CO_2 INTERFEROMETER FOR GOL-3 MULTIMIRROR TRAP

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Laser interferometry is an extensively used diagnostic for fusion experiments. Well-known problems of the method such as vibration, stability of the initial phase, a refraction and uncertainty in the phase shift are resolved in this paper as a result of the matching of the interferometer parameters with parameters of the GOL-3 multimirror trap. An initial phase of CO_2 (λ=10,28 μm) Michelson interferometer is controlled remotely with piezoelectric. The piezoelectric ceramics is also used to calibrate the interferometer. To exclude the effects of stray magnetic fields all elements of the interferometer is made of dielectric materials. The LN2 cooled HgCdTe photodiode is used for interferogram registration with time resolution of ~10 ns. The interferometer showed excellent performance with minimal maintenance.

I. INTRODUCTION

Interferometry is the main method of diagnosis for all modern fusion research facilities. The effective methods of eliminating the vibration interference, which associate the method in optical range on the large installations of the type tokomak, are found in the insisted time. Most effective of them are two-colored[1] and dispersion[2] interferometers. The traditional method of the fixation of optical elements by a massive frame[3] is also used. Other factors (sensitivity at zero, refraction, calibration, ambiguous interpretation of the phase) restricting the use of conventional interferometers are successfully solved by using a quadrature interferometer[4].

To measure the plasma density distribution along the multimirror trap GOL-3 (12 m) should have several interferometers. Therefore, their production by using the above methods significantly complicates the measurement of plasma density. However, due to small cross-section of traps (45x45 cm^2), many problems of interferometry of large facilities can be solved here by easy means.

A simple CO_2 interferometer is described in this paper.

II. CO_2 INTERFEROMETER

During construction of the interferometer we paid special attention to the following factors.
1. Optimization of the wavelength to increase the sensitivity of the measurement of plasma density on the one hand and reduce the effects of refraction and the vibrations from the other side.
2. Selection of reliable and consistent pair laser-detector.
3. Making all parts of the interferometer of dielectric materials in order to prevent the influence of scattered pulsed magnetic fields.
4. Excluding the rigid mechanical connection between the interferometer frame detector, laser and other elements of the facility.

II.A. Substantiation of a wavelength selection

The averaged plasma density in the Gol-3 facility is about of ~$3\cdot10^{14}$ cm^{-3} (plasma diam. ~8 cm). A phase shift for those values is

$$\Delta\varphi[\mathrm{rad}] \sim 2\pi\cdot 4,46\cdot 10^{-14} 3\cdot 10^{14}\lambda \times 8 = 673\lambda[\mathrm{cm}]. \quad (1)$$

For $\lambda = 10^{-3}$ cm and a Michelson-type scheme the shift is equal of ~ 1,3 rad (0,4 of fringe).

The estimate of refractive bending of a laser beam from the relation

$$\theta \sim \frac{r_e\lambda^2}{2\pi}\,\mathrm{grad}\,n_e \cdot diam\,, \quad (2)$$

($r_e = 2\cdot10^{-13}$ cm is the classical electron radius) for λ = 10 μm gives value of $\theta = 10^{-5}$ rad for grad $n_e = 10^{15}$ cm^{-4} (in the assumption that the cross section of the plasma cylinder was transformed into 3-mm layer along the laser beam). Corresponding deflection of the probe beam at a distance ~1 meter (detector location) gives negligible value of 0,01 mm.

It is reasonable to assume that the level of vibration on the large-scale facility GOL-3 is similar to the level of large tokomaks such as D-III or JET: ~ 100μm at a frequency of 100 Hz[5,1]. The same order of vibration measured on the similar GOL-M facility[6]. Experience shows that, following the above paragraphs 3 and 4, in these conditions can be on the frame size of about a meter fairly easily achieved sensitivity of the interferometer is equal to 10^{-4} of fringe for $\lambda = 10{,}6$ μm with the frame of about a meter of size. That corresponds to the amplitude of vibration of optical elements ~10 angstroms.

Thus, the 10-micron wavelength is well suited for interferometric measurements of the plasma density inside rang from 10^{-4} up to 1 of fringe ($n_e l \sim 10^{12} - 10^{16}$ cm^{-2}) at the GOL-3 facility.

