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MASTER

NOVA Integrated Alignment/Diagnostic Sensors

Final Technical Report

Lawrence Livermore Laboratory

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1. Introduction

Under Contract 3772003 to the Lawrence Livermore Laboratory, Aerojet ElectroSystems Company has investigated a number of alignment system design topics for the NOVA and SHIVA upgrade lasers. Prior reports dealt with the Main Beam Alignment System, and with Multipass Amplifier Alignment Concepts. This report, which completes the contract, examines ways in which the Return Beam Diagnostic (RBD) package and Incident Beam Diagnostic (IBD) packages may be reconfigured to a more integrated package. In particular, the report shows that the RBD optics may be directly integrated in the Pointing Focus and Centering (PFC) sensor, and that the IBD optics may use the same basic common configuration as the PFC/RBD package.

2. Background

2.1 SHIVA PFC Sensor Package

Under Contract 5900403, AESC recently completed the fabrication of 20 Pointing, Focusing and Centering (PFC) sensors for the SHIVA system. These PFC sensors, one of which is shown in Figure 1, provide outputs which indicate: 1) the lateral displacement (pointing) of the focused laser image in the target chamber with respect to the center of a spherical surrogate target; 2) the longitudinal displacement of this image with respect to a reference point on the surrogate target; and 3) the centering of the incident laser beam at the target chamber final focus lens. When implemented in an appropriate servo loop, the PFC sensor permits automatic pointing and centering, and manual focusing, to be accomplished. Tests have demonstrated pointing accuracy capabilities of better than one micrometer, and focus accuracy capabilities of better than 25 micrometers, in the prototype sensor configuration.

The PFC sensor optical system, shown in Figure 2, views reflected energy from a spherical surrogate target in the target chamber, or from the centering screen, by looking through the final turning mirror of the system. The PFC sensor uses the residual 2% transmission of this turning

