Diagnostic System to Study sub-THz Emission from Open Trap at Strong Beam-Plasma Interaction

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Abstract. This article describes the diagnostic complex for investigation of plasma electromagnetic emission during beam-plasma interaction. Multichannel polychromator is used for measurements of spectral power density in frequency band of 100 ÷ 500 GHz. Two-channel polarimeter is used for obtaining information about emission polarization. The new cryogenic detector will be used for measurements of electromagnetic radiation over 600 GHz. Calorimetric detectors can also be used to increase the number of possible spatial registration points. Because experiments data interpretation depend on local plasma parameters such as plasma density or temperature diagnostic, complex include system of registration of density based on CO_2-interferometry and Nd-laser scattering. The information about plasma temperature is obtained from diamagnetic loops.

INTRODUCTION

The investigation of plasma electromagnetic emission is important fundamental task of modern astro- and plasma physics. Explanation of the solar and planet radio-emission is usually associated with the plasma processes. For example solar type III radio bursts are associated with nonlinear coalescence of plasma waves in electromagnetic wave, which leads to generation at double plasma frequency $2\nu_p$ [1, 2, 3]; in the case of external magnetic field the radio emission is generated near the double upper-hybrid frequency $2\nu_{UH} = 2\sqrt{\nu_p^2 + \nu_H^2}$ [4, 5]. There may also be radiation at the upper-hybrid frequency as the result of scattering of plasma waves on plasma density fluctuations [4].

The experiments on the relaxation of the electron beam in plasma were carried out on the GOL-3 facility (multi-mirror plasma trap) at which an intense electromagnetic emission was observed at upper-hybrid frequency and its second harmonic. Intense radio-emission was registered during relaxation of the electron beam in plasma with relativistic (∼ 1 MeV) [6, 7, 8, 9, 10] and sub-relativistic (∼ 100 keV) [11, 12, 13] electron beams. Since the radiation frequency corresponds to the upper-hybrid frequency, the increase of the plasma density will lead to an upshift of radiation frequency. This phenomenon allows creating frequency tunable generator of electromagnetic waves based on beam-plasma interaction. For plasma density $n_e \simeq 10^{14} \div 10^{15}$ cm^{-3} the expected radiation frequency lies in the areas $\nu_{UH} \simeq 150 \div 300$ GHz and $2\nu_{UH} \simeq 300 \div 600$ GHz.

To perform a detailed investigation of the radiation generation in beam-plasma system, an installation GOL-3T was created [14]. Schematically this facility is shown in Fig. 1. Beam electrons absorbtion by elements of construction was measured by hard bremstrahlung. The density is measured in two cross-sections of the plasma column by two laser diagnostics. One of them is the Michelson interferometer based on CO_2 laser ($\lambda = 10.28$ μm)[15]. It allows to obtain information about evolution of $\langle n_e l \rangle$, where l is the plasma column diameter. The interferometric scheme was mounted on damping platform in order to reduce the influence of vibrations of the system during activation of the accelerator dischargers. As a detector in the system is used a HgCdTe photodiode cooled to LN_2 temperature (77 K). The time resolution of this diagnostic is about 10 ns.

The second diagnostics is Thomson scattering system [16] based on Nd:YLF-laser ($\lambda = 1.053\,\mu$m). The scattering system measures the density in 8 spread points of the diameter of plasma column at a preset time moment. Avalanche photodiodes are used as detectors of scattered radiation from eight spatially independent observation points along beam chord in plasma column. Registration of the scattered photons carried out at 90° to the initial direction of the incident laser beam (in this case the Salpeter parameter is equal to $\alpha_S \simeq 2 \cdot 10^{-2} \ll 1$ (for $n_e \simeq 10^{14}$ cm^{-3} and $T_e \simeq 100$ eV) – it means that laser scattering system work in Thomson scattering regime. (That is, not in a regime of collective scattering.) Thomson scattering system can also be used for measurements of plasma electron temperature.

The plasma diamagnetic pressure is measured by diamagnetic loops located in various cross-sections along the axis. Usually plasma diamagnetism increases during the beam passing through the plasma column. The electron beam currents in various parts of the device are measured by a set of Rogowski coils. The energy of the injected beam electrons is calculated from the measurements of an accelerator diode voltage. We measured the angular spread of the beam electrons and their energy distribution in some additional experiments. For measurements of emission spectrum we use multichannel polychromator, for measurements of polarization ratio in narrow frequency band – polarimeter. In addition to these diagnostics a set of VUV-detectors and Rogowski coils are also used.

