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A semiautomatic method for optical radar probe alignment.

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Abstract: - An optical radar, for periodic inspection in the fusion machine or more in general in any hostile environment, has been developed by the Italian National Agency for New Technologies, Energy and the Environment (ENEA). This Laser scanner system is named In Vessel Viewing System (IVVS) and it comprises a mechanical probe, a Control and Data Acquisition System, and a customized Radar Electronic System [1].
IVVS needs an alignment system to correctly align the laser beam, coming from the passive module, to the scanning head. A possible alignment system is based on two motorized mirrors with 4 degrees of freedom.
In this paper a semiautomatic alignment procedure, using motorized mirrors and customized software, is described.

Key-Words: - In Vessel Viewing System (IVVS), laser alignment system, alignment image.

1 Introduction

IVVS is a viewing and ranging system based on a customized Optical Radar [2] developed in ENEA.
IVVS has been designed and tested in order to operate inside hostile (high temperature, ultra high vacuum, radiation up to about 3MGy) fusion experimental devices [3, 4].

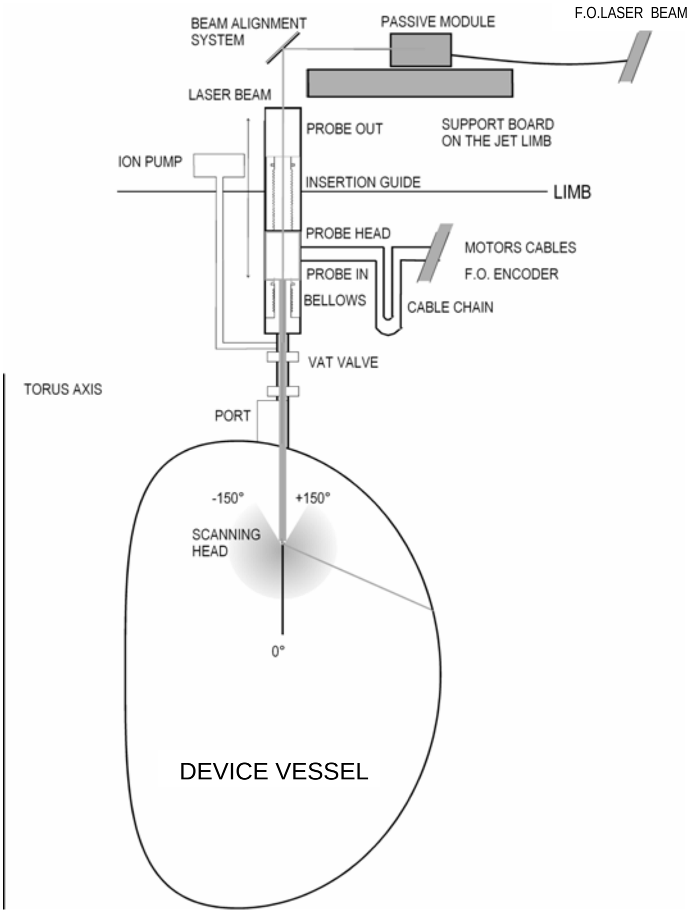

Fig. 1. Layout of the IVVS probe inside the JET tourus machine

Fig. 1 shows a possible IVVS insertion through a vertical port with the laser beam launched in air. Scope of the beam alignment system is to set the laser spot at the centre of the scanning prism.

2 Laser scanning description

On the tip of the probe, there is a scanning head with a prism that is able to rotate around 2 orthogonal axes: tilt and pan.
The laser beam launched by the passive module is reflected by the 2 mirrors of the *beam alignment system*, Fig. 3 , before passing through the probe. Eventually the laser beam is deflected by means of the prism located at the end of the probe itself.
The prism revolution around tilt and pan axes deflects the laser beam to perform a polar scanning of the vessel. The backscattered light is collected by the *passive module* and processed by the Radar Electronic System and the control and data acquisition system, to achieve high resolution images [4, 5].
To obtain good quality images it is necessary that the mirrors direct the laser beam exactly to the centre of the scanning prism. To simplify the alignment procedure a pattern is drawn on the back of the scanning prism, Fig. 2.

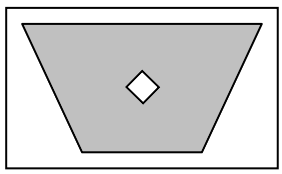

Fig. 2. Marker painted on the back of the scanning prism.