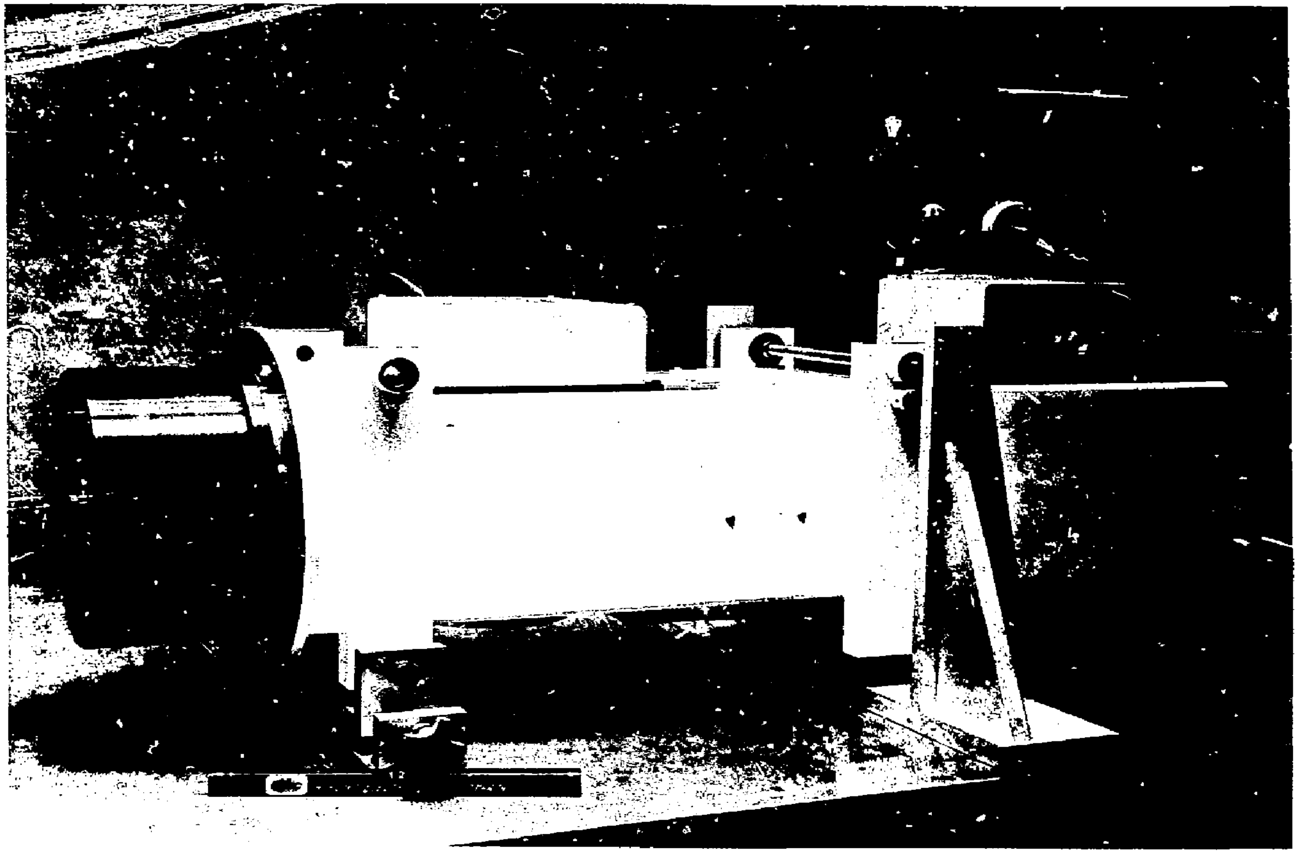

FIGURE 1. SHIVA PFC SENSOR

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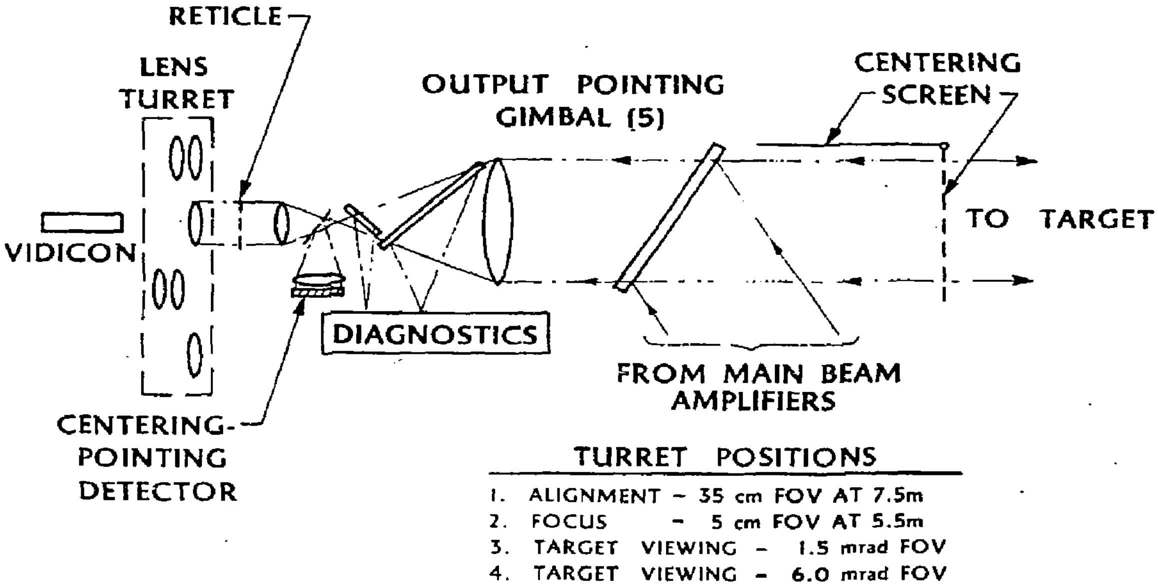


FIGURE 2

SHIVA PFC SENSOR OPTICAL CONFIGURATION

mirror to view the reflected energy. In its pointing, centering and focusing modes of operation, the PFC sensor acts as a reimaging optical system, reimaging the plane of the centering screen upon a silicon Lateral Photovoltaic Effect detector, and upon a silicon target vidicon. The degree of demagnification used in the reimaging process is dependent upon the operating mode of the PFC sensor.

In the centering mode of operation, the PFC sensor determines, by means of the Lateral Photovoltaic Effect detector outputs, the position of the incident beam wave front at the location of the centering screen. The error signal output then drive the first turning mirror to center the beam at the prescribed location on the centering screen.

