DEVELOPMENT AND INVESTIGATION OF PULSED PINCH PLASMAS FOR THE APPLICATION AS FAIR PLASMA STRIPPER

Marcus Iberler†, Thilo Ackermann, Bernhard Bohlender, Christian Hock, Xu Ge[1], Joachim Jacoby, Dominic Mann, Alexander Puth, Joerg Wiechula, Institut für Angewandte Physik, Frankfurt am Main, Germany, [1]GSI Helmholtzzentrum für Schwerionen, Darmstadt, Germany

Abstract

The planed Facility for Ion Research (FAIR) is a new international accelerator laboratory at the GSI in Darmstadt, Germany. The main topic at this facility is aimed to heavy ion research. The FAIR project in comparison to the existing facility GSI extends the research area by raising the energy of ion beams. After creation of the ion beam at the ion source the state charge is low. Therefor the demand for acceleration of the beam to the highest possible energy is a highly ionized charge state of the beam. For beam stripping to get higher charge state, the traditional tools are gas stripper and foil stripper [1, 2]. Hence Plasma is suggested to be a stripper medium. In Frankfurt are different kinds of Pinch Plasmas under investigation for Stripper. The constricting effect on the plasma or conductor is produced by the magnetic field pressure resulting from the current or by the Lorentz force produced by the current flowing in its own magnetic field. In addition to separate the high pressure discharge chamber of the accelerator a plasma window will be used [3]. This contribution gives an overview of the plasma properties and shows first results of different beam times at the GSI.

INTRODUCTION

After creation of the ion beam at the ion source the state charge is low. Since the final energy of an ion is related to the charge state of the ion during acceleration, the technique of employing a stripping medium between acceleration stages in heavy ion accelerators is frequently used. For stripping to get higher charge state, the traditional tools are gas stripper and foil stripper. However, the gas stripper has a lower stripping efficiency while the foil stripper will be mechanically destroyed by the energy deposition by high energy ion beams [1]. For gaseous or solid stripping media, the charge-state distribution of a particular ion beam reaches equilibrium after traversal of a certain thickness of the target material which is independent of the initial charge state of the incident ion beam. In practice, carbon-foil lifetimes are limited by radiation damage, forward sputtering, and thermal and mechanical stresses which lead ultimately to foil breakage. The limitations of these two commonly used strippers were the principal motivation for searching for an alternative stripping medium. An alternative to use foil or gas stripping plasma, offers an attractive possibility [1, 2].

The following table 1 shows theoretical results of calculations for the charge state equilibrium of an Uranium 4+ ion beam of different energies after stripping with a cold gas and plasma. The stripping efficiency is dependent from the beam energy and the gas and Plasma density.

Table 1: Theoretical Calculation of the Equilibrium Charge state of Uranium beam with an initial charge state of Q = 4 with cold gas and plasma [4].

Energy MeV/u	Cold gas < Q >	Plasma < Q >	λ cm $n_e = 10^{17}cm^{-3}$	λ cm $n_e = 10^{18}cm^{-3}$
1	13	49	230	23
3	37	64	800	80
10	75	86	2200	220

The effect of plasma for the increase of the equilibrium charge states has been already proved in experiments with a Z-pinch [2]. A linear Z-pinch discharge between two metal electrodes placed inside a chamber filled at low pressure with gas was one of the earliest and simplest schemes of plasma heating and confinement. The Z-pinch is a simple, pulsed-power-driven, plasma compression system, in which the azimuthal-magnetic field of a cylindrical-plasma discharge compresses the plasma by a self-generated jxB force [2]. For high current a plasma confinement lengthwise of the discharge vessel appears. Z-pinches are susceptible to a variety of instabilities like kink and sausage instabilities that limit their ability to attain extreme energy density during confinement.

However the Spherical Theta Pinch plasma is via a coil inductively coupled and is in comparison to the z-pinch very stable [5].

A linear Screw Pinch combines the properties of an excellent confinement of a Z-Pinch and the stability of a Theta Pinch. The screw pinch is a plasma column immersed into an axial magnetic field and carrying an axial current.

EXPERIMENTAL SET UP

In this section the experimental set up of the two different pinch plasmas will be explained.

