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RAPORT SINS - 2/ V

DEPARTMENT OF THERMONUCLEAR RESEARCH ANNUAL REPORT 1993

Edited by
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Soltan Institute for Nuclear Studies,
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Department of Thermonuclear Research Annual Report 1993 presents a short review of theoretical, experimental, and technological studies performed within the framework of the research program - Plasma Physics (8 topics denoted V.1-V.8) and 2 grants devoted to plasma technology (under separate contracts with the State Committee for Scientific Research). Theoretical studies of a tokamak edge plasma, inner shell ionization by positrons, heat transfer in thin foils, and numerical simulation of HV pulse generators, are summarized. Experimental studies of X-rays and charged particles (including fusion protons) emitted from Plasma-Focus facilities, as well as measurements of plasma-ion streams generated by IONOTRON devices, are described shortly. Also presented are technological studies on data acquisition systems and material engineering, in particular the modification of solid surfaces with the plasma-ion streams.

Raport roczny 1993 Zakładu Badań Termojądrowych przedstawia kIótki przegląd badań teoretycznych, eksperymentalnych i technologicznych, przeprowadzonych w ramach programu badawczego Fizyka Plazmy (8 tematów oznaczonych V.1-V.8) i 2 grantów dotyczących technologii plazmowej (w ramach oddzielnych kontraktów z Komitetem Badań Naukowych). Podsumowane są badania teoretyczne plazmy przyściennej w tokamakach, jonizacji powłok wewnętrznych przez pozytrony, transportu ciepła w cienkich foliach i numerycznej symulacji generatorów impulsów HV. Opisane są krótko badania eksperymentalne promieniowania X i cząstek naładowanych (w tym protonów pochodzących z reakcji syntezy), które emitowane są z układów Plasma-Focus, a także pomiary strumieni plazmowo-jonowych wytwarzanych przez układy typu IONOTRON. Przedstawione są również badania technologiczne dotyczące układów akwizycji danych i inżynierii materiałowej, a w szczególności modyfikacji powierzchni ciał stałych za pomocą strumieni plazmowo-jonowych.

Рапорт за 1993 г. Отдела термоядерных исследований представляет собой короткий обзор теоретических, экспериментальных и технологических исследований проведенных в рамках исследовательской программы - Физика плазмы (8 тем обозначенных V.1-V.8) и 2 специальных субвенций на работы по плазменной технологии (в рамках отдельных контрактов с Комитетом по научным Исследованиям). Представлены итоги теоретических исследований пристеночной плазмы в токамаках, ионизации внутренних оболочек позитронами, транспорта тепла в тонких фольгах и численной симуляции генераторов импульсов в.н. Коротко описаны экспериментальные исследования рентгеновского излучения и заряженных частиц (в том числе протонов из реакции синтеза), эмитируемых установками типа PF (плазменный фокус), а также измерения плазменно-ионных струй генерируемых установками типа IONOTRON. Представлены также технологические исследования связанные с системами обработки данных и технологией материалов, и особенно с модификацией поверхности твердых тел при помощи плазменно-ионных струй.

CONTENTS

1.PREFACE

by M.Sadowski

In 1993, research activities of the Department of Thermonuclear Research (P-V) at the Soltan Institute for Nuclear Studies (SINS) in Świerk near Warsaw, Poland, were mainly a continuation of previous studies [B1], but some new theoretical problems and experimental tasks were also undertaken.

The theoretical and experimental studies were performed within a frame of a basic research project - Plasma Physics (comprising 8 topics denoted V.1 - V.8), and technological studies were supported additionally by two grants from the State Committee for Scientific Research.

The theoretical studies concerned a modified model of tokamak edge plasmas, the inner shell ionization by positrons, the filamentation phenomena within high-current pinch discharges, heat transfer in thin foils exposed to plasma streams, and the numerical simulation of HV pulse generators.

The experimental studies concentrated on investigation of X-rays, fast electrons, various ion species, and fusion produced protons emitted from different Plasma-Focus (PF) facilities. Other experimental efforts were devoted to mass- and energy-analysis of ions carried by intense plasma streams generated by IONOTRON-type devices.

Technology oriented studies concerned a new opto-electronic system for data acquisition, the adaptation of PF facilities for experiments with material engineering, and the modification of solid surfaces with pulsed plasma-ion streams. Some technological efforts were connected with the modernization of HV pulse generators, and in particular triggered 2IC8 spark gaps.

In 1993, particular attention was paid to the scientific collaboration with other departments at SINS (e.g., with the P-II and P-IX departments), as well as with our foreign partners at the Institute für Plasmaforschung (IPF) at Stuttgart University, Germany, and the PF Group at the Kurchatov Institute of Atomic Energy in Moscow, Russia. We have also participated in activities of the International Group working on a project of the International Center for Dense Magnetized Plasmas (ICDMP).

Other efforts were devoted to the popularization of plasma studies. The P-V Department participated in the organization of the National Scientific Symposium PLASMA'93, which was held in Warsaw, Poland on September 29-30, 1993. Numerous invited lectures and talks were given at international and domestic meetings, as can be seen from the list enclosed.

2. THEORY AND COMPUTATIONAL PHYSICS

2.1. Modified Model of Tokamak Edge Plasma within Grad's Approach (V.5c)

by M.Rabiński

The fluid approach used for the description of tokamak edge plasma overestimates the transport coefficients (heat conductivities and longitudinal viscosities) within the regions where validity of the hydrodynamic approximation is violated. In this case heat fluxes are not determined by the local temperature gradients but they depend nonlocally on profiles of plasma parameters. Over the past few years several approaches have been applied to obtain a more realistic theoretical model. In the beginning, the nonlocal electron heat flux formulation has been implemented because of its relative simplicity.

A more sophisticated model of transport coefficients* has been used in the BOUND_1D package of one-dimensional codes. Plasma transport has been described by a two-fluid model with viscous stresses and heat fluxes treated as independent variables. Equations for the nonlocal transport coefficients have been derived in the frame of 21 moment Grad's approximation, contrary to the commonly applied 5 moment approach.

Recently, Grad's model has been modified by introducing gradient terms, *explicitly* giving classical viscosity [C5]. The integrity of the formulation has been proved all along during numerical calculations. It has been found that the time in which the steady state solution becomes established is significantly longer than that needed for classical solutions. This caused by the complicated relations between variables in equation sets describing transport coefficients.

In the nearest future the BOUND_1D code will be developed into the GRAD_1D package. With the new program, selection of a particular Grad approximation ought to be facilitated. Access to the following models will be guaranteed: a full 21 moment approach; 13 moment description; 13 moment approach worked out by Radford**, with higher moments put equal to 21 moment values in the limit of classical transport; a classical 5 moment approach.

It is justified to assume that the comparative studies of the above models may show the significance of introducing new terms and equations when passing to a higher stage of Grad's expansion [C5,C17]. This analysis will create the basis for the selection of a most effective theoretical formalism relevant to transport phenomena in the edge plasma.

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* Rabiński M.: Edge Plasma Transport in the Grad Approach, 18th Europ. Conf. on Controlled Fusion and Plasma Physics, Berlin 1991, vol 15C, part III, 33-36.

** Radford G.J.: The Application of Moment Equations to Scrape Off Layer Plasmas, Contrib Plasma Phys 32 (1992) 3/4, 297-302.

2.2. Kinetic Fluxes in the Plasma Sheath in an Oblique Magnetic Field - Analytical Estimations

by Z.Jankowicz

Despite many efforts aimed at understanding and describing edge plasma transport towards the wall in a magnetic field parallel or oblique to the wall, this problem still remains an open question. It is obvious that the case of an oblique magnetic field is rather typical in a majority of magnetic configurations (diverters or toroidal limiters) and there exist two components of plasma fluxes going towards the wall: the parallel flow along the magnetic field lines, relatively well described by existing theories, and the perpendicular transport of mass, energy, and momentum which is usually taken from experimental data.

Consider the case of a collisionless non-neutral plasma in a magnetic field oblique to the wall and to the electric field at the wall. The magnetic field is assumed as constant in space. Let us also assume that the ion Larmor radius and the Debye length are of the same order (there is no small parameter in the problem). It is well known that such a case has no analytical solution; the only integral of motion is the energy of the particle. This stimulated a numerical approach: a typical analysis is the electrostatic PIC simulation. This, however, requires a large number of particles, and results of such a consideration can not be used directly as boundary conditions in *fluid codes aimed at modelling SOL plasmas.*

Considering a collisionless plasma one can start from the Vlasov equation and find first an integral of particle motion in a crossed homogenous magnetic and constant or linear electric field. An angle between directions of the magnetic and electric fields in such a case can be considered as arbitrary between 0^0 and 90^0. Considering an electric field with a variable shear or a gradient one limits all analytical analysis to a very small angle. Only then can we find an approximate analytical solution of the problem.

Knowing the velocity limits for particles escaping to the wall, one can determine the hydrodynamic fluxes if the shape of the distribution function is known. This can be taken only from the solution of the plasma presheath. However, a suitable shape of the distribution function (the truncated Maxwellian function cut off differently in all three dimensions, in accordance with results of the escaping orbit analysis) can be considered as a good approximation on the entrance of the plasma sheath.

Simultaneously, knowing characteristics of the Vlasov equation in the region of a weak electric field (linear or parabolic potential), one can find the local distribution function in those regions and determine local gradients.

The analysis considered is devoted to the program presented above. The fluxes obtained by such a consideration depend on the magnetic field, its direction in respect to the wall, and its intensity. Following considerations by R. Chodura, one can assume the modified Bohm condition for an oblique flow of a plasma along the magnetic field. In the limiting case of a perpendicular magnetic field, the fluxes are independent on it and coincide with fluxes calculated by a similar procedure known from literature [C27,C28].

2.3. Theory of Inner Shell Ionization by Positrons (V.5b)

by M.Gryziński, M.Kowalski

Calculations have been based on well known binary encounter (b.e.) relations, derived by Gryziński*, where the change of kinetic energy of the charged particle on its way to central parts of the atom was of primary importance. Experimental results** indicate that in the case of positrons this effect is very important. Since the velocity of an electron depends upon the position of the latter on the orbit, one must perform averaging over a velocity distribution of atomic electrons. The mean energy of the electron in the shell is equal to W. In the case of ionization by electrons, the ionization cross section may be given in analytical form [A10]:

$$\sigma_i^-(x,k) = \frac{\pi e^4}{U_i^2}\,\frac{1}{[(x+k)^{1/2}+1]^2}\left[1+\frac{2}{(x+k)^{1/2}}+\frac{2}{3}\left(1+\frac{1}{x}\right)\right]\left(1-\frac{1}{x}\right),$$

where $x=E_\psi/U_i$ is the projectile energy in relative units, with respect to the ionization potential U_i, and the parameter $k=W/U_i$, which depends upon the number of electrons in the shell considered and an effective charge of the nucleus. For heavy atoms and for inner shells, k is close to unity.

In the case of positrons the ionization cross section is given by

$$\sigma_i^+(x,k) = \frac{\pi e^4}{U_i^2}\left\{\frac{4}{\pi}\int_0^{\sqrt{(x/k-1-1/k)/2}}\frac{du}{(1+u^2)^2}\,\frac{1/k}{(x/k-1-u^2)}\left[1-\frac{1/k}{x/k-1-2u^2}+\frac{2}{3}ku^2\right]+\frac{4}{\Pi}\,\frac{2}{3}\int_{\sqrt{(x/k-1-1/k)/2}}^{\sqrt{(x/k-1-1/k)}}\frac{du}{(1+u^2)^2}\,\frac{(x/k-1-u^2-1/k)^{3/2}}{(x/k-1-u^2)u}\right\},$$

and has to be calculated numerically. The results is plotted in Fig.1.

Trying to improve theory one must be aware of the difference between experimental results of Lennard's (▽) and Schneider's teams (○) on L-shell ionization. We have noticed that in Lennard's experiment the positron (electron) beam was perpendicular to the foil surface, while in Schneider's experiment it was at 45°.

