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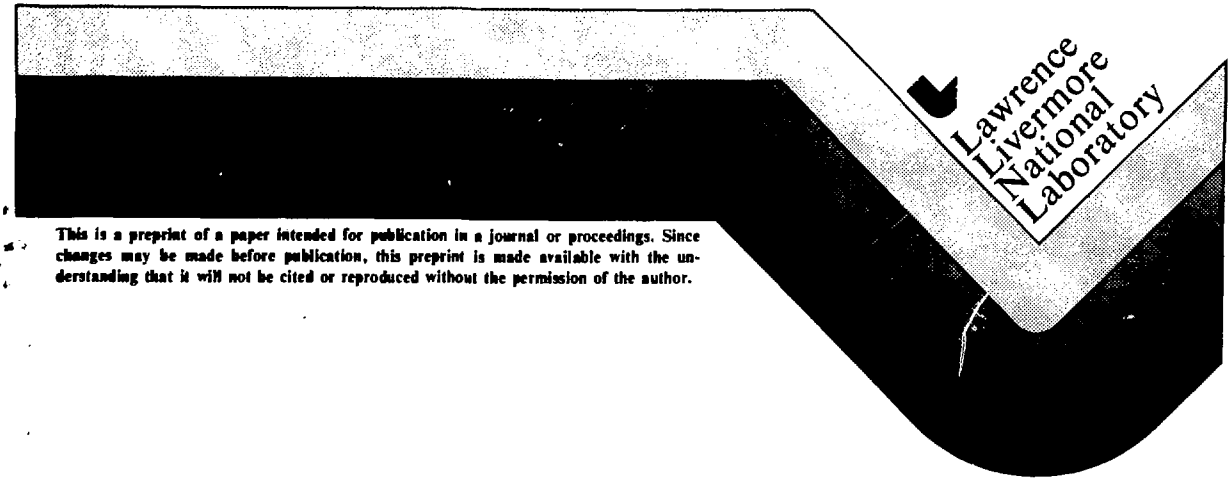

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DEVELOPMENT OF PROCEDURES TO ENSURE QUALITY AND INTEGRITY IN TANDEM MIRROR EXPERIMENT-UPGRADE (TMX-U) DIAGNOSTICS SYSTEMS*

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Abstract

The diagnostic systems for Tandem Mirror Experiment-Upgrade (TMX-U) have grown from eleven initial systems to more than twenty systems. During operation, diagnostic system modifications are sometimes required to complete experimental objectives. Also, during operations new diagnostic systems are being developed and implemented. To ensure and maintain the quality and integrity of the data signals, a set of plans and systematic actions are being developed. This paper reviews the procedures set in place to maintain the integrity of existing data systems and ensure the performance objectives of new diagnostics being added.

Introduction

The diagnostic instruments on Tandem Mirror Experiment-Upgrade (TMX-U) have grown from eleven initial systems to more than twenty systems [1]. These systems encompass more than 268 sensors, 70 vacuum-penetration flanges, 700 control and monitor signals, and 45 crates containing over 380 computer automated measurement and control (CAMAC) modules. Three 21MXE computers acquire the data contained in the CAMAC modules using 29 computer input/output slots and numerous CAMAC interface hardware. In addition to the above computers, five desk-top computers provide the control and acquisition functions for five instruments not connected to the 21MXE computers.

A dedicated support staff of ten people is available to service and modify the existing instruments and install new hardware. When necessary, numerous part-time support personnel supplement the work of the dedicated support staff. The charter of the diagnostic support staff is: 1) to maintain diagnostic instruments that reliably produce meaningful, relevant, definable plasma parameters; 2) to modify diagnostic instruments to improve the utility and quality of existing hardware; 3) to develop and install new reliable instruments that expand the plasma-parameter data base and provide a better characterization of machine performance.

Because of the many different systems, the staff structure, and the large number of components, achieving the above charter in a credible time frame requires some formal organization of the hardware and implementation procedures. Hardware organization starts with the indentification of diagnostic hardware by standard instrument names and the partition of hardware into support subsystems. Within subsystems, major components are identified. This matrix subdivision of the diagnostic hardware allows an organized breakdown of the work and helps reduce confusion.

