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DATA ACQUISITION SYSTEM DESIGN FOR PRODUCTION MEASUREMENTS OF MAGNETS FOR THE FERMILAB ANTI-PROTON SOURCE

B.C. Brown, D.J. Harding, M.F. Gormley, M.E. Johnson, A.J. Lennox
K.J. McGuire, J.E. Pachnik, J.K. Plymale, R.A. Shenk, A.A. Wehmann

Fermi National Accelerator Laboratory*
P.O. Box 500
Batavia, Illinois 60510

Abstract

A semi-automatic measurement system has been constructed and operated for measurement of more than 400 magnets for the Fermilab Anti-Proton Source Project. A single VAX 11/730 computer with a serial CAMAC highway driver supports multiple measurement stations. Independence of the measurement stations is provided at the system level. Modern software design structures are implemented using standard modules whenever possible including (especially) commercial packages. Measurement results are obtained for evaluation at the time of the measurement. Convenience and accuracy of measurer interaction is provided using a forms entry system. For convenience of data analysis, a query-based data management tool accesses data bases which describe both equipment and results. Results are shared over a DECnet network. The design is well suited for quality control, for laboratory equipment testing/repair and for experimental R & D in a shared-resource, shared-data environment.

Introduction

The quality control magnet measurement system for the Fermilab Antiproton Source Project (TeV I)[1] was required to provide detailed measurements of the field strength and field shape on more than 400 bending and focusing magnets for a pair of 8 GeV antiproton storage rings. The field measurements achieve high precision (better than 100 parts per million for field shape, almost the same for dipole field strength and about 500 ppm for quadrupole field strength). The production quality control measurements were used in adjusting unacceptable magnets, in choosing placement for accepted magnets and in analyzing resulting lattice properties of the storage rings. In addition, prototyping measurements of several additional types were required to complete the magnet design and fabrication procedures of these and other magnets. The design of the measurement system hardware and software addresses a number of problems which this project shares with many laboratory measurement and quality control projects.

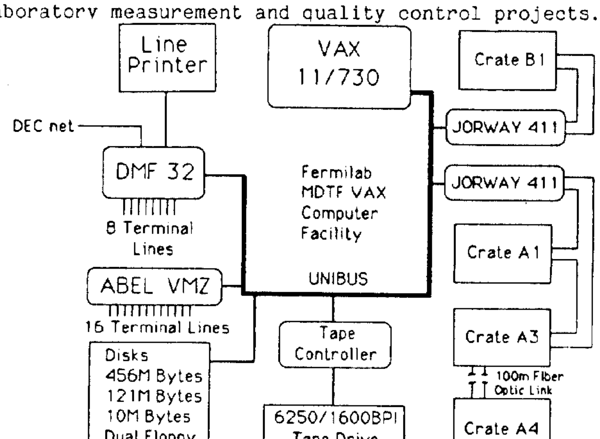

Figure 1: Hardware for MDTF VAX Measurement System

*Operated by Universities Research Association, Inc., under contract with U.S. Department of Energy.

In order to reduce human error, we implemented a semi-automatic measurement system in which the magnet measurer selected settings and directed the measurement process; but the computer system read all switch settings and controlled magnet current, probe motion and data collection. Such a system is software intensive. This justifies selecting a computer system which provides a comprehensive code development environment. In our environment, development of measurement and analysis techniques overlaps in responsibility and (unfortunately) in time with the measurement and data analysis process. This suggests the use of a multiuser computer system to allow shared access to databases and measurement results by the data review group and the code development group while measurements continue. Any observation of suspicious data can be reviewed immediately to distinguish faulty measurements from unusual magnets without interrupting the measurement process. The semi-automatic measurement system requires a large amount of code for determining equipment status and allowing operator selection of measurement sequence. This code creates a large demand for address space without a commensurate demand for computing power. This suggests use of a virtual memory computer architecture to avoid the program development overhead associated with overlay program structures.

