# A RELATIONAL DATABASE FOR MAGNETS AND MEASUREMENT SYSTEMS AT THE FERMILAB MAGNET TEST FACILITY

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Abstract

A magnet measurement system based on relational database technology has been developed for use at the Fermilab Magnet Test Facility (MTF). Results of magnetic field strength and field shape measurements are stored in the database for use in understanding accelerator and beamline operation. In addition to measurement results, the database is used to store measurement history and the commands which prescribe measurement sequences along with supporting parameters that control how each measurement is performed.

The system contains more than 200 tables with more than 1500 columns. The design of the tables is documented in the form of diagrams, design documents, as well as through tables which store, within the database itself, descriptions of each table and column.

## I. SOFTWARE ENVIRONMENT

Software for a magnet measurement system[1],[2] has been created at Fermilab. This paper describes the database design and implementation which supports that system and provides access to the measurement results as well as the complete description of the measurement environment. We use the Sybase[1] relational database system, employing features of the standard relational model plus additional vendor specific features which have reduced implementation effort. The measurement system was developed primarily to support testing of magnets for the Fermilab Main Injector Project[3], but it also has been used to measure magnets for other applications.

## II. DATABASE DESIGN OVERVIEW

There are several distinguishing features in the MTF database design including:

- Tables with closely related functionality are grouped together into "virtual databases." For example, measurement data obtained by rotating a coil in the field are stored in the "harmonics"virtual database, while measurement data obtained by scanning and measuring the the field at various points are stored in "pointscan."
- Data are grouped into related tables based on natural hierarchies derived from data collection (points, runs, sequences) and data processing (raw, reduced, analyzed) relationships.
- Special procedures called *triggers* are executed to enforce the integrity of the relationships between data entered into the various database tables.
- To simplify referencing data in different tables, unique serial numbers are generated and used as the primary key for data that is cross-referenced in other tables.
- The database is used to store not only the results of measurements, but the prescription for how each measurement is performed and the history of measurements performed on each test subject.

## III. VIRTUAL DATABASES

Tables with related information are grouped together into "virtual databases." The Sybase *data owner* concept is used to implement the virtual databases by creating a pseudo-user of the same name to own each "virtual database." There are two categories of virtual databases, those containing measurement results and those containing measurement commands and support data. Each of the virtual databases and its purpose is identified in the following subsections.

### A. Measurement Results Virtual Databases

The following virtual databases are implemented for storing results of magnet measurements:

*harmonics:* contains tables for storing the data obtained when a magnet's field strength or field shape is measured by rotating a coil.

*flatcoil:* contains tables for storing the data obtained when a magnet's field strength or field shape is measured by ramping the magnet while measuring flux with a stationary coil, or by translating the coil within the field.

*pointscan:* contains tables for storing the data obtained when a magnetic field is measured at individual points, using either a Hall element or an NMR probe, or both.

*currents:* contains tables for storing the magnet current measured during a measurement.

*results:* contains tables for storing the measured magnet properties. Data in these tables are derived from data stored in the other Measurement Results Virtual Databases after applying appropriate data selection, analysis and perhaps fitting techniques.

### B. Measurement Support Virtual Databases

Virtual databases in this category are used to store information that supports measurements, as opposed to storing actual results of magnet measurements. The virtual databases in this category include:

*admin:* identifies personnel involved in measurements, documents describing measurements; serial numbers generated by the system are also stored here.

*subjects:* identifies magnets tested or available for testing, information about the components used in assembling the

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[1] Sybase, Inc. 6475 Christie Ave., Emeryville, CA, 94608

magnet, and which magnet design group each magnet belongs to.

*calibrations:* contains information about how data obtained from readout devices is converted into appropriate engineering units of interest. Also stores an historical record of what calibration constants were used to convert data.

*facilities:* identifies and provides details about test stands, readout devices, measurement probes, *etc.* that are used in measurements.

*instruments:* identifies the collection of devices used to perform each measurement.

*logbook:* stores checklists, which prescribe the sequence of steps performed during a measurement. Provides an historical record of activities performed during testing (e.g., when magnet was mounted on the stand, when and by whom each measurement was performed, etc.).

*ramps:* stores the list of currents at which each measurement is performed, along with details about how to accomplish the ramps.

*quality control:* stores values against which measurement results can be compared to determine whether magnetic properties are within expected ranges.

