INSTYTUT PROBLEMÓW JĄDROWYCH
im. ANDRZEJA SOŁTANA
ИНСТИТУТ ЯДЕРНЫХ ПРОБЛЕМ им. А.СОЛТАНА
SOLTAN INSTITUTE FOR NUCLEAR STUDIES

RAPORT SINS 2128/ V

DEPARTMENT OF THERMONUCLEAR RESEARCH

ANNUAL REPORT 1991

OTWOCK-ŚWIERK 1992

SOLTAN INSTITUTE FOR NUCLEAR STUDIES

RAPORT SINS 2128/ V

DEPARTMENT OF THERMONUCLEAR RESEARCH

ANNUAL REPORT 1991

Edited by
MAREK SADOWSKI
WIESŁAW PAWŁOWICZ

Soltan Institute for Nuclear Studies,
Department of Thermonuclear Research,
05-400 Otwock-Świerk, Poland

OTWOCK-ŚWIERK, FEBRUARY 1992

Raport Roczny 1991 Zakładu Badań Termojądrowych przedstawia krótki przegląd badań teoretycznych, eksperymentalnych i technologicznych przeprowadzonych w ramach dwóch programów badawczych: Fizyka Plazmy (8 tematów oznaczonych V.1-V.8) i Opracowanie Układów do Diagnostyki i Akwizycji Danych (8C-4S2K). Opisane są badania teoretyczne dotyczące analizy plazmy przyściennej w tokamaku, stosowalności odwrotnej transformacji Abela dla obiektów silnie refrakcyjnych, modelowania działania generatorów udarowych oraz analizy procesów przechwytu elektronów w zderzeniach $p+H^+$. Krótko podsumowane są badania eksperymentalne wiązek korpuskularnych i promieniowania X z różnych układów plazmowych, rozwój technik diagnostycznych i układów akwizycji danych, a także eksperymenty z generacją kriogenicznych tarcz do badań plazmowych. Przedstawione są również badania technologiczne dotyczące modernizacji urządzeń typu PF i RPI oraz zastosowania urządzeń typu IONOTRON do modyfikacji powierzchni półprzewodników i metali.

Department of Thermonuclear Research Annual Report 1991 presents a short review of theoretical, experimental, and technological studies carried out within the framework of two research programs: Plasma Physics (8 topics denoted V.1-V.8) and Development of Diagnostics and Data Acquisition (8C-4S2K). Theoretical studies of a tokamak edge plasma, validity of inverse Abel transformation for strongly refracting objects, simulation of the pulse generators operation, and a numerical analysis of electron capture in $p+H^+$ collisions, are described. Experimental studies of corpuscular beams and X-rays from different plasma facilities, development of diagnostic techniques and of data acquisition systems, as well as experiments with the generation of cryogenic pellets for plasma research, are shortly summarized. Also presented are technological studies concerning the modernization of the PF - and RPI-type facilities and the application of the IONOTRON-type devices for the modification of semiconductor and metal surfaces.

Рапорт за 1991 г. Отдела Термоядерных Исследований представляет собой короткий обзор теоретических, экспериментальных и технологических исследований проведенных в рамках двух исследовательских программ: Физика Плазмы (8 тем обозначенных V.1-V.8) и Разработка Систем Сбора Данных и Диагностики (8C-4S2K). Описаны теоретические исследования пристеночной плазмы в токамаке, применимости обратной трансформации Абеля для объектов с сильной рефракцией, моделирования действия ударных импульсных генераторов и анализа процессов захвата электронов в столкновениях $p+H^+$. Коротко описаны экспериментальные исследования корпускулярных пучков и рентгеновского излучения из разных плазменных установок, развитие методов диагностики и систем сбора данных, эксперименты с генерацией криогенных мишеней для плазменных исследований. Представлены также технологические исследования, связанные с модернизацией установок типа PF и RPI, и применением установок типа IONOTRON для модификации поверхностей полупроводников и металлов.

CONTENTS

1. PREFACE

by M. Sadowski

In 1991, research activities of the Department of Thermonuclear Research (P-V) were mainly the continuation of previous studies [1]. Theoretical and experimental studies were carried out within a framework of two research projects: Plasma Physics Studies (comprising 8 topics V.1-V.8) and Development of Diagnostic and Data Acquisition Systems (8C-4S2K). Some technological studies were performed under additional contracts.

The theoretical studies were devoted to an analysis of a tokamak edge plasma, validity of the inverse Abel transformation when strongly refracting axisymmetrical objects are under investigation, and simulation of the operation of current- and voltage-pulse generators. Separate efforts were connected with a numerical analysis of electron capture in $p + H^+$ collisions.

The experimental studies concerned the corpuscular beams and X-rays emitted from different PF-facilities (PF-360, MAJA-PF), as well as those generated in the RPI-type devices (IBIS, SOWA-400). Other efforts were devoted to the generation of cryogenic pellets needed for nuclear and thermonuclear research.

The technological activities were concentrated on the modernization of the PF- and RPI-type facilities, and in particular – on adaptation of the IONOTRON SW-30-87 device for the operation with the repetition increased up to 3 shots per minute. Particular attention was paid to the application of the IONOTRON-type devices for the modification of semiconductors and metals.

Some studies mentioned above have been carried out within a framework of the scientific cooperation with the other departments P-IX and P-II. Some PF studies have been performed in the cooperation with the IPF in Stuttgart (FRG). Results of the German -Polish cooperation were summarized at the Plasma Seminar held in Świerk on Sept. 12-13, 1991. Another activity was the 3rd Meeting of Working Group for International Center of Dense Magnetized Plasma (ICDMP), which was held in Świerk on Dec. 11-13, 1991. This annual report contains a list of all the contributions to those meetings, which were given by the P-V staff, as well as other references.

2. THEORY AND COMPUTATIONAL PHYSICS

2.1. Edge Plasma Transport Analysis in Grad's Approach (V.5a)
by M. Rabiński

Modelling of a tokamak scrape-off plasma in the framework of the fluid approach overestimates the transport coefficients in a region where validity of hydrodynamic model is violated. Thus, one can observe a discrepancy between experimental data and computational results for temperatures and concentration in the SOL midplane. Several approaches have been applied to obtain a more realistic theoretical description. Usually the nonlocal electron heat flux formulation* is implemented. On the contrary to that approach, the BOUND1D package of one-dimensional codes has been improved by introducing a more sophisticated model of heat fluxes and viscous stresses in the Grad's approach**. At first, a set of differential equations for the nonlocal transport coefficients has been taken according to the Igitkhanov & Yushmanov paper***. However, computational studies [2] have shown that the applied time independent description leads to irrationally large values, which destabilize subsequent calculations.

A critical analysis of the results made it possible to find several unmotivated simplifications preceding the model equations. First of all, it was found that the steady state formulation is improper for the simulation of plasma dynamics. As a result a new, improved model for nonlocal heat fluxes and viscous stresses was developed [2]. Equations describing the nonlocal heat fluxes and viscous stresses have been derived within the 21 moment Grad's approach, on the basis of general formulae given by Zhdanov for a multicomponent plasma****. For consistency with a dynamic model of the plasma transport, the time derivatives have not been neglected.

The first computational results obtained from the model described above, have shown that the previously reported unphysical solutions disappear. At the time, some studies have been started [3] to develop a consistent system of boundary conditions, both for the plasma model and nonlocal transport coefficients. Inclusion of additional variables (higher order moments) introduced by the Grad's method makes the analysis a more complex problem.

---

* J. Luciani, P. Mora, J. Virmont: Nonlocal Heat Transport Due to Steep Temperature Gradients; Phys. Rev. Lett. 51 (1983) 18, pp. 1664-1667.

** M. Rabiński: One-Dimensional Modelling of Tokamak Edge Plasma Transport in Grad Approximation; Contrib. Plasma Phys. 30 (1990) 1, pp. 121-126.

*** Yu. Igitkhanov, P. Yushmanov: Non-Local Transport in the Scrape-Off Tokamak Plasma; Contrib. Plasma Phys. 28 (1988) 4/5, pp. 341-344.

**** V. Zhdanov: Transport Phenomena in Multicomponent Plasma (in Russian); Energoizdat, Moscow 1982.

2.2. Validity of Inverse Abel Transformation at Investigation of Strongly Refracting Axisymmetric Objects (V.4a)

by W. Pawłowicz

Interferometry and refractometry are the optical diagnostic methods often used when a volume density distribution of a transparent object is to be determined. Numerical methods of raw data inversion are usually based on the straight path approximation (interferometry) or the assumption of a weak refraction (refractometry). When the object under study is partially opaque, such assumptions are evidently invalid because of the strong refraction of probing rays approaching a critical density region.

There have been examined [4] results of the approximate (under the weak refraction assumption) Abel inverse transformation applied to refraction and optical path difference data (OPD) calculated for the strongly refracting axisymmetric electron density profiles. A computer simulation has been carried out for exponential electron density distributions which may be used to describe an electron density profile of a laser-produced plasma analytically. Parameters of these profiles were chosen to cover a range of the experimentally observed electron density shapes when high power laser beam - plasma interaction is under study.

For a given wavelength and electron density profile, sets of the exact values of refraction angles and OPD have been calculated. Then, the obtained quasi-experimental data have been inverted using the standard inverse Abel transformation (an orthogonal polynomials approximation).

It has been found that the difference between the exact and inverted values does not exceed 20%, except for the low density region, where it rises distinctly because of numerical errors in the approximation procedure. This is a common problem when the polynomials approximation is applied to a discrete distribution of data approaching a constant value at the low density object border.

Taking into account the presented results, one may conclude that, for the profiles investigated and for reasonable scale length factor values, the refraction and OPD data inversion schemes based on the weak (or negligible) refraction assumption can work even if the strong refraction of the probing radiation occurs. It is true within the whole range in which the standard inverse Abel transformation may work, i.e., within the uniquely determined data range limited by the ray crossing effect only. A general proof of this statement is rather difficult and not known up to date, but some qualitative arguments may be presented*.

* W. Pawłowicz: Investigation of laser-produced plasma density distributions (in Polish); Ph.D.Thesis (WAT, Warsaw 1988) - unpublished.

2.3. Simulation of Pulse Generators with FEEDER and GENRAT Numerical Programs (V.8)

by B. Bartolik

Methods of a numerical simulation of pulse current generators supplying the experimental plasma devices have been studied and improved. In particular, the ROZRZUT program has been modernized. The ROZRZUT program, which is a simple model of a circuit with the "field-distortion" spark gap, takes into account the triggering dispersion phenomena. It uses the modified Heilbronner formula* and the Rompe-Weizel formula to describe a triggering process. The first formula describes a delay beetween the ignition and triggering, and the second gives a spark resistivity change during a discharge in the circuit.

The ROZRZUT program has been modernized to verify the model of the spark gap proposed by Bartolik and Kociecka [5]. The Heilbronner formula, used for the dual-gap spark gap, gives proper results only for the gap triggered at first. It was proposed to treat the triggering process in the second gap, as taking place under new conditions (modified by a spark in the first gap). The program has been modified to facilitate the analysis of numerous experimental data. It was rewritten in the C language and equiped with the graphic output to present all important variables. Using that program, it was possible to compare many aspects of calculated results with experimental measurements and to verify the proposed method [5]. The detailed comparison has been done by K. Kociecka [6].

