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SSC MAGNET STRING TESTS

Summary by J. D. Jackson
Detailed discussion by Peter J. Limon

The following is a brief summary of the magnet string tests for the SSC, together with an assessment of the risks inherent in a decision to proceed with construction before the various results of the tests are known. The important subject of tests on individual magnets, as well as string tests, is covered in a somewhat more detailed supporting discussion prepared by Peter J. Limon.

Summary

As part of the Engineering Development program to assure the quality, reliability, and cost effectiveness of the SSC magnets and magnet related systems, the following systems tests are planned:

1. Half Cell Test - A test of a half cell of prototype magnets (5 full-scale dipoles of the high field type, one unit of the low field) to establish cryogenic operating parameters, quench propagation between magnets, quench protection devices, installation and vacuum integrity procedures, etc. The Half Cell Test is scheduled to commence in November 1986, with results reported by April 1987. To meet this schedule, fabrication of the test facility must start in January 1986.

2. Accelerated Life Tests - A test of a half cell of pre-production magnets, with rapid ramping, many quenches, and many thermal cycles. A reasonable sample of randomly selected magnets tested in this way will provide early enough information on minor design flaws to permit modifications that will result in enhanced reliability and smoother operation of the actual accelerator. The Accelerated Life Tests are scheduled to commence at the end of FY 1987, at a time when the magnet design is close to final. Results will be timely for influence on the final production design.

3. Systems Development Facility - A facility is planned to evolve out of the Half Cell Test as more prototype magnets are available. Many of the components associated with the magnets need not have their final design established and fabrication commenced as early as the magnets because the time and cost factors are not as great. The systems development facility will be a test bed for the creation of a coherent total engineering design.

Results on magnets will emerge as a matter of course, but the purpose of the facility is to create and develop the other accelerator systems in a multi-magnet string (perhaps as long as 1 km) with the full complexity of the main ring. As an extension of the Half Cell Test, this facility would commence operation at mid-year in FY 1987 and continue well into the construction phase since it will be the only realistic test facility until the first sector of the ring becomes available.

Assessment

The test program described above will help assure the creation of a reliable, efficient, cost effective SSC. The experience with the Tevatron and the R&D program so far shows that there are no fundamental technical problems to be solved for individual components. Magnets, cryostats, quench protectors can be built and operated to specifications. The test program addresses the engineering development aspects of the technical systems. As such, the Half Cell Test is a major milestone. If the magnet string and related devices perform as expected, by mid FY 1987 the Phase 1 program will have clearly accomplished its major goal, the establishment of the technical feasibility of the SSC.

The Accelerated Life Tests and the Systems Development Facility are important, but not crucial. They address engineering improvement issues that do not have major impact on the overall cost or schedule of the project. They do bear on easy and reliable installation, commissioning and operation of the facility, and on the engineering design of the myriad of technical components beyond the magnets.

The CDG actually believes that enough experience has been gained that the successful construction during calendar 1986 of 8 to 10 prototype magnets meeting specifications will be sufficient evidence in itself that the SSC can be built and that no major revisions are needed on the magnets. A more conservative view would require in addition the successful completion of the Half Cell Test (with at least a month of operation). The Accelerated Life Tests and the Systems Development Facility are important as the magnets and the whole accelerator move into construction, but the absence of results from them carries no significant risk to a decision to proceed.

Without the results of the Half Cell Test, the only risk apparent is a delay of perhaps six months to a year, should that test uncover a major flaw in the systems aspect of the facility. (The individual components will have been thoroughly tested by then.)

An irrevocable decision to proceed with construction before the fabrication of a number of SSC prototype magnets of adequate field quality and strength is not desirable from anyone's point of view. On the other hand, an early decision to move towards construction has considerable advantage and negligible risk. A Conceptual Design Report will exist in April 1986. Declaration of intention to construct, predicated on the success of the Phase 1 program, can set in motion site and contractor selection in parallel and lead to the earliest possible start on construction.

JDJ:dm
Attachment

Tests of Individual Magnets and Systems of Magnets

Peter J. Limon

A number of tests must be performed on the magnets that are being developed for the SSC. The primary reason for performing the tests is to assure the proper design, fabrication, and quality control of magnets and magnet-related systems. There are, in general, four types of tests that should be considered:

1. Operations of existing accelerators and tests of previously built magnets that are of similar or related designs.

2. Laboratory tests of components, sub-assemblies, and models of the magnets.

3. Tests, operation, and magnetic field measurements of single prototype, preproduction, or production magnets.

4. Operation and tests of the behavior of several magnets as a system, sometimes referred to as string tests or systems tests.

The entire program of tests fits together to maximize the probability that the resulting accelerator will perform at high efficiency, while minimizing construction cost and technical risk. Some of the tests should be completed early in the R&D phase, so that design changes can be made with the smallest impact on cost and schedule. Other tests can be completed later in the project, since they will not have a significant impact on the design or construction of the magnets or other devices.

