Measurement and analysis of the radiation losses in DAMAVAND Tokamak

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Abstract. Radiation losses play an important role on reaching to break-even conditions in Tokamaks. In this paper the results of measurement by a bolometer in Damavand Tokamak have been presented & analyzed. Meanwhile, we have explained our future research program on the base of last modifications in the control system of the DAMAVAND.

1. Introduction
Between candidates of the future Fusion reactors, Tokamak is the most important one and in 4 last decades very big projects have been done on it and in the 2006 the building of ITER have started in France. In Tokamaks fusion reactions happen in very high temperature plasmas (tens of million Kelvin) [1–5]. In the research with them, multiple parameters of the plasma like plasma temperature, plasma density, plasma current, radiation losses and so on must be measured [1, 6]. In a power plant the output power must be considerably more than the input power, thus the losses have high importance in energy balance in Tokamaks and must be known carefully. A lot of power losses in Tokamaks are related to the line radiation of impurities and radiation of neutral particles, especially in the VUV and SXR range [5,7].

It must be noted that a bolometer only obtains a spatial canal of information and the recorded signals by it related to radiated power from a finite part of the Tokamak plasma. With respect to that in our experiments the determination and control of the plasma position was impossible, we could not certainly conclude about the amount of radiation losses and only we could investigate the variation of it in general form.

By a new control system that installed 6 months ago on DAMAVAND, we can control and change the position of the Plasma with high accuracy, thus it is possible to bring the dense Plasma region in front of the window of bolometer and record the main part of the radiation losses, it is estimated that the accuracy of the results would be improved about 10 times.

2. DAMAVAND Tokamak
DAMAVAND is a Tokamak with a noncircular cross section (D-shape). For research activities in this device, several diagnostics have been used like: rogowskii coils for measuring the current, 40 magnetic probes for study of the magnetic field position, 2 saddle loops: one in the z- direction for...
study the vertical movement and another in the r-direction for study the horizontal movement, Langmuir probes, photoelectron spectrometer, microwave interferometer, charge-exchange analyzer, hard x-ray detector, bolometers for measuring the radiation losses, and so on. The main parameters of this device are noted in Table 1.

| Table 1. The main parameters of the DAMAVAND |
|---------------------------------------------|
| Parameter                              | Value             |
| Major radius                           | 36 cm             |
| Minor radius                           | 7 cm              |
| Aspect ratio                           | 5.1               |
| Elongation of cross section             | 1.2 – 1.4         |
| Toroidal magnetic field                | 1.2 Tesla         |
| Maximum density of the plasma          | $3 \times 10^{19}$ m$^{-3}$ |
| Ion maximum temperature                | 150 eV            |
| Electron maximum temperature           | 300 eV            |
| Maximum plasma current                 | 35–40 kA          |
| Volume of the vacuum vessel            | 0.91 m$^{3}$      |
| Maximum confinement time of the plasma | 21 ms             |

3. Results and discussion

In DAMAVAND a bolometer with a pyroelectric detector (PD) is used for measurement of heat losses from the plasma by radiation and particle fluxes. It is made from a pellet of the ceramics made of lead circonate-titanate, this pellet is 10 mm in diameter and 400-500 µm thick. The PD sensitivity is 5mV cm$^2$/W. The relation between amplitude of the output signal of the bolometer and the radiated power is approximately $P = 1.18 V$, that $P$ and $V$ are the power at watt and voltage at volt, respectively. The PD has high registration efficiency in the wave length range 0.5–300 A and in the range of the charge exchange neutrals with the energies 0.1-10 keV. The bolometer is placed upon a mobile coaxial lead-in and by its rotation moves back and forth.

In figures 1–4 four samples of the best results of measured signals by the bolometer in DAMAVAND in the experimental conditions noted in below with Hydrogen as working gas. $P = 4 \times 10^{-5}$ torr. Voltages of the capacitor banks:

TFB= 1.8 kV    EFB$_1$= 1.7 kV    EFB$_2$= 1.2 kV
FIB= 4kV       SIB= 2.6 kV         SFB= 2.6 kV

This is the optimum mode of the performance of DAMAVAND that in it the best results are $I_{p_{\max}} > 30$ kA and $\Delta t_{\text{plasma}} = 21$ ms have been achieved; only in this mode the results of the experiments are repeatable and controllable.

In these figures horizontal axis shows time in milliseconds and the vertical axis shows the output signal of bolometer in volts that as noted before, its conversion factor is $P = 1.18 V$. It is observed from these figures that in all of these cases the maximum of the radiation dissipation power at any time is less than 6 watts and the plasma life time is about 18 ms or less. One can observe that the output signal of bolometer in this time interval changes rapidly and unorderly, that it can happen for 2 reasons. First, because the little distance of the bolometer from Tokamak, from its point of view the plasma seems as a great source of radiation and by this diagnostic we can only investigate a part of it and because that in these experiments the position of plasma is not controllable, with the movement of the plasma the zone of it that is situated opposite to the bolometer changes and therefore the input radiation flow of the bolometer will change according to the features (plasma density, density and type of impurities and so on) of this zone. Second, because the life time of the plasma of the DAMAVAND is low, the number of sampling that we can do in this interval is low, therefore, it is
possible that in different samplings the number and energy of arriving photons to bolometer change randomly that it may make the differing of its output signal.

Also it is seen that in these cases the maximum values of signals and their time width are close together, the general forms of them are similar to each other, too. These results show that generally the values of the dissipated radiation power in all of these experiments are very close together.

Figure 1. The output signal of bolometer in an experiment at the optimum mode of operation

Figure 2. The output signal of bolometer in another experiment at the optimum mode of operation

From the investigation of the 20 experiments that have done in 2 days in DAMAVAND, it has been observed that in all of them the value of the amplitude of the plasma current and life time of the plasma have not a big difference (the maximum about 7–8 percent), the measured signals by bolometer in these experiments change rapidly up and down, but the maximum amplitudes of them and the life times of the plasma and the maximum of the plasma currents in all of experiments are very close together, that it can be a sign of the optimizing working condition in our experiments that causes the maximum value of plasma current and its life time and reproducibility of the experimental results.

It must be noted that a bolometer gives only a spatial channel of data. Therefore, these signals are related to the radiated power from a limited zone of the plasma of DAMAVAND that with respect to that in these experiments we had not the possibility of the determination and control of the position of this plasma, it was not possible to suggest carefully about the amount of the dissipated radiation power and we could only discuss about the form of its variation. By using a new control system that presently installed on DAMAVAND, it is possible to control the position of the plasma very carefully and change it desirable [8] and move the dense and hot zone of plasma opposite the window of bolometer and measure the main part of the dissipated radiation power, it is estimated that the results of the future experiments will be exact more than 10 times in comparison with now.
4. Conclusions
The measured signals by bolometer in DAMAVAND Tokamak change very rapidly and abnormally. From investigation and analysis of these signals it seems that value of the radiation power dissipation in DAMAVAND in lifetime of the plasma is highly variable but there are not notable difference between the maximum of its amplitude and the total amount of it in multiple accomplished experiments at optimum mode. But for accurate estimation about the radiation dissipation we need a proper control system that by it we can bring plasma to proper position and keep there as possible, such system is constructed for DAMAVAND and installed on it now and it is predicted that in future experiments the accuracy of the results will increase notably. Also, for accurate estimation of the dissipated power, one bolometer is not enough and an array that made of several bolometers must be used and by finding the spatial profile of the radiation power do an accurate estimation and it is one of the future programs in our research lab.

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