The ROZRZUT program makes possible the simulatation of the triggering dispersion phenomena, basing on the experimental results obtained by Kociński** and the phenomenological model developed by Bartolik et al.***. The modernization of ROZRZUT program has been used to improve the triggering phenomena treatment in FEEDER and GENRAT programs simulating the operation of pulse current generators. Now, both programs can be used as design tools within a well defined application range.

---

* B. Bartolik, K. Kocięcka: Numerical Evaluation of HV pulse Shapes at Spark-Gap Circuits (in Polish); Archiwum Elektrotechniki, Vol. 28, No. 3, 1979, p. 613.

** L. Kociński: Arc in controlled double gap switch - statistical distribution of breakdown time; Proc. of 5th Int. Symp. on Switching Arc Phenomena, Łódź, 1985, Part 1, p. 92.

*** B. Bartolik et. al.: Numerical Simulation of Pulse Generators Operation Taking into Account Switch Jitter (in Polish); Proc. of Symp. "Plazma'88", p. 215, Jachranka 1988.

2.4. Simulation of Pulse Generator Operation and Its Experimental Verification (V.8)

by K. Kocięcka

Investigation of a 2IPB spark-gap of the field-distortion-type has been carried out to determine experimentally some basic characteristics of the spark-gap, such as: the Heilbronner constant defining a spark-over moment, an ohmic resistance, a discharge development time, and a discharge moment jitter depending on operational conditions and the electrical circuit parameters [6].

The measured characteristics make possible the verification of the results obtained with numerical programs simulating the pulse generator operation (using a spark-gap of the type considered).

Some results of investigation are presented in Figs 1 and 2, which show the Heilbronner constants change during a discharge and a time dependence of the spark-gap impedance, as measured in aperiodic and periodic circuits.

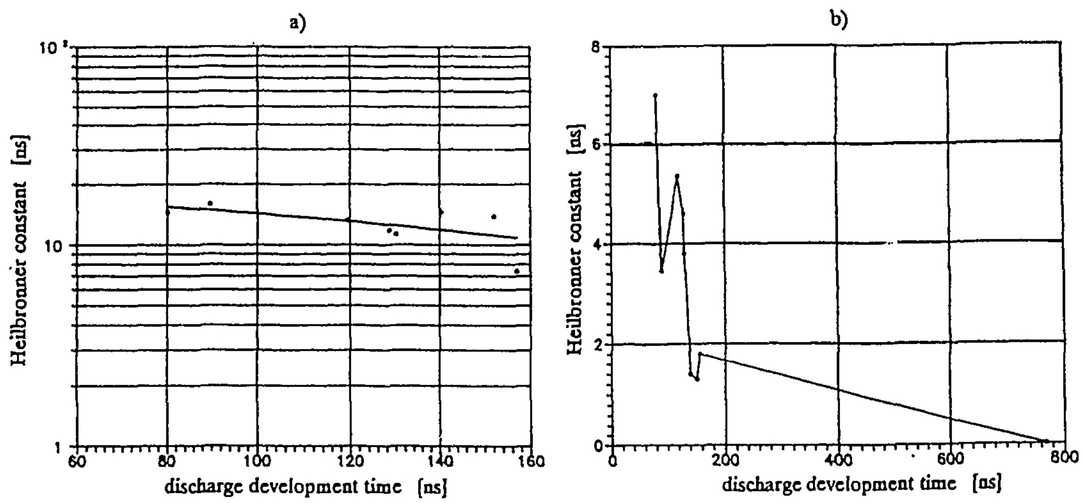

Fig.1. The Heilbronner constant T1 versus discharge development time and measured in relation to: a) high-voltage electrode, b) ground electrode.

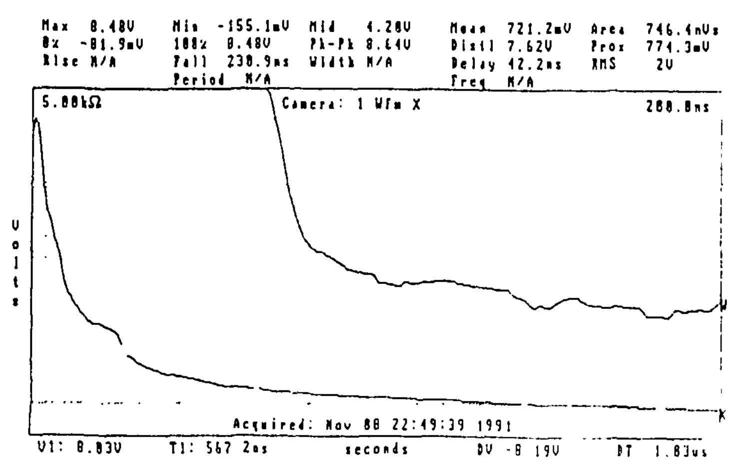

Fig.2. Time-dependent impedance of the spark-gap.

2.5. Numerical Analysis of Electron Capture in $p+H^+$ Collisions (V.5b)
by M. Gryziński and M. Kowalski

Scattering of protons (electrons or positrons) on the hydrogen atom is very usefull for verification of different theories (classical, semiclassical and quantum ones) by a comparison of the capture, ionisation and excitation (to the 1s, 2p, 3d states) cross-sections with the experimental data. The classical theories solve a set of the newtonian equations assuming a classical model of the hydrogen atom.

The presented classical calculations [7,8] are based on the free-fall hydrogen model*, which takes into account the polarisation effect. The set of the three body differential equations given in the frame of the centre of mass of the whole system, has been solved numerically:

$$\dot{p}_i = -\frac{1}{r_{ae}}\frac{\partial V}{\partial r_{ae}}\mu(\mu q_i - q_{i+3}) - \frac{1}{r_{be}}\frac{\partial V}{\partial r_{be}} q_i - \frac{1}{r_{ab}}\frac{\partial V}{\partial r_{ab}}\frac{\mu}{M}\left[\frac{\mu}{M_b} q_i + q_{i+3}\right], \quad \text{for } i=1,\ 2,\ 3$$

$$\dot{p}_i = -\frac{-1}{r_{ae}}\frac{\partial V}{\partial r_{ae}}\mu(q_i - \mu q_{i+3}) - \frac{1}{r_{ab}}\frac{\partial V}{\partial r_{ab}}\left[\frac{\mu}{M} q_{i-3} + q_i\right]. \quad \text{for } i=4,\ 5,\ 6$$

where: a - projectile nucleus, b - hydrogen nucleus, e - hydrogen electron,
q_i and p_i - the relative cartesian coordinates and the momenta of three particles,
V - the potential energy of the system, μ and M - the reduced masses of the particles ($\mu = m_b \cdot m_e/(m_b+m_e)$, $M = m_a(m_b+m_e)/(m_a+m_b+m_e)$).

To calculate the cross sections use has been made of the statistical Monte Carlo method, solving the equations at random initial conditions. Some results of the calculations are shown in Figs.1 and 2. Creation of the positronium in $e^+ + H$ collisions is presented in Fig.1, and probability of capture in Fig.2. A good agreement between calculated and experimental electron capture probability is shown.

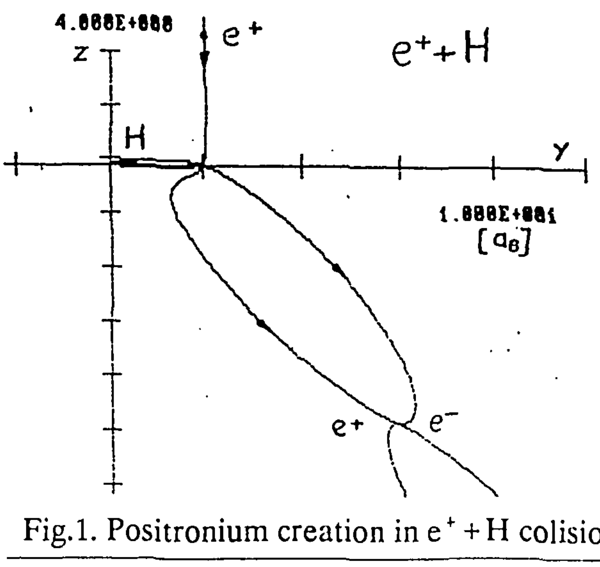

Fig.1. Positronium creation in $e^+ + H$ colision.

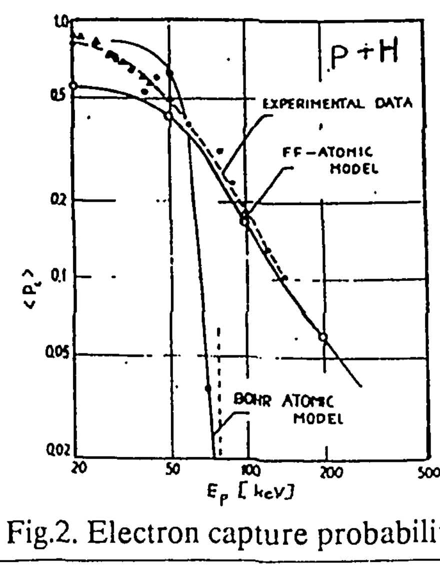

Fig.2. Electron capture probability.

* M. Gryziński, Phys. Rev., A138 (1965), p. 336.

3. EXPERIMENT

3.1. <u>Faraday Cup Analysis of Ion Streams Produced by IBIS Facility</u> (V.3 - Zad. 3)
by J. Baranowski

The biased charge collector* was used to measure current densities up to 200 A/cm^2 for low energy deuterons (E $\approx$ 100 eV), and to 10 - 40 A/cm^2 – for high energy ions (E $\approx$ 20 keV). Basic physical parameters of the detector are shown in Fig.1a. At the typical aperture size of 0.002 cm^2, the total ion current can be measured within the range from 0.1 to 0.5 amperes. The cup was located inside an experimental chamber at the distance of 40 cm from the electrodes plane. This arrangement allows a bias voltage of −1000 V to −1200 V to be applied to the control grid of cup in order to stop electrons, to confine plasma, and to permit the extraction of deuterons from a region of a high density plasma [9].