1. Operations and tests of existing accelerators and magnets

(a) The Tevatron

Probably the most important test result for the SSC is the existence and efficient operation of the Tevatron. It answers the primary question, "Can superconducting accelerators work?" Not only does the Tevatron work, but it works well. It is useful, not only as a demonstration, but as a data base of information, and a source of expertise about how to proceed in designing and building the SSC. The experience that already exists and the opportunity to perform new experiments on a superconducting accelerator is invaluable. The manpower that was trained during the design, R&D, installation, and operation of the Tevatron forms a significant fraction of the people working on the SSC.

As a measure of the significance of the Tevatron as a test, we note that in its fixed target operation it has already been through more ramping cycles than the SSC will have in its whole lifetime as a collider. This sort of accelerated life testing (relative to SSC operation) is a demonstration that the SSC can be made to work well, and that its magnet systems will be reliable. Understanding of the engineering aspects of superconducting accelerator magnets has progressed amazingly far since the start of large scale R&D, in the mid-1970's. Because of the success of the Tevatron, there is no longer any doubt that magnets of sufficient quality and performance can be produced in quantity.

(b) The CBA magnets

The CBA experience is often taken as an example that one cannot always succeed in building a working superconducting magnet. The evidence does not support that conclusion, however. The fact is that there were early problems with the magnet design. These problems were solved, however, and the final design of the magnet was shown by tests to be excellent, both in field quality and operational behavior. Unfortunately, others were active during the period of difficulty. The invention and development of stochastic cooling, and the resulting opportunity to have proton-antiproton colliding beams at good luminosity, provided access to the CBA energy domain sooner and at less cost than could the CBA.

There is a lesson to be learned from the experience. It is important to be sure that the magnets are well designed before one proceeds with construction. The thorough set of magnet tests prescribed for the SSC address this requirement.

(c) HERA Magnets

HERA is a proton-electron collider with a 800 GeV superconducting proton storage ring, being built at DESY. Construction has already started, and the magnets are being built in industry. There have been tests of short model magnets, and there will be a string test of one cell (six dipoles) of magnets by the end of 1985. These magnets are very similar to the high-field type D of the SSC except that the physical aperture is much larger. The string test will be relevant to the SSC high field designs.

(d) Other Tests

A number of other accelerator-type superconducting magnets have been built and tested. In particular, the Japanese and the Soviet Union have each successfully tested magnets of their own design, both types rather similar to the Tevatron dipoles. Early models of the magnets discussed in the Reference Designs Study have been built and successfully operated at BNL, Fermilab, and TAC. The TAC accomplishment is quite significant, because the magnet type is a completely different concept, a superferric magnet.

2. Laboratory Scale Tests

The purpose of laboratory tests during the early phase of magnet design and development is to understand the behavior of components, sub-assemblies, and assembly procedures, by performing well-known and accepted engineering tests. Examples are the fatigue tests of collars, the measurements of the cryogenic properties of possible cryostats and magnet supports, and the building, testing and magnetic measurements of short model magnets.

The organizations involved in the SSC R&D have already performed a large number of laboratory tests, involving low and high field magnets, one-in-one and two-in-one designs, different coil manufacturing techniques, various kinds of support structures and superinsulation, and so forth. These are all part of the R&D of magnet concepts, and are expected to yield in a very cost effective way a design that is very close to final before any full size prototypes are made.

3. Single Magnet Tests

Tests and magnetic measurements of single prototype, preproduction, or production magnets will be continued throughout the development and construction of the SSC. In the R&D phase of the project, most of the specific information about the properties of the magnets will come from such tests. In addition to field quality, these tests yield information about cryogenic behavior, mechanical stability, reproducibility, electrical insulation, lifetime, failure rates, vacuum integrity, quench propagation and protection, in short, almost every aspect of the design.

Previous experience, particularly with the Tevatron program, demonstrates the importance of single magnet tests. Magnetic measurements and thermal cycling of the magnets showed that the early design of the coil anchor was not sufficient to maintain a stable vertical plane. This discovery resulted in an effective new design early enough in the construction schedule that there was very little delay or cost penalty. High voltage tests of single magnets resulted in a re-design of the coil insulation, especially in the quadrupole magnets.

Important features of such tests are that they are done very early in the prototype production, and that they are quite complete. Hence, they catch most of the design flaws at a time when changes have minimum impact on the cost and schedule of the project.

As construction proceeds, single magnet tests are used as a check on the quality control of production. Cryogenic tests might be performed on only a fraction of the magnets, although some tests will be required on every magnet. The extent of production tests will be determined by such factors as failure rate, and quality control.

4. Multiple Magnet Tests

A few properties of the magnet system cannot be determined by single magnet tests, but must use a configuration of several magnets. The most significant of these tests, in terms of their impact on the total project cost and schedule, can be done with a small number of magnets. The multiple magnet tests are discussed in some detail in "The Report of the Task Force on SSC Magnet System Test Site", SSC-SR-1001, October, 1984. In that report, it is envisioned that there are three types of multiple magnet tests. These three tests are developed from the experience of building the Tevatron, and are a natural extension of that work. Among the important phenomena that were investigated at the Tevatron were the propagation of quenches from magnet to magnet, the protection scheme and its required sensitivity, the bypass of current around quenching magnets, and the pressure rise during quenches. In addition, a number of cryogenic parameters were measured with greater accuracy than they could be in single magnets, and considerable information about installation procedures and vacuum leak hunting was gained.

