Laser radar sensor for hostile environments

M. Ferri De Collibus, L. Bartolini, A. Coletti, G. Fornetti, C. Neri, F. Pollastrone , M. Riva, L. Semeraro

ENEA,Italian national agency for new technologies,energy and environment, Via E. Fermi 45,00044 Frascati, Rome, Italy, ferri@frascati.enea.it

ABSTRACT

A prototype of a laser in vessel viewing and ranging system has been developed at ENEA laboratories. It is based on an amplitude modulated (AM) laser radar specifically designed to withstand with the severe ITER (International Thermonuclear Experimental Reactor) conditions. The sensor is able to perform at the same time, viewing and ranging of in vessel surface during maintenance procedure; this means that the system has to properly operate under UHV (10^{-9}mbar), HT (up to 200^{o}C), HB(up to 6T) and gamma radiation (up to 5MGy total exposure). The sensor is foreseen to be introduced by means of a proper carrier through a divertor port. A series of viewing and ranging tests have been performed on the system to better evaluate its main characteristics that can be resumed in auto-illumination, large field of view, zoom capability, range and intensity simultaneous pictures, high dynamic range. The small dimension of the optical head allows to use this sensor in hostile and limited clearance environments; its applications areas are: nuclear (nuclear plants decommissioning, hot cells), industrial (furnaces check and high temperature environments), civil protection , spelaeology (places with difficult access), mapping of volcano craters.

1. INTRODUCTION

Machines for thermonuclear fusion research like JET [1] and ITER [2] need periodic inspections to check damages on the vessel components. In future reactors , where large amounts of neutron and gamma radioactivity will be produced, CCD and electronics systems directly inserted inside the vessel cannot be successfully used [3]. To overcome this problem a prototype of a AM laser radar has been developed at ENEA laboratories in the framework of EFDA (European Fusion Development Agreement) activity. In a AM laser sensor scheme [4], the laser beam amplitude is modulated (up to hundreds of MHz); intensity and phase shifting of the reflected beam (with respect to launched one) are simultaneously detected. High resolution intensity and phase pictures are obtained by means a dedicated electronic system.

2. ELECTRO OPTICS LAYOUT

Two main blocks compose the electro optics scheme: the active and the passive modules. The active module has been designed to be placed outside the bio-shield and contains the laser, the photodetector and all the electronic apparatus. The passive module (fig. 1) has the scanning system and the optical components of the transceiver; both are connected by means of radiation resistant optical fibers. A 10 mW, 830 nm laser diode is amplitude modulated at 80 MHz with a 80% modulation depth . The sounding beam is transmitted on the target by means of a rotating prism which scans the scene over 165*360^{0} field of view and the scattered signal is collected by the transceiver (fig.2).

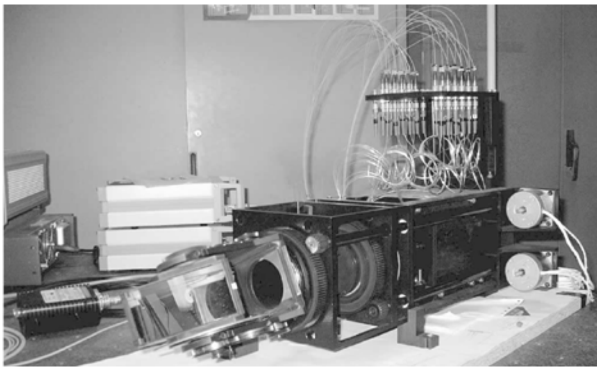

Fig. 1. Passive module

This consists in a monostatic hybrid optical scheme involving two optical sections: the first is a diffraction limited antenna transceiver (DLAT) , which is a small aperture transceiver that sends a coherent single mode focused laser beam on the target, the second is a large aperture multispeckle receiver (LAMR) which has a 50 mm collected lens and focal length 150mm. To increase the ranging accuracy a large number of speckle is collected and a coherent bundle of single mode optical fibers is used to avoid the dispersion effect typical of large diameter fibers, so the signal is transmitted over long distances without resolution degradation.

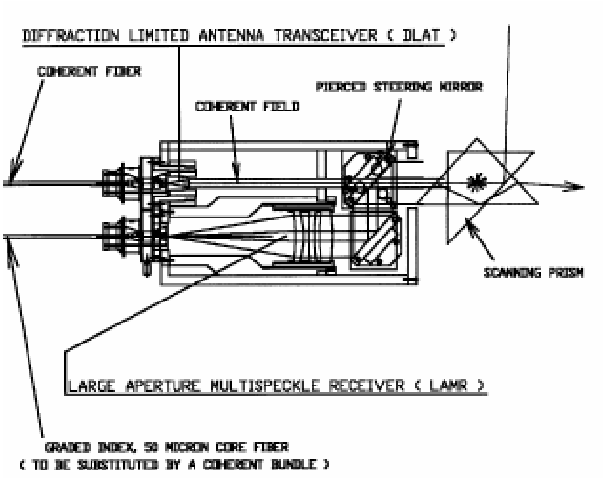

Fig. 2. Optical layout

The collected optical power (Eq. 1), the current signal to noise ratio (Eq. 2) and the range noise (Eq. 3)are shown in the following equations:

$$P_R = \frac{P_i \, \varepsilon \, T \, \rho \, A^2 \cos\Theta}{4 R^2} \qquad (1)$$

$$SNR_i = \sqrt{\frac{P_R \, \eta \, \tau}{h \nu}} \qquad (2)$$

$$\sigma = \frac{c}{2\sqrt{2}\,\pi \, m \, f_m \, SNR_i} \qquad (3)$$

where P_i is the sounding power, ε the optical efficiency, T the transmission of the interferential filter, ρ the reflection coefficient of the target, cos(Θ) the lambertian factor, R the target distance, η the quantum efficiency of the detector, τ the integration time, ν the laser frequency, m the modulation depth, f_m la modulation frequency and PST is the stay time pixel . The radar equations (fig. 3-4-5) show typical values of the main parameters for example in 2-7 meters range:

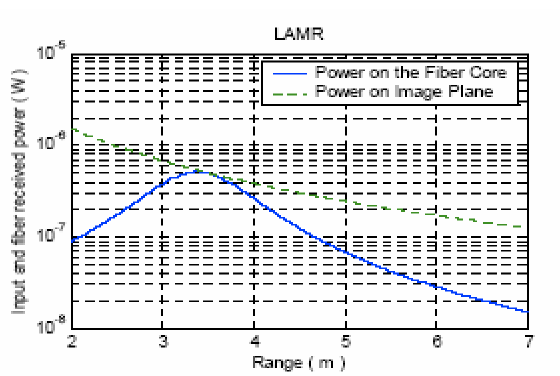

Fig.3. Collected power

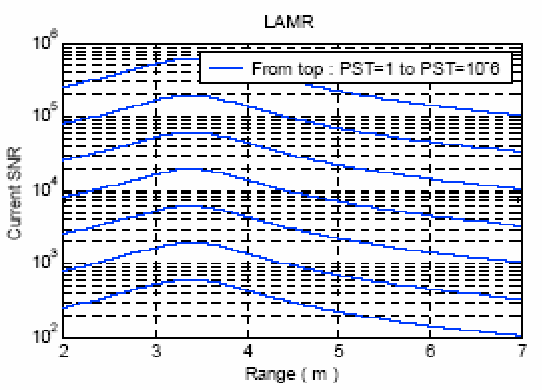

Fig. 4. Current SNR

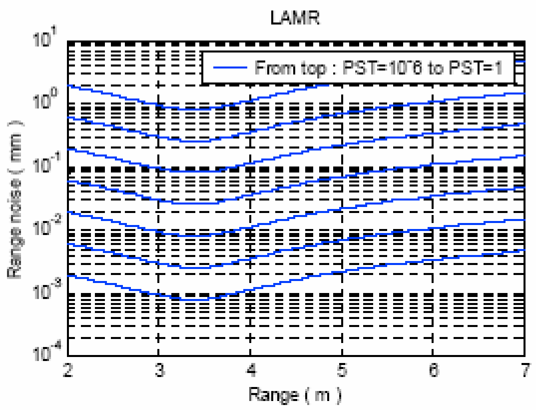

Fig.5. Range noise

the measurements can be extended up to several hundredth of meters with good range resolution by increasing the optical power and the frequency modulation. In this case we have foreseen a double modulation frequency scheme (for example 1 MHz and 200 MHz) to avoid unambiguous range measurements.

3. MECHANICS

The probe scanning head (fig. 6) has been designed taking into account the space available, the inner components assembling procedures, the mechanical, electrical and optical procedures and the optical fibers bending radius [5] . The weight of the probe is approximately 20 kg. The rotation speed ripple is controlled using very accurate gearing and a gear play recovery system. The prism position is detected by means of two optical encoders modified to meet the vacuum and the radiation specifications. The rotation encoder disk is fixed to the prism while the revolution encoder disk is fixed to the inner pipe. The encoder disks are read by means of optical fibers by the electronic system placed in the control room .
Table 1 summarizes components and materials used for the sensor.

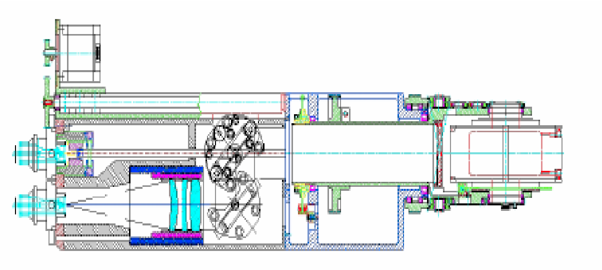

Fig. 6. Probe

4. SYSTEM ARCHITECTURE

The main parts of the sensor are shown in fig.7. In the active module is placed the laser source , detector and all the electronic components to amplifier and filter the signal. The laser beam is sent via single mode optical fiber to the passive module where the light is focused on the target. The collected reflected light by the lens is focused on the coherent bundle and sent in the active module to be detected.