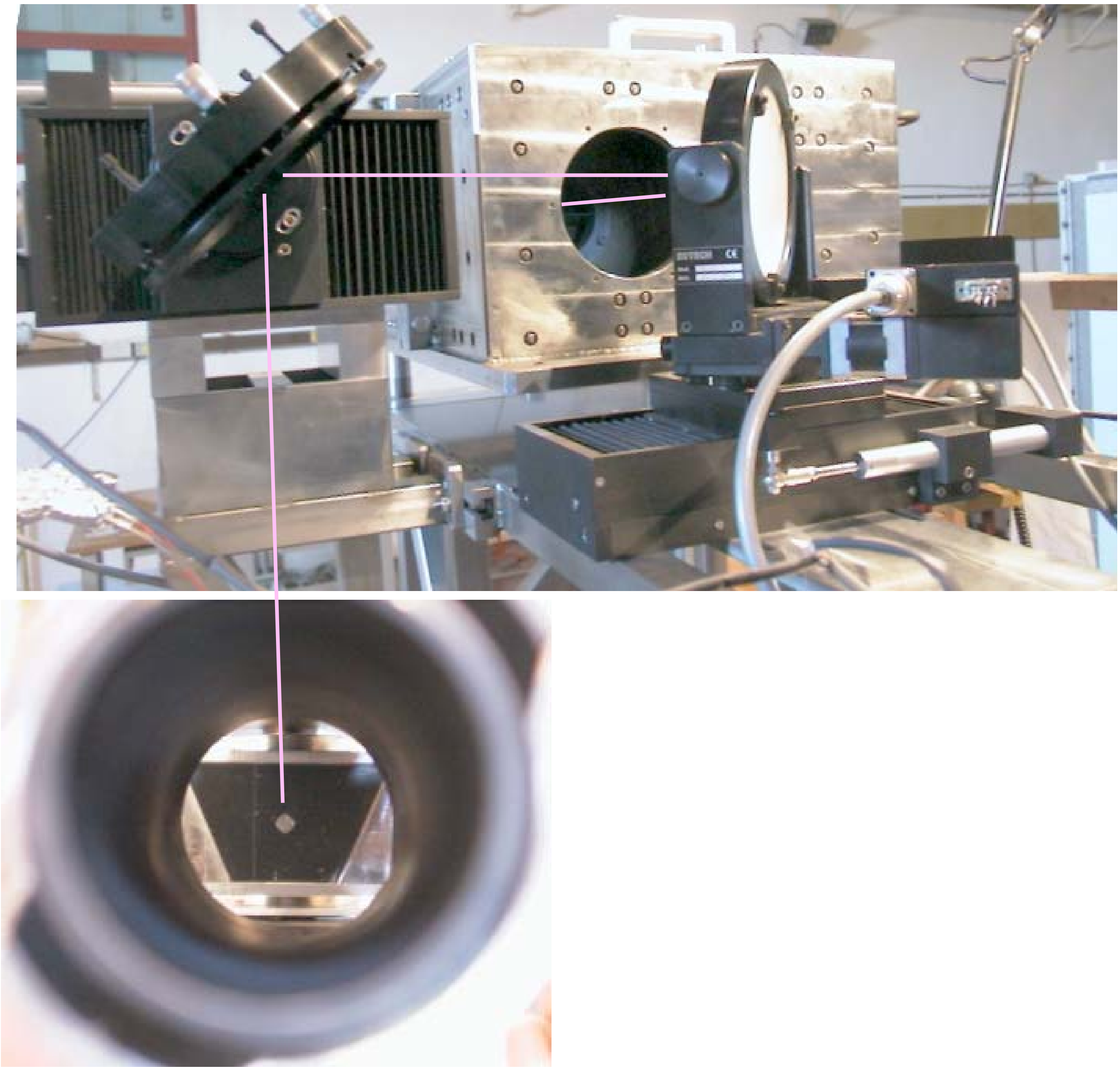

Fig. 3. Photo of the IVVVS system present in the ENEA laboratories.

3 Present alignment scanning system

The alignment system consists of 2 motorized mirrors. The first mirror has 3 degrees of freedom associated with 3 step motors (q1 x1-translation, α1 Z1-rotation, β1 rotation orthogonal to Z1 (Euler rotation)), Fig. 5.
The second mirror has only one translation degree (q2 y2-traslation) associated with one step motor. The two mirrors are equipped with high accuracy mechanical reduction gears. All the motors are radiation resistant.

Fig. 4. Alignment mirrors.