By designing the production quality control software to produce complete answers on line, one obtains review of the answers by the measurement staff. In addition, the software becomes more valuable for any special tests in which a physicist or engineer wishes to examine results on line. This solution has also the advantage that the computer is adequate for further measurement analysis and archiving, allowing the data user to work in the same environment for both immediate and archival data evaluation.

Hardware Configuration

In assembling a system at the Fermilab Magnet Development and Test Facility (MDTF) for these measurements a VAX 11/730[2] was chosen as a suitable virtual memory computer, allowing us to take advantage of software available from the high energy physics community. The hardware configuration is shown in Figure 1. This VAX is sufficiently powerful for most of our computing needs and can operate in a less controlled ("factory floor") environment.

A measurement station consists of a rack of electronics which controls a measurement stand on which a magnet is measured. The station is interfaced to the computer through a CAMAC Crate attached to a Jorway 411 CAMAC Serial Highway Driver. Existing driver software[3] was modified so that VAX/VMS[2] system services can be invoked to provide exclusive access to a crate (ALLOCATE device) for a measurement process. This separates usage of the Crates at the system level so that measurements at one station are not able to disturb the hardware on another station. The CAMAC Crates house ADC's, counters, I/O registers, stepping motor controllers, power supply controllers and a CAMAC interface to the GPIB (IEEE 488) Bus. High precision digital voltmeters are interfaced via the

GPIB. Additional hardware was purchased or fabricated when necessary to meet our requirement that all essential features be read by the computer, whether controlled by measurer or computer.

The Environment For Data Management

For management of our hardware description databases and our measurement results databases, we chose DATATRIEVE (DTR)[2]. This data management tool employs a query language to facilitate data selection and an interface to FORTRAN to allow the query language to be used from within FORTRAN measurement programs. Files suitable for DATATRIEVE can also be written and read directly by FORTRAN. This avoids the overhead of the data management system when response time is critical.

The hardware database is coordinated by an Identity database which correlates a Fermilab ID with manufacturer data and, when available, an electronically read identification code. Additional databases store Calibration, Configuration, CAMAC Operation and Service History information. By controlling information in the databases the data analysts assure themselves that correct component identification and calibration are carried through the analysis. Special effort was used to provide electronic identification codes for all critical components.

The results of measurements are written to files which are also accessible with DATATRIEVE. The unit for measurement is a RUN in which some magnet property is measured in a few minutes as directed by the measurer. Data are written in raw files with as few modifications to the electronically read data as possible. The data reduction step calculates and applies corrections for equipment calibration and drift and then averages and/or fits the data. The results are written to reduced data files which contain all information available from a single data RUN. Analysis proceeds with programs which combine RUNs to provide normalized magnet shape and strength information which is written to analyzed files. Each file contains header information which identifies the measured object, personnel, parameters and time. This information, when combined with the hardware database information, allows later reprocessing if improved calibration information or analysis procedures become available. These single-RUN raw and reduced files are also combined into indexed files for examination of measurement or magnet trends.