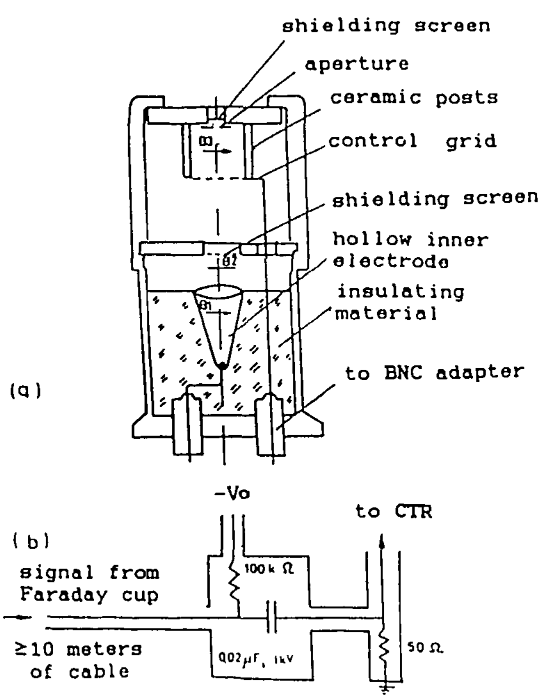

Fig.1. Faraday cup scheme.
a) Construction (B_1 = 500 G, B_2 = 100 G, and B_3 = 10 G produced by permanent magnets).
b) Electrical bias circuit.

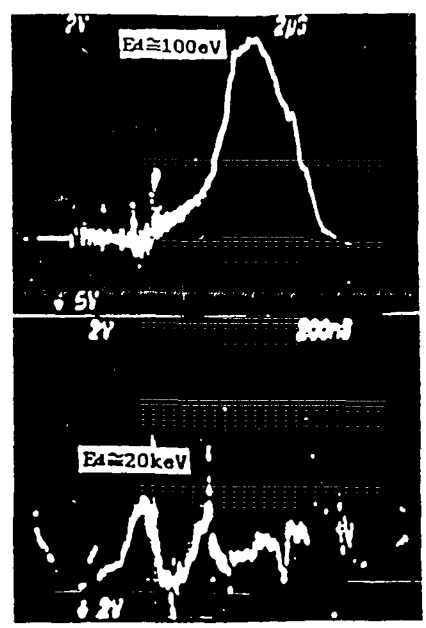

Fig.2. Time-resolved signals from the biased charge collector; 1 V signal corresponds to 10 A/cm^2 ion flux density.

---

* C. Eichenberger et al.; Journal of Appl. Phys., Vol. 48, No. 4, 1977.

3.2. Investigation of Particle Beams (Ion, Electron and Fusion Products) and X-Ray Emission from PF-360 Device at PF-Type Discharges (V.3a)

by J. Żebrowski, M. Sadowski, A. Szydłowski, and E. Al-Mashhadany

In 1991, within the scope of studies of physical phenomena occuring in high-current plasma pinch devices, investigations of particle beams (ion, electron and fusion proton) and of the X-ray emission from the PF-360 device have been carried out [10,11]. The investigations may be summarized as follows:

1. Detailed studies of relativistic electron beam energy spectra have been carried out with a magnetic spectrometer. An influence of initial gas conditions, power supply parameters, and of e-beam converting Al-foil thickness upon the detected X-ray radiation have been examined. It has been found that the experimental chamber filling with deuterium causes an increase in the electron emission from a plasma. An example of electron beam energy spectrum is presented in Fig.1.
2. Ion distribution maps and angular distributions of high-energy ions (mainly fusion protons emitted from a plasma) have been measured with the use of an ion pinhole camera equipped with the CR-39-type track-detectors. An example of such distributions is presented in Fig.2. It has been found that CN-type detector foils are in general more sensitive to a wide range of ions, but to detect fast protons it is better to use the CR-39-type detectors.
3. An influence of experimental conditions upon the occurence of hot spots (plasma zone of increased X-ray emission) has also been examined. A considerable effect of the argon admixture to the working gas on occurence of the hot spots has been found.

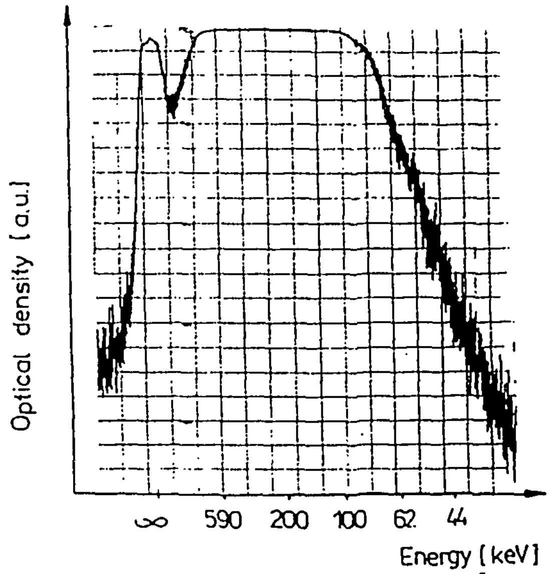

Fig.1. Energy spectrum of an electron beam (initial gas pressure - 4 Tr D_2, charging voltage - 34 kV, neutron yield - $2.8 \cdot 10^9$).

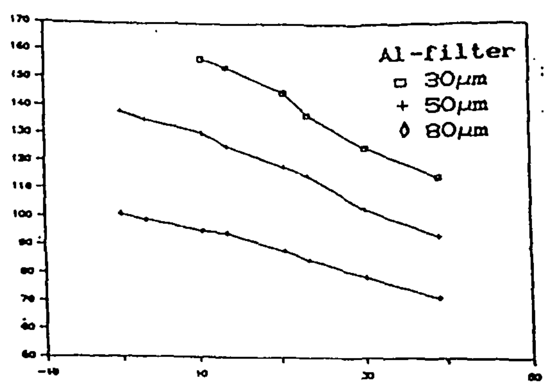

Fig.2. Angular distribution of ion tracks, as measured for 31 PF shots (initial gas pressure - 3 Tr D_2, charging voltage - 34 kV, neutron yield - $1.67 \cdot 10^{11}$).

3.3. Study of X-Ray and Electron Beam Emission from MAJA-PF Facility (V.3b)
by L. Jakubowski, M. Sadowski, and J. Żebrowski

Investigation of electron beams emission from MAJA-PF facility has been carried out to correlate the obtained data with X-ray emission measurements and to compare the results with those obtained with the other devices of that type [12,13]. In the experiment, the MAJA facility was equipped with cylindrical electrodes and operated in the plasma-focus régime.

To detect electron beams, special PCV-foils have been applied. There has been observed the emission of broad (some cm^2) and inhomogeneous electron beams directed towards the center of the inner electrode. At high intensity, on the broad beam background, some intense microbeams (1 mm in diameter) have been observed, as shown in Fig.1.

By registration of the Čerenkov radiation (induced by electron beams) there has also been examined the time development of the e-beam emission. It has been found that, usually, there appear several pulses. At the total emission time of 100-200 ns, the single pulse time-width ranges from 20 up to 100 ns (Fig.2). Using a magnetic spectrometer, the electron energy spectrum has been measured and found to be within the range of 50 to 600 keV.

Fig.1. Inhomogeneous electron beam pattern, as registered with the special PCV-foil. On the broad electron beam background, there is visible a distinct micro-structure.

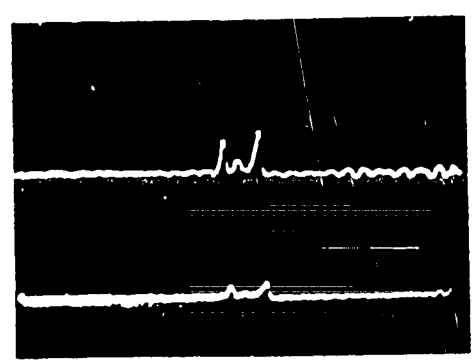

Fig.2. Time-resolved emission of the Čerenkov radiation induced by electron beams emitted from MAJA-PF facility. The detected signals consist usually of several peaks with time-width of 20-100-ns.

3.4. Improvement of X-Ray and Ion Diagnostic Techniques (8C-4S2K)
by E. Składnik-Sadowska, M. Sadowski, and J. Baranowski

In order to study physical phenomena in a plasma, it is necessary to apply appropriate diagnostic techniques. Therefore, in conjuction with research projects realized in the P-V Dept., there are carried out continous efforts to develop new diagnostic equipment.

To make possible detailed studies of X-rays emitted from different plasma facilities, there were designed various pinhole cameras enabling time-integrated X-ray pictures to be obtained. Recently, in order to make possible time-resolved X-ray studies, those cameras have been equipped with additional miniature scintillation detectors. Therefore, the equipment described enables simultaneous time-integrated time-resolved X-ray measurements [14], as shown in Fig.1.

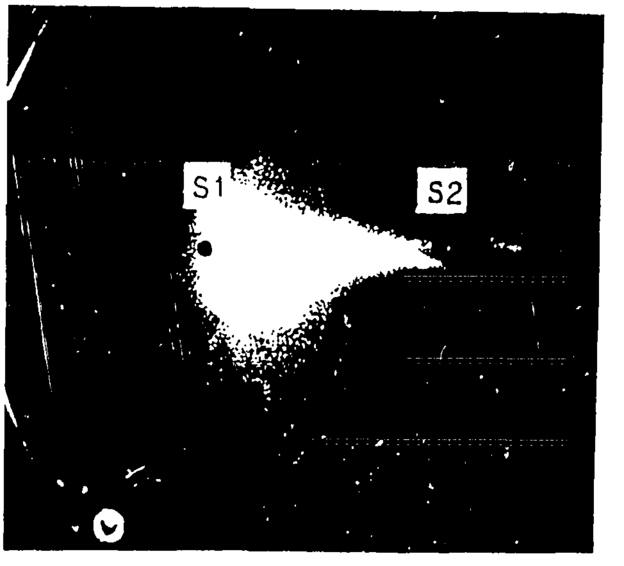

Fig.1. Time-integrated and time-resolved X-ray data obtained from a single shot.

To study the ion emission, there were designed different ion-pinhole cameras equipped with nuclear track detectors.

To perform time-resolved ion measurements use was made of miniature scintillation detectors placed in chosen points of an ion image. Recently, in order to facilitate an analysis of X-ray and ion-signals, as shown in Fig.2, there has been developed a new technique [14] based on the Digitizing Camera System (DCS).

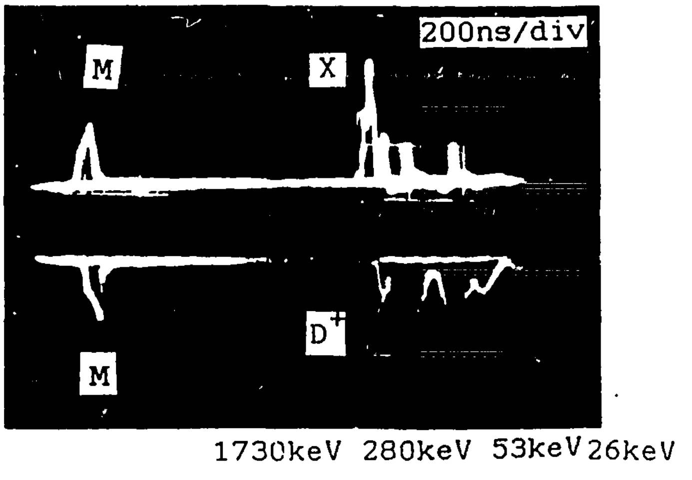

Fig.2. Correlation of X-ray and ion signals.