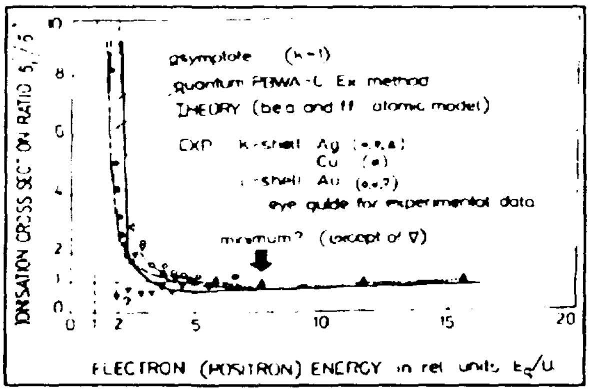

Fig.1. Ionization cross sections ratio for electrons $\sigma^-(x,k)$ and positrons $\sigma^+(x,k)$.

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* M. Gryziński and J. Kunc, J. Phys. **B 19**, 2479 (1986).

** H. Schneider and I. Tobehn, Phys. Lett. **A156**, 303 (1991).

2.4. Analysis of Filamentation Phenomena within a Pinch Column of High-Current Plasma Discharges (V.5a)

by M.Sadowski, W.Pawłowicz, R.Miklaszewski, W.Stępniewski

Theoretical studies were preceded by an analysis of experimental data on filamentation phenomena, and in particular those about quasi-radial filament appearance during the formation and propagation of the current sheath in PF-type discharges, as well as of those about appearance of quasi-axial filaments during the compression of the pinch column. We performed a review of theoretical models used to describe those phenomena.

In order to explain the filamentation, we proposed a simple new theoretical model based on the assumption that during a decay of a pinch column and filaments, the physical system should change its structure according to the energy conservation law. Simple theoretical computations have shown that for a given number of current filaments, the linear density of magnetic field energy is higher than that in the case of a uniform pinch column. This determines the direction of changes. The results were presented at an international seminar [C1].

In the second stage, within a frame of the scientific collaboration with the Institute of Plasma Physics and Laser Microfusion (IPPLM) in Warsaw, in order to determine the influence of the filamentation we performed Monte-Carlo calculations of trajectories of deuterons within the pinch column for different current distributions, i.e., for the uniform distribution and for an assumed filamentation. Those computations have shown that in the case of the filamentation, the ions generated at larger radius can be "trapped" inside the pinch column, and as a result the angular distributions of emitted ions have more distinct maxima. The results of that analysis were presented at the national plasma symposium [C25].

Additionally, within a framework of investigation on non-linear processes, in the close collaboration with E.Infeld (P-VIII) we performed a theoretical analysis of conditions necessary for the formation of surface solitons. Experiments were suggested results of these studies were presented at the 1993 international conference in Bochum [C11].

2.5. Numerical Analysis of Heat Transfer in Thin Foils Exposed to Plasma Streams*

by M.Rabiński, J.Appelt, W.Komar

Apart from plasma physics, surface and thermal effects are important problems in the exploitation of nuclear fusion devices operated at high energy levels or with increased repetition rates. Plasma beams can also be used for practical applications, e.g., pulsed heat treatment and implantation. Taking into consideration the importance of thermal problems, some studies have been started to determine thermal loads from a plasma stream directed at the surface of a thin foil. Difficulties with direct investigation of such a sample from outside has caused the necessity to solve the inverse problem**.

A mathematical model of the phenomenon considered is given by the two-dimensional conduction equation in the axial cross-section of a cylindrical body***. The choice of boundary conditions results from the nature of heat transfer at the sample surface. During the plasma, impact a time- and space-dependent flux of energy acts at the outer (plasma irradiated) surface. After the discharge, heat transmission between the sample and the hot gas occurs according to Newton's law of thermal conductance. These phenomena determine the nature of boundary conditions to be considered. Throughout the process both surfaces irradiate energy as described by the Stefan-Boltzmann law.

Spectroscopic measurements of light emitted from the inner surface of the metal foil (opposite to plasma irradiated one) have been considered as the basic experimental methods (see Technology, section 4). Computations have been carried out for different materials, densities of heat flux, and pulse shapes, in order to investigate their influence on a signal, as shown in Fig.1.

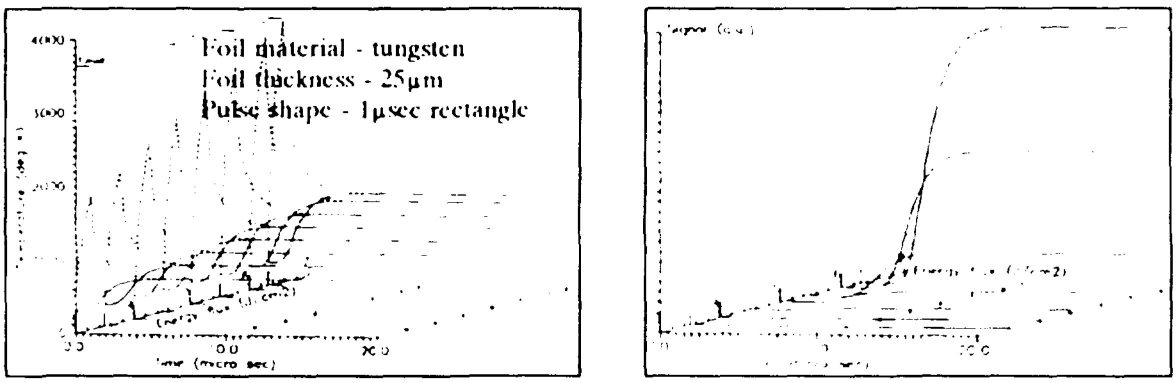

Fig.1. Temperatures at outer (dashed lines) and inner (solid lines) surfaces of the foil and corresponding measurement signals.

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* Work supported by the State Committee for Scientific Research (Poland) under the contract No 20970 9101.

** Rabiński M.: Contrib. Plasma Phys. **32** (1992), 474-479.

*** Rabiński M. *et al.*: Numerical Method of Solving Two-Dimensional Heat-Conduction Equation, INR 1917/XXIV/PP/A

2.6. Improvement of Numerical Simulation Methods of Operation of Pulse HV Supply-Systems (V.8a)

by K.Kocięcka

A model of the two-gap, controlled switch, for which parameters were determined on the basis of laboratory tests of the 2IPB type spark-gap, has been applied to perform a numerical simulation of the HV-pulse cable generator operation. Results of the computations have been compared with the measurements of voltage pulses produced by two different generators which were switched by means of trigatrons of 3IC1- and 3IC3-type. Excellent agreement of the results has demonstrated that the numerical model, which was elaborated mainly for the field-distortion type spark-gaps, can also be used for trigatrons.

The results of investigations on the numerical simulation of the operation of different pulse generators have been presented in several papers [A2-A4,A11,C15]. Studies of the influence of the switch properties on the development of discharges, as produced by HV pulse generators, have been summarized in a PhD Thesis [B8].

The results of calculations and measurements allow us to conclude that the numerical programs prepared at the IPJ-Świerk for the simulation of the HV pulse generator operation are suitable for design of generators as well as for the interpretation of the results of their laboratory investigations. In particular, by means of these programs, the switching processes can be simulated. Conventional simulation programs as SPICE, PSPICE and NAP, which are available on the market, do not enable the modelling of complex transient processes which occur within the spark-gaps.

It was concluded that it is worth - while to continue research on simulation programs for multi-step HV pulse generators. In such cases the use of a mode applied for the single-step generator can lead to considerable errors.

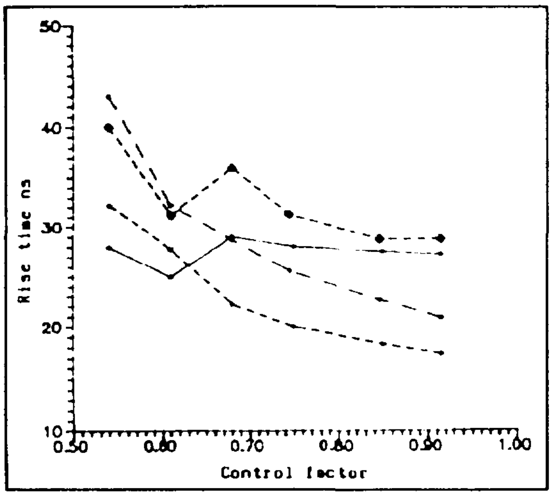

Fig.1. Comparison of measured and theoretical characteristics of the HV Pulse Generator equipped with the 3IC1 trigatron (d=0.4 cm, p=0.225 MPa), continuous line - experiment, dashed line - calculation, (+) - discharge development was taken into account.

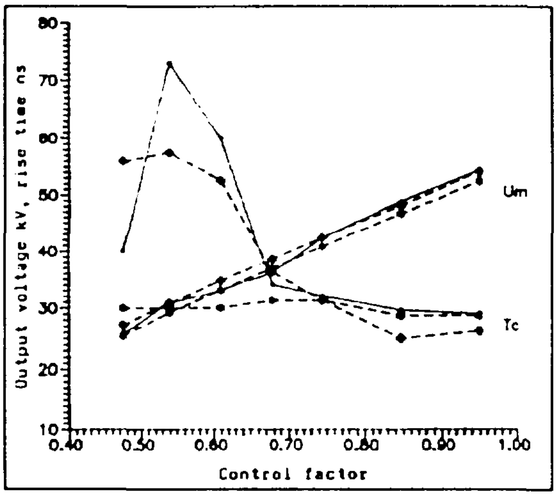

Fig.2. Comparison of measured and theoretical characteristics of the HV Pulse Generator equipped with the 3IC1 trigatron (d=0.25 cm, p=0.225 Mpa), continuous line - experiment, dashed line - calculation, (+) - discharge development was taken into account.

3. EXPERIMENT

3.1. Investigation of X-Ray Emission and Fast Electrons from MAJA-PF Facility (V.3a/4)

by L.Jakubowski, M.Sadowski, J.Żebrowski, E.Baronova (KI-Moscow), and V.Vikhrev (KI-Moscow)

The MAJA-PF Facility [B1] was used for extensive studies of fast electron beams as well as soft and hard X-rays in correlation with the time-resolved current (dI/dt) and neutron-induced signals. It was observed that intense electron beams, which are emitted in the up-stream direction, can interact with the surface of the center electrode or pass through an axial hole. In the second case it was found that the cross-section of the pulse electron stream, at the distance of about 40 cm from the plasma-focus region, can amount to several cm^2 and is non-homogeneous. The pulsed e-beams usually last 20-60 ns and they correlated with the current peculiarity (dip) and X-ray emission [C8,C9,C16], as shown in Fig.1.

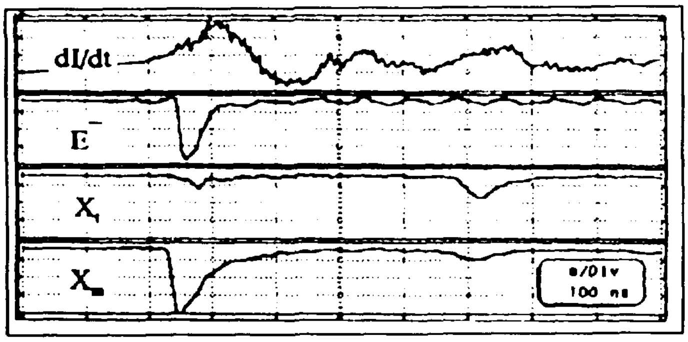

Fig.1. Time-correlation of fast e-beams (E) and X-ray pulses (X_{hr}, X_s) with the dI/dt waveform, as registered for PF shot at p_0=1.7hPa (20% Ar).

Extensive measurements of soft and hard X-rays were performed with a pinhole camera (equipped with thin Be-filters) and a set of plastic scintillators. This made it possible to determine time - and space - correlations of e-beams, X-rays, and neutrons. Particular attention was paid to investigation of miniature regions of an increased X-ray emission (hot spots), and their time - and space -correlations [C16].

