KnE Engineering
ICoSE Conference Proceedings
ICoSE Conference on Instrumentation, Environment and Renewable Energy (2015), Volume 2016

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Conference Paper

Numerical Studies on Pinching Radius Effects to Current Densities of NX2 Plasma Focus

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Abstract

The pinching radius of ion beams effects are observed throughout the current densities obtained in the truncated end of NX2 plasma focus anode. The numerical experiments were carried out using RADPF code operating from 11 to 14kV of applied voltage using Neon as the filling gas with range of pressure 1.0–5.0 Torr. Energy beam acquired is studied with reference of the pinch radius and current densities. The theoretical calculations are studied. The radial speed will describe the energy transferred and will contribute to the drive parameter. The pinching radius of ion beam generated from the system plays an essential role in the determination of current densities that affects the energy beam produced. The highest energy beam, 156 J obtained at 4.0 Torr, where the current densities 7.3x10^{9}Am^{-2}and pinch radius 1.68mm.

Keywords: Plasma Focus, pinching radius, current density, energy beam

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Received: 1 August 2016
Accepted: 18 August 2016
Published: 6 September 2016

Publishing services provided by Knowledge E

Selection and Peer-review under the responsibility of the ICoSE Conference Committee.

1. Introduction

The studies on Plasma Focus, PF device have manoeuver many findings on the future insights of energy sources [1, 2] due to its competency to produce multi-radiations such as soft X-rays, neutron, electrons and ions. The radiations are obtained through compression of plasma column. The dynamics enclosed in the system started when the current sheath is accelerated towards the open end of the inner electrodes by the Lorentz force J_r x **B**. The dynamics of the plasma and current sheath are important as it will highly affect the detail profiles of radiation output [3]. Gribkov [4] highlighted the fast ion beam generated within PF after current abruption and pinch phenomenon at the truncated end of anode (Fig. 1). Akel [5] described the decrease in induced voltage of the pre-pinch radial phase will affect the acceleration of the ions and will reduces the ion energy with higher pressures. Bhuyan [6, 7] mentioned the studies of energy flux of ion beam in PF and its characterization endeavor to possess broad understanding on fundamental physics, understand the mechanism of the production and the generation of high-energy ion.

Ion beam production is an important phenomenon to distinguish the properties of ions beams emitted from PF. In Fig. 1, beam of fast deuteron generated at plasma diode will interact with the hot and dense plasma at focus pinch column. Lee [8, 9], Gribkov [12] and Pimenov [10] have done substantial studies on ion beam based on the

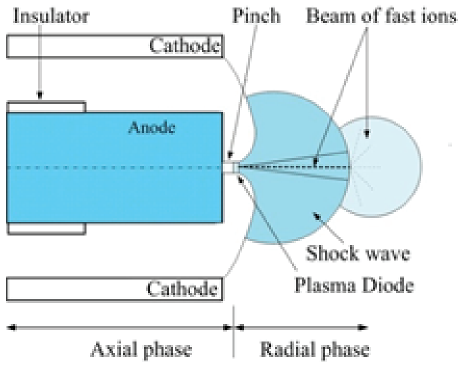

Figure 1: Schematic of the plasma dynamics in plasma focus device.

beam target mechanism. Lee defined beam that passing through a plasma target as cross-section = reaction rate (beam ion number flux x number of target particles). The beam kinetic energy and pinch inductive energy were associate to attain the numbers of beams ions per unit plasma volume traversed, n_b and beam ion speed, v_b according to the gas properties of neon [8]. This interrelation is governed by f_e parameter. f_e, defined as the fraction of energy converted from pinch inductive energy to beam kinetic energy. The equations consists of the effective charge Z_{eff}, mass number M, mass of the proton, electron and the diode voltage, U, Mass number of neon ion, M is 20 whilst m_p is 1.673x10^{27} kg. After computing extensive data fitting, Lee [8], described U = V_{max} ·V_{max} is the maximum induced voltage of the pre-pinch radial phase. The derivation principle of flux J_b ,(Eq. 1) is significant for the studies of ion beam properties. The narrow beam will exit along the pinching axis after the post-pinch of shock wave. Flux, J_b(ions $m^{-2}s^{-1}$) is determined at the truncated of plasma anode based on the ion number per unit cross-section. By having estimation on plasma exit, the ion number per unit cross-section fluence, $J_b\tau$, energy beam and current densities properties are given in Eq. 2,3 and 4 [8, 9].

