LPPFusion Report
June 10, 2020

Summary:

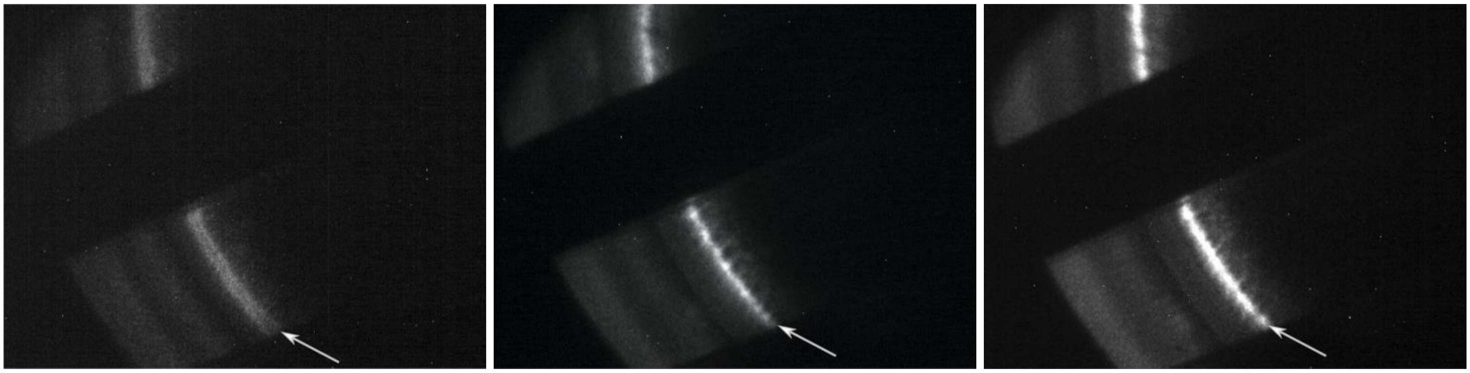
- **ICCD Video Reveals Shocks**
- **Major Software Upgrades Aid Thermal, Mechanical Simulations**
- **Plasma Simulation Advances**
- **Videos Gain New Visibility**

ICCD Video Reveals Shocks

A full sequence of images of the current sheath of LPPFusion's FF-2B experimental device shows that a shock wave is the most likely proximate cause of the disruption of filaments that has limited fusion energy yield. Our rapidly-advancing effort to provide new switches for FF-2B provides a path to eliminating the oscillations that cause these shock waves.

The first stage of operation of our FF-2B fusion experimental device produces a sheath of electric current running through a plasma along a ceramic insulator between our beryllium anode and the cathode that surrounds it. Back in November, 2019, the first images that our ICCD camera provided of the current sheath showed clearly that tight filaments of current were being created inside our FF-2B device. That was good, because the filaments are the first step in compressing the plasma and the more the plasma is compressed, the more fusion yield we get.

However, the images also showed, as we reported in January that the orderly filaments were getting disrupted at the leading edge of the current sheath (to the right in the images in Figure 1). At the time, we thought that the oscillations in current at the start of the pulse were creating two separate sheaths. The interaction between the sheaths were then disrupting the filaments. This in turn limited the yield, since a symmetric compression requires a symmetric array of filaments.