In order to study fusion products, and in particular fast protons from reactions, there have been applied modern track detectors (CR-39 films and PM-355 super-grade plates) [14]. Other examples of the development of various diagnostic techniques, have been presented in connection with studies of breakdown and ionization processes in PF-discharges [15].

3.5. Computer Aided Densitometry and Optical Laser Diagnostics Systems (V.4a)

by W. Pawłowicz and M. Sadowski

A new system has been completed for the two-dimensional computer aided densitometric analysis of pictures. It gives possibility to digitize, to analyse, to visualize and to obtain hard copies of images, as registered in experiments carried out in the laboratory [16]. The images, which are detected using an external CCD TV camera, are digitized by the VFG-512BC frame-grabber board (PC extension card), displayed on two monitors (monochrome and colour ones) and they can be printed out using an external printer.

A block diagram of the system is shown in Fig.1. The system resolution is 512x512 pixels at 256 gray levels (8-bit AD converter), and its usefulness is defined by the hardware and software capabilities. Except of the standard software, a computer program IMG was written to meet the specific demands of the experimental data analysis. An example of the picture analyzed using that program, is presented in Fig.2, where the image of intensity of X-rays emitted from a plasma (and registered by means of a pinhole camera) was transferred to equidensity contours (Fig.2a) and a 3-dimensional picture (Fig.2b).

Another system for plasma optical diagnostics (shadowgraphy, interferometry) is currently under construction [16]. The main part of that system is a pulse ruby laser. The scheme of the laser oscillator is shown in Fig.3. The main task is to shorten the pulse duration below a few ns. The short pulse is necessary to investigate the fast developing structure of a plasma in plasma-focus experiments.

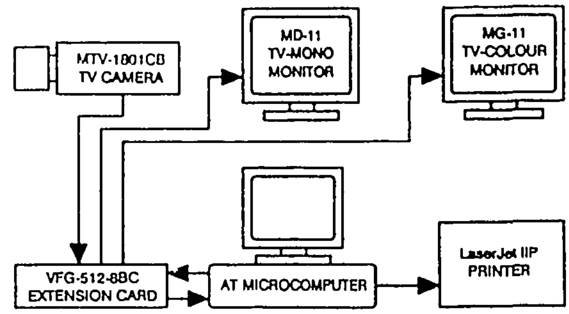

Fig.1. Block diagram of the system for densitometric analysis of optical images.

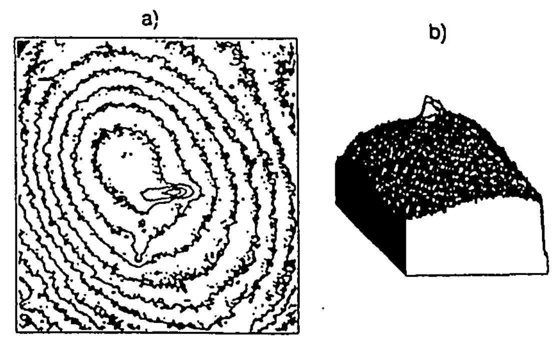

Fig.2. Image of X-rays emitted from a plasma and detected with XPCA pinhole camera. The result has been obtained in experiment on MAJA device. Numerical analysis and the pictures have been made with the IMG computer program.
a) equidensity contours, b) 3-D picture.

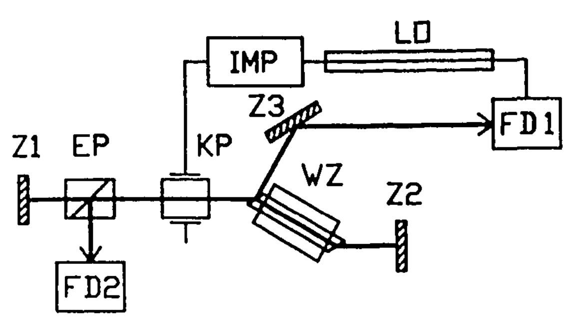

Fig.3. Scheme of the ruby laser oscillator: Z1, Z2, Z3 - mirrors; EP - polarizer; KP - Pockels cell; WZ - laser head; FD1, FD2 - photodiodes; LO - delay line; IMP - voltage pulse-generator.

3.6. Generation of Cryogenic Pellets for Experiments with Dense Plasmas (V.4b)

by A. Szydłowski and E. Składnik-Sadowska

A reliable method to produce uniform droplets of cryogenic liquids has been investigated and developed. An apparatus has been built* at SINS to test the feasibility of using the solid or liquid deuterium pellets for studying pellet-plasma interactions within a plasma focus device. The apparatus is capable to produce sufficient quantities of liquid hydrogen at a controlled temperature and pressure [17]. Using the liquid helium coolant, the cool-down time from the room temperature down to 14° K level has been measured to be equal to 2.5 h (Fig.1). Liquid hydrogen was produced by pumping the gaseous hydrogen through a heat exchanger of the cryostat cooled with liquid helium. The liquid flowed out of the cryostat nozzle in the form of spray. In the further experiments use was made of liquid argon because its physical properties are similar to those of liquid hydrogen, but the boiling temperature of argon is higher and it is easier to produce a liquid jet. Recently, a smooth jet of liquid argon has been obtained. For the training purposes, an auxiliary steel vessel equipped with the same jet assembly as the cryostat has been built in order to make possible the production of ordinary liquid droplets. Pictures of water droplets produced by the jet assembly and illuminated by a stroboscope lamp, are shown in Fig.2.

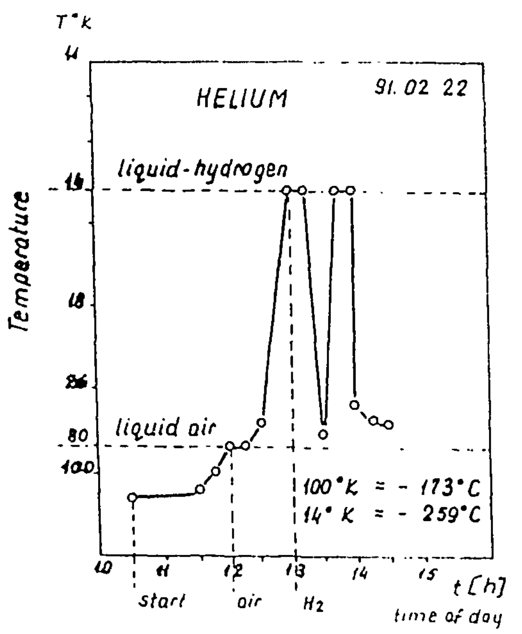

Fig.1. Temperature of the cryostat heat exchanger versus time. Liquid helium was used as a coolant.

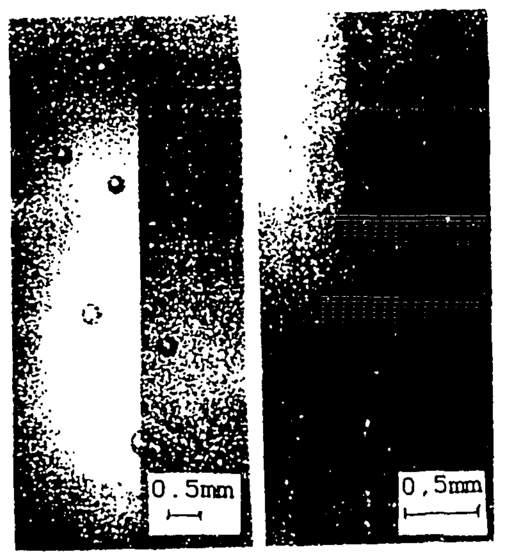

Fig.2. Liquid droplets produced by the jet assembly and illuminated with a stroboscope lamp (the photos were taken under a microscope).

* M.Sadowski, A.Szydłowski, E.Ćwiek; SINS Report No. 2104/P-V/PP/A, Świerk 1990.

3.7. Tests of PGN Plasma-Focus Device as a Source of Soft X-Ray Pulses (V.1a)
by J. Kuciński

The PGN Plasma-Focus device of an energy capacity of 5 kJ was put in the operation many years ago* in order to optimize the neutron yield at a higher repetition rate. There were also performed some tests of the X-ray emission optimization**, which revealed a very irregular X-ray emission. Recently, taking into account a rising interest in the application of PF devices as source of X-ray pulses, a new series of tests has been carried out [18].

It has been found that a proper choice of the electrode configuration, and the use of neon (as the working gas) makes it possible to avoid hard X-ray components, to reduce dimensions of the X-ray source (as shown in Fig.1), and to improve the shot-to-shot reproducibility.

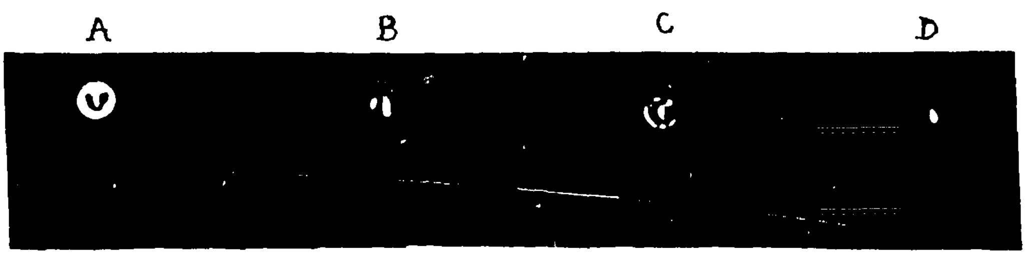

Fig.1. X-ray pinhole picturces from different PF-shots: A – with D_2, B and C – with another anode and reduced D_2 pressure, D – with the optimized anode and Ne-filling.

To preform time-resolved X-ray measurements, use has been made of a PIN-type diode. It has been found that with the Ne-filling, practically only one X-ray pulse with FWHM equal to 100 ns is emitted, as shown in Fig.2. The PGN device has been run with the repetition of 2 pps.

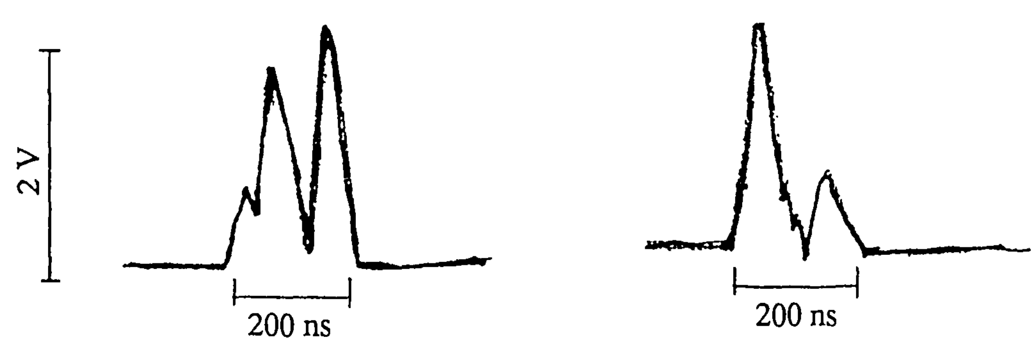

Fig.2. PIN diode X-ray signals: a) D_2 - filling, b) Ne - filling.

