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REVIEW OF THE TANDEM MIRROR EXPERIMENT-UPGRADE (TMX-U) MACHINE-PARAMETER-INSTRUMENTATION SYSTEM*

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REVIEW OF THE TANDEM MIRROR EXPERIMENT-UPGRADE (TMX-U) MACHINE-PARAMETER-INSTRUMENTATION SYSTEM*

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Abstract

The Tandem Mirror Experiment-Upgrade (TMX-U) machine consists of seven major machine subsystems: magnet system, neutral beam system, microwave heating (ECRH), ion heating (ICRH), gas fueling, stream guns, and vacuum system. Satisfactory performance of these subsystems is necessary to achieve the experimental objectives planned for TMX-U operations. Since the performance quality of the subsystems is important and can greatly affect plasma parameters, a 233-channel instrumentation system has been installed. Data from the instrumentation system are acquired and stored with the plasma diagnostic information. Thus, the details of the machine performance are available during post-shot analysis. This paper describes all the machine-parameter-instrumentation hardware, presents some typical data, and outlines how the data are used.

Introduction

The operating parameters for the seven major subsystems in the TMX-U must be evaluated because the performance quality of these subsystems can affect the plasma parameters. A 233-channel machine-parameter-instrumentation system was installed to monitor these seven subsystems. The waveforms that are produced by this instrumentation system are collected for two reasons. The first allows analysis of power input, system stability, gas dynamics, and other short-time effects that occur within the time scale of a TMX-U physics shot. The second reason is to log long-term parameter variations such as minute-, day- or week-long trends. The vessel background pressure is one type of long-term parameter acquired.

In the following sections the details of signal acquisition and analysis will be presented and the uses of the data for both physics and subsystem evaluation will be discussed.

Signal Acqusition

The signals acquired from TMX-U are digitized waveforms. The seven subsystems involved in this acquisition and the types of data are listed in Table 1. The waveform recorders require voltage inputs so that signal conditioning occurs at the subsystem before the signal is routed to the digitizing equipment.

Table 1. The parameters of the seven TMX-U subsystems monitored by a 233-channel machine-parameter-instrumentation system.

Subsystem	Parameter type	Number of channels
Magnet system	Current	17
Neutral beam system	Voltage, current	96
ECRH	Detected power	4
ICRH	Forward, reflected power	2
Gas fueling	Voltage, pressure	22
Stream guns	Voltage, current	4
Vacuum system	Pressure	69

Signal calibration is the responsibility of the subsystem personnel.

Signal Processing and Use

After the digitized signals are loaded into memory, the diagnostics computer system processes the data necessary to evaluate the most recent physics shot and the remaining data are used in a similar manner for later system analyses. The data are used to determine the quality of the previous shot only if something failed to operate properly or some unusual feature in the other physics diagnostics was noted. However data from these signals are most often used extensively to illustrate events that correlate in time. For example, plasma density variations are correlated with the turn on or turn off of heating and fueling systems. This correlation is usually made during physics analysis after a day's run. The long-term measurement data are analyzed less frequently. For example, vacuum system data are acquired over a period of months and are analyzed between operating cycles. The signal processing and application details for each subsystem follow.

Magnet System

The power supply currents for the 17 magnet circuits are acquired as a record of system operation. These signals are heavily filtered before being digitized and are sampled at a fairly slow rate (1 kHz) because the magnets operate for 3 to 4 s. The use of these data for physics calculations is minimal. The data have been useful though in doing postmortems on magnet system problems. Since there are many magnet-current configurations used, these data also provide a permanent record and a means to calculate the magnetic field anywhere in the vessel for the configuration.

Neutral Beam Systems

The acquisition process, on the neutral-beam systems, records the power-supply voltages and currents, and the output of a secondary-emission detector (SED) for each of the 24 neutral-beam systems. Each neutral beam injector assembly is characterized on the TMX Test Stand to determine models for its focus and power output as a function of perveance ($IV^{-3/2}$). These models allow the diagnostics computer to perform calculations of summed current and power input per region. Also, there are SED's mounted in the beam dump region. Variations in the SED signal, when referenced to no-plasma background shots, give information about particle trapping allowing an additional (coarse) analysis of plasma characteristics. This process is illustrated in Fig. 1.