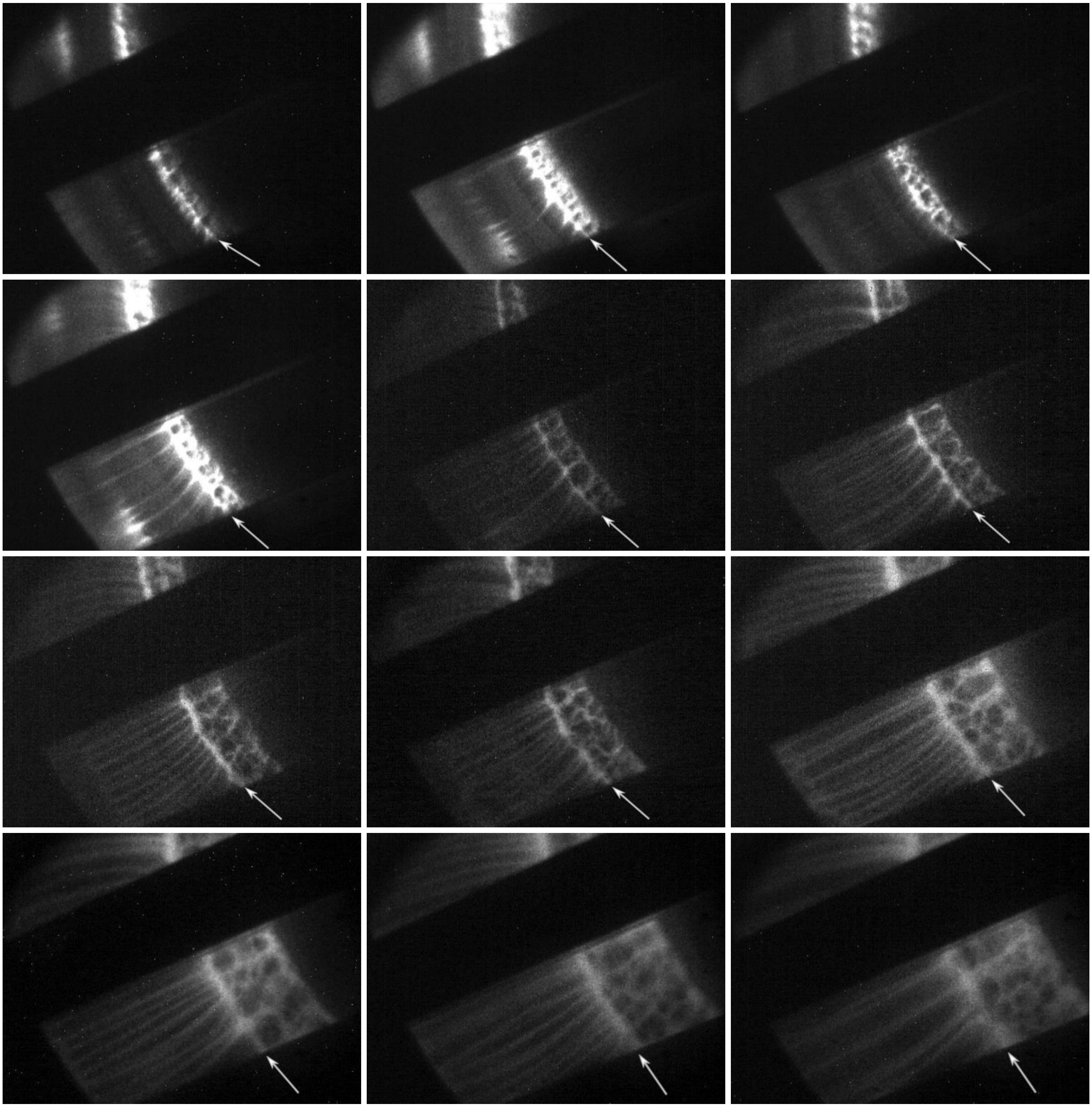


Fig. 1 This sequence of ICCD images, taken from November 2019 through January 2020 during similar shots of our FF-2B device now extends from 230 to 1100 ns, almost three times as long as our previous series (see Jan. 22 report). The images show what appears to be shock waves (bright wavy line) propagating through the current sheath, disrupting the filaments as it goes. This is a side view, looking at the sheath through the gaps between the cathode vanes (black strips). The insulator is to the left and the end of the anode is off-screen to the right.

But more data make for better hypotheses. In December 2019 and January, 2020, we were able to get additional images from later in the current pulse—extending up to 1100 ns, about two-thirds of the way to the peak of the current. They showed that a double sheath was not a good explanation of the images. Two sheaths would have traveled at almost the same velocity, with the rear one traveling about 90% of the distance that the front one traveled.

Instead our new images showed that the line separating the orderly filaments and the disordered ones traveled only a bit more than half as fast as the leading edge of the sheath.

