LASER VIEWING SYSTEM FOR IN-VESSEL INSPECTION AND CONTROL IN LARGE FUSION MACHINES (JET AND ITER)

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Abstract

An amplitude modulated laser in-vessel viewing system for JET and ITER fusion machines has been developed in ENEA Frascati laboratory for control and maintenance purposes.
The system has a very versatile configuration so that it can be tailored to be applied in several fields in which the lack of accessibility and hostility of the environment of sounded target is the main problem of the vision task.
The developed system is an incoherent electro-optical device in which an amplitude modulated diode laser beam is steered through a single mode optical fiber and a focusing collimator toward a target by a prism based scanning camera; the back scattered signal is collected by a completely passive optical receiver situated in hostile environment (Temperature 350 °C, Vacuum 10^{-9} mbar, radiation background 3 x 10^4 Gy/hr for JET experimental conditions) and focused through a suitable optical fiber path on a avalanche photodiode surface situated in a safety environment.
The received signal is then acquired and processed and the pixel rows and columns lines are restored by means of optical encoders tied to scanning prism itself to obtain a high quality image of the scanned scene. The scanning accuracy is better than one millimetre at ten meters of distance; this is in fact a sufficient resolution to achieve an image quality to highlight all defects and damages due to plasma disruptions during the machine shots.
Laboratory tests on an insertion probe mock-up have been performed by scanning real large aperture scene and the obtained results are discussed.

1 GENERAL DESCRIPTION AND WORKING PRINCIPLE

An 840 *nm* laser beam, generated by an optical module placed in control room, is routed into an optical fiber to a scanning mechanism inside the vessel [1,2,3].
With respect to the launched beam, both intensity and phase shifting of the backscattered light are detected. On the basis of the signal intensity, the target picture is reconstructed, whereas on the basis of the signal phase shifting, the target ranging can be performed. The Laser In Vessel Viewing System (LIVVS) for JET includes a scanning probe. The probe supports the laser scanning prism [see figs. 1 and 2], makes it rotate, in both pan and tilt directions, and is equipped with two optical encoders to measure the laser beam scanning angles. In order to match the vessel movements (due to the thermal gradients), an appropriate beam alignment system is placed above the LIVVS probe. It should be pointed out that owing to the laser technology, no additional light sources are required. All the relevant components are rated for in vessel conditions, that is ultra high vacuum (10^{-9} *mbar*), 350°*C* (scanning head), neutron (about 10^{21} n/m^2) and radiation (3 x 10^4 Gy/h; 5 x 10^6 Gy total). The required accuracy is 1 *mm* @ 10 *m*, the target distance ranging from 0.5 to 10 *m*.

Fig. 1 (Probe head)

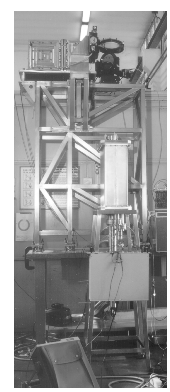

Fig. 2 (Frascati mock-up)

2 LIVVS ARCHITECTURE

The general LIVVS architecture is shown in Fig 3.

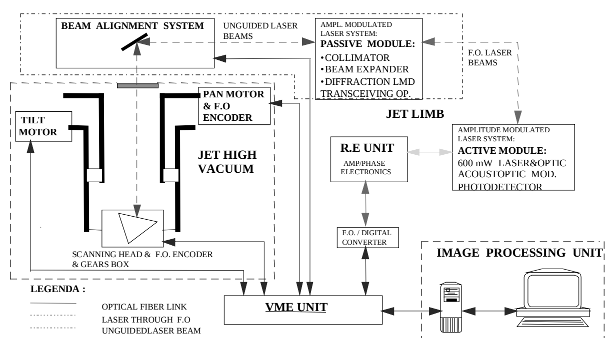

FIG.3 JET LIVVS BLOCK DIAGRAM

The LIVVS main parts are (see Fig. 3):

Active and passive optical modules.

The active laser module (Fig. 4) sends, by means of a coherent optical fiber, the laser signal from the control room to the passive optical module, 120 *m* far away. This is hosted near the probe unit. The laser beam is launched to the target, through the beam alignment module and the probe scanning head. The passive module (Fig. 5) collects the backscattered light and sends it to an avalanche photodiode (APD) located in the active module, in the control room.

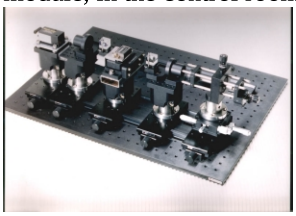

Fig 4 (Active module)

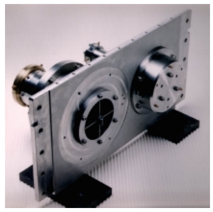

Fig. 5 (Passive module)

Radar Electronics (RE) unit.

The radar electronics is an hardware equipment that receives the APD output and calculates, at 100 kHz speed, the amplitude and phase signals from the backscattered beam and send them to the VME unit to be stored.

VME unit.

The VME unit has two main tasks: the first is to drive, by means of a custom board, the pan and the tilt motors for the probe and the four movements of the beam alignment system. The second one is to acquire the data coming mainly from the encoders and the radar electronics, to pack it, and to store locally on VME disk or to send data across the network to the image processing workstation. The VME boards were developed in collaboration with the IST institute of Lisbon (Portugal). [4,5].

Beam alignment unit

The alignment unit allows to match the laser spot to the center of the prism. Four motors and the related encoders permit a semi automated alignment procedure.

Image processing unit

The image processing unit is a UNIX Silicon Graphics workstation. Here is possible to visualize the acquired images, to perform elaborations and to save the images suitable for printing.