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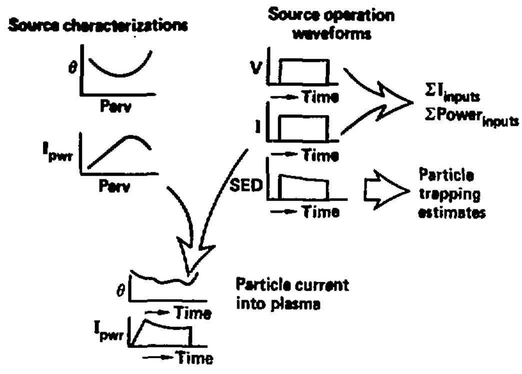

Fig. 1. The acquisition process for neutral-beam signals.

Microwave Heating (ECRH)

The ECRH system uses high-power gyrotron oscillators, operating at 28 GHz, to heat electrons in the end cells of TMX-U. Collecting data on the power input and absorption are important to determine the effectiveness of this system in heating the plasma. This requires that waveguide-launched power and plasma-attenuated signals be acquired to perform the necessary analysis.

Forward- and reverse-waveguide power is monitored using mode couplers. Since the gyrotron output is a complex circular mode, the desired TE_{01} and undesired TE_{02} modes are subtracted for power correction. A set of microwave horns is also positioned across the plasma, opposite the ECRH linear-polarizing reflector, to measure the microwave beam pattern and power absorption within the plasma. Another microwave horn is positioned to measure the power contained within the region as a cavity and it does not strongly couple the incident power.

Plots like those shown in Fig. 2 allow the beam pattern to be coarsely checked and in this case indicate that absorption is 50% and cavity power is low. As the experiment progresses and modeling continues to develop, the attenuation signals may eventually be used to determine plasma density or electron temperature.

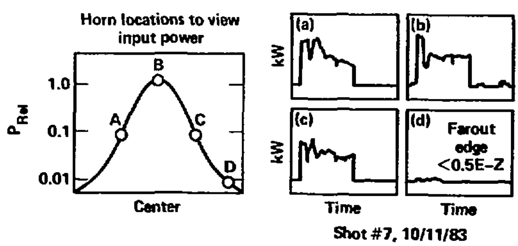

Fig. 2. An example of microwave heating (ECRH) plots.

Ion Heating (ICRH)

A second rf-plasma-heating system was a high-power, low-frequency transmitter operating at about 3 MHz with pulse power output approaching 200 kW. The antenna structure used in the TMX-U vessel allows magnetic coupling to the plasma and is basically an inductor. The system model is shown in Fig. 3 and illustrates both the use of directional couplers to

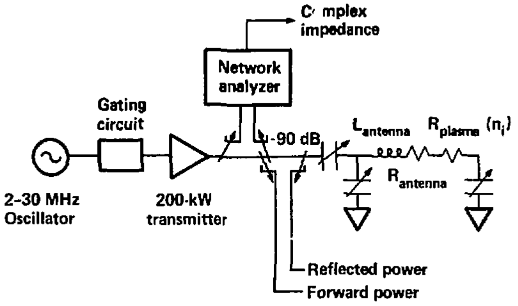

Fig. 3. System model of the ion heating (ICRH) monitoring system.

measure foward and reverse power and the use of a network analyzer to obtain the complex forward- and reflected-wave components. The complex power measurements are used to calculate the instantaneous antenna impedance. The amount of power coupling to the plasma is determined by comparing the antenna impedance vs time to the "background" and plasma shots. The trajectory of the antenna impedance vs time is shown for a plasma shot in Fig. 4. Without plasma, the impedance vs time is a constant and near the 50 Ohm point at chart center with appropriate offset to maintain power delivery as the plasma loading changes.

