Lawrenceville Plasma Physics, Inc

High technology research, development and consulting in plasma physics, X-ray sources, and Focus Fusion

Focus Fusion Report

September 18th, 2012

- **New evidence for dense filaments**
- **Arcing solutions in sight**

Summary: Arcing persists, but there is a "silver lining" (literally) and a new micro-ohm meter will help. Experimental evidence shows that we are producing the fine filaments we need for high density, but they are disrupted by arcing.

Arcing occurs when electric current jumps through tiny gaps between two pieces of metal carrying the current, causing vaporization of the metal. The uneven mixing of metal vapor with FF-1's deuterium plasma disrupts the symmetry needed for good compression and thus high density.

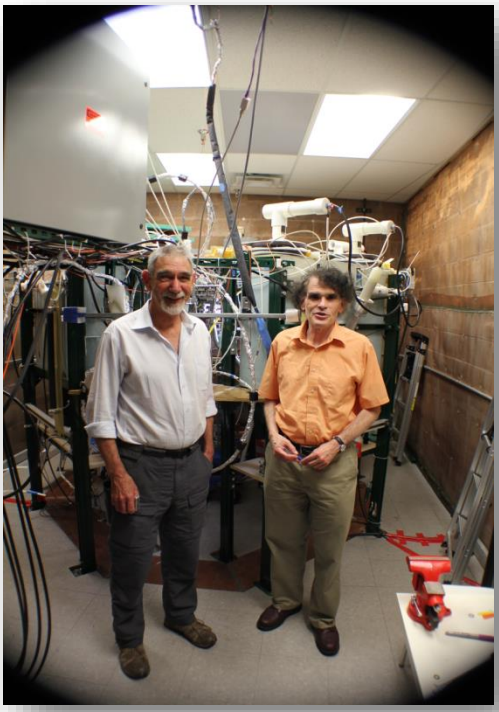
Ivana Karamitsos and Derek Shannon stack layers of adhesive kapton film, taking care not to create bubbles that would leave room for electrons to accelerate. These four layers of kapton are then cut and applied to the inner steel buss to protect the ceramic hat insulator from "feelers" of electricity that could lead to breakdown.

LPP's research team is convinced the arcing can be cured, since our colleagues in other facilities, with similar currents, have licked this problem. It is a question of our learning and applying the best techniques to do this right. In our small field, the answers are not in textbooks, but we believe we have enough insights to provide the answers after a little more experimenting.

The first tests of our new method of attaching the tungsten teeth to the copper cathode plate were delayed by machining and aligning glitches until the end of July. Those tests showed that we had solved the arcing between the tungsten and copper. But arcing persisted between the copper pieces and the steel plates to which they are bolted. (See our Illustrated Intro to Arcing, below.)

This arcing seemed to be due to microscopic gaps between the copper and steel, which could be smoothed out by applying greater pressure to the bolts. We had previously doubled the number of these bolts from sixteen to thirty-two, and in August we substituted stronger titanium bolts for the brass bolts in the cathode and increased the stress on the anode's steel bolt. Nonetheless, arcing still occurred. Our new resistance and waveform tests (reported in June) helped us to detect arcing quickly, but we had to take time to repair arcing damage to the electrode surfaces.

A renewed search of the literature turned up data that showed that the contact resistance—the resistance between the two conducting plates—could not be reduced sufficiently by the pressure we could apply. To avoid arcing, the voltage difference between the two plates has to be reduced to about a volt. With million-amp currents, this means the contact resistance has to be less than one micro-ohm. The published studies showed that, with our design, we could not achieve the pressures needed to get to that level.



Chris Lee at left with Eric Lerner and Focus Fusion-1

So, based on suggestions by our colleague Chris Hagen of the NSTEC Gemini dense plasma focus facility at the Nevada National Security Site, we put indium wire between the two plates. Indium is a very soft, conductive metal that squishes out to form a good bond between two metals. In our first test of this method in early September, arcing was reduced, but was still substantial. Since metal is one million times denser than our plasma, any arcing is harmful.

