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Lawrence Livermore National Laboratory, University of California

Livermore, CA 94550

ABSTRACT

Several diagnostics measure the particle sources and losses in the Tandem Mirror Experiment-Upgrade (TMX-U) plasma. An absolutely calibrated high-speed (0.5 ms per frame) filtered (6561 Å) video camera measures the total ionization source as a function of radius. An axial view of the plasma automatically integrates the axial variations within the depth of field of the system. Another camera, viewing the plasma radially, measures the axial source variations near the deuterium fueling source. Axial ion losses are measured by an array of Faraday cups that are equipped with grids for repelling electrons and are mounted at each end of the experiment. Unequal ion and electron (nonambipolar) radial losses are inferred from net current measurements on an array of grounded plates at each end. Any differences between the measured particle losses and sources may be attributed to ambipolar radial losses and/or azimuthal asymmetries in the particle-loss profiles. Methods of system calibration, along with details of computer data acquisition and processing of this relatively large set of data, are also presented.

I. INTRODUCTION

In any fusion device, diagnostics for particle confinement are very important. In most tandem mirror machines, the particle confinement has been determined by particle-loss currents of ions and electrons. To determine the axial particle confinement, particle losses from the ends of the linear machine are measured as a function of radius. Radial losses could be measured in a similar manner, but this would require a large number of detectors to determine the particle loss at each axial location. In practice, this method requires a large number of segmented, floating walls that could be biased to measure either ion or electron losses; this technique has proven too complicated for large machines and has not been used. The normal experimental technique measures the net particle current that is lost axially out the ends of the machine. This is a measurement of the nonambipolar radial transport because the ion that is lost radially from the magnetic flux tube has a corresponding axial electron loss. Ambipolar radial losses, in which ions and electrons are lost radially, are not measured by this technique. To complement these techniques, we made time-resolved, imaged measurements of the plasma source, which were compared with the particle-loss diagnostics and were used to determine the importance of ambipolar losses.

In Sec. II, we briefly describe the particle-loss diagnostics used on the TMX-U and then discuss the particle source measurements in detail in Sec. III. Section IV compares the two sets of data. The details of the TMX-U device are outside the scope of the present discussion; Refs. 1-2 provide a useful overview.

II. PARTICLE-LOSS DIAGNOSTICS IN TMX-U

A schematic of the TMX-U device and the particle confinement diagnostics are shown in Fig. 1. As discussed above, both radial and axial plasma losses are obtained from electrical currents that are measured at each end of the device. A two-dimensional array of Faraday cups is located on each end wall of TMX-U to measure the axial ion-loss current as a function of position. These current detectors are equipped with grids that are negatively biased to 3 kV to repel electrons. In addition, moveable end-loss analyzers (ELA) are located on each end; power supplies provide a swept positive or negative voltage to measure ion or electron current as a function of energy. These ELA's can be moved spatially on a shot-by-shot basis for comparison with the Faraday cup currents.

An end-loss ion spectrometer (ELIS) located on each end of TMX-U measures the end-loss ion current distribution as a function of energy and mass near the axis of the plasma. These sophisticated diagnostics are useful for many measurements on TMX-U, which are described in Ref. 3. For the purposes of particle balance, they provide better rejection of high-energy electrons, which would penetrate the negative-bias voltage of the Faraday cups or ELA's and thereby reduce the ion current. As such, the ELIS diagnostics verify the on-axis ion-loss current.

The net particle-loss current is measured by an array of collecting plates mounted at each end of the machine; these plates are segmented in radius and azimuth. The measured negative-net currents correspond to a net electron current that is lost axially; this current equals the nonambipolar radial-ion current.

All of these data are merged together in the main TMX-U diagnostic computer to determine the particle-loss current. The discrete Faraday cup signals are acquired in CAMAC-compatible digitizers, read by the computer, and integrated as a function of radius; this is the axial ion-loss current. The point ELA and ELIS measurements are used to verify the Faraday cup signals. The net current as a function of radius is obtained by simply adding the current from the desired segments. This is the nonambipolar radial current.

III. MEASUREMENT OF PLASMA SOURCE

A high-speed video camera measures the light emission from the plasma; the plasma source is then calculated from these data. The camera is equipped with a 6561-Å interference filter with a bandwidth of 30 Å so that only deuterium neutral atom emission is measured. The view of the Spin Physics SP-2000 camera system is parallel to the longitudinal axis of the machine from the end wall so that an axial integral is automatically obtained. The limits on this integration are determined by the optical-system's depth of field and the plasma shape. Tests of the optical system indicate that the depth of field is large enough to include a major portion of the central cell. The plasma flux tube is the other fundamental limitation because a particular flux tube has a different physical radius depending on the axial position (see Fig. 1), particularly in the end plug. However, we have measured the axial dependence of the emissions by viewing the plasma at right angles and most of the emission originates from a region near the gas-box fueling source in the central cell. The plasma cross section is quite constant in this region; therefore, the camera system can accurately measure the axial integral.

The camera system uses a solid-state sensor that is not susceptible to the magnetic, x-ray, or electrical interference present in the TMX-U environment. The ultimate full-frame time resolution is 0.5 ms per frame. The camera control unit, located outside of the TMX-U experimental area, stores the data on a high-speed magnetic-tape drive. The control unit also contains a digitizer, frame buffer, and computer interface. Between TMX-U shots, the data is read from the tape, digitized, and stored in a microcomputer. The microcomputer also controls the camera unit via a standard IEEE-488 bus and allows remote playback, recording, and changes in camera parameters. The system can digitize a portion of the total frame that contains useful data, resulting in a compression from about 5 megabytes of data to slightly less than 1 megabyte per TMX-U shot. This microcomputer is located in the main TMX-U control room and communicates with the camera control unit by a fiberoptic link.

