Ответственный за выпуск - С.Г.ПОПОВ
Подписано к печати I,IУ-I980г. МН 067I3
Усл. 0,9 печ.л., 0,8 учетно-изд.л.
Тираж 290 экз. Бесплатно
Заказ № I09.

Отпечатано на ротапринте ИЯФ СО АН СССР

СИБИРСКОЕ ОТДЕЛЕНИЕ АН СССР
ИНСТИТУТ ЯДЕРНОЙ ФИЗИКИ

N.V.Filippov, T.I.Filippova

DETERMINATION OF PARAMETERS OF HIGH POWER ION BUNCHES GENERATED IN A PLASMA FOCUS

ПРЕПРИНТ 80-109

Новосибирск

DETERMINATION OF PARAMETERS OF HIGH POWER ION BUNCHES GENERATED IN A PLASMA FOCUS.

N.V.Filippov, T.I.Filippova

I.V.Kurchatov Institute of
Atomic Energy,Moscow, USSR.

High-current systems such as vacuum sparks,plasma diodes and a noncylindrical Z - pinch (a plasma focus) are used lately together with usual accelerators for the generation of powerful ion beams (J B) [1,2]. In a plasma focus the current plasma shell, compressed by the magnetic field of the current, is used as a formative high voltage line and for a power sharpening.In this system original magnetic storage with a region of a dense high temperature plasma - plasma focus (PF) as a load is formed. Simultaneous action of electrodynamic and plasma effects leads to conditions under which the sufficient part of the total current is transfered by the plasma ion component during small temporal intervals of order several nanoseconds. Maximum energy of generated particles exceeds initial voltage of a power source (a capasity bank) more than 10^2 times and reaches 3-5 MeV. Small dimensions of acceleration region and pinch magnetic field configuration determine conditions under which accelerated particles move to the cathode in the form of narrow directed ion bunches. Hard electron and ion beams generation in PF occurs only on the conditions, that the current contraction on the system axis is not accompained by the considerable compression of the substance as this takes place in the case of dense plasma pinch. The necessary conditions are realized in regimes of a low current shall where the the conditions of substance flowing from compression region is facilitated.

Small addition of a heavy gas impurity for example Xe [3] is necessary for the realization of these regimes. PF becomes a source of powerful JB, if the configuration of the anode surface is such that the direct contact of compression region with metal anode is lacking during the current shell cumulation. Interaction of high energy ions with selected targets causes intensive nuclear reactions used for the determination of temporal and energy characteristics of generated beams. In paper [1] the reactions $^{12}C\ (d,n)\ ^{13}N$; $^{27}Al\ (d,p)\ ^{28}Al$ in combination with the time of flight spectrometry method were used for the diagnostic of the hard component of the deutron bunch (DB). As the cross sections of these reactions are small at $E_d < 0{,}7$ MeV , so this method is not effective for the investigation of a soft part of energy distribution.

2. Device and instrumentation.

The main contents of the present work the study of deutron energy distributions in DB in the range $0{,}1\ \text{MeV} < E_d < 1\ \text{MeV}$. The experiments has been performed on MG device [5] with the working voltage of 15 - 18 kV and the gas mixture initial pressure of (0,5 - 1,0) Torr D_2 + (10 - 20) m Torr Xe. The divice scheme and the instrumentation lay out are shown in Fig.1.

In the input of a 4 m - long drift tube (DT) a vacuum electromechanical valve (K) is mounted which permits to open an aperture 16 mm in diameter in a time of 1.5 ms and at the moment of a complete opening to initiate a discharge. The device allowed several operating modes.

I. The valve is continuously opened, the pressure in the drift tube P_t equals that of the gas in the chamber Pch, and a generated deutron bunch (DB) propagates through the gas with P_t = Pch causing dd - reactions in the drift region.

2. The valve is closed, DT is filled with deuterium at a pressure which is 2 to 30 times higher than Pch, and at the moment of the complete valve opening DB starts to move through the high-pressure gas. The intensity of dd - reactions increases proportonally to P_t / Pch.

3. The valve is closed and the drift tube is evacuated up to $P_t \sim 10^{-5}$ Torr. In this case deutwrons spread over the low - pressure gas outrunning the expanding gas cloud which gets into DT while the valve is opened.

In the butt-end of DT an ion detector is mounted - an isolated graphite collector (ГК) 10 cm in diameter. This served at the same time as a graphite target. Neutrons from the $^{12}C\ (d,n)\ ^{13}N$ reaction were recorded by a photodetector D_1 , simular to that described in ref. [1] . The tube length is chosen so that at the moment when DB gets to the collector the pressure near it does not exceed 10^{-4} Torr. To reduce additionally the collector-chamber conductance, electric and magnetic isolation of the collector was used [5]. Since dispersion in the drift space at $P_t \ll$ Pch became low, the possibility arose to study the softest part of DB.

