PFRC-2 X-ray report from the run of 2020/02/05

Prepared 2020/03/12

Charles Swanson

Machine configuration:

Inner 4x L-2-B set coils on each side powered by 2x TSD60-832/480+HS Magna-Power power supplies

Outer 4x L-2-B set coils on each side powered by “Big Blue,” Kinetics Control Systems Model SVRR-0125PM42TSY

L-2-A set coils on each side powered by “Big Blue,” Kinetics Control Systems Model SVRR-0125PM42TSY

Nozzle coils powered by rollaround power supply

SEC pumped by Leybold-Heraeus TurboVac 450, probably closed

CC pumped by 100 l/s Varian TV 141 Navigator, fully open

FEC pumped by Leybold-Heraeus TurboVac 450, partially open

Seed plasma RF frequency 27 MHz

RMF frequency 4.3 MHz

Room temperature flux conservers

H2 gas feed into SEC

X-ray configuration:

SDD3, serial number 19777, in CC midpoint mount installed on 2016/08/30 and whose variable apertures were changed on 2019/02/21

SDD1, serial number 27054 after repairs, in CC radial scan mount installed on 2018/01/24

X-ray scope C1: RMF on/off

X-ray scope C2: SDD3 SCA8, channel 0 to 1023

X-ray scope C3: SDD1 SCA8, channel 0 to 1023

X-ray scope C4: SDD gate signal

X-ray scope F2: Persistent histogram of C2

X-ray scope F3: Persistent histogram of C3

Run parameter envelope:

Magna-Power current 200 - 203 A

Big Blue current 328 – 334 A

Nozzle current 143 – 144 A

CC gas pressure 0.406 – 0.486 mTorr

Seed forward power 21 W

RMF forward power 62 – 72 kW

Experiments:

Aperture comparison with SDD3 to characterize suspected pileup spectrum

Long exposure at low aperture with SDD3 to obtain most trusted x-ray spectrum

Later long exposure at low aperture to evaluate drift

4x radial scans with SDD1

Pressure comparison with SDDs 1 and 3

Radial scan, recording count rate

Summary:

Parameters were found to drift and be irreproducible over an hours-long timescale, making short time between subsequent spectra essential

However, accumulations of only a few pulses (<60) occurring over short durations were *also* found to be irreproducible, which I speculate is due to individual pulses being varied in x-ray emission, requiring many pulses to average out.

Pressure was found to vary inversely with spectrum average energy

Either pileup or parameter drift precluded the possibility of confirming lack of pileup in the small-aperture, long-exposure SDD3 accumulations, but the most trusted spectrum corresponds to an electron density of 2.8E+12 /cc and an electron temperature of 50 eV. Spectra recorded from SDD1 during this same time broadly agree.

Radial scans were found to be somewhat irreproducible for the reasons described above. The best radial scan shows a peak in x-ray count rate at 4.5 cm and almost no emission outward of 7.5 cm. The faster scans, which were less reproducible, are consistent with this picture.

Recommended future work:

In the summary section, I speculate that individual RMF pulses are varied in terms of x-ray emission. This could be determined by taking 10 spectra of 100 pulses, or 100 spectra of 10 pulses, rather than 1 spectrum of 1000 pulses.

I recommend that we install a UV filter to remove pileup from the spectrum.

In the summary section, I speculate that some of the drift over the hours-long timescale is due to gas pressure drift. I recommend that we perform a 2 hour drift run during which the pressure is not allowed to vary by more than 5%. If we find that we are able to keep the x-ray spectrum constant, I recommend that we re-do the aperture comparison between Aperture 1 and Aperture 2.