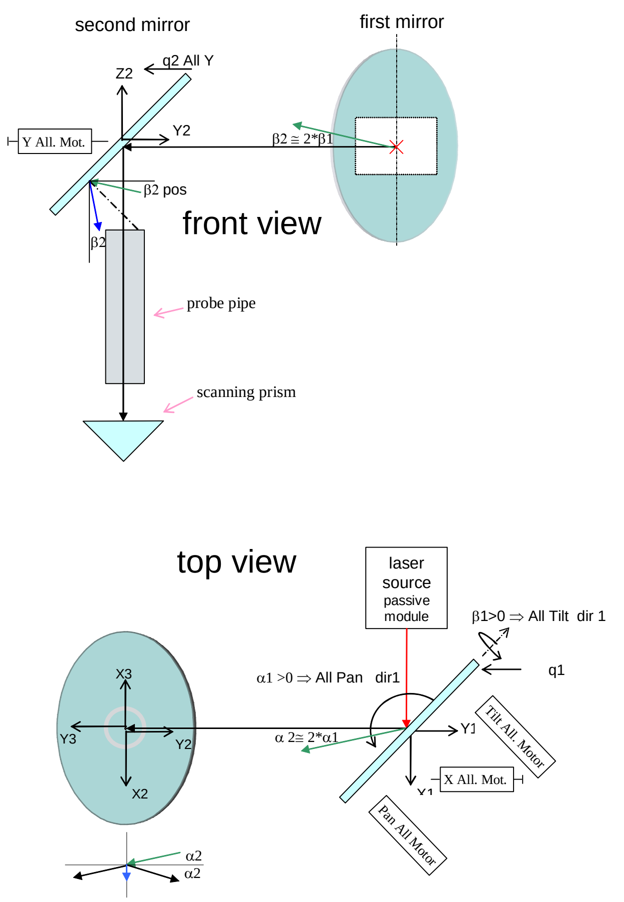

Fig. 5. Schematic diagram for mirrors freedom degree (not in scale).

3.1 Alignment image

Alignment image has to be created by using the same Radar Electronic System and Control and Data Acquisition System which are used for normal viewing operations, with the addition of a specific software interface. Moving the first and second mirrors following two synchronized trajectories, the laser beam scans orthogonally the space above the second mirror, as shown in Fig. 6.

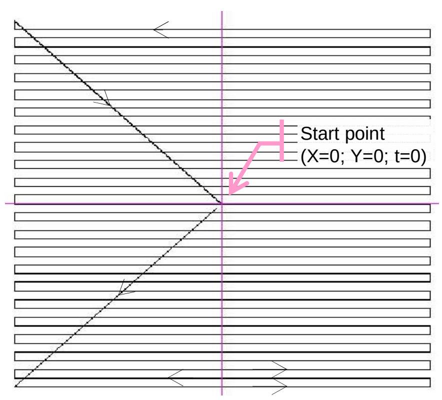

Fig. 6. Laser beam trajectory during the alignment image scanning.

The back scattered light received by the radar electronic unit is converted, acquired and eventually used to produce an alignment image. The focus of the laser beam focuses on the vacuum vessel, therefore the consequent *alignment image* is out of focus. However it is possible to obtain understandable images Fig. 9.

4 Problem Solution for the alignment

To perform a correct laser alignment it is necessary to know the correct parameters which are: α1 and β1 angular displacement of the first mirror, the translation q1 of the first mirror, and the translation q2 of the second mirror.

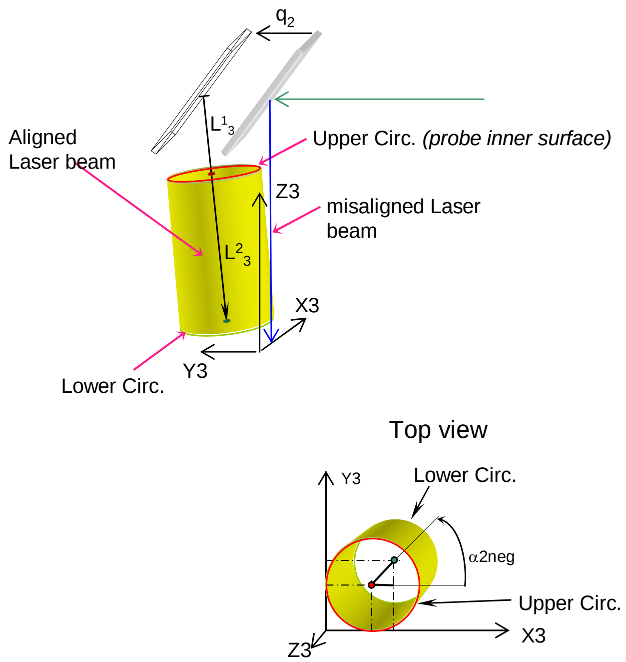

Fig. 7. Example of alignment.