To further reduce confusion, we have attempted to organize the implementation procedures for the diagnostic work. To accomplish this, we subdivided the work effort into maintenance procedures and modification and development procedures. Maintenance procedures are concerned with ensuring the quality and integrity of existing instruments. Modification and development procedures are meant to attain improved instrument performance.

The organization of hardware and procedures has facilitated the development of diagnostic standards which should permit attainment of the desired instrument quality. The following text outlines the standards and procedures in place or under consideration for the TMX-U diagnostic subsystem. Procedures dealing with development and modification will be presented first followed by maintenance discussions. These procedures and standards are meant to improve and ensure the performance quality of each diagnostic instrument.

Definition of System Development and Modification Changes

Quality assurance is defined as all those planned and systematic actions necessary to provide adequate confidence that a system or component will perform satisfactorily in service [2]. Application of quality assurance techniques to diagnostic systems and components requires that we define satisfactory performance for that particular system or component. Defining satisfactory performance is not enough. The development of the necessary planned and systematic actions to assure this performance is also required. The degree to which any quality assurance procedures are successful depends heavily on the degree to which the above definition and development are taken seriously.

To establish a good technical definition of satisfactory performance, some project planning is necessary. Planning is the most important phase of a research project [3]. Often, it is the most difficult discipline to establish given the nature of research. Realizing the importance of project planning, the TMX-U management staff has instituted a system that emphasizes the development and review of a technical plan before a project or change is initiated.

Shortly after the completion of the TMX-U major device fabrication, a configuration control system was instituted that required a review of all major proposed facility changes. The goal for this control system is to formally review and assess the cost and technical impact of proposed hardware changes involving significant effort. Using the Change Request system as the first step in improving the definition quality for diagnostic changes has been fairly successful. The system provides the basis for requiring a more detailed definition of what the satisfactory performance parameters are for diagnostic changes.

To initiate a significant change or addition in any TMX-U subsystem, a "Change Request" form must be filled out and submitted to a configuration control board. The board evaluates Change Requests on technical merit and program need. A typical Request Form will contain a title and a descriptive statement of the goal of the change. For major diagnostic changes, an extensive physics proposal is usually generated. Physics proposals usually contain: 1) a technical justification for the recommended change; 2) an analytical evaluation of the instrument

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performance parameters; and 3) an outline of the hardware specifications required to achieve the desired performance parameters. Items 2 and 3 are the first steps used to define the satisfactory performance that is required of the diagnostic system or change.

Further definition of the hardware specifications is achieved if the Change Request is approved and sent to engineering for the development of a Technical Impact and Cost Estimate (TICE). A credible cost estimate usually requires the development of an implementation plan that is consistent with the physics proposal. To develop this plan, the Change Request originator and assigned engineers meet to review system requirements and identify major hardware and software components. From performance specifications, the component specifications are developed and an implementation plan outlined. The implementation plan generally includes a system block diagram showing major components and component interfaces. Using the developed information, a cost estimate is generated and returned to the configuration control board for evaluation.

All the above specification information forms a good basis to define satisfactory performance for most components that are required to achieve a diagnostic change. If implementation is approved, other necessary specification information can be developed during the design phase.

Implementation of Development and Modification Changes

Design

After reviewing the implementation plan and cost estimate contained in the TICE, the configuration control board can approve, modify, or veto the Change Request. Detail design work is started by the issuance of a configuration control board directive (CCBD) approving implementation.

Using the system specifications and block diagram, we develop a detailed system design and identify commercial hardware. System designs include hardware layouts and cable diagrams. Hardware layouts show the relationship between all major components and existing installed hardware. These include, but are not limited to, equipment support structures, access platforms, rack locations, and rack layouts. The cable diagrams detail internal machine sensor wiring, trunk cable use, and all equipment cables necessary for system installation and operation. The development of these drawings is a very interactive process with many informal discussions.

