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IWDMP'2000

12-14 October 2000, Kudowa Zdrój, Poland

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ABSTRACTS

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IWDMP'2000

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INTERNATIONAL WORKSHOP ON DENSE MAGNETIZED PLASMAS

IWDMP'2000

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TOPICS OF SCIENTIFIC PROGRAM

1. Theoretical analysis of Z-pinch discharges
2. Theoretical analysis of various phases of PF-type discharges
3. Experimental facilities for Z-pinch and/or PF-type studies
4. Development of diagnostic methods for Z-pinch and PF experiments
5. Results of recent Z-pinch and PF experiments
6. Applications of Z-pinch and/or PF devices

ABBREVIATIONS:

IL – INVITED LECTURE

OP – ORAL PRESENTATION

INVITED LECTURES

IL – 1

INDUCED M = 0 INSTABILITY IN FAST CAPILLARY DISCHARGES AND POSSIBLE UTILIZATION FOR X-RAY LASERS

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High-current linear discharges confined by their own magnetic field are subject to magnetohydrodynamic instabilities, which perturb the straight plasma column. One example is the m=0 mode which is characterized by the development of necks contracting rapidly towards the axis with the ion sound speed. This leads to rapid heating of the plasma in the neck region and hence also to fast ionization of the atomic species.

The hot plasma flows out of the necks with velocities of the order of or higher than the ion sound speed, the multiply ionizes species interacting with the cold plasma outside the necks. Coulomb scattering between the ions is effective, but charge transfer collisions may dominate if suitable ions of lower charge state or neutral atoms are involved. This process is highly selective in populating only specific excited levels thus resulting in population inversion, which exists for a short time in two thin layers at both ends of a neck [1].

Ablative capillary discharges usually operate in a stable regime, since the ablated wall material outside the plasma column should stabilize the pinch column. However, investigations with capillaries made of polyacetal revealed that a m=0 instability can occur at the second current maximum: imprints of the instability are seen on the capillary wall, and the derivative of the current gives a respective indication. Simultaneously with the instability a short pulse in axial direction is seen on the Balmer-alpha transition of CVI at 18.2 nm. It is interpreted as amplified spontaneous emission by the short-lived active layers explained above [2].

The instability occurs only with a specific sample of polyacetal as wall material, and its wavelength also increases with the length of the capillary which proved harmful to a gain of the laser emission increasing exponentially with length. Therefore investigations were carried out where the instability is induced by a waved structure pressed into the inner wall of the capillary. The instability now occurs reliably and exponential growth of the laser emission is observed.

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International Workshop on Dense Magnetized Plasmas – IWDMP'2000
Kudowa Zdroj, Poland, October 12-14, 2000.

IL – 2

STABILIZING OF Z-PINCH AND PLASMA FOCUS DISCHARGES DUE TO THICK WIRES

P. Kubeš*, J. Kravárik*, M. Paduch**, K. Tomaszewski**, M. Scholz**, A. Szydlowski***, Y.L.Bakshaev****, P.I.Blinov****, A.S.Chernenko****, E.M.Gordeev****, S.A.Dan'ko****, V.D.Korolev****, A.Shashkov****, V.I.Tumanov****, V. Romanova*****

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This contribution deals with the results of the diagnostics of the impact of the plasma imploded with mega-amper z-pinch or plasma focus devices to the Al or C wires of 100-300 μm in diameter placed in the center axis. The discharges were operated with a maximal current of 1.5 – 3 MA. Experiments were performed on two devices, PF 1000 at IPFLM in Warsaw and Stand 300 in Moscow.

The PF-1000 plasma focus device reached the maximum of 1.5 MA current at the pinch phase. The Al and C fibers of 3 cm in length were fixed to the central electrode face on its axis at the initial pressure of 2-3 torrs of hydrogen. The XUV emission in K-shell wire lines was generated by the impact of the collapsing hydrogen current-sheath to the fibers. After XUV emission the fiber corona surface emitted in the visible lines and kept its diameter constant during a ~ 500 ns period [1,2].

The pulse power S-300 machine reached 3 MA at the rise time of 100 ns. The liner of the array system type (cylindrical form, 1 cm in diameter, 60-80 tungsten wires each of 6 μm in diameter and 1 cm in length) was imploded to the Al wires of 250 μm in diameter which were located in the liner axis. The following three features of the pinched plasma were changed under the presence of the Al wire in the liner axis: longer time of the phase of the minimal diameter, lower intensity of keV emission and forming of the dense magnetized plasma corona of the central wire with jets of the hot plasma emitting in Al K-shell lines [3].

The diagnostics showed that the wire corona in both types of experiments was formed by dense, cold and relative stable plasma. The plasma in the wire corona, embedded by the imploded current-sheath, was confined by a self-magnetic field and absorbed the important part of the current. At the pinch phase a ~ 20 ns pulse in the K-shell emission was observed from the surface of the corona. The fast transformation of magnetic fields, induction of the electric field and accelerated electron beams are probably the reasons for this K-shell emission. It seems interesting to study these phenomena for fusion and x-ray laser research applications.

1. M. Scholz et al: *Czech. J. Physics, 50 Suppl.3 (2000), 150-154.*
2. P. Kubeš et al: *Proc. 7th International Conference on X- Ray Lasers, France, 2000 - in press.*
3. P. Kubeš et al: *Proc. 13th International Conference BEAMS 2000, Japan 2000 - in press.*

II – 3

THE ROLE OF ANOMALOUS RESISTIVITIES IN PLASMA FOCUS DISCHARGES

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The existence of plasma microturbulence in Plasma Focus (PF) devices is a widely accepted fact within the PF community. This microturbulence must be generated as a final stage of microscopic instabilities, which could develop during certain phases of the plasma evolution. Among the candidate instabilities to occur in these devices, the lower hybrid drift instability is the one with better possibilities, because its triggering condition (electron drift velocity approaching ion thermal velocity) has reasonable chances to be fulfilled [1].

The main effect of the development of this instability is the modification of the collision frequencies in the plasma, which adds an anomalous term to the plasma resistivity. The theory for evaluating this extra term exists, and has been already used in PF 1D numerical simulations [2] and in Z-pinch calculations [3,4].

The role of this anomalous resistivity in PF behaviour has been the subject of considerable speculations. In this work, a 1D MHD calculation of the pinch stage in a PF device will be presented, including anomalous resistivity effects, and their influence on electric fields and the discharge current will be discused.

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IL – 4

PINCH MODES IN THE SPEED2 PLASMA FOCUS

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Deuterium discharges in the SPEED2 plasma focus (80kJ, 200kV, 2 MA, 400ns) [1] have been found unexpectedly stable within the operational regime as a neutron source. Only at higher filling pressures (above 6 mbar) sometimes m=0-type instabilities appeared in the pinch column, especially in discharges of lower efficiency (moderate dynamics and neutron yield).

Enhancing the electromagnetic radiation by doping these discharges with heavy gases (e.g. neon, argon) distinctly two pinch modes are produced, the micropinch mode (MPM) [2] or the stable column mode (SCM) [3], with a transition regime where the initial SCM is followed by the MPM. Micropinches are local radiative collapses initiated by m=0 instabilities of low-energy-density pinch plasmas. These instabilities and the successive micropinches can be suppressed by kinetic deuterons produced during dynamical compression of high-energy-density deuterium plasma sheaths. Depending on the relaxation of this fast deuteron component the pinch column can be stabilized for several tens of nanoseconds. While the short-lived (appr. 1 ns) micropinches erratically appear as point-like successive flashes along the pinch axis with temperatures around 1 keV and about solid density the reproducible SCM, optimized with respect ot the compressin ratio, forms a powerful linear radiation source of temperatures and densities similar to the MPM..

The SCM needs powerful (fast) drivers in order to use the kinetic ion stabilization, but not necessarily MA currents as available from the SPEED2 driver. This opens the possibility to establish the SCM also in compact experiments like SPEED3 (8kJ, 80kV, 0.8MA, 300ns) or even SPEED4 (2kJ, 40kV, 250kA, 300ns).

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IL – 5

RECENT PROGRESS IN 1 MJ PLASMA-FOCUS RESEARCH

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This paper reports on actual operational characteristics of PF-1000 and preliminary results of investigations performed with a new set of Mather-type electrodes, operated at energy levels up to 800 kJ. The diameters of coaxial anode and cathode were 231 mm and 400 mm, respectively. The both electrodes were about 600 mm in length, but the basis of the inner one was embraced with a tubular ceramic insulator of 113 mm in length. The experimental chamber was filled up with a pure deuterium under different initial pressures. The electrode system was powered by a powerful current-pulse generator, with capacity C= 1347.4 μF, condenser bank. The maximum charging voltage amounted to 35 kV, and the reported PF experiments were performed within an energy range from 500 kJ to 800 kJ.

Dynamics of a current-sheath was studied by means of two high-speed streak cameras and the two frame camera. The frame camera was used to the side-on observation of the pinch. The high-speed smear pictures were taken through slits oriented in the radial direction. On the basis of the pictures taken behind the radial slit, average radial compression and expansion velocities were estimated.

Time resolved X-ray signals were measured with PIN diodes covered by different filters.

The total neutron yield, i.e. the number of neutrons produced by a single discharge and emitted into different directions, was measured by means of four silver-activations detectors.

Taking into account the above mentioned diagnostic systems and characteristics of the PF-1000 facility should include the following objectives:

- achievement of a maximum neutron yield for stored energy 0.5 – 0.8 MJ,
- determination of neutron emission characteristics (time distribution, emission anisotropy, relative contribution of different mechanisms to Y_{tot}),
- investigation of the relation between the neutron yield and plasma sheath dynamics, particular attention has been paid to the pinch filament characteristics and its connection with the neutron yield.

IL – 6

ON THE INFLUENCE OF GAS PUFF LOADS ON PLASMA FOCUS DYNAMICS

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The plasma focus is a source of pulsed radiation, which is of interest in various fields of physics and technology. Relatively slow current rise time of the (usually capacitive) generator (in the range of one to few microseconds) leads to intensive and short bursts (in the one to several hundred nanosecond range) of soft and hard X-rays, collimated electrons and ions. Fast nuclear fusion neutrons may also be produced if the device is operated e.g. with deuterium filling.

Research activity in optimising the emission characteristics of a plasma focus has predominantly been preformed during the last decades in the experimental field. Applications include soft x-ray microscopy, soft x-ray and electron beam lithography, and metal coating by ion sputtering. For optimisation the following parameters are usually varied: electrode and insulator geometries, voltage, impedance and energy of the generator, filling pressure. The electric characteristics of the discharge have to be matched to the geometry and gas density in such a way that current maximum is reached around the final compression phase. Variation of the energy input is therefore rather limited for a given accelerator geometry and/or filling density.