---

* J.Kuciński, A.Jerzykiewicz: J. Techn. Phys. 24 (1983) 3.

** Dept. Thermonuclear. Res. Annual Report 1988; SINS Report No. 2074/P-V/PP/A, Otwock-Świerk, Feb.1989.

3.8. Measurements of Electron Beam Interaction with Plasma Stream in Modified SOWA-400 Facility (V.6a)

by M. Gryziński, W. Komar, and J. Stanisławski

In order to investigate interaction of electron beams with a plasma stream generated by the modified SOWA-400 facility there has been constructed a new diagnostic system [19] with a 100 ns pulse electric gun (electron energy - 70 keV, the maximum beam current - 20 mA) and a beam position detector (NE102 scintillator with 5 μm-thick Al foil, and a fast camera with an image intensifier), as shown in Fig.1.

As a result of the electron beam interaction with a plasma, there occurs only a deflection of the probing beam in magnetic and electric fields. It has been found that the attenuation and scattering of the electron beam are negligible.

Possibility of the determination of plasma-stream collective fields by means of that method was veryfied by some additional measurements performed with a Rogovski coil, a magnetic probe and the Langmuir probe located at a distance of 1.4 m from the SOWA-400 facility.

Investigation of plasma stream properties, as performed so far, can be summarized as follows:

- energy of the collective motion of the plasma stream is about 15 keV;
- the maximum stream current is equal to 2 kA (current density - 150 A/cm^2);
- the current direction suggests that the main carriers are electrons;
- the maximum magnetic field at the border of the plasma stream is equal to 45 Oe;
- electric potential of the plasma stream reaches -5 kV;
- an axial component of electric field in the plasma stream is equal to 1 kV/cm.

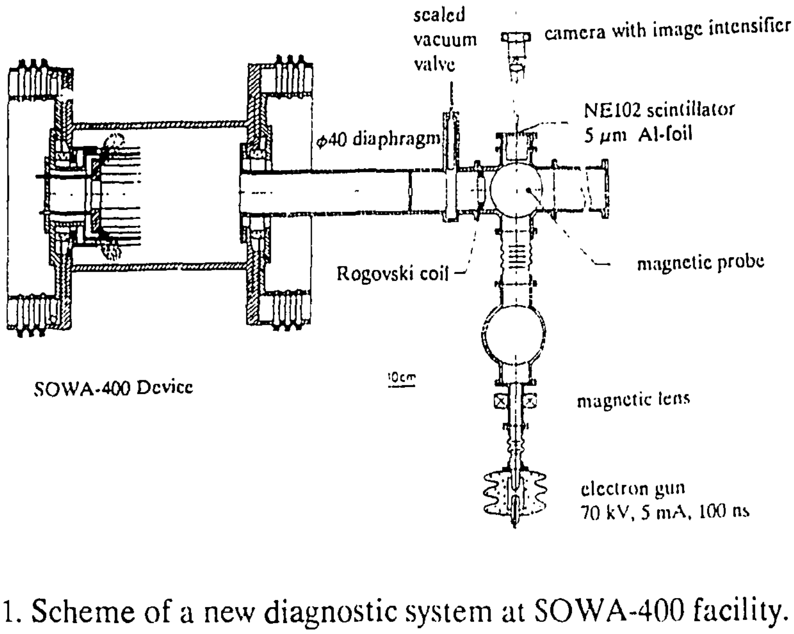

Fig.1. Scheme of a new diagnostic system at SOWA-400 facility.

3.9. Tests and Preliminary Measurements with HP 16500A/16530A/16531A Logic Analysis System (8C-4S2K)

by L. Jakubowski, W. Pawłowicz, and M. Sadowski

The HP 16500A is the mainframe of a flexible system offering a modular structure for plug-in cards with a wide range of state, timing, oscilloscope and pattern generator capabilities. The key features of the HP 16500A are: the mainframe with five card slots, an 9-inch colour monitor, a touchscreen, dual 3.5-inch disk drives, intermodule triggering and time correlation of gathered data, the HP-IB and RS-232C interfaces for output to a printer and controller interface. To perform the desired measurements, the HP 16530A/16531A 100-MHz digitizing oscilloscope module has been installed to the HP 16500A mainframe. The HP 16530A is a 400-megasample/s timebase card, and the HP 16531A is a 2-channel acquisition card. The block diagram of the system being currently used (along with some external equipment) is presented in Fig.1. At that configuration the system is equivalent to a four-channel digitizing oscilloscope with additional possibilities of data storing, analysing, transfer to and from an external controller (computer), as well as printing a hard copy from the monitor screen [20].

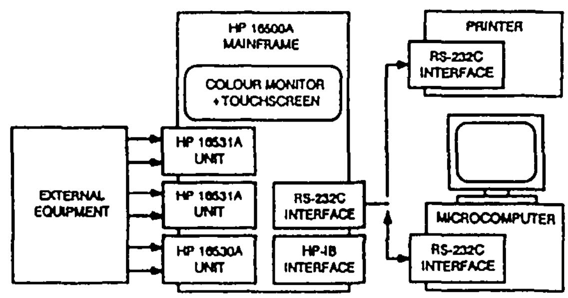

Fig.1. Block diagram of the HP 16500A system.

After preliminary tests of the system functions (controlled by the standard software), the command and data interchange between the HP 16500A and AT-microcomputer was successfully checked.

The system was used in experiments with the MAJA-PF device to record and store four digitized signals of a discharge current- and voltage-waveforms, and X-ray and neutron detectors signals. An example of the results obtained is presented in Fig.2, which shows a copy of monitor screen, which was obtained with the system software option, and the HP LaserJet IIP printer.

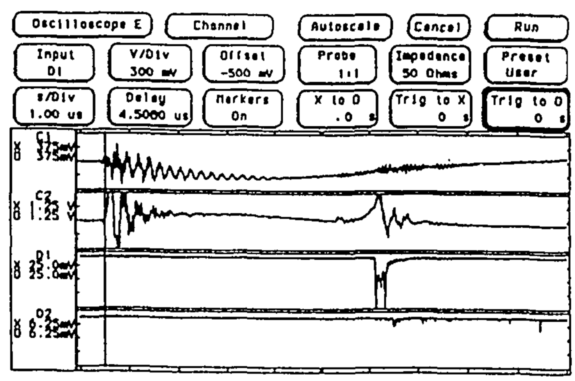

Fig.2. Time-resolved signals measured with HP 16500A system in experiment on MAJA-PF device. The signals have been registered simultanously in one shot.
C1 - discharge current,
C2 - discharge voltage,
D1 - X-ray detector signal
D2 - neutron detector signal.

4. TECHNOLOGY

4.1. Multichannel Optoelectronic Transmission System for TOKAMAK Experiments

(V.8 - Zad.3)
by M. Bielik

A multichannel optical-waveguide transmission system has been designed and manufactured* as a part of the Tokamak T-15 automatic control and data acquisition system. Some channels are planned to be used for the transmission of experiment control signals and other for the data transmission.

The system contains an opto-electronic emitters-amplifiers crate and its power supply unit providing possibility of operation at an increased potential*. It also contains an optical waveguides network consisting of the 20 TS-21-type fiber lines, and a receivers crate.

The emitters crate and power supply unit should be placed closely to an experimental measuring equipment, and the receivers crate, inside an isolated automation control room. To ensure the full galvanic separation of the emitter and receiver moduluses, the on-state signal and the power supply unit switching on- and off-signals are also transmitted by the optical waveguide.

Because of the interchannel insulation requirements, the transmission channels are individually supplied from a DC/DC converter located inside the emitters crate. A frequency bandwidth of the system described is within the range from 0.05 Hz to 100 kHz at 6 dB/oct. attenuation above the upper frequency limit. The system sensitivity is equal to ±30 mV, ±100 mV or ±300 mV depending on the range, and a 50% dynamic overload without the output pulse (±5 V) distortion is admissible. The permissible output load is 600 Ω, and the signal to noise ratio for the whole circuit is above 40 dB.

The parameters of the optoelectronic transmission system in question satisfy the requirements assumed previously for the T-15 Experiment at the Kurchatov Institute of Atomic Energy in Moscow, according to the initial agreement about the scientific cooperation.

---

* M. Bielik and R. Rybicki: Optoelectronic Emitters Crate and Its Power Supply System with 1 kV Interchannel Insulation (in Polish); SINS Internal Report 0-25/P-V/90, Świerk 1990.

4.2. Data Acquisition System up to 250 MHz (V.2)
by M. Bielik

The low-frequency data acquisition system for receiving and controlling signals from the main modules of a VHV pulse accelerator has been designed and manufactured [21]. It enables to control the supply HV level for a Marx generator, a forming Blumlein line, the VHV diode, and a gas pressure value inside switching spark-gaps.

Because the computer-aided acquisition system is sensitive to electromagnetic interference signals, there has been provided the full galvanic separation of external signal sources, i.e., HV dividers, current shunts, and vacuummeters.

The low-frequency signal amplitude is converted to frequency (V/F) with constant amplitude and then converted to optical pulses (E/O) transmitted through fibre optic cables. Inside a Faraday cage, light pulses are converted into electric signals (O/E), and after that frequency to amplitude conversion is performed. The conversion constant of 1V/5kHz, with account of limited frequency response of LED characteristics, has been obtained.

After testing all the transmision channels, output signals jitter and voltage drift, the amplitude to frequency VF-1 converter and the multichannel (O/E) & (V/F) converter have been designed and built. A general view of the converters is presented in Fig.1.

The obtained accuracy of measuring channels within a voltage range from 1 V to 10 V at unipolar input signals is better than 1%.

The system operation has been succesfully tested at the VHV pulse accelerator in the Efremov Institute in Sankt Petersburg, within a framework of the scientific cooperation.

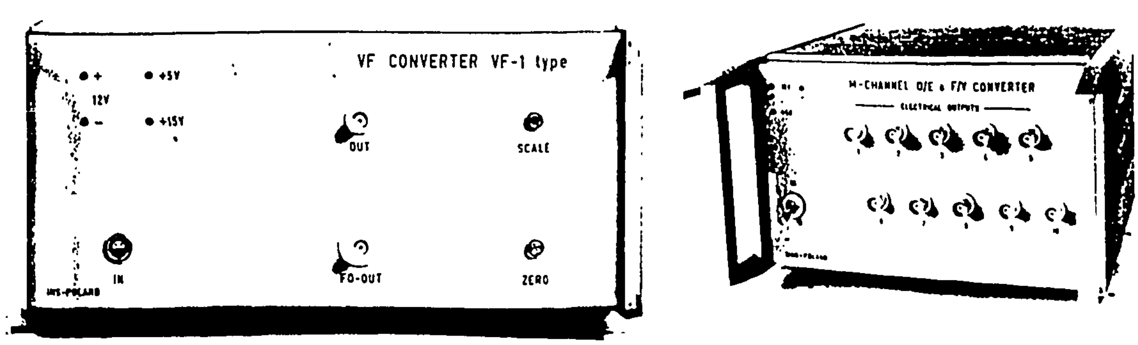

Fig.1. General view of amplitude to frequency VF-1 and the multichannel (O/E) & (V/F) converters.