What's going on here? We think the most likely explanation is a shock wave traveling back along the current sheath, disrupting the filaments as it travels. A shock wave (a wave traveling faster than the speed of sound in the plasma) would be created when the current oscillations that we've observed caused the current to rise, fall, then rise again.

If this hypothesis is correct, eliminating the dip in the current due to the oscillation in the current will also eliminate the shock, allowing the filaments to be orderly and symmetric all the way into the compression phase. From other researchers' work, we can see that lower-current machines, that have small oscillations also have orderly filaments (Fig. 2).

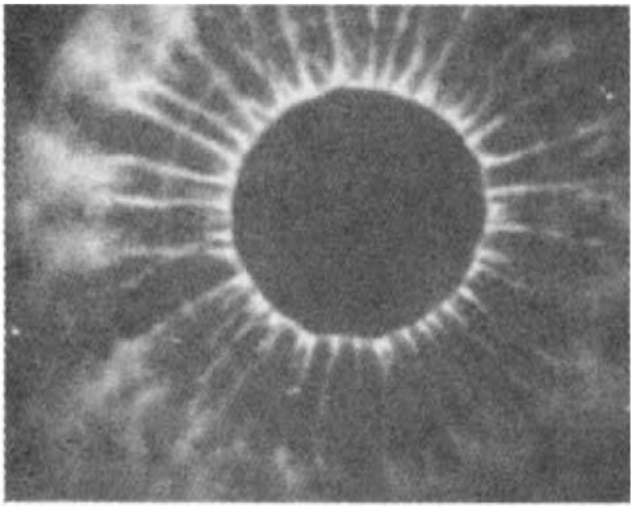


Fig. 2, Images of filaments in a smaller plasma focus device, showing orderly filaments and no shock wave. The view is looking along the axis of the anode (central dark circle). (Image from plasma-focus pioneer Winston Bostick).

The good news is this: if we require that the current not drop, the new switches will likely provide that. The switches will allow a faster rise in the current and a greater peak current. By making the rise time about 20% shorter and the peak current about 20% higher, they will make the rate of current rise over 40% higher. Right now, for these last shots, the oscillations were only 5-10 % larger than the current rate of rise. (Figure 3) But if the oscillations get no bigger—and we don't see why they should—then with the new switches the oscillations will be less that 75% of the size needed to produce a dip in the current—they will only produce a ripple, but no dip. So, we can expect no shockwave.