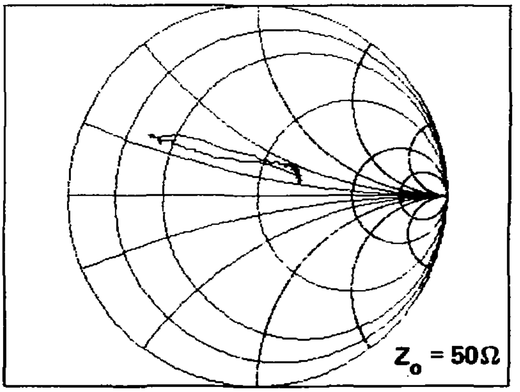

Fig. 4. A example of a trajectory plot showing antenna impedance vs time.

Gas Fueling

Measurement of the fueling gas flow (deuterium) into the experiment is obtained by digitizing the plenum pressures of the fueling valves. The derivatives of the pressure waveforms are used to calculate gas flow. The valves on TMX-U use piezoelectric-crystal actuators and are controlled dynamically to profile gas flow. Typical voltage input, pressure, and flow waveforms are shown in Fig. 5.

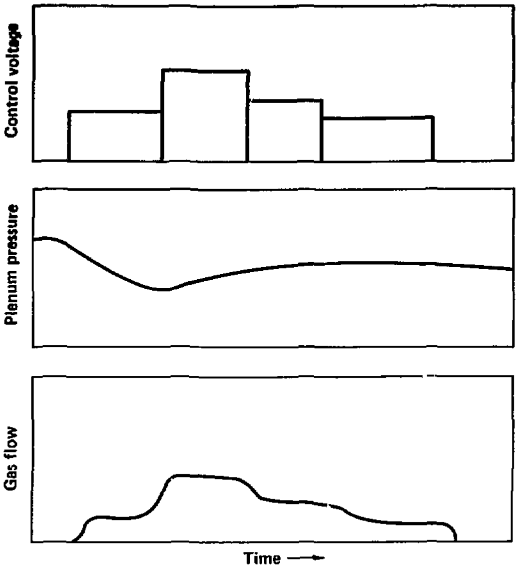

Fig. 5. Typical voltage input, plenum pressure and gas flow waveforms for gas fueling measurements.

Stream Guns

The plasma streaming guns are used to generate a source of target plasma when a high density plasma is required at start up. The power supplies consist of pulse forming networks (PFN) for the fast solenoid and the arc discharge gun. The pulses are 10-20 ms long and have a lot of character. These signals are acquired only for record-keeping purposes.

Vacuum System Measurements

The internal construction of TMX-U is quite complicated because of the elaborate measures taken to maintain low-system pressures, isolate high-gas-load regions and maximize pumping rates of the deuterium and hydrogen gas near the plasma. A system of 23 Bayard-Alpert ion gauges and controllers is used within the vessel to acquire data regarding gas dynamics during a physics shot and also log general system characteristics over long periods of time [1]. This ion-gauge system operates in three time realms: slow-ion gauges (SIG) archive single data points every 10 min to provide long-term histories of vacuum system performance. Medium ionization gauges (MIG) record pressures at 1 s intervals over the 4 min shot cycle. These data are useful to detect changes in the vacuum system performance due to leak development, gas desorption, or getter failure. The fast-ion gauges (FIG) are the the third gauge system. To allow analysis of the system during a physics shot, these gauges are controlled by the diagnostics computer and sample chamber pressures at a 5 kHz rate. The computer analysis is useful between shots because it is a good mearsure of machine vacuum performance and may provide information that relates to a developing problem. For example, a long pump-down rate of the pressure after a plasma shot is an indication of poor gettering quality of the walls or some other problem such as a leak.

An example of an SIG plot for the center-cell region of TMX-U is shown in Fig. 6. The background pressures of 10^{-8} Torr before the run, 10^{-6} Torr average pressure during the physics shot run, and the methane (CH_4) desorption from warming the LN-cooled liners, are indications that the vacuum system is functioning properly.