4.3. Modernization of PF-300 Facility Control System (V.1b)

by M. Bielik

Within a scope of the PF-300 facility modernization after its long exploitation, the replacement and modification of worn parts of the device have been performed [22]. All the changes can be summarized as follows:

- new power supply units have been installed;
- there have been mounted the new TS-21-type optical waveguides, which are equipped with high-quality heads providing better stability of optical connections;
- the OR-1-type optoelectronic receivers have been modernized, and the power supply units with special low inter-turn capacitance transformers have been applied;
- a new 5-channel optoelectronic receiver of the OTP-1 type has been designed and manufactured;
- the optical waveguide connections between the control desk and the control system placed inside the Faraday cage have been modernized;
- a new C-cassette of the low-frequency signal processing system has been designed and manufactured. It consists of the O/E-1 optical detector for acquisition of signals from the G-M neutron counters, the PCC-1 controller of the PC-extension DCB-card and neutron channel monitoring, and the O/E-2 unit containing 7 O/E-detectors and 7 F/V-converters. Signals from the O/E-2 unit are transmitted to the PC-extension ADDA card, and 5 VF-1-type converters transmit low-frequency signals from HV dividers, deuterium pressure gauges etc.

4.4. Service and Routine Maintenance of the PF-360 Facility (V.1c)

by J. Witkowski

The PF-360 plasma-focus facility has been used for basic and applied studies, and its service maintenance has been provided continously. During occasional routine tests, some changes or renovations of different parts of the facility have been performed:

- a system for measuring the deuterium pressure inside the experimental chamber has been modernized, i.e., the U-tube manometer has been replaced by an electronic pressure gauge connected to a digital meter located within the control room;
- inspection of the 2IC3 and 3IC3 spark-gaps has been carried out, and some corrosion of the main electrodes as well as contamination with oil vapours have been removed;
- inspection of the spark-gap voltage dividers revealed burnout of some resistors, which have been replaced;
- damaged nonlinear resistors have also been replaced;
- damaged rubber elements of pneumatic system have been replaced by pressure joints of the Rilsan type;
- inspection and adjustment of air-cleaning plant have also been performed.

4.5. Design and Tests of Fast Electromagnetic High-Pressure Gas Valve (V.6b)

by J. Stanisławski

To produce a dynamic gas cloud in the radial plasma compression region of the POSEIDON Plasma-Focus facility in Stuttgart (a so called gas-puff target experiment) within a framework of the German-Polish scientific cooperation there has been designed a new fast high-pressure valve [23]. The assembly drawing of the gas-valve, as placed within the inner electrode of POSEIDON facility, is presented in Fig.1.

The main parts of the valve are:

- a movable cylindrical piston containing a gas plenum,
- a low-inductance coil driving the piston,
- a pneumatic system for the valve return closing.

The operation principle of the valve is simple. When the driving coil is powered by a high-current pulse, a corresponding current pulse is induced inside the tubular metal piston. An electrodynamic interaction of those currents causes axial motion of the piston and the opening of the gas plenum. Working gas can then flow out through special holes in the front-flange, and it can form a gas target. After that a pneumatic system can shift the piston back to the initial position.

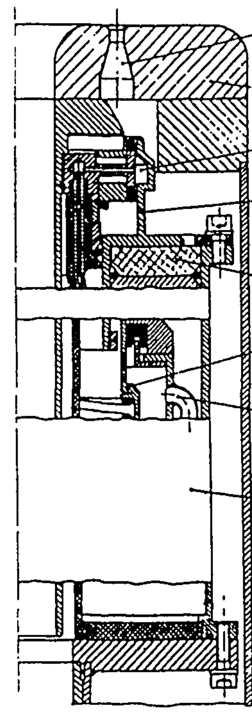

Fig.1. Assembly drawing of a gas-valve within inner electrode of POSEIDON facility.

The primary pulse current is produced by a capacitor bank discharge in a circuit consisting of a spark-gap, an insulating transformer, and the valve coil. The characteristics of the valve system are as follows:

- gas plenum volume	5 cm^3
- operational pressure	up to 50 bars
- condenser bank capacity	120 μF
- nominal charging voltage	2.7 - 2.9 kV

Preliminary studies, which were performed with the POSEIDON facility in Stuttgart, have demonstrated that the application of the Ar-gas puffing changes the PF compression and causes the appearance of hot spots, which can be considered local sources of relatively hard X-rays.

4.6. Modernization and Simultaneous Operation of SOWA-1000 Pulse Generator Sections (V.6 - Zad.3)

by M. Gryziński and W. Polak

To improve operational reliability of the SOWA-1000 pulse generator sections, there have been introduced some changes in their construction. It has been proposed to improve the construction of the spark-gaps, and the main pulse power supply cable in the following way:

- to make an additional hole in the spark-gap initiating electrode in order to facilitate ignition and to improve the gas blowing out;
- to make some changes in the electrode head and the spark-gap electrode joint to improve their durability;
- to apply a special two-sided expansion sleeve in order to improve the electrical coupling of the main pulse power supply cable and its tip (from the side of the spark-gap).

4.7. Adaptation of SW-30-87 IONOTRON Facility for Higher Repetition (V.6 - Zad.4)

by E. Borowska and K. Czaus

The operation of the IONOTRON SW-30-87 facility at a high-repetition rate is very important for technological applications. After the modernization of the IONOTRON in 1991 the repetition rate was increased from 1 shot per 3 minutes up to 2 shot per minute. This result has been obtained by essential changes in the IONOTRON power supply system [24].

The resonant LC transducers have been applied inside the main power supply unit of the condenser bank, and in the power supply unit of pulse gas valve. Some significant changes of the pulse generator electrical circuit construction have also been made.

The proper operation of IONOTRON SW-30-87 device at the high-repetition rate, has been checked by the registration of current-voltage waveforms for discharges with the N_2 working gas filling.

It has been found that the IONOTRON SW-30-87 facility can be run with the repetition of 3 shots/minute for a longer time if an additional Root's pump is applied and the main power supply unit is doubled.

4.8. Modification of IONOTRON SW-30-87 Facility Supporting Equipment

(V.6 - Zad.5)

by K. Czaus

To improve the operation of the IONOTRON SW-30-87 facility some construction changes have also been made in the supporting equipment used for technological research. The main improvements are as follows:

- the commercially available system of a rotational-table control has been replaced by a specially designed unit because the commercial one was sensitive to overvoltages during the IONOTRON operation;
- a new control unit prototype has been made, in order to enable the fully automatic control of a specimen exposure within the existing specimen exchanger (6 specimen capacity);
- some construction modifications of the pneumatic system and of a drive transfer from the table to the exchanger wheel have been introduced (an elastic disk clutch has been additionally applied),
- the adaptation of the existing specimen exchanger has been proposed in order to increase its capacity up to 50 specimens, what is of particular importance for the IONOTRON operation at the high-repetition rate.

4.9. Modernization of PF-046 Device for Surface Modification of Materials

(V.6 - Zad.6)

by J. Appelt

In 1991, the main effort was connected with the construction of a new energy storage system for PF-046 machine in order to replace an inefficient and worn one [25].

Two sections of a pulse generator, as designed previously by the SOWA-team, have been manufactured and tested. Finally, some typical PF measurements have been performed and the current- and voltage-characteristics as well as neutron yield and the X-ray emission have been measured. The main technical parameters of the new PF-046 device and some results obtained are presented in Fig.1.

Parameters of the PF-046 device:

C	-	40 μF
L	-	160 nH
R	-	32 mΩ
E_0	-	25 kJ
I_{max}	-	380 kA
Y_N	-	$2 \cdot 10^9$ neutrons

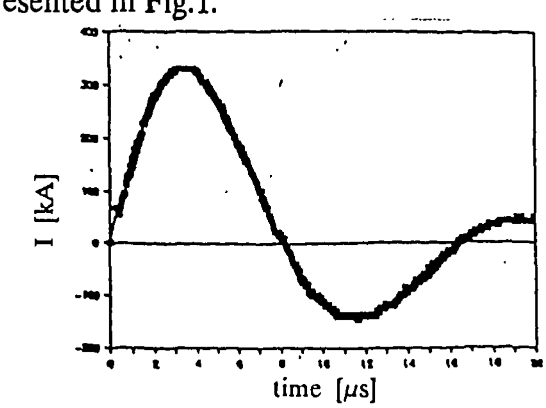

Fig.1. Technical parameters of the PF-046 device and the discharge current waveform.

4.10. High-Intensity Pulse Ion Beam Modification of Semiconductors (V.7a)

by J. Piekoszewski#, J. Langner, J. Białoskórski#, A. Czaus, C. Pochrybniak#, Z. Werner#, and J. Zaręba#

The application of the HIPIB method* for the hydrogen passivation of a polycrystalline silicon and the formation of n-p junctions in the poly-Si by means of the PID technique** has been investigated [26].

The aim of the hydrogen passivation was to introduce hydrogen atoms into the poly-Si in order to passivate defects and thus to increase the diffusion length (L_n) of the minority carriers. In experiments, fifteen poly-Si based photovoltaic cells have been irradiated with 2 to 20 hydrogen plasma pulses of energy density ranging from 1.3 to 3.2 J/cm^2. One group of the samples was irradiated from the back side, the other from the emitter side. Spectral Response (SR) and I-V measurements revealed that the values of L_n remained unchanged after the irradiation, whereas the junction deteriorated .The lack of changes in the L_n value may be due to two factors: the initial L_n value was relatively large (70 μm) and the dose of hydrogen atoms (not exceeding 10^{16} cm^{-2}) was too low. The deterioration of the junction was presumably due to the break discharge through the sample. In further experiments, a better electrical insulation of the junction will be provided and higher doses will be applied.

Thus far, we have been successful in the formation of p^+-n and n^+-p photovoltaic structures on the monocrystalline n and p-type silicon. In the present work, the effort is directed toward the doping of the poly-Si material. At the begining the commercial SILSO-WACKER p-type samples have been used. Two batches (10 samples each) have been prepared for the irradiation with PF_5 and BF_3 plasma pulses. Before the PID processing one batch was etched with a selective NaOH etchant, and the other with the CP_4 isotropic etchant. The emitters have been formed by the sequence of pulses: 0.8, 0.8, and 1.8 to 2.2 J/cm^2. All the samples have shown the type conversion from p to n^+. Sheet resistance ranges from 216 to 93 ohm/sq, and the standard deviation from 11% to 35%. Preparations of photovoltaic cell are in progress.

SINS Dept. P-IX

* J. Langner, K. Czaus, E. Górski, M. Gryziński, A. Horodeński, J. Piekoszewski, C. Pochrybniak, Z. Werner, and A. Wójtowicz: IONOTRON – a High Intensity Ion Pulse Producing Machine for Material Processing; Phys. Research, 8, 167 (1988).