A new degree of freedom in the choice of parameters can be accomplished is one applies gas puffing instead of static filling. In former experiments gas puffing was used either in the "ignition region", i.e. near the insulator at the back end of a Mather type plasma focus or in the "focus region" where the final compression to a magnetized plasma of high density with strongly anomalous resistance takes place. Gas puffing allows to a certain degree the decoupling of plasma conditions in the ignition phase from the final focus phase. This concept has extensively been investigated in many gas-puff Z-pinch experiments whereas only few experiments have been performed with plasma focus devices.

We will report on experiments with a fast valve, which was inserted in the anode of a large plasma focus. Gas puffing was applied in the downstream direction. 24 miniature (2mm diameter) nozzles, tilted by 15 ^{0} to the axis, formed a convergent conical gas target at the end of the inner electrode. The interaction of the radially converging current carrying plasma sheath with the injected target was investigated by various diagnostics including image converter streak pictures, Schlieren frames, modified voltage and current signals of the discharge.

The main aim of those experiments was to investigate the modified plasma pinch dynamics and its influence on the emission characteristics of electrons, X-rays and neutrons. It was found that one can get an increase in the neutron yield by about 80 %. This is an indication of a modification of the pinch compression in such a way that more favourable conditions of dynamic electromagnetic field distributions for the acceleration of ions can be accomplished.

We propose for the future to try to transfer to special plasma focus conditions theoretical investigations on (single and multiple) gas puff and wire loads, which were performed during the last years for the compressional Z-pinch.

IL – 7

STUDIES ON TIME CORRELATIONS OF THE X-RAY EMISSIONS IN VARIOUS PHOTON ENERGY RANGES AND ELECTROMAGNETIC PARAMETERS OF THE PLASMA FOCUS DEVICE

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Extensive experimental studies carried out over a period of about five years in this laboratory were aimed at finding time correlations between various physical quantities characteristic for the plasma focus discharge.

In a first series of experiments the time correlations between some electromagnetic quantities (voltage, current derivative) and the harder X-ray emissions (photon energies from a few 10's keV to a few 100's keV) has been investigated. Subsequent experimental studies included the plasma focus X-ray line emission at about 1 keV photon energy.

Most of the experiments were done on the IPF-2/20 plasma focus device [1]. Supplementary data were obtained in preliminary experiments carried out on the new IPF-6S3 device [2]. The plasma focus experimental data were compared with results obtained in this and other laboratories on vacuum spark discharges [3] and fast Z-pinch devices.

The correlation between the onset times of the X-ray emissions in three energy ranges has been studied on the IPF-2/20 plasma focus device, working at 16 kV and 11 kJ with various gas □□fillings. Soft X-ray line emission at about 1 keV photon energy (H- and He-like neon ion resonance lines) was detected by means of a crystal spectrometer equipped with photoelectric detection [4]. Medium energy X-ray emission (5-30 keV) was detected by filtered PIN diodes. Hard X-rays (energy above 100 keV) were detected by scintillator-photomultiplier detectors. In most of the measurements all detection devices were placed in a plane perpendicular to the electrode axis at about 1 cm in front of the central electrode. The visible light emission from the collapsing plasma sheath was taken as the time reference in the correlation studies. It was found that the onset times of the plasma focus X-ray emission in the energy ranges specified above were highly correlated (correlation coefficients close to unity were found). This was not the case for the duration and intensity of the same emissions. The same high values of the correlation coefficients were found from the analysis of the plasma focus X-ray emissions in the three energy ranges and certain features of the electromagnetic signals

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IL – 8

X-PINCH AS A SOURSE FOR X-RAY BACKLIGHTING

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IL – 9

APPLICATION OF PULSED PLASMA ACCELERATORS FOR SURFACE MODIFICATION

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The pulsed coaxial plasma accelerator of the Marshall type was used in experiments discussed in this paper. A relatively long time delay between the pulse of gas filling and the discharge switching on was chosen, with a result of the operation in the accelerating regime instead of the formation of the compression region (plasma focus) at the accelerator output. A power supply system (the condenser bank) with relatively low stored energy of 60 kJ was utilised in these experiments. Plasma streams with ion energy up to 2 keV, the plasma density of (2-3) x 10^{14} cm^{-3}, and plasma energy flux density (10-30) J/cm^{-2}, were generated. As far as those plasma streams were utilised for the surface modification of different materials, different working gases were used (mainly nitrogen, but hydrogen, helium and their mixtures were also used). The description of an experimental installation and some results of previous investigations of surface treatments by plasma streams are presented in [1-2].

In the recent paper there are presented experimental results of an improvement of metal surface physical properties (first of all tribological characteristics) after the irradiation of the samples with pulsed plasma streams. The improvement was due to the hardening and nitration (in the case of the use of nitrogen). Such treatment led to melting of the surface layer and subsequent fast its solidification.

The treatment process optimization was carried out with variation of plasma energy fluxes, plasma density and energy of ions.

An X-ray analysis, the cross-sectional metallography, and measurements of microhardness and wear tests of the processed samples were applied for investigation of the phase structure and tribological properties of the modified layer.

It was shown that microhardness of the steel samples was increased by several times after the plasma irradiation. For previously quenched steels the maximum value of microhardness was higher, as compared with no-quenched steel, and it was achieved for lower processing dozes. Formation of austenites, carbides, and nitrides in the modified fine-grained surface layer (with a depth up to 30 μm) was observed, as a result of the plasma processing. Wear dynamics of the treated samples was also investigated. The possibility to achieve a sufficient decrease in the wear rate of treated samples was demonstrated.

It was also shown that for the same energy, a load increasing the energy of ions (decreasing the plasma density) leads to improvement of surface roughness. Sufficient changes in the phase contentment (primarily γ-Fe with the formation of interstitial phases in the form of carbonitrides) were observed. This is a possible reason for achieving the surface hardening.

The modified layer has a fine grain structure and it has an increased resistance with respect to the etching. Therefore, one can expect an increased corrosion resistance of the plasma treated surfaces also.

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IL – 10

SIMULATION OF THE SOLAR WIND SHOCK WAVE WITH PLASMA FOCUS

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The aim of the experiments is to reproduce and study in laboratory quasi-perpendicular supercritical collisionless shocks similar to the Earth-Solar Wind shock, by way of using the plasma focus facility as the plasma source. The experiments were performed on the PF-3 facility (Filippov-type plasma focus) at a level of energy supply of about 1 MJ. Directed plasma jets are produced with axial velocities ~ 10^7 cm/s after compression of a current-plasma sheath in the initial stage of plasma focus formation. These jets then travel through an ambient plasma resulting of early gas ionization by X-ray radiation from the plasma focus, and at an angle of 90° to the 2500 G external magnetic field applied by a system based on rear-earth magnets. Our experimental conditions allowed us to reach a range $M_\alpha \sim 5 \div 10$.

ORAL PRESENTATIONS

OP – 1

ANOMALOUS RESISTIVITIES DUE TO LOWER HYBRID INSTABILITIES IN PLASMA-MAGNETIC FIELD INTERFACES

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Anomalous plasma resistivity can arise in dense plasmas as a consequence of the development of the Lower Hybrid drift Instability (LHI), which is triggered whenever the electron drift velocity v_d becomes comparable to or greater than the thermal ion velocity, v_i. This effect was discussed and carefully evaluated for theta-pinch plasmas [1], and later on used in the modeling of the pinch stage in a Plasma Focus device [2] and in solid fibre Z-pinch plasmas [3-6]. The feasibility of using the theory developed in the context of theta-pinches to Z-pinch plasmas was particularly discussed in the works by Chittenden [5,6].

The rationale behind the inclusion of this effect in Z-pinches, as mentioned by Robson when studying the possibility of obtaining radiative collapses [3,4] is the fact that, the frequently used steady state profiles of current density, j (uniform) and plasma density, n (parabolic) for these pinches have a diverging v_d at the pinch border. In this work, we will resume and comment his results, adding some consequences for radiative collapses.

Conceptually, the possibility of diverging v_d seems to be a far more general situation than Z-pinches, and in this work we will study it in general for plasma-magnetic field interfaces existing in other configurations, like that found in devices producing travelling current sheets (Plasma Focus devices, imploding pinches, etc.). We will show that it is essential to account for this effect in steady state situations, and that it could be also important in time varying ones.

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OP – 2

THEORETICAL STUDY OF THE PLASMA PINCH WITH HELICAL STRUCTURE

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Many cases of the dense and full ionisation plasma behave with helical structure. That is the case of both space and laboratory plasma. Experimental data and theory indicates that helical structure is a typical for the final phase of z-pinch evolution [2, 3, 4]. This can be also the typical state for some kinds of the cosmic plasma (earth aurora, galactic jets).

Presented theoretical study essentially generalised the previous one [1], that was based on the axially, not helical structure. The knowledge of the equilibrium state of helical structures is important for determination of the initial conditions in the numerical simulation of instability of such plasma structures, which is the main aim of our research group.

The suggested model is characterized by following assumptions:

- steady state ($\partial/\partial t \equiv 0$)
- full ionisation
- magnetohydrodynamic approximation (till the momentum equation for velocity)
- thermodynamic equilibrium
- ideality
- cylindrical symmetry ($\partial/\partial\varphi \equiv 0$; $\partial/\partial z \equiv 0$)

Basic equation system for plasma consist of Maxwell' Equations for electric and magnetic field, equation for mass conservation, fluid equation of motion and Ohm's law. Conclusion of the equation system, that renders the model self-consistent, is made by the equation for pressure (status equation, isotropic distribution of the microscopic velocity is assumed). The energy loss is passing due recombination, bremsstrahlung and synchrotron radiation respectively. The electric charge density is assumed to be nonzero value that leads to the presence of nonzero electric field. It is also taken into account the case of an anisotropies Ohm's law and nonzero viscosity. In cylindrical coordinates this model leads to system of the ordinary differential equation.

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OP – 3

SIMULATION STUDIES OF ATOMIC PHYSICS IN CAPILLARY DISCHARGES

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Fast capillary discharges are widely studied as a prospective medium for lasing in soft x-ray region. Detailed knowledge of kinetics of ionization and excitation states is needed both for diagnostics and application of capillary discharges.