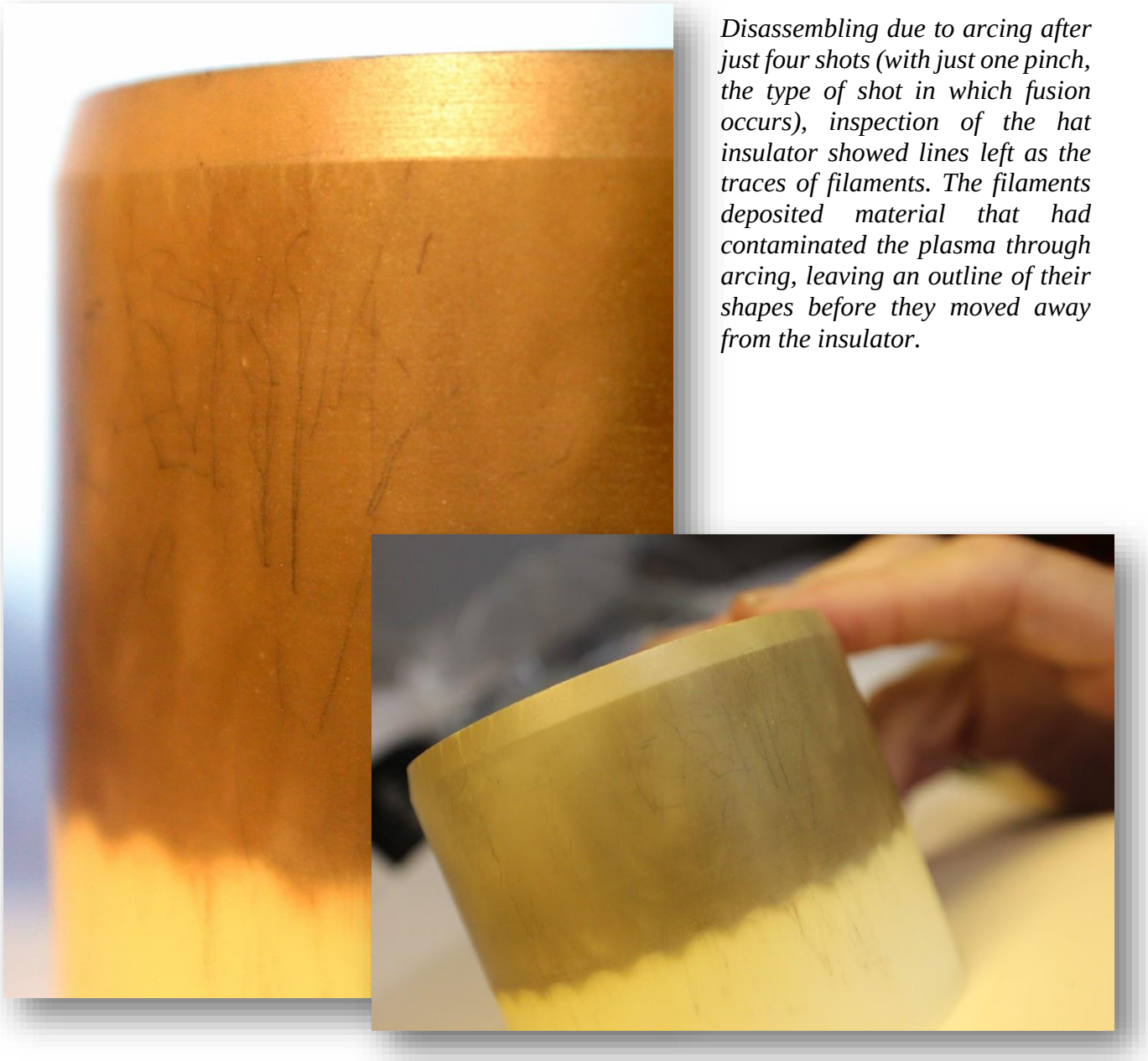
Thanks to a timely visit by Focus Fusion supporter and New Zealand chemical engineer Chris Lee, we rapidly saw that we had overlooked one source of contact resistance. The stainless steel plates are covered with a protective layer of chromium oxide. This keeps them shiny, but has a high electrical resistance. When current flows, the thin layer of oxide cracks, but only lets through thin spurts of current, keeping contact resistance high and allowing for arcing.