In order to extend observations of "hot spots", use was made of an additional admixture to the working gas, and in particular of argon (up to 20%). It was found that with a small argon admixture (below several percent), about 200 ns after the current dip numerous "hot spots" lasting up to 10 ns appear.

Additionally, within the framework of the scientific cooperation with the Kurchatov Institute in Moscow we performed assembling and preliminary tests of a new X-ray spectrometer [B13]. We also prepared a new program [B14] needed for the transmission and processing of experimental data from the Hewlett-Packard digital analyzer.

3.2. Laser Diagnostics Systems for Interferometry and Shadowgraphy at MAJA-PF Facility (V.6a)

by W.Pawłowicz

Optical diagnostic methods (interferometry, shadowgraphy) are often applied for studies of hot plasmas, e.g., for measurements of an electron density distribution, observations of plasma symmetry and dynamics. The studies of a plasma-focus pinch, which is characterized by a life time of several ns, dimensions of some mm, and maximum density of 10^{19}-10^{20} cm^{-3}, requires an optical probing pulse with FWHM value of about 1 ns, if frame registration is applied.

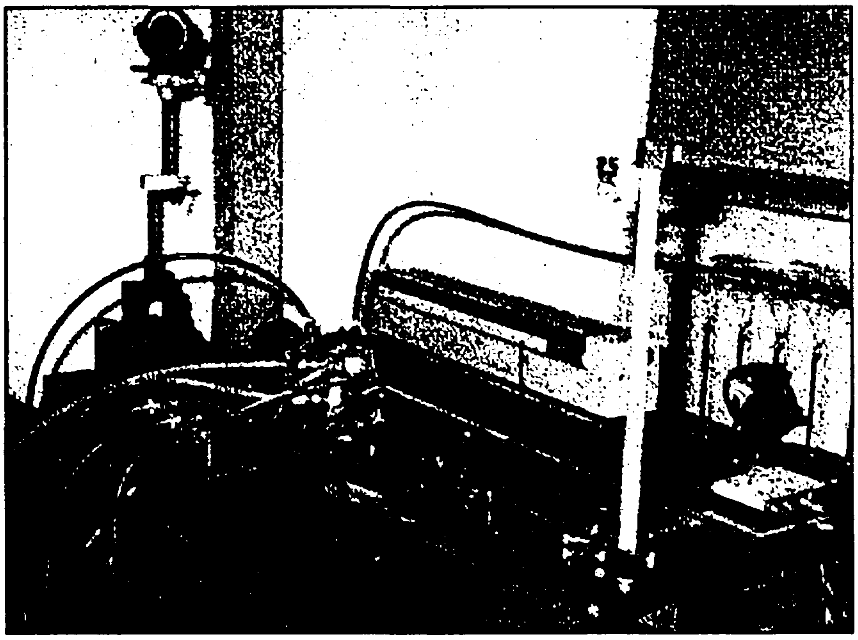

Fig. 1. General view of the ruby laser oscillator assembled at the MAJA-PF plasma-focus facility.

In order to study the MAJA-PF plasma-focus facility, a special optical diagnostic set-up has been designed. For preliminary studies, the diagnostic ruby laser [B1] generating pulses with duration time of 25 ns (FWHM), was assembled and tested. This laser equipment is presented in Fig.1.

In order to enable the probing of the pinch column, some mechanical parts of the MAJA-PF experimental chamber have been adapted. We designed and assembled optical windows, a special protecting screen of the output window, and additional mirrors for directing the diagnostic beam. In order to make possible the optical probing of a plasma during PF experiments, one should also install additional registration equipment, and in particular a system for the synchronization of the diagnostic laser pulse with the MAJA-PF discharge.

3.3. Investigation of Ions and Electrons Emission from High-Current Discharges in the PF-360 Facility (V.3a/4)

by M.Sadowski, J.Żebrowski

Detailed investigations of ion and electron emission have been carried out at the PF-360 facility over several years. The results were summarized at the recent z-pinch conference in London [C2].

In 1993, we performed studies of time correlations of X-rays and charged particle beams. Particular attention was been paid to the development of diagnostic techniques, e.q., time-resolved ion pinhole cameras, and a special Cerenkov-type detector for electron beam measurements. These new diagnostics techniques have been described in two papers presented at the plasma diagnostic conference in St. Petersburg [C6,C8]. Recent results of ion and electron emission measurements have been included a paper presented at the international plasma conference in Lisboa [C9] and at a plasma symposium in Warsaw [C23].

During the second semester a new expanded digitizing systems HP16500/16501 for the acquisition of experimental data was installed. It has made it possible to register up to 12 waveforms simultaneously, 1 GHz probing in four channels. An example of such measurements is presented in Fig.1.

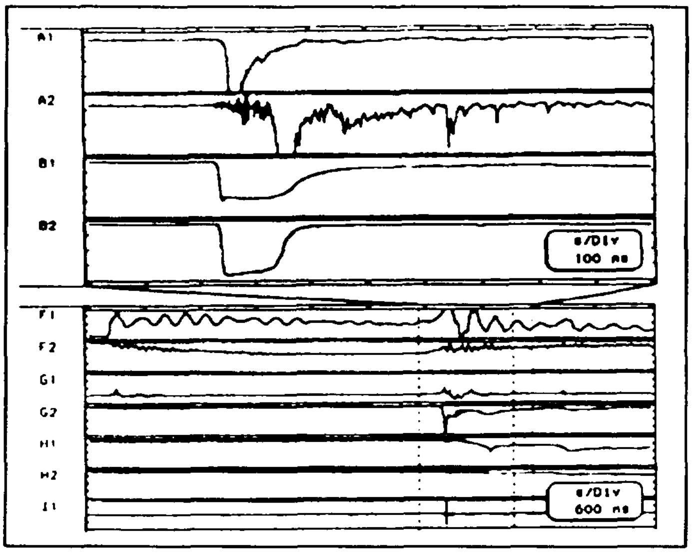

Fig.1. Typical waveforms obtained from one discharge within PF-360 facility at p_0=4.25hPa D_2, U_0=30kV, W_0=147kJ, Y_n=3.6x10^{10}. The traces represent neutrons (A1-A2), ions (B1-B2), U(t), I(t), dI/dt, 3 different Rmin measurements, and MCP trigger pulse.

Recently, a new pulse high-pressure valve was installed in the PF-360 facility, which can be used for dosing the working gas into the pinch region, along the z-axis of the system. Within a framework of the collaboration with IPF-Stuttgart, a spherical 4-frame X-ray pinhole camera equipped with the MCP intensifier has also been installed. This has made it possible to obtain 4-frame pictures of soft-rays from each PF discharge. Results of preliminary measurements with that camera are to be presented in a separate paper.

3.4. Measurements of Fusion-Produced Protons at the PF-360 Facility (V.3a/3)

by E.M.Al-Mashhadani, M.Sadowski, A.Szydłowski

Studies of fast protons originating from d-d reactions can supply valuable data about hot plasmas and mechanisms of nuclear reactions. These data are obtainable from the other branch of the same reaction. Unfortunately, proton diagnostics is more complicated and only a few proton measurements have been reported. During experiments performed with the PF-360 device, angular distributions and energy spectra of fusion-produced protons were measured. For that purpose, use has been made of the CR-39 and PM-355 nuclear track detectors. The samples of the CR-39 and PM-355 plastics were first calibrated with monoenergetic proton beams from two accelerators [A7].

Other samples of the NTDs cut from the same delivery as the calibrated ones were covered with 80-μm-thick Al-foil and fixed to a semicircular support. The support was placed inside the main experimental chamber of the PF-360 device at a distance of 340 mm from the ends of the electrodes. After irradiation with protons and deuterons emitted from a series of twelve PF discharges under controlled conditions, the detector samples underwent the same etching process as the samples used during calibration. Selecting the tracks with respect to their diameters on each sample, after its etching, it was possible to determine proton energy distributions.

Taking into account the proton energy loss in the Al-foils, the spectra of primary protons emitted in different directions were calculated. The main characteristic of the determined spectra is their maxima observed at energy values greater than 3.02 MeV (resulted from the d-d reaction energy). It proves that fusion protons are produced by fast deuteron beams propagating along the electrode axis. The fast deuterons have a broad energy distribution ranging up to about 5.5 MEV, as shown in Fig.1. The results obtained were presented in two papers [A8,C7,C20] and their detailed analysis has been given in a Ph.D. Thesis [B2].

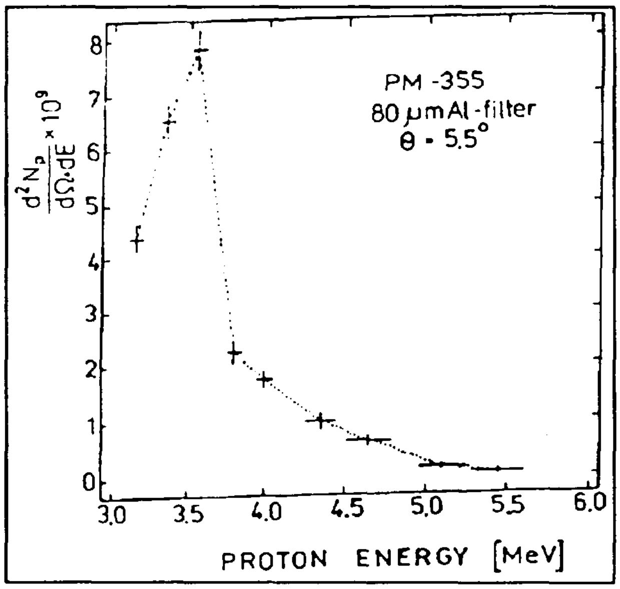

Fig.1. Energy spectra of fusion-produced protons obtained in experiments with the PF-360 device.

3.5. Multiframe X-Ray Measurements within the PF-360 Facility

by St.Kienle (IPF-Stuttgart), M.Sadowski, H.Schmidt (IPF-Stuttgart), E.Składnik-Sadowska, J.Żebrowski

Within the framework of the scientific collaboration between IPJ-Świerk and IPF-Stuttgart in 1993, we performed multiframe X-ray measurements within the PF-360 facility. The main aim of these measurements was to investigate the dynamic behavior of a plasma pinch under different operational conditions. The experiments were carried out with pure D_2-filling, D_2-filling with static Ar-admixture, and D_2-filling with additional Ar-gas-puffing.

The 4-frame camera system, which was brought here by the IPF workers, made possible the registration of X-ray radiation for 4 independent time intervals. In the experiments described, the exposition of each frame was 5 ns. Time delays in relation to the first frame were 7.5 ns, 20 ns, and 30 ns, respectively. Additional time-integrated X-ray pictures were taken with pinhole cameras at different magnifications and at different angles to the z-axis (1:2.25 for $\alpha=85°$, and 1:1 for $\alpha=54°$). The PF-360 facility was operated mostly at 147 kJ, 32 kV, with a basic gas pressure of 3 Tr D_2. During each discharge the voltage- and current-waveforms, the X-ray and neutron pulses, dI/dt and R_{min}-signals, as well as 2 end-on ion-signals, were registered with a multi-channel digital oscilloscope with an additional expansion box (HP16500A, 12 channels).

The time resolved X-ray measurements revealed that the plasma pinch in the PF-360 device is reproducible in a macroscopic sense and that the plasma column exists 30 to 50 ns before oneset of the m=0-instability which divides the plasma column into separate pieces (Fig.1).

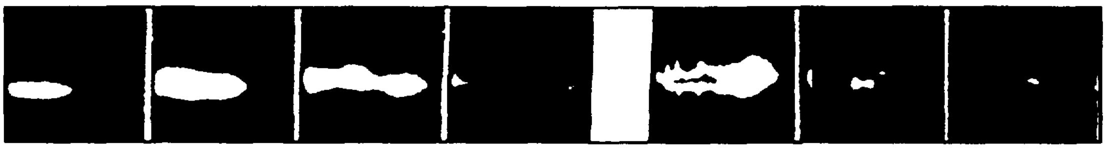

Fig.1. Time-resolved X-ray pictures of the pinch column within the PF-360 facility for two shots (32 kV, 147 kJ) at p=3 Tr D_2 + 0.2 Tr Ar. The camera was placed side-on. The 125-μm-dia. pinhole was covered with a 3-μm-thick Al-filter. Time t=0 correspond to the maximum compression.

