Database for Accelerator Optics

B. Autin, F. Di Maio, M. Gourber-Pace, M. Lindroos, J. Schinzel

CERN, PS Division
CH-1211 Geneva 23, Switzerland

Abstract

The Automated Beam Steering and Shaping (ABS) project aims to provide an automatic, generic and reliable software system to ensure the provision of high quality particle beams to users of an accelerator complex. An important component of this project is the access to validated reference data describing the different components installed in the machines, such as monitors as well as the optical and magnetic properties of all magnets. These properties are dependent on the type of particle, on the energy and on the destination of the beam. The data model must therefore be able to represent several particle beams along different trajectories through the same element. Furthermore, the database design must be sufficiently general to allow the description of the elements from a simple dipole to complex multicoil magnets. For a given operation, the sequence of optics elements with the parameters appropriate to the type of beam must be extracted, suitably formatted and passed as input to a beam optics program. This paper describes the problems encountered during the analysis, the resulting data schema and the software developed for data maintenance. Examples are given for the machines of the CERN PS complex.

1 Introduction

Databases for accelerators have been designed to fit the numerous requirements imposed by ever more complex machines[1]. The purpose of this database is to serve as a general reference document similar to an electronic parameter list describing the input values needed for optics calculations. Much of the data describing the optics of the machines in the PS Complex currently resides on paper and on files. A first feasibility test[2] which took place during 1996, revealed the importance of providing a data model which is sufficiently general to describe all possible machine configurations. The aim of using a database is to provide a single, correct source of data, essential for on-line beam correction. These corrections are considered as perturbations of the reference machine documented in the database. The database is thus static and unaffected by accidental variations. This warrants the reproducibility of an operation. An operation defines the list of components which act on a particle beam, the component positions and their optics parameters. By specifying the operation particle and momentum, the position and shape of the particle beam can be calculated and corrections made. The result is observed using beam measurement monitors.

The architecture of the database is developed around the concept of a machine operation. It accommodates the description of the complex magnets used to make up a machine. Care has been taken to avoid any redundant data. The current system is restricted to the bending and focusing parameters of a complex of machines. The object management software, ACCIS (ACCelerator Information System) which is used to describe, edit and browse the data, is described.

2 Machine operation

A machine operation as defined here is the action of passing a beam from one part of a machine to another for a given purpose such as injection and acceleration. An examples in the CERN context is the 5-turn extraction from the PS to the SPS. An operation requires a sequence of optics components, e.g. magnets and monitors, which are used to act on or measure the beam and the corresponding set of reference optics properties. An operation also requires the position of each component along the beam trajectory.

2.1 Beam path

The sequence of components is derived from a database object known as a beam path. A beam path describes the physical structure of a part of an accelerator or transfer line and may be used to describe more than one operation. An example is shown in Fig. 1. The beam path Linac/Booster transfer line is made up of two transfer-line sections, the Linac transfer line LT and the Linac to Booster line LTB. The LT section is made up, for example, of the dipole LT.BHZ10, the focusing quadrupole LT.QFN20 and defocusing quadrupole LT.QDN22. The LTB section includes two quadrupoles and a beam position monitor LT.UMA10.

To create a sequence of optics components, a beam path is expanded into its component parts and then stripped of all non-optics components.

So that beam path parts can be reused in different operations, the parts of a beam path should not include elements situated on different branches of line sections. The branching of the LTA transfer line into the LT and LTE lines is represented as three sections. LTA includes the branching component LT.BHZ10. This is shown in Fig. 2.