To eliminate the oxide coating we are plating the steel pieces with nickel and then silver (the silver lining), which will allow a continuous metal contact from the silver-coated copper, through the indium to the silver-coated steel.

In addition, we have ordered a micro-ohm meter that can measure the tiny contact resistances that cause arcing. This means we can test our electrodes before putting them in the machine and firing. Since electrode assembly takes a couple of hours, and assembling, firing and taking apart FF-1 takes a week, we expect that any remaining problems, if they exist, will be far more rapidly detected and resolved.

Tracks on insulators show tiny filaments, and the effects of arcing

Since we have been firing only a few shots during each test cycle, we have been able to see the tracks made on the insulators by individual current filaments. The arcing produces carbon that mixes with the filaments' plasma and then is deposited on the insulator. This plasma "writing" has shown us the filaments are indeed forming at about the 100-micron diameter we predicted (see figure 2). But they are irregular and, in the area of most severe arcing, they don't appear. This is firm evidence that the arcing is disrupting the filamentation needed for high density and thus high fusion yield. Since the arcing occurs at a different place than the filament formation, and there is not enough time for the blast from the arcing to hit the filaments, arcs are probably affecting the

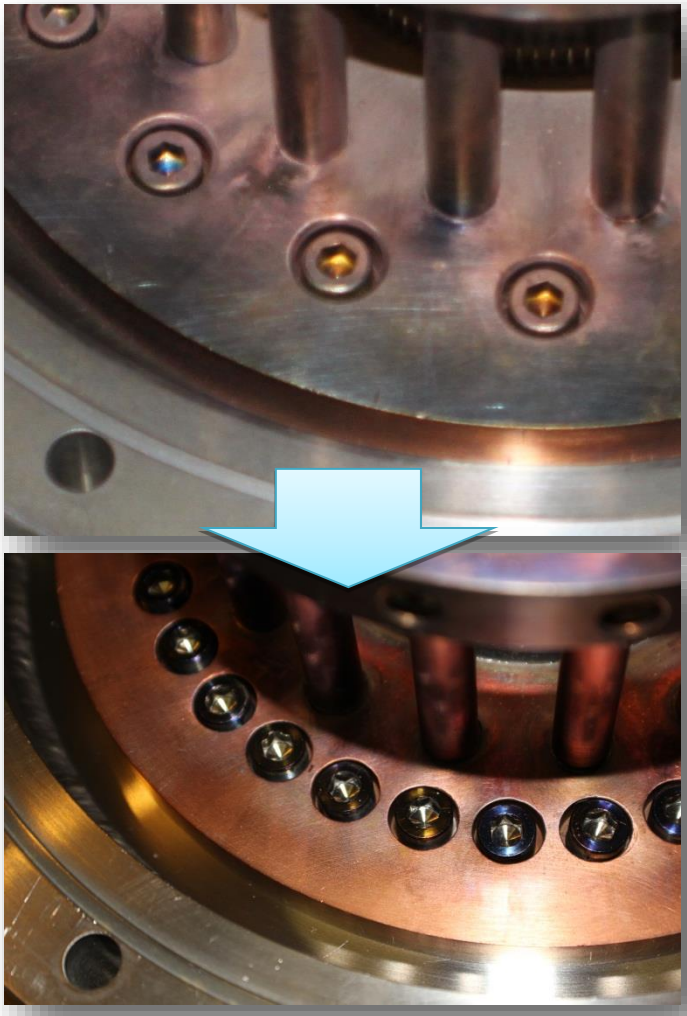


Disassembling due to arcing after just four shots (with just one pinch, the type of shot in which fusion occurs), inspection of the hat insulator showed lines left as the traces of filaments. The filaments deposited material that had contaminated the plasma through arcing, leaving an outline of their shapes before they moved away from the insulator.