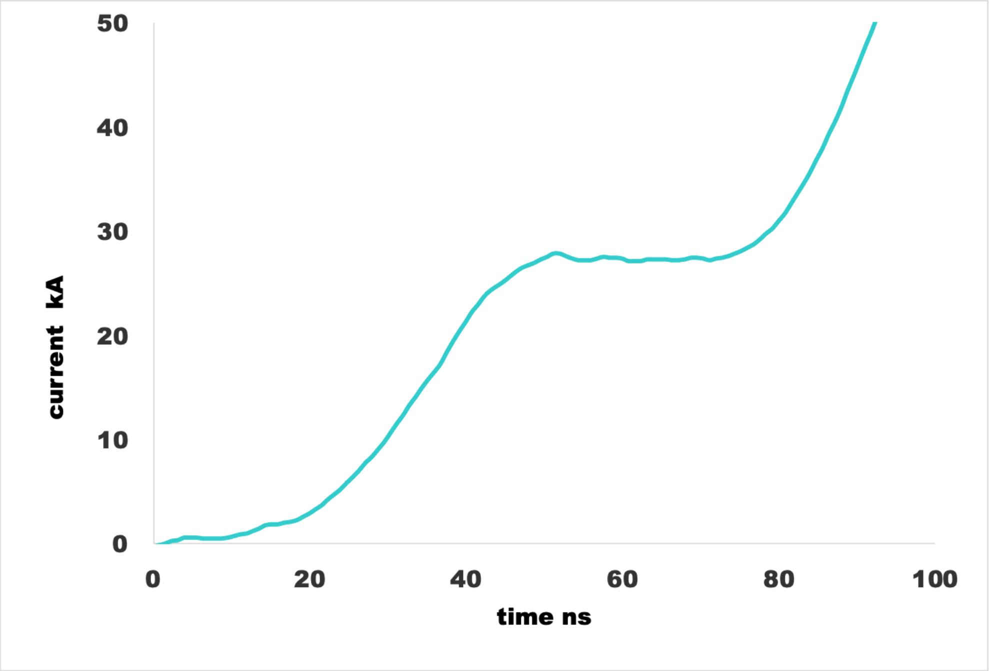


Fig. 3. In one of the last shots we took on January 17, shot 4, the dip in current (shown here at 55 ns) due to oscillations is barely noticeable. The faster rise time in current that we expect with the new switches should eliminate the dip altogether.

Major Software Upgrades Aid Thermal, Mechanical Simulations

Our CIO, Ivy Karamitsos, carried out a major IT upgrade thanks to the Wefunder crowdfunding investments that we gained this March. The upgrade cost just under $40K, but it was a long overdue investment into our infrastructure as we needed improved in-house capabilities for our engineering drawing software and simulation productions. We also purchased SolidWorks PDM, a project data management system, with this SolidWorks upgrade. This can help us to keep track of design versioning by various team members while ensuring the full compatibility of multi-layer components within each project. The upgrade includes a custom-made workstation for the simulation module, designed by Systems Administrator Jose Varela, and a network license server which will help our ongoing collaboration with many of our consultants, allowing them to work with us remotely.

With the new system in place, LPPFusion is expanding its use of a number of simulations in preparation for a new set of experiments in the fall. LPPFusion Mechanical Engineer Rudy Fritsch is working on a thermal and mechanical dynamic simulation of new anode designs. He is using a recently upgraded version of the commercial SolidWorks simulation suite combined with our new and faster hardware. The simulation will model the range of stresses that the anode will be subject to with the higher current expected from the new switches, showing how the part will react.

During the few microseconds that each shot lasts, the millions of amps of current moving through the anode will compress it through the pinch force—the same basic phenomena that compresses the plasma to produce fusion. At the same time, the resistance of the beryllium to the current will be heating it up, with the current and heat concentrated by the current filaments. That causes expansion. A third big effect is the ten-nanosecond-long pulse of heat from the plasmoid, mostly from X-rays. While most of the X-rays will harmlessly pass through the beryllium, the lowest-energy ones will be absorbed in the outer few microns of the metal.

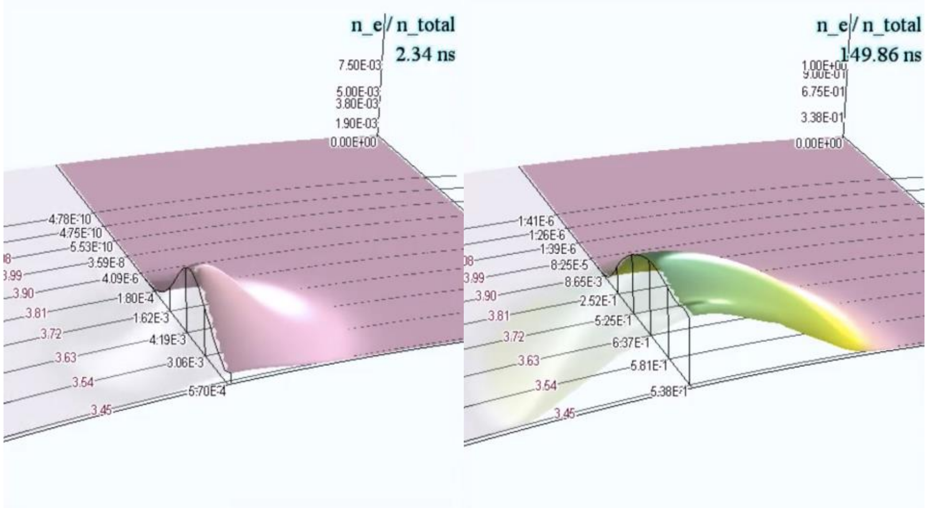
The inertia of the solid beryllium will prevent it from moving significantly during the shot. But the unbalanced forces, and deposited heat will act as “instantaneous” impulses that will start the anode vibrating after the pulse passes. The simulation will model these vibrations, showing us the maximum stresses.

