Experiments and Simulations on the Possibility of Radiative Collapse in the Plasma Focus PF-1000

M. Akel,[1] J. Cikhardt,[2] P. Kubes,[2] H.-J. Kunze,[3] S. Lee,[4] M. Paduch,[5] and S. H. Saw[4]

[1] Department of Physics, AEC, Damascus, P.O. 6091, Syria
[2] Czech Technical University, Prague, Czech Republic
[3] Institute for Experimental Physics V, Ruhr-University Bochum, Germany
[4] INTI International University, Nilai, Malaysia
[5] Institute for Plasma Physics and Laser Microfusion, Warsaw, Poland

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We report starting investigations on the possibility of radiative collapse in the plasma focus device PF-1000.

The *concept of radiative collapse* has been known for a long time and was introduced in 1957 independently by Braginskii and Pease for pure *z-pinch* plasmas of hydrogen/deuterium.

S. I. Braginskii, Sov. Phys. JETP **6**, 494 (1957)
R. S. Pease, Proc. Phys. Soc. **70**,11 (1957)

They started from a z-pinch in Bennett equilibrium

$$(1+Z)N_i kT = \frac{\mu_o}{4\pi} I^2$$

which is independent of the pinch radius r.
N_i = number of ions per unit length, $T_e = T_i = T$.
r depends on the *energy balance* between Joule heating P_I and radiation losses P_{rad} by bremsstrahlung.

In equilibrium $P_I = P_{rad}$

In this case a unique current exists, which is known as Pease-Braginskii current I_{PB}:

$$\frac{I_{PB}}{\text{MA}} \approx 0.27\sqrt{\ln\Lambda}\left(1+\frac{1}{Z}\right)$$

It holds for homogeneous density and temperature profiles; weak temperature dependence is through Coulomb logarithmus. No internal magnetic fields and no plasma end losses! The factor 0.27 changes with refined calculations!

Interesting case: no power balance !

We introduce the time constant for energy loss by radiation

$$\tau_{rad} = \frac{(3/2)\,(1+Z)N_i kT}{P_{rad}}$$

and obtain from the energy equation

$$\frac{1}{r}\frac{\mathrm{d}r}{\mathrm{d}t} = \frac{3}{4}\frac{1}{\tau_{rad}}\left(\frac{I_{PB}^2}{I^2} - 1\right)$$

$I > I_{PB}$ contraction
$I < I_{PB}$ expansion

Is PF-1000 suited to see a contraction/collapse?

Minimum requirement:

Atom	Fully Ionized	50% stripped	I_{PB}
H/D	40 eV		1.70 MA
He	160 eV	30 eV	1.27 MA
Ne	4000 eV	680 eV	0.94 MA

The maximum current at the typical operating voltage of 27 kV with D_2 filling is in PF-2000 about 2 MA, the pinch current is about 2/3 of that

→ *Small chance to see an effect with D_2 discharges, discharges in He are at the boundary, but starting with Ne and heavier gases those plasmas remain of interest.*

Furthermore, heavier gases are not fully ionized and line radiation from the ions can exceed the bremsstrahlung emission by up to several orders of magnitude, thus reducing the critical Pease-Braginskii current drastically !

Unfortunately in two experimental campaigns past year the device could not be operated at sufficiently high currents, and only a few usable results were obtained for D and He. For Ne discharges we turned, therefore, to earlier experiments which had been already analyzed under *different* aspects and reported.

The following table summarizes our results so far:

Shots	Number of shots	Gas	p/ Torr	U/ kV	I_{max}/MA	I_{pinch}/ MA	d/ cm	r_{min}/a	r_{min}/a sim.
10095ff	3av.	Ne	0.5	23	1.7	1.14	0.53	0.023	0.13
10125ff	4	Ne + D_2	0.55	23	1.7	1.2	0.53	0.023	0.12
10103ff	3av	Ne + D_2	0.8	23	1.8	1.33	0.57	0.024	0.09
10112	1	Ne + D_2	1.0	23	1.95	1.38	0.75	0.032	0.05
10063ff	4	D_2	1.5	23	1.8	1.25	1.4	0.061	
10630	1	D_2	1.5	21	1.7	1.2	1.3	0.057	0.19
10915	2	He	0.9	16	1.2	0.9	1.0	0.044	0.18

The column r_{min}/a (minimum plasma radius to anode radius gives the measure for compression)

The values were derived from interferograms

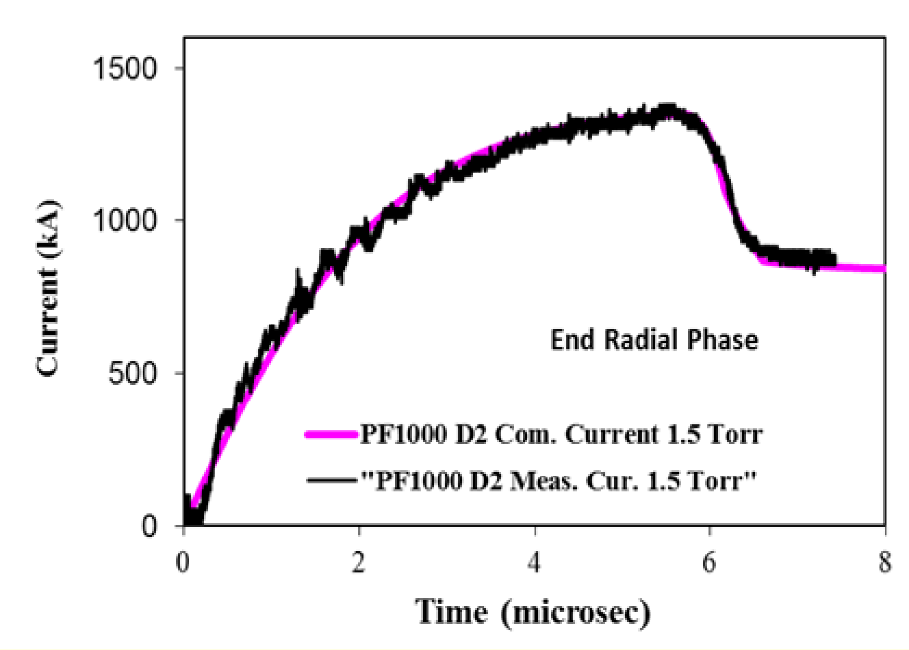
The interpretation poses a problem:

Zippering during compression phase!
End losses which would reduce I_{PB}?
Internal magnetic fields?

The second leg of our studies are numerical simulations of the complete plasma focus discharge employing the 5 phase Lee model code, which calculates the radial trajectories and includes, in addition to bremsstrahlung, line and recombination radiation.

Inputs are first the bank parameters
tube parameters
charging voltage
gas parameters and filling pressure

Then, a calculated current waveform is fitted to an experimental current waveform by 4 model parameters.



This figure shows a fitting of the model current to the experimental current for a deuterium filling with 1.5 Torr

With these model parameters calculations were done for the discharges of the above table, and the last column gives the obtained values r_{min}/a .

In all cases the normalized experimental minimum radius is smaller than the computed one!

One possible explanation:

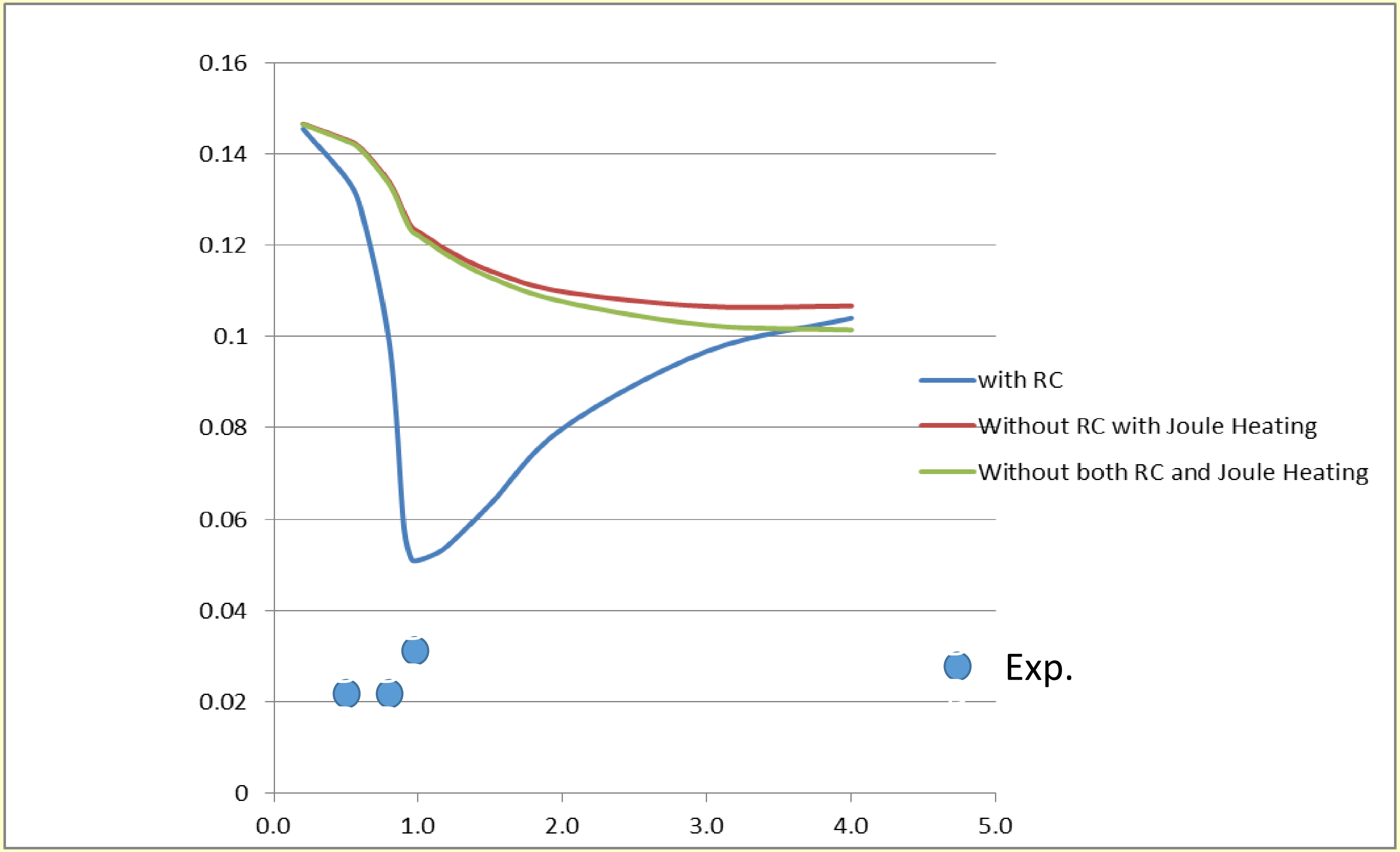
zippering and end losses

Identification of the influence of radiation:

Simulations were carried out with and without radiation losses

For D_2 and He discharges no essential differences in the dynamics and in the minimum radius showed up

This was different with Ne as the next figure reveals



Turning off radiation losses changes the dynamics of the piston and the final minimum radius !
The influence of radition is obvious

The combination of experiment and simulation thus gives guidance to the studies of radiation effects in focus discharges