Here, the results of simulations of discharge dynamics in an initially evacuated capillary are post-processed using detailed atomic physics models. K-shell spectroscopy model is used to compute temporally resolved line x-ray spectra that may facilitate interpretation of spectroscopy measurements. This model is also applied in order to find optimum parameters for recombination pumping scheme of suitable K-shell transitions.

The results are also presented of detailed study of plasma atomic physics including excitation states of all ionization states of light ions. Such a model is particularly important for relatively low discharge energies and for spectroscopic diagnostics in visible and near UV region.

OP – 4

RECONSIDERATION OF THE THERMONUCLEAR POSSIBILITIES OF Z-PINCHES

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This paper reconsiders the Z-pinch (including plasma focus devices) as a basis for a future thermonuclear fusion reactor.

Experiments on Z-pinches always have small, high temperature and high density plasma regions that arise spontaneously in a Z-pinch neck. A burn wave might be initiated in the Z-pinch column if in this small plasma region a Lawson-like condition were fulfilled. For a deuterium-tritium Z-pinch the thermonuclear burn wave can start if the thermonuclear power exceeds a certain threshold. The threshold can be expressed in terms of the neutron yield Y produced by a similar Z-pinch in pure deuterium. It is:

$$Y_{DD} > 2\div3\ 10^{13} * h * I^2, \qquad (1)$$

Here I is the peak discharge current (in MA), h is length of the neutron-emitting region (in cm), and Y_{DD} is the neutron yield due to the D-D reaction.

As an example, a deuterium load on the 2 MA Angara-5 machine provides $Y_{DD} = 3*10^{12}$ from h ~ 1cm. Angara-5's yield is thus 40 times lower than required for burn wave initiation. If the neutron yield were to increase as the fourth power of the peak current, the current must be increased $40^{1/2} \sim 6$ - fold to get a burn wave in a DT load

The paper gives the results of modeling for a Z-pinch with D and DT fuels in support of the criterion (1). According to the model, the neutron's origin (from thermonuclear reactions of from acceleration) does not change the criterion (1).

OP – 5

SELF-ORGANIZATION OF HIGH CURRENT – CARRYING PLASMAS: DYNAMICS OF FORMING OF TOROIDAL PLASMOIDS IN PLASMA COLUMNS AND TUBES

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In [1] it was shown theoretically and experimentally, that toridal plasmoid of θ - pinch type (TPP), H-filament, may be formed in a cavity of plasma column. In this report in the MHD frames [2] and particles method [3] the dynamics of such plasmoid forming is studied in detail. The influence of TPP on the redistribution of current between the core and the peripheral part of plasma column or tube is also discussed. Such redistribution of the current plays an important role in plasma focus and liner discharges.

In investigations of tube plasma with the anti-parallel current the various regimes of realization of TTP including the condition of the forming of the quasi-stationary plasmoids threaded the central external current were studied. In the work, from the point of the clearing up their common properties, independent from the used approximation, the comparative analysis of TTP is done. Such properties are first of all topological (structural) characteristic of discharges. These results show from one hand on the necessity to solve 4D (nonstationary 3D) model of real plasma at the moment of putting the task and from the other hand to take into account the processes chronology in plasma from breakdown up to the final stage. The 4D plasma dimensions is proved experimentally in [4] where plasma gets at the initial stage 3d structure which is transforming later consequently trough a number of quasistationary states from to the space periodic structure of E – type to the structures of H - type. The process of the H-filament forming as well as the grid structure forming is clear observed in a cavity of Z-pinches.

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OP - 6

REPRODUCIBILITY CONDITIONS FOR THE PULSED X-RAY EMISSION IN A VACUUM SPARK DISCHARGE

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The pulsed X-ray emission from a vacuum spark discharge has been intensely studied for many years. We have been developing a vacuum spark device as a pulsed X-ray source for the calibration of X-ray detectors [1].

A lot of studies have been made concerning the optimization of the vacuum spark device as an X-ray source. During the experiments, the changed parameters were the capacitor energy, the anode-cathode geometry, the anode material, and the trigger pulse amplitude. For the maximization (more than 10 J per pulse) of the X-ray emission, the best combinations of these parameters have been found [2].

The experiments showed that the main problem in the vacuum spark device operation was the reproducibility (in the "amplitude-time" domain) of the X-ray pulses. From this reason we concentrated our work on the favorable conditions for an adequate reproducibility.

The main conclusion is that the reproducibility depends on the triggering conditions. A high-power, very fast high-voltage trigger-pulse is required. In order to fulfill these conditions, a pulse transformer, and an air spark gap have been added to the initial triggering device [3].

The vacuum spark anode is electrically connected with the storage capacitor (12.5 μF/12.5 kV), which provides the energy in the vacuum spark discharge. The peak discharge current is about 100 kA, with a rise-time of 2.5 μs. A surface barrier detector with an aluminum filter of 25 μm thickness is used to detect the X-ray pulses.

The final conditions for obtaining "X-ray" and "di/dt" pulses showing a good "amplitude-time" reproducibility will be presented in the paper.

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OP- 7

DETERMINATION OF THE PLASMA PARAMETERS IN A CAPILLARY DISCHARGE

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A pulsed capillary discharge has been the subject of a various experimental and theoretical studies [1-2]. A jet of copper-hydrogen plasma with a cylindrical symmetry has been developed as a light source for spectroscopic measurements. The method has consisted in generating an electrical discharge between two electrodes mounted at the two ends of the capillary in a hydrogen atmosphere. A storage capacitor (17.5 μF), charged at high voltage (5-10 kV), has been used as the energy source.

The capillary discharge made it possible to obtain a metal vapour plasma with the plasma components originating from the elements mixed within the wall of the capillary. There is therefore the possibility to obtain a metal plasma made up of elements that in the normal state are solid, their source being other than the electrodes of the discharge circuit. The copper-hydrogen plasma jet has been produced by the ablation of the capillary wall consisting of a copper-embedded elastomer.

The electron density of the plasma has been obtained by using the H_β spectral line of the hydrogen component plasma. The H_β spectral line is degenerated and broadened especially by ions and electrons of the plasma (the Stark broadening). The electron temperature has been determined by means of the Boltzmann method applied to the Lorentz copper profiles emitted by the plasma jet [3-4].

The experimental values have been obtained after the solution of the inversion problem (Abel inversion) and the deconvolution of the experimental spectral lines. The copper and hydrogen lines have been broadened principally by the Stark effect. The electron density of the plasma has been found to be about $2x10^{17}$ cm^{-3} and the electron temperature about 20000K.

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OP – 8

ROLE OF INITIAL VAPOR DENSITY IN Z-PINCH POLYACETAL CAPILLARY DISCHARGE

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Pinch regime of a capillary electrical discharge may result in non-stationary properly hot and ionized plasma, suitable for soft x-ray laser pumping [1]. Lasing at 46,9 nm (Ar^{+8}) has been achieved in a pinching (collapsing) plasma column inside argon filled capillary discharge. Overheated plasma is created on the axis and collissional excitation is a dominant laser pumping process there.

We intend to use a pinch regime to heat the plasma during its collapse and then to create non-stationary under-cooled plasma during a quick plasma expansion. Recombination pumping of hydrogen-like ions may take place there. We aim to get C^{5+} laser active medium through a pinching electrical discharge in a polyacetal capillary [4]. Generally, there is no pinching regime if discharge is developed inside an evacuated capillary. To get a pinching regime the capillary should be initially properly filled.

We analyze potential pinching in capillaries, pre-filled by material ablated from the capillary wall by subnanosecond laser pulse. Plasma column dynamics is described by means of a simplified "snow-plow" model and influence of the external circuit is accounted [2]. Dependence of optimum initial concentration of ions on the capillary radius and initial voltage has been expressed. Having in mind an 1 mm diameter, 2.5 cm long polyacetal capillary [3], the estimated optimum initial concentration 10^{17}- 10^{18} cm^{-3} may be achieved if several tens of milijoule of laser radiation is quickly absorbed by the capillary wall.

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OP – 9

LONG TIME IMPLOSION Z-PINCHES

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The experiments with neon, argon, krypton and xenon implosions have been performed with the GIT-12 generator at current levels of 2.2 – 2.5 MA, and with the IMRI 4 device at the current level of 0.4 MA. The main goal was to perform a study of an unstable gas-puff of a large diameter. Attention was focused on dynamics of the implosion of such a gas-puff, and in particular on an influence of the gas-puff mass and atomic constitution on the macroscopic parameters of the implosion.

It has been established that during the implosion the wavelength of RT oscillations increases, and it reaches the value of 0.8 –1 cm at the final stage. When this takes place, some toroidal bubbles appear in the plasma shell bulk. The unstable implosion of a gas-puff, with a great atomic weight, is accompanied by an increase in the resistance of the gas-puff to a value exceeding the Spitzer resistance by two or three orders of magnitude during the run-in phase. We have also found that some kinds of the anomalous resistance can exist for all the studied gases during the whole stagnation phase.

It is possible to suppress RT instability with a help of a structured load, e.g., with a double gas-puff or the gas-puff upon a wire array. The effect of the structured load has been demonstrated in experiments with plasma radiation sources.

OP – 10

CONSIDERATIONS ABOUT SELF-ORGANIZATION IN PLASMA STRUCTURES IN Z-PINCH DISCHARGES

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Self-organization refers to the evolution of a system from a random initial stage into a recognizable preferred position or shape, coming mostly from the internal dynamics of the system itself and in the absence of other imposed constraints [1]. We apply this theory to Z-pinch phenomena. For self-organization to occur, and in this case due to an electric current and a self-magnetic field, there has to be a process, which essentially involves [2]:

1) Existence of open structures, i.e., the Z-pinch is an open structure, since it is part of the electric circuit.
2) Pumping-in of free energy, in the form of Joule heating and the Lorenz force during the implosion of the plasma. The magnetic energy transforms into kinetic and thermal energy.
3) The plasma becomes unstable and the developed instabilities are mainly of the Rayleigh-Taylor and MHD type.
4) Inception of a critical stage during the implosion and the pinch phase.
5) Existence of a structural model with the possibility of bifurcate, i.e., either destruction or self-organization, due to a self-magnetic field.
6) Anomalous production of entropy, growth of chaos, i.e., rise of plasma temperature due to the increase of current, magnetic field, and plasma density.
7) Expulsion of the produced entropy, i.e., expulsion of energy by the emission of photons, electrons and ions.
8) Inception of newly organized structures (ring or helical), with two possibilities: with the incoming if useful energy it is possible to repeat from 1). If this cycle is present, possibly this could be the reason for a second pinch phase (pinch pulsing) and a rapid transformation of the magnetic field configuration. With the lack of useful energy the plasma organized structures dissipate and get destroyed.