2.2 Topology

To position optics components along a beam path, the

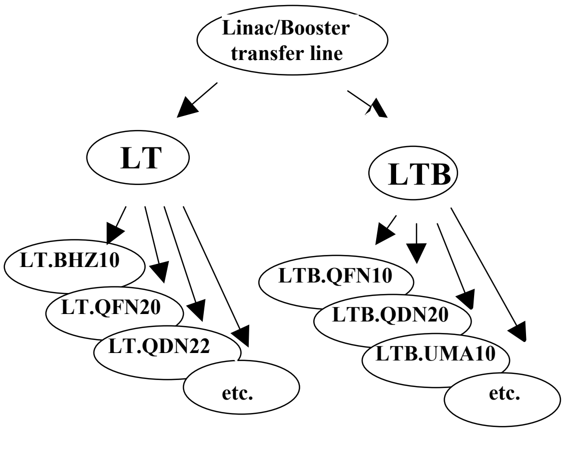


Fig.1: A Linac/Booster beam path

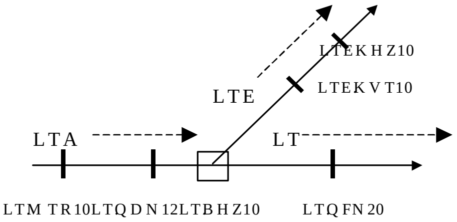


Fig.2: LTA line splitting into LT and LTE

linear displacement between the entry point of each element with respect to the start of the parent object must be defined. Taking the example in Fig.2, the dipole LTBHZ10 must be positioned relative to the parent machine part LT, and LT relative to the beam path LT-LTB. For magnets the entry point indicates the start of the magnetic field.

2.3 Reference optics and correction

On-line correction for steering or matching a beam is the daily task of the operation crew. A correction requires the solution of a linear system characterised by a matrix whose elements represent the effect of a unit correction at a monitor. For example, the data required for correcting the closed orbit in the PS ring includes the reference optics of one hundred magnets producing the main magnetic field as well as that of quadrupoles to set the transverse tunes. It also includes the horizontal/vertical dipole correctors and the monitors which measure the displacement of the beam in a transverse plane at a given position in the ring. This data is then passed to a symbolic optics program [3] for treatment. A resulting correction to a field strength can be converted to a current variation given the measured magnetic rigidity in Tesla metres, that is the particle momentum / electric charge. Monitor readings can be used to compare measured and calculated beam profiles.

The corrections currently being explored are steering and matching for the injection of particles from the Linac into the Booster and for the transfer between the Booster and PS, as well as for the closed orbit correction of the PS and the correction of the coherent transverse oscillations at injection into the PS ring.

2.4 Component usage in an operation

The information describing how a component is to be used in an operation is called the 'usage'. The term indicates whether a component is to be used for correction in the operation, and, if so, for what type of correction. While monitors have no other reference parameters, magnets may have optics parameters. These are referenced by the usage which belongs to the relationship between the component and operation. If this relationship is removed, so is the usage. The magnet optics, however, may be referenced by other components and are therefore preserved. In the database no distinction is made between a corrector and any other magnet. All magnets may have optics parameters and may be used as correctors. An example of a usage is shown in Fig.3.

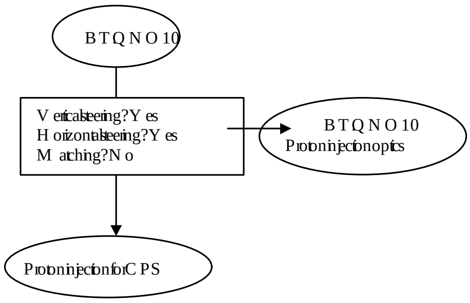


Fig.3: A quadrupole with the reference optics used for both steering and matching during CPS injection.

3 Magnets

Magnets, both those used in the PS today and those foreseen for LHC [4], can be complex. A magnet may be supplied by a current passing through more than one coil. The same power source may supply several coils. A magnet may be operating in an unsaturated or in a saturation regime depending on the current being supplied. Coils may be used to correct the reference magnetic field in order to adjust the tune and chromaticity as well as to compensate irregularities in the magnetic field. Correction magnets may themselves have a nominal field. When a magnet is made up of superposed coils, the magnetic fields may overlap. A coil of a magnet may provide a field with a single polarity, such as a dipole or quadrupole, or a field which is made up of several field components.