In the pointing and focusing modes of operation, the centering screen is removed and the PFC sensor reviews energy reflected from the spherical surrogate target placed at the center of the target chamber. This surrogate target has the property that focused beam pointing errors in the target chamber result in strongly magnified wave front translations of the beam reflected backwards through the focus lens. The surrogate target size has been scaled with respect to the focus lens focal length such that this magnification in SHIVA is approximately a factor of 1000. Thus, a one micrometer pointing error results in a 1 mm translation of the reflected wave front at the centering screen. The PFC detector senses this wave front offset and provides error signals to the high resolution output pointing gimbal.

System focusing is indicated by the silicon target vidicon in the PFC sensor. This mode uses an optical property of the surrogate target, which is that energy which is focused at a distance of one-half radius ahead of the center of the surrogate target will be reimaged, when reflected back towards the PFC sensor, at a distance of one focus lens focal length toward the PFC sensor.

This image is magnified by a value numerically equal to that magnification achieved for the pointing function; thus, the image diameter at the reimage point for an f/6 diffraction limited system becomes approximately 14 millimeters. Longitudinal motions of this reimage point (the centering screen plane) have little effect on focus accuracy due to the high longitudinal magnification (10^6) of the system.

Viewing of this image by means of the silicon target vidicon in the PFC sensor permits determination of that location of the final focus lens which results in minimum image size at the reference focus location. Subsequent to such reference focusing, the focus lens may be defocused to any desired location dictated by target considerations.

The PFC sensor also has the capability for reimaging objects at the center of the target chamber upon the vidicon, with various levels of magnification. One of these levels of magnification is such as to provide diffraction limited performance and thus allow examination of structure across an image of the laser beam in the target chamber. A second function of this viewing mode is to permit the PFC sensor to look across into the opposing beams, facilitating beam alignment by permitting observation of opposing beam spatial filter pinholes. In a third mode of operation, the PFC sensor may view the real target in a obscurrogate mode of operation, permitting real target alignment either for on-axis or off-axis targets under conditions when operation of the automatic pointing system is not appropriate.

2.1.2 SHIVA Reflected Beam Diagnostic Package

The reflected-beam diagnostics (RBD) package shown in Figure 3 is a submodule of the SHIVA PFC sensor. During a target shot, the RBD will measure the amount of energy reflected from the target along each beam line, will provide multiple-image photographs of the target plane, and will provide for connections to an external streak camera via fiber optics.

Combination of the RBD package with the PFC sensor is permitted by a moveable beam dump mirror in the PFC sensor which, together with a reentry mirror, permits the PFC objective lens and vidicon to function with