The experiments with the gas-puffing through holes in the front-plate of the inner electrode showed that the PF-360 facility can be operated with an additional gas target. Under suitable pressure of the injected gas (3.5 MPa Ar), with a time delay of 500 μs (between the pulsing of the valve and the beginning of the discharge), it was possible to achieve a significant increase in the compression of the pinch column. In such a case several bright hot spots appeared very close to the z-axis.

3.6. Time-Integrated Studies of Gas-Puffed PF-Discharges within the POSEIDON Facility (V.3a/1)

by L.Jakubowski, M.Sadowski, E.Składnik-Sadowska, J.Stanisławski, A.Szydłowski, and H.Schmidt (IPF-Stuttgart)

Within the framework of the scientific collaboration with IPF-Stuttgart in 1993 we continued experimental studies of gas-puffed high-current PF-discharges [A1] within the large experimental POSEIDON facility operated at the 135 kJ/41.6 kV level [C3]. Those studies were carried out by H.Schmidt of IPF and Polish investigators delegated from Dept. P-V to Stuttgart.

A new series of experiments was performed with the use of different nozzles to obtain better convergence of the gas stream injected into the focus region. Various diagnostics were applied to perform the investigation in question. The influence of deuterium and argon gas-puffing on the pinch dynamics was observed by means of an image converter camera operated in the streak mode. Additional frame pictures were taken side-on with a pulsed planar diode (with exposure time of 3 ns). The pinch phase was also studied by means of Schlieren photography (with 1-ns-pulse N_2-laser). The soft X-ray emission was registered side-on by means of a pinhole camera equipped with a 10-μm-thick Be-window. We also carried out time-integrated measurements of hard X-ray emission and fusion neutrons.

The results of the gas-puffed experiments can be summarized as follows [C19]:

1. It was demonstrated for the first time that the POSEIDON facility can also be operated in a well controlled way with the injection of an additional gas target.
2. Application of D_2 - or Ar -puffing changes the dynamics and emission characteristics of PF discharges considerably. In general, the neutron and hard X-ray yield decrease. However, under appropriate gas conditions the neutron yields can be increased up to 30%, as shown in Fig.1.
3. It was observed that D_2- or Ar -puffing enables the formation of hot spots, but it also causes a rise of turbulences.

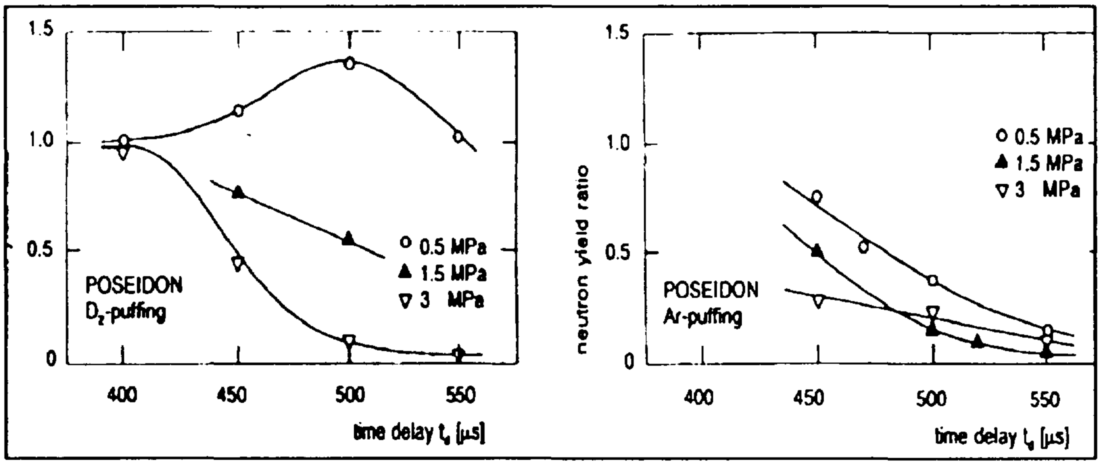

Fig. 1. Average neutron yield for different PF discharges with D_2-puffing (on the left) and Ar-puffing (on the right) as a function of the valve delay time (t_d).

3.7. Time-Resolved Studies of Gas-Puffed PF-Discharges within the POSEIDON Facility (V.3a/2)

by L.Jakubowski, M.Sadowski, E.Składnik-Sadowska, J.Stanisławski, A.Szydłowski, and H.Schmidt (IPF-Stuttgart)

The main aim of those experiments was to study the interaction of the current-sheath with a gaseous target, which was produced by the pulsed injection of Deuterium or Argon through special nozzles in front of the inner electrode [A1] and to investigate time-correlations of basic phenomena occurring within gas-puffed PF discharges [C26].

Hard X-rays and neutrons have been registered with two scintillator/photomultiplier detectors positioned side-on and end-on at a distance of 4,5 m from the pinch. The e-beam signals (Figs. 1 and 2) were obtained with 3 miniature Čerenkov detectors (one with diamond), were placed behind the gas valve at a distance of 1m from the anode front plate (in the up-stream direction). The use of N_2-laser pulses made possible the time calibration of measuring channels with accuracy of ±0,5 ns.

The results of the time-correlation studies can be summarized as follows [C26]:

1. For PF discharges without an additional gas-puffing or with a small amount of injected gas, time-resolved measurements of neutrons and electron beams usually emit 2 pulses. With higher values of valve pressure (pv), only single pulses of neutrons and electron beams are emitted.
2. The emission of fast electron beams is correlated with neutron emission; the first pulse correlates with the maximum compression, and the second one with a m=0 instability. This suggests that the fast electron beams are generated by mechanisms similar (or strongly correlated) to those responsible for the acceleration of ions, which produce neutrons mainly by beam-target interaction.

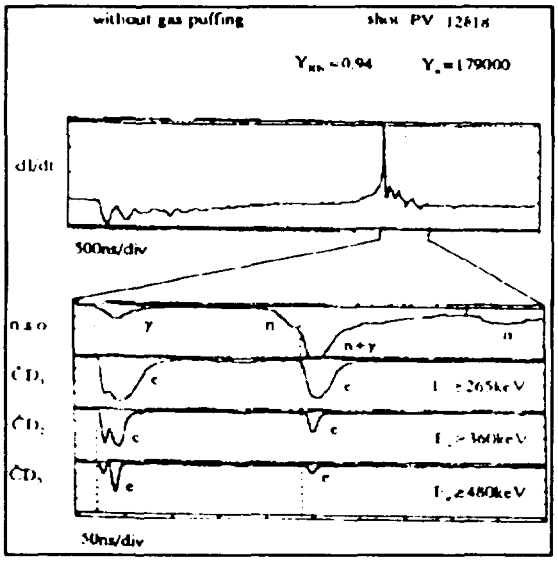

Fig.1. Time-correlations of electron beams, neutrons, and current-derivative peaks for PF discharges without gas-puffing, at p_0=2hPa D_2, 135kJ/41kV.

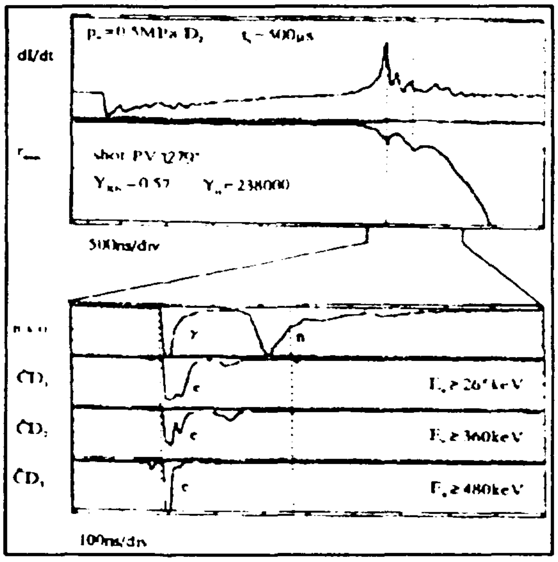

Fig.2. Time-resolved Čerenkov signals, as obtained from e-beams for a discharge with D_2-puffing (p_v=0.5 MPa, t_d=500 μs), in comparison with neutron-, current-, and r_{min}-signals.

PL9701885

3.8. Preliminary Experiment with the Injection of Cryogenic Microtargets (V.3b)

by A.Szydłowski, and E.Składnik-Sadowska

In 1993, year the generator of cryogenic microtargets [B1] was still under construction, and the aim of main efforts were concentrated on the freezing of cryogenic liquid droplets. We have tried to achieve that by the introduction of these into a vacuum chamber filled with a gas (argon, nitrogen, air) under a pressure lower than the operational pressure in the target chamber (in which the droplets are created). Due to vaporization of some mass from the a surface of the droplet, the remainder can be cooled down and frozen. Such frozen balls are more resistant to collisions during their transport and there is a better chance to bring them into a hot plasma region. For that purpose, we designed and manufactured new nozzles, which should enable the penetration of created microtargets through four successive vacuum chambers, under the condition that the pressure differences between the individual volumes are controlled.

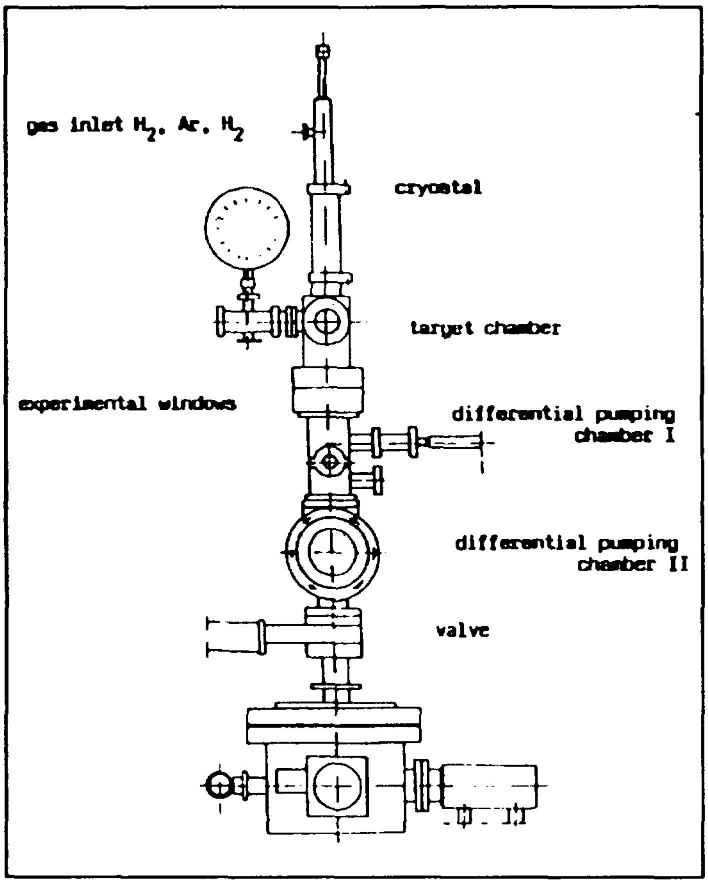

Fig.1. Scheme of the system for cryogenic targets injection.

We have also tested a new type of piezoelectric transducer which had inner diameter a little larger than the diameter of the glass capillary used. Therefore it was possible to fix the capillary more tightly within the transducer body. As a result, a cryogenic jet could effectively be broken into separate droplets, which were produced at different frequencies of voltage driving powering the transducer.

The new jet assembly did not need the exact frequency stabilization. Uniform droplet trains were generated at frequencies differenting from resonance. Because of a lack of funding it was impossible to supply a required quantity of liquid helium or assemble a closed helium circulation system. Therefore in the second part of 1993 the preliminary cryogenic experiments were stopped pending new funds. The experimental results obtained so far were summarized in a paper presented at the Symposium "Plasma'93" [C18].