We have observed plasma rings in XUV emission, and spirals in the visible region which we assume as self-organized structures in Z-pinch discharges, in experiments with fibers realized in the Kurchatow Institute in Moscow, in the device Stand-300 [3]. Based on these ideas we have calculated the amount of entropy expelled from a mega-amperic Z-pinch implosion. We concluded that from a typical [4] temperature T=3.48x10^5 K, and knowing that the expelled energy was E approx. 10^2 J, the total decrease of entropy came as S approx. 2.87x10^-4 J/K. The principal reason for self-organized phenomena is the high density of the magnetic energy.

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OP – 11

STUDY OF DEUTERON MOTION IN A FILAMENTARY PF PINCH COLUMN FOR DIFFERENT CONFIGURATIONS OF FILAMENTS

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The emission of energetic ions from Plasma-Focus (PF) facilities has been studied for a long time [1-2], but the nature of non-thermal ion sources has not been explained well enough. According to numerous experimental observations the PF pinch column has a complex internal structure, which can influence velocity and spatial distributions of fast ions considerably. It was observed experimentally that during the acceleration (run-down) and collapse phase of the current-sheath (CS) layer there are formed quasi-radial filaments [3], and during the PF pinch formation there appear also quasi-axial filaments [4]. Different mechanisms have been considered in order to explain these filamentary phenomena, but no satisfactory theoretical model has been elaborated so far.

This paper is a continuation of the previous work [5], and it presents some new results of the 3-D model computations of deuterons' motion within the PF pinch column, which have been performed under different assumptions about the filamentary configuration. In order to obtain analytical expressions for magnetic and electric fields, it has been assumed that the current filaments constitute thin conducting rods, distributed symmetrically around the PF pinch z-axis. The configuration of such filaments has been chosen to be in a good agreement with the available experimental data. The electric field was calculated on the basis of the Faraday's law. Changes of the pinch-column shape, before and just after the maximum compression, have also been taken into account.

It has been shown that a magnetic field, corresponding to the filamentary structure, has regions of a small value not only on the z-axis, but also in space off the axis. Such regions can constitute magnetic channels for accelerated ions escaping from the PF pinch column. This mechanism can explain some peculiarities observed in the angular distribution of the investigated ions (e.g., of fast deuterons). Taking in account different parameters, i.e., a number of the current filaments, a number of the filament layers, presence or absence of the central filament, there were performed computations under various initial conditions. The initial energy of ions was assumed to be from 10 keV up to 200 keV. The obtained results have shown different possible ion-motion regimes, and they have demonstrated a relatively good agreement with the measured ion angular distributions.

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OP – 12

ULTRAFAST X RAY INTROSPECTIVE IMAGING OF METALLIC OBJECTS USING A PLASMA FOCUS DEVICE

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A compact Plasma Focus operated in Deuterium is used as an ultrafast high intensity radiation source for introspective radiographic imaging of metallic objects. The Plasma Focus device is composed by a 10.5 uF condenser bank charged up to 30 kV (4.7 kJ) and a cylindrical stainless-steel chamber 157 mm long and 96 mm diameter. The electrode configuration is Mather-type, being the electrodes diameters and length: 38 mm, 72 mm and 87 mm respectively [1]. The samples to be imaged were located outside the Plasma Focus chamber, about 1 m away from the chamber wall, which is 3 mm thick. High-sensitivity, fast-response commercial radiographic film was used as x-ray detector. A set of experimental images is presented showing a very high penetration power of the x-ray beam and then demonstrating that the small PF is suited for introspective visualisation of pieces manufactured on metal.

A photomultiplier tube coupled to a NE102A plastic scintillator was used to monitor the X-ray yield in every shot. The photomultiplier signal was used as an aid to decide whether to develop the x-ray film or to add another shot on it. Under normal circumstances, only one shot is needed to get an image when working in the range 3 to 5 mbar of filling pressure. Even in those cases where two or three shots were superimposed on the same film, the obtained image resulted sharp and with good contrast, indicating that the radiation source has a small size and is located almost in the same place from shot to shot.

Our results indicate that Aluminum pieces having tens of mm in depth can be easily imaged with submillimetric details. Stainless-steel pieces were be also introspectively imaged with the same resolution.

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OP – 13

ION TRAJECTORIES AND NEUTRON SPECTRA FROM GPM MODEL INFLUENCE OF THE HALL ELECTRIC FIELD

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The consequences of Gyrating Particles Model for neutron spectra and ion trajectories will be presented. We solve equation of motion of deuterons for different initial distributions of velocity and position of generation. Constant current density and possible filamentary structure have been assumed. Collisions with a pinch plasma and deuteron gas outside a pinch column have been taken into account. Side-on and end-on neutron spectra as well as anisotropy are computed having trajectories of deuterons. Influence of the Hall electric field on deuterons' trajectories has been investigated.

OP – 14

PLASMA FOCUS AS A LENS FOR INTENSE ION BEAM FOCUSING

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Some fundamental problems of high energy physics (beam emmitance decreasing and luminosity enhancement in GeV-colliders) and technological applications (nuclear microprobe, material modification) challenge the elaboration of nonconventional schemes for ion beams focusing with plasma using [1-3].

The theoretical and experimental investigations of the focusing processes of the intense ion beam of MeV range energy by means of plasma focus produced with coaxial plasma dun have been carried out. Proton beam of 5 MeV energy, 100 mA current, and 30 μsec time duration was produced at the proton accelerator "Ural-5" with radio frequency quadruple (RFQ) radial-phase focusing for beam current increasing. Plasma lens was formed during plasma flow injection from a coaxial plasma gun into nonuniform magnetic field of a short coil and plasma focus arising. The parameters of the plasma were the followings: plasma density $10^{11} - 10^{15}$ cm^{-3}, temperature 1 – 3 eV, and time duration 500 μsec. The magnetic field value was 500 – 1000 Oe.

Theoretical study and macroparticles simulation was performed to evaluate the focusing properties of the plasma focus formation. The space charge compensation and the role of the electric and magnetic fields existing in the plasma on the focusing processes have been considered. The influence of HF instabilities and polarization phenomena on ion beam focusing was estimated. Magnetic probes and optic spectroscopy diagnostics was used for temporal and spatial plasma geometry investigation. Ion beam portrait was determined at the luminescence screen. In the experiments performed the focusing coefficient was obtained as ten times beam compression at the length of 30 cm. Changing gas volume input, gun voltage, time delay, magnetic field value etc. the dependence of focused ion beam diameter upon various parameters of the plasma focus lens has been investigated. It was revealed that the main focusing effect was caused by the azimuth magnetic field of the currents carried by the plasma.

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OP – 15

VERIFICATION OF PLASMA DYNAMICS MODEL FOR IPD ACCELERATOR

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During the IPD (Impulse Plasma Deposition) process plasma is generated in the working gas due to a high-voltage high-current pulse discharge, ignited within an interelectrode region of a coaxial accelerator [1]. System of two coaxial metal electrodes (a cylinder and a rod, insulated from the other by a ceramic material), in which plasma is accelerated by the Lorentz force, is widely used in the surface engineering. In IPD accelerator this configuration is used for synthetising the amorphous- and nanostructured high-melting materials in the form of coatings deposited on different substrates [2, 3].

The simplified two-dimensional snow-plow model [4] has been evaluated previously for computational modeling of plasma behaviour. It has been found that the plasma dynamics along the electrodes and within the plenum behind strictly depend on the discharge parameters (voltage, pressure, condenser bank capacity, electrodes dimension). In particular, conditions favourable for the specific deformation of the current sheet were modeled [5]. This z-pinch region seems to be very important for the phase composition formation of the material that is synthetised in the impulse plasma.

In the present studies the real dynamics of the current sheet, as well as its shape, has been examined experimentally in the interelectrode region and at the front face of the central electrode. The high-speed cameras have been used for observing the spreading of the plasma. It was found that the qualitative or even semi-quantitative correlation between the model and observed results exists.

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OP – 16

B-DOT PROBES FOR MONITORING THE SHAPE OF THE CURRENT LAYER IN PF-1000

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The analysis of current density distribution in the interelectrode space in plasma focus discharge is very important for optimization of the process. B-dot probes have been developed to measure the structure and position of the current sheet as a function of time. The results of the measurements will be compared with the ideal case described by 2D snow-plow model.

Magnetic probes are located on the ring installed around the outer electrode. There are 4 groups of 3 probes every 90°. Each probe can be placed on different distance from inner electrode, and the whole ring can be moved toward Z-axis. The system can measure the structure of the field with the spatial resolution ±1 mm.

OP – 17

EXPERIMENTAL SET-UP FOR NEUTRON EMISSION INVESTIGATION ON PF-1000

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Experimental set-up and diagnostic system used during the first neutron experimental session on PF-1000 device will be described. Basic elements of the system are as follows:

- four coupled optical cameras looking through one optical path (two optical frame cameras and two cameras working in a streak mode),
- two independent neutron counting systems (based on indium and silver activation),
- two neutron probes (scintillator with photomultipliers) placed in electromagnetically sealed eurorak stands,
- two P-I-N photodiodes (registering visible and soft X-ray emission),
- standard electrical measurements (Rogowski coil, current derivative, voltage).

Pictures and waveforms are captured in computer memory by automatic registration and synchronization system.

OP – 18

A METHOD OF IMPURITY DIAGNOSTICS IN DENSE PLASMA SYSTEMS

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The analysis of a plasma impurity composition in the coaxial plasma systems (such as plasma accelerators, magnetic-plasma compressors, plasma focus, and others) is of great importance fundamental problem of plasma physics. Knowledge of the impurity composition has a special significance for the quasi-stationary plasma accelerators (QSPA) and their different applications. Information about quantity of impurities is very important for the optimization of plasma energetic parameters, and it is connected with the interpretation of technological and modeling experiments, using such plasmas. The quantity of impurities is responsible for a value of radiation losses, when an analysis of the energy balance is performed for the plasma-target interaction.

In recent work we proposed a spectral method for the determination of the impurity concentrations with respect to the concentration of the main plasma (hydrogen in our case). The main characteristics of our plasma streams (including shield-layer plasma) are as follows: the electron concentration – 10^{16}-10^{17} cm^{-3}, the electron temperature – 0.5-4.0 eV. Obviously, the model of the local thermodynamic equilibrium (L.T.E.) is the best approximation for our conditions.