CERN PS magnets are used as an example. Each is made up of two halves, a magnetic focusing sector and a magnetic defocusing sector. Each sector is composed of several coils: the main coil and correction coils. The main coil defines the nominal magnetic field of the bare machine (no correctors included). It is a combined function coil as it provides both bending and focusing fields. The correction coils include a backleg winding coil, acting as a radial correction dipole. A pole face winding coil with quadrupolar and sextupolar components is used at high energy in order to compensate saturation effects and to adjust the natural chromaticities of the machine. A special loop with a quadrupolar component is used at high energy to control the transverse tunes of the machine.

Beam splitting magnets may act in a different way on different particle beams. The PS booster vertical distributor magnet consists of six dipoles located in the same vertical plane but in sequence on the injection line (Fig.4).

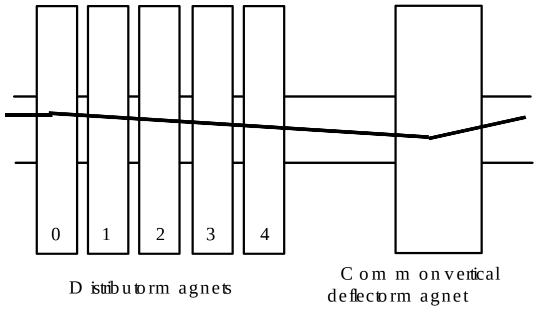


Fig.4: The Distributor consists of five dipoles positioned in the same plane but in sequence on the injection line. The fifth magnet is a common deflector magnet

Each of the five first dipoles, so called distributor magnets, have one single nominal bending angle. The sixth magnet serves as a common vertical deflector, also with one single bending angle. To get to the lowest PSB ring, only distributor magnet 0 is active and to get to the top ring, four of the distributor magnets are active. In both cases the common deflector magnet is at its nominal value. Consequently, the database has, in addition to dealing with non-active magnets, also to deal with magnets with a single nominal bending angle but with different edge-up and edge down angles.

3.1 Magnet elements

In order to cope with the definition of composite magnets in the database, the concept of magnet element has been introduced. A magnet element provides a magnetic field generated by a current passing through a single coil or by no current at all if it is a permanent magnet. For example, an LHC magnet is composed of three magnet elements: the main dipole, the correction sextupole and the correction decapole. Each coil is connected to a single power source, supplied by one or more power supplies. A composite magnet may be made up of several sequential or superposed magnet elements with totally or partially overlapping fields. Magnetic fields may have a single component, such as a dipole or quadrupole component, or may be described by several field components. Eight components are currently included in the data model. The optics field strengths used for matrix calculations are given in particle and momentum independent units which reduces the number of operations to be defined to a minimum. The justification for the choice of field model parameters is described below.

3.2 Magnet field model

The field model is the one of a hard edge magnet with a transverse field whose Taylor expansion is truncated at the octupole term. The field is thus characterised by dipole, quadrupole and sextupole coefficients. Each coefficient has an upright and a skew component so that the field is determined by eight independent coefficients. The field coefficients are those measured in the laboratory with the reference system of the measurement bench. In the case of iron magnets, the field is, to a very good precision, upright and the skew components are negligible. In superconducting magnets, the skew components have to be considered. Inside a machine and especially in transfer lines, the magnet orientation may be different from its orientation in the laboratory. Its longitudinal axis *Oz* is always colinear to the beam orbit and the only angle which matters in practice is the angle about *Oz* called the *tilt* of the magnet. The tilt is a special attribute of a magnet element.

The Lorentz force exerted by the magnetic field on a particle is proportional to the field itself integrated over the magnetic length l of the element, to the particle electric charge and inversely proportional to the particle momentum. To each field component corresponds an optical coefficient, namely the particle deflection, the integrated focusing strength Kl, measured in m^{-2} and the first and second radial derivatives of Kl. As was the case for the field, there are upright and skew optical coefficients.