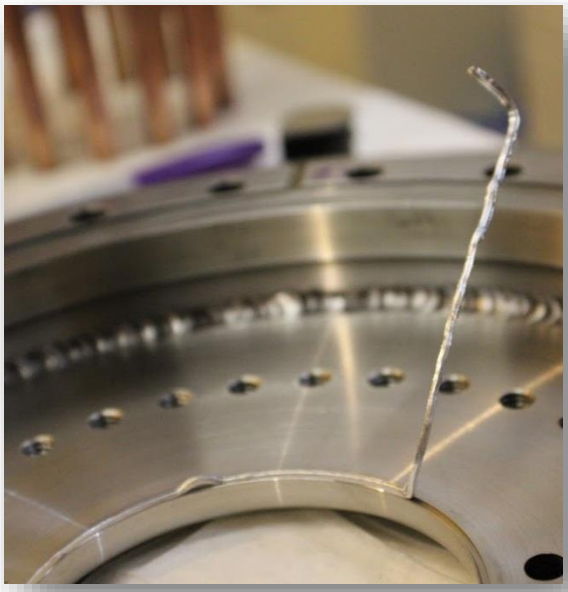
filaments indirectly, by depositing an uneven layer of contaminants like carbon onto both the anode and insulator surface. As the filament in the next shot passes over these contaminants, they pick up a heavy dose of heavy elements. This can either disrupt the filament entirely—like throwing a tennis ball through a smoke ring—or cause them to move more slowly than less-contaminated ones. Even a change in filament velocity of only a few percent can cause them to arrive too early or too late for good compression.

This plasma writing gives us greater confidence that as soon as the arcing is fixed, better filamentation, higher densities and higher yield will be produced.