We applied the criteria of Griem [1] and Biberman [2] in order to use correct L.T.E. correlation for impurity elements, which are present in the QSPA plasma. For all elements and ionization states (significant for our plasma) the electron density and temperature ranges, for which L.T.E. conditions are fulfilled, have been adduced. We used the spectroscopic data presented in [3]. In a number of cases a comparison between the two criteria was performed. It is well known, at the L.T.E. conditions the ratio between spectral lines intensities of two different elements (for example hydrogen and any impurity ion) depends upon the full (sum on ionization states) concentrations of these elements. This dependence can be obtained using the Saha-Boltsman equations with known the electron concentration and temperature. In that way, using measured intensities of the corresponding lines, we have possibility to estimate a ratio between the hydrogen concentration and any impurity. All our calculations were performed with the use of the MathCad program. They were carried out mainly for the most intensive impurity lines within the most convenient (from the diagnostic point of view) spectral range of the visible and in ultraviolet radiation.

This technique can be used for the diagnostic of the periphery zone of the Plasma-Focus (PF) discharges where the L.T.E. conditions must be executed. The advantages of this method in a comparison to others, as well as its possible errors, are considered and discussed.

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OP – 19

TIME-INTEGRATED DIAGNOSTICS OF X-RAY EMISSION FROM PLASMA FOCUS – PRELIMINARY RESULTS

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X-ray emission from the Plasma-Focus device varies in a complicated way in dependence on time and it is usually monitored by the use of a scope. Sometimes the knowledge about the absolute amount of X-ray radiation is needed especially when the applications of the source of this kind are considered. This parameter can be measured using the traditional time-integrating diagnostic method such as the use of a photographic film. A more precise method is the one with the use of thermoluminescence dosimeters (TLDs) [1,2]. It will be considered in detail in another paper at this conference [3]. Films and TLDs are not sensitive to electrical noise and they are preferred to other methods in the case of dealing with high-energy discharges, but they are cumbersome and time consuming when reading out the collected data. Semiconductor detectors (SDs) can be used in a current mode (with the output signal delivered to a scope) and in an integrating mode (with the use of a charge preamplifier). In both applications special precautions should be taken to avoid capturing noise. In the integrating mode the interference is especially dangerous, as it is difficult to separate the X-ray signal from the captured and integrated noise.

In this work both types of detectors, TLDs and SDs are used. The aim of the work is checking up the possibility of using the diagnostics of that kind at the Plasma Focus, developing the proper variants of detection heads, and mutual comparison of the obtained results. As SDs we use phododiodes, type FLM (ITE, Warsaw, Poland) that are of a thick active layer (380 μm, more than for a standard photodiode) and thus suitable for registration of harder part of X-ray emission up to about 20 keV. As TLDs we use the types TLD100 (LiF:Mg,Ti) or GR200A (LiF:Mg,Cu,P) types made from LiF material 920±30 μm thick. The energy dependence of the X-ray absorption for two stacked TLDs of that kind is very similar to the dependence for one 380-μm FLM photodiode. This gives the possibility of a prompt comparison of the results of measurements independently of the spectral shape of the emission from the investigated X-ray source.

Preliminary tests of the measuring systems have been carried on by the use of a pulsed cold-cathode X-ray lamp (Dina 1, Russian production) which emits radiation in a broad range of photon energies with the maximum at about 30 keV. The main tests have been realized at Plasma-Focus facilities at IPPLM, Warsaw. In this work we evaluate the constructed measuring systems and discuss the possible errors at estimation of the absolute values of X-ray emission.

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OP – 20

REFINED DESIGN OF A NEW DRIVER FOR FAST CAPILLARY DISCHARGE

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Probably the most challenging features of high current pulse capillary discharges is a possibility to work as a soft X-ray laser. There are two main ways to the population inversion in capillary discharges: electron-collisional recombination pumping scheme and electron-collisional excitation pumping scheme.

The recombination pumping scheme usually uses hydrogen-like ions the upper laser level of which is populated by three-body recombination, while the lower laser level is effectively depopulated. This is accomplished in evacuated small diameter (≤1 mm) capillaries, in which plasma is created by ablation of wall material and remains in close contact with the walls ensuring so a rapid conductive cooling. The apparatus with this type of capillary is very simple: the evacuated capillary has a sufficient dielectric strength to work in a self-breakdown regime. In this case it is sufficient to connect both ends of the capillary to the condenser bank (built usually symmetrically around the capillary) and charge it to the capillary breakdown voltage [1, 2]. Therefore, no spark-gap is necessary - nevertheless, sometimes near the capillary mouth a triggering electrode is mounted.

On the other hand the excitation pumping scheme usually uses neon or nickel-like ions the upper laser level of which is populated by electron collisions. This may be achieved in gas filled capillaries of larger diameter (~3-6 mm) by fast current rise - as high as $\sim 1\text{-}4.10^{12}$ A/s in a pre-ionised gas, which ensures a rapid detachment from the capillary walls (by Z-pinch effect). In this way the amount of material ablated from the walls is kept small and a limited number of particles is heated [3]. However, the capillary with a pre-ionised gas must be isolated from the charging capacitor by a spark-gap - for symmetry reasons usually mounted on the capillary axis in the vicinity of the capillary high-voltage electrode [3, 4]. Such an arrangement has a number of disadvantages discussed in the paper. These can be avoided with "transparent" capillary (with free radiation escape from both its ends) fed by radial Blumline pulse forming line [5]. The optimized design is the subject of this paper. We used the combined technique of electrostatic field mapping (which helps to determine the minimum safe dimensions of insulators, optimal roundness of the conductor edges and mutual capacitance of individual components) and equivalent circuit analysis, similar to that which we used for the design of our previous driver [6].

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OP – 21

FAST CURRENT GENERATOR FOR THE X-RAY BACKLIGHTNING DIAGNOSTIC

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A compact pulsed power generator was designed and constructed to drive an X-pinch (Z-pinch) load used as an intensive point-like source of X-ray flash for backlighting diagnostics. The generator consists of a primary storage capacitor bank, an intermediate power compression stage and a magnetically insulated vacuum transmission line loaded by exploding wires of X-pinch load. The intermediate power compression stage provides shortening of the load current rise-time to a desired value of several tenths of ns required for a good performance of X-pinch. It is based on inductive energy storage concept and an opening switch application.

The capacitor bank consists of 16 capacitors of 0.1 μF arranged in four rows of four banks in parallel in each. The rows are connected by low-impedance strip-lines to a common multi-gap rod-type gas switch installed in front of a collector electrode of the air-vacuum interface. The discharge time of the capacitor bank to the storage inductor formed by the strip-lines with the gas closing switch and the air-vacuum interface with the section of the opening switch module is in a range of 0.4 to 0.45 μs. At the maximum charging voltage of 40 kV the peak discharge current exceeds 200 kA.

A long conduction time plasma opening switch (μs-POS) is used as the opening switch to transfer the stored magnetic energy into the MITL and the load. The plasma opening switch is a critical element of the generator. The most important output parameters of the pulse generator depends strongly on its performance. The design of the POS constructed is based on the most recent our developments of μs-POS, and in particular, a new configuration of the electrodes with a plasma trap in the output transition region. The POS performance is one of subjects of the experimental testing of the generator. As an alternative solution, an exploding wires fuse is considered as the opening switch. For this reason the opening switch module has a special port with an additional air-vacuum interface for installation of fuse wire array. With a fuse opening switch more energetic capacitor bank may be used to produce a higher level of the output current.

The MITL formed by two coaxial electrodes of 80 and 90 mm in diameter and 0.5 m long delivers the fast rising current pulses to the remote X-pinch load. The inductance of the line and X-pinch wires together with holders increases the rise-time of the load current to 60-70 ns at its peak value of 120-150 kA for a peak opening switch voltage of 100 kV. The design of the MITL and an X-ray output window meets the requirements of the generator application for backlighting diagnostic inside of the gas-filled chamber of the PF-1000 plasma focus at IFPILM.

OP – 22

X-RAY DIAGNOSTICS OF PLASMA USING THERMOLUMINESCENT DOSIMETERS

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The thermoluminescent dosimeters (TLDs) are used not only in the field of personnel monitoring (dosimetry) service for ionizing radiation to the medical, industrial and research communities but also have been used for measurements of X-rays emitted from different pulsed plasmas, ranging from various laser-generated plasma devices [1-4] to, for example, High-Energy Radiation Megavolt Electron Source [5]. The application of LiF:Mg,Cu,P (GR 200A), LiF:Mg,Ti (TLD 100), CaF_2:Dy (TLD 200) dosimeters for measurement of X-rays emitted from hot and dense plasmas is presented for spectral range above 1 keV. Particular attention is paid to calibration of TLDs using monochromatized synchrotron radiation. The minimum detectable X-ray dose is discussed. Responses of different TLD types irradiated by X-rays emitted from an Al-plasma generated by a pulse laser are compared.

The advantage of thermoluminescent dosemeters as detectors of X-ray or VUV radiation from the plasma lies in the possibility to use them as secondary standards in calibration measurements of radiation from about 5 eV to tens of MeV. The TLDs can be calibrated with standard radionuclide sources or with a beam of monochromatized synchrotron radiation (MSR) of known intensity. The detection of X-ray radiation by TLDs is affected neither by an electrical interference nor by a strong magnetic field. A large number of TLDs can be simultaneously used in an experiment but only a single readout unit for determination of their themoluminescent (TL) responses is needed. The application of TLDs makes only time-integrated measurement of X-rays possible. The fading of the TL signal ranges from days to weeks in the dependence on the TLD type.

For absolute measurements of plasma X-rays, we calibrated TLDs using both the standard ^{55}Fe radionuclide and the MSR in the 1 keV to 6 keV range. Results of our preliminary spectral measurements are analyzed.

The ratio of sensitivities of different TLDs was determined and the aging effect of TLDs was investigated.

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OP – 23

HIGH-RESOLUTION X-RAY SPECTROGRAPH FOR 1.5-400 keV RANGE, EQUIPPED WITH A COMBINED CAUCHOIS-JOHANSSON CRYSTAL

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We have designed and built a wide-band, high resolution X-ray crystal spectrometer for applications to high-temperature plasma diagnostics. A new feature of this device is a thin cylindrical quartz-crystal with an optical radius R. The 10(-1)0 crystal planes with 2d = 0.85 nm have the radius equal to 2R. They focus softer X-rays in the reflection (Johansson) geometry upon the Rowland circle of the radius R. At the same time the crystal focuses harder X-rays in the transmission (Cauchois) configuration with the 0001 crystal planes, and 2d = 0.36 nm.

