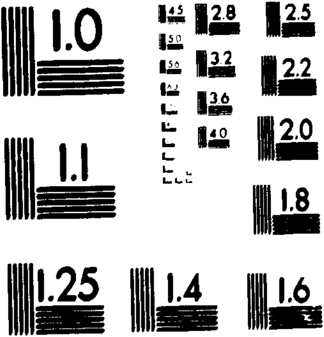

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Association EURATOM-ENEA sulla Fusione

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SUMMARY

This report contains the part of the Frascati Laboratorio Fusione Laser activity related to the Apparatus (target chamber, position and alignement system, diagnostics) to be used in the interaction experiments with the ABC laser system.

RIASSUNTO

Questo rapporto contiene una descrizione dell'attività svolta dal Laboratorio Fusione Laser nella preparazione dell'apparato sperimentale (camera da vuoto, sistema di posizionamento) e delle diagnostiche da utilizzare negli esperimenti di interazione che verranno effettuati con il laser ABC.

1. INTRODUCTION

The aim of the Laser Fusion Laboratory activity as well as some results of the laser-matter interaction experiments performed in the past have been discussed previously in 1985 report [1]. The present report will be mainly devoted to the presentation of a part of the equipment prepared for the interaction experiments with the ABC laser system. More explicitely a description is given of

- part of the diagnostic equipment;
- the target positioning and replacing system;
- the target alignment procedures.

In evaluating the performances of these systems and methods, it could be useful to remember that in the experiments with the ABC laser, light pulses of 2÷3 ns FWHM at a wavelength of 0.527 μm will be focussed on areas having diameters of 350÷500 μm; since the laser energy will be of the order of 100 J, power densities of $10^{12}\div10^{13}$ W/cm^2 will result.

When focussed on spherical targets with the sizes already specified, these pulses will drive ablative implosions. Typical performances could be implosion velocities of $4\div8\times10^6$ cm/s, corona temperatures of 0.3-1 keV, coronal plasma velocity of $\sim 2\times10^7$ cm/s, and, in the optimistic case of a uniform illumination and stable implosion, a target volume variation of about 1000. As shown in Refs [1, 2, 3] these experiments could be representative of part of the hydrodynamics of MJ thermonuclear targets when directly imploded with laser pulses of longer durations (e.g., $t \rightarrow t\times3$) and shorter wavelengths (e.g., $\lambda \rightarrow \lambda/2$).

2. DIAGNOSTICS

Several of the diagnostics routinely used in the low power density experiments have been described in previous reports [1]. Here the focus is on two diagnostics that we expect will give initial reliable semiquantitative informations about the distribution of energy deposition on the target surface. It should be recalled that since the experiments will be performed in the ablative regime, the quality of target illumination will be a more crucial element than in exploding pusher driven implosions or, more generally, in experiments where high power densities are used.

2.1 Optical Diagnostics

Information about the quality of the energy distribution on the target surface can be obtained by time resolved optical diagnostics.

In our experiments the typical hydrodynamical times are of the order of 3÷6 ns for the implosion and ~ 0.7 ns for the coronal plasma transit time through a length of the order of the target radius R; thus, we can expect, after a time of the order of 1 ns, a quasi-stationary corona evolving in times of the order of the implosion time. In these conditions optical diagnostics using a probing beam with a duration t_0 = 200 ÷ 300 ps will succeed in giving time resolved views of the coronal plasma and opaque regions. In fact, Assuming an implosion velocity of $v=8\times10^6$ cm/s, the plasma profile shift is vt_0 = 24 μm; thus, if interferometry is considered, it is easy to show that a fringe shift of up to $R/vt_0 \approx 10$ can be detected without substantial blur. This conclusion is supported by our previous experiments: high quality interferograms have been obtained in interaction experiments having similar space-time scales (see [1,5]).

The system has been designed to produce four images at different istants in the same shot. Care has been taken in making the image processing optics flexible enough to render techniques such as schlieren, dark field shadowgraphy, interferometry, etc., possible through minor changes in the optics.

The system used to produce four short diagnostic pulses at either 0.527 μm or 0.351 μm starting from the ABC long pulse used for target irradiation is shown in Fig. 1. A fraction of the diverging beam after the ABC M20 amplifier [1] is first spatially filtered and them transferred towards the implosion region through a lens properly chosen to have the target in a beam waist. The beam is shaped to a one nanosecond pulse by using a Pockels cell driven by the same (properly delayed) pulsed voltage driving the ABC optical shutters.

Two orthogonally polarized replicas are then produced and a mutual time delay is created. Since type II 2ω generators require both the polarizations to be present, the green pulse is produced only when the two pulses overlap. To illustrate, calculations relevant to our situation are presented in Fig. 2. A similar method can also be used in the case of 3ω generation: in this case a delay between ω and 2ω is introduced for the THG cell. The system is shown in Fig. 3.

The probe beam, about 300 ps long, is split into four differently delayed parts which are used to probe the target in a plane orthogonal to the symmetry axis of the ABC focussing optics.

The target four-beam illumination scheme is shown in Fig. 4. In the same figure the imaging and a processing optics is also represented.

Having a laser pulse with a light degree of spatial coherence it is possibe to use an interferometer giving on the same plate both shadography and interferometry the irradiated target.