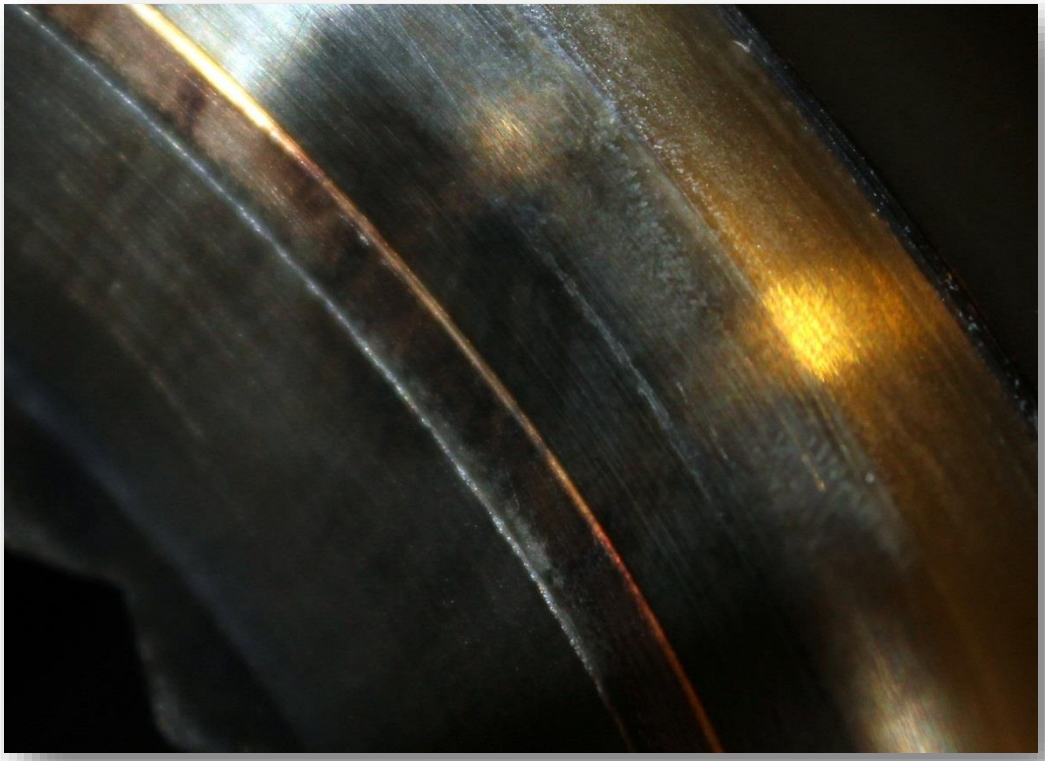
Arcing Illustrated: A Plasma's Progress



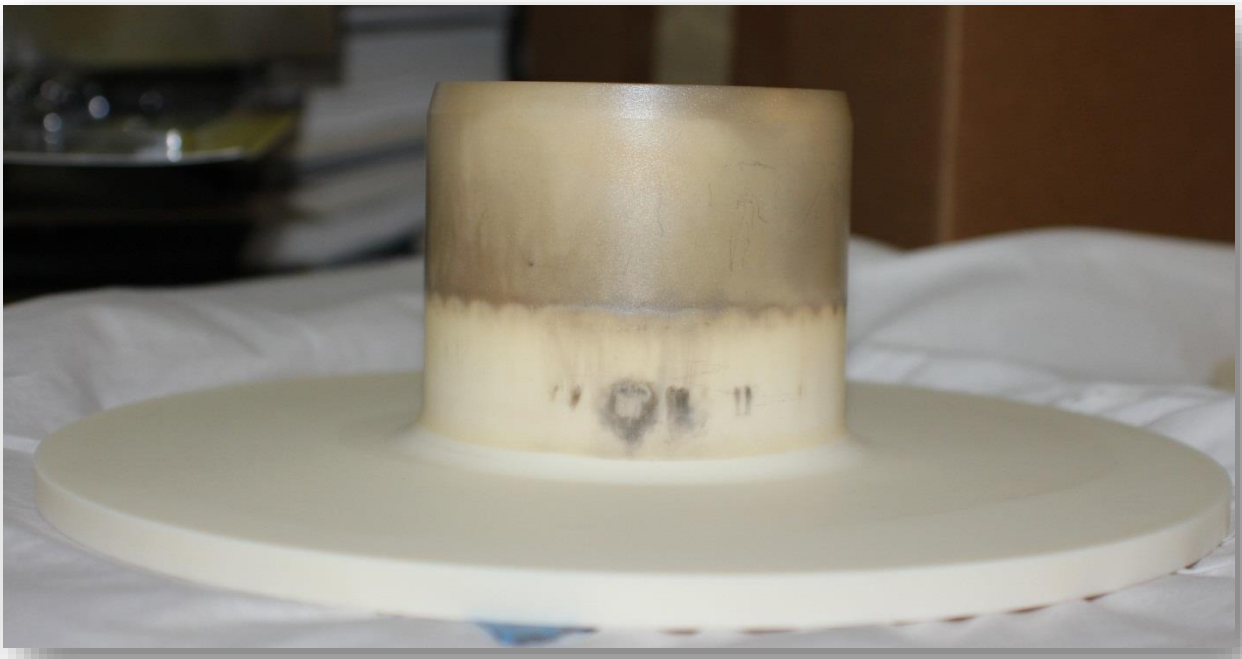
Left: Brass bolts pressing the copper cathode base to its steel buss were doubled, then switched to titanium to allow greater torque to be applied, in hopes of sufficiently crushing the copper to remove the gaps where arcing occurs.