These planes are perpendicular to the surface and to the 10(-1)0 planes. In contrary to the usual Cauchois scheme, we made the optical radius of the crystal surface equal to the Rowland circle's radius. It is shown that for this type of the transmission crystal, a position of a line does not depend on the position of the source, and a width of the line does not depend on the source size.

The paper presents a theoretical analysis of the developed instrument and its corresponding calibration data obtained with an X-ray tube. Such a calibrated spectrometer can be used for heavy-ion velocity measurements through the determination of a Doppler shift, as well as for simultaneous measurements of the Bremsstrahlung and line emission from hot dense plasmas. Besides the reflection and transmission of the crystal planes parallel and perpendicular to the crystal surface, we have also analyzed various inclined cuts of the same crystal. The 3-400 keV energy range is provided with the 0001 cut and the inclined 10(-1)2, 10(-1)3, 10(-1)4, 10(-1)5, 10(-1)6 cuts in transmission geometry.

In order to expand an energy range of the device we propose to use the same crystal in the Johansson geometry with the corresponding inclined cuts: 20(-2)1, 30(-3)1, 40(-4)1, and 50(-5)1. The paper presents also X-ray tube spectra, which were obtained in the reflection regime, as simple illustration for the fact that the single quartz crystal can provide the whole 1.5-400 keV energy range.

OP – 24

INFLUENCE OF DIAPHRAGMS ON MEASUREMENTS OF IONS EMITTED FROM DENSE MAGNETIZED PLASMAS*

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The paper concerns the diagnostics of ions escaping from dense magnetized plasma (DMP) discharges. Particular attention is paid to the basic problem of the separation of such ions from the investigated plasma, under condition that this process should not disturb the velocity (and energy) distribution functions of the measured ions.

In the first part of the paper there are considered different questions connected with the application of strong electrical fields needed to separate ions from a dense plasma stream. Also described is an influence of the spatial electrical charge of the separated ion beam during its transportation from a separation system (e.g. an input diaphragm) to the analyzing and detecting systems. Basing on the early papers [1-3], the penetration of the ion beam through the input diaphragm (of the r_1 radius), as well as through the output one (of the r_2 radius), is considered and some critical values of the ion flux density are determined.

The second section of the paper describes a three-step procedure, which is often applied in studies of various DMP discharges [4-7]. The first step is the reduction of the initial plasma concentration (below 10^9 cm^{-3}) without a considerable deformation of the velocity distribution function and a mass-spectrum of the analyzed plasma stream. The second step is the obligatory separation of an ion beam from the plasma stream of the reduced density, and the third step is an analysis of the separated ions. There is also described a method applicable for the determination of primary plasma parameters on the basis of mass- and energy-spectrum measurements of the separated ions.

In the third part of the paper there are specified conditions, which should be fulfilled by the diaphragms to be used for the ion studies. Examples of the applied measuring systems are given, and some results of the performed ion measurements (including the recent studies) are commented.

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OP – 25

NEUTRON AND FAST ION EMISSION FROM PF-1000 PLASMA FOCUS FACILITY EQUIPPED WITH NEW LARGE ELECTRODES.

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Corpuscular diagnostics of high-temperature plasmas are considered to be the most substantial source of the data about the plasma parameters. Nuclear reaction products (neutrons, protons, trytons, ^{3}He-ions etc.) as well as primary energetic ions bear a lot of valuable information on nuclear reaction mechanism, ion energy distribution, and even on magnetic fields surrounding the hot plasma are. Therefore, in order to measure the total neutron yield and angular distribution of 2.45 MeV neutrons emitted from PF-1000 facility, we manufactured four silver counters and disposed them suitably around the discharge chamber. The counters were calibrated in situ using an Am-Be neutron source of precisely defined intensity of 1.5 10^7 neutrons/sec 4π. The fast ion emission (mainly energetic deuterons) was measured by means of a miniature pinhole camera equipped with solid state nuclear track detectors of the CR-39 and PM-355 types. The first experimental data have shown that the angular distribution coefficient of neutron emission (φ_0 /φ_{90}) is correlated to the D_2 gas discharge pressure and to fast ion fluxes registered along the electrode axis. For lower discharge pressure (1 - 2 torrs) neutron emission appeared to be more anisotropic and intensive ion beams were measured. When the PF-1000 device was operated at higher pressure (~10 torrs) neutron emission tended to be almost isotropic and fast ion emission disappeared. The pictures as taken with fast streak and frame cameras also show that the discharges performed in low pressure operational regimes revealed a more turbulent plasma column resulted probably in high overvoltages and strong magnetic and electric fields. These fields accelerate primary ions to high energies, which in turn increase the contribution of the accelerator mechanism to the total neutron yield and lead to the higher anisotropy coefficient of the neutron emission.

OP – 26

STUDIES OF PLASMA-FOCUS DISCHARGES WITHIN THE PF-360 FACILITY EQUIPPED WITH PLANAR D_2O-ICE TARGETS *

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The paper reports on investigations of dense magnetized plasmas produced within the modernized PF-360 facility [1], which was operated with additional planar cryogenic targets placed in the front of the electrode outlet and covered with D_2O-ice layers [2].

The first section of the paper explains physical principles of the recent PF experiments with the planar D_2O-ice targets. Basing on the results of the previous studies of the fast ion beams emitted from PF discharges [1-3], there are given some estimates of the possible beam-target reactions (and fusion-produced neutrons) for the chosen experimental conditions.

In the second section there is described the construction of the planar cryogenic target, which was equipped with special Dewar-type tubes for a liquid nitrogen flow. Also described are technical tests of that equipment, which were performed within an auxiliary vacuum stand.

The third section of the paper presents results of diagnostic measurements performed during several series of the recent PF experiments, which have been carried out with the use of the developed planar cryogenic targets. In addition to routine measurements of discharge voltage- and current-waveforms, there are presented time-integrated and time-resolved data referring to X-ray and fast neutron pulses. Particular attention has been paid to the optimization of the fusion neutron yield.

In the fourth part of the paper there are given some comments on the obtained experimental results, and in particular there are presented conclusions referring to methods and prospects of a further optimization of the neutron emission from PF facilities by means of special cryogenic targets containing deuterium.

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OP – 27

STUDIES OF PLASMA-FOCUS DISCHARGES WITHIN THE PF-360 FACILITY EQUIPPED WITH NEEDLE D_2O-ICE TARGETS *

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The paper reports on investigations of dense magnetized plasmas produced within the modernized PF-360 facility [1], which was operated with additional "needle-like" cryogenic targets placed in the front of the electrode outlet and covered with D_2O-ice layers [2].

The first section of the paper explains physical principles of the recent PF experiments with the "needle-like" D_2O-ice targets. Referring to results of the previous experimental and theoretical studies of ion motion within the collapsing current-sheath (CS) layer and PF pinch column [3], there are given some estimates of the beam-target reactions (and fusion-produced neutrons) for the chosen experimental conditions.

In the second section there is described the construction of the "needle-like" cryogenic target, which was equipped with a special Dewar-type tube for a liquid nitrogen flow. Also described are laboratory tests of that equipment, which were performed by means of an auxiliary vacuum stand.

The third section of the paper presents results of diagnostic measurements carried out during several series of the recent PF-360 experiments performed with the use of the described "needle-like" cryogenic targets. In addition to routine measurements of discharge voltage- and current-waveforms, there are presented time-integrated and time-resolved data about X-ray and fast neutron pulses. Particular attention has been paid to the determination of experimental conditions when the fusion neutron emission can be increased.

The fourth part of the paper contains some comments on the obtained experimental results and an explanation why the higher neutron yields have been achieved with the use of the planar cryogenic targets [4]. Also presented are conclusions referring to methods and prospects of a further neutron yield optimization by means of "needle-like" cryogenic targets, containing deuterium.

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OP – 28

INVESTIGATION OF PLASMA-FOCUS DISCHARGES IN THE PF-360 FACILITY WITH ADDITIONAL D_2 GAS-PUFFED TARGETS *

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The paper describes experimental studies of dense magnetized plasmas produced within the modernized PF-360 facility [1], which was operated with an additional D_2-gas puffing into the region of the collapsing current (CS) sheath and PF pinch formation, i.e. into space in front of the electrode outlet.

In the first section of the paper there are summarized results of the previous gas-puffed experiments performed with other PF facilities [2-3], and there are explained reasons of a choice of experimental conditions for the reported PF experiments.

The second part of the paper describes the construction of a special fast-acting gas valve. There are also described auxiliary experimental systems: a working gas supply unit, an auxiliary current-pulse generator for the electromagnetic drive, and a pressurized-air system for the pneumatic return-drive. Results of the laboratory test of the whole equipment, which were carried out by means of a special vacuum stand, are also presented.

In the third section of the paper there are presented results of the recent PF-360 experiments, which have been performed with the use of the described gas-puffing system. This system is able to produce relatively dense gaseous targets in the neighborhood of the electrode outlet. If a pure deuterium gas is used for the initial filling and the additional puffing, it is possible to increase a fusion neutron yield under determined experimental conditions. In addition to routine measurements of discharge voltage- and current-waveforms, there are presented time-integrated and time-resolved data about X-ray and fast neutron pulses. Particular attention has been paid to the determination of experimental conditions (operating pressures as well as time delays between the triggering of the valve and the initiation of the main PF discharge) in order to obtain the highest fusion neutron yield [4].

The fourth part of the paper contains comments on the obtained experimental results. Also presented are conclusions referring to prospects of the neutron yield optimization by means of the developed technique of localized gas-puffed targets.

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OP – 29

ANISOTROPY OF THE NEUTRON EMISSION FROM PF-360 FACILITY OPERATED WITHOUT AND WITH SOLID-STATE TARGETS*

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The paper reports on detailed studies of an anisotropy of the fusion-produced neutrons emitted from the modernized PF-360 facility [1], which has been operated with a pure deuterium-gas filling, without and with some additional solid-state targets containing deuterium atoms.

The first part of the paper describes a measuring system consisting of two scintillator-photomultiplier (pmt) sets and five silver-activation counters, which have been placed at different angles to the PF-pinch axis. The scintillator-pmt sets have been designed for time-resolved measurements of hard X-rays and neutron pulses, as well as their correlation with other traces, e.g. discharge voltage- and current-waveforms, X-ray signals, fast electron pulses, and pulsed ion beams. The silver-activation counters, containing Geiger-Muller tubes covered with pure silver foils and protected with appropriate paraffin moderators, have been designed for time-integrated measurements of neutron fluxes. They have been applied particularly for studies of an angular distribution of fast neutrons, which originated from fusion reactions occurring within the PF-360 experimental chamber.