II.B. Selected laser and detector

Since the start-up of the GOL-3 facility[7], the interferometry there became a daily diagnostic tool that is constantly being upgraded. A three wavelength helium-neon laser (0.68, 1.15, 3.39 μm; (3-10) mW) with uncooled silicon photodiodes and cooled (77 K) Ge:Au photoresistors are used before now in the two Michelson interferometers. Time resolution of the detectors was about of 1 microsecond. The interferometers provide a wide range of measurements of linear plasma and hydrogen densities and if required the vibration level at two point of the GOL-3 trap long of twelve meters.

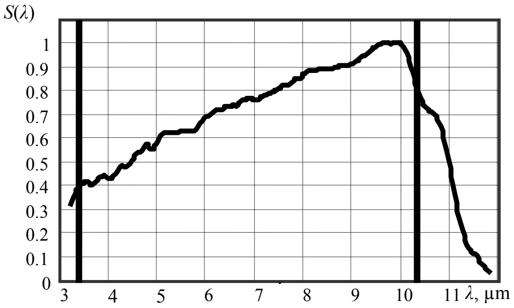

Fig.1. The spectral sensitivity of HgCdTe photodiode. The wavelengths of helium-neon (3.39 μm) and CO_2 (10.28 μm) lasers are marked by solid vertical lines.

Commercial compact (47x6x10 cm^3) RF-exited waveguide CW single-mode (TEM_{00}) LCD-CO_2 laser (JSC "PLASMA") with the wavelength of $\lambda = 10.28$ μm is used. A power of laser beam (diam. of 2 mm) is equal 15 W. Relative instability of laser power after a half-hour warm-up is equal to ±8%. The divergence of the laser beam is no more than 8 mrad, the degree of polarization is equal of 100:1. Remote control laser is realized by TTL signals. Both RF power supply and laser emitter are water-cooled. Resource of laser operating is equal at least 5,000 hours.

To increase the sensitivity of the interferometer and temporal resolution LN2 cooled HgCdTe photodiode was produced (Institute of Semiconductor Physics, SB RAS, Novosibirsk). Time resolution of photodiode is equal of ~10 ns. The region of the spectral sensitivity of detector is shown in the Fig.1, Ref.8. The photodiode is characterized by a low threshold power (NEP) equal of $3.8 \cdot 10^{-13}$ WHz$^{1/2}$ and 10^{-19} WHz^{-1} in the direct and heterodyne regimes, respectively. The diameter of the active area of the diode is equal of 250 μm. The cooled Dewar maintains the operating temperature of the diode in the interval of 77 to 80 K during 8 hours.

II.C. Layout of the interferometer

Layout of the CO_2 interferometer is shown in Fig.2.

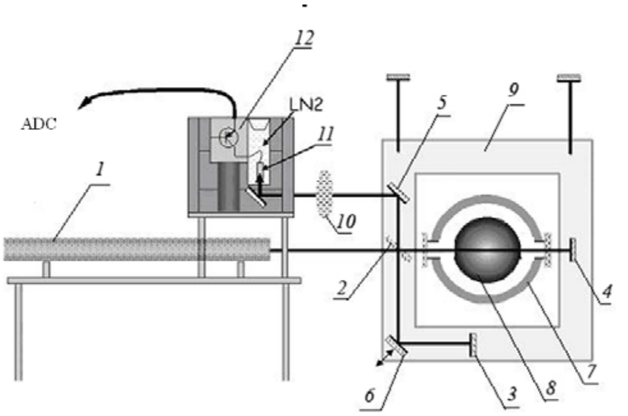

Fig.2. Schematic of interferometer.
1.CO_2 laser; 2. Beam splitter (sprayed BaF_2); 3,4,5. Mirrors; 6. Mirror moved by piezoceramics; 7. Plasma chamber with ZnSe windows; 8. Plasma; 9. Dielectric (epoxy-glass laminate) frame with supports; 10. Lens (BaF_2); 11. HgCdTe photodiode; 12. Preamplifier.