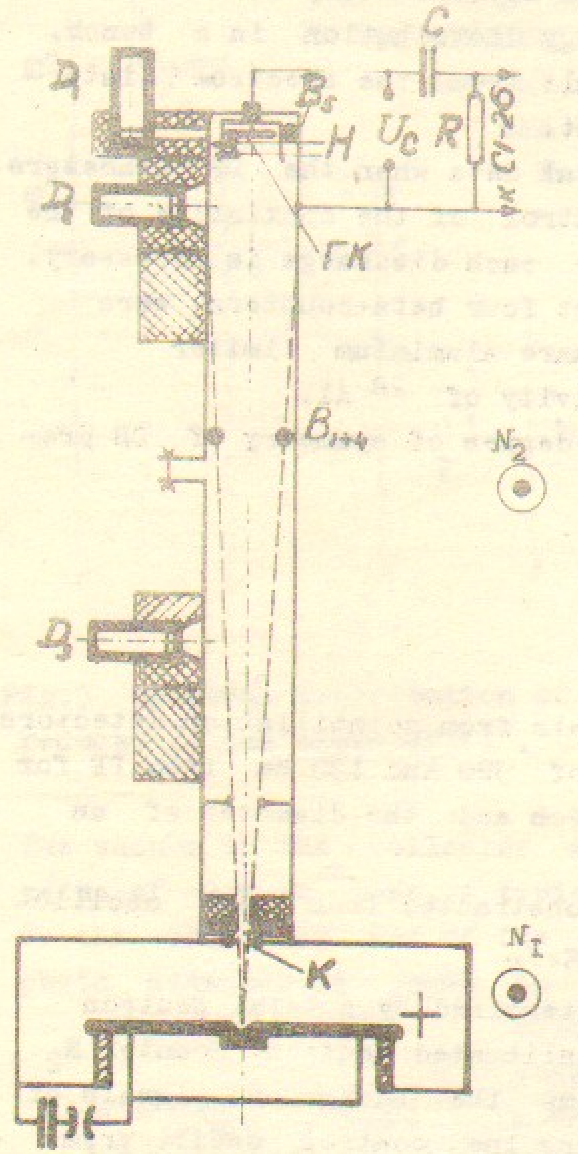

Fig.1 Device and instrumentation scheme.

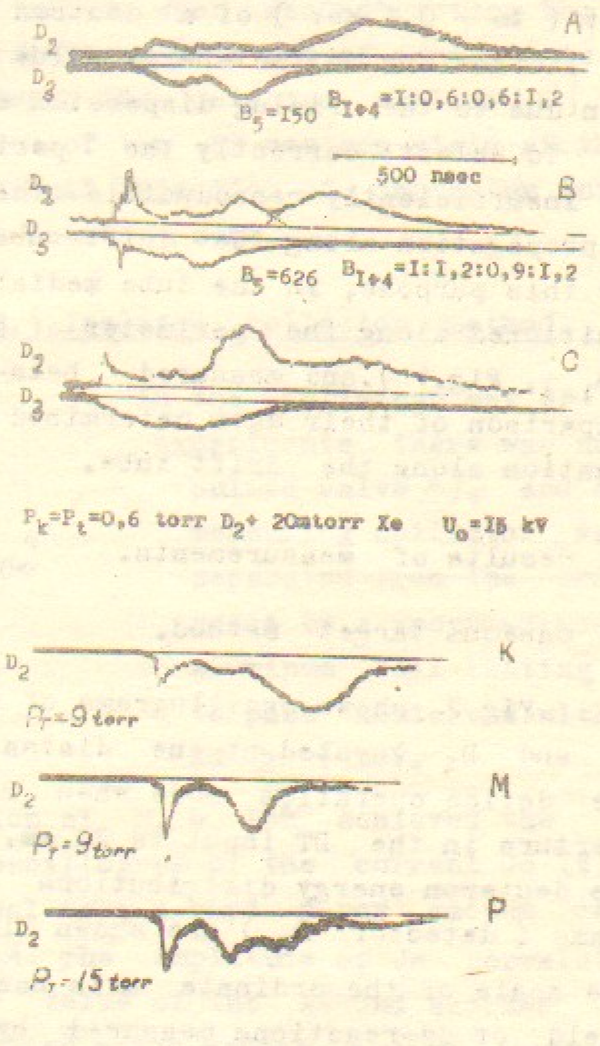

Fig.2 Signals from neutron detectors at P_t = Pch and $P_t >$ Pch.

