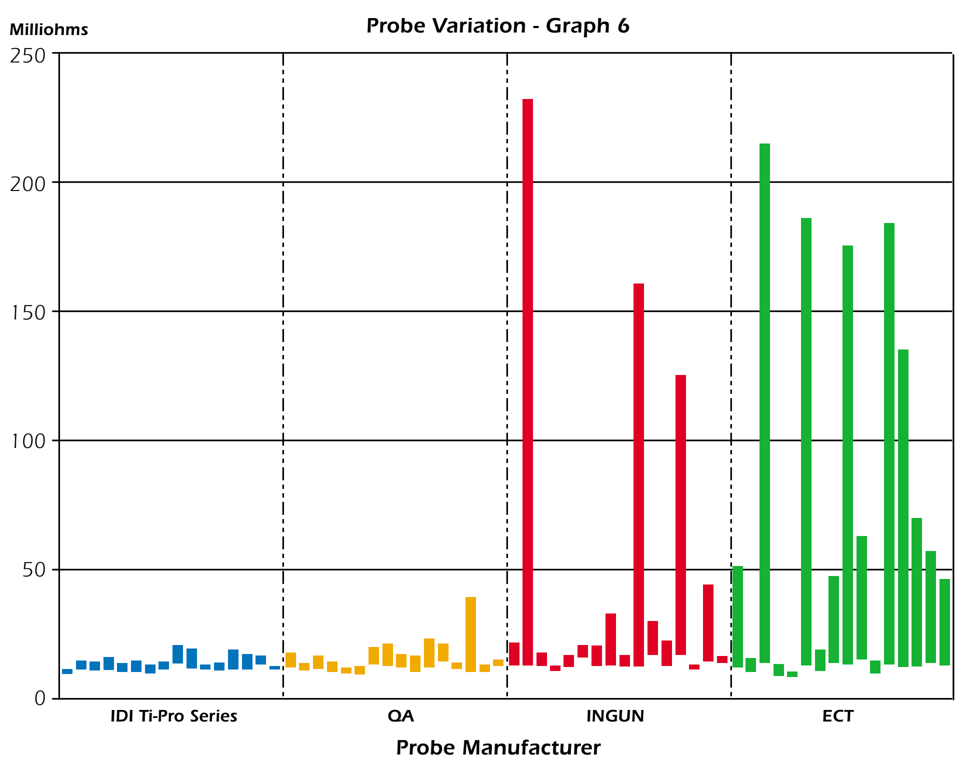
Graphs 5 and 6 show results of the contaminated electrical test. Note the resistance level of the Ti-Pro ICT probes as compared to competitors. Even under severe contamination, the ICT exhibits significantly lower resistance than competitor probes. This indicates contamination was blocked from entering the internal probe cavity thus preventing contact issues and consequent high resistance.



The tested probes were dissected to reveal the degree of internal contamination. As predicted, the ICT internal spring/plunger cavity was free from contamination. Competitor probes allowed contamination to enter the cavity, allowing the possibility of internal contact problems.

Graphs 5 and 6 – Contaminated Environment Test





Conclusions

The Ti-Pro ICT Probes outperform all other probes in every critical aspect of In-Circuit Test; pointing accuracy, consistent resistance, low resistance and durability. As a result, test yields increase as false opens caused by probe failures are dramatically decreased, if not eliminated.

Consider the following:

What impact would an increase of yields from 92% to 97% have on your company if you tested 5000 boards in a week?

The Matrix shows a difference of 250 boards (4850 - 4600 = 250).

1. ***The 250 boards must be re-tested to determine if they are in fact, bad.***
2. ***The cost of retest is expensive.***
   Cost of Retest = Machine Time + Labor + Opportunity Cost of not Testing Good Boards Accurately (lost through-put)
3. ***Assume 50% of first pass rejected boards are actually good.***
4. ***$50/hr labor; $250/hr machine time; $300/hr opportunity cost;***
   Test time = 5 minutes; then $600/hr x 5/60 hrs = $50 Cost per Test
5. ***0.50 x 250 x $50 = $6,250***
6. ***If 5000 boards are tested weekly: 52 x $6250 = $325,000***
7. ***In this example a 5% increase in yields results in an annual savings of $325,000.***