$$J_b = 2.75 \times 10^{15}\left(\frac{f_e}{M\ Z_{eff}}\right)^{1/2}\left\{\frac{ln\left[\frac{b}{r_p}\right]}{r_p^2}\right\}\left(\frac{I_{pinch}^2}{U^{1/2}}\right) \tag{1}$$

$$\text{Fluence}\left(\text{ions m}^{-2}\right),\ J_b\tau\ =\ 2.75 \times 10^{15}\tau\left(\frac{f_e}{M\ Z_{eff}}\right)^{1/2}\left\{\frac{ln\left[\frac{b}{r_p}\right]}{r_p^2}\right\}\left(\frac{I_{pinch}^2}{U^{1/2}}\right) \tag{2}$$

$$\text{Current density, Am}^{-2}\ =\ J_b \times e \cdot Z_{eff}\ \text{(ion charge)} \tag{3}$$

$$\text{Energy in beam, } (J)\ =\ n_b \times Z_{eff}\cdot U \tag{4}$$

These equations were incorporated in the Radiative Dense Plasma Focus, RADPF to study ion beam generation. Study are conducted by using different applied voltage to analyse the effects of pinching radius, current densities and energy beam obtained from the system.

2. Methodology

The current densities were studied at variation voltage to see its correlation with pinch radius. 11, 12, 13 and 14 kV voltages applied to the NX2 plasma machine where the static inductance, 20 nH, capacitance, 28 μF, stray resistance, 2.3 mΩ, cathode radius, 4.1 cm anode radius and length is 1.9 and 5 cm. Experiment conducted using 1.0- 5.0 Torr range of operating pressures with Neon as the working gas. The thermodynamics of neon gas and NX2 PF device configuration were incorporated in the RADPF code to ensure the system is reliable and consistent with the actual NX2 plasma focus machine. RADPF was used due to its capacity in comprehend the operation system of PF devices by incorporating the snow plough (axial phase) and slug model (radial phase). After amassed the NX2 machine configuration into the working platform of RADPF, the actual and computed experimental data were validate to ensure data are coordinate. The discharge current signal comprises the system dynamics and the information on properties of multi-radiation, so, it was identified as the points of reference. The profiles of the discharged currents start from the breakdown phase until the end of pinch phase; and along the phases, it will signify the Joule heating, radiative emissions, and the expended column current flow that abruptly transited from the narrow pinch. The validation of computed PF system with the actual experiments were determined by current fitting techniques[11] that comprises model parameter of mass shedding effects and current shedding factor f_m, $f_{c,(axial)}$/ f_{mr}, $f_{cr\ (radial)}$. These parameters were scrutinized by parts to ensure interrelation with the dynamics, thermodynamics, electrodynamics, and radiation events of the PF. In the first stage to fit the measure current, the axial model parameter, f_m, f_c, were tuned to fit the actual the current inclination. This process was continues at the peak current zone until the peak current are prudently agree with the measured current profile. Then the second stage fitting process on the radial phase where, f_{mr} and f_{cr} were tuned until the slope of current dip and the end of dip in typically good agreement with the measured current profile. Nevertheless, the significant discrepancy of the computed and measured current profile after the current dip can be negligible, as our scope of study centered upon the radial phase; as in radial phase encompass appealing physic phenomenon to be in focus at. In instance, when the computed current profile was fitted with the measured current profile, the system ready to be run for detailed experimental calibration. The experiments conducted gives significant pattern on the results in RADPF. The data obtained were then accumulated by using Microsoft visual basic.

3. Results and Discussion

Fig. 2a shows the well fitted current profiles of the computed and actual PF machine with an average fitting deviation of ~5.87%. Good current discharge obtained when current dip is position at the region close to the peak current. The scrutiny deviation are due to the time delay in the spark gap switching during actual experimental. The axial phase duration is about 1.18 μs, then it's continuing with radial phase that last only at 0.214 μs where the radial phase ends at 1.399 μs. It can be observed in the Fig.