The second part of the paper presents results of the neutron measurements performed during several series of PF experiments, which were carried out without and with planar cryogenic targets [2] covered with controlled "heavy-ice" (D_2O) layers. Particular attention has been paid to anisotropy of the neutron emission.

The third part of the paper considers the experimental results and it comments on different reasons of the observed neutron anisotropy. Basing on previous experimental and theoretical studies of PF phenomena, various mechanisms of the fast neutron production are taken into consideration, and some conclusions about influence of the additional targets are presented.

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OP – 30

RADIATION CHARACTERISTICS OF LIGHT GAS FOCUS PLASMAS

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The main goal of the experimental studies reported in this paper was to identify the determining radiation characteristics of focus plasmas produced in various light gases and gas mixtures. These studies were primarily aimed at basic physics processes, but they were also related to the development of the plasma focus device (PFD) as a soft X-ray source within the SIREX-M project [1] carried our in the Dense Magnetised Plasma Laboratory at NILPRP, Bucharest.

The experiments were carried out on the IPF-2/20 plasma focus machine (13 kJ, 400 kA at 18 kV) working with a variety of pure light gases (hydrogen, deuterium, helium, neon, argon) and their mixtures [2] and equipped with a broad set of diagnostics.

The X-ray emission in three photon energy bands was simultaneously recorded by the following means: a convex mica crystal spectrograph [3] for the spectral range 0.1-1.5 nm, filtered PIN diodes for the 5-20 keV energy band, and scintillator-photomultiplier (S-PM) detectors for the 150-300 keV energy range. Time integrated X-ray images were obtained by a filtered (beryllium and aluminium) 1:1 magnification pinhole camera. The X-ray measurements were always accompanied by standard electrical measurements (current and current derivative, voltage), as well as by the detection of the visible light emitted from the pinch region.

The crystal X-ray spectrograph, two PIN diodes and the pinhole camera, as well as one S-PM detector viewed radially the pinch region, while a second S-PM detector was placed along the discharge axis in front of the anode. The two PIN diodes were carefully collimated such that the

X-ray emission from the pinch plasma could be clearly distinguished from that coming from the electrode (anode) end. Various aluminium and titanium filters were used to define the energy bands detected by the PIN diodes. The S-PM detectors were also collimated using thick lead shields and housings.

Among the particular findings of the studies carried out under the conditions described above one could mention: the existence of intense hard X-ray emission from the bulk plasma at distances well away from the electrode (anode) surface; the existence of a strong correlation between the X-ray emission in the 5-20 keV band and the time evolution of the PFD electromagnetic parameters (voltage and current derivative); the dependence of the He-like and H-like spectral line emission on the working gas composition for equivalent electromagnetic and gas loading conditions (e.g., intense line emission of the H-like ions was obtained in pure neon, while in deuterium-neon mixtures the He-like ion line emission was strongest); the occurrence of a late X-ray emission at about one microsecond from the main emission.

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OP – 31

DENA, A NEW PF DEVICE

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In this paper we are going to introduce "Dena", a new plasma focus facility, Filippov type, with a condenser bank, C= 0.288 mF, and a maximum supplied energy, W_{max}= 90 kJ (at V_{max}= 25 kV). The facility is installed and started to work in the first period of this year (2000). Major points of the paper are:

- The geometrical parameters of the facility, its construction, and its functionality.
- The electrical parameters of the system, such as the initial inductance, impedance, and quarter period (or rise time) of the total discharge current.
- Diagnostics system, consisting of semiconductor SXR detector, HXR detector with NaI-scintillator, photo-multiplier with fast plastic scintillator, soft X-ray pinhole camera, current derivative probes, magnetic probe, Rogowski coil, neutron counter, and the data acquisition system.
- Preliminary results from the first experiments, obtained under different conditions such as, different gases, different bank voltages, and two different kind of anode inserts.
- Possibility of controlling the mode of Filippov type plasma focus operation, by changing anode configuration, and initial discharge condition. Different mode with enhanced neutron, HXR-yield, SXR-yield, and hot spot production was obtained.

OP – 32

TECHNICAL PROBLEMS FOR THE CONTROL AND COMMAND SYSTEM OF A PLASMA FOCUS DEVICE

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The paper presents the technical problems related to the electrical control and command system (ECC system) for the plasma focus installation IPF-4/5A [1] having the following main parameters: 1 MA plasma current and 40 kJ energy stored at 20 kV charging voltage. The ECC system was designed to operate in a very harsh environment due to high voltages (pulsed and d.c.), high currents with very high derivatives (10^{12} A/s), intense nuclear radiation (neutron and hard X-rays) pulses. The ECC system provides personnel and apparatus protection against dangerous events and centralised controls of all protection devices and plasma focus device subassemblies [2]. In order to prevent any electromagnetic coupling between the high power plasma installation and the ECC system, the latter is separated from the former by a galvanic separation barrier consisting of fibber optic cable assemblies for analogue signals and low stray-capacitance transformers for logical signals. The ECC system applies 23 interlocked logical commands, acquires and processes 28 logical states, acquires, processes and displays continuously the main slow-varying signals coming from IPF-4/5A subassemblies. All the plasma focus installation operational sequences are governed by strict hard and soft interlocking using in parallel two control and command systems [3]: one based on PC-control methods and another based on classical control techniques.

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OP – 33

A FUSION-FISSION HYBRID REACTOR DRIVEN BY HIGH-DENSITY PINCH PLASMAS

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The feasibility of a fusion reactor based on a high-density pinch device is rather uncertain. Such a fusion device could however be used to trigger a subcritical fission assembly and generate enough heat to make the resulting hybrid fusion-fission system economically interesting. A conceptual design for a 200 MW hybrid fusion-fission reactor has been developed to be used as a heat source for district heating [1]. The fission, heat-generating blanket is based on the CANDU

reactor technology, while the fusion fast neutrons are provided by a high-density, pinch plasma. The reactor has a vertical cylindrical configuration, with the neutron source on the axis being surrounded by radial (fission) and axial (tritium breeding) blankets [2].

The basic assumption regarding the fusion neutron source is that in a pinch plasma (high-density Z-pinch and plasma focus [3] configurations are considered) a fusion power level of 10 MW can be achieved. In a first conceptual design a repetition rate in the range 1-10 Hz is chosen for the neutron generator as an optimum value determined by technological problems raised by high energies per pulse, on one hand, and high repetition rates, on the other. The electromagnetic energy driver uses a modified Marx configuration to obtain an output pulse of 2 MV (starting from 100 kV charging voltage). The short-circuit parameters of such a driver (20 MA peak current with 800 ns rise-time) allow for a broad parameter range for the driver-load coupling.

The axial blanket is expected to produce a part of the needed tritium, the balance being supplied by the tritium produced in CANDU reactors. The radial blanket consists of 256 pressure tubes, each housing 8 standard CANDU fuel bundles. At equilibrium this blanket is fuelled with depleted uranium (0.3% U235) bundles for a discharge burnup of about 14,000 MWd/tU. The coolant (180 °C, 10 bar) is light water in a natural convection flow. The pressure tubes are arranged in 3 loops in order to assure post-fission heat removal without fuel cladding failure after a loss of coolant accident.

An outstanding feature of the design is that no active components (pumps, valves, etc.) are necessary within the reactor containment area, all the hybrid system control being ensured by the fusion component of the reactor.

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<u>OP – 34</u>

TOMOGRAPHIC SYSTEM BASED IN PLASMA FOCUS X-RAYS

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Radiation pulses from plasma focus provide unique characteristics compared with other radiation devices, namely very short flashes (10-50 nanoseconds) of high intense beams. This feature opens interesting possibilities in industry and medicine. Very short radiation pulses have been proposed in recent years for ultra-fast tomographic scanning to obtain fast cross-sectional information (Venere et al, 2000). Three-dimensional images of the internal structure of key components or critical parts in production lines have an enormous potential from the point of view of quality control. One can imagine a step in a production line where the quality of certain critical components is automatically monitored by means of tomographic identification of material defects.

A computed tomography is a three-dimensional image of an object constructed from a certain number of photographs of the attenuated radiation passing through the object at different angles. In order to construct a perfect tomography, infinite projections are required. However, certain images can be reconstructed from a finite number of projections (although with some distortion). The present work is oriented to develop an image processing system, which takes advantage of radiation flashes from plasma focus, optimizing the emission-detection-reconstruction procedure.

A computer system for 3D reconstructions using radiographic images of objects x-rayed with a plasma focus was developed. The technique is able to automatically determine the position of the rotation axis, reconstruct the 3D-attenuation map, and display inner cuts of the object. The software runs in PC and was implemented in Visual C++ using object-oriented technology.

An experimental radiographic session was performed using a compact device (Moreno et al, 2000). A small-chamber 30 kV, 4.7 kJ plasma focus described in detail in other communication to this Conference was used as x-ray source. A stainless steel BNC elbow was placed on the electrodes' axis, 83.5 cm away from the focus, outside the stainless steel chamber. No special procedures were required to filter out or to enhance the production of particular wavelengths. Attention was devoted to guarantee the filling gas purity, to make sure that the X radiation was not generated merely because of a large amount of impurities. All the shots were made at filling pressures of 4-5 mbar pure deuterium.

The sample was mounted on a small acrylic platform that rotates to allow for taking images at different viewing angles. The rotating axis was set vertically and 8 viewing angles were used: 0, 30, 60, 75, 90, 105, 120, and 150 degrees. The axis was marked with a sharp metallic needle. The processing and visualization of the inner cuts shows details down to 0.3-mm resolution.

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OP – 35

STUDY OF HIGH-SPEED PLASMA JETS BY OPTICAL TECHNIQUES

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The process of interaction of a solar wind with a magnetic field essentially depends on an angle of interaction and on the Mach number. Therefore definition of the velocity and the profile of plasma jets plays the important role at the laboratory simulation of the collisionless shock waves. For definition of these parameters the diagnostic set consisting of light probes, high-speed streak cameras and electron-optical converters was developed. This diagnostic set allows to make measurements both average velocity of the plasma jets and instantaneous velocity in the zone of interaction with a magnetic field, and also to investigate dynamics of the changing of the instantaneous velocity. In this paper the results of experiments on the plasma jet studies on the PF-3 facility are represented. The effect of the plasma jet braking at the interaction with the magnetic field was shown.

OP – 36

THREE-CHANNEL X-RAY DETECTION HEAD FOR DIAGNOSTICS OF PLASMA IN A NOISY ENVIRONMENT

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A compact, three-channel noise-resistant detection head based on semiconductor detectors has been built for the diagnostics of X-ray emission from plasmas.