## IV. MEASUREMENT RESULTS ORGANIZATION - RAW AND REDUCED DATA

Data points are the set of measurement results which characterize a given state of the magnet and measurement apparatus, such as a probe angle and flux, or a probe location and NMR field measurement. Data points are collected in sets called runs in which data are grouped by the measurement system operations used to acquire the data. Examples of runs include a magnet current excitation sequence, or a transverse probe movement (scan). For convenience of both programming and measurement specification, runs are grouped into related sets called sequences. A sequence normally carries out the operations required to measure a specific magnet property such as its strength *vs.* magnet current.

Data obtained from magnet measurements are stored with three levels of processing. Raw data consists, as nearly as possible, of direct instrument readings. Raw data for a measurement are stored with minimal conversions, thus permitting reprocessing effort to begin from the basic information. Reduced data are stored after all conversions to engineering units and all processing which can be done on a per run basis have been completed. Wherever possible, the reduced data describes the measurement results to be evaluated at measurement time. When further analysis is useful or required, the resulting analyzed data are also stored in the database.

The structures used to store measurement results reflect the measurement and reduction structure based on sequences, runs and points by using a related hierarchy of (master-detail) tables for sequences, runs and points for both raw data and reduced data. This design is repeated for the 'flatcoil', 'harmonics', and 'pointscan' measurement styles, with variations reflecting only the fundamental differences between the measurement techniques

Further analysis may combine more than one run, may involve different measurement styles and perhaps utilizes knowledge of physical properties of the magnets under measurement. The output from this analysis is less dependant on measurement system specifics and therefore of more general interest. The 'results' virtual database tables store these analyzed data. Properties measured by complementary techniques are stored here, allowing cross-checks to be performed on the data.

## V. THE SERIAL NUMBER GENERATOR

Sybase provides a feature called a stored procedure by which Structured Query Language (SQL) commands which are stored in the database. Triggers cause the execution of these stored procedures when specified database events, such as the insertion of a data row, occur. This feature is utilized to create a 'serial number' as a primary key for most of our tables. The insertion trigger code obtains the value to be stored as the primary key from the 'serial_generator' stored procedure which provides a unique integer value and records the table for which it has been requested. The commonality provided by the frequent use of 'serial numbers' as foreign keys permits us to create most of our trigger code for relational integrity automatically[4]. Since a single data type is used for most primary keys, a single column can reference a row in almost any table. Using a single comments table, comments are linked to almost any object defined within the database.

## VI. SUPPORT TABLES - AN EXAMPLE

We will use the design of the *subjects* virtual database to illustrate some of the ways we use the relational model to capture the data we use about magnets and their components. Figure 1 illustrates this design graphically. The database design assumes that test subjects are identified products from a production series. It implements the usual "parts explosion" paradigm common to engineering design. The series table labels the design of the series of objects and the properties of that series are stored in the *series_attributes* and *series_text_attributes tables*. The nature of these properties is stored in the *series_attributes_defn* table. Individual subjects are identified in the *subjects* table and are identified as an instance of the series using a foreign key to the *series* table.

The hierarchical structure that defines the parts which are specified in the series design is stored using the *series* table to store the labels of the parts and the *series_components* table to declare their relation to the object (series) of which they are a part. The identity of a specific component of a subject is defined in the *subjects* table while the relationship to the base object in the *series/series_component* hierarchy is made specific in a *subjects/subject_components* hierarchy. This design permits us to identify and store a complete parts list in a compact form.

For the Main Injector magnets, the magnet, the yoke parts (two half cores), and coil parts (2 dipole or 4 quadrupole main coils and 4 quadrupole trim coil windings) are stored. Information which tracks parts in more detail can be stored here but at this time is not. Note that the column *series_components.component_role* defines the way a part is used in a magnet.