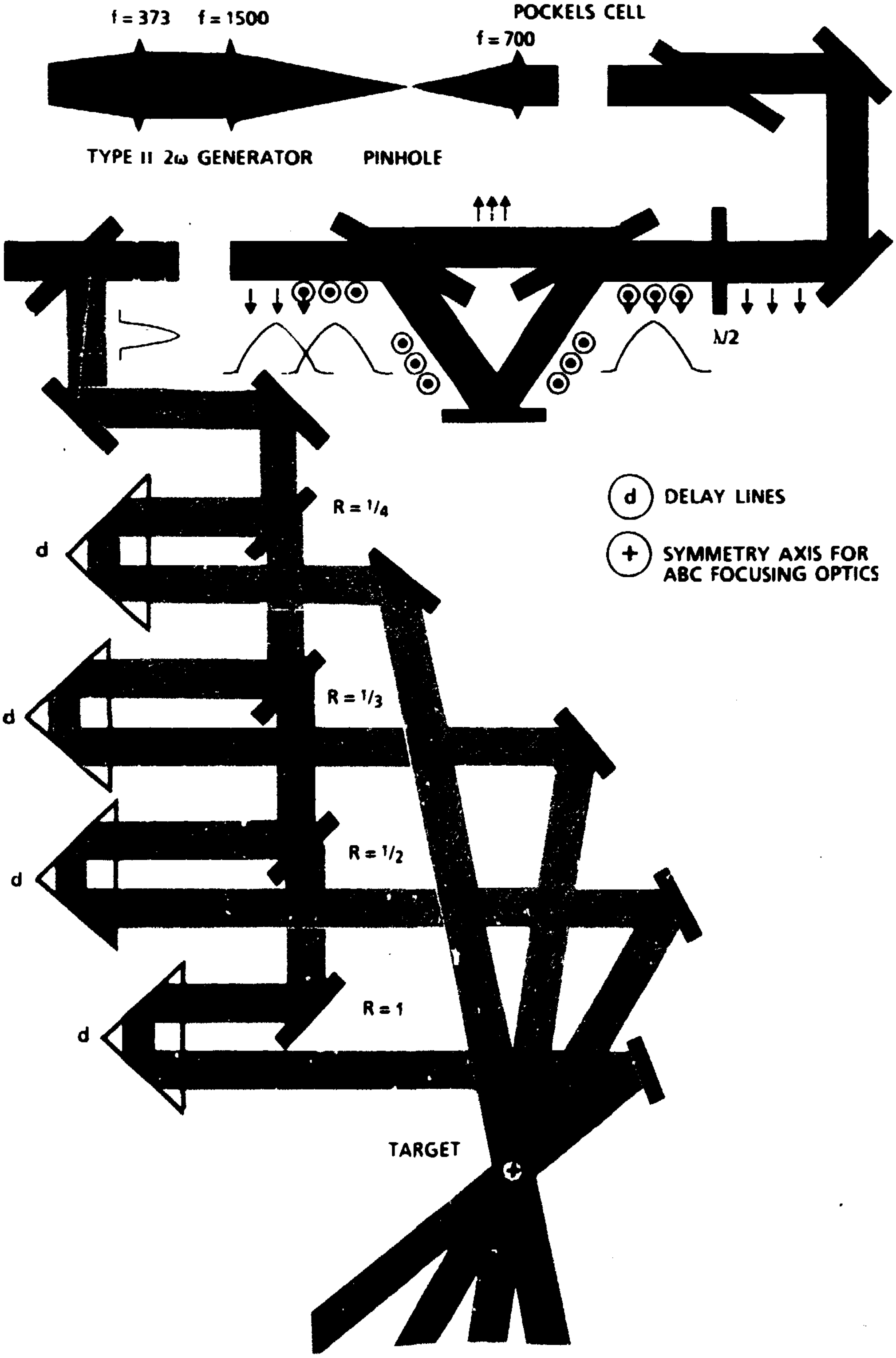

Fig. 1 The system used to generate four short light pulses at 2ω for optical diagnostics in the ABC experiment

For this purpose we use a polarization interferometer based on the Wollaston Prism. Each diagnostic beam is first polarized by the polarizers P in our such a way

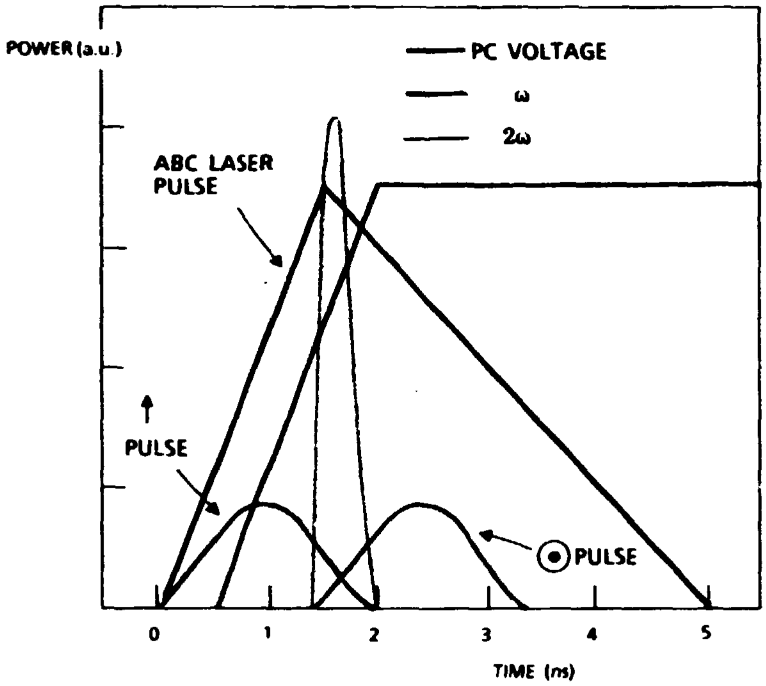

Fig. 2 Calculated time dependence of the 2ω short pulses as produced by the system represented in the previous figure