Once the system drawings are complete and component details sufficiently delineated to permit a detail design, a design review may be scheduled. The purpose of the review is to present all design information and look for incompatibilities between components or inconsistencies with system goals. For lesser changes, the design review may be informal or dropped altogether.

Component designs are initiated when component specifications are considered firm and unlikely to change. For electrical components, circuit designs are worked out by an engineer or senior technician. Computer simulations or bench prototypes may be made to check design validity. Prototyping is usually reserved for larger, more complex components. After the design and desired prototype tests are complete, the circuit designs and pertinent packaging information is given to a designer. The designer generates detailed fabrication drawings. Prior to actual fabrication, drawings are checked by the design engineer and necessary corrections are made.

Mechanical components are designed by mechanical designers working closely with engineers, technicians, and physicists. Designs are checked by an assigned mechanical engineer, or mechanical coordinator and frequently by the TMX-U mechanical project engineer.

Component Acquisition

Component acquisition is accomplished using a mixture of outside procurements and in-house fabrication. When commercial hardware consistent with developed specifications can be identified, it is acquired using standard purchasing techniques. For all procurements, a purchase order is written, reviewed, signed, and delivered to the purchasing department. Standard, vendor-product, purchase orders generally contain vendor supplied identification information along with originator desired options. Generally no formal hardware specifications are provided.

For procurements that require the supplier to develop equipment, detailed specifications are generated. These specifications include all the descriptive details necessary to ensure that the component will meet performance requirements. In addition, acceptance tests that demonstrate component performance are usually requested. Specifications are developed as a joint effort between the user and engineering. Extensive specifications are generated with the aid of an engineering specification support group. Before a specification is released to purchasing, it is reviewed at both the project-engineering level and division-leader level.

In-house fabrication of electrical equipment can be done by support fabrication technicians or dedicated system technicians. For components requiring significant work, fabrication technicians are generally used. To initiate fabrication work, an electrical coordinator first orders all nonstock parts. Next, he writes a work order and forwards it to the fabrication shop supervisor. The work order contains all the fabrication documents generated for the specific hardware. If during fabrication specific parts are not available, substitutions are only made with the design originator's consent. No individual tests are made on parts unless the assigned engineer requests and details a test.

Generation of mechanical components requires the fabrication and assembly of parts. To fabricate mechanical parts, system technicians, in-house fabrication technicians, or outside vendors can be used. Use of fabrication technicians or outside vendors requires a formal written work order. For outside vendors, the work order is similar in form to a purchase order. These work orders contain all design drawings and specifications developed during the design. We do not usually use system technicians as part fabricators. Since system technicians are quite familiar with system requirements, they perform the major role in assembly and debugging of parts. In addition, the more senior technicians may function as the designer for some components. In this capacity the technician interacts heavily with other designers and engineers.

Testing and Debugging

After fabrication, electrical hardware performance is tested and evaluated to see if design requirements have been achieved. Hardware characteristics checked during the testing may vary depending on specific component functions. Detail testing criteria are generated by the designer or the engineer during design. At a minimum, all major component functions are checked. If necessary, performance deficiencies are corrected jointly by the

engineer and evaluating technician. The evaluating technician keeps test records for future reference. On completion of all testing and debugging, the fabrication documents are updated to reflect necessary modifications.

Mechanical component testing and debugging is accomplished during various phases of component and subsystem assembly. Major concerns are vacuum penetration integrity, electrical wiring accuracy, and alignment accuracy. The vacuum integrity of vacuum components is usually checked on a test stand. Electrical wiring is checked against a wiring diagram using continuity tests. For assemblies where high voltages are expected, hi pot measurements are made.

Systems Integration and Testing

Satisfactory systems implementation requires that all hardware is installed per equipment layouts. For electrical subsystems, this means that racks, equipment, and cables must be installed as planned. Unavoidable deviations from designs are evaluated to make sure that system performance is not compromised and that important documentation is updated. Updating documentation is important because inaccurate documentation handicaps our maintenance effort and jeopardizes the integrity of future designs.