Two types of Si photodiodes are used in the head; both fabricated at ITE, Warsaw, Poland. One is the BPYP03 (used in one channel), made from low-resistance silicon and characterised by a thin dead layer (about 0.15 μm). The active layer of the photodiode is voltage-dependent and can be set to as low the value as 2 μm. That makes the photodiode insensitive to hard radiation above 5 keV. It is suitable for measurements of a soft component of X-ray radiation in the range of 2-4 keV. Another photodiode (used in two remaining channels of the head) is marked FLM. It is fabricated from high-resistance material and is of a thick, 380-μm active layer (at the bias above 100 V). It is useful for measurement of a hard component of X-ray emission up to 20 keV. The adjustment of the energy range in an individual energy channel is obtained by the use of a proper entrance filter.

The head is vacuum-tight and is equipped with a clamping connector NW-40 for attaching to an experimental chamber. To make the head resistant to the noise produced by the plasma-generating facilities, the construction has been designed with great care. The head is isolated from the experimental chamber. Double shielding of the detectors mounted inside was used and the transmission of the output signal through the double shielded cable was provided. The head is of small dimensions and of tight construction. The compactness of the head has been achieved by the use of electronic components (photodiodes, charge-bank capacitors) in a form of bare chips (without casing) and by the use of the shortest connections possible. To make the shielding more efficient the head is supplied from a battery. A small DC/DC converter was provided (supplied from a 9-V battery) to deliver high voltage (200 V) to detectors. Due to the low loading of the battery (about 2 mA) the equipment can operate unaided for 100 hours.

The head has been checked on X-ray pulses from cold-cathode X-ray lamp and later on the pulses from laser plasma and from Plasma-Focus device. In the work the obtained results are discussed and conclusions concerning any possible improvements in the construction are drawn out.

OP – 37

MULTICHANNEL CALORIMETERS FOR MEASUREMENT OF FLOWS OF X-RAY RADIATION IN A RANGE FROM 10 UP TO 200 KEV

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3 and 8-channel calorimeters were developed and applied on " Plasma focus " facility (DPF) with flat geometry of electrodes (Filippov type) for measurement of a hard x-ray radiation yield and its spectral distribution.

The radiation was absorbed in targets by thickness from 0.1 up to 1 mm made of various metals from Al up to Pb. The change of temperature of targets was measured by thermocouples. The sensitivity ~ 0.001 K was achieved. The targets were positioned one after another so, that forward served filters for the following behind it. All complete set of targets as a whole works as a set of bandpass filters. The selection of suitable metal for each target allows to use them in a range of energy of quantums close to K-jump, where the crossection of photoabsorption is essential more, than that of elastic and unelastic scattering. It allows to neglect influence scattered quantums, that considerably simplifies calculations.

With the help of 3-channel calorimeter the dependences of quantity and hardness of x-ray radiation (HXR) from such initial conditions, as the working gas, voltage of the condenser bank (Uc) and initial inductance (L_0) of a discharge circuit were investigated. It is revealed, that the dependence of an yield of HXR from Uc is not monotonous, and has a maximum at some (not maximal) value of Uc. An introduction of additional inductance increasing L_0, this maximum is moved together with increasing of U_0 and grows on value. With the help of 8-channel calorimeter the more detail estimation of the form of a spectrum HXR was made for one set of initial working parameters of the facility.

OP – 38

AN INTERNAL STANDARD FOR FAST NEUTRON ACTIVATION ANALYSIS SPECTRA OBTAINED BY MEAN OF PLASMA FOCUS DEVICES

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The origin of some activation peaks which appears in a X-ray spectrum of a Fast Neutron Activation Analysis (FNAA) measurements, obtained with a Plasma Focus (PF) device, has been determined. The PF neutron source gives rise to neutron burst of different intensities. To know the exact neutron flux illuminating a sample at any discharges an external neutron counter is normally used. The nature and behaviour of the indicated peaks suggest to use (one of) them as internal standard for neutron production instead of an external counter. This technique allows more reliable and accurate elemental determinations.

OP – 39

0.2-KJ AND 2-KJ HIGH REP RATE DENSE PLASMA FOCI: THEIR DESIGN, TECHNOLOGY, AND APPLICATIONS

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The paper presents different designs of several medium and small size Dense Plasma Focus (DPF) chambers intended for various applications, a description of technologies used in these facilities, and some results reached with these devices by using various diagnostic techniques.

In present experiments DP Foci have been used mainly as an X-ray source. Application of these sources in science and industry implies absolutely new and very strict demands on the construction and technology of the devices used. These devices should have a high repetition rate (typically 1...15 Hz) and a long lifetime (over 1 million shots). Their switching elements, collector and chambers must withstand a high quasi-continuous heat load (up to 100 kW). They have to operate with different working gases and preferably in a wide range of pressures. High energy density at the central part of the chamber anode and necessity to provide a channel for radiation extraction demand a special construction and specific materials implementation in this region. All these points are discussed in the report.

Capabilities of the described techniques are illustrated by results of the recent successive experimental studies carried out with the facilities, located at the Nanyang Technological University (NX1 and NX2) as well at the Lebedev Physical Institute (PF-0.2). These devices were equipped with elements, which have been elaborated as the joint efforts of a collaboration of several research institutes [1,2]. All design and technology problems resolved in the course of its implementation are discussed in connection with the chambers' construction and the physical phenomena related (surface breakdown and initial stage, contradictions between demands at the initial and final stages, etc.).

In specific applications, intended for science (flash radiation biology, chemistry [3]) and industry (microlithography, micromachining [4]) and explored by us, different constructions and special regimes of DPF operation are necessary. In particular, spectral range of X-rays generated by the device should be tuned. It can be done in DPF by various means including materials used for a chamber construction and its filling. The working media such as deuterium, neon, argon and krypton are under discussion. Results on the interaction of the DPF-generated X-rays with specific materials are presented, and future perspectives of these and other possible applications are discussed.

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OP – 40

INVESTIGATION OF THE PULSE PLASMA STREAM INFLUENCE ON THE LITHIUM CAPILLARY-POROUS SYSTEM

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The important aspect in the developing concept of the lithium thermonuclear reactor [1] is the substantiation of the stability of the Lithium Capillary-Porous System (CPS) to the influence of plasma (the first wall, divertors and others).

The investigation done on the plasma quasi-stationary accelerator QSPE (TRINITI) demonstrated the great stability of the CPS with various porosity to the pulse influence of hydrogen plasma. Such stability seems to become possible due to the creation of the near surface ionized layer of lithium vapor providing the resistance of CPS base since between plasma pulses this CPS base is replenished by liquid lithium due to the capillary forces. In comparison, the condensed material is destroyed in the similar conditions intensively.

In this report we present some results of the first series of the CPS tests conducted on the Plasma Focus (PF) installation for the purpose of the study the behavior of the lithium CPS in the condition simulating the influence of plasma in the various regimes of the operating of the thermonuclear reactor. The parameters of PF [2]: energy – 4 kJ, maximum current – 400 kA. The axial velocity of plasma stream is about 10^7 cm/s. Plasma density in this stream is near 10^{18} cm^{-3}. The samples of CPS were placed on the Z-axis of the installation at the different distances from the anode to provide the various flux density of plasma. The experiment was done with use of laser diagnostics – shadow and interferometry, time resolved pinhole camera and others.

The preliminary analysis of the received results confirms the high resistance of the lithium CPS to the pulse influence of plasma.

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OP – 41

EXPERIMENTAL STUDY OF A POWERFUL ENERGY FLOW EFFECT ON MATERIALS ON PF-1000 INSTALLATION

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The paper presents a brief description of recent experiment on the metallic sample irradiation by combined effect of an X-ray and a high-energy ion beam and a hot plasma jet at the PF-1000 device [1]. Special techniques making possible to place and change specimens under the tests inside the vacuum chamber of the device is described. The DPF device was operated in a high-energy ion generation mode using pure hydrogen as a working gas. Energy store of the installation was 600 kJ. The experiment is based on the results of the irradiation experiment, which have been obtained with a DPF device of essentially lesser energy store [2] at small distances from the source. Thus the main aim of present work was to repeat previous regimes with this more powerful radiation facility at higher distances and to make next step in material testing with the higher energy density. The following diagnostic techniques were applied to control a device operation mode and the irradiation parameters:

- monitoring of the discharge current and the hard X-ray pulse as well as the hard X-ray doze measuring,
- plasma jet movement observation by means of a streak camera,
- high energy ($E > 70$ keV) ions measurement by means of CR-39 track detectors [3].

The experiment was carried out with samples of different materials regarding as the perspective ones for the high loaded zones of pulsed thermonuclear installations as well as with those important for diagnostics:

- pure metals: Cu, Ti, Fe, V, W and carbon;
- Cu-4%Ni, Cu-10%Ga, Ti-6%Al-4%V alloys;
- austenitic steel Cr12Mn20W1 which contains either 0,1% or 0,25% of carbon;
- wafers of the n-type Si, which was alloyed by phosphorus.

The total number of specimens, which was subjected to the illumination, is 26. Irradiated samples then have been investigated using optical and scanning electron microscopy as well as by means of X-ray structure analysis. Most typical forms of surface damage were observed for each tested material. So were fixed: evaporation, fusion and radiative erosion of surface layer, blistering, flaking, and crater formation phenomena. Irregular sedimentation of Cu, which was evaporated from the DPF anode, has been sometimes noted.

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PRELIMINARY STUDY ON X-RAY SOURCE FROM PLASMA FOCUS DEVICE FOR FAST RADIOGRAPHY

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Because of a large number of potential applications, plasma derived flash X-ray sources have been subjected of attention in the last years. Characteristic of this sources is a short and intense pulse of X-ray radiation from a few eV (50 eV) to 0.5 MeV.

In Plasma Focus device, measurements of the effective photon energy are not suitable with conventional methods as solid state scintillation spectrometer because the intrinsic instability of the pinch output phase prevents a direct comparison between different measurements. For this reason, a preliminary radiographic recording with filter of different thickness and in different position was developed to evaluate the effective energy.

The aim of the present work is to test the intensity of X-ray emission in the hard X-ray region (EX more than 10 keV) from Plasma Focus, in order to give a very profitable radiation source for medical and industrial fast radiography.

The source is a Plasma Focus (Physics Department of University of Ferrara) with capacitor bank energy of 7 kJ, 0.7 MA of peak electrode current and a filling pressure of 6 torr (4.5 mbar) of a mixture of D2+Ar because the emitted X-rays are weakly dependent on the amount of Ar.