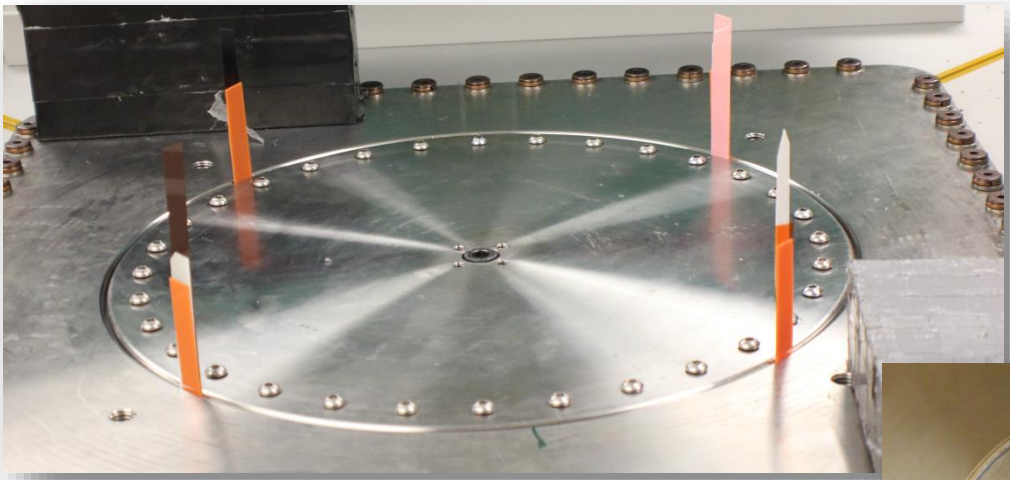


Right: A .040" wide groove was machined into the steel in which indium wire could be placed, as seen here after a test to make sure the indium would squish enough to completely remove any gaps between the contacts.

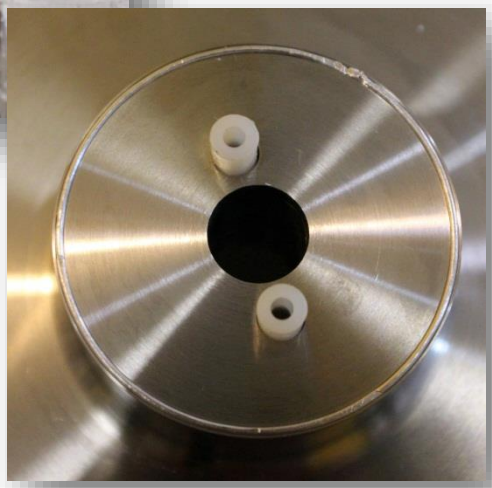


The contact between cathode copper steel (above) still showed a small degree of arcing, however, and deposited material on the outside of the hat insulator (below).