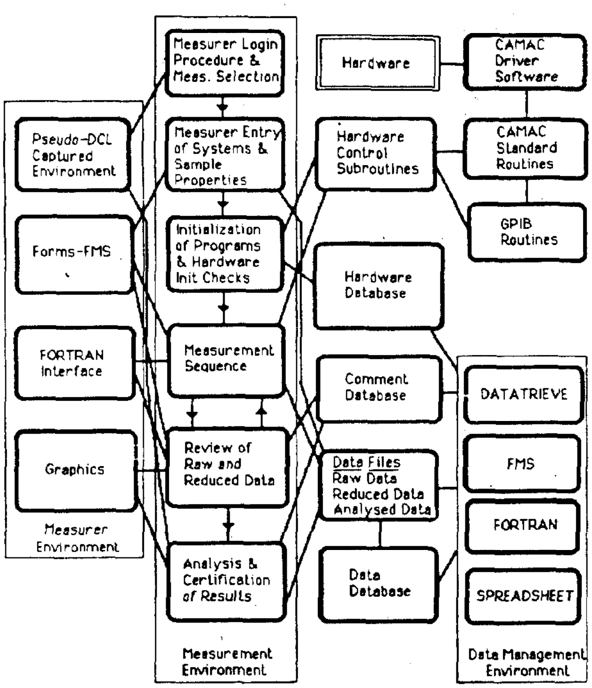

Figure 2: Structure of Software System

The Measurer Environment

If the measurer is provided with adequate tools and training, detailed re-examination of the measurements is not required. Only analyzed results need examination for acceptance and placement of magnets in the antiproton rings. The programs and hardware are expected to provide routine information whenever possible. All hardware settings are read by the computer. Reminders of measurement sequence and suitable limits on critical results are supplied by the program. The measurer concentrates on control of measurement flow and evaluation of results. Following the measurement sequence, an evaluation sequence uses the analysis programs to obtain magnet properties. Thus the measurer can assess the completeness of the measurement sequence, evaluate the results and call management attention to identified problems.

Forms Management System (FMS)[2] software is used to allow easy data entry, including error correction. This software interfaces to FORTRAN programs used in the measurements and to DTR used for database updates. Other operator input comes through a single set of FORTRAN input routines. Graphs are displayed on the graphics terminal at the measurement station and are later printed for archiving using DIGS[4], a Fermilab graphics package. To allow measurements to use the resources as fully as possible without jeopardizing the multiuser environment, a special restricted environment (designated MSR:) was developed within the VMS operating system using the DIGITAL COMMAND LANGUAGE (DCL).[2] Many system utilities are available within MSR in addition to the measurement programs. Since the measurer has limited options, the MSR environment can allow programs to change program priority and exercise extensive, otherwise dangerous, privileges within the VMS operating system. Selection of PRODuction, TEST or OLD measurement program sequences can be made using MSR: commands.

The Software Structure

Figure 2 illustrates the components of the measurement system software. By using commercial tools where possible, attention could be focused on the unique aspects of the measurement process. A sequence of operations to be performed must be described, then encoded in computer programs and measurer procedures. Each of these must be documented for the data analyzer. For the TeV I project two complete sequences of measurements are defined. Using a rotating Morgan Coil[5] probe, HARMONICS measures field shape inside the pole tips of the quadrupoles. Using one or a pair of planar coils, FLATCOIL provides field strength and field shape data on the horizontal plane for all magnets. The tools for hardware control, operator interaction and database management can be shared with other measurements.

The measurement programs are coded in FORTRAN. DTR and FMS are used through their interfaces to FORTRAN. The DIGS software is called as subroutines. The program is modular and libraries are used to store the modules. Control information is frequently passed as function subroutine values. Information needed from or for the DCL environment is conveniently passed with logical names established within the MSR: environment. Data are passed through the program system both as argument lists and through shared, labeled COMMON. Satisfactory alternate structures to handle the large lists of variables were not found. The use of COMMON is controlled by maintaining libraries of COMMON blocks which are included in programs during compilation. The limitations in programming efficiency due to coupling programs through COMMON were found as expected. Nevertheless, we found that up to eight programmers could work together efficiently to produce the two measurement sequences.

Performance Issues

From February 1984 through March 1985 this system tested Antiproton Source magnets as they were fabricated. The design and implementation of the measurement system were successful in allowing regular reviewing of the data, monitoring of magnet repairs/improvements, and selecting magnets for installation. Both measurement hardware and magnet production problems were identified and solved (or avoided.) Some drift in calibration properties was tolerated by identifying the sources and providing adequate cross checks on the measurements. The flexibility of the design and the unification of efforts afforded by the single software system for collection and review of data were important. A broad array of tools all found use in data evaluation: predesigned reports, DTR data selection, graphics within DTR, histogram and graphics packages from the high energy physics community, and a spreadsheet program. As the system became busy, extensive use was made of the DECnet network to pass data and code to other VAX computers. Some specialized measurements and all calibration efforts have been carried out within this measurement system framework.