Systems integration is not considered complete until the functions of all systems are checked and are found to be performing to required specifications. To achieve complete systems integration, the control, analog processsing, and digital recording subsystems are checked separately. To test control subsystems, all control functions are exercised and observed under simulated operating conditions if possible. Analog processing and transport subsystems are usually checked with simulated signals. When possible, the test signals are injected at the diagnostic sensors and monitored at the recorder inputs.

Maintenance Procedures

Identification of Failure

To ensure the quality of the data obtained by the installed instruments, it is necessary to continually monitor the recorded data. During machine plasma cycle operation, physics staff is assigned to monitor the operation of most diagnostic instruments. Monitoring techniques for each instrument vary, but the design of most instruments permit an operator to review most of the diagnostic signals prior to computer acquisition. To achieve this, a significant number of the data channels that are being acquired is input to transient recorders that have analog playback of recorded data. A dedicated set of scopes and analog switching units provide a convenient method of viewing the data stored in most instrument data recorders. These monitor scopes are all located in the racks associated with each instrument.

Further monitoring of key data channels is done at the shot leader console. Here a set of seven to eight scopes display a few playback signals from some key instrument recorders. In addition, data from any data-recorder channel can be plotted on a display monitor that is connected to one of the data-base computers.

The above monitor procedures rely on plasma generated signals to assess instrument performance. Comparison of present data signals with past data signals can reveal possible hardware problems, but this data comparison is not totally conclusive.

Further evaluation of instrument performance is achieved using background shots and test signal data. Background shot data are obtained when all machine systems are operated in a manner that does not generate a plasma. This mode is achieved when the machine is cycled without a seed plasma. Data acquired under background conditions is analyzed to assess the level of noise generated by machine systems. Deviations from previous background data are useful in identifying instrument hardware failures. This technique is helpful in locating a change in instrument grounding conditions.

A more involved evaluation of system integrity is achieved with the use of test signals. Some of the more complex systems are designed to accommodate insertion of test signals at appropriate points. Injection of test signals usually requires the setup of some test hardware. Tests of this nature are rarely done during plasma cycle operation unless there is suspicion of a critical instrument failure. Data gathered during this evaluation is valuable in troubleshooting when a hardware failure is detected.

Correction of Failures

When instrument failure is suspected, a service request form is filled out to document the failure details. The form serves as a communication aid in describing the failure symptoms and probable location. This is important since the servicing technician might not have witnessed the actual failure symptoms. If support staff is available, critical instrument failures are worked on immediately. Otherwise maintenance requests are entered in a log and serviced as time, priority, and manpower dictate. Procedures required to fix an instrument failure are documented on the service form and returned to engineering for review and archival. A comprehensive log is kept which includes all active and completed service requests. Periodic studies of the log are made to uncover recurrent problems that require significant resources to correct. Steps required to eliminate recurrent failures are implemented as Change Requests or maintenance items depending on the magnitude of the effort.

Maintenance Aids

Because of the large number of diverse instruments and limited support staff, the need to expedite troubleshooting and repair of defective hardware is of paramount importance. Accurate documentation, backup hardware, and dedicated test equipment are some of the major maintenance aids which help reduce instrument repair time.

During the installation of the initial diagnostic instruments, extensive documentation was provided for all diagnostic subsystems. The system documentation packages contain detailed cable diagrams, equipment layouts, and component wiring diagrams. These documents, along with vendor hardware manuals, serve as a complete reference guide to service personnel. In addition, the documents also serve as a good communication tool when hardware changes are considered.

The formal documentation policies have continued through the operational phase of TMX-U. However, with a reduced drawing staff, keeping up with drawing modifications and providing support for new system implementation drawings has reduced the quality of documents available to diagnostic personnel. To overcome this deficiency, a computer aided graphic station has been procured and made operational. With this system, documentation updates can be made in much less time by a larger pool of people.

Using the instrument documentation and a fair description of failure symptoms, a list of potentially defective components can be generated. At this point, further tests may be conducted to reduce the number of components under suspicion. Once the number of suspect components is reduced to an acceptable level, hardware substitution is used to pinpoint the defective component. Since most diagnostic hardware is made up of CAMAC components, most component substitutions can be readily accomplished.