The treatment of oscillogrames of collector current Jc (t) including the time-of-flight permitted to reconstract the shape of the particle energy distribution in a bunch.

The time-of-flight spectrometry method was also used to determine a deuteron spectrum in the first two cases (1,2), when a limited part of the drift tube was used as a gaseous target. The region of intensive dd-reactions was determined by the location of photodetectors D_2 and D_3 and limiting paraffin blocks. Together with an inverse square dependence of the neutron flux density on the distance, the used collimation gave the possibility to obtain from detectors clearly defined signals from the neutron flux traversing the target. The gasous target method permits to study a "softer" part (to 0.1 MeV) of a deutron energy distribution in a bunch. The limitations on the energy value result from the spectrum distortion due to the rising dispersion effect.

To select correctly the experimental data when the DB parameters are insufficiently reproducible the control of the coaxiality of the DB propagation along the drift tube for each discharge is necessary. For this purpose, in the tube medial part four beta-counters were positioned along the perimeter of a square aluminium limiter (B_{1-4}, Fig.1).and measured beta-activity of ^{28}Al. Comparison of their data determined the degree of symmetry of DB propagation along the drift tube.

3. Results of measurements.

A. Gaseous target method.

Fig.2 shows oscillograms of signals from scintillation detectors D_2 and D_3 located at the distances of 320 and 130 cm from PF for the device operation mode when P_T = Pch and the diameter of an aperture in the DT input is 20 mm.

The deuteron energy distributions reconstracted from these oscillograms (detector D_2) are shown in Fig.3.

The scale of the ordinate axis was determined by a total neutron yield of dd-reactions measured by a calibrated neutron counter N_2 (Fig.1). When treating the oscillograms the background signals of neutrons from PF are deduced according the control oscillograms when the DT inlet was closed. The position of the hard x-ray emission peak shifted by the time of flight of γ - quanta was assumed to be the origin of the time count. The intensity of the hard component of DB being studied was controlled by an induced beta - activity in an aluminum target positioned at the place of the graphite collector in the tube butt-end.

The readings of counters B_{1-4} and B_5 (Fig.2 A,B) characterize the degree of DB symmetry and relative activity of the target.

Similar measurements were performed for the case when DB is let into a high - pressure gas (mode 2). The obtained experimental results are also shown in Fig.2 (K,M,P) and Fig.3. The operation at $P > $ Pch results in the increase of amplitudes of signals D_2 and D_3 due to the high density of the gaseous target. However, this increase is accompanied by a change in the bunch spectral composition which is difficult to include when reconstructing the initial distribution. This set of experiments has confirmed the detected earlier [6] increase of the PF neutron yield at the additional injection of deuterium into the chamber zone.

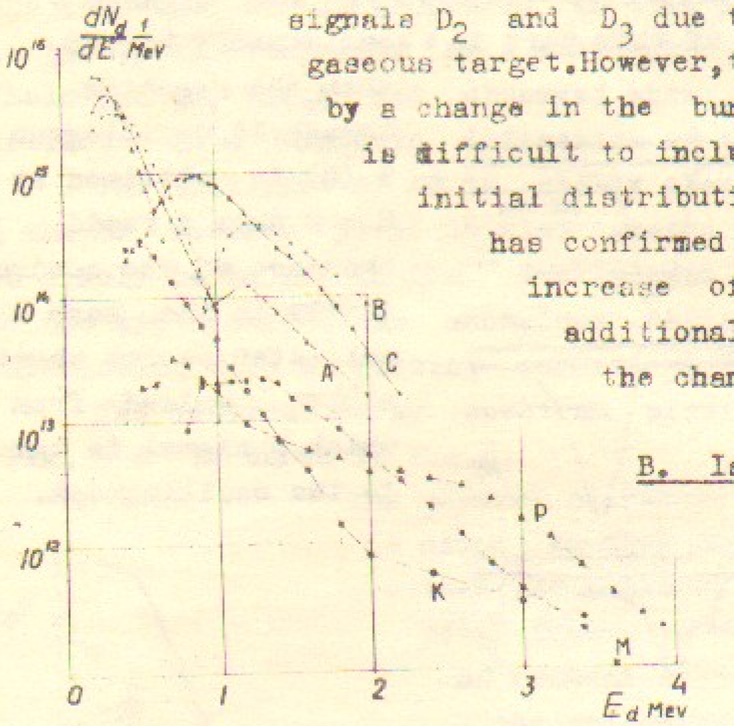

Fig.3 Spectral distribution of DB reduced to the angle of 14°.