A correction is first expressed in physical units such as radians for a deflection, m^{-2} for a beam envelope or a tune shift. The physical unit is converted into a current or a voltage via a calibration coefficient which is defined as the derivative of some field coefficient with respect to the current (or the voltage). With this definition, the calibration coefficient may be a function of the current as it happens when a magnet operates in a saturated regime. Dividing the calibration coefficient by the magnetic rigidity achieves the transformation of physical into engineering units.

3.3 Calibration

In the data model a magnetic element is described by a magnetic field which has a magnetic length and field measurement points taken at different currents or voltages for each of the eight upright and skew components. A magnetic field description may be shared by many magnet elements such as those in the main magnets of the CERN PS. Fig.5 shows the definition of calibration data for a magnet element.

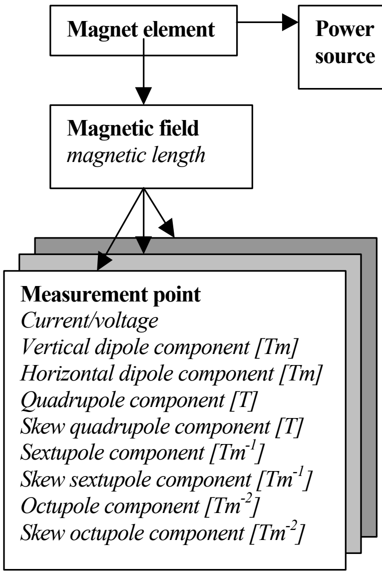


Fig5: The database definition of a magnetic field referenced by a magnet element

3.4 Reference optics

A magnet element may be tilted, and the angle of tilt may be defined in milliradians. The magnet optics parameters include the vertical and horizontal bending angles given in milliradians, the upright and skew quadrupole strengths in m^{-2}, sextupole strengths in m^{-3} and octupole strengths in m^{-4}. They also include the optics type, currently dipole or quadrupole, and the angles of the normal to the entry and exit magnet faces, edge up-stream and edge down-stream, and the trajectory length. A set of magnet optics parameters may be used in more than one operation, but only one set may be referenced per operation. The model is summarised in Fig6.

4 Database functionality

The data model may be extended to reference data stored in ORACLE tables maintained outside the ABS system, such as in the PS control system [5] and survey databases.

ABS specific object methods have been developed to pass treated optics data to a symbolic optics program where it can be used to generate the reference optics and correction matrices for an operation. These methods also provide lists of positioned correctors and monitors as well as calibration data and power supply names to application programs [6].

The symbolic optics program requires a formatted list of optics elements with their properties in order to calculate a matrix to describe the nominal optics as well as a list of correctors and monitors with their positions. In order to generate the data describing a beam optics channel, the operation beam path would first be expanded into its component elements. The resulting data is then stripped of those elements which are not used in the operation. The channel is assumed to start and end at the beginning and end of the beam path. The position of each element can be derived from the displacement of each element given relative to the parent machine part in the beam path structure. The operation optics of each magnet element is treated: positions and drift spaces calculated, the data formatted and then sent to the symbolic optics program. Lists of correctors and monitors are included in the expanded information with their position relative to the start of the beam path. In order to import this data into the symbolic optics program, the user has to type a simple command followed by the operation and type of steering correction he wishes to treat