SHIVA PFC/RBD SENSOR PACKAGE

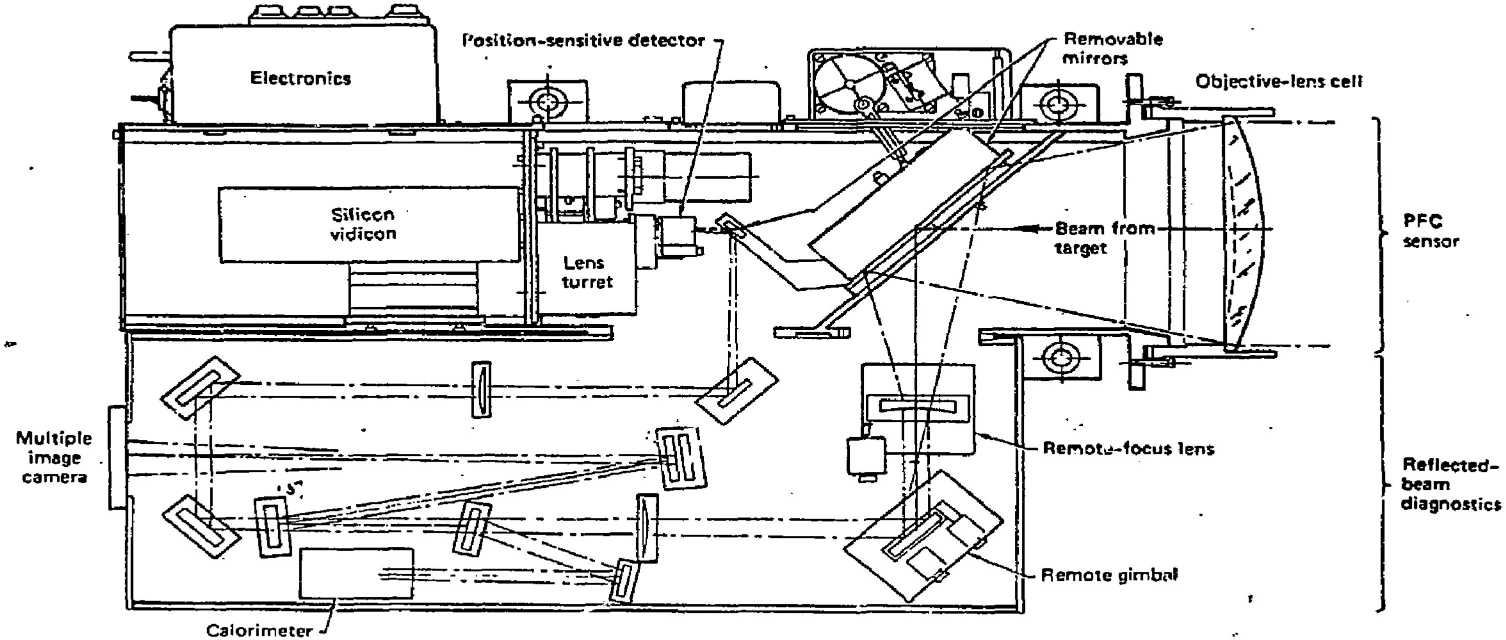


FIGURE 3

the RBD package. Alignment of this beam dump mirror package is relatively critical, and the complexity of the mirror assembly causes it to be a significant PFC sensor cost item.

2.1.3 SHIVA Incident Beam Diagnostics Package

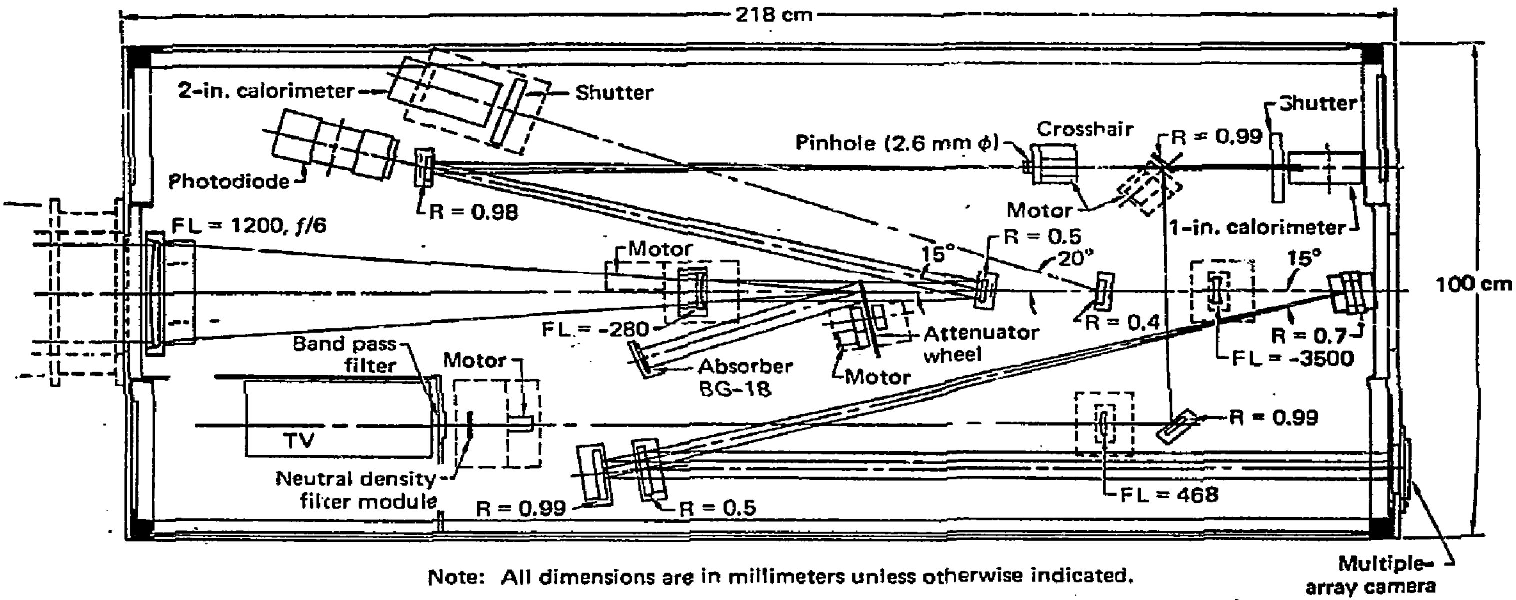
The output of each laser arm will be monitored by an incident-beam diagnostics package before the beam is incident on the target. This package, illustrated in Figure 4, intercepts that portion of the main beam transmitted by the final turning mirror. The IBD package monitors the total incident-beam energy and the focusable beam energy, records equivalent target-plane spatial characteristics, and provides the pinhold-imaging optics and vidicon required for spatial-filter pinhole alignment. In addition, some IBD packages contains an integrating photodiode, which is periodically inserted into the beam to measure amplified spontaneous emission. A prepulse monitor (an add-on module) may be attached to any IBD package to determine the energy contained in pulses that arrive before the main pulse and that can destroy the target if sufficiently energetic.