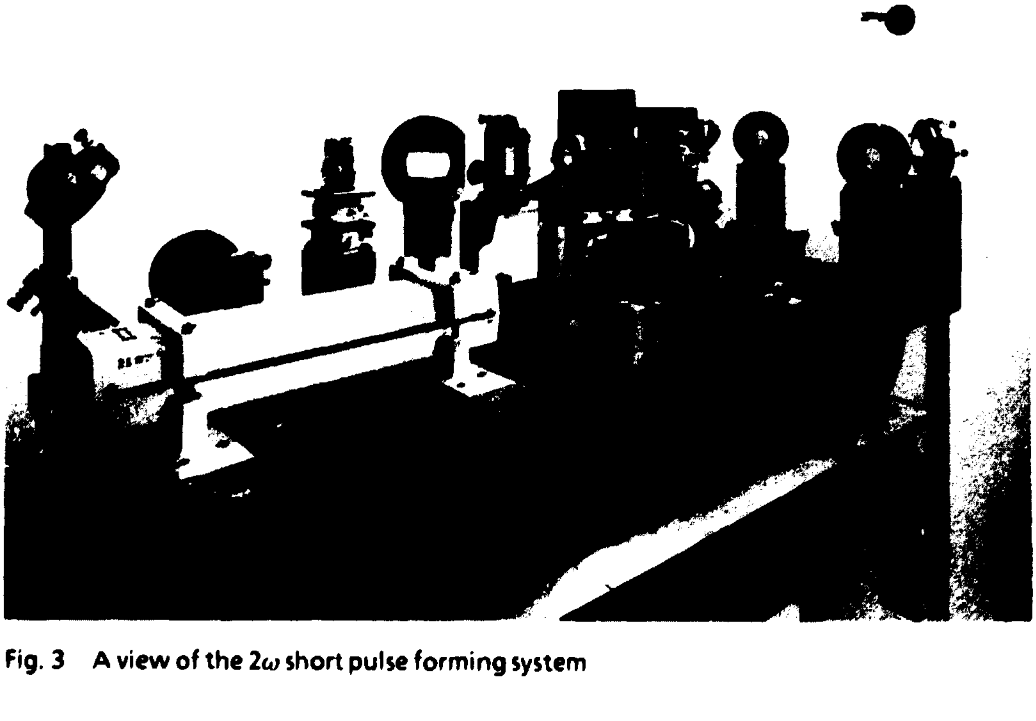

Fig. 3 A view of the 2ω short pulse forming system

to generate through the Wollaston prism two beams with the same intensity. The last polarizer P, allows to obtain the fringes in the overlapping region of ordinary and extraordinary beams coming out of the Wallaston prism. By means of a suitably placed diaphragms the illuminated region can be centered round the target image in