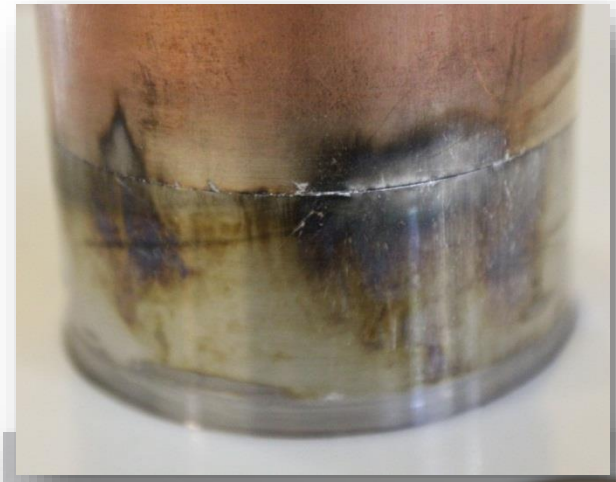




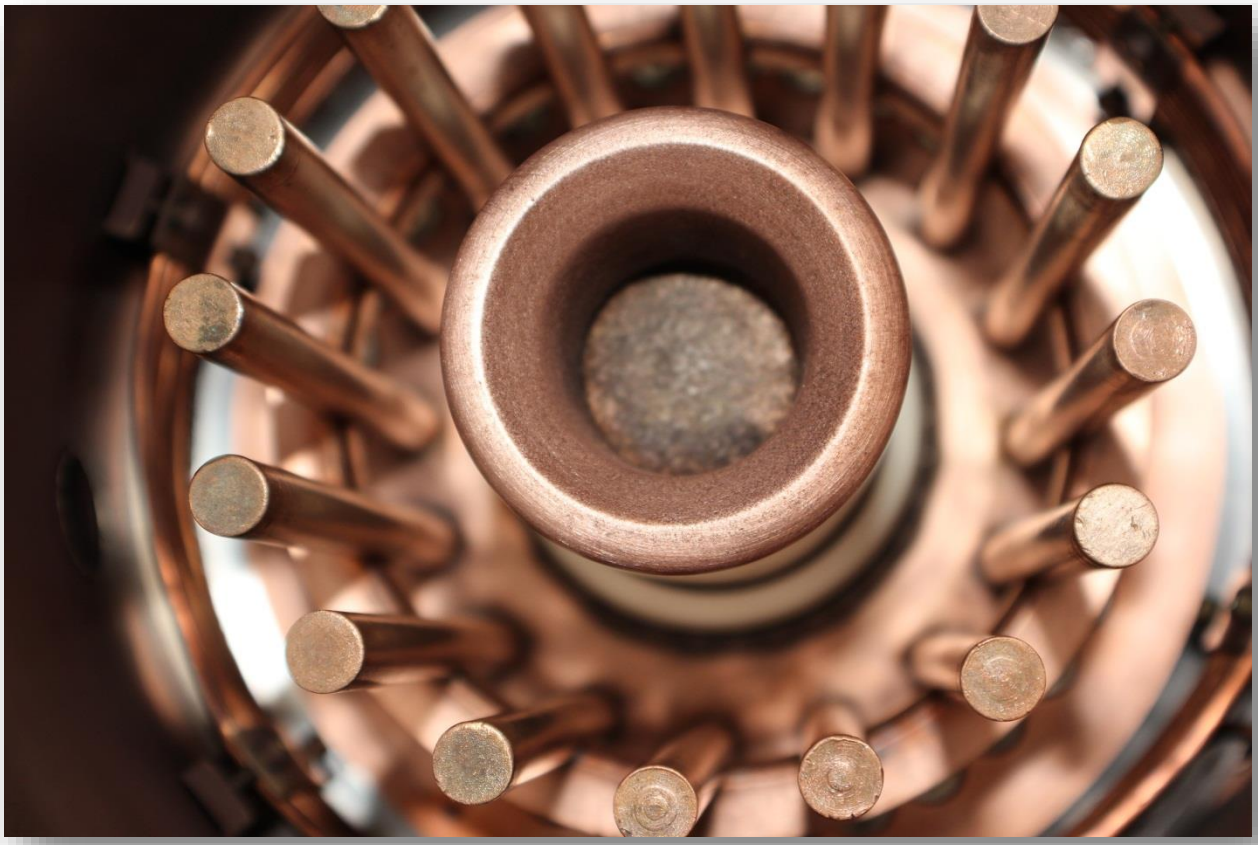
Below: The central bolt passes through to where the steel will meet the copper anode, and indium was also applied to allow any gaps at the current contact to be squished away.



Above: The reverse of the anode's steel buss, where after new mechanical calculations much greater torque was applied to the central bolt to squeeze out arcing.



Left: Arcing persisted most likely due to indium oxide that acted as an insulator. This will be removed with an acid wash during the next assembly. This will prevent metal and carbon ions from entering the plasma and depositing on the insulator (see below), processes which we believe disrupt filamentation & higher densities.



Soon to be shiny: While progress has been incremental, Focus Fusion-1's electrodes and insulator will be clean and re-assembled again by the end of this week. If the silver plating of the cathode steel buss and acid washing of the indium end arcing once and for all...

...Past fusion records should fall!