3. NOVA Integrated PFC/RBD Package

The present PFC and RBD packages are the results of a parallel evaluation of the two packages, rather than an integrated design. Such an integrated concept has the potential of providing the same information, but at somewhat lower complexity and cost. For example, the PFC sensor, when originally designed, contained a simple dump mirror to direct energy from the vidicon and detector at firing. The movable mirror presently seats on a kinematic mount to provide the pointing consistancy of a few microradians necessary for satisfactory operation of the RBD package. However, this moving mirror could be eliminated in an integrated package.

Figure 5 is an example of such an integrated package. The sensor, scaled for NOVA as shown, provides all of the PFC sensor functions, as well as the required RBD functions. Provision for an external streak camera

SHIVA IBD SENSOR PACKAGE



Note: All dimensions are in millimeters unless otherwise indicated.

FIGURE 4

PFC/RBD SENSOR PACKAGE

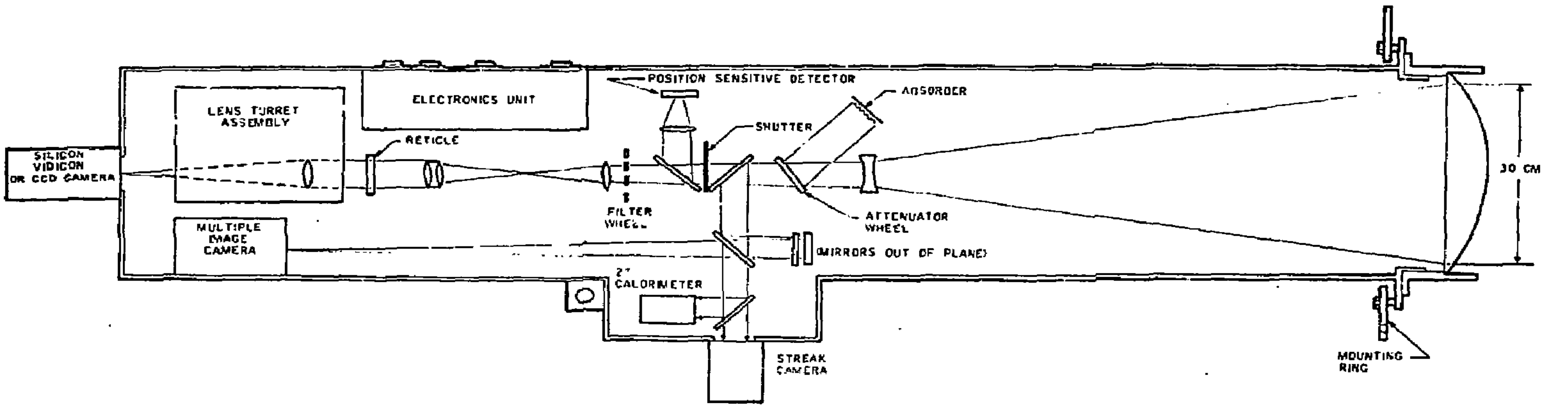


FIGURE 5

is provided, as well as a calorimeter capability and a one dimensional multiple image camera.

In this package, the present PFC sensor objective lenses have been scaled, at the same f/number, to accomodate the anticipated 30 cm NOVA beam diameter. The beam is then diverged, in a negative lens, to a focus approximately one meter behind the negative lens. This configuration provides a net magnification at the focus of 4.2, relative to the target chamber, presuming an f/6 target focus lens. This net magnification is lower than that of the SHIVA multiple image camera magnification of 7.6. The reduction is justified by the expectation of larger targets in NOVA, compared to that of SHIVA.