The most serious unsolved problem with this design was our limited ability to achieve adequate real time response for the rotating coil harmonics measurements within the VMS multiuser environment. Although the usual time response was much better than required for recording digitizations at 50 ms intervals, under normal system use we found that frequently several adjacent points were missing in a 1024 point data run. Although we believe this may be solvable with suitable driver or system changes, we chose the simple expedient of suspending all competing jobs for the one minute duration of the data run. This restriction to the multiuser environment was painful but successful.

Although we also found that we could easily saturate the computing power of the VAX 11/730 (due to the CPU intensive nature of the I/O operations), up to 3 (of 4 available) measurement stations can operate simultaneously at some cost in efficiency. To reduce effects of delay on data quality, the data collection portions of the measurements are coordinated by a queue so only one station collects data at a time. Measurement set-up and analysis activities proceed with lower priority. Much of this computing load is associated with fairly simple data collection code, including mechanical motion/error detection code which could be adequately handled in a small "process control" program. Other system aspects were very comfortable. The down time due to computer failure was not important to the measurement schedule.

Ideas For Future Growth

These limitations suggest a growth path for measurements in which the unifying features of multiuser system, database description of equipment and data, and measurer environment are maintained. Improvements to the real time response and system computing power limitations suggest adding local computing power. One might add CAMAC Auxiliary Crate Controllers which could be programmed to carry out the routine data collection tasks if those tasks require better real time response or if simple tasks are CPU intensive. The code intensive (address space intensive) portions of the measurement sequence involved with equipment set-up and measurer interaction could be maintained on the VAX. The alternative of providing computers for each measurement station but connecting them through DECnet in place of the serial highway may be desirable soon as new hardware is introduced.

Summary And Conclusions

A new quality control magnet measurement system has been assembled and used during production of the Fermilab Antiproton Source magnets. The independent measurement stations implemented with Serial CAMAC and GPIB worked well, providing a convenient environment for the hardware system employed. If we compare our results with those achieved during measurement of the Tevatron superconducting magnets,[6] we find that the new design has resulted in important improvements. The combination of semi-automatic hardware with the forms and database software resulted in substantially reduced measurement errors. We are pleased with the overall integration achieved with this measurement system.

Of broader interest is our success in employing commercial software packages in creating a fully customized measurement system. The commercial DTR and FMS software and the FERMILAB DIGS package generally met our needs with very few constraints. In addition, the features available in these rather fully developed packages allowed considerable enhancement over the minimal systems we would have created just to solve our immediate needs. We believe our success was not tied to the specific products selected but represent the flexibility and integrability of well selected modern software modules.

Acknowledgments

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References

[1] Design Report Tevatron I Project, Fermilab Batavia, IL. September 1984; J. Peoples, The Fermilab Antiproton Source, IEEE Trans. On Nucl. Sci., NS-30 1970 (1983); G. Dugan, Tevatron I, invited paper this conference.

[2] DEC, VAX, VMS and DATATRIEVE are trademarks of Digital Equipment Corporation. FMS and DCL software are also obtained from DEC.

[3] The driver software was originally written by Charles Granieri at SLAC. Modifications for independent allocation of crates was carried out by Marvin Johnson at FNAL.

[4] J.O. Ingebretsen, Device Independent Graphics System (DIGS) FERMILAB SP0012, September 1981; D.B. Burch and J.O. Ingebretsen, VAX DIGS Users Guide, FERMILAB PN158, February 1984.

[5] G.H. Morgan, Proceedings of 4th International Conference on Magnet Technology, Brookhaven National Laboratory, 787 (1972)

[6] B.C. Brown et. al., IEEE Trans. On Nucl. Sci., NS-30, 3608, (1983)