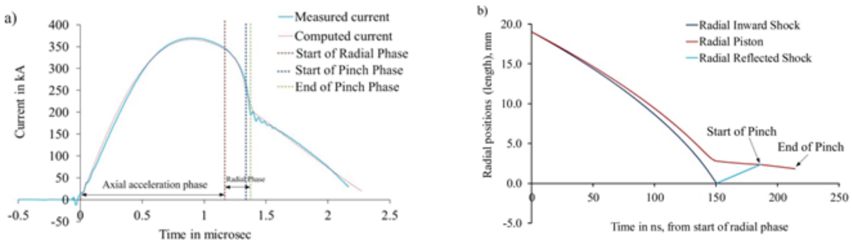

Figure 2: (a) Computed and measured current profile fitting, (b) Positions of shock front and magnetic piston for 1.7kJ NX2 PF operated at 2.6 Torr (Neon).

2b, within very short duration time of 214 ns, the radial inward shock phase started several tens of nanoseconds before entering the slope of current dip. The shock front was then reflected after 151 ns from the start of radial phase and the plasma column started to pinch at 186 ns that last for only 27.9 ns before it rapidly collapsed. The experiment were continue to study the current densities trend by integrating with the Eq. 3 and 4.

Fig. 3 shows the increasing of the current densities with the increase in gas pressure at the applied voltage, where the pinch radius is started to decreased. The results start to give a different pattern upon reaching certain value of pressure. From Fig. 3, maximum current densities $7.3x10^9 Am^{-2}$ are achieved from 14 kV applied voltage with optimum pressure 4.0 Torr, results in smallest pinch radius 1.68 mm. The biggest pinch radius, 4.22 mm attained from the system will results in $4.3x10^8 Am^{-2}$from 11 kV applied voltage at pressure 5.0 Torr. From the result, it is evident the current densities phenomenon is affected by the pressure. This is due to the number of the ions and density of the plasma medium contributing to diffusion and transfer of energy. Thus, at optimum pressure, the electrons and ions are efficiently accelerated by the field. This will increase the number of ions collides where energy is transfer; so, more gas is ionized and will cause more generation of ions and electrons with higher energies which accelerate toward the cathode and the anode. Inadequate or over pressure might deliberate the effectiveness of the PF system. In achieving optimal pinch radius and current densities, it is important to stimulate the system using optimum pressure. The electrons and ions from the optimum pressure would stimulate driving force to pinch the pinching radius area. From the results, a consistency number of pinch radius at its minimum gives out maximum number of current density.

In Fig. 4a; the selected applied voltage would give same pattern, where increasing of pinching radius will lead to the decreasing in current density. At its radius locality, it will give identical pattern and values of current density. The increase of pinch radius from 1.68 mm to 5.58 mm would consent the current densities decreases from $7.3x10^9 Am^{-2}$to$2.2x10^8$ Am^{-2}. This assures that pinching radius affect the current densities. These were further studied with respect of the pinch radius where 1.8mm and 2.6mm were plotted by its current densities (Fig. 4b). The current densities are increase with the increase in applied voltage where the pinch radius getting smaller.

The highest current densities obtain for 2.6mm of pinch radius is 2.7 $x10^9$ Am^{-2}at 14kV, whilst the minimum is 2.1 $x10^9$ Am^{-2}at 11kV. Significant different of current densities observed at 1.8mm pinch radius; where the maximum current densities