Spherical Theta-Pinch

One research activity of the working group Plasma physics is focused on the use of pulsed spherical Theta Pinch as a plasma stripper device. A major feature of the pinch plasma is the use of a large spherical discharge vessel surrounded by seven spherical arranged induction coils, which is connected to a capacitor bank via transmission line. In resonant circuit the discharge is working

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with an eigenfrequency below 50 kHz. The measurement were done with a stored energy will be 5kJ [5]. The induction currents reach high values and moderate current rise times. The stored energy is switched by a high voltage semiconductor stack. One of the principal advantages of this concept is the high energy transfer efficiency of up to 80% and the potential of high pulse repetition rates [7]. For the integration into the beam line differential pumping systems are at each side of the discharge vessel. Figure 1 shows the experimental set up of the spherical plasma stripper device including the two differential pumping systems and the used high voltage thyristor stack.

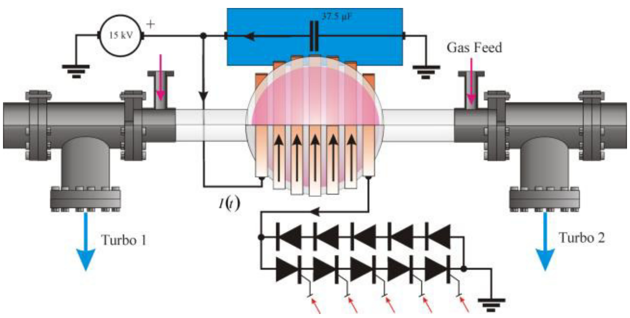

Figure 1: Experimental set-up of the Theta Pinch plasma including differential pumping system [8, 9].

Linear Screw-Pinch

In case of the linear screw pinch the axial current flows between two conducting electrodes limiting the pinch along the axis. The cylindrical return coil is situated at some distance from the surface of the plasma column. In the alternating pinch the plasma column is confined by a magnetic field which rotates in a plane tangential to the plasma surface. The final confinement of a pinch is always dependent of the initial ignition. To control the ignition of the plasma the Z-Pinch is coupled to a hollow cathode discharge. Figure 2 shows a schematically drawing of the Linear Screw Pinch with electrode system of the Z-Pinch, the hollow cathode and the Theta Pinch coil.

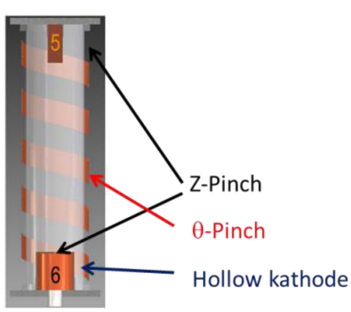

Figure 2: Schematic drawing of the Linear Screw Pinch.

Within the equivalent circuit the Z-Pinch the Theta Pinch and the Plasma are in serial.

EXPERIMENTAL RESULTS

While the Theta Pinch already was tested during various beam times at the accelerator facility GSI the Linear Screw pinch was investigated about the plasma parameter in the plasma physic Lab at the University Frankfurt. The experimental results now are separated in the different pinch plasmas.

Theta Pinch

For synchronisation of the plasma of the theta pinch to the ion beam the investigation of the ignition behaviour are of importance. The ignition and luminous effect of the Plasma was measured with a fast photodiode. The following Figure 3 shows the current and ignition behaviour of the Spherical Theta Pinch. The capacity of the experimental set up was 34 µF. The measurement was performed at a voltage of 9 kV at a pressure of 25 Pa (H_2). From the oscillating photodiode signal it can be seen that the ignition of the plasma will start during the second half wave of the oscillating current and the brightest luminescence effect is within the third half wave.

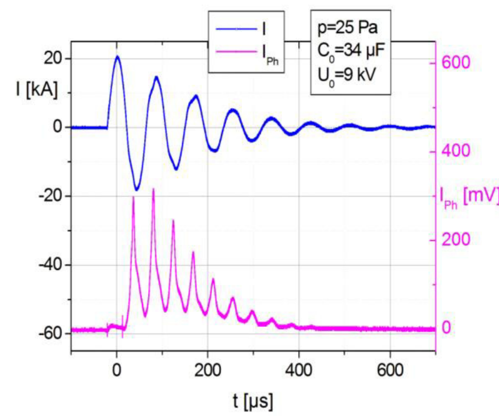

Figure 3: Current and ignition behaviour of the Spherical Theta Pinch plasma [8].