Experiments: Aperture comparison with SDD3 and long-exposure with small aperture

Started 13:16, Spectrum 09

Ended 15:08 (long exposure), Spectrum 11

Experiment parameter envelope:

Magna-Power current 200 A

Big Blue current 331 A

Nozzle current 143 A

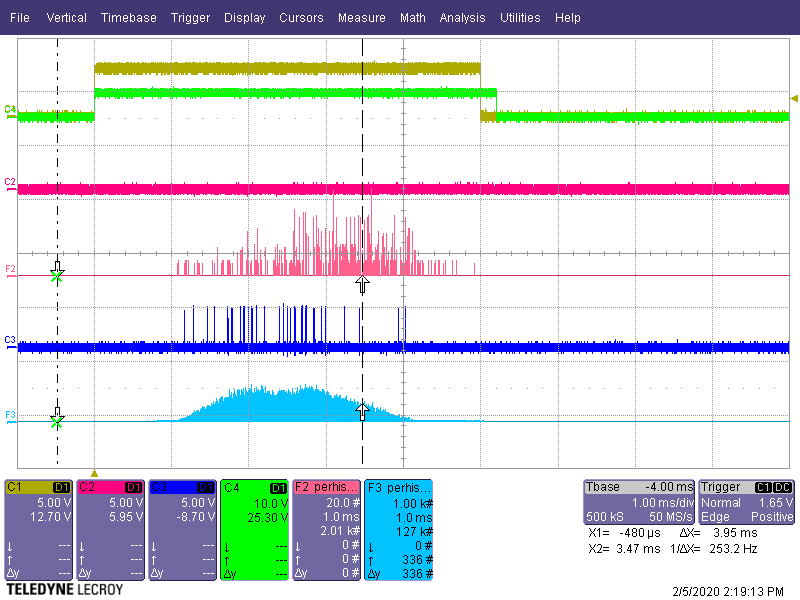
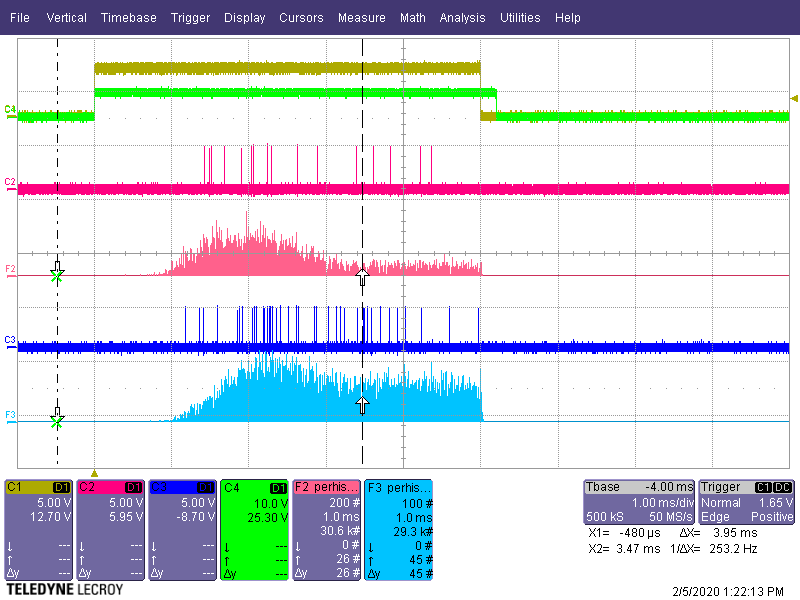
CC gas pressure 0.466 mTorr

Seed forward power 21 W

RMF forward power 72 kW

Figures:





Numerical results:

|  |  |  |
| --- | --- | --- |
|  | Spectrum 09, Aperture 2 | Spectrum 11, Aperture 1 |
| Raw count rate above threshold | 3300 /s | 49 /s |
| Volumetric count rate above threshold | 8.2E+08 /s/cc | 6.2E+07 /s/cc |
| Maxwellian fit temperature | 29.9 eV | 49.7 eV |
| Maxwellian fit density | 2.3E+15 /cc | 2.8E+12 /cc |
| <E – Ethreshhold> | 52 eV | 80 eV |

Comments:

At first glance, it would appear that this is evidence that either Aperture 2 or Aperture 1 or both are too large and are allowing pulse pileup. However there is a complicating factor: Spectrum 11 was allowed to accumulate for almost two hours, and we have reason to believe that parameters changed on this timescale.