To support the substitution process, a large amount of certified backup hardware is available to maintenance technicians. All of the vendor supplied backup equipment has been processed by the Lawrence Livermore National Laboratory instrument shop where it is tested and calibrated to make sure it meets performance specifications. In addition to repairing and testing hardware returned to the instrument services, shop personnel periodically test scopes and other equipment installed in the diagnostic facility.

When the hardware is not standard CAMAC components, the specific unit may have to be removed and repaired by a system technician or sent to the instrument service facility. System technicians only repair defective commercial hardware when there is no backup unit available. If the unit is designed by TMX-U staff, repairs are done by system personnel. Repairs are not complete until the component has completed the acceptance tests defined by the assigned diagnostic engineer.

To further aid and expedite the maintenance effort, dedicated test equipment is used. Hardware standardization permits dedicated test equipment developed for a specific component to be used throughout the diagnostic subsystem.

To save time in checking cable installation, two dedicated instruments are used. A semiautomatic cable checker allows rapid verification of the point to point cable continuity and readily locates shorts between elements of a multi-conductor cable. A time domain reflectometer is used to determine the location of cable system anomalies. The use of the reflectometer to pinpoint cable faults has saved valuable technician time.

Because of the heavy use of transresistance amplifiers, portable and programmable current sources are in frequent use. Portable, battery-powered sources are used to test installed transresistance amplifiers. Portable sources only provide a first order evaluation of performance. Generally, this is only a check of dc gain and offset. The programmable sources are used for extensive tests of gain vs bandwidth and linearity.

The heavy use of CAMAC hardware and implementation of diagnostic instruments using distributed computers has prompted the need for a dedicated off-line test and development station. This system is being assembled using a desk-top computer, three CAMAC crates, and various CAMAC interfaces. When complete, the system will be used to develop, test, and debug both CAMAC hardware and software.

Air Cycle Procedures

Because of the limited titanium getter lifetime, periodic air cycles are required of the TMX-U vessel. During the air cycles the vacuum vessel is returned to atmospheric pressure so all the worn-out getter wires can be replaced. To accomplish the re-gettering objective, all getter wires must be replaced. Obtaining access to all of the wires requires the removal of some diagnostic sensors and some vacuum penetration flanges. The removal of the sensors and flanges destroys the integrity of diagnostic instruments to which the elements are associated. To ensure that the integrity of these instruments is recovered some special procedures have been instituted.

To keep track of disturbed hardware, lists are made of each flange and sensor that is removed during an air cycle. This list is used by diagnostic engineers and technicians to plan the reinstallation and testing procedures. The reinstallation of all diagnostic hardware is done according to initial design or design documentation that has been modified. During installation of sensors and probes, orientation and alignment is closely checked. Just prior to closing the machine, electrical continuity of the signals is checked. Checks are made using either test signals or continuity testers. When possible continuity checks are made from the sensor or probe tip to the specified data recorder input channel. In addition to continuity checks, the grounding integrity for each sensor is verified. Flaws found during the tests are repaired and checked a final time. After all the tests are completed, a document summarizing the results is circulated to the physics and support staff.

To further verify the integrity of as much diagnostic and machine hardware as possible, full-power dry runs are started as soon as the vessel pressure is low enough to operate the machine neutral beams. During these runs, all the diagnostic systems are powered up and the data base computer activated. By viewing the data recorder plots of injected and background signals, the integrity of most instruments is verified.

Conclusions

The size of the diagnostic systems presently installed on TMX-U is very large and will continue to grow and change. Because of the system size and complexity, steps have been taken to ensure the quality and integrity of instruments installed or being installed. With the formalization of some implementation procedures, the ability of the diagnostic staff to achieve the subsystems charter has been improved. Using only some of the procedures outlined above, the support staff has been able to maintain a credible support effort. When the procedures outlined are ignored, confusion increases and the quality of the diagnostic data is jeopardized. The present staff, as a matter of pride, is continually looking for methods to improve our support capability and quality. The utility of installing a more detailed and rigid procedural system is being considered.

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