	Number of Boards Tested						
First Pass Yield (%)	**50**	**100**	**500**	**1000**	**5000**	**10000**	**25000**
98	49	98	490	980	4900	9800	24500
97	49	97	485	970	4850	9700	24250
95	48	95	475	950	4750	9500	23750
94	47	94	470	940	4700	9400	23500
93	47	93	465	930	4650	9300	23250
92	46	92	460	920	4600	9200	23000
91	46	91	455	910	4550	9100	22750
90	45	90	450	900	4500	9000	22500
89	45	89	445	890	4450	8900	22250
88	44	88	440	880	4400	8800	22000
87	44	87	435	870	4350	8700	21750
86	43	86	430	860	4300	8600	21500
85	43	85	425	850	4250	8500	21250
80	40	80	400	800	4000	8000	20000
75	38	75	375	750	3750	7500	18750

Titanium-Pro ICT Series improves yields and saves money!

Appendix 1: Life Cycle Test Methodology

IDI's Life Cycle Testers use a modified 4-wire Kelvin test. Two wires are soldered to the receptacle and two wires are soldered to a contact plate, typically sterling silver. During measurements, two wires inject a constant current into and out of each probe/receptacle, and a separate pair of wires convey the consequent voltage drop.

The voltage drop includes:

1. The resistance of the contact plate.
2. The constriction resistance between the probe and the contact plate.
3. The resistance between the probe and the receptacle.
4. The resistance of the solder joints.

The current source forces a constant 25 milliamps of current during setup and testing with a precision shunt.

The standard contact plate for a life cycle test is sterling silver. This material is economical, low in resistance, and has good corrosion resistance properties. Contact plates may also be fabricated from either half hard beryllium copper plated with .000050" gold (50 micro inches) over .005" silver, or hardened steel. The type of plate we used is determined by the test. For white paper testing, the sterling silver plate is used.

There were two separate life cycle tests run on probes for this paper.

Standard Test

Thirty-two (32) receptacles are mounted in a manner similar to actual field use ¾ vertical, point up orientation, press fit to specifications ¾ into a G-10 fiberglass matrix block. The receptacles are populated with probes.

A machine tool slide guided sinusoidally-oscillated sterling silver contact plate compresses the probes within .001" of the rated stoke. At setup, the rated stroke is verified with a built in dial indicator. A precision 25,000 step per revolution micro-stepping motor cycles, stops and registers the contact plate within .001" of the rated stroke. Resistance measurements on each probe are taken every 1,000 cycles.

In addition to testing resistance, the life cycle tester determines loss of stroke (resulting from spring failures or otherwise). The slide guided contact plate incrementally releases probe stroke at 10% length intervals from the rated stroke. Continuity is checked at every interval, on every probe. An error message similar to "Probe 4 has lost 10% of its rated stroke" is printed on the report should a failure be detected. Every 20,000 cycles, loss of stroke is checked.

2.5° Side Load Test

The mounting holes in the G-10 fiberglass block are drilled at a 2.5° angle. The receptacles and probes are then installed in the block. The tip of the plunger is offset 0.0144" from true center.

$$\tan 2.5^\circ = \frac{\text{Horizontal Offset}}{\text{Plunger Extension}}$$

$$0.04366 = \frac{x}{.330}$$

$$x = 0.0144''$$

This test simulates wear from side loading. Resistance readings are taken every 1000 cycles for the entire 200,000 cycles of the test. Stroke loss is tested every 5,000 cycles throughout the 200,000 test.

Contaminated Environment Test

A contamination mixture is created of equal parts surface grinder dust, bench grinder shavings, cast iron drill shavings, and Kansas City road dirt mixed in a rosin core flux. The mixture is applied to the plunger tips and shafts pretest. Resistance is measured every 1,000 cycles for the entire 100,000 cycles of the test. Loss of travel and spring force are analyzed every 5,000 for the length of the test.

Appendix 2: Pointing Accuracy Measurement & Calculation

Measurement:

IDI uses a 3-wheel concentricity gage to hold the probe at the top of the barrel. The center point of the plunger tip is measured at the minimum and maximum location through a 360° rotation using an optical comparator at 20x magnification. This result is the TIR (Total Indicator Runout). One half of the TIR is the pointing accuracy. A probe exhibiting TIR of .003" will exhibit hit range within ± .0015" of its center.