The output of the negative lens is divided, after the negative lens, between the PFC functions and diagnostic functions. Experience has indicated that sufficient energy is available, even with such attenuation, to adequately perform both the PFC and diagnostic functions. Additional attenuation must be provided, however, to bring the system within a safe operating range. Linear aperture scaling, and appropriate glass choice can bring the energy density at the negative lens to as high as $5 j/cm^2$ for 100% reflection from the target, and a 2% transmitting mirror. Even though a factor of two attenuation is attained in the beam splitter, providing linear operation of the calorimeters, the high beam energy density may even require attenuation before the negative lens. The method of attaining this added attenuation is not yet defined.

The desired dynamic range of 10:1 against reflected energy variation is easily attained, as a return beam energy of 10% of 3375 joules provides 1.6 joules at the calorimeter, without attenuation. A 10:1 further attenuation still provides operation within the calorimeter dynamic range.

The multiple image camera is likewise within performance requirements with the additional 10:1 attenuation. Assuming a ten image camera, with a dynamic range of 10^3, the weakest image at a reflected beam energy level of 3375 joules with a 3 mm target is $0.5 m\ joule/cm^2$. The brightest image at 10% of maximum beam power (about 300 joules) is $67 m\ joule/cm^2$. Thus, the multiple image camera operates nicely within its dynamic range with the addional attenuation.

The diagnostic outputs are split off without requiring the moveable mirror of the SHIVA PFC sensor. The cost, however, is the negative-positive lens pair shown in the Figure. As the system operates essentially on axis and the lenses are fairly small, the trade seems worthwile. Further, the configuration permits the use of a drop-in shutter to protect the vidicon and detector. At high energy density levels, a mirror and absorber may be necessary. The quasi-collimated beam also permits the insertion of attenuating filters well ahead of the vidicon, as well as a transmission beam splitter. Both factors alleviate design difficulties encountered in the SHIVA PFC sensor.

Following the shutter, 50% of the CW alignment laser energy is split off to a lens assembly and a Lateral Photovoltaic Effect Detector, the same detector used in the SHIVA sensor. As in that sensor, the lens and detector are so positioned as to reimage the centering plane (typically one focal length ahead of the target chamber final focus lens) on the detector, with approximately a 30:1 demagnification.

Using techniques as in the SHIVA PFC sensor, the centering screen is reimaged also upon a reticle, which provides a vidicon position reference, independent of the turret alignment. As many as six lens sets may be mounted in the turret, providing, for example, two levels of magnification when viewing the centering screen, and two fields of view when viewing the target chamber focal point. Capability is also present for viewing the opposing beam spatial filter pinholes, with appropriate magnification, for beam alignment purposes.

Mounting of the sensor is somewhat simplified. A mounting ring, at the entrance aperture, is indicated in the figure, together with a single strut mounting at the back of the sensor. The electronics are located in the package, on a swingout mounting, rather than outside the package as at present.