Using the coordinates of the centres of the upper and lower circumferences that can be seen in the alignment image Fig. 8, it is possible to know these 4 parameters.

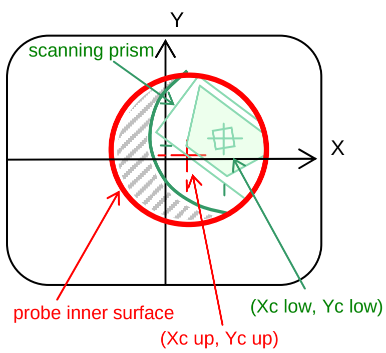

Fig. 8. Schematic alignment image (unaligned probe).

In general the IVVS system is previously aligned using a manual procedure, therefore the misalignment angle is very little max ±0.2°. The present procedure makes possible to recovery that value with an accuracy of about ±0.005°.
In this situation α1 and β1 are so little that the following approximated formulas ca be used (1).

$$
\begin{aligned}
\alpha_1 &= -1/2 \cdot \text{atan2}\,(L''_3, (Xc_{low} - Xc_{up})) \\
\beta_1 &= -\frac{1}{\sqrt{2}} \text{atan2}\,(L''_3, (Yc_{low} - Yc_{up})) \\
q_2 &= Yc_{low} + \left(Yc_{low} + L_2 + L_3\left(1 + tg(\sqrt{2}\beta_1)\right)\right) \cdot tg(\sqrt{2}\beta_1) \cong \\
&\cong Yc_{low} + L_3 \cdot tg(\sqrt{2}\beta_1) \\
q_1 &= \frac{Xc_{low} + (L_2 + L_3 + q_2) \cdot tg(2\alpha_1)}{tg(45° + \alpha_1)} \cong Xc_{low} + L_3 \cdot tg(2\alpha_1)
\end{aligned} \qquad (1)
$$

where:
Xc_{up} and Yc_{up} are the coordinates of the centre of the probe inner surface;

Xc_{low} and Yc_{low} are the coordinates of the marker in the prism;

L_2 is the distance between the first and the second mirror;

L''_3 is the length of the IVVS pipe;

L_3 is the distance between the second mirror and the prism.

5 Alignment software description.

The software for the alignment procedure consists on a command window and a graphics window that shows the alignment image.
The program source code was written in C++ language using the GL, GLU, GLUT graphics library in a Silicon Graphics® computer.
The Fig. 9 shows an image of an unaligned probe.