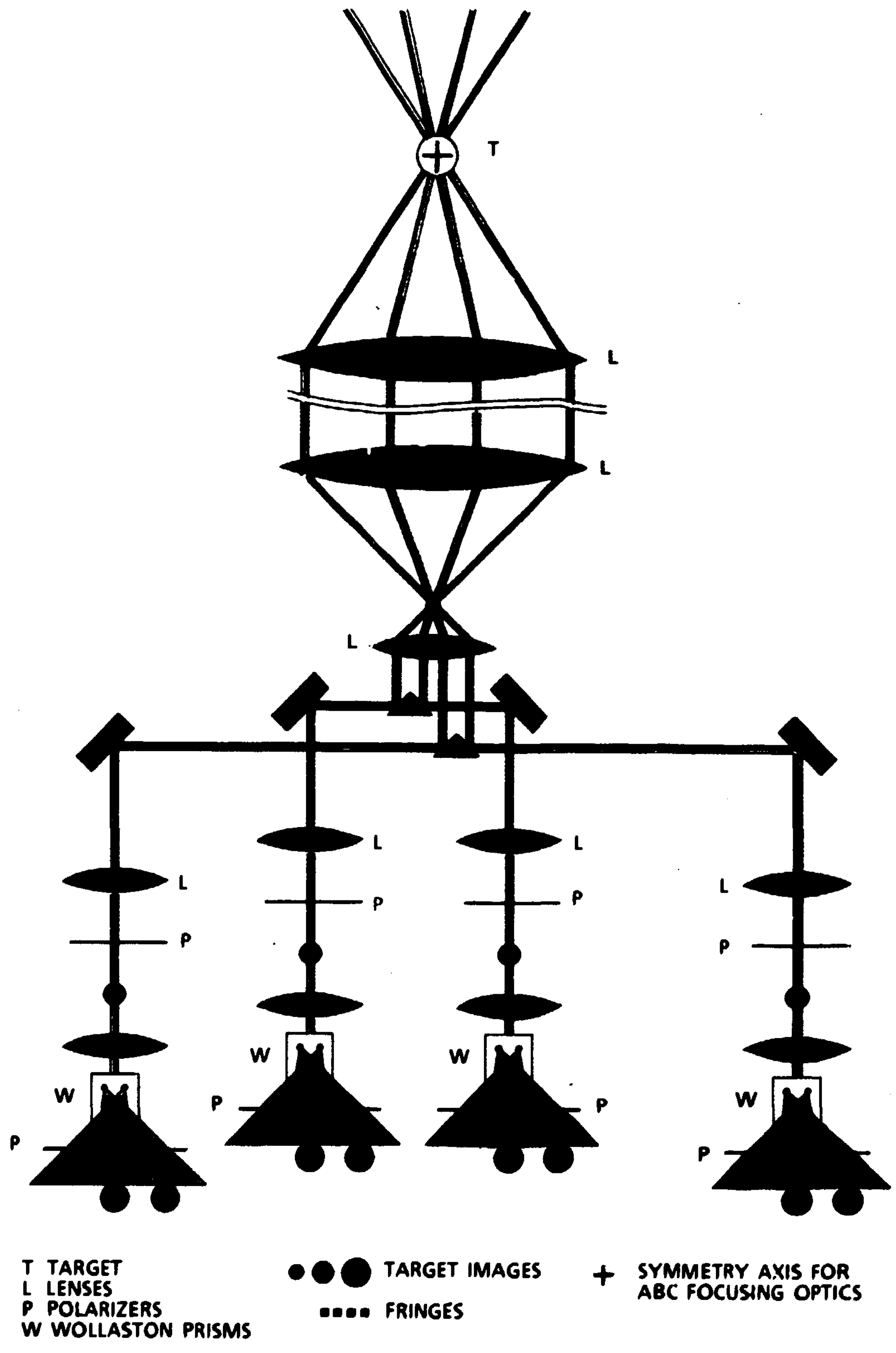

Fig. 4 The imaging system for the optical diagnostic

such a way to have, on the plate, two magnified target images one in the overlapping beams region and the other out of this region (see Fig. 4). In this way interferograms and shadowgraphs can be taken on the same plate.

In addition, we can also produce a probing beam nominally as long as the target irradiation one by changing the voltage delay to the pockels cell and by rotating the λ/2 plate (Fig. 2). In this case by inserting a mirror, behind one of the last processing lenses represented in Fig. 4, an irradiated target image is easily produced on the slit of a streak-camera, by a proper optics, for time resolved one-dimensional shadography.

The streak camera used in our experiment is Hamamatsu system allowing time resolutions of up to 2 ps; this system includes: TV camera HTV C1000-18 with a SIT tube incorporated for image pickup and a video frame memory to achieve a wide variety of image analysis (tridimensional display, densitometry, ecc.). Acquired images can be preprocessed, displayed and recorded in real time; moreover, the rapid data transfer to a host computer (PDP11/64-DIGITAL) can be accomplished through direct theory access (DMA) for further data processing and analysis.

The whole of the optical diagnostics apparatus is shown on the right hand side of Fig. 5.

2.2 Temperature, Charged Particles and Reflected Light Measurements

The target chamber for the interaction experiments is a stainless steel spherical vessel with a diameter of 150 cm and formed by two vacuum-tight ($\sim 1.5\times 10^{-6}$ torr) shells stuck together (see Fig. 5) made by Fratelli Naretto S.a.s. Torino (italy).

Fig. 5 The irradiation room; the optical diagnostic imaging system is placed on the right

Diagnostics tested in past experiments performed at power densities of 10^{12} W/cm^2 with a 5 J laser will be used in the next experiments using the ABC laser. Figure 6 shows an inner view of the target chamber; this includes focusing lenses, the automatic target replacement system (ATRS) and diagnostics.

At present we have prepared: diodes for time resolved temperature measurements [4], charged particle collectors [1], fiber optics for space-time resolved studies on target reflected light and an apparatus for target imaging in reflected light [6]. For space resolved temperature measurements [4] and x-ray imaging we have prepared the new system described in the next section.

2.3 Pinhole Camera Soft X-Ray Imaging

As the first of these diagnostics, we shall consider the simple target pinhole imaging in the soft x-rays emitted from the corona. In the experiments the image is registered on a microchannel plate: this method, in addition to the information on the uniformity of illumination, can also give a space-resolved, time-integrated temperature measurement by associating the filter method to photon counting [4]. Since the energy E of the photons contributing to the image scales approximatively as $(TS)^{1/4}$, where T is the plasma temperature and S the filter thickness, it is possible, by reducing S, to render the contribution of the lower energy photons ($E \sim E_{ion}$) emitted near the ablation front more relevant for the imaging process [4]. In our experiments a highly emitting ablation front will exist all along the implosion process because of the long laser pulses used. On the plate the highest photon densities correspond to smaller ablation front velocities, i.e., to the first stages of the interaction and to the stagnation time.

In Fig. 6 the pinhole camera is the roughly conical structure at the center of the picture. A drawing of the system is given in Fig. 7. Four soft x-ray images are formed on a large (9×11.5 cm^2) channel-plate by four pinholes, each image being processed by different absorbers.

A preliminary alignment of the system is made with the vacuum chamber open. In this case we put in the fire position a diffusing spherical target having a diameter of the same order as that of the targets used in the actual experiments. Pulling out the absorber holder, placed half a way between the pin-holes and the MCP, a first pin-hole positioning is made as follows: two Ion Argon laser beams processed to have the same features as those of the ABC beams are focused on the target to simulate fire conditions. By using pin-holes having diameters of the order of a few hundred μm it is possible to have four target images on a plate introduced to simulate the MCP. When the four images result correctly positioned, the pin-hole holder (Fig. 8) is