4. Incident Beam Diagnostics Package

The incident beam diagnostics package, shown in Figure 6, uses

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IBD SENSOR PACKAGE

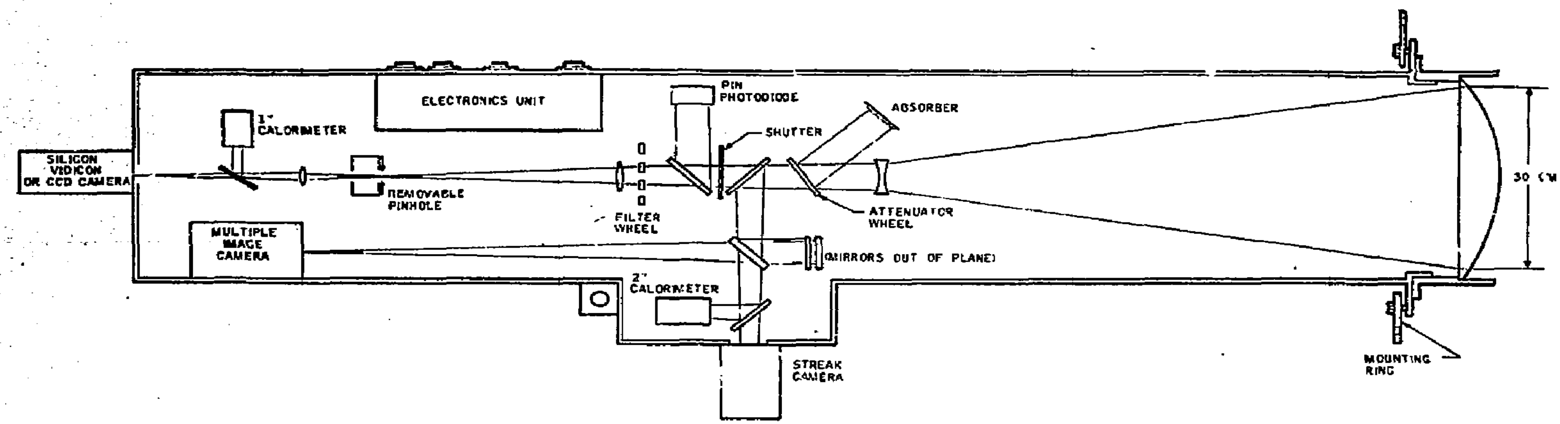

FIGURE 6

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the same housing and the same basic optical configuration as the PFC/RBD package of Figure 5. The housings for the two units, as well as objective lenses and a significant number of smaller optical components, could be identical, as shown in the figures.

The multiple image camera and calorimeter units are similar, however, the IBD package provides two dimensional information (intensity and image plane variations), by the addition of the double, partially reflecting mirror shown in the figure. As indicated, the energy is folded out of the plane of the paper for the multiple field camera.

In the IBD package, a fast response photodiode package is substituted for the Lateral Photovoltaic Effect detector of the PFC/RBD package. A removable pinhole and calorimeter has been located in place of the vidicon imaging system and turret, with reimaging optics provided for the vidicon. This pinhole assembly performs the desired function of measuring the amount of energy imaged within a prescribed diameter. The vidicon permits alignment of the beam spatial filters, as their apertures are reimaged at the pinhold plane. This capability is somewhat redundant, incidentally, with the similar capability of the vidicon in the PFC/RBD package.

As with the PFC/RBD package, magnification values are somewhat smaller than with the SHIVA packages, due to the larger anticipated target sizes. For example, the magnification from the target chamber to the pinhole is 2.1 in this case, compared to 10 for the original system. Similarly, the magnification to the multiple image camera in the new design is 4.2, compared to 17 for the SHIVA package. Presuming 1 mm diameter targets as a minimum, the new pinhole would be 2/mm in diameter. The image at the camera would be 4.2 mm, subtending 42 lines at 10 lines/mm film resolution. Thus, the reduction in magnification should be justifiable in terms of NOVA target scaling.

The same energy density problem exists in the IBD as in the RBD package. Presuming that the energy per beam is scaled according to aperture area, and that better glasses provide a factor of 3 higher energy density capability in the laser, approximately 3400 joules could be present at the final pointing mirror, and 68 joules at the IBD aperture with 2% mirror transmission. An energy density of over $5 j/cm^2$ is present at the negative lens with these values. Alternatives are: reduce turning mirror transmission; place attenuator at a larger diameter position in the beam (which may entail a reflective attenuator due to astigmatism); increase the diameter of the negative lens; or obtain a negative lens and coating to withstand this energy density. The best solution, or combination of solutions is not yet clear.

It is clear, however, that the indicated IBD package provides a reduction in size from the current configuration, and permits a potential cost reduction due to its commonality with the PFC/RBD package configuration.

5. Cost Comparisons

Detailed cost analyses of the two modified sensor packages have not been performed, therefore only qualitative comparisons with the SHIVA costs are possible. The following factors are clear, however:

1) The cost for the SHIVA production PFC sensors, including objective lenses, beam dump mirrors and TV cameras was about 10% below the \$51.5K per unit projected for a 20 cm aperture diffraction limited system in an earlier report under this contract.

2) It was predicted in the same report that the change to 30 cm aperture would result in costs of about \$58K.

3) The elimination of the beam dump mirror and its associated positioning accuracy requirements appears to achieve a net savings, in spite of the additional optics needed to perform the dual role of the PFC/RBD system.

4) The complexity of the IBD package is somewhat less than the PFC/RBD unit, due to elimination of the turret.

Thus, based on a similar quantity of units, the factors above would lead to the cautious conclusion that the two packages would each cost of the order of the present PFC production sensor, namely about $50K.

Applying an 85% learning curve, assuming 100 units were built (50 PFC/RBD and 50 IBD), and recognizing that 20 units were built for SHIVA, the average production cost might be of the order of $35,000.