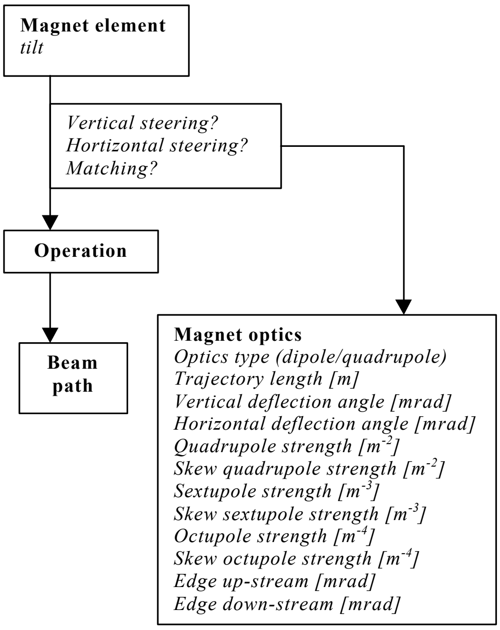
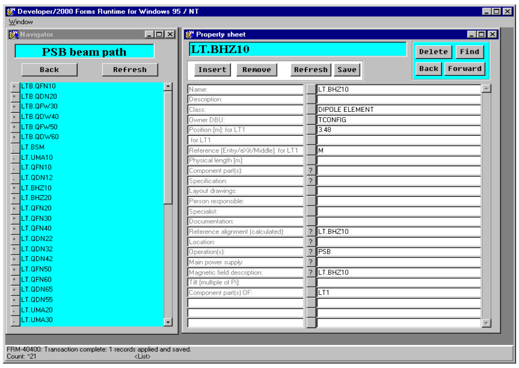


Fig6: The description of the optics of a magnet element for an operation.

5 Data management software (ACCIS)

The software used to manage the data is ACCIS (ACCelerator Information System), a generic object management system developed at CERN. The data repository is the relational database management system ORACLE. The software provides tools to define object classes as well as a basic set of object management methods on top of which methods particular to the ABS can be built. Once the object classes have been defined the user can immediately start to enter data without further software development using a generic formatted screen for data entry (Fig7).



PSB beam path

- LTB.QFN10
- LTB.QDN20
- LTB.QFW30
- LTB.QDW40
- LTB.QFW50
- LTB.QDW60
- LT.BSM
- LT.UMA10
- LT.QFN10
- LT.QDN12
- LT.BHZ10
- LT.BHZ20
- LT.QFN20
- LT.QFN30
- LT.QFN40
- LT.QDN22
- LT.QDN32
- LT.QDN42
- LT.QFN50
- LT.QFN60
- LT.QDN65
- LT.QDN55
- LT.UMA20
- LT.UMA30

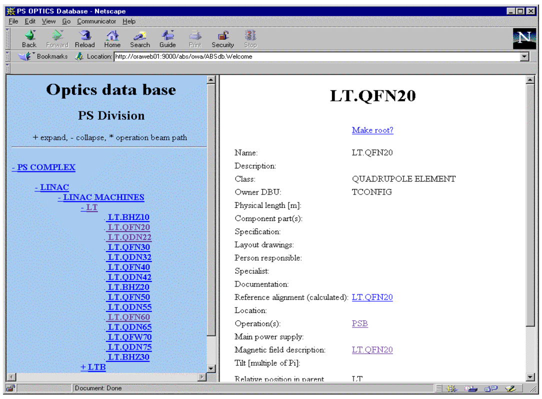
LT.BHZ10

Name: LT.BHZ10
Description:
Class: DIPOLE ELEMENT
Owner DBU: TCONFIG
Position [m]: for LT1 3.48
for LT1
Reference [Entry/eXit/Middle]: for LT1 M
Physical length [m]:
Component part(s): ?
Specification: ?
Layout drawings:
Person responsible:
Specialist:
Documentation:
Reference alignment (calculated): ? LT.BHZ10
Location: ?
Operation(s): ? PSB
Main power supply: ?
Magnetic field description: ? LT.BHZ10
Tilt [multiple of Pi]:
Component part(s) OF: LT1

FRM-40400: Transaction complete: 1 records applied and saved.
Count: *21 <List>

Fig 7: The ORACLE Forms data entry and maintenance screen.