After the digital data has been acquired, the signals are multiplied by calibration factors to obtain the absolute brightness of the emission line as a function of radius. We measured the camera response on a test stand and found that the signal was quite linear with the input light signal and contained no large spatial variations. A blank, unexposed frame was subtracted from the data to correct for any signal offsets. The camera was absolutely calibrated by the standard techniques described in Ref. 4. A tungsten reference lamp was operated at 35.0 A, with a tolerance of 0.25%. The whole optical system, including the filter and lenses, was in place when the calibration was performed.

The next step of the data processing is to integrate the data array to a particular radius so that we can compare the result with the particle-loss diagnostics. Matrix techniques are used to speed up the integration and allow a calculation of the final results between TMX-U shots. A geometry mask is created, which is a matrix that has 1's where the data is to be integrated and 0's where it is not. This array is computed only once, and then the integration consists of a dot product (each data element times its corresponding element in the mask) followed by a sum of the resulting matrix. This decreases the processing time by a factor of 3. This technique also allows easy integration of very complicated shapes.

By knowing the number of ionizations per photon emitted, we are able to calculate the plasma source. As described in Ref. 5, this is a very weak function of electron density for the plasma parameters in TMX-U (1 to 5×10^{12} cm^{-3}). Above about 20 eV, it is also a weak function of electron temperature. Therefore, for the core of the TMX-U plasma (above 50 eV), this factor is about 10 ionizations per photon and relatively insensitive to plasma parameters. At the edge of the plasma, the temperature plays a more important role. In addition, some of the ionization in the edge is due to molecular processes that result in a different ratio of ionizations per photon. As discussed in Ref. 6, the ratios may increase to 20-30 ionizations per photon in this region.

The final result of the processing is the ionization current integrated to a particular radius as a function of time. This processed data is sent to the main TMX-U computer by a data link and is compared with the particle-loss measurements. More detailed analyses, such as radial-ionization profile measurements, are performed off-line while the TMX-U experiment is not operating.

IV. COMPARISON OF PARTICLE SOURCES AND LOSSES

The particle balance equation for the whole machine can be written as:

$$qV \frac{dn}{dt} = I_s - I_{\parallel} - I_{\perp} - I_A \quad ,$$

where n is the plasma density, V is the plasma volume, q is the electron charge, I_s is the plasma source from the camera data, $I_{\parallel}$ is the axial ion loss from the Faraday cups, $I_{\perp}$ is the nonambipolar radial-loss current, and I_A is the residual current required to balance the equation. The derivative of the plasma density is computed by smoothing and differentiating the interferometer data from the central cell and end cell. The terms in this equation are computed between each TMX-U shot, and the results are plotted as a function of time. The radial integral is computed for 10, 20, and 25 cm.

A detailed analysis of the experimental results is outside the scope of the present discussion and will be the subject of future papers. Briefly, though, the calculated residual current for most TMX-U plasma shots is small. That is, the ionization source measured with the camera system agrees with the measured plasma losses. This implies that the particle-loss currents are usually a good measure of the particle confinement and that ambipolar losses are small. Under some conditions, however, there are residual currents; experiments are underway to study these conditions.

ACKNOWLEDGMENTS

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REFERENCES

[1] D. E. Baldwin and B. G. Logan, Phys. Rev. Lett. 43, 1318 (1979).

[2] D. P. Grubb, S. L. Allen, J. D. Barter, et al., Phys. Rev. Lett. 53, 783 (1984).

[3] J. H. Foote, B. E. Wood, M. D. Brown, and G. M. Curnow, "Plasma Measurements with the TMX-U E||B End-Loss-Ion Spectrometers," these proceedings.

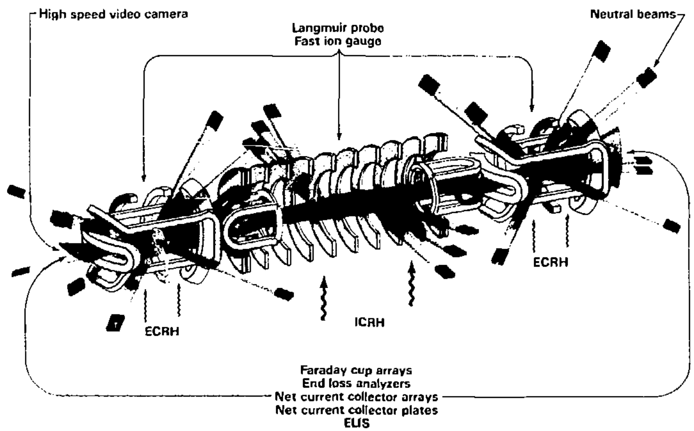
[4] R. Stair et al., Journal of Research of the National Bureau of Standards-A, 64A, 291 (1960).

[5] L. C. Johnson and E. Hinnov, J. Quant. Spec. Radiative Transfer 13, 333 (1973).

[6] D. H. McNeill, M. G. Bell, B. Grek, B. LeBlanc, Edge Region Line Emission in the PDX Tokamak," Princeton Plasma Physics Laboratory, Princeton, NJ, PPPL-2085 (1984).

FIGURE CAPTION

Fig. 1. The diagnostics used to measure particle balance on TMX-U. Most of the diagnostics are located on the end walls of the machine. The high-speed camera views the plasma column from the end wall.



S. L. Allen - Figure 1