** J. Piekoszewski, M. Gryziński, J. Langner, Z. Werner, and G. C. Huth: A New Approach to Photovoltaic Junction Formation by Using Pulse Implantation Doping Technique; J. Physique, 43, 1353 (1982).

4.11. High-Intensity Pulse Ion Beam Modification of Metals (V.7b)

by J. Piekoszewski#, J. Langner, J. Białoskórski#, A. Ciurapiński##, A. Turos###, and L. Waliś##

Two series of experiments on the modification of the N9 tool steel and 19H2N4W heat-resisting steel by hydrogen and nitrogen ion pulses, generated by the RPI-type IONOTRON and IBIS devices, have been completed [27]. The irradiation was carried out under the following conditions: 10 pulses with energy density between 4 and 6 J/cm^2 (IONOTRON), and 5 pulses with energy density between 5 and 7 J/cm^2 (IBIS). The irradiated samples were examined by means of the CXMS method. Analyses of the nitrogen content in selected samples were also carried out with the use of the $^{14}N(d,\alpha)^{12}C$ nuclear reaction. Qualitative inspection of the CXMS spectra, as taken from over 30 samples, revealed the following regularities:

- all the irradiated samples of the N9 steel showed the pulse induced paramagnetic phase (presumably an austenite), independently of the kind of ion species and the source of pulses (IONOTRON or IBIS);
- none of the 12H2N4W samples irradiated in the IONOTRON with hydrogen or nitrogen pulses showed any change in their phase structure;
- only the nitrogen pulses generated by the IBIS source induced significant changes in the 18H2N4W steel samples, which was manifested in the CXMS spectra by a distinct central peak.

The most heavely doped 18H2N4W samples have shown unexpectedly high doses of retained nitrogen up to $5 \cdot 10^{17}$ atoms/cm^2, i.e., the level considered as the upper limit in the conventional implantation processes. Perhaps, the facts outlined above will open an entirely new branch of investigations in the field of surface modification research. The elaboration of the collected data along with the interpretation of the processes observed are in progress.

SINS Dept. P-IX

Institute of Nuclear Chemistry and Technology, ul. Dorodna 16, 03-195 Warsaw

SINS Dept. P-I

5. PUBLICATIONS, CONFERENCE PROCEEDINGS and REPORTS

1. Department of Thermonuclear Research Annual Report 1990, Edited by M. Sadowski, SINS Report No. 2114/P-V/PP/A, Otwock-Świerk, March 1991.

2. Edge Plasma Transport in Grad Approach, by M. Rabiński, Proc. 18th European Conf. on Controlled Fusion and Plasma Physics, Berlin, 3-7 June 1991 (EPS, Geneva), Vol. 15C, Pt. III, pp. 33-36.

3. Studies of Time-Dependent Grad Model for Non-Local Transport Coefficients of Edge Plasma, by M. Rabiński, SINS Internal Report No. 0-22/P-V/91, Świerk 1991 - in Polish.

4. Validity of Inverse Abel Transformation at Investigation of Strongly Refracting Axisymmetric Objects, by W. Pawłowicz, SINS Report No. 2120/P-V/PP/A, Otwock-Świerk, August 1991, Proc. 21st ECLIM, Warsaw, October 21-25, 1991.

5. Use of Numerical Programs for Studies of Operation of Current Pulse Generators (in Polish), by B. Bartolik, K. Kocięcka, SINS Internal Report No. 0-16/P-V/PP/91, Świerk 1991.

6. Simulation of Pulse Generator Operation with FEEDER and GENRAT Numerical Programs (in Polish), by K. Kocięcka, SINS Internal Report No. 0-26/P-V/91, Świerk 1991.

7. Classical and Quantum Treatments of $p(e^{\pm})$ + H Colllisions, by M. Kowalski, Proc. 4th European Conf. on Atomic and Molecular Physics - to be published.

8. Numerical Analysis of Electron Capture at Nuclei (Positrons) and Hydrogen Atom Collisions (in Polish), by M. Kowalski and M. Gryziński, SINS Internal Report No. 0-30/P-V/91, Świerk 1991.

9. Preliminary Measurements of Ion Plasma Beams with Faraday-Cup Detector (in Polish), by J. Baranowski, SINS Internal Report No. 0-25/P-V/91, Świerk 1991.

10. Studies of High-Energy Electron Beams Emitted from PF-Type Discharges, by M. Sadowski, L. Jakubowski, and J. Żebrowski, Proc. 18th European Conf. on Controlled Fusion and Plasma Physics, Berlin, 3-7 June 1991 (EPS, Geneva 1991), Vol.15C, Pt. II, pp. 233-236.

11. Investigation of Particle Beams and X-Ray Emission from PF-360 Device (in Polish), by J. Żebrowski, M. Sadowski, A. Szydłowski, and E. Al-Mashhadany, SINS Internal Report No. 0-31/P-V/91, Świerk 1991.

12. High Energy Beam Emission of the POSEIDON Plasma-Focus, by H. Herold, L. Jakubowski, M. Sadowski, and H. Schmidt, DPG Fruhjahrstagung, Kiel, 12-14 March, 1991; Verhandlungen der DPG No. 5/1991.

13. Hot Spot Formation and Emission Characteristics of the Plasma Focus, by P. Antsiferov, D. Franz, H. Herold, L. Jakubowski, A. Jonas, M. Sadowski, and H. Schmidt, Proc. 18th European Conf. on Controlled Fusion and Plasma Physics, Berlin, 3-7 June 1991 (EPS, Geneva 1991), Vol.15C, Pt. II, pp. 221-224.

14. Improvement of X-Ray and Ion Diagnostic Techniques Used for Studies of Plasma Streams, by E. Składnik-Sadowska, J. Baranowski, J. Hoszowska, Z. Puchalski, and M. Sadowski, Proc. XXth Intern. Conf. on Phenomena in Ionized Gases, Pisa, 9th July 1991 (CNR, Pisa 1991), Vol. Contributed Papers 3, pp. 843-844.

15. Breakdown and Initial Ionization in High-Current Carrying Discharges, by M. Sadowski, Proc. XXth Intern. Conf. on Phenomena in Ionized Gases, Pisa, 9th July 1991 (CNR, Pisa 1991), Vol. Invited Papers.

16. Computer Aided Densitometry and Optical Diagnostics Systems (in Polish), by W. Pawłowicz and M. Sadowski, SINS Internal Report No. 0-20/P-V/91, Świerk 1991.

17. Method of Cryogenic Pellets Generation for Experiments with Dense Plasmas (in Polish), by A. Szydłowski and E. Składnik-Sadowska, SINS Internal Report No. 0-23/P-V/91, Świerk 1991.

18. Test of the Plasma-Focus Device PGN as Soft X-Ray Pulse Source (in Polish), by J. Kuciński, SINS Internal Report No. 0-32/P-V/91, Świerk 1991.

19. Measurements of Electron Beam and Plasma Stream Interaction (in Polish), by M. Gryziński, W. Komar, and J. Stanisławski, SINS Internal Report No. 0-27/P-V/91, Świerk 1991.

20. HP 16500A/16530A/16531A Logic Analysis System Tests and Preliminary Measurements (in Polish), by L. Jakubowski, W. Pawłowicz, and M. Sadowski, SINS Internal Report No. 0-24/P-V/91, Świerk 1991.

21. 250 MHz Data Acquisition System (in Polish), by M. Bielik, SINS Internal Report No. 0-28/P-V/91, Świerk 1991.

22. PF-360 kJ Experiment - Control System Modernization (in Polish), by M. Bielik, SINS Internal Report No. 0-29/P-V/91, Świerk 1991.

23. Fast Electrodynamic Gas Valve (in Polish), by J. Stanisławski, SINS Internal Report No. 0-19/P-V/91, Świerk 1991.

24. Adaptation of IONOTRON SW-30-87 for Higher Repetition Rate Operation (in Polish), by E. Borowska and K. Czaus, SINS Internal Report No. 0-21/P-V/91, Świerk 1991.

25. Use of Plasma Focus Device for Surface Modification of Alundum Ceramics, by J. Appelt, SINS Report No. 2118/P-V/PP/B, Otwock-Świerk, May 1991.

26. High-Intensity Pulsed Ion Beams in the Surface Modification of Solids - Experiments Carried out in Poland, by J. Piekoszewski, J. Langner, J. Appelt, J. Baranowski, J. Białoskórski, A. Ciurapiński, K. Czaus, S. Gębalski, E. Górski, M. Gryziński, A. Horodeński, L. Nowicki, C. Pochrybniak, E. Składnik-Sadowska, J. Suwalski, J. Tacikowski, A. Turos, L. Waliś, Z. Werner, J. Zaręba, and W. Ziemski, Surface and Coatings Technology 45 (1991), pp. 385-391.

27. High-Intensity Pulsed Ion Beams in Material Processing: Equipment and Applications, by J. Piekoszewski and J. Langner, Nucl. Instrum. Methods in Phys. Research B53 (1991), pp. 148-160.

6. LECTURES PRESENTED AT SEMINARS AND SYMPOSIA (UNPUBLISHED)

1. M. Sadowski: Progress in Plasma Studies at IPJ; an invited lecture presented at the PF Seminar in IPF-Stuttgart on May 16, 1991.

2. J. Stanisławski: Fast Electrodynamic High-Pressure Gas Valve; a contribution presented at the PF Seminar in IPF-Stuttgart on May 16, 1991.

3. M. Gryziński: Atomic Collisions and Atomic Model; a lecture presented at the Seminar in the Institute de Physique in Fribourg on May 2, 1991.

4. M. Gryziński: Electrons and Coulomb Barrier Tunelling in Low Energy Nuclear Collisions; a lecture presented at the Seminar in the Institute de Physique in Fribourg on May 6, 1991.

5. M. Sadowski: Main Directions and Achievements of Thermonuclear Fusion Research (in Polish); an invited lecture presented at the Symposium on Applications of Electromagnetism in Modern Technology held in PAN Center in Mądralin n. Warsaw on Sept. 2, 1991.

6. J. Langner: Application of Intense Plasma Streams to Solid State Surface Modyfication (in Polish); a contribution presented at the Symposium on Applications of Electromagnetism in Modern Technology held in PAN Center in Mądralin n. Warsaw on Sept. 2, 1991.

7. L. Jakubowski, M. Sadowski, and J. Żebrowski: E-Beam and X-Ray Studies at MAJA-PF Facility; a lecture presented at the German-Polish Seminar in IPJ-Świerk on Sept. 12, 1991.

8. J. Kuciński, Sz. Brandt, and L. Jakubowski: X-Ray Measurements at PGN Plasma-Focus Device; a lecture presented at the German-Polish Seminar in IPJ-Świerk on Sept. 12, 1991.

9. J. Appelt, J. Langner, and J. Piekoszewski; Use of PF Device for Modification of Solid-State Surfaces; a lecture presented at the German-Polish Seminar in IPJ-Świerk on Sept. 12, 1991.

10. E. Składnik-Sadowska and A. Szydłowski; Production of Cryogenic Targets for Plasma Experiments; a lecture presented at the German-Polish Seminar in IPJ-Świerk on Sept. 13, 1991.