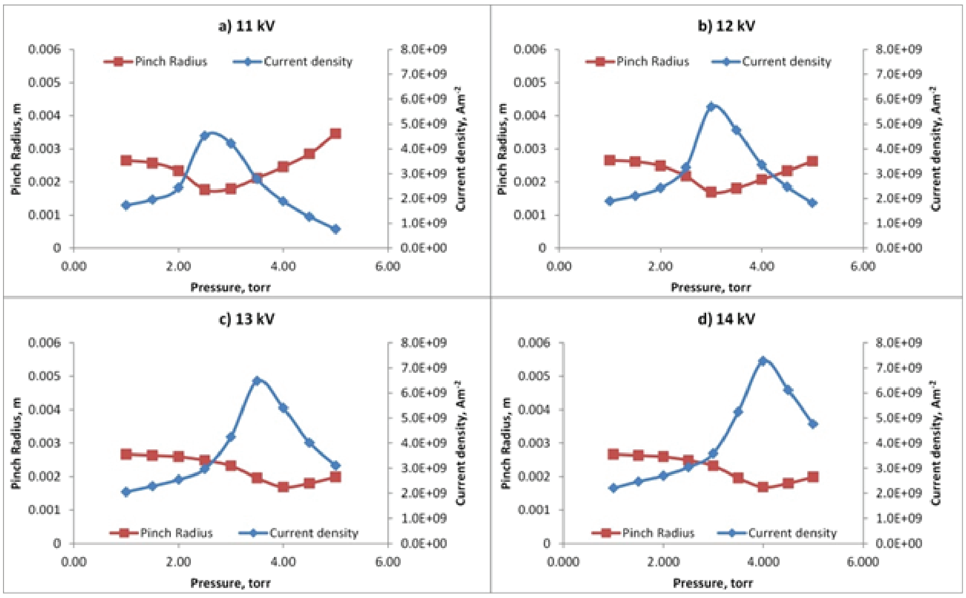

Figure 3: Current densities and pinch radius correlation with pressure with 11,12,13 and 14 applied voltages.

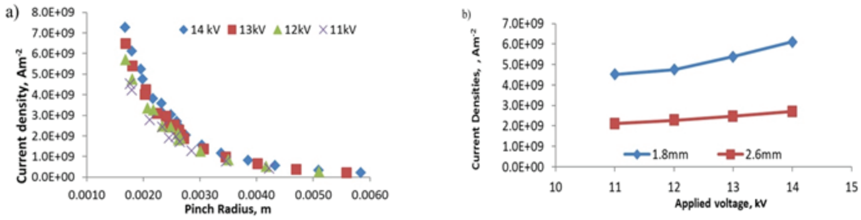

Figure 4: Correlation between current densities and pinch radius at different applied voltage.

obtained is 6.1x10^9 Am^{-2}at 14kV whilst the minimum is4.5 x10^9 Am^{-2} at 11kV. The poles apart between 1.8mm and 2.6mm pinch radius relative to the current densities, practically shows the current densities is dominated by the pinch radius. The phenomenon explained as follows. At optimum pressure with apt voltage applied, the Lorentz force will works efficiently and results in the optimum inward radial force. This allows significant constrain in the pinch area that compress the current flow per unit area.

4. Conclussion

The maximum energy beam 156 J is achieved at constrain pinch radius, the minimum energy beam obtained at the largest pinch radius with 38.4 J. The compression in the radius of ion beam gives higher current densities. Adding up from the applied voltage and optimum pressure applies, this study shows that the pinching radius of ion beams will affects the current densities generated at truncated end of NX2 plasma focus anode. From the current densities and pinch radius result, thus, we can estimate and control the energy beam requisite. This approach is significant to be used for applications in material deposition, modification and other relative industrial studies.

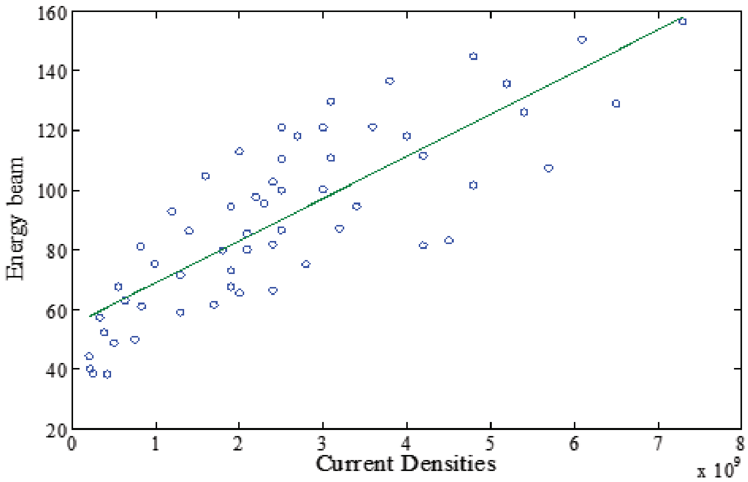

Figure 5: The energy beam correlation with the current densities.

Acknowledgement

We would like to thank the Institute of Advanced Photonics Science, UTM, Malaysia and Mybrain15 for providing research facilities. This research work has been supported by Grant FRGS 4F519 and Ministry of Higher Education Malaysia. Our gratitude also goes with the Universiti Riau and Ministry of Research Technology and Higher Education with KLN Projects 2015.

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