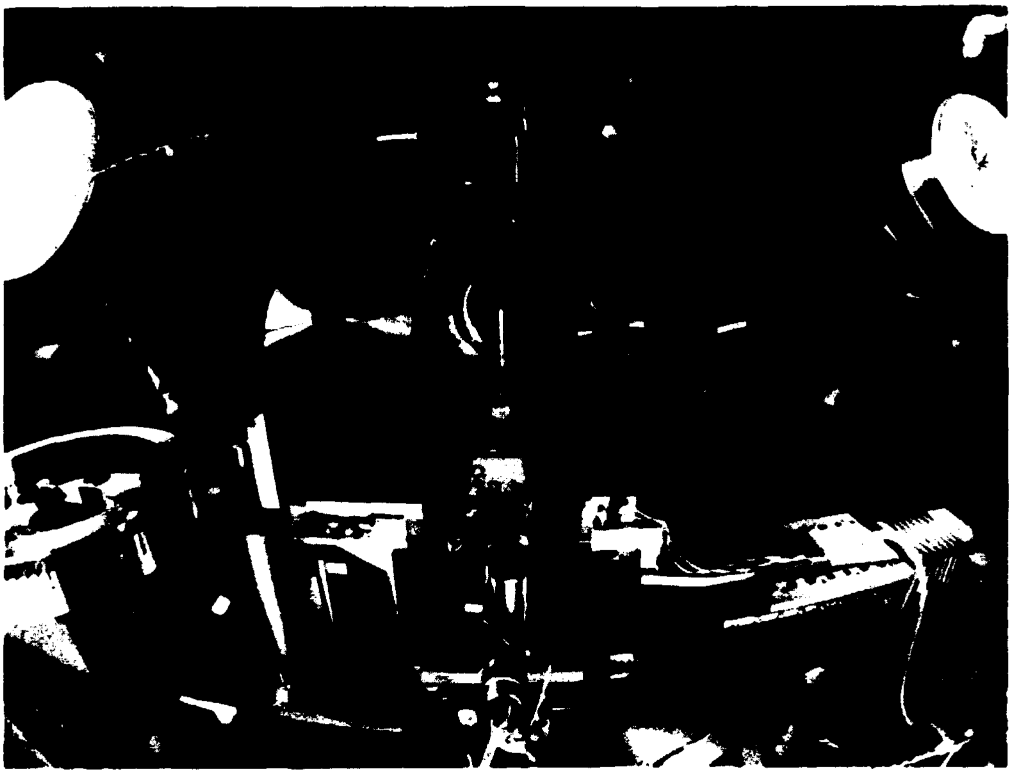

Fig. 6 A view of the target chamber of the ABC laser system

locked to maintain the alignment when the pinhole are substituted by the ones used during the measurements (ϕ~5÷10 μm) [4], and the absorbers holder is inserted. Corrections to the initial alignment as well as to the magnification can be made, without breaking the vacuum, by a micropositioning system for the pinhole assembly.

In addition to the advantage of having images at different typical photon energies in the same shot, this approach makes possible to have a single shot, space-resolved, temperature measurement through the determination of three filter transmission ratios, the more conventional space-integrated, time resolved, counterpart being given by diodes [2.5].

3. TARGET POSITIONING AND REPLACING SYSTEM

We now describe the present ATRS. This is a new device properly designed to substitute a previous, less flexible (prototypic in character) device.

The operating performances specifications given to the engineers of the manifacturing company Contek S.r.l. Varallo Sesia (Italy) are described in the following.