11. A. Jerzykiewicz and PF Team: Status of PF-1000 Experiment at Kaliski Institute; a lecture presented at the German-Polish Seminar in IPJ-Świerk on Sept. 12, 1991.

12. M. Sadowski: Comments on German-Polish Cooperation and Summary of Presented Papers; a lecture presented at the closing of the German-Polish Seminar on Physics and Applications of Plasma Focus and Z-Pinch Systems, held in IPJ-Świerk on Sept. 12-13, 1991.

13. M. Sadowski: X-Ray Studies in PF-Devices at IPJ; an invited lecture presented at the WE-Heraeus-Seminar on Pinchplasma Systems as Compact, Intensive X-Ray Sources for Scientific and Technical Applications, held in Physikzentrum-Bad-Honnef on Oct. 29-31, 1991.

14. M. Sadowski: Breakdown Phenomena in Plasma-Focus Devices; a contribution presented at the 3rd Meeting of the Working Group of International Center for Dense Magnetized Plasmas, held in IPJ-Świerk on Dec. 11-13, 1991.

15. M. Sadowski: Ion-Beams Emitted by Plasma-Focus Devices; a contribution presented at the 3rd Meeting of the Working Group of International Center for Dense Magnetized Plasmas, held in IPJ-Świerk on Dec. 11-13, 1991.

16. J. Kuciński et al.: Operation of PGN Device as a Source of X-Ray Pulses (in Polish); a talk given at the Plasma Seminar in IPJ-Świerk on Dec. 20, 1991.

17. M. Bielik et al.: Modernization of PF-360 Facility (in Polish); a talk given at the Plasma Seminar in IPJ-Świerk on Dec. 20, 1991.

18. J. Witkowski et al.: Technical Maintenance and Servicing of PF-360 Facility (in Polish); a talk given at the Plasma Seminar in IPJ-Świerk on Dec. 20, 1991.

19. M. Bielik et al.: Development of a Data Acquisition System up to 250 MHz (in Polish); a talk given at the Plasma Seminar in IPJ-Świerk on Dec. 20, 1991.

20. J. Żebrowski et al.: Investigation of Corpuscular Beams and X-Rays from PF-360 Facility (in Polish); a talk given at the Plasma Seminar in IPJ-Świerk on Dec. 20, 1991.

21. M. Sadowski et al.: Investigation of X-Rays and Electron Beams in MAJA Facility (in Polish); a talk given at the Plasma Seminar in IPJ-Świerk on Dec. 20, 1991.

22. J. Baranowski: Development of an Ion Collector and Preliminary Measurements (in Polish); a talk given at the Plasma Seminar in IPJ-Świerk on Dec. 20, 1991.

23. W. Pawłowicz and M. Sadowski: Completing of Systems for Computer Densitometry and Interferometry (in Polish); a talk given at the Plasma Seminar in IPJ-Świerk on Dec. 20, 1991.

24. E. Składnik-Sadowska and A. Szydłowski: Production of Miniature Cryogenic Targets (in Polish); a talk given at the Plasma Seminar in IPJ-Świerk on Dec. 20, 1991.

25. M. Rabiński: Studies of a Dynamic Grad's Model (in Polish); a talk given at the Plasma Seminar in IPJ-Świerk on Dec. 20, 1991.

26. M. Gryziński and M. Kowalski: Numerical Analysis of Electron Capture (in Polish); a talk given at the Plasma Seminar in IPJ-Świerk on Dec. 20, 1991.

27. J. Stanisławski et al.: Assembling of Electron Gun and Measurements in SOWA-400 Facility (in Polish); a talk given at the Plasma Seminar in IPJ-Świerk on Dec. 20, 1991.

28. J. Stanisławski: Design, Assembling, and Tests of High-Pressure Gas Valve (in Polish); a talk given at the Plasma Seminar in IPJ-Świerk on Dec. 20, 1991.

29. M. Gryziński and J. Stanisławski: Modernization and Tests of Simultaneous Operation of SOWA-1000 Generator Section (in Polish); a talk given at the Plasma Seminar in IPJ-Świerk on Dec. 20, 1991.

30. K. Czaus et al.: Adaptation of SW30 Ionotron for Higher Repetition (in Polish); a talk given at the Plasma Seminar in IPJ-Świerk on Dec. 20, 1991.

31. K. Czaus et al.: Systems of Control and Exchange of Samples at Higher Repetition (in Polish); a talk given at the Plasma Seminar in IPJ-Świerk on Dec. 20, 1991.

32. J. Appelt: Operation of a Modified PF-046 Device for Technological Purposes (in Polish); a talk given at the Plasma Seminar in IPJ-Świerk on Dec. 20, 1991.

33. K. Kocięcka: Simulation of Operation of Pulse Generators (in Polish); a talk given at the Plasma Seminar in IPJ-Świerk on Dec. 20, 1991.

34. M. Bielik et al.: Multichannel Opto-Electronic System for Data Transmission up to 100 kHz (in Polish); a talk given at the Plasma Seminar in IPJ-Świerk on Dec. 20, 1991.

35. W. Pawłowicz and M. Sadowski: Operation, Tests and Preliminary Measurements with HP16500A Analyzer System (in Polish); a talk given at the Plasma Seminar in IPJ-Świerk on Dec. 20, 1991.

36. M. Sadowski: Summary of the Plasma Seminar (in Polish); a talk given at the Plasma Seminar in IPJ-Świerk on Dec. 20, 1991.

7. LIST OF VISITORS

1. Dr. C. Zaccagnini
   from the Galileo Vacuum Tec in Florence, Italy, visited the Dept. P-V on February 14, 1991.

2. Prof. O. Pecherskij
3. Mr V. Yeremkin
   both from the Scientific Research Institute of Electro-Physical Equipment in St. Petersburg, Russia, visited the Dept P-V on April 1-8, 1991.

4. Dr. R. Karbowik
   from the Private Company in Los Angeles, USA, visited the Dept P-V on April 15, 1991.

5. Col. J. W. Schuman
6. Dr. H. Hackett
   both from the US European Office of Aerospace Research and Development, London, Great Britain, visited the Dept P-V on April 24, 1991.

7. Dr. J. Jagiabbai
8. Mr P. Hiappini
9. Mr A. Granieri
10. Mr E. Damico
11. Mr J. die Brase
    all from the CISL in Roma and Venice, Italy, visited the Dept P-V on June 20, 1991.

12. Dr. P. G. Avanzini
13. Dr. F. Rosatelli
14. Mr A. di Vita
    all from the Ansaldo Ricerche in Genova, Italy, visited the Dept P-V on July 7, 1991.

15. Dr. H. Schmidt
    from the IPF Stuttgart University in Stuttgart, F.R.G., stayed at the Dept. P-V from Sept. 2 until Sept. 14, 1991, within a framework of the German-Polish scientific cooperation programme.

16. Mr S. Detlef
from the IPF Stuttgart University in Stuttgart, F.R.G., stayed at the Dept. P-V from Sept. 2 until Oct. 12, 1991, within a framework of the German-Polish scientific cooperation programme.

17. Prof. R. Wienecke
from the IPF Stuttgart University in Stuttgart, F.R.G., visited the Dept. P-V on September 12-13, 1991, during the German-Polish Seminar.

18. Prof. G. Decker
19. Dr. W. Kies
both from the IEP Duesseldorf University in Duesseldorf, F.R.G., visited the Dept. P-V on September 12-13, 1991, during the German-Polish Seminar.

20. Prof. J. Kunc
from the University of Southern California in Los Angeles, USA, visited the Dept. P-V on September 16-18, 1991.

21. Dr. P. Thomas
from the JET Undertaking, Abingdon, Great Britain, visited the Dept. P-V on September 16-18, 1991.

22. Prof. O. Pecherskij
23. Mr V. Yeremkin
both from the Scientific Research Institute of Electro-Physical Equipment in St. Petersburg, Russia, stayed at the Dept. P-V from Sept. 23 until Sept. 30, 1991, within a framework of a scientific cooperation programme.

24. Dr. V. Zoita
from the Institute of Atomic Physics in Bucharest-Magurele, Romania, stayed at the Dept. P-V from Dec. 9 until Dec. 15, 1991, within a framework of a scientific cooperation programme.

25. Dr. H. Bruzzone
from the Buenos Aires University in Buenos Aires, Argentina, stayed at the Dept. P-V from Dec. 10 until Dec. 20, 1991, within a framework of a scientific cooperation programme.

26. Dr. A. Bernard
from the Centre d'Etudes de Limeil-Valenton in Villeneuve St. Georges, France, visited the Dept. P-V on Dec. 11-13, 1991, during the 3rd Meeting of ICDMP.

27. Dr. P. Choi
from the Blackett Laboratory of Imperial College in London, Great Britain, visited the Dept. P-V on Dec. 11-13, 1991, during the 3rd Meeting of ICDMP.

28. Dr. V. Gribkov
from the P.N. Lebedev Physical Institute in Moscow, Russia, visited the Dept. P-V on Dec. 11-13, 1991, during the 3rd Meeting of ICDMP.

29. Prof. F. Mezzetti
from the Ferrara University in Ferrara, Italy, visited the Dept. P-V on Dec. 11-13, 1991, during the 3rd Meeting of ICDMP.

30. Dr. H. Schmidt
from the IPF Stuttgart University in Stuttgart, F.R.G., visited the Dept. P-V on Dec. 11-13, 1991, during the 3rd Meeting of ICDMP.

31. Prof. Ch. Luo
32. Dr. X.X. Wang
both from the Tsinghua University in Beijing, P.R. China, visited the Dept. P-V on Dec. 11-13, 1991, during the 3rd Meeting of ICDMP.

8. LIST OF STAFF.

8.1. Scientific Staff

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

8.2. 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. Wyszyński Władysław, Eng. - employed part-time.
10. Ziemski Waldemar, M.Sc. - employed until March 1991.

8.3. Technicians

1. Cywiński Krzysztof
2. Czajkowska Joanna
3. Gątarczyk Krzysztof
4. Gniadek Krzysztof
5. Grzeszczyk Zdzisław
6. Jankowski Marek
7. Jęda Andrzej
8. Karpiński Paweł
9. Kasperski Krzysztof
10. Kołakowski Bernard
11. Kołnierzak Ryszard
12. Koszewski Grzegorz
13. Królik Jerzy
14. Kuk Mirosław
15. Kwiatkowski Marek
16. Machalski Piotr
17. Michalik Krzysztof
18. Nawrocka Halina
19. Pijanowski Wojciech
20. Rybicki Ryszard
21. Staszkiewicz Bogdan
22. Trembicki Andrzej
23. Wiraszka Andrzej
24. Zagórski Jerzy - employed until Oct. 1991.

8.4. Workshop

1. Jędrzejczyk Marek
2. Szoch Sławomir
3. Niewiadomski Andrzej

8.5. Administration Staff

1. Gawrońska Alicja
2. Presner Franciszek - employed part-time.
3. Salamońska Anna