PL9701886

3.9. Adaptation of IONOTRON SW-30 Device for Diagnostic Measurements (V.4a)

by K.Czaus, J.Baranowski, W.Polak, E.Składnik-Sadowska

The IONOTRON SW-30 device has been adapted to enable calibration measurements of diagnostic equipment. The devices existing up to now were designed mainly for technological purposes and the calorimeter measurements of ion beams are not reliable. Therefore the vertical vacuum chamber of IONOTRON has been replaced by a horizontal one. The Thomson spectrometer and other diagnostic equipment have been adapted for measurements to be performed (Fig.1). To facilitate access to the experimental chamber, the condenser bank and other auxiliary equipment have been moved to a more convenient location. The main technical parameters of the adapted IONOTRON SW-30 device are:

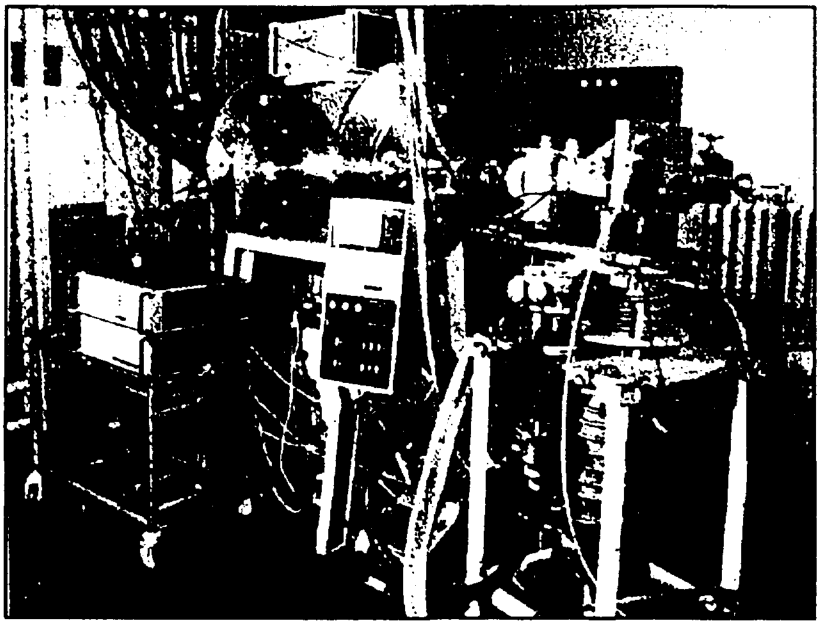

Fig.1. General view of the new IONOTRON SW-30 device.

Condenser bank energy	30 kJ
Discharge current	260 kA
Discharge half-period	8,5 μs

PL9701887

3.10. Mass and Energy Measurements of Ions Emitted from IONOTRON Device (V.4b)

by J.Baranowski, E.Skladnik-Sadowska

Mass and energy distributions of ions from plasma streams generated within the IONOTRON device for different working gases, (Hydrogen, Nitrogen and Argon) were investigated [C10,C24]. A Thomson parabola spectrometer was aligned along the symmetry axis of the system. Before the recent series of experiments, the ends of the external electrode-rods were covered with a thin layer of Lithium (2 cm in length). In all the experiments the delay time τ was variable parameter. It can be seen from the results shown in Fig.1 that H^+, N^+, N^{+2} and N^{+3} ions can have an average energy higher than the voltage applied between the electrodes (U=35 kV).

It has been found that the lithium plating of the external electrode influences the production of ions. In Fig.2 we present the spectra of protons, which originated from the electrodes for the cases with and without Lithium plating. The experiments suggest that the heating mechanism of ions (within the region between the electrode ends) depends very strongly on the τ_p value, where τ_p is the propagation time of a front of the gas-cloud from the valve. For the cases with delay time $\tau > \tau_p$ we observed high yields, which suggest the appearance of a local thermal equilibrium and high local temperatures.

We concluded that investigations of neutral and charged particles within plasma streams are of primary importance for the optimization of IONOTRON-type facilities [B3, B6].

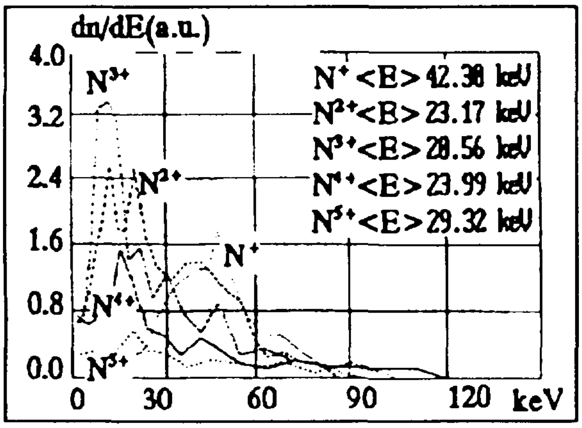

Fig.1. Energy spectrum of nitrogen ions emitted from a plasma generated by the IBIS facility, $\tau = 300 \mu s$.

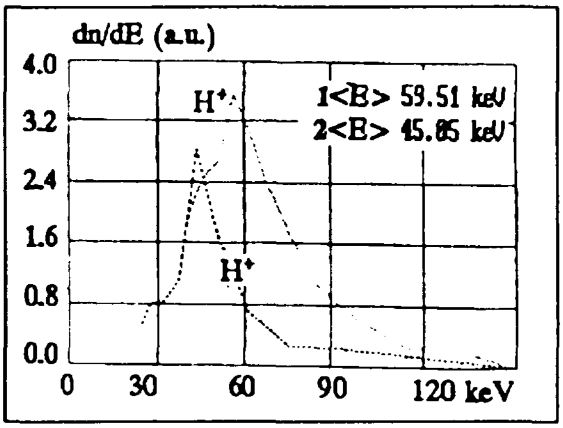

Fig.2. Energy spectrum of hydrogen ions emitted from nitrogen plasma generated by the IBIS facility ($\tau = 180 \mu s$) at standard operation conditions (curve ...) and at lithing covered anode (curve ---).

3.11. Design and Application of a Faraday Cup for Measurements of Ions and Electrons (V.6b)

by J.Baranowski, E.Składnik-Sadowska

In addition to diagnostic studies performed within the framework of research on ion-plasma streams, we carried out several series of measurements of ion currents in plasma streams generated by a new IONOTRON SW-30 device (see Experiment, section 9). These studies were performed for different working gases (nitrogen, deuterium) and various values of gas-valve time delay τ.

A new Faraday cup was placed on the symmetry axis of the device at distances of 0.6-1.3m from the electrode ends. The density of electron current was measured by inverting the polarity of the so-called "active grid". The energy of the main condenser bank of the new IONOTRON device was smaller than that in the IBIS facility, and as a result densities of ion- and electron currents were lower by about one order of magnitude. The measurements with the Faraday cup were treated as auxiliary diagnostics for the fast estimation of plasma currents. The densities of ion currents from the plasma streams studied amounted to 100 A/cm^2 and they depended strongly on the time delay τ. The discharges were very reproducible as regards the low energy ions. Some typical current waveforms have been presented in Fig.1. It can be seen that the electron current has been almost completely compensated by the ion one.

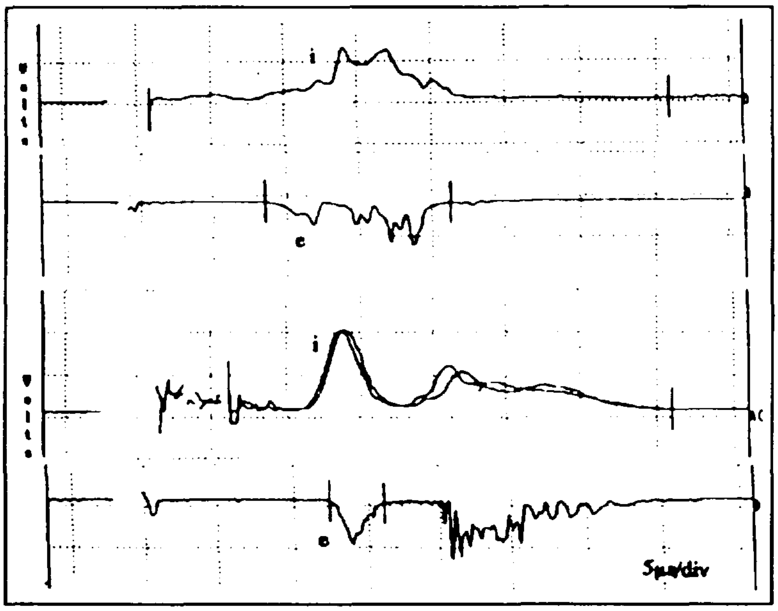

Fig.1. Ion and electron current signals as registered for deuterium (upper picture) and nitrogen plasma for delay time of 300 μs.

The method described above was also applied at the MAJA-PF facility. The ion current was measured with the Faraday cup placed at a distance of 0.2m from the electrode ends. In that case the density of ion currents was several A/cm^2, and energy of ions generated within the facility was about 20-30 keV, as determined taking into account energy loses in a gas filling up the experimental chamber.

PL9701889

3.12. Study of Transients of IR Radiation Emitted by Target Interacting with a Pulsed Plasma Beam Generated in the IONOTRON Device (V.4c)

by W.Komar, J.Stanisławski, J.Langner, J.Piekoszewski (P-IX), J.Białoskórski (P-IX)

The method relies upon the observation of changes in the intensity of IR radiation emitted by the surface of a silicon target exposed to pulsed plasma beams. To measure the intensity of IR radiation, a semiconductor photodetector is used. Since a silicon wafer is transparent within the IR range, the radiation emitted from its exposed surface can be observed behind the target. The silicon wafer plays a double role, i.e., it serves simultaneously as the target and as a shield for the detector. In order to relate the IR radiation intensity with the detector signal for a given temperature distribution inside the target, a theoretical model was worked out. In this model, the self absorption and multiple reflection within the target as well as geometrical conditions have been taken into account, whereas the heat transport by radiation is neglected (semi-transparency approximation). The calculations have been performed taking into account the temperature distribution determined with the use of the MELT program, which was applied within the frame of the cooperation with the P-IX Dept. It has been found that at a temperature close to the melting point, the strong absorption of the IR occurs within the hot layer. The detector signal changes its intensity while not following the changes in the temperature distribution within the target.

The measurements have been performed on the modified SOWA-400 system. A measuring gauge with the detector (operating within the wavelength range of $2 \div 12$ μm) and the target have been positioned at the front of the electrode ends, on the z-axis of the plasma system. Electromagnetic interference has been reduced to a level enabling the measurements to be performed with the use of the IR detector. Preliminary measurements have shown that the IR radiation from a plasma and different parts of the experimental system affects the measured signal substantially. In spite of interpretational problems, one may conclude that at the beam energy density of about 2 J/cm^2 the temperature of the target surface is close to the melting point, and the heating time is much longer than the interelectrode overvoltage pulse and the duration of high energy ion streams.

PL9701890

4. TECHNOLOGY

4.1. An Alternative System for Data Acquisition (V.2)

by M.Bielik and J.Langner

In 1993 the System of Data Acquisition (SDA), applicable for slow-variable transients, was completed [C4,C21]. The realized system consisted of 10 voltage-to-frequency (V/F) converters which operate using the frequency modulation method and the conversion (E/O) of output pulses into optical signals. Such signals are transmitted through a fiber-optic network and registered by a 10-channel receiver, where they are converted back into electrical signals (O/E), and (after passing the frequency-to-voltage converter) to analog waveforms corresponding to the input signals [A4].

The system has been designed for the registration of the following experimental data:

- waveforms of charging voltage supplied to capacitive energy-storage systems and triggering units,
- waveforms of current charging the capacitor banks,
- values of pressure of an insulating gas in spark gaps of the switching and triggering systems,
- values of pressure of the working gas in the main discharge chamber,
- values of pressure in pneumatic systems connected with control equipment used for experiments.

