Determination of spatial resolution for electron density profile measurements using a two color expanded-beam multichannel heterodyne interferometer in TJ-II

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A two color (CO_2, λ=10.6μm / Nd:YAG, λ=1.064μm) expanded-beam multichannel heterodyne interferometer has been installed on the TJ-II Stellarator (R=1.5 m, a<0.2, B=1 T) for high spatial resolution electron density profile measurements. The system is based on the already operational single channel two color heterodyne interferometer [1], and both (single channel and expanded beam multichannel) will coexist during the current campaign sharing the same plasma access port. For the multichannel system, the plasma is illuminated with an elliptical 100 mm probe beam (major diameter). The choice of a suitable demagnification system and the configuration of the detector arrays (dimensions and separation between adjacent elements) have allowed us to achieve the required specifications for diagnostics. The theoretical calculation of the spatial resolution is based on the theory of Gaussian beams and the diffraction-limited criterion. Experimental validation of the high spatial resolution obtained has been obtained using a prototype CO_2/He-Ne expanded-beam heterodyne interferometer [2].

I. HIGH SPATIAL RESOLUTION TWO COLOR MULTICHANNEL HETERODYNE INTERFEROMETER FOR TJ-II STELLARATOR.

Figure 1 shows the optical layout of the CO_2/Nd:YAG expanded beam multichannel heterodyne laser interferometer installed on TJ-II. The optical design software, Zemax, was used to design the interferometer, to obtain the Gaussian characteristics of the beams at any point in the setup, and to optimize the positions of the optical elements. In this figure you may also observe both the reference and measurement arms where the beams are configured by means of a telescopic system with two off-axis convex and concave spherical mirrors (SM5-SM6 and SM1-SM2, respectively) and an aperture (10×100 mm^2) which was employed due to the rectangular size of the plasma access window. The probe beam is steered to the plasma using a periscope configuration (Figure 2) then reflected by a rectangular mirror located at the top of the port and, finally, it returns to the periscope. The vertical size of the probe beam within the plasma is 105 mm. Both beams are demagnified by a factor of 3.5 by a telescopic system composed of two off-axis concave spherical mirrors (SM3-SM4 and SM7-SM8). After this procedure, the reference and measurement beam spots are recombined using a beam splitter (BS2) and, after this, the interferometric signals are measured by two linear detector arrays (one for each wavelength). The vertical size of the spots within the sensitive area of each detector are 36 mm for CO_2 and 34 mm for Nd:YAG .