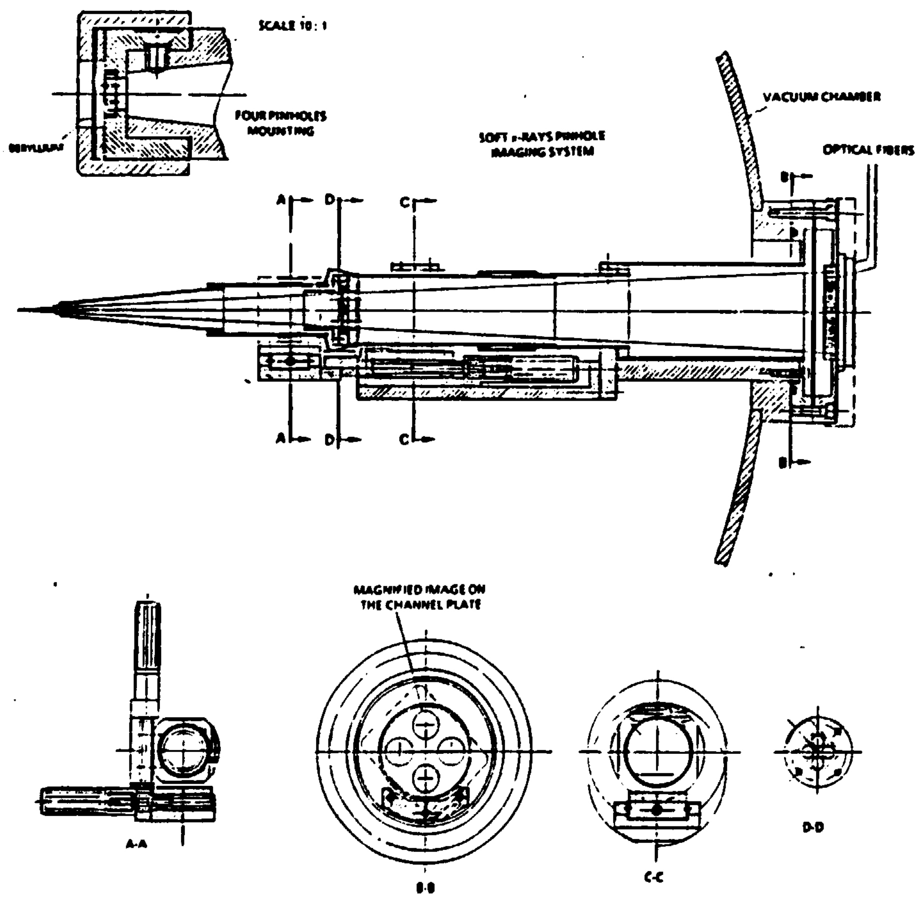

Fig. 7 The ABC pin-hole camera soft X-rays imaging system

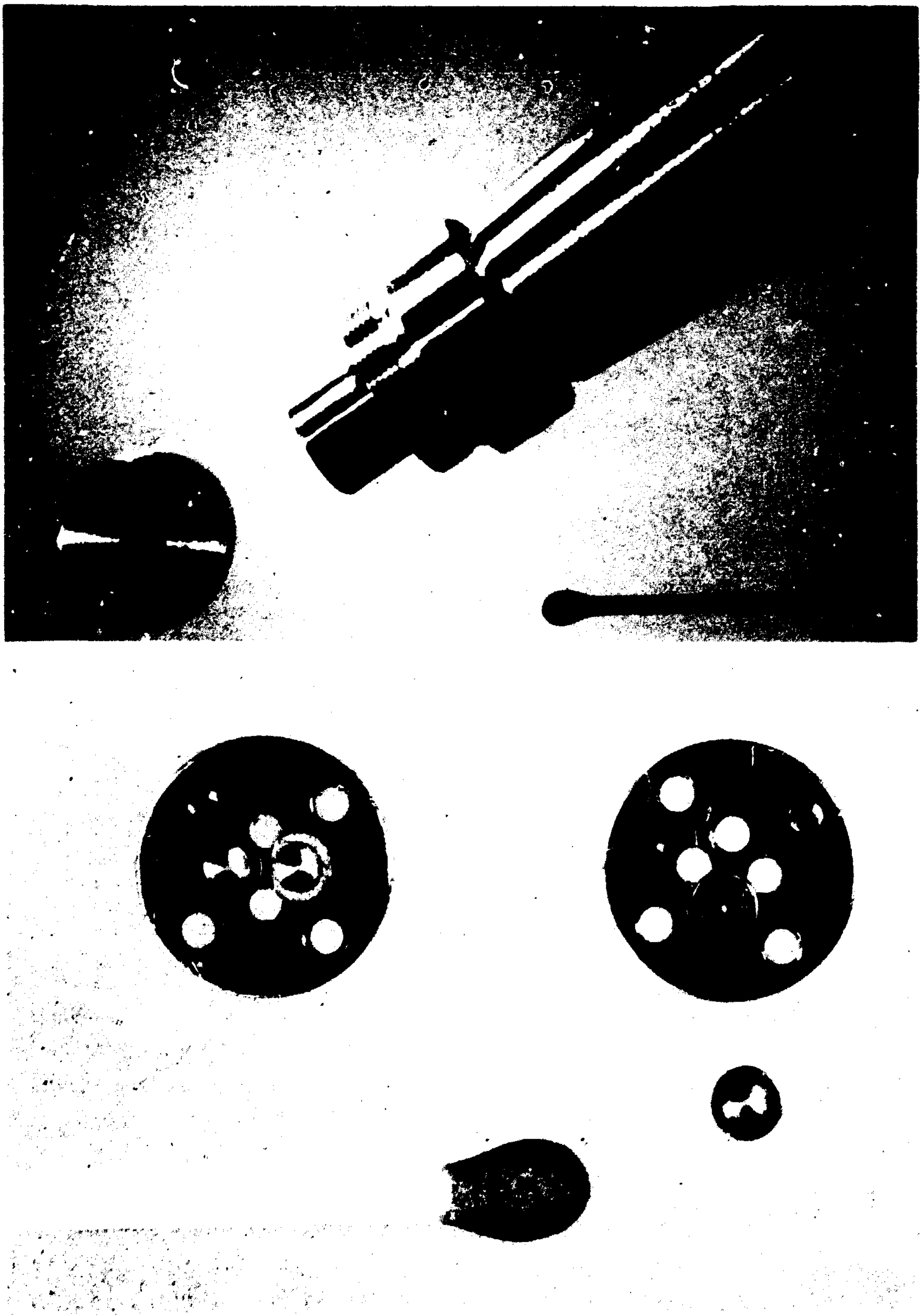

Fig. 8 The four-pin-holes mounting of the X-ray camera

The ATRS presented in Fig. 6 is designed to replace one hundred succession targets without breaking off the vacuum conditions. Each target can be placed on the same assigned position within 1 μm and rotated around an axis by means of micropositioning mechanical modules driven by remotely controllable stepping motors.

The operating performances for each module are:

1) Normal Mode: pushing a button (marked + or -) causes the motors to move in the desired direction. When the motion is stopped, the step increment results on a numerical display. This operating mode is completely dependent on the human partecipation.
2) Programed mode: on the keybord of each device, it is possible to assign a set of parameters (direction, number of steps, steps/s, etc.). Pushing the botton marked with *start* causes the motor to move as requested by the programed operations and, at the end of the run, the effective number of steps, counted from the origin, results on the numerical display.
3) Computer controlled position: same as above with the devices controlled by an APPLE IIE using an IEEE 488 interface card.
4) After the execution of the operations in point 1) or 2) or 3), the absolute positions of each mechanical module (in terms of number of steps counted from the origin) are recorded on the permanent memory card through the interface card and remain at the controller disposal.

By means of the PRO-DOS-implemented APPLE IIE controller, suitable software has been developed to operate the system as a whole by a programed sequence. This sequence can be divided into three steps:

- The selected target is taken from the store, placed on a little arm carried between the focussing lenses, and deposited at approximatively the firing position;
- After the target is transferred approximatively, according to the operator requirements on the controller keybord, the three stepping motors are used for the precise positioning in the firing place, and the system status is then put in stand-by for the shot;
- After the shot has been made, it is possible to choose for *end of operations*, or for a newly selected target positioning procedure.