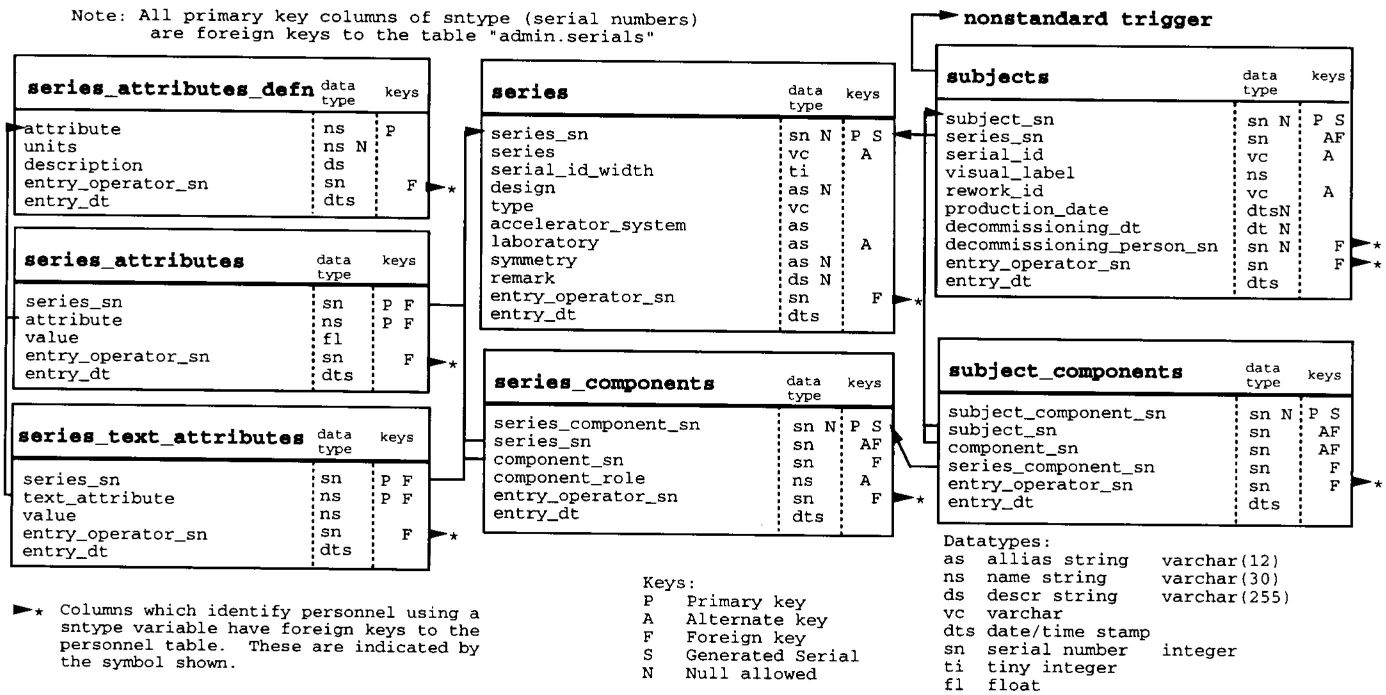


Figure. 1. Graphic representation of the *subjects* virtual database which stores magnet and magnet component information.

## VII. DOCUMENTATION

The system of documentation which is used to record this design[5] includes the use of a tool (TOT[2]) to record the table definitions, primary and foreign keys as well as descriptions of each table and column. This information is summarized graphically as illustrated in Figure 1. In addition, each virtual database is documented with a report which explains overall purposes and all special design considerations.

## VIII. CONCLUSIONS

A database has been designed and implemented for magnet measurements which allows a single set of database tools to be used to access the measurement command structure, control and conversion parameters, raw, reduced and analyzed measurement results, and measurement history along with the list of measured objects, and a comment and assessment system. Measurements of more than 85 magnets have been recorded with the current system. The format is suitable for incorporating results from previous measurement systems into the same data storage structure.

## References

[1] J.W. Sim et al. Software for a Database-Controlled Measurement System at the Fermlab Magnet Test Facility. In *Proceedings this conference.*

[2] B. C. Brown et. al. Software Design for a Database Driven System for Accelerator Magnet Measurements. In *Conference Record of the 1991 IEEE Particle Accelerator Conference, San Francisco, May 6-9, 1991*, page 2134. Institute of Electrical and Electronic Engineers, 1991.

[2]This tool also generates SQL code that supports table creation and management.

[3] D. Bogert. The Fermilab Injector Complex. In *Proceedings this conference.*

[4] B.C. Brown et. al. Table of Tables – A Database Design Tool for SYBASE. TM 1707, Fermilab, January 1991.

[5] B.C. Brown et. al. Overview of a Database System for Magnet Measurements. Technical Report MTF-92-0003 1.3, Fermilab, July 1992.