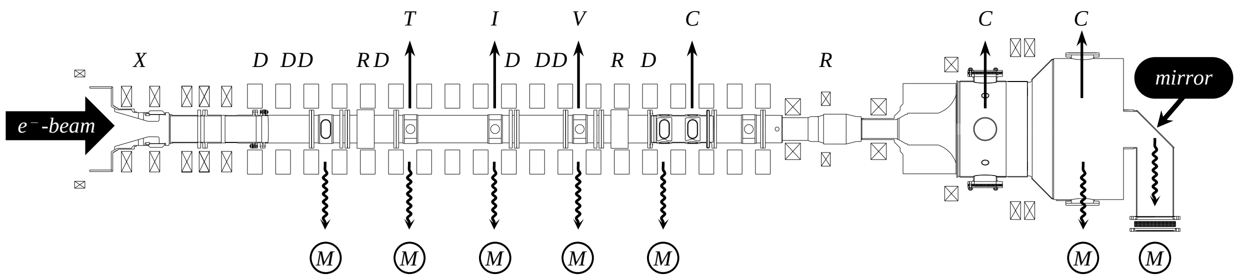

FIGURE 1. Scheme of the location of different diagnostics at GOL-3T facility. *X* – detectors of hard X-ray; *D* – diamagnetic loops; *R* – Rogowski coils; *C* – CCD-cameras; *V* – vacuum ultraviolent detector; *T* – Thomson scattering; *I* – Michelson interferometer; *M* – detectors of subterahertz radiation. Radiation propagating along the axis is measured via rotary metal mirror.

RADIOMETRIC DIAGNOSTIC SYSTEMS

As it was mentioned above, an intense electromagnetic emission at emphasized frequencies (ν_{UH} and $2\nu_{UH}$) may occur in beam-plasma experiments due to nonlinear plasma processes. The 8-channel polychromator is used for measurements of the spectrum of radiation in the range $100 \div 550$ GHz [17]. The polychromator is a device that allows registering the spectral power density in several independent frequency bands. Good time resolution ($\tau \leq 2$ ns) of the polychromator is achieved through the use of Schottky diodes as the detectors. ADC12500 (analog-to-digital converter) [18] are used for registration such fast processes. The registered radiation emerges from vacuum chamber through the teflon windows.

In addition, the GOL-3T diagnostic complex includes a set of single detectors that allow to observe radiation in wide range (from 100 to 400 GHz). These detectors are movable and can be displaced around facility axis for measurements of axial distribution of electromagnetic radiation.

In the new series of experiments one is able to register the electromagnetic waves that propagate along the axis of the facility (direction of the beam propagation). The metal mirror was set in plasma expander chamber for deflection of radiation to side (see Fig. 1), because the teflon window is not able to withstand the heat load from the electron beam. It should be noted that the theory propose that the preferred direction of the emission at $2\nu_{UH}$ depends on the plasma density [19]. In the case of high density plasma ($n_e \simeq 10^{15}$ cm^{-3}), one can expect that the main part of emitted radiation will propagate in direction along the axis of the facility. At this plasma density $\nu_{UH} \simeq 300$ GHz and $2\nu_{UH} \simeq 600$ GHz (magnetic field $B = 4$ T). First experiments in these experimental conditions were reported in [20]. In this regard, we will extend our radiometric systems by two principally new detectors types. The first type is quasioptical superconductive hot electron bolometer. The frequency bandwidth of this device ranges from 0.3 to 3 THz. Its sensitivity element is the NbN-film bridge (thickness $\sim$ 4 nm) integrated in a planar logarithmic spiral antenna on a high-resistance silicon substrate. A bolometer is mounted on the holder with silicon lens. One of the contacts of the sensitivity element is connected to a central conductor of 50 Ω microstrip transmission line, the other contact is grounded. The bolometer itself is placed in a helium cryostat. Radiation enters to a cryostat through the high density polyethylene input window and IR-filter. The sensitivity element is heated to a temperature close to the critical one (the required accuracy of 0.1 K), then it is shifted by direct current. Registered signal is a response to a pre-modulated incident radiation (*continuous emission cannot be measured*). This signal is pre-amplified and fed to the output of the device. NEP (noise-equivalent power) of this device is less than 10^{-12} W/ $\sqrt{\text{GHz}}$, and the time resolution lies in the range 1 ÷ 5 ns.

The second type of new detectors are pyroelectric detectors based on optical radiation receiver [21]. The radiation absorber is set in front of the device for thermal conversion of THz-radiation to infrared spectrum area. Therefore, the frequency characteristics of absorber determine the sensitivity band of detector. This type of detectors does not permit to resolve data in time: It allows only to register emission in selected frequency band for entire experiment duration.

CONCLUSION

Currently, a complex of plasma diagnostics on the GOL-3T is set up for investigation of plasma emission during beam-plasma interaction. The expansion of radiometric diagnostics complex is planned in the near future. For registration of radiation in frequency band above 550 GHz we will use the cryogenic bolometer detector with time resolution better than 10 ns.

Future experiments will be aimed at measurement of dependence of the power density spectrum of emission that propagates along the facility axis on the variations of the local plasma parameters.

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