Spectrum 11 depicts a plausible electron population. The electron density as measured by the interferometer is 3.1E+12 /cc, falling to 9.4E+11 /cc by 2 ms into the pulse. The initial value is close to the 2.8E+12 /cc Maxwellian fit.

Spectrum 09 depicts a plausible electron temperature, but its Maxwellian fit density of 2.3E+15 /cc is contradicted by the interferometer measurement. As always, the SDDs respond to electrons above a certain energy only, in this case 256 eV, and this spectrum may simply be indicative of a non-Maxwellian distribution.

From this data, we can not confirm that aperture 1 of the CC midpoint mount is small enough to exclude pulse pileup, but if it is, electron temperatures and densities of 50 eV, 2.8E+12 /cc are indicated.

Experiment: Later long-exposure, small-aperture spectrum to evaluate drift:

Started: 15:09, Spectrum 25

Ended: 16:15, Spectrum 25

Experiment parameter envelope:

Magna-Power current 200 A

Big Blue current 331 A

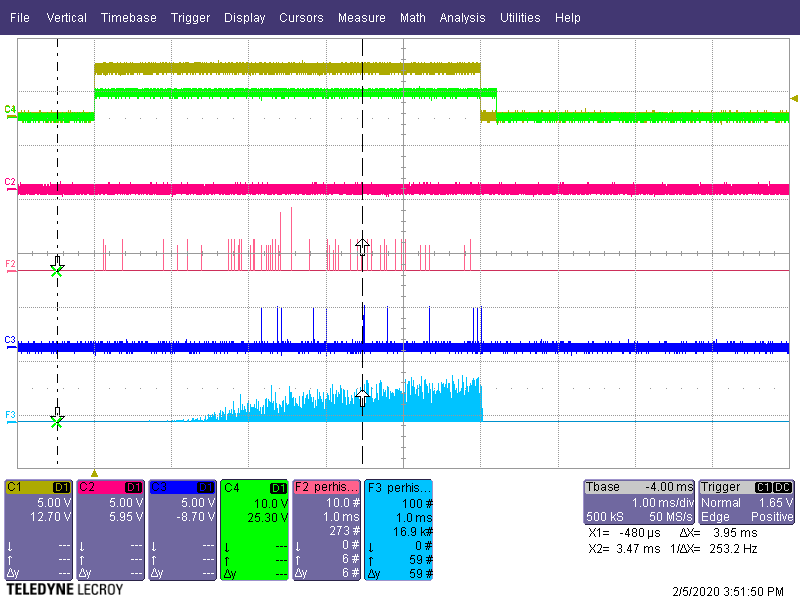
Nozzle current 143 A

CC gas pressure 0.466 mTorr

Seed forward power 21 W

RMF forward power 72 kW

Figures:



Comments:

Comparing Spectrum 11 and Spectrum 25 reveals that the slope of the x-ray spectrum shortened significantly over the course of these accumulations. Spectrum 11 was accumulated from 13:24 to 15:08. Spectrum 25 was accumulated from 15:09 to 16:15.

Experiment: 4x radial scans with SDD1

First Scan:

Started: 13:24, Spectrum 12

Ended: 15:23, Spectrum 26

“Quickscan”:

Started: 15:23, Spectrum 27

Ended: 15:33, Spectrum 33

“Quickscan 2”:

Started: 15:39, Spectrum 34

Ended: 15:41, Spectrum 35

“Quickscan 3”:

Started: 15:43, Spectrum 36

Ended: 15:59, Spectrum 43

Experiment parameter envelope:

Magna-Power current 200 A

Big Blue current 331 A

Nozzle current 143 A

CC gas pressure 0.466 mTorr

Seed forward power 21 W

RMF forward power 72 kW

Figures:

Initial Scan:



“Quickscan”:



“Quickscan 3”:

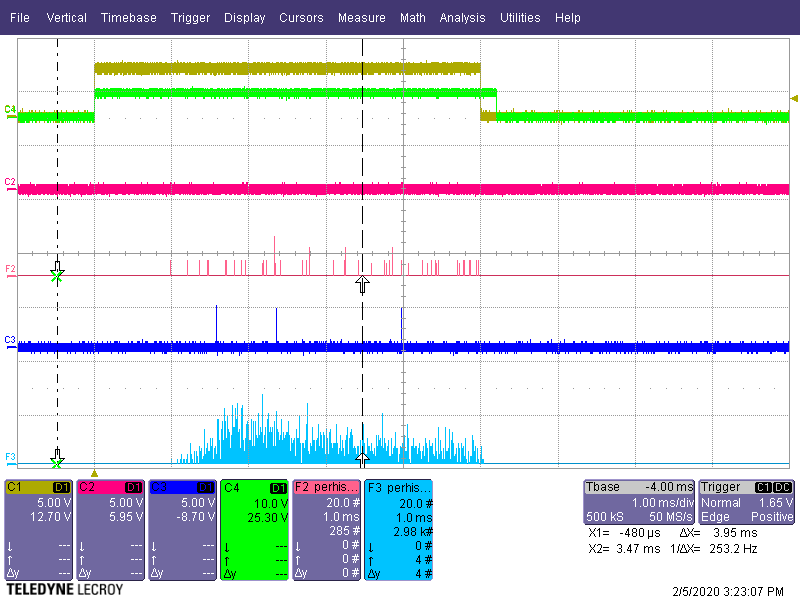
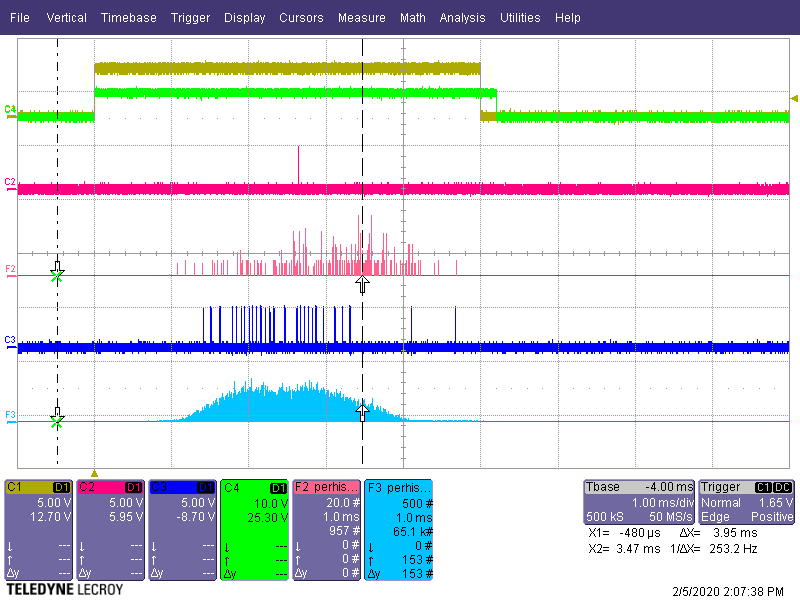


A downward trend in energy overall:



Some characteristic spectra:





Comments:

Irreproducibility of the spectrum:

In the figures that plot volumetric count rate vs radial intercept, there is not a clear pattern in the “quickscans”. The quickscans were very short scans, wherein only a minute was spent at each radial intercept, recording an average of 60 pulses. It could be that 1) the pulses are relatively reproducible but conditions change on a minute-long timescale or 2) pulses themselves are varied on x-ray production. If (1) is true, we should take many short-exposure spectra in a short duration. If (2) is true, we should take many long-exposure spectra in a long duration. Based on other data recorded this day, it is likely that both are true: there is variation over the span of an hour and individual pulses are varied in x-ray emission.

Peakedness of the count rate:

Regardless of the irreproducibility, it is clear from the highest-quality data (“initial scan”) and consistent with the quickscans that the x-ray emission peaks between 3.5 and 6.5 cm and there is very little outward of 7.5 cm.