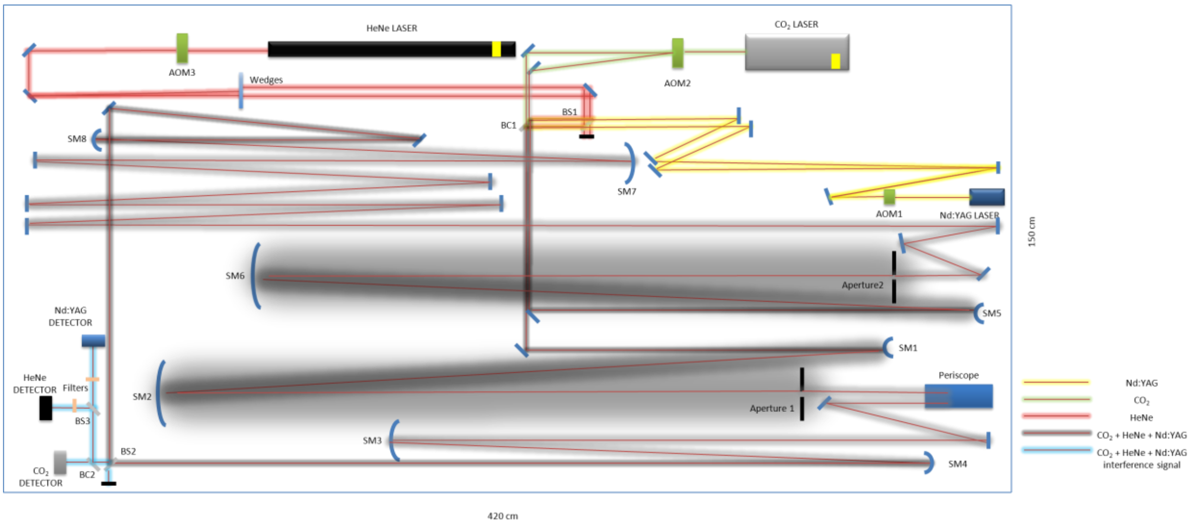

Figure 1

The Nd:YAG signal is detected by a PIN photodiode array with 35 elements (4.4×0.9 mm^2 each one) and the CO_2 detector array, designed with the collaboration of Vigo Systems, is composed of 32 high responsivity photovoltaic elements (3.3×0.5 mm^2). The spacing between the elements is 1 mm for both arrays. In the Figure 3 we show a detail of both linear detector arrays installation on the set-up. The outputs of the arrays are amplified and filtered before the multichannel phase detector [3]. One of the main requirements of the system has been to make the system insensitive to mechanical environmental vibrations which have been achieved by subtraction. Figure 4 shows how both wavelengths (CO_2: red line, Nd:YAG: blue line) are capable of tracking the induced vibrations. This fact allows us to obtain a RMS residual error in the line-integrated electron density measurement due to the uncompensated vibrations (Figure 5) around 7×10^{16} m^{-2}.

