CONF-900944--9

UCRL-JC-103596
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FENIX, A Test Facility for ITER and Other New Superconducting Magnets

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This paper was prepared for submittal to the
1990 Applied Superconductivity Conference,
Snowmass Village, Co, 9/24-28/90

September 21, 1990

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FENIX, A TEST FACILITY FOR ITER AND OTHER NEW SUPERCONDUCTING MAGNETS

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UCRL-JC--103596

DE91 000654

Abstract

The Fusion ENgineering International eXperimental (FENIX) Test Facility which is nearing completion at Lawrence Livermore National Laboratory, is a 76-t set of superconducting magnets housed in a 4-m-diameter cryostat. It represents a significant step toward meeting the testing needs for the development of superconductors appropriate for large-scale magnet applications such as the International Thermonuclear Experimental Reactor (ITER). The magnet set is configured to allow radial access to the 0.4-m-diameter high-field region where maximum fields up to 14 T will be provided. The facility is fitted with a thermally isolated test well with a port to the high-field region that allows insertion and removal of test conductors without disturbing the cryogenic environment of the magnets. It is expected that the facility will be made available to magnet developers internationally, and this paper discusses its general design features, its construction, and its capabilities.

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract number W-7405-ENG-48.

Introduction

Lawrence Livermore National Laboratory (LLNL) is, with the support of the Department of Energy (DoE), constructing a new facility at LLNL to meet test specifications for the International Thermonuclear Experimental Reactor (ITER).

The Fusion ENgineering International EXperimental Magnet Facility (FENIX) is a significant step forward in meeting the testing requirements necessary for the development of superconductors for large-scale, superconducting magnets.

A 14-T, transverse field covers a test volume of 150 x 60 x 150 mm in length. Here conductors of the size to be used in ITER can be tested.

Proposed conductors for ITER measure ~35 mm on one side and will operate at currents of up to 40 kA at fields of ~14 T. The testing of conductors and associated components, such as joints, require large-bore, high-field magnet facilities; FENIX will be the only facility available that can match ITER conditions. Consequently, FENIX will be the gate way to the next phase of conductor development for ITER.

FENIX is being constructed using the existing A_{2o} and A_{2i} magnets from the idle MFTF (Mirror Fusion Test Facility). The east and west A_2 pairs will be mounted together to form a split-pair solenoid. The pairs of magnets are now installed in a 4.0-m cryostat vessel located in the HFTF (High-Field Test Facility) building at LLNL. Each magnet is enclosed in its own cryostat, the existing 4.0-m vessel serving only as a vacuum chamber.

Figure 1 shows the two magnets being installed in FENIX. Figure 2 shows the second magnet being lowered into place in the four-meter vacuum vessel.