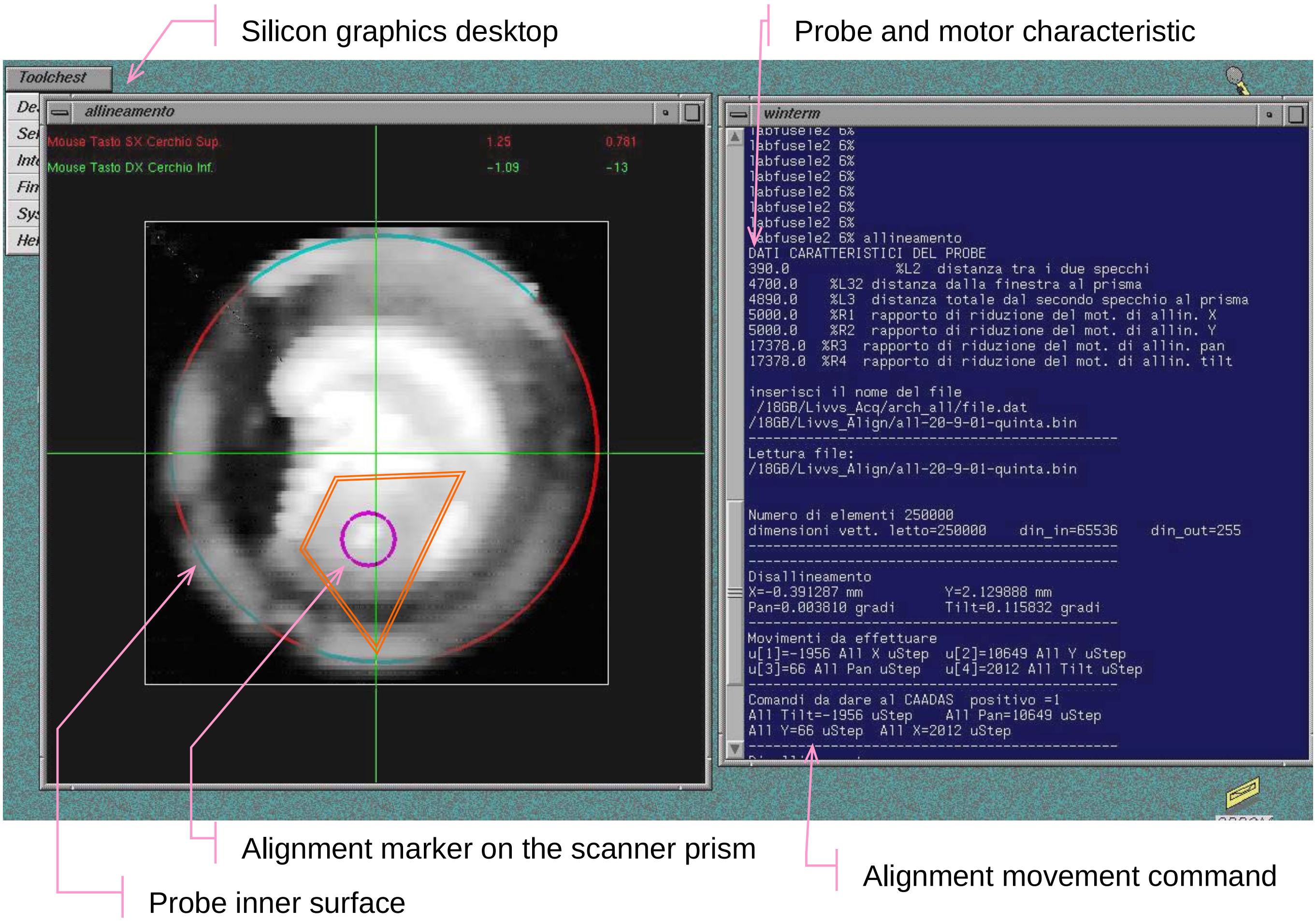

Fig. 9. Silicon graphics screen during the alignment procedure.

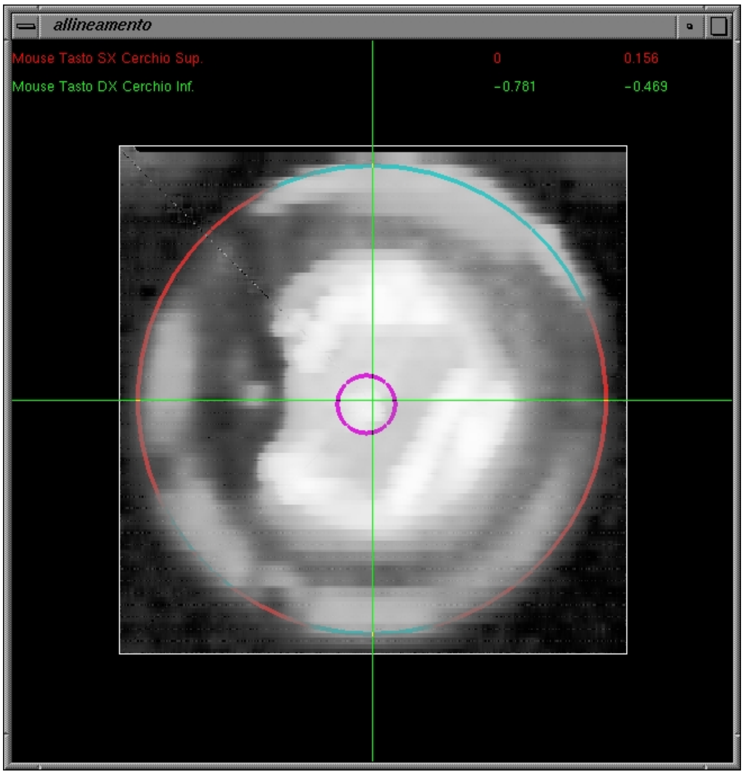

Fig. 10. Alignment image after the alignment procedure

It is possible to select the centres of the circles related to the probe inner surface and the back scanning prism, by clicking on the graphics window with the left and right mouse buttons. The centres coordinates are shown in the top border of the graphics window. By clicking on the central mouse button, the command window shows the calculated movements to be performed by the alignment motors.

6 Conclusion

The method and the alignment software procedure were tested, with the IVVS probe installed in ENEA Frascati laboratories, with good results. Generally speaking, by performing one alignment procedure a good approximation is obtained. If it is necessary, the alignment accuracy can be can be improved by iterating the procedure.

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