(a) The Half Cell Test

The length of the string of magnets for this test is determined by the excitation current bypass scheme. For the SSC the length is at least one half cell of magnets (e.g., five dipoles of the type D, plus one spool piece; for type C, three 35m modules and a spool piece).

It is expected that most of the important modifications to the design of the magnets will be established very early in the test. Installation difficulties, for example, will be evident as soon as installation starts.

The Half Cell Test is scheduled to start at Fermilab in November 1986. This schedule requires that fabrication of the test facility be started about January 1986. The initial cost of the test facility was estimated in the Test Site Report at about $1 million, including salaries, a small refrigeration building, and a housing for the magnet string. The cost of operations for one year has been estimated at $800 thousand, including salaries, cryogens, and power.

The benefit that can be derived from such a test is much greater than the investment. The major gain is in the design of the quench protection system. A change from passive to active quench protection with the installation of heaters, for example, is a minor change if done early, but a major change and major cost if done later by retrofitting. On the other hand, if one could demonstrate the effectivness of passive protection, several million dollars could be saved, and the whole system could be made much simpler.

Another important early test is a measure of the pressure rise in the cryostats during a quench. It is obvious that an underdesigned cryostat could be expensive if not caught early in the prototype production of magnets. An overdesigned cryostat is less disastrous, but also costly.

There is no question that the Half Cell Test is necessary to conduct, and is cost effective. Most of the results will be gotten early in the test sequence, and can be fed back into the design easily. Later parts of the test are more important to the systems that are connected to the magnets but are not part of the magnet construction, such as quench protection software. Much information will be learned about those things, but the main emphasis will be on the magnets.

(b) The Accelerated Life Tests

The purpose of the Accelerated Life Tests is to find those subtle things in the magnet design that will lead to reduced lifetime. The test is specifically designed to find problems like the fatigue in the cables leading out of the magnet coils of half the magnets in the Tevatron.

In general, this is done as a multiple magnet test of a half cell of dipoles. The aim is to stress the dipoles to very high levels, in order to accelerate any fatigue, or other lifetime limitations. This is done by rapid ramping, inducing many quenches, and many thermal cycles. The half cell is useful because it increases the statistical significance of the magnet sample, and because such an arrangement also tests intermagnet connections, and other parts of the system.

The Accelerated Life Test should begin as soon as magnets are available that are close to the final design. The test should eventually be performed with magnets that are randomly taken from the production line. Presently, the Accelerated Life Test is schduled to start near the end of fiscal year 1987. The cost of fabrication has been estimated at about $850 thousand, including manpower. The operating cost for one year was estimated at $1 million, including manpower, cryogens, and power.

The benefit involves both cost and accelerator downtime. The simple repair of the wear-out phenomenon in the Tevatron took four months of around-the-clock work in the accelerator tunnel. It appears that the benefit/cost ratio is potentially quite large, and that the tests can be performed in a timely way to affect the magnet construction. It is expected that the nature of the design changes will not be great, so long as production has not proceeded too far.

(c) Systems Development Facility

The accelerator is made up of very many components and systems other than the magnets. The final design and fabrication of those systems usually is not required as early as the magnet design, since the time of fabrication, and the cost impact of each system is not as great as for the magnet systems. Nevertheless, most of the systems must be developed before there is a significant number of magnets installed in the SSC tunnel, in order that the accelerator has a coherent total engineering design into which all systems fit. In order to facilitate the systems development, the CDG proposes a multiple magnet system referred to as the Systems Development Facility. Its purpose is not to test the magnet systems, although there will certainly be some knowledge about the magnet system derived from the Development Facility, but instead to be a test bed used to develop the other accelerator systems. All of the systems that do not involve beam can and will be developed and tested on such a system.

The Systems Development Facility is expected to be longer than the Half Cell Test, perhaps as long as one percent of the SSC rings. That is because one of the main features of the SSC is its large scale, and it seems prudent to test the systems on a large scale facility. The system could be an extension of the Half Cell Test, or it could be an independent facility, depending on convenience, manpower, and other factors. If it were fabricated as an extension of the Half Cell Test, it could start in early calendar year 1987, by adding more magnets to the Half Cell Test when it is completed. It is expected that the Facility would operate for a considerable time, overlapping with the construction phase of the SSC, since it will be the only realistic test facility until the first sector of the ring is available, sometime in mid-1990.

The cost of the Systems Development Facility has been estimated at an additional $1.5 million for fabrication, over and above the cost of the Half Cell Test. It will cost about $1 million per year to operate. The cost benefit is derived from the ability to make complete tests of many of the systems aspects of the SSC before tunnel installation. A realistic test facility for refrigeration simulation, controls development, power supplies, and software development will save money, and decrease the amount of time needed to commission the rings. The cost of changing a system once it is in the tunnel is much greater than the development cost, even if the changes in the system are minor.