HgCdTe photodiode is protected from X-ray by 5 cm layer of lead. The Figure shows that the detector block and the CO_2 laser is mechanically isolated from the frame. The frame is held by metal rods in suspended state. The interferometer is integrated into the data of acquisition system of the GOL-3 facility[9].

II. D. Calibration and control the initial phase

With the interferometer arm length of meter and dielectric fixing elements there is usually a problem of stability of the initial phase of the interferometer. This problem is easily solved here with the help of a piezoelectric element (KP-1, ELPA Company) in the reference arm of the interferometer (6 in Fig.2). The piezoceramic element moves the mirror to 5 microns at a voltage of 200 V. By varying the voltage one can easily set the required initial phase of measurement.

To calibrate the amplitude and initial phase of the interference signal the voltage on the piezoelectric element is shunted by thyristor.

Measurements within the “fractional fringe” with control of the initial phase and amplitude of the interference signal by piezoelectric element practically eliminates the problem of sensitivity at extremes and ambiguous interpretation of phase shift, as well as the problem of calibration[10].

III. MEASURING THE LINEAR ELECTRON PLASMA DENSITY

As mentioned above the main goal of interferometry at the facility GOL-3 is the measuring distribution of plasma density along the length of the trap. This interferometer is mounted on a length of about 9 m from the point of injection of heating relativistic electron beam (REB) (0.8 MeV, 25 kA, 12 μs) in plasma with a given profile. Plasma is created by direct discharge in a profiling deuterium gas.

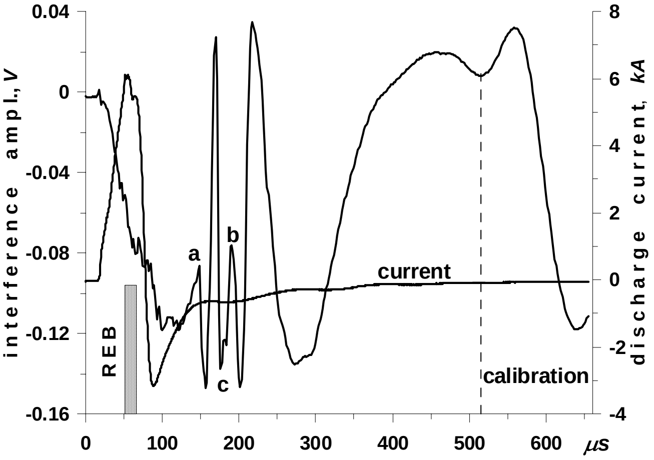

Fig.3. Typical waveforms of discharge current and interferogram.

A typical example of the interferogram is shown in Fig. 3. From the interferogram one can be easily determined the initial phase. It is equal to π+0.2π. In the interval (π+0.2π; 2π - 0.2 π) sine is well approximated by a linear dependence, therefore interferogram in this range properly reflects the temporal behavior of the linear density of the plasma. It is clear that reaching a peak (100 μs), the plasma begins to decay along with the decrease of the discharge current.

However, at point *a* density begins to rapidly grow practically at zero-order total current level. After reaching a maximum at *b* (point of cusp), it begins to disintegrate. The sharp rise of plasma in *a* due to the arrival of plasmoid is formed during discharge current at the nearest (1m) plasma limiter. It seems, partial scattering of the probe beam at the formed a "coat" at the end of the discharge (~500μs) due to decrease in the amplitude calibration. Fluctuations of interferogram (especially at the point *c*) apparently due to by refraction.

Linear density of the plasma at the time of the injection beam (50μs) is equal to (0.4 fringe $\cdot 5.5\ 10^{15}$) = $2.29 \cdot 10^{15}$ cm^{-2}. The corresponding density of the plasma at a diameter of 8 cm is $n_e = 2.87 \cdot 10^{14}$ cm^{-3}.

IV. CONCLUSIONS

Interferometer showed excellent performance, with minimal maintenance. The initial phase of the interferometer varies monotonically only during the main experiment because of the heating coils of the magnetic field. This phase change is easily compensated by varying the voltage on the piezoelectric element. As a result of interpretation of interferograms is no difficulty. If necessary the interferometer simple tuned to another wavelength within the range of the sensitivity of HgCdTe photodiode.

Now the second such interferometer is mounted near (~1m) from injection point of REB in multimirror trap.

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