Further of importance for the efficiency of ion stripping is the electron density. For this time resolved measurements of the electron density were performed. The electrical parameter like capacity (37.5µF), voltage (16kV) and the pressure (60Pa) were identically to those of the beam time. To determine the electron density the Hβ broadening was measured. Like the luminescence behaviour the first peak of the electron density was measured at the second current half wave and the maximum electron density of $3.6*10^{16}$ cm^{-3} was achieved at the third current half wave [8, 5,].

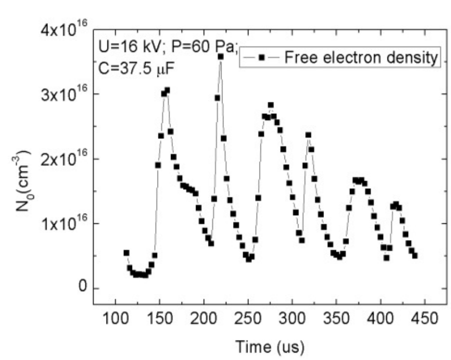

Figure 4: Time resolved electron density [8].

During a beam time the charge state distribution was measured for cold gas and plasma. The beam was Au^{+26} with an energy of 3.6MeV/u. Figure 5 shows the charge state distribution after crossing the stripping cell with cold gas and plasma. On the top of the Figure 5 are the different achieved charge states. The electron density was in the range of $3.5*10^{16}cm^{-3}$. In presence of plasma the transmission of the ion beam through the stripper cell was 58%. It can be seen that the charge state distribution with plasm is shifted to higher ionisation degree of the Au-beam. The maximum charge state with plasma is between +27 to + 30 whereas with cold gas the main charge distribution is between +26 to +28.

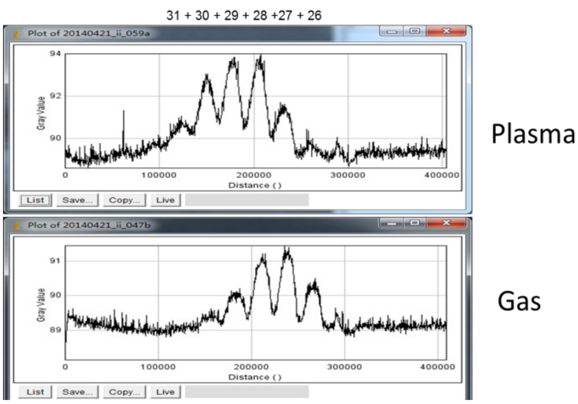

Figure 5: Charge state distribution of an 3.6MeV/u Au^{26+} Ion beam after crossing a fully ionised hydrogenplasma in comparison to a cold gas [8].

Linear Screw Pinch

One important feature of the linear screw pinch is the steady state pre ionization of the gas discharge. For first investigations the capacity was 13.8µF, maximum voltage 9kV and the working pressure range between 1-800Pa. The maximum stored energy was only 560J. Due to measurement of the Hβ broadening the maximum electron density was determined to few 10^{16} cm^{-3}. Against the Spherical Theta Pinch the ignition of the plasma starts with first rising of the current. Optical investigations of the Plasma show that the ignition starts from the bore hole of the hollow cathode. During the whole discharge the plasma shows a steady confinement during the maxima of the oscillating current. For further investigations a upgrade to an energy of 5kJ is under construction. The next table points the working parameter and maximum achieved results of the linear screw pinch.

CONCLUSION

For the next beam time a new stripper cell with cylindrical coil and symmetrical power connection was designed, in order to eliminate asymmetric magnetic fields. Through the diamagnetism of the plasma along the entire z-axis, the ion beam will be sufficiently protected from the influence of asymmetric magnetic fields. Because of the cylindrical design of the coil, the efficiency of the energy transfer will be decreased from 85% to a maximum of 50%. Due to the new coil design the energy storage system has been increased from 5 kJ to 50 kJ. Thus, the energy deposition into the plasma is expected to be increased by a factor of 8. Within this configuration the expected plasma densities are of $3x10^{23}$ m^{-3}. To separate the pressure from the stripper to the vacuum of the accelerator a plasma window was designed is now under investigation.

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