3 IMAGE FORMATION

The in vessel scanning system is made up by a prism rotating around two axis (tilt and pan, see fig. 6).

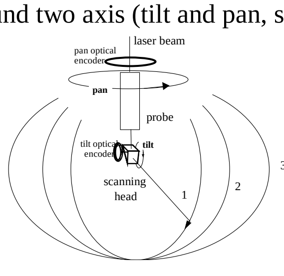

Fig 6

In this way the laser beam is polar deflected above the in-vessel surface in a quasi-spherical field of view (-10° to 150° tilt, 180° pan see fig. 7).

In fig. 8 the deflection angle of laser beam is shown depending on the prism rotation.

In the a) position the laser beam is not deflected by the prism (dead zone) and this position is used to perform the alignment procedure.

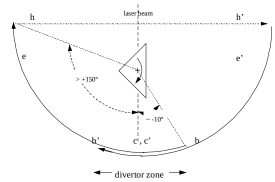

Fig. 7

The b) position is the first one useful for scanning; here the beam is deflected of about -10° degree referred to the 0 as defined in fig. 8.

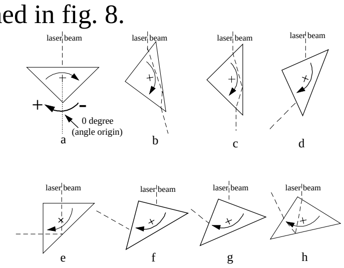

Fig 8

From this point, further rotating the prism of about 80° degrees, the laser beam is deflected from –10° degree to about +150° degree. In particular in the c) case the spot is perfectly vertical on the tokamak divertor zone and in the e) case the spot is deflected of an angle of 90 degree. Further continuing the rotation the laser spot exceed the prism vertex and the scansion is symmetrically repeated in the other side of the vessel from h' to b' (see fig. 7). It has to point out that the overall scansion is performed by only 180° degrees of probe axial rotation and that the divertor zone is twice scanned, therefore it is possible to improve the image quality in this zone taking into account the two information.

A "complete general view" of the vessel is performed tilting the prism with constant rotation speed of about 1 turn per second, and rotating the prism axially with the probe (pan) with a constant speed of 1/3 of turn per hour. Moreover, it is also possible to perform a "zoomed view" reducing, at the same time, the tilt and pan scanning angles and, also, the scanning velocity down to 0.06 turn/second, for tilt, and to 1 turn in three hours, for pan: in this way the same amount of pixels can be acquired from a reduced area of the vessel performing a more accurate view.

During the scanning RE radar electronics, connected with the optical head, gives out two 100 kHz digital information, the first representing the amplitude of the back-reflected laser beam and the second the phase shifting between the launched and the back-reflected laser beams.

As mentioned before, the control/acquisition system acquires and stores the RE and optical encoders output signals together with the value (time-stamp) of an internal VME timebase having the resolution of 1 microsecond. The time-stamp is used to interpolate positions between two consecutive encoder marks.

4 IMAGE GALLERY AND DISCUSSION

Figs. 9 and 10 are typical laboratory images. The first image shows a portion of a laboratory acquisition. The overall raw image was about 800 MBytes. The image was acquired in about 20 minutes and has about 40 Mpixels (each pixel in the raw image is coded with 20 bytes). The portion in the image is the range 0 to 180° degree of panning, 10° to 90° degree of tilting**.**

The second one shows a plant acquisition in the laboratory. Note that there is no additional light illuminating the scene and then, all the target pixels are illuminated in the same way, while the intensity of the backscattered light depends on the surface characteristics and the beam incidence angle.

Figs. 9 and 10.

It must be pointed out that the image is a grey scale one with a 24 bit amplitude dynamics. Sometime is necessary to stress a subrange of such dynamics to avoid loss of information. This is possible with the near-grey pseudo colouring or with a LUT-remap in the subrange.

Fig. 11

Fig. 11 shows a real zoom of a portion of the fig. 9 image. In this image there is no big distortion, in fact it is part of a 3D projection of the image onto a sphere.

The fig. 12 and 13 shown the Amplitude/Range capability of the system. A little statue called "putto" was taken by the system both in amplitude and in range, with an accuracy better than 1 mm @ 10 m.

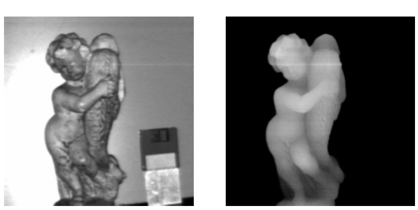

Fig. 12 and 13

The important fact to say is that the images are simultaneously acquired, i.e. each pixel is correlated.

5 VISUALIZATION ENVIRONMENT

At moment the visualization system is developed using software developed by ENEA that use OpenGL software library and a tool set to transform the raw data in clean object to be viewed. There is a collaboration with the CASPUR university consortium to build a graphical interface able to view and manipulate the acquired images. The software used is AVS/Express. In the fig. 14 there is a screenshot of the interface in developing.

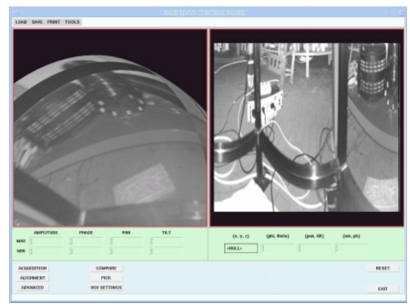

Fig. 14

6 CONCLUSION

The LIVVS system described in the paper has demonstrated to satisfy the required performances. At moment the LIVVS is foreseen to be installed and tested within the current year, depending also on the JET experimental program.

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