The performances of the system as a whole (mechanics and electronics) were tested verifying, in a number repeated tests, the agreement between mechanical and numerically displayed positions taking special care over the mechanical modules with one half-step corresponding to 1 μm.

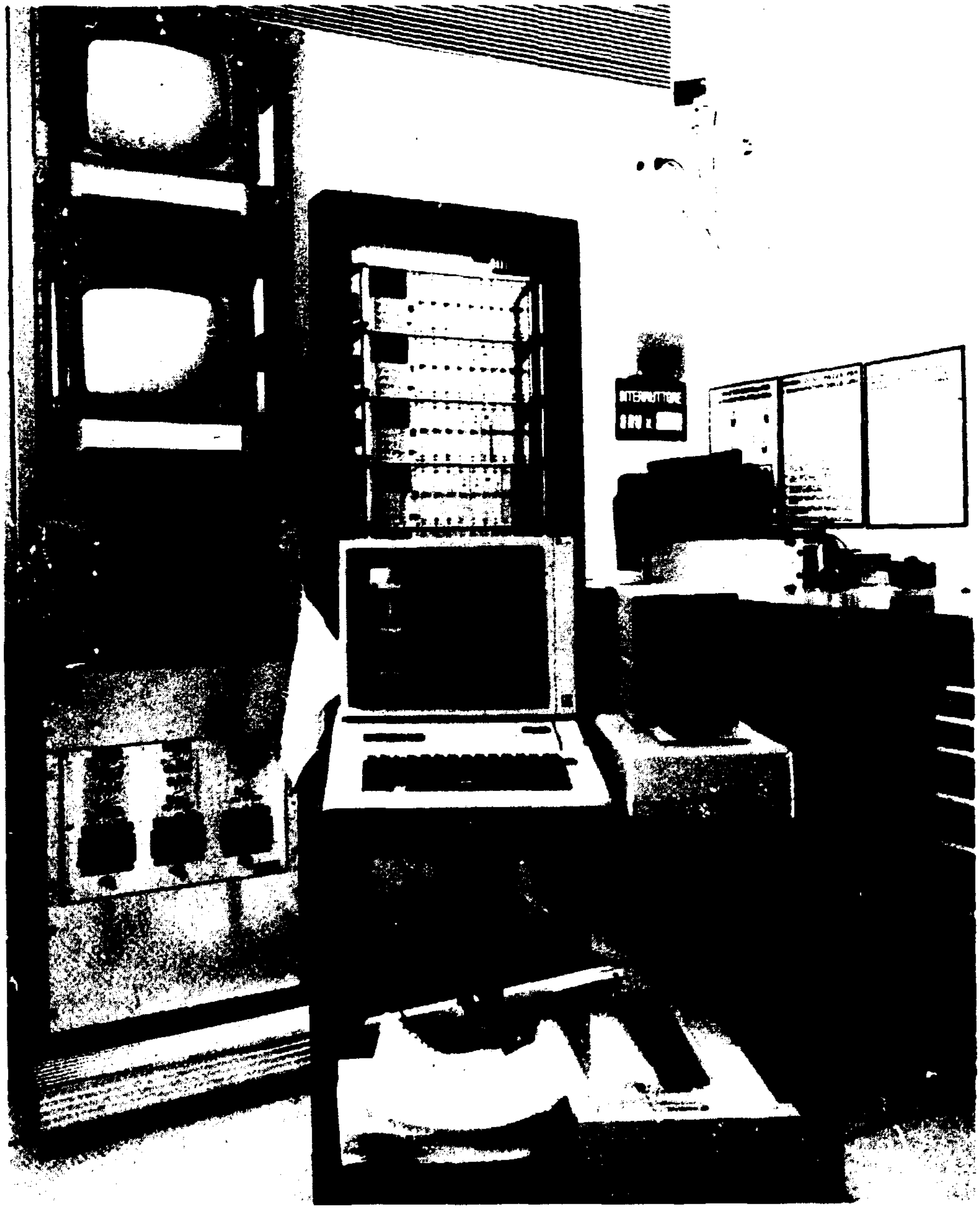

Fig. 9 The new electronics for the target replacing and positioning system and for the pin-hole camera motors.

The control system for target replacing and positioning is shown in Fig. 9.

4. TARGET ALIGNMENT PROCEDURES

One of the focussing systems for the light of the ABC laser system is formed by two F/1, focal length f = 85 aspherical lenses with a hole on the optical axis.