A model of the vessel gas propagation has also been developed for TMX-U. The vacuum system simulation code DYNAVAC V 2.3 is an upgraded code allowing use of a larger number of volumes; 61 volumes are now used to simulate the structure of TMX-U. DYNAVAC permits a time analysis of a set of volumes at uniform pressure, each having a time-dependent gas source with individual pumping speeds and conductances, to and from the other volumes. The pressures of the volumes are calculated by solving a set of coupled differential equations at each step in time. The large model for TMX-U is required because of the magnitudes of pressure gradients in the different regions of the vessel. The model currently in use for TMX-U is shown in Fig. 7.

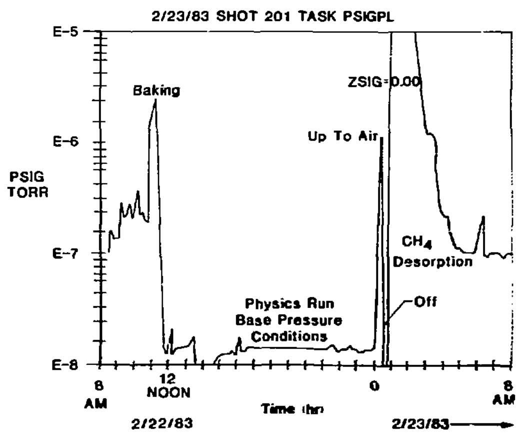

Fig. 6. An example of a SIG plot for the TMX-U center-cell region.

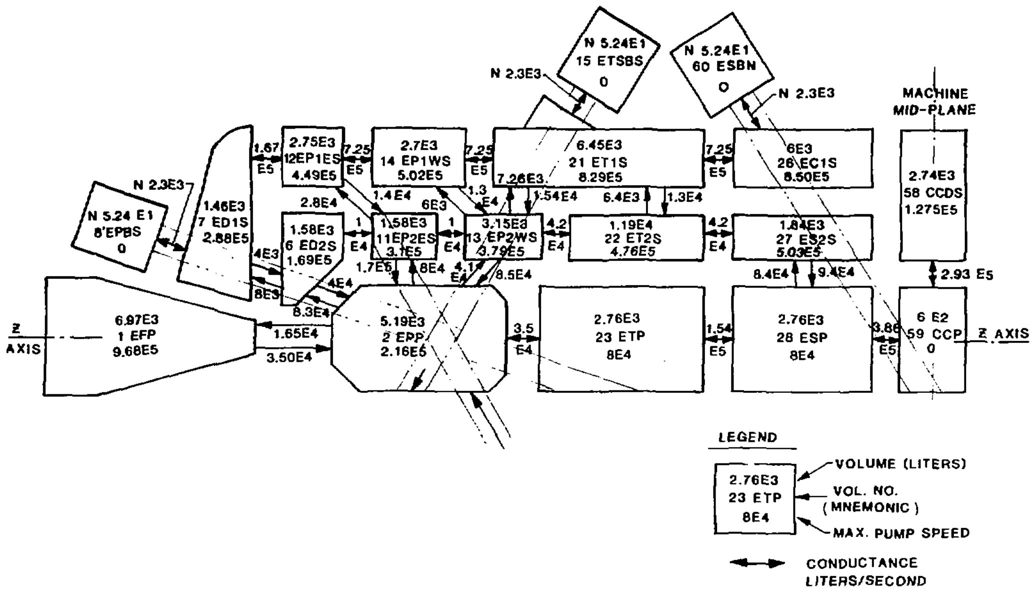

Fig. 7. The vacuum-system model consists of 61 volumes and is used to simulate the structure of TMX-U.

Conclusions

This paper discusses some 90% of the channels of data acquisition used for machine parameters. The additional channels are used in system analysis in similar manners to those already described. The data records maintained in this system are useful at the present time for analysis of subsystem performance and plasma physics issues. However as the experiment progresses and plasma models develop, these data records will undoubtedly be useful in evaluating plasma performance for the periods before the models were developed. The ability to reanalyze system operation is considered to be a necessary feature of TMX-U.

Reference

1. M. O. Calderon, et al., "Vacuum Measurements on the Tandem Mirror Experiment-Upgrade (TMX-U) Fusion Experiment," International Union for Vacuum Science, Technique, and Application Conference, Madrid, Spain, August, 1983.