B. Isolated collector method.

In the preliminar set of experiments there was no pulsed valve *), and a measuring collector was separated from the drift space by a vacuum-dense aluminum foil letting to pass deuterons with Ed $\geqslant$ 1 MeV.

The vacuum in the collector section at P_t = Pch achieved the value of 3×10^{-5} Torr. A typical oscillogram of the current Jc (t) to the collector and of the signal from a hard x-ray vacuum cell photo detector is shown in Fig.4. The amplitude of Jc correlates with the value of the second shorter x-ray pulse which passes easily through a lead screen of a photodetector. The location of this peak is assumed to be the moment of the DB hard part generation. The energy distributions for particles with Ed $\geqslant$ 1 MeV reconstacted from these oscillograms, corresponded to those obtained earlier [1] . When working with a pulsed valve (in the absence of a foil) lower energy deuterons reached the collector. Fig.5 shows a set of oscillogram from the collector Jc (t) together with signals from scintillation

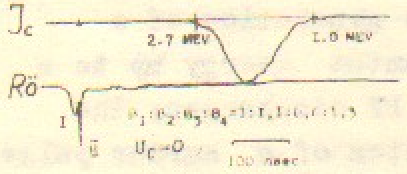

Fig.4 Signals from a collector Jc (t) for DB that has passed 10^{nm}Al.

---

*) This set of experiments has been carried out jointly with V.V.Myalton.

detector D_1 recording neutron emission of the $^{12}C(d,n)^{13}N$-reaction. In the oscillograms 5 (A,B,C,E) the pulse from D_1 corresponds to the moment of getting on the collector - target of the highest - energy part of DB. The energy of this part is considerably higher than the reaction threshold. Oscillogram 5 (C) is obtained at H = 0 when a rapid increase of the conductivity in the near - collector region shunts a 91Ω - load from which a signal is taken to the oscillograph.

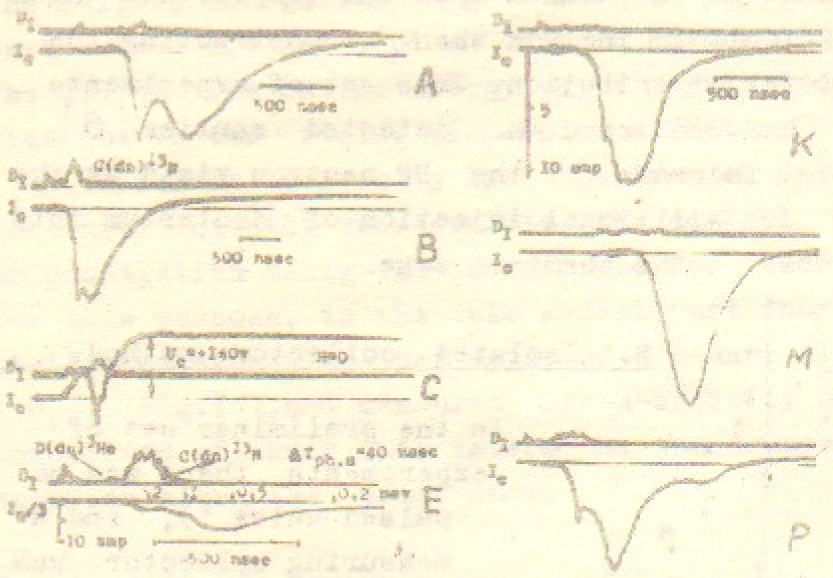

Fig.5 Signals Je (t) from a collector when operating with a pulsed valve.

Discussion.

In the studied mode of the device operation the fast deuteron spectrum is of a nonmonotonuous character, generally with two maxima - (200 - 300) keV and (1 - 1.5) MeV. The character of spectra allows us to suppose that there are at last two phase of the PF development in which high-energy particle fluxes are generated. One of these phases coinsides in time with the generation of a " medium "- hardness x-ray emission with a quantum energy up to a hundred keV, which is generally observed in PF discharges; the other one coinsides with the moment of generation of a harder pulse of a megavolt energy range.

The first phase has a duration (30 - 100) ns and coinsides with the time of a neutron generation in PF. The second one which sets in generally 20 - 40 ns later, has a considerably shorter duration (~ 5 ns) and a nonsufficient reproducibility from pulse to pulse. Such an energy distribution is discovered also in the paper of Bostick et al. [7], but there maxima are shifted towards lower energies, which is the result of difference in the energy and geometry of the experiment.

The acceleration of the second group of particles occurs in the electric fields generated in this phase ; indication to this fact in the proportionality of a multi-charged aluminum ion energy to their charge, which was observed when working with an isolated collector at a magnetic deflection of the beam.