The pointing accuracy of a probe is defined as the variation in actual location of the probe tip from test to test and is internal to the probe.

There are three primary factors that determine pointing accuracy:

1. Working clearance between the plunger and barrel.
2. Retained length of the plunger in the barrel.
3. Extended length of the plunger.

In all previous designs, the plunger sits at an angle in the barrel due to the working clearance. It is this angle and the base location of the angle that determine pointing accuracy.

Pointing Accuracy Calculation – Standard Design

In a standard probe design, the clearance between the plunger and the barrel is exactly the same at the top of the barrel as it is at the bottom or tail of the plunger inside the barrel. Therefore, the centerline of the plunger and the centerline of the barrel will cross at 1/2 the retained length of the plunger.

The nominal working clearance on a Size 25 (100-mil center, .250" max. travel) probe is .002". The retained length is nominally .335", and extended length is .330". Pointing accuracy is calculated by two similar triangles. The first triangle has a y-axis length of .335/2 = .1675 (1/2 the retained length), and an x-axis length of .002/2 = .001 (1/2 the working clearance). This allows the maximum angle (q) calculation at which the plunger sits in the barrel.

$$\text{Tan } q = .001/.1675$$
$$\text{Tan } q = .00597$$
$$q = .342°$$

The nominal pointing accuracy is calculated as follows. The y-axis of the triangle is equal to 1/2 the retained length of the plunger plus the extended length of the plunger (.335/2 + .330) or .4975". The angle of the plunger is .342°.

$$\text{Tan } .342 = x / .4975$$
$$.00597 = x / .4975$$
$$.00297 = x = \text{Pointing Accuracy}$$

The pointing accuracy for a Size 25 probe is .003". This means that the tip of the plunger will hit within a radius of .003" from the centerline of the probe barrel. The formulas above may be simplified to:

$e = \pm c\,(a/b + .5)$ where
- e = pointing accuracy
- c = working clearance = .002
- a = extended length = .330
- b = retained length = .335

$$e = \pm .002\,(.330/.335 + 1/2)$$
$$e = \pm .002\,(.985 + .5)$$
$$e = \pm .002\,(1.485)$$
$$e = \pm .00297$$
$$e = \pm .003$$

Pointing Accuracy Calculation: SX Design

With the addition of the SX crimp to the barrel, the point at which the centerline of the probe intersects the centerline of the barrel is shifted closer to the top of the barrel. The centerline intersection shift occurs because the clearance at the top of the barrel is tighter than the clearance at the end of the retained length. This shortens the length of the y-axis improving the pointing accuracy. The total working clearance in an SX probe is .00125" (.001" at the plunger tail and .00025" at the top of the barrel). Consequently, the centerline of the plunger crosses the centerline of the barrel at 4/5 or (.00025/.00125) from the top of the barrel. The pointing accuracy of an SX probe is calculated as follows:

Tan q = c/(4/5*b)	center line crosses at 4/5 of retained length
Tan q = .00125/(4*.335/5)	b = retained length - .335
Tan q = .00466	c = working clearance - .00125
q = .267°	
Tan .267 = e / (a + b/5) where	e = pointing accuracy
e = Tan .267 (.330 + .335/5)	a = extended length of plunger
e = Tan .267 (.397)	b = retained length of plunger
e = .0019"	

Most competitors' designs (QA roll top, ECT Pogo Plus) can be calculated accordingly.

Pointing Accuracy Calculation: Titanium Pro Series ICT Design

The ICT technology eliminates the working clearance between plunger and barrel at the barrel top. The four bifurcated beams at the barrel top center the plunger in the barrel resulting in the barrel centerline and plunger centerline crossing at the barrel top. The plunger seat angle in the barrel is determined by the retained length and the working clearance at the retained length.

Tan q = c/b	center line crosses at top of the barrel
Tan q = .0008/.235	b = retained length - .235
q = .195°	c = working clearance - .0008
Tan .195 = e / a	where e = pointing accuracy
	e = Tan .195(.330)
	a = extended length of plunger - .330
	e = .0011"