For each design of the anode—different shapes and sizes of holes for example—we’ll do a number of simulation runs with different combinations of currents and plasmoid radiation, to sample the range of conditions we expect. We anticipate that the simulations will be a major help in selecting an optimum design.

Plasma Simulation Advances

Another simulation LPPFusion is working on is modeling the early stages of the current sheath within the plasma. This original simulation software is being developed by LPPFusion Simulations Researcher Dr. Warwick Dumas. It differs from the most common plasma simulations, called MHD, in accurately distinguishing the way electrons and ions behave when they are moving in the direction of the magnetic field, as compared with when they are moving across the field. The MHD approximation assumes that the particle acts the same way in all directions. This assumption leads to wrong models in our plasma focus device, because of its powerful magnetic fields. However, abandoning this simplification makes the computation of the simulation far more difficult, so Dr. Dumas has been working on the algorithms for some time.

In the past month, the simulation has been able to model the development of the current sheath in the first 220ns of the pulse, bringing the model up to the starting time of our ICCD image series. So, we will soon be able to compare simulations with observations. It is easy in the simulation to switch on or off the oscillations in the total current that we observe with our real machine. If the simulation models are validated, we may be able to get more insight into the effects of the oscillations and how to avoid them.



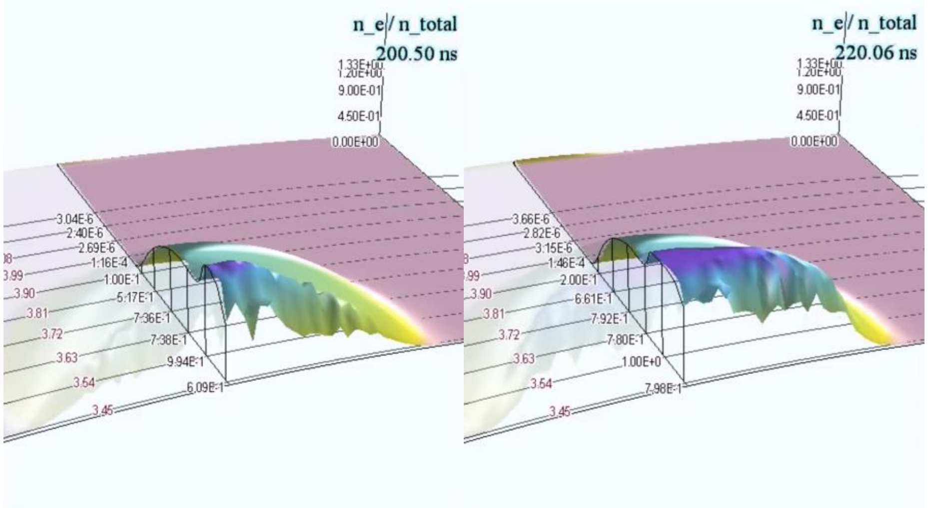


Fig. 4 Frames from a recent run of Dr. Dumas' simulation show a horizontal cross section of the region within a cm of the insulator around the anode. The insulator edge is toward the bottom of the frame. Increasing heights and deeper colors show increasing levels of ionization—the proportion of atoms that have lost their electrons. As the simulation progresses, ionization levels first rise smoothly over a large region. But then a sharp ridge of ionization, which appears to be forming filaments of current, boosts the ionization toward 100%. This ridge may correspond to the bright line seen in the first photo of the sequence in Fig. 1. More simulations are needed to be sure.

Videos Gain New Visibility

In a sign of growing interest in new ideas in cosmology, the first video in LPPFusion's ongoing series on "The Real Crisis in Cosmology" has now received nearly 150,000 views, far more than our other videos. We expect that this will attract new interest as well to our work in fusion. Lerner recently participated in an online teach-in on the coronavirus crisis. His presentation on "Energy, Finance, and the Coronavirus" is available here.