The system described above can be used for measurements in very large scale experimental facilities and it makes possible the computer processing of data. The amplitude of an input signal should be a 0-10 V, for both polarities. For this range of voltage the conversion rate is equal to K=1V/10kHz. Accuracy of the whole transmission system is about 99.5% except for U_{in} < 1 V when the influence of a ripple voltage in the U_{out} signal appears. A long-term drift of the U_{out} value for a constant U_{in} signal does not exceed 3 mV. The system has been tested at the PF-360 experimental facility in Świerk and during laboratory tests of the ANGARA module at the NIIEFA in St. Petersburg, Russia [B4]. If besides computer processing, an additional control is required, e.g., by an operator of the experimental facility, then the signals entering the F/V converter can be transformed once again into optical ones (E/O) and transmitted through optical cables to a control desk, where they can be processed (O/E and F/V) under conditions of complete galvanic isolation [B11,C22].

4.2. Adaptation of PF Facilities for Material Engineering Experiments (V.1a)

by J.Langner, L.Jakubowski, J.Piekoszewski (P-IX), M.Sadowski, H.Schmidt (IPF-Stuttgart)

In recent years it has been shown that it is possible to form coatings adhering well to a substrate, using the so called (HC) Hot Coating technique. The aim of studies carried out in 1993 was to verify the usefulness of large PF facilities for forming hard coatings, (e.g., titanium nitride layers).

In the framework of this task, several units of equipment necessary to accomplish experiments with the PF-360 facility (in Świerk) and POSEIDON facility (at Stuttgart) were designed and manufactured. In particular

- front plates with Ti inserts, for the center electrodes,,
- a holder enabling one to take samples within the discharge area,
- a set of miniature calorimeters to measure the energy density distribution within plasma streams,
- a batch of substrates made of various kinds of metal (1H18N9T, ST3, copper and titanium).

During the preparation phase, the operation of the POSEIDON facility was tested with a nitrogen filling of its experimental chamber. We tested to see whether it is possible to operate the facility under dynamic gaseous conditions, i.e., with an additional amount of nitrogen injected by the high-pressure pulse valve. It was found that the mean energy density of the plasma stream (at different distances from the electrodes) ranges from 10 to 30 J/cm^2, and that the homogeneity of the ion beams is fairly good, especially at larger distances (40-50 cm) from the electrode ends. Using an ultra high-speed photo camera with the so called Planar-Diodes and a Schlieren type interferometric system with the N_2 pulsed laser, it was possible to take pictures of the initial phases of the metallic plasma and Ti vapor expansion. After selection of the experimental conditions, several series of experiments were performed for comparison at the PF-360 and POSEIDON facilities. Some selected samples are now being examined, and it is expected that results of these examinations will enable us to assess the usefulness of the method in question and they will suggest further experimental efforts.

4.3. Modification of Solid Surface Properties (V.7a)

by J.Langner, J.Piekoszewski (P-IX), J.Białoskórski (P-IX), K.Czaus, J.Kuciński, C.Pochrybniak (P-IX), Z.Werner (P-IX), and L.Guzman (Trento University), A.Miotello (Trento University), F.Rosatelli (Ansaldo Ricerche), S.Rizzo (Ansaldo Ricerche)

Following previous experiments [A5], a experiments on thin metal coating (Al,Ni) formation on metallic substrates (Cu, steel) were performed in 1993 using plasma-ion beams. The beams were produced by the IONOTRON device, operated in the Deposition by the Pulse Erosion (DPE) mode. In some cases the coatings were additionally doped using the doping process in the Ionotron operated in the Pulse Implantation Doping (PID) mode. In the first phase of the experiment, the correlations of the DPE process efficiency and the time delay between the working gas injection and the initiation of the discharges (in hydrogen, nitrogen and argon) were investigated. Optimum ranges of the time delay Δt for N_2 and Ar have been defined. In the next stage of the experiment, the set of Ni/Cu, Al/Cu and Al/steel samples were investigated in cooperation with Trento University, Italy.

It has been found that:

- the coatings exhibit very good adhesion to the substrates;
- during the DPE process of several microsecond duration, the coating/substrate structures are melted down to a depth greater than 2μm;
- the solid solution with fcc structure, lattice parameter 0.35954 nm, and the mean composition $Ni_{15}Cu_{85}$ is produced in an Al/Cu system;
- in an Al/Cu system additionally doped with nitrogen by the PID method amorphisation of the surface layer occurs. This can be expected in view of the phase diagram and the cooling rate achieved (10^9- 10^{10} K/s);
- the efficiency of DPE-Al is about two times higher for steel substrates (1H18N9T) than for Cu substrates. However, the smoothness (Ra and Rz) is better for Cu than for steel substrates.

The results were presented at international conferences [C12-C14] and have been submitted for publication [A12-A13].

Within the scope of the research program on the application of high density ion beams for the modification of semiconductors, the results of the PID application in polycrystalline solar cells have been published [A6], and two photovoltaic modules constructed of 3-inch silicon solar cells manufactured by means of PID doping have been completed and demonstrated.

4.4. Modification of Surfaces of Infusible Materials by a Plasma Method in the PF-046 Device (V.7c)

by J.Appelt

In 1993, the possibility of the modification of surfaces of infusible materials by means of carbon ions (atoms) was analyzed. In the case of constructional steel, an additional layer of a thickness ranging from several to above a dozen micrometers, which contains carbon atoms, can change surface properties by an increase in hardness. The main aim of the studies in 1993 was to perform tests to see in such a modification of steel is interesting from a technological point of view. For this purpose we designed and manufactured a special insert made of graphite to be fixed on the front plate of the center electrode. An additional experiment has also been performed in order to investigate homogeneity of a plasma stream, which was heating a target and transporting the material to be deposited.

Several series of PF discharges have been carried out with hydrogen filling for a wide range of operational pressure, using the same graphite insert within the center electrode. It has been found that there are no difficulties connected with the spraying of graphite. We produced several samples with carbon layers spread over the Al_2O_3 substrate. These samples are now analyzed by means of the RBS method to determine the carbon concentration.

In addition, we performed irradiation of the 18-HGT steel samples designed for carbonizing (cementation). The tests have not shown a required increase in hardness of the surface. Therefore, new samples made of other kinds of steel have been manufactured in order to check whether their structure and composition give fair promise for a positive result of the experiment. These samples will be prepared for future tests.

PL9701894

4.5. Modernization of the 2IC8 Spark Gap and Its Laboratory Tests (V.8b)
by J.Witkowski

On the basis of an analysis of all the results obtained during the testing of different pulse generators, which were assembled and operated in the industrial laboratories ZWAR-Przasnysz and IEL-Międzylesie, its has been found that some constructional changes are needed to improve the operation of the 2IC8 spark gap. In order to reduce a jitter time and to secure regular operation, first of all the construction of the triggering electrode has been modified. This electrode has been designed in the form of two hemispherical sectors, in which a pin electrode insulated with a ceramic micanite was placed (in a passage). The initial breakdown can now develop over the surface of the ceramic insulator.

In the new construction, we also changed the direction of a working gas (dry air) flow from transversal to longitudinal in relation to the main electrodes. This should improve the electrical arc suppression, in particular during switching of the generator producing HV pulses with millisecond characteristic times.

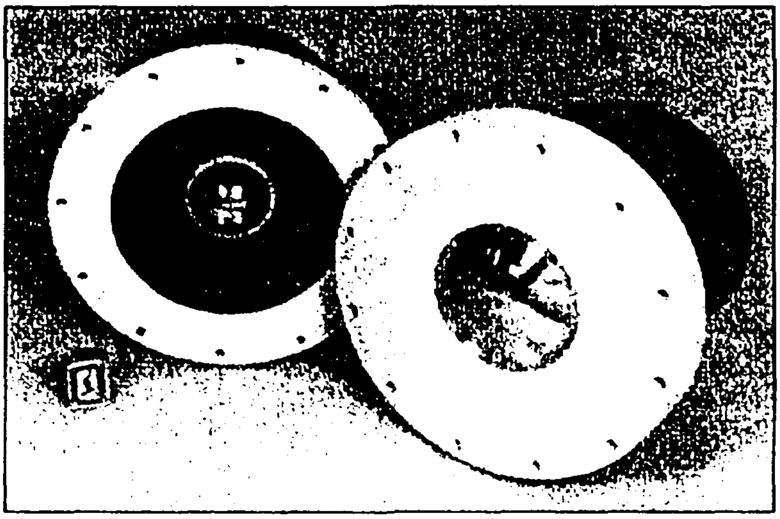

Fig.1. General view of the 2IC8 spark gap.

On the basis of the altered technical documentation, we manufactured four modified spark gaps of the 2IC8-W type. One of those spark gaps has already been tested in order to determine a static breakdown voltage and a jitter time. It has been found that the parameters mentioned above are satisfactory. A complete investigation of the cooperation of several 2IC8 spark gaps will be carried out after the completion of a new model of a four stage pulse generator to be performed in 1994.

5. PUBLICATIONS, CONFERENCE PROCEEDINGS AND REPORTS

A. Publications

1. GAS-PUFF TARGET EXPERIMENTS WITH POSEIDON PLASMA-FOCUS FACILITY
   H.Schmidt, M.Sadowski, L.Jakubowski, E.Składnik-Sadowska, J.Stanisławski
   Plasma Phys. and Contr. Fusion - in press

2. HV CABLE PULSE GENERATOR, PROPERTIES AND NUMERICAL SIMULATION OF ITS OPERATION
   A.Jerzykiewicz, K.Kocięcka
   Przegl. Elektrotech. R.LXIX, Z.6 (1993), p.126-131 - in Polish

3. EQUIVALENT INDUCTANCE OF PULSE HIGH CURRENT GENERATORS
   K.Kocięcka, A.Jerzykiewicz
   Arch. Elektrotechniki - in press, in Polish

4. SIMULATION OF DISCHARGE DEVELOPMENT WITHIN TWO-GAP TRIGGERED SPARK-SWITCH: PART I, RESISTANCE OF ARC IN THE TRIGGERED SPARK-GAP ON THE BASIS OF STATISTICAL STUDIES; PART II, NUMERICAL MODELING OF BREAK-DOWN PROCESS WITHIN TWO-GAP TRIGGERED SPARK-SWITCH
   K.Kocięcka
   Arch. Elektrotech.- in press, in Polish

5. INTRODUCTION OF NITROGEN INTO METALS BY HIGH INTENSITY PULSED ION BEAMS
   J.Piekoszewski, J.Langner, J.Białoskórski, B.Kozłowska, C.Pochrybniak, Z.Werner, M.Kopcewicz, L.Waliś, A.Ciurapiński
   Nucl. Instr. and Meth. B 80/81 (1993) pp. 344-347

6. IMPLANTED AND PLASMA-PULSE ANNEALED SOLAR CELLS IN NOVEL MODIFIED BRIDGMAN GROWN POLYCRYSTALLINE SILICON
   J.Piekoszewski, Z.Werner, J.Langner, C.Pochrybniak, J.Białoskórski, J.Zaręba
   Electron. Technology 26, 2/3 (1993) pp. 119-127

7. CALIBRATION OF NUCLEAR TRACK DETECTORS USED FOR MEASUREMENTS OF FAST PROTONS (0.2-4.5 MEV)
   M.Sadowski, E.M.Al-Mashadani, A.Szydłowski, T.Czyżewski, L.Głowacka, **M.Jaskóła**, M.Wieluński
   Nucl. Instr. and Meth.- in press

8. MEASUREMENTS OF FUSION PRODUCED PROTONS WITH MODERN NUCLEAR TRACK DETECTORS
   E.M.Al-Mashadani, M.Sadowski, A.Szydłowski
   Sov. J. Plasma Phys. - in press

9. THE JET PRELIMINARY TRITIUM EXPERIMENT
   J.M.Adams, **Z.Jankowicz** et al (JET TEAM).
   Plasma Phys. and Contr. Fusion 34 (1992) pp. 1749-1758