ACCIS includes a WEB browser for interrogating the data. An example of a WEB page is shown in Figure 8. The browser has the WEB look-and-feel, when the user clicks on a reference field, a new page will be displayed. The ACCIS Web pages, however, are dynamically created from data in the database using procedures also stored in the database using the ORACLE WebServer facilities. Therefore as soon as the data is changed, the modification can be seen using the browser.



http://oraweb01:9000/abs/owa/ABSdb.Welcome

Optics data base

PS Division

+ expand, - collapse, * operation beam path

- PS COMPLEX
  - LINAC
    - LINAC MACHINES
      - LT
        - LT.BHZ10
        - LT.QFN20
        - LT.QDN22
        - LT.QFN30
        - LT.QDN32
        - LT.QFN40
        - LT.QDN42
        - LT.BHZ20
        - LT.QFN50
        - LT.QDN55
        - LT.QFN60
        - LT.QDN65
        - LT.QFW70
        - LT.QDN75
        - LT.BHZ30
      - + LTB

LT.QFN20

Make root?

Name: LT.QFN20
Description:
Class: QUADRUPOLE ELEMENT
Owner DBU: TCONFIG
Physical length [m]:
Component part(s):
Specification:
Layout drawings:
Person responsible:
Specialist:
Documentation:
Reference alignment (calculated): LT.QFN20
Location:
Operation(s): PSB
Main power supply:
Magnetic field description: LT.QFN20
Tilt [multiple of Pi]:
Relative position in parent LT

Document: Done

Fig 8: The Optics database Web browser.

6 Evolution and conclusion

The main aim of the Accelerator Optics Database is to fully describe the machine operations in an accelerator complex and to import the data into a symbolic optics program for generating correction matrices. The database must also provide lists of correctors and monitors and calibration data to the application software. The objectives have been achieved for the Linac to Booster transfer with the correction information for vertical steering. The magnet element concept has also been verified by using the database to describe the more complex CPS and LHC magnets. Since the testing of the system has begun, anomalies have been detected arising from incorrect reference parameters which have subsequently been corrected, i.e. the Accelerator Optics Database can be used to verify the correctness of the data.

The ACCIS software allows the definition of further descriptive properties without the necessity of modifying the software. There is no need to restrict the data entered to that required for the ABS project. Indeed apart from the structural decomposition of an accelerator or transfer line, the database also includes specification data that provides supplementary on-line information to operators. This data can also be seen using the Web browser and is being increasingly interrogated. This information could be eventually extended to include a complete documentation of the PS complex.

The data entered into the earlier version of the database has been successfully migrated into the new object model. The next step is to complete and check the description of the remainder of the PS complex operations.

Acknowledgements

The authors would like to thank L. Giulicchi, A. Lombardi and M. Martini for their help in providing the data for this project.

References

[1] R. Bailey, A. Belk, P. Collier, M. Lamont, G. de Rijk, M. Tarrant, "Development of the LEP High Level Control Software using Oracle as an On-line Database", Proc. of ICALEPCS, Berlin, Germany, Oct 18-22, 1993.

[2] B. Autin, V. Ducas, O. Jensen, A. Kazymov, M. Lindroos, J. Schinzel, and E. Wildner, "Generic Configuration Management System for Documentation and Beam Optics Applications in the CERN PS Complex", Proc. of ICALEPCS, Chicago (USA), Oct 29-Nov 3, 1995.

[3] B. Autin, E. d'Amico, V. Ducas, O. Groner, M. Martini, E. Wildner, "Beam Optics, a Program of Analytical Beam Optics", to be published as a CERN report.

[4] H. Grote, "Data base for MAD", private communication.

[5] J.H. Cuperus, M. Lelaizant, "Integration of Relational Database in the CERN PS Control System", Proceedings of this conference.

[6] M. Arruat, A. Jansson, F. di Maio, G.-H. Hemelsoet, M. Lindroos, O. Tungesvik, "Generic Automated Beam Steering and Beam Shaping Programs", Proceedings of this conference.