Uniformity of slope:

In the plots of spectra, the slopes of the spectra are quite uniform. If these were piled up spectra or RMF noise, one would expect that the slope of the spectrum would grow longer with increasing count rate. That this does not happen may indicate that we are receiving one-to-one x-rays (not pileup) from an FRC of constant temperature but radially varying density.

Decrease in slope over the course of the run:

In the “downward trend in energy overall” figure, you can see that the earlier spectra recorded “hotter” x-rays than later spectra. These average energies above the threshold correspond to Maxwellian fit temperatures of approximately 50 eV before the quickscans, and 35 eV after the quickscans. From this data, it is apparent that conditions change over an hours-long period.

Agreement with the long exposure from SDD3:

The Maxwellian fit temperature and density of Spectrum 16 agree well with the Maxwellian fit density and temperature of Spectrum 11, the long-exposure, small-aperture accumulation of SDD3. Spectra 16 – 23 broadly agree with Spectrum 11, which was accumulated during the accumulation of these other spectra. Before Spectrum 16, the slope is too shallow/hot to agree with Spectrum 11, and after Spectrum 23, the slope is too steep/cold to agree with Spectrum 11. This agreement provides evidence in support of the spectra being one-to-one x-rays, and evidence in support of a 2E+12 /cc, 50 eV plasma during this scan.

Experiment: Lower pressure by 20%

Started: 16:28, Spectrum 46

Ended: 16:33, Spectrum 49

Experiment parameter envelope:

Magna-Power current 200 A

Big Blue current 331 A

Nozzle current 143 A

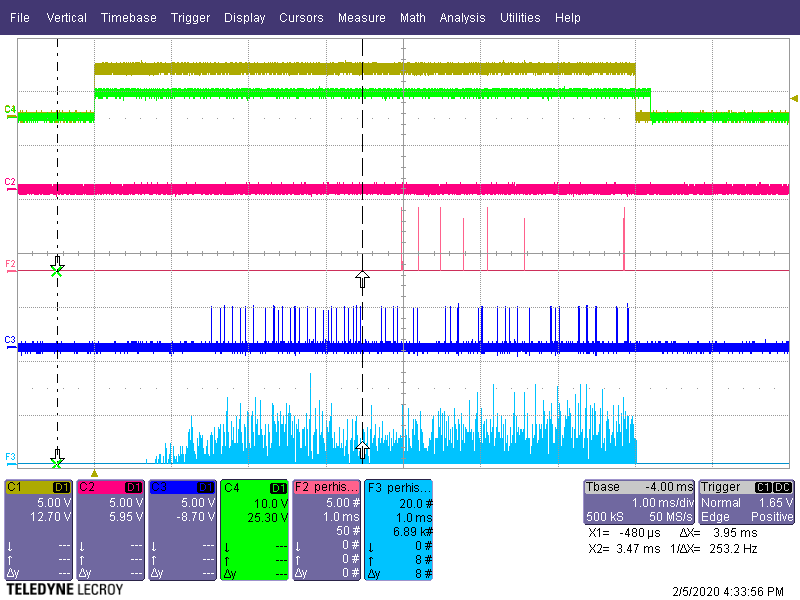
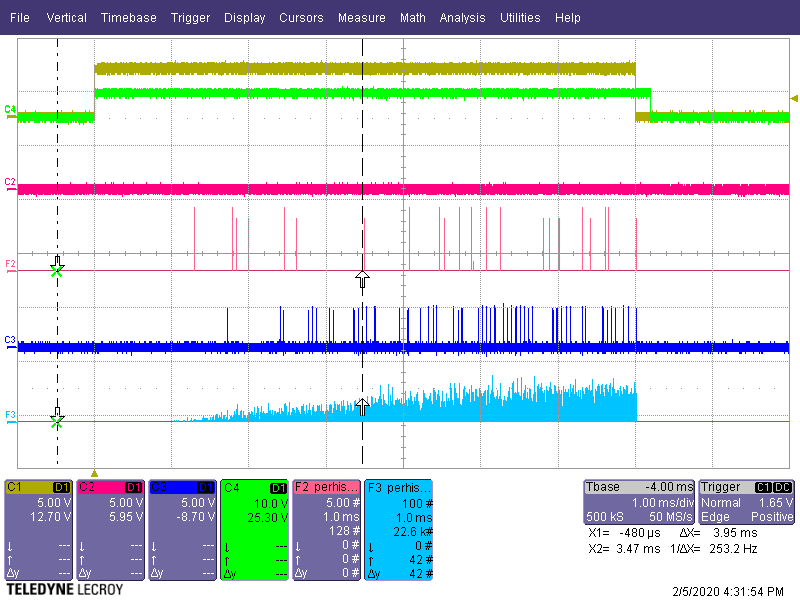
CC gas pressure 0.406 – 0.486 mTorr