10. THEORY OF INNER SHELL IONIZATION BY POSITRONS
M.Gryziński, M.Kowalski
Phys. Rev. Lett. - in press

11. PROTECTION CHARACTERISTIC OF MO-VARISTORS AT FAST RISING CURRENT IMPULSES
A.Jerzykiewicz, W.Drabik, K.Kocięcka, J.Witkowski
Przegl. Elektrotech. - in press, in Polish

12. COATING DEPOSITION BY HIGH INTENSITY PULSED ION BEAM EROSION
J.Langner, J.Piekoszewski, C.Pochrybniak, F.Rosatelli, S.Rizzo, **J.Kuciński,** A.Miotello, L.Guzman, L.Moro
Materials and Manufacturing technology - in press

13. DEPOSITION BY PULSED EROSION; FORMATION OF NICKEL COATING ON COPPER
J.Langner, J.Piekoszewski, C.Pochrybniak, F.Rosatelli, S.Rizzo, **J.Kuciński,** A.Miotello, L.Guzman
Surface and Coating Technology - in press

B. Reports, Books, and Patents

1. DEPARTMENT OF THERMONUCLEAR RESEARCH ANNUAL REPORT 1992
M.Sadowski, W.Pawłowicz (Editors)
IPJ Report No. SINS-2142/V (OINTEA, Otwock-Świerk, 1993)

2. STUDIES OF NUCLEAR FUSION REACTION PRODUCTS IN THE PF-360 PLASMA-FOCUS FACILITY
E.M.Al-Mashhadani
Ph. D. Thesis (IPJ, Otwock-Świerk 1993) - in press

3. INVESTIGATIONS ON INFLUENCE OF EXPERIMENTAL CONDITIONS ON THE EMISSION PLASMA-IONS STREAMS IN THE RPI-TYPE SYSTEMS
J.Baranowski
Ph. D. Thesis (IPJ, Otwock-Świerk 1993) - to be published, in Polish

4. DATA ACQUISITION SYSTEM FOR FAST AND SLOW TRANSIENTS
M.Bielik, J.Langner
Inter. Report (Dept. P-V IPJ, Otwock-Świerk 1993) for NIIEFA in St. Petersburg (within the framework of the scientific collaboration)

5. HIGH-CURRENT ARC IN DEUTERIUM WITHIN A PRESSURE RANGE 1-100 Pa
J.Baranowski
Project No 62/IPJ/93 for the State Committee of Scientific Research (IPJ, Otwock-Świerk 1993) - in Polish

6. INVESTIGATIONS OF NEUTRAL- AND CHARGED-PARTICLES WITHIN PLASMA STREAMS
E.Składnik-Sadowska
Project No 63/IPJ/93 for the State Committee of Scientific Research (IPJ, Otwock-Świerk 1993) - in Polish

7. DEVELOPMENT OF NEW MULTI-CHANNEL ČERENKOV TYPE DETECTORS FOR ANALYSIS OF ELECTRON STREAMS EMITTED FROM HIGH-TEMPERATURE PLASMA
L.Jakubowski
Project No 64/IPJ/93 for the State Committee of Scientific Research (IPJ, Otwock-Świerk 1993) - in Polish

8. INFLUENCE OF PROPERTIES OF TWO-GAP TRIGGERED SPARK-GAP ON DEVELOPMENT OF DISCHARGE IN HV-PULSE GENERATORS CIRCUITS
K.Kocięcka
Ph. D. Thesis (PW, Warsaw 1993) - in press, in Polish

9. AUTOMATIC CONTROL SYSTEM FOR REGULATION OF PRESSURE IN SWITCHING SPARK-GAPS
M.Bielik, W.Wyszyński
Patent Description No. PEW 1/93 (IPJ, Otwock-Świerk 1993) - in Polish

10. CONTROL AND IDENTIFICATION SYSTEM OF ACCIDENTAL BREAKDOWN OF SPARK-GAPS IN CURRENT PULSE GENERATORS
M.Bielik, R.Rybicki
Patent Description No. PEW 2/93 (IPJ, Otwock-Świerk 1993) - in Polish

11. DATA ACQUISITION SYSTEM FOR FAST AND SLOW TRANSIENTS
M.Bielik, J.Langner
SINS Internal Rep. No.0-2/P-V/93 (IPJ, Otwock-Świerk 1993) - in Russian

12. CHEMISTRY AND NUCLEAR TRANSFORMATIONS
M.Gryziński
Nauka i Przyszłość, 5/30 (1993) - in Polish

13. X-RAY SPECTROGRAPH FOR 3-4 A RANGE PREDESIGN AND ALIGNMENT
E.Baronova, **L.Jakubowski**
SINS Internal Report - to be published - in Russian

14. TRANSMISSION AND PROCESSING OF OUTPUT DATA FROM THE HP-DIGITAL OSCILLOGRAPH
V.Vichrev, **L.Jakubowski, W.Komar**
SINS Internal Report - to be published, in Russian

C. Conference Proceedings

1. EXPERIMENTAL EVIDENCE AND THEORETICAL ANALYSIS OF FILAMENTATION WITHIN HIGH-CURRENT PINCH COLUMN
M.Sadowski, W.Pawłowicz
Proc. Third Polish-Japanese Joint Seminar on Modelling and Control of Electromagnetic Phenomena, Kazimierz, 19-21 April 1993 (IEE&IFTR, Warsaw 1993), pp. 117-120

2. TIME-INTEGRATED AND TIME-RESOLVED MEASUREMENTS OF X-RAYS AND CHARGED PARTICLES FROM PF-360 FACILITY
M.Sadowski, J.Żebrowski, E.M.Al-Mashhadani
Proc. Third Intern. Conf. on Dense Z-Pinches, London, 19-23 April 1993 (Imperial College, London 1993), Paper H1 - in press

3. ANNULAR GAS PUFF TARGET EXPERIMENTS WITH POSEIDON PLASMA-FOCUS
L.Jakubowski, M.Sadowski, H.Schmidt, E.Składnik-Sadowska, J.Stanisławski, A.Szydłowski
Proc. Third Intern. Conf. on Dense Z-Pinches, London, 19-23 April 1993 (Imperial College, London 1993), Paper P31 - in press

4. A NEW ACQUISITION SYSTEM FOR FUSION EXPERIMENTS SLOW VARIABLE TRANSIENTS
M.Bielik
Proc. 16th Symposium on Plasma Phys. & Tech., Prague, 27-29 April 1993 (IPP, Prague 1993)

5. MODIFIED MODEL OF TOKAMAK EDGE PLASMA WITHIN GRAD'S APPROACH
M.Rabiński
Proc. First Carolus Magnus Summer School on Plasma Physics, Vaals, Sept. 6-17, 1993

6. DEVELOPMENT OF PLASMA DIAGNOSTIC TECHNIQUES IN POLAND
M.Sadowski
Proc. 6th Nat. Top. Conf. on High-Temperature Plasma Diagnostics, St. Petersburg, May 26 - June 1, 1993 (TRINITI, Moscow 1993), Invited Paper, p.197

7. MEASUREMENTS OF FUSION PRODUCED PROTONS WITH MODERN NUCLEAR TRACK DETECTORS
E.M.Al-Mashhadani, M.Sadowski, A.Szydłowski
Proc. 6th Nat. Top. Conf. on High-Temperature Plasma Diagnostics, St. Petersburg, May 26 - June 1, 1993 (TRINITI, Moscow 1993), Paper 7.7, p. 152

8. DIAGNOSTICS OF PULSE ELECTRON BEAMS EMITTED FROM PF-TYPE FACILITIES
L.Jakubowski, M.Sadowski, J.Żebrowski
Proc. 6th Nat. Top. Conf. on High-Temperature Plasma Diagnostics, St. Petersburg, May 26 - June 1, 1993 (TRINITI, Moscow 1993), Paper 5.16, p. 120

9. EXPERIMENTAL STUDIES OF DENSE MAGNETIZED PLASMAS PRODUCED BY PF-TYPE DISCHARGES
M.Sadowski, L.Jakubowski, M.Kowalski, E.M.Al-Mashhadani, E.Składnik-Sadowska, J.Żebrowski
Proc. 20th EPS Conf. on Contr. Fusion and Plasma Phys., Lisboa, July 26-30, 1993 (EPS, Geneve 1993), Vol. 17c, Part II, pp. 537-540

10. STUDIES OF MASS- AND ENERGY-SPECTRA OF IONS WITHIN INTENSE PULSE PLASMA STREAMS
J.Baranowski, M.Sadowski, E.Składnik-Sadowska
Proc. XXII Intern. Conf. on Phenomena in Ionized Gases, Bochum, Sept. 19-25, 1993 - paper accepted but unpublished

11. SURFACE SOLITONS IN PLASMA DEVICES
E.Infeld, M.Sadowski
Proc. XXII Intern. Conf. on Phenomena in Ionized Gases, Bochum, Sept. 19-25 (Ruhr-Universität, Bochum 1993) pp. 289-290

12. COATING DEPOSITION BY HIGH INTENSITY PULSED ION BEAM EROSION
J.Langner, J.Piekoszewski, C.Pochrybniak, F.Rosatelli, S.Rizzo, **J.Kuciński,** A.Miotello, L.Guzman, L.Moro
Proc. Eighth Int. Conf. on Surface Modification of Metals by Ion Beams SMIB'93, Sept.3-5, Kanazawa, Japan - in press

13. DEPOSITION BY PULSED EROSION; FORMATION OF NICKEL COATING ON COPPER
J.Langner, J.Piekoszewski, C.Pochrybniak, F.Rosatelli, S.Rizzo, **J.Kuciński,** A.Miotello, L.Guzman
Proc. 7th Int. Conf. on Surface Modification Technologies SMT'93, Oct.31-Nov.3, Sanyo, Japan - in press

14. HIGH INTENSITY ION PULSE PROCESSING OF MATERIALS
J.Piekoszewski, J.Langner, C.Pochrybniak, Z.Werner, J.Białoskórski, K.Czaus, L.Waliś, A.Ciurapiński
Proc. Int. School and Symposium on Physics in Material Science ISSPMS'93, Sept.12-18, Jaszowiec, Poland - in press

15. INFLUENCE OF ARC RESISTANCE ON THE PULSE SHAPE IN CIRCUITS SWITCHED BY CONTROLLED PRESSURIZED SPARK-GAPS
A.Jerzykiewicz, K.Kocięcka
Proc. 6th Int. Symposium on Strong Arc Phenomena SAP'93, Sept.27-Oct.1, Łódź, Poland, 1993, pp. 28-32

16. INVESTIGATION OF X-RAY EMISSION AND FAST ELECTRONS FROM THE MAJA-PF FACILITY
L.Jakubowski, M.Sadowski, J.Żebrowski
Proc. Sci. Symposium "PLASMA'93" (CBK, Warsaw 1993), pp. 175-178 - in Polish

17. MODIFIED GRAD'S MODEL OF TOKAMAK EDGE PLASMA
M.Rabiński
Proc. Sci. Symposium "PLASMA'93" (CBK, Warsaw 1993), pp. 159-162 - in Polish

18. PRODUCTION OF CRYOGENIC MICROTARGETS FOR PLASMA EXPERIMENTS
E.Składnik-Sadowska, A.Szydłowski
Proc. Sci. Symposium "PLASMA'93" (CBK, Warsaw 1993), pp. 246-249 - in Polish

19. TIME-INTEGRATED STUDIES OF GAS-PUFFED PF-DISCHARGES WITHIN POSEIDON FACILITY
L.Jakubowski, M.Sadowski, E.Składnik-Sadowska, J.Stanisławski, A.Szydłowski
Proc. Sci. Symposium "PLASMA'93" (CBK, Warsaw 1993), pp. 187-190

20. MEASUREMENTS OF FAST PROTONS FROM NUCLEAR FUSION REACTION IN THE PF-360 FACILITY
E.M.Al-Mashhadani, M.Sadowski, A.Szydłowski
Proc. Sci. Symposium "PLASMA'93" (CBK, Warsaw 1993), pp. 183-186 - in Polish