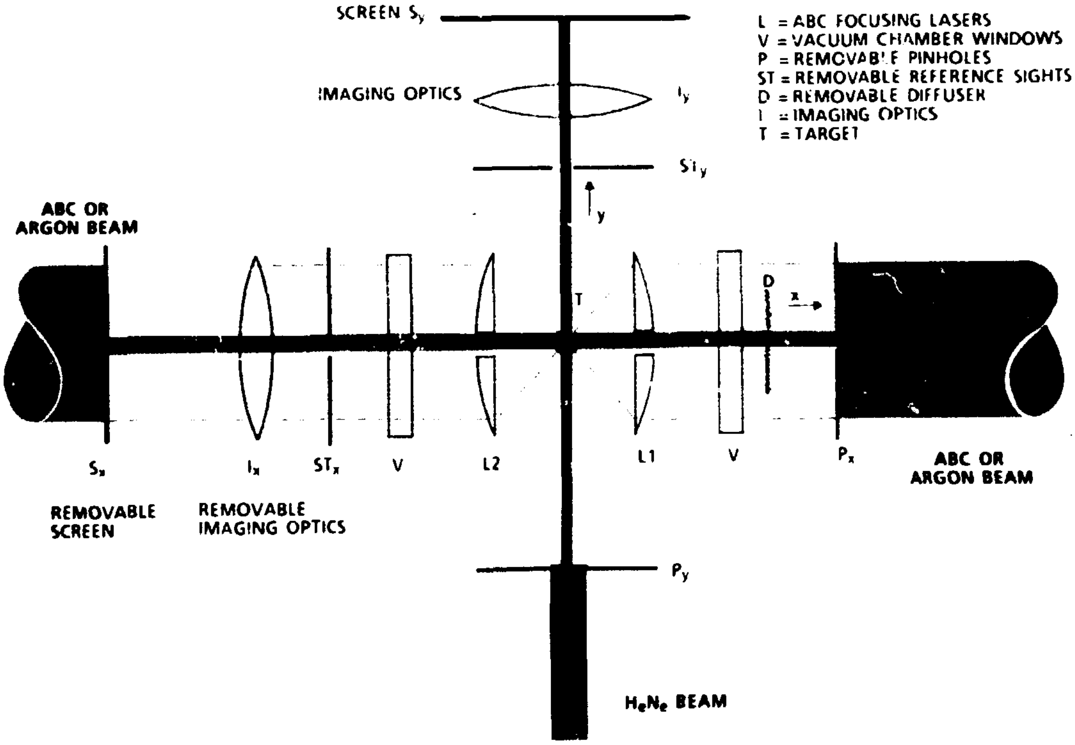

Fig. 10 Schematic view of the alignment optics

The target alignment procedures for this case start with the choice of the first time firing place (FTFP) which is a conventional firing place used to align the diagnostics. It is useful to have a procedure to find the FTFP with a precision sufficient enough to avoid diagnostics realignment in case of loss of the - by far more precise - references used to align the target in the actual shot operations.

The FTFP is determined by two coplanar laser beams produced by the projection of the pinholes P_x and P_y on the sights ST_x and ST_y (Fig. 10), D not being inserted at this stage. Although P_x, P_y, ST_x and ST_y, are removable, they can be placed in the same position within 10 µm. The beam along x (the irradiation symmetry axis) is produced projecting P_x on the side of the L_1 lens with an argon laser beam properly expanded and aligned to simulate the ABC beams (a similar beam is also used on the arm of L_2). The direction along y is simulated by projecting P_y with an He-Ne laser beam.

A spherical target T is then imaged on the screens S_x and S_y by I_x and I_y and placed at the center of the diffraction patterns of P_x and P_y. This procedure guarantees that FTFP can be found with sufficient precision to avoid realignment of all the present diagnostics mounted on the experiment.

After this target positioning work, P_y and ST_y are removed and the resulting good quality magnified target image is used to place a precise reference on the permanent screen S_y. This reference will be used for target positioning along x in the actual shot alignment operations. A reference is also taken on S_x.

The alignment of the ABC focussing lenses L_1 and L_2 proceeds in two steps.

First the foci of L_1 and L_2 are placed in the plane y, z (z is orthogonal to x and y of Fig. 10): this result is obtained by a Foucault procedure in which a sharp blade aligned on the reference S_y is used. Of course, during this operation ST_x and P_x are removed. Since L_1 and L_2 are motorized along x, a by-product of this work is a memorized confocality coordinate to be used as a reference for focussing under vacuum conditions.

Second operation is to superpose the foci along the x axis. This is done by using a transparent disk target aligned on the references taken on S_x and S_y. With P_x and ST_x removed and the diffuser D inserted on a part of the green beam used to simulate ABC, a highly magnified image ($M \simeq 60$) of the target T can be formed on S_x using L_2 and a modified I_x. At S_x, together with a very good quality image of T, a sharp focal spot due to the nondiffused part of the beam appears. The lens L_1 is then positioned in the plane (z,y) so as to bring the bright focal spot in the center of the disk. These operations are then repeated for the alignment of L_2.

In this system, the previously described operations require direct access to the focussing lenses.

Once the ABC lenses are properly positioned, the target is aligned under vacuum conditions for shot operations as follows: A target is taken from the reservoir, by using the automatized system described in the previous section, and accurately placed at the reference S_y. If the target T is transparent, the positioning in the (y,z) plane is made by imaging T on S_x by I_x, L_2 and D. Then T is placed so as to put the spot due to L_1 in the center. If the target is opaque, a reference is taken for the focal spot of L_1 on S_x, and then the target is positioned upon it. The required target illumination conditions are then produced by symmetrically moving L_1 and L_2 along x, by using their stepping motors.

5. ACQUISITION DATA SYSTEM

Electrical signals obtained as output of the diagnostics or laser monitoring are registered by Tektronix R7912 and Tektronix 7912AD programmable digitizers. Both types of digitizers are supported by commands of the Tek SPS VO2 Basic. This software package is file compatible with Digital Equipment Corporations RT-11 Software. Two PDP-11, CP1164 and CP110, are avalaible as indipendent controllers (each with 240 K words of memory) for 7912AD and R7912 Digitizer respectively.

The data from the 7912AD is read into the controller via a IEE488 Interface while all the logic function necessary for computer control of the R7912 Digitizer are provided by R7912/CP Bus interface circuit card. In both cases the interface driver is part of the Tek SPS V02 basic as well as the graphics and signal processing packages avalaible for suitable display of signals.

Additional Software for filing, displaying and handling of acquired data, after each shot, was entirely developed in our laboratory.

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