Seed forward power 21 W

RMF forward power 72 kW

Figures:





Numerical results:

|  |  |  |
| --- | --- | --- |
|  | Spectrum 47, 0.486 mTorr | Spectrum 49, 0.406 mTorr |
| Raw count rate above threshold | 9,900 /s | 13,000 /s |
| Volumetric count rate above threshold | 9.8E+7 /s/cc | 1.3E+8 /s/cc |
| Maxwellian fit temperature | 31.4 eV | 49.3 eV |
| Maxwellian fit density | 1.2+14 /cc | 5.8E+12 /cc |
| <E – Ethreshhold> | 46 eV | 64 eV |

Comments:

A 20% decrease in pressure was sufficient to make the spectrum behave as it did during the initial scan. The slope became shallower/hotter and the Maxwellian fit parameters matched better the interferometer measurement. It may be that much of the variability over an hours-long timescale is due to pressure drift.

Experiment: Radial scan, recording time trace

Started: 13:24, Spectrum 12

Ended: 15:23, Spectrum 26

Experiment parameter envelope:

Magna-Power current 200 A

Big Blue current 331 A

Nozzle current 143 A

CC gas pressure 0.466 mTorr

Seed forward power 21 W

RMF forward power 72 kW

Figures:

|  |  |
| --- | --- |
| 12-SDD1-0divs.mca  0.5 cm radial intercept  1:24 – 1:32 |  |
| 13-SDD1-0divs-drift.mca  0.5 cm radial intercept  1:32 – 1:36 |  |
| |  | | --- | | 14-SDD1-1divs.mca  1.5 cm radial intercept  1:36 – 1:44 | |  |
| 15-SDD1-2divs.mca  2.5 cm radial intercept  1:44 – 1:55 |  |
| 16-SDD1-3divs.mca  3.5 cm radial intercept  1:55 – 2:08 |  |
| 17-SDD1-4divs.mca  4.5 cm radial intercept  2:07 – 2:20 |  |
| 18-SDD1-5divs.mca  5.5 cm radial intercept  2:20 – 2:28 |  |
| 19-SDD1-3divs.mca  3.5 cm radial intercept  2:28 – 2:35 |  |
| 20-SDD1-4divs-reshield.mca  4.5 cm radial intercept  2:35 – 2:45 |  |
| 21-SDD1-8divs.mca  8.5 cm radial intercept  2:45 – 2:47 |  |
| 22-SDD1-7divs.mca  7.5 cm radial intercept  2:47 – 2:56 |  |
| 23-SDD1-6divs.mca  6.5 cm radial intercept  2:56 – 3:05 |  |
| 24-SDD1-5divs.mca  5.5 cm radial intercept  3:05 – 3:10 |  |
| 26-SDD1-7divs.mca  7.5 cm radial intercept  3:10 – 3:23 |  |

Comments:

This is potentially an interesting measurement because in principle it can tell us the time-history of the radial profile. However in practice it was not reproducible; see the same radial position at multiple times.

There are some hints that at intermediate radial intercepts (3 – 5 cm), the count rate was low, then peaked, then dropped, while at extreme radial intercepts (0 and 7 cm), the count rate was more uniform throughout. This would indicate that the hot spot formed and dissipated.