21. DATA ACQUISITION SYSTEM FOR SLOW VARIABLE TRANSIENTS WITH FIBER OPTIC SEPARATION
M.Bielik
Proc. 17th Symposium on Fusion Technology (SOFT, Rome, 1993) Vol. 2, pp. 993-996

22. APPLICATIONS OF OPTOELECTRONICS IN PLASMA EXPERIMENTS
M.Bielik
Proc. Sci. Symposium "PLASMA'93" (CBK, Warsaw 1993), pp. 242-245 - in Polish

23. INVESTIGATIONS OF ION AND ELECTRON EMISSION FROM HIGH-CURRENT DISCHARGES IN THE PF-360 FACILITY
M.Sadowski, J.Żebrowski
Proc. Sci. Symposium "PLASMA'93" (CBK, Warsaw 1993), pp. 179-182 - in Polish

24. MASS- AND ENERGY-MEASUREMENTS OF IONS WITHIN INTENSE PLASMA STREAM
J.Baranowski, E.Składnik-Sadowska
Proc. Sci. Symposium "PLASMA'93" (CBK, Warsaw 1993), pp. 195-198 - in Polish

25. MOTION OF IONS WITHIN A PINCH WITH FILAMENTARY STRUCTURE
M.Sadowski, R.Miklaszewski, M.Scholz, W.Stępniewski
Proc. Sci. Symposium "PLASMA'93" (CBK, Warsaw 1993), pp. 133-136 - in Polish

26. TIME-CORRELATIONS OF GAS-PUFFED PF DISCHARGES WITHIN POSEIDON FACILITY
L.Jakubowski, M.Sadowski, E.Składnik-Sadowska, J.Stanisławski, A.Szydłowski, H.Schmidt
Proc. Sci. Symposium "PLASMA'93" (CBK, Warsaw 1993), pp. 191-194

27. THE THEORY OF TOKAMKS - ACHVIEMENTS AND PROBLEMS
Z.Jankowicz,
Proc. Sci.Symposium "PLASMA'93" - invited paper (CBK, Warsaw 1993), pp.46.

28. KINETIC FLUXES IN THE PLASMA SHEATH IN AN OBLIQUE MAGNETIC FIELD. ANALITICAL ESTIMATIONS
Z.Jankowicz
Abstract, Proc. 4th Internat. Workshop on Plasma Edge Theory in Fusion Devices, Oct.1993, Varenna, Italy, p. E2.

6. LECTURES AND TALKS GIVEN AT EXTERNAL SEMINARS AND SYMPOSIA (unpublished)

1. Development of Plasma Diagnostic Techniques in Poland
M.Sadowski, May 26 - June 1, 6th National Topical Conference on High-Temperature Plasma Diagnostics, St. Petersburg

2. Gas-Puffed Experiments on POSEIDON
E.Skladnik-Sadowska, June 16, Institut fuer Plasmaforschung, Stuttgart

3. Design and Operational Tests of Fast Electrodynamic Valve for Production of Gas Targets
J.Stanisławski, June 16, Institut fuer Plasmaforschung, Stuttgart

4. Nuclear Transformations (in Polish)
M.Gryziński, June 17, IEA, Otwock-Świerk

5. Optimization of High-Current Discharges of the PF-Type (in Polish)
M.Sadowski, Sept. 6-8, 3rd Symposium of Polish Society for Electromagnetism Applications, Zaborów

6. Present Status of Thermonuclear Research in Poland and All Over the World (in Polish)
M.Sadowski, Sept. 20-23, XXXII Meeting of Polish Physicist Society, Cracow

7. Technological Application of Pulsed Plasma Streams (in Polish)
J.Langner, Sept. 29, National Conf. "Plazma'93", CBK, Warsaw

8. Plasma-Focus Studies within Frame of Polish-German Scientific Collaboration
M.Sadowski, Nov. 1-3, Inter. Workshop on High Temperature Plasmas, IFAS University, Tandil, Argentina

9. Recent Achievements of Thermonuclear Research (in Polish)
M.Sadowski, Dec. 3, IFD UW, Warsaw

10. Concept, Main Aims, and Perspectives of International Center for Dense Magnetized Plasmas (in Polish)
M.Sadowski, Dec. 14, General Plasma Seminar, Warsaw

7. PLASMA SEMINARS with the PARTICIPATION of DEPT. P-V SCIENTIFIC STAFF

1. Present Status and Estimate of Plasma Research on Discharges of the Z-Pinch Type (in Polish)
   S.Denus, Jan. 12, General Plasma Seminar, SINS, Warsaw

2. Numerical Simulation of Complex Electrical Systems Used to Supply Plasma Experiments (in Polish)
   B.Bartolik, Feb. 9, Plasma Seminar, SINS, Świerk

3. Studies of Plasma Generated with Laser Beam - Continuous Optical Discharge (in Polish)
   Z.Peradzyński, Feb. 16, General Plasma Seminar, IBTP, Warsaw

4. Phenomena of Chaos and Self-Organisation in Plasma (in Polish)
   A.Turski, March 16, General Plasma Seminar, IBTP, Warsaw

5. Active Plasma Experiments in Cosmic Space (in Polish)
   Z.Kłos, April 20, General Plasma Seminar, Center for Space Research, Warsaw

6. Physical Problems of Laser Nuclear Fusion (in Polish)
   J.Wołowski, May 18, General Plasma Seminar, IPPLM, Warsaw

7. Change of Structure in Classical Physics and Plasma (in Polish)
   E.Infeld, June 15, General Plasma Seminar, SINS, Warsaw

8. Physics and Technique of Star Wars (in Polish)
   S.Denus, June 21, General Seminar, SINS, Świerk

9. Current Generation for a Fast Z-Pinch
   G.Linhart, Sept. 23, Plasma Seminar, SINS, Świerk

10. Application of Electrical and Magnetic Fields in Contemporary Technology (in Russian)
    O.Piecherski, Oct. 8, General Seminar, SINS, Świerk

11. X-Ray Emission from Micropinches in the DPF-78 Plasma Focus
    H.Schmidt, Nov. 16, General Plasma Seminar, SINS, Warsaw

12. Russian Federal Nuclear Center WMMII-EF Arzamas (in Russian)
S.A.Suharev, Dec. 16, Plasma Seminar, SINS, Świerk

13. Studies of Plasma Physics in ISKRA Laser Facility (in Russian)
V.Bessarab, Dec. 16, Plasma Seminar, SINS, Świerk

8. LIST OF VISITORS

1. Mr Detlef Schulz
   from the Institut fuer Plasmaforschung in Stuttgart, Germany, visited the Dept. P-V on March. 19, 1993.

2. Mr Stanley Hyduke
   from the Automated Logic Co. in Newbury Park, USA, visited Dept. P-V on March 22-23, 1993.

3. Mr Norman Gruczelak
   from the Gruczelak and Associates, Inc. in Ventura, Ca.93001, USA, visited Dept. P-V on March 22-23, 1993.

4. Mr Yasuhisa Hoshi
   from the NISSIN High-Voltage in Methuen, MA, USA, visited Dept. P-V on April 22, 1993.

5. Mr Makoto Tanaka
   from the SUMITOMO Co. in Vien, Austria, visited Dept. P-V on April 22, 1993.

6. Mr Kiyotaka Fukahori
   from SUMITOMO Representatives, in Warsaw, Poland, visited Dept. P-V on April 22, 1993.

7. Mr Heinz Thiemann
   from the Arbeitsgruppe Weltraumphysik u. Technologie in Freiburg, Germany visited the Dept. P-V on Sept. 10, 1993.

8. Prof. J. Linhart
   from the University of Ferrara in Ferrara, Italy, visited the Dept. P-V on Sept. 23, 1993.

9. Dr Eduardo Bobadilla Lopez

10. Prof. German J. Piderit Alvear

11. Mr Rosamel Munoz Quintana
    all from the Chilean Commission of Nuclear Energy in Santiago, Chile, visited Dept. P-V on Oct. 04, 1993.

12. Prof. Oleg Pieczerskij
    from the NIIEFA in St-Petersburg, Russia, visited Dept. P-V on Oct. 5-15, 1993.

13. Dr Elena Baronova

14. Dr Victor Vikhrev

both from the Russian Scientific Center "Kurchatov Institute" in Moscow, Russia, stayed in Dept. P-V for a scientic collaboration from Oct. 15 until Nov. 29, 1993.

15. Dr Hellmut Schmidt
    from the Institut fuer Plasmaforschung at Stuttgart Uni., Germany stayed in Dept. P-V for a collaboration from Nov. 3 until NOv. 17, 1993.

16. Dipl. Ing. Stephan Kienle
    from the Institute fuer Plasmaforschung at Stuttgart Uni, Germany, stayed in Dept. P-V for scientific training from Nov. 3 until Dec. 17, 1993.

17. Prof. Pavel Kubes

18. Prof. Josef Kravarik

19. Dr Jan Pichal

20. Ing. Jiri Haki
    all from the Technical University in Prague, Czech Rep., visited Dept. P-V on Nov.11, 1993.

21. Dr Karel Kolacek
    from the Institute for Plasma Physics in Prague, Czech Rep., visited Dept. P-V on Nov.11, 1993.

22. Prof. Stanislav A. Sucharev

23. Prof. Aleksander V. Bessarab

24. Prof. Stanislav M. Kulikov
    all from the All-Union Scientific Research Institute of Experimental Physics in Arzamas, Russia, visited Dept. P-V on Dec. 15, 1993.

9. LIST OF STAFF

9.1. Scientific Staff

1. Appelt Jacek, Ph.D. - partially employed.
2. Baranowski Jarosław, M.Sc.
3. Bielik Mirosław, Ph.D.
4. Gryziński Michał, Ph.D. – Assoc. Prof.
5. Jakubowski Lech, Ph.D.
6. Kocięcka Krystyna, M.Sc.E.E.
7. Kociński Lech, M.Sc.E.E. – on leave of absence from Oct. 31, 1993.
8. Komar Włodzimierz, M.Sc.
9. Kowalski Marian, M.Sc.
10. Kuciński Jacek, Ph.D. – on leave of absence from Oct. 31, 1991.
11. Langner Jerzy, Ph.D. – Deputy Head of Department.
12. Pawlowicz Wiesław, Ph.D. - from June 1993 employed partially.
13. Rabiński Marek, Ph.D.
14. Sadowski Marek, Ph.D.D.Sc. – Professor – Head of Department.
15. Składnik-Sadowska Elżbieta, Ph.D.
16. Szydłowski Adam, Ph.D.
17. Żebrowski Jarosław, M.Sc.E.E.

9.2. Engineers

1. Borowska Elżbieta, M.Sc.E.E.
2. Czaus Krzysztof, Eng.
3. Ćwiek Ewa, Eng.
4. Kowalski Marek, M. Sc.
5. Mirowski Robert, M.Sc.M.E.
6. Polak Wawrzyniec, Eng.
7. Stanisławski Jacek, M.Sc.E.E.
8. Witkowski Jan, Eng.

9.3. Technicians

1. Cywiński Krzysztof - employed until Oct. 30, 1993.
2. Czajkowska Joanna - employed until Sept. 30, 1993.
3. Gątarczyk Krzysztof
4. Gniadek Krzysztof
5. Grzeszczyk Zdzisław
6. Jankowski Marek
7. Jęda Andrzej - employed until March 31, 1993.
8. Karpiński Paweł
9. Kasperski Krzysztof
10. Kołakowski Bernard
11. Kołnierzak Ryszard - employed until Sept. 30, 1993
12. Koszewski Grzegorz
13. Królik Jerzy
14. Kuk Mirosław
15. Kwiatkowski Marek
16. Machalski Piotr - employed until March 31, 1993.
17. Michalik Krzysztof
18. Nawrocka Halina
19. Pijanowski Wojciech
20. Rybicki Ryszard
22. Trembicki Andrzej
23. Wiraszka Andrzej

9.4. Workshop

1. Jędrzejczyk Marek
2. Kloch Józef
3. Niewiadomski Andrzej

9.5. Administration Staff

1. Gawrońska Alicja
2. Salamońska Anna

Wydaje Instytut Energii Atomowej - OINIEA
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