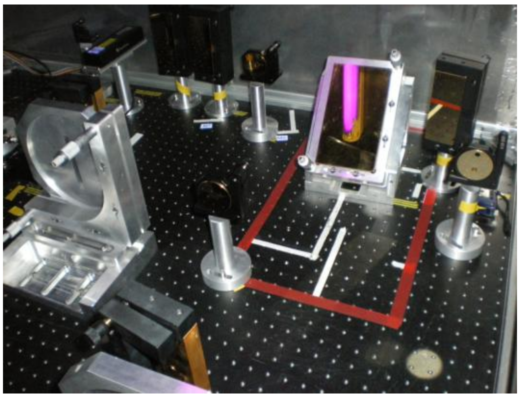

Figure 2

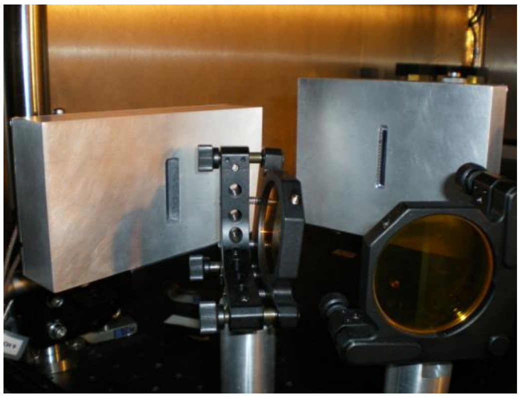

Figure 3

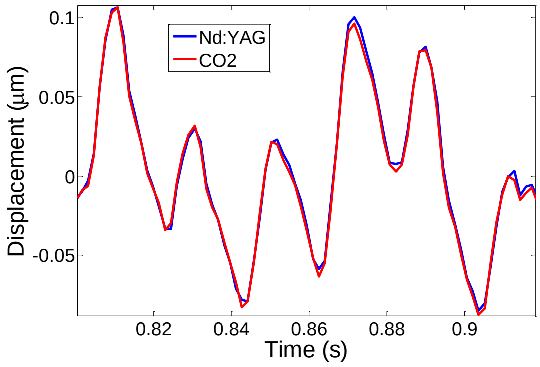

Figure 4

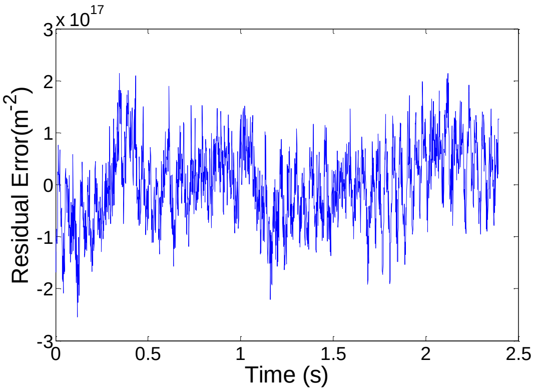

Figure 5

II. EVALUATION OF THE SPATIAL RESOLUTION OF THE INTERFEROMETRIC SYSTEM FOR TJ-II.

An evaluation of the spatial resolution was previously done on a CO_2/He:Ne heterodyne Interferometer prototype at Carlos III University [2] using a rectangular aperture varying its vertical size and observing the different diffraction patterns. This preliminary experiment allowed us to validate the design procedure using Zemax. In any case, we proceed to verify the actual spatial resolution in the final system. The following set up has been used: Two obstacles (8.9 mm of height and 20 mm of large), separated 12 mm, have been placed within the path of the reference arm at the same distance as that of the plasma to the input of the demagnification system (15.2 meters) and we observe the image on the detector array located at 3.8 m. The focal lengths of the spherical mirrors are f_{SM7}= 1750 mm and f_{SM7}= 500 m. This set up has been simulated by Zemax (Figure 6). The dimensions of the shadows and aperture obtained with the Nd:YAG wavelength (Figure 7) are shown and compared in the Table I:

	Shadow Size (mm)	Aperture Size (mm)
Simulated Values	3.00	4.00
Experimental Measurements	2.94	3.89

Table I

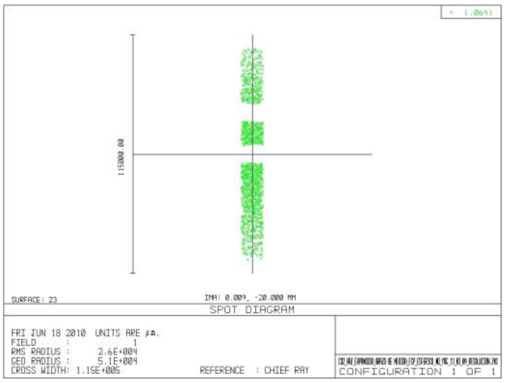

Figure 6

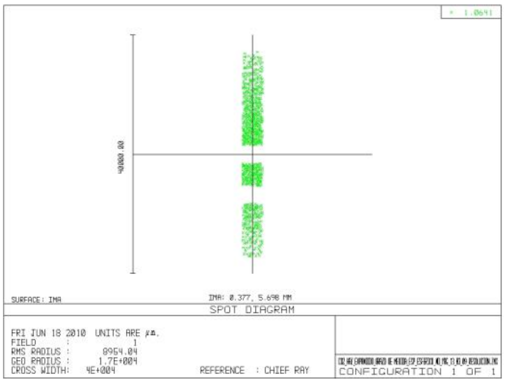

Figure 7

These results have demonstrated the validity of the design methodology obtaining the proper mechanical vibration subtractions and the use of Zemax as a tool in order to determinate the spatial resolution both in a preliminary set up and in the final system. This multichannel heterodyne laser interferometer is just ready for operation and the first electron density profile measurements are expected during the last weeks of the 2009/2010 campaign.

References

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[2] P. Pedreira, L. Esteban, A. R. Criado, P. Acedo, M. Sánchez and J. Sánchez. 36th EPS Conference on Plasma Phys. Sofia. 33E, P-4.187 (2009)

[3] L. Esteban, M. Sanchez, J. A. Lopez, O. Nieto-Taladriz, J. Sanchez. Fusion Engineering and Design (2010)