Table 1. Components and materials used

Component	Material
Probe	INCONEL 600
Bearings	AISI 440 stainless steel and ceramics, no lubricant
Gears	INCONEL 600
Encoder disk and collimator	Borofloat with chromium marks
Prism	Fused silica with multi-layered anti-reflective coating and gold reflective coating an the base with ITO protection
Optical fibers	High purity synthetic silica core with doped silica cladding and aluminum coating
Black coating	Black chrome

The radar electronic equipment [6] allows to obtain amplitude and phase shifting with high accuracy, the two angular coordinates of prism are read by means of optical encoders and two tilt and pan motors move the scanning head.

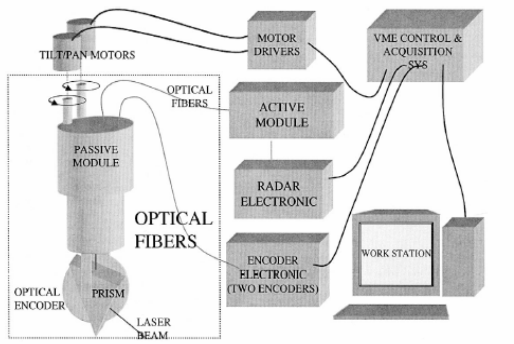

Fig. 7. Control system layout

5. VIEWING AND RANGING TESTS

The main characteristics of the system are synthesized in auto illumination, monostatic configuration, zoom capability, wide scanning angle, high dynamic range, high depth of field, intrinsic robustness. Typical range resolution is 500 micron for 3-10 msec pixel stay time (PST) at 10 meters of distance. We show some intensity and phase images to demonstrate the potentiality of the sensor. A portion of 1639*734 pixel of an acquired image of 52000*2206 is shown in the fig.8, and some details are shown in fig.9 and fig.10. It is possible to appreciate the system viewing performance with different material(stainless-steel, aluminium, black marble, cables, plaster cast etc.); good quality amplitude images are also obtained with a reduced PST (40μsec).

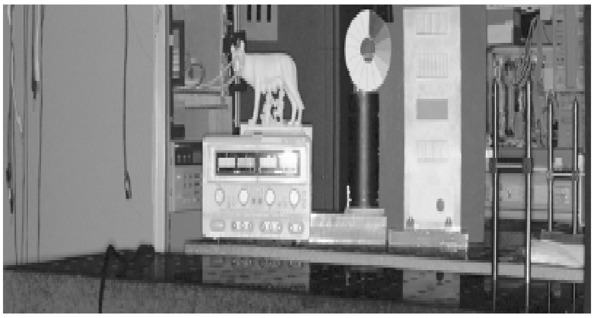

Fig. 8. Intensity image

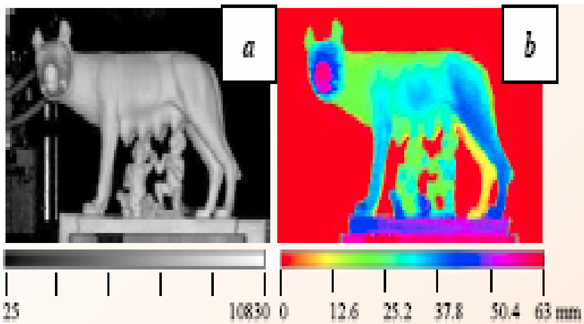

Fig. 9. Wolf detail, amplitude and range

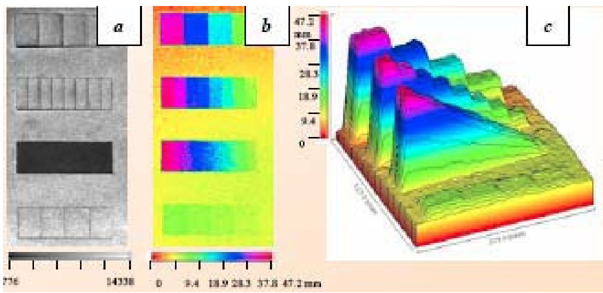

Fig. 10. Stairs detail, amplitude, range and 3D picture

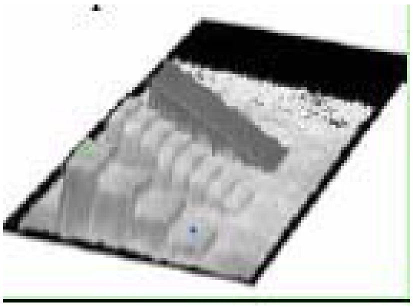

Fig. 11. Data fusion

Merging the simultaneously acquired viewing and ranging data and by means of a dedicated software visualization, a three dimensional image is obtained where geometry and colour surface are taken out from the phase and intensity data (fig.11).

6. CONCLUSIONS

The measurements have demonstrated that this laser radar sensor is suitable to work under ITER in vessel thermonuclear constrains; its viewing and ranging capabilities have been evaluated. The dimension and the weight of the optical head, the system electro-optics project (passive and active module separated) allow its use in several application fields and in hostile conditions (high temperature, high vacuum, high magnetic field and nuclear environment)..

7. REFERENCES

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