The soft part of DB is stably observed in all the discharges (the PF neutron yield is also stable in these regimes). This part is likely to be due to the development of collective effects and to the appearance of an anomalous resistance in the result of the plasma interaction with a flewing current [8].

The deutron energy spectrum plotted from the oscillogram of Fig. 5-E is shown in Fig.6.

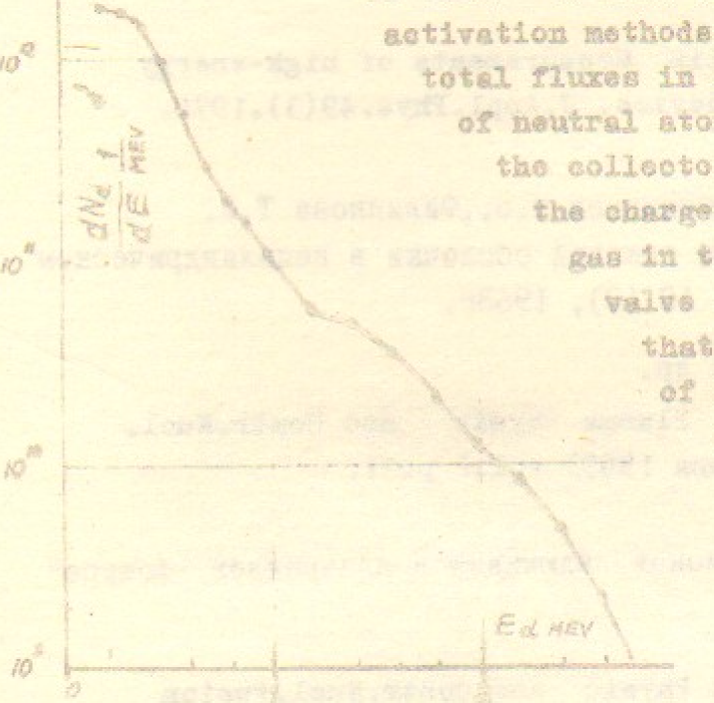

Fig.6 Energy distribution for fast deuterons that have reached a collector (reconstructed from osc.5 E).

The general character of the dependence $\frac{dN_d}{dE}(E)$ is close to that of distributions obtained by the activation methods. The difference in the deuterom total fluxes in connected with a high quantity of neutral atoms which are not recorded by the collector. Even when working with a valve, the charge-exchange and scattering on the gas in the space between PF and the valve (25 cm) appeare tobe so large that a sharp reduction of the number of particles with $E_d < 200$ keV is observed in the spectra.

A double structure of energy distributions can be associated with the character of losses from the cumulation zone. The reproducibility of the compression first phase (the soft part of DB) is connected with a rather regular axial ejection of the plasma from the current compression zone which has the shape of a short pinch in theseq regimes. This can also explain a high reproducibility of the neutron emission. Then the azimuthal asymmetry of the compression process develops generally, which results in an irregular radial ejections of the matter. This increases the velocity of the collective process development in the pinch and leads to the practically complete desruption of the conductivity current and realization of conditions for generation of the hard particle group. In this phase of PF due to dynamic dissipation of a magnetic field energy, the conditions can be also realized for particle acceleration, which has been noted in the most papers on high current discharges.

REFERENCES

1 Филиппов Н.В., Филиппова Т.И., "Исследовзние дейтонных пучков, генерируемых в плазменном фокусе". Письма в ЖЭТФ, 25(5), 1977г.

2 R.L.Gullickson and H.L.Sahlin Measurements of high-energy deuterons in plasma-focus device. J.Appl.Phys.49(3).1978.

3 Базденков С.В., Гуреев К.Г., Филиппов Н.В., Филиппова Т.И. "О возможном механизме срыва токовой оболочки в нецилиндрическом -пинче". Письма в ЖЭТФ, 18 (3), 1963г.

4 Агафонов В.И., Голуб Г.В., и др. Plasma Physic and Contr.Nucl. Fusion Research. IAEA (Vienna 1969) vol.2 p.21.

5 Филиппов Н.В., " Ускорение ионов алюминия в плазменном фокусе" ЖЭТФ 76(5) 1979г.

6 Ch.Maisonnier et al. Plasma Physic and Contr.Nucl.Fusion Research. IAEA (Vienna 1969) vol.2 p.77.

7 W.H.Bostick et al. IAEA Innsbruck Austria 1978. CN/U3-3

8 A.Bernard et al. IAEA Innsbruck Austria 1978. CN/U-4