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A High Flux Pulsed Neutron Source Using a Plasma Focus Device

A. Patran[1, 2], R. S. Rawat[1], J. M. Koh[1], S. V. Springham[1], T. L. Tan[1], P. Lee[1], and S. Lee[3]

1. Natural Sciences Academic Group, National Institute of Education, Nanyang Technological University, Singapore – 637616
2. on leave of absence from National Institute for Laser, Plasma and Radiation Physics, Magurele – Bucharest, Romania
3. International Center for Dense Magnetised Plasmas, Warsaw, Poland

Abstract

The NX2 device, a low energy plasma focus machine, at National Institute of Education, Singapore, was originally designed to operate in neon, for microlithography experiments. It is now modified with a new electrode system to make it operate efficiently with deuterium and other working gases. With new design, a remarkable average neutron yield of $(6.9\pm1.3)\times10^8$ neutrons/shot has been obtained. We also report an extremely high pressure operating regime at which the optimum neutron production is obtained. The compact design of the machine, together with the repetitive capabilities of the NX2 pulser (16 Hz maximum) make the NX2 device in the current configuration an interesting candidate for applications as a laboratory-size and environment-friendly neutron source.

Introduction

The plasma focus is well known for its ability to produce numerous types of radiation such as X-rays, ions, electrons and neutrons (when operated in deuterium) [1]. After the efforts to convert these machines into fusion devices did not lead to the desired results, the existing facilities, as well as the newly-constructed devices were converted mainly into powerful X-ray sources for research and for applications like microscopy, microlithography, MEMS, etc. Most of the neutron experiments were unusually confined to the academic research field. The NX2 device was originally designed to operate in neon, for microlithography experiments [2]. In the past, several attempts to adapt this device for working in other gases failed. We decided to design a new electrode system, along the lines of speed-enhancement experiment done by A. Serban [3]. Though we did not used stepped-anode [3] but a tapered anode configuration was adopted for speed enhancement.

Device and Experimental Set-up

The experiments were carried out on the NX2 device, a plasma focus device with the following parameters: capacitance 27.6 μF, quarter period time 1.3 μs, charging voltages between 6 and 15 kV, maximum current up to 480 kA and stored energy up to 3.2 kJ. The original device was described by Zhang [2].

It was found [3] that changes in the parameter $I/a/\sqrt{\rho_0}$ (where I is the discharge current and a is the anode radius and ρ_0 is the density) can lead to dramatic changes in the neutron yield. However, this parameter cannot be freely changed, since the discharge current is dictated by the electrical parameters of the machine, while the anode radius cannot be changed too much for technical reasons. To ensure that breakdown conditions are unchanged when we change a, we use anodes which are not cylinders, like in a classical plasma focus device, but tapered towards the open end; the tapered part has to be optimised in terms of length and diameters for optimum results. The radius, a, of the end of the taper has to be suitably small if a high pressure operation is required and anode length has to be such that axial run down phase time matches the quarter period of the discharge.

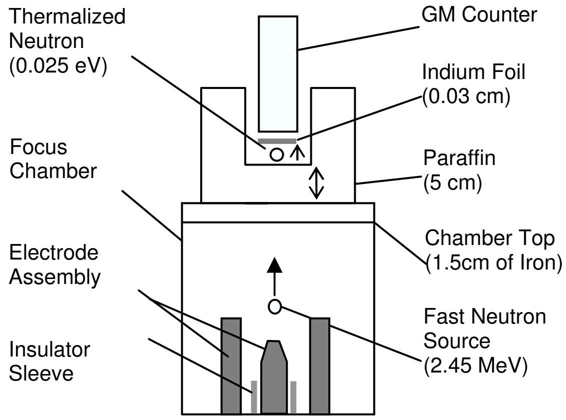

Fig.1: Schematic of experimental set-up.

During our experiments different electrode shapes and lengths were investigated in order to determine the optimum conditions for neutron generation. For each electrode geometry, the rest of the operating parameters were fine-tuned, to maximise the yield.

The indium foil thermalised neutron activation detector was used to measure the total neutron yield, as shown in Fig.1. For each set of operating condition a total of ten shots are fired. The indium detector was calibrated using four superheated liquid detectors ("bubble detectors"), BD100R-type, produced and absolutely calibrated by Bubble Technology Industries Inc., Chalk River, Ontario, Canada; the calibration error for each detector was better than ±20%. For our experiments, the error may be bigger than the one given by the manufacturer, due to a number of factors, including the impossibility to accurately count a statistically-significant number of bubbles formed in the detector, source location, neutron scattering from surrounding structures, etc. Therefore, our calibration factor for the indium detector was calculated in the worst possible scenario, choosing among the four bubble detectors the one indicating the lowest neutron yield. Due to this fact, our absolute neutron yield could be 40% underestimated.

Optimised Neutron Yield and Discussions

The neutron yield, for the electrode geometry which gave us the best results, is presented in Fig.2. As can be seen from the graph, the maximum was found to be $6.9 \pm 1.3 \times 10^8$ neutrons per shot, with the following set of conditions: anode length 35 mm, insulator free length 30 mm, pressure 20 mbar deuterium and voltage 14.5 kV. The shape of the curves suggests that different mechanisms may come into play at different pressures. Time of flight diagnostics were used for some shots and an average anisotropy factor (defined as, signal at 0^0/signal at 90^0) of 1.3 ± 0.3 was found suggesting that on average the beam target interaction is due to ions moving in the forward direction, away from the anode. The anisotropy may drop below one in some shots. This may be due to the random nature of the diagnostic but can also suggest that on these shots, the ions may have been turned significantly by the electromagnetic fields. In addition, the fastest neutrons detected in 0^0, 90^0 and 180^0 to the forward direction had energies higher than 2.5 MeV which supports the above explanation.

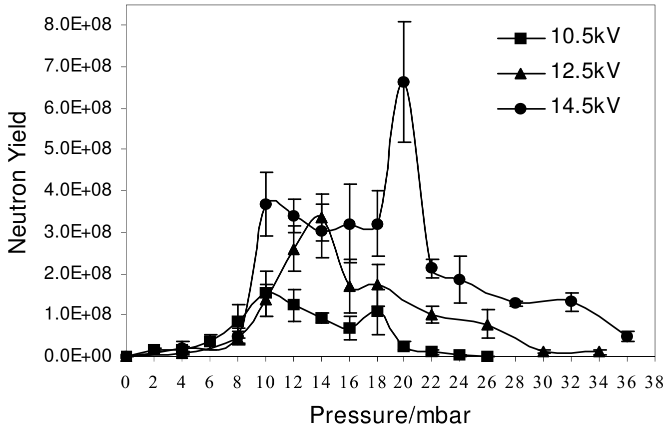

Fig.2: Neutron yield results.

The recorded neutron yield is the highest ever reported for a device in this class. Overall, the neutron production is better than that obtained from other laboratory-sized D-D neutron sources if we operate the plasma focus repetitively and the yield per shot remains the same as our low repetition rate experiments. The advantage of our plasma focus device as a neutron source lies in the fact that it is pulsed, which is a huge advantage in a number of applications (like, for instance, certain neutron activation techniques) where neutron tubes cannot achieve these levels of emission in pulsed mode.

Another point worth mentioning is the extremely high optimised pressure, one order of magnitude higher than what other plasma focus devices currently use [4]. This high density of the operating gas may be responsible for the increase in the neutron yield as compared to other similar machines. The increase in the deuterium gas density will definitely lead to the increase in neutron yield due to enhancement in both thermonuclear and beam–target emission components. In any case, there are certain advantages while operating in this extremely-high pressure regime: as high pressure operation will allow more reliable gas breakdown across the insulator compared to low pressure breakdown. So the sensitive parts of the high voltage insulation (especially the insulator sleeve) are protected at high operating pressures, while the reproducibility is extremely good. This last feature is extremely important while operating the device in repetitive mode, as a neutron source.

Conclusions and Future Work

At this moment, NX2 performs extremely well as a laboratory-size, environment-friendly neutron source, with emission levels never reported before on other machines in this class. However, more detailed work is required to clarify certain aspects of our work. A next step would be to start operating the machine (with suitable radiation protection) in repetitive mode. Certain characteristics, like the maximum number of shots in a series without changing the gas and the average number of shots between scheduled maintenance works have to be found before we can propose the machine as a neutron source for applications. Finally, it is worth mentioning that the neutron production could be increased (by two orders of magnitude) if the machine is operated with tritium as filling gas. This could push the maximum production towards 10^{11} neutrons/shot, again comparable with the neutron tubes using tritiated targets and with advantages given by the repetitive operation.

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References

[1] J. W. Mather, in *Methods of Experimental Physics*, edited by H. Griem and R. Lovberg, Academic Press, New York, Vol. 9, Pt. B, p. 187 (1971).

[2] G. Zhang, *Plasma Soft X-Ray Source for Microelectronic Lithography*, Ph.D. thesis, Nanyang Technological University, Singapore (1999).

[3] A. Serban, *Anode Geometry and Focus Characteristics*, Ph.D. thesis, Nanyang Technological University, Singapore (1995).

[4] A. Bernard, H. Bruzzone, P. Choi, H. Chuaqui, V. Gribkov, J. Herrera, K, Hirano, A. Krejci, S. Lee, C. Luo, F. Mezzetti, M. Sadowski, H. Schmidt, K. Ware, Proposal prepared on the request of UNESCO (1993).