

RADIAL DENSITY AND TEMPERATURE PROFILES OF AN IMPLoding Z PINCH HELIUM GAS PUFF

P. Zehnter, A. Bardot, J.Y. Boutin, D. Friart, L. Jacquet, J. Pornet¹, A.M. Gasque,
P. Romary², S. Dan'ko, Y. Gorbulin, Y.G. Kalinin, A. Kingsep³

¹ CEA / Bruyères le Châtel, BP 12, 91680 Bruyères le Châtel, France

² CEA / CESTA BP 4, 33114 Le Barp, France

³ Russian Research Center Kurchatov Institute, Kurchatov sq. 123182 Moscow, Russia

Abstract

In this paper, we will describe a simple method to determine the density and temperature profiles of an imploding helium gas puff. The helium gas is magnetically imploded by means of Ambiorix, a 6 TW generator located at CEA/CESTA. In order to decrease MHD instabilities and to reduce the radial electronic thermal conductivity, an axial B_z magnetic field was generated by two Helmholtz coils. To determine the density and plasma temperature profiles, we used a set of filtered different XRD, a time integrated pinhole camera and numerical results given by a 1.5 MHD code. These results are similar to those given by a spectrometer measuring the K-lines of tracers mixed in 1% atomic addition on pure helium. We observed clearly the effect on the final temperature of the presence of tracers.

1. Introduction

A collaboration between french CEA parts and the Kurchatov Institute of Moscow has begun in 1993. A new way to transform a large part of magnetic energy stored in a Z-Pinch was first proposed by L. Rudakov [1, 2, 3]. This concept is based on the effect of B_z field influence to limit the radial thermal conductivity of electrons [4, 5]. A hollow cylinder of helium gas (low atomic number Z) produced by a supersonic annular nozzle is imploded by mean of the Ambiorix generator. Compression of the liner induces compression of the magnetic flux onto the axis.

1-D MHD simulations predict a plasma corona with high density and low temperature and a central core with low density and high temperature. It turns out that such a profile can be obtained only by the presence of the axial magnetic field which reduces the thermal conductivity of electrons. When magnetisation of electrons is turned off in coefficient transport, the temperature profile is very smooth.

Various methods are presented here to measure the temperature and density of the liner. The first one is base on XRD with different filters coupled with an X-ray pinhole camera and an optical streak camera with a slit along the radius. The second one is based on a spectrometer measuring the K-lines of tracers mixed in 1% atomic addition on pure helium.

Tracers are the following : neon for T_e between 200 and 500 eV and argon for $T_e > 1300$ eV ($T_e=0.3*Z^{2.9}$).

2. Experimental setup

The present experiment has been performed on AMBIORIX [6], a pulsed power generator located at CESTA. Ambiorix is a 6 TW generator with a 300 kJ Marx bank. The output parameters are the following : 1.2 MV, 2.4 MA with a 50 ns rise time on a 0.5 W vacuum diode.

The helium liner shell is produced with a supersonic nozzle by means of fast valves. The mean diameter of the nozzle is 40 mm with a shell thickness of 1.5 mm. The plasma length is 10 mm. The magnetic field is generated by two Helmholtz coils around the diode which generate the field before the current into the diode. Such a schedule allows producing of an uniform axial B_z in the liner volume [7]. The initial density profile of the liner has been measured with a Michelson interferometer and is in very good agreement with initial conditions given for the 1D MHD code. The total mass of the liner is 80 μg .

The set of diagnostics is the following :

To measure the temperature of different parts of the pinch, neon and argon tracers were mixed with the helium plasma. We observed with a curved mica spectrometer the neon He_α and H_α lines (922 and 1022 eV) and the He_α lines of argon (triplet : 3107, 3125, 3140 eV). An X ray pinhole camera give a time integrated picture of the plasma. The optical streak camera can also give access to the corona radius, the implosion time and compression velocity. Five detectors were used with different filters. A general and well known idea is to observe the radiative recombination tail which is a function of temperature.

For such a plasma with density in the order of 10^{20} cm^{-3} and temperature in the order of 100 eV, the mean free path of photons is much more than the plasma size. Therefore no opacity effects have to be taken into account.

The method proposes to consider each part of the pinch and to observe at different spectral ranges. Then, low photon energy range (low temperature) can be measured with thin filters, high temperature (high photon energy range) can be observed with thick filters.

To deconvolve the signals, the methodology is :

- first, getting the measurement of the central plasma core and the corona part on the pinhole camera. The corona part is also observed by means of the optical streak camera.
- second, considering two different parts with constant density and temperature profiles. It is possible to get a set of values for each zone which fit well with experimental signal for each detector.
- third, fitting this simple profile with the one given by the code. It is possible to find out after many iterations a realistic profile. The physical aspect is the following :

The total free-free + free bound bremsstrahlung emissivity coefficient is given by :

$$J(n_e(r), T_e(r), \nu) = A \cdot n_e^2(r) \cdot \sqrt{T_e(r)} \cdot \left(1 + \frac{Z(r)^2 \cdot E_{\text{th}}}{T_e(r)}\right) \cdot e^{\frac{-h \cdot \nu}{k \cdot T_e(r)}}$$

$Z(r)$ is the atomic number, T_e is the electronic temperature, n_e the density.

Let $S_i(h\nu)$ be the sensitivity of the detector number i in C/ keV. Taking into account the i filter transmission $T_i(h\nu)$ associated with detector n° i , it is possible to get information from different spectral range of energy.

The signal received by the detector is :

$$V_i = A1 \cdot \int_0^{r_1} \int_{\nu_1}^{\nu_2} S_i(h\nu) \cdot T_i(h\nu) \cdot n_e^2(r) \cdot \sqrt{T_e(r)} \cdot \left(1 + \frac{Z(r)^2 \cdot E_{IH}}{T_e(r)}\right) \cdot e^{\frac{-h\nu}{k \cdot T_e(r)}} \cdot r \cdot dr \cdot dh\nu$$

The first approximation is to consider the hot central core for high energy photons ($h\nu > 2$ keV). This part has to be observed with thick filter. Then, corona response to this signal is less than 10 %. Therefore a first calculation for the core temperature can be made under the assumption that the profile is constant. With the knowledge of detector voltage and the plasma size of hot core, it is possible to calculate the density.

The same calculations can be made for corona temperature. For very thin filter, the voltage of the detector is mainly due to the corona. For “normal” filter, the voltage of the detector is a combination of each part.

Our detectors were absolutely calibrated in our laboratories by means of fluorescent targets. Our theoretical models for detectors can be fit with these measurements. Filters were also absolutely calibrated in transmission.

The set of filters for this experiment was:

For the central part (high temperature, low density)

- 2 Pin diodes, Ti 45 μm + Al 9 μm + Mylar 2.5 μm , Zn 15 μm + Mylar 2.5 μm

For both central part and corona part

- 1 Pin diode ,CCl 45 μm + Mylar 5 μm

For the corona part

- XRay Diode with gold photocathode Mylar 2.5 μm and Pin diode CCl 15 μm + Mylar 2.5 μm

In this experiment, all detectors were protected from anode and cathode emission by a thick copper collimator.

3. Experimental results

a) First experiments were done with neon and argon tracers in 1% atomic addition on pure helium gas. The applied axial magnetic field is $B_z=0.3$ T. The neon He_α and H_α lines (922 and 1022 eV) and the He_α lines of argon (triplet) were observed. The H_α lines are very weak compared with the He_α lines. Therefore the temperature can be estimated between 200 and 500 eV.

The He_α lines from argon were not observed (3rd order) but we observed the radiative recombination tail from hydrogen like and helium like ions from neon (1.36 keV and 1.2 keV). It means a temperature between 1000 and 1300 eV.

The streak camera and pinhole camera give a central part with a radius 0 to 1.2 mm and a corona part between 1.2 mm and 1.6 mm. The compression ratio is of the order of 10. The length of the emissive zone of the pinch is 8 mm and the emission is homogeneous along the z axis. We find a central part with a temperature of 1100 eV (between 900 and 1200 eV) and density $6.5 \cdot 10^{19} \text{cm}^{-3}$. The corona part is with temperature of 250 eV (between 150 and 400 eV) and density $5 \cdot 10^{20} \text{cm}^{-3}$.

These values are in very good agreement with the spectroscopic ones.

Compared to the values given by the code without impurities, the plasma temperature of the central part is less than the calculated one (1.9 keV) for a radius between 0- 800 μm . The calculated density of the corona part is $1.2 \cdot 10^{21} \text{cm}^{-3}$ for a radius between 800 μm and 1.3 mm.

b) Second experiments were done without neon and argon tracers. The applied axial magnetic field is $B_z=0.3 \text{ T}$.

As previously, the streak camera and pinhole camera give a central part with a radius 0 to 1.2 mm and a corona part between 1.2 mm and 1.6 mm. The compression ratio is also in the order of 10. The pinch seems to be a little more instable and 50% of the pinch contributes to X-ray emission. We find a central part with temperature of 2000 eV (between 1800 and 2200 eV) and density $2.2 \cdot 10^{19} \text{cm}^{-3}$.

The corona part is with temperature of 300 eV (between 250 and 350 eV) and density $4 \cdot 10^{20} \text{cm}^{-3}$. We get very good agreement between calculation and experiment.

4. Conclusion

We have presented a method to measure the density and temperature profile. We find that impurities in light gas decrease the final predicted temperature by a factor of two (2000 eV without tracers, 1000 eV with). We also demonstrated the effect of B_z axial magnetic field on the decrease of radial thermal conductivity. In this experiment, the liner implosion is stable enough to consider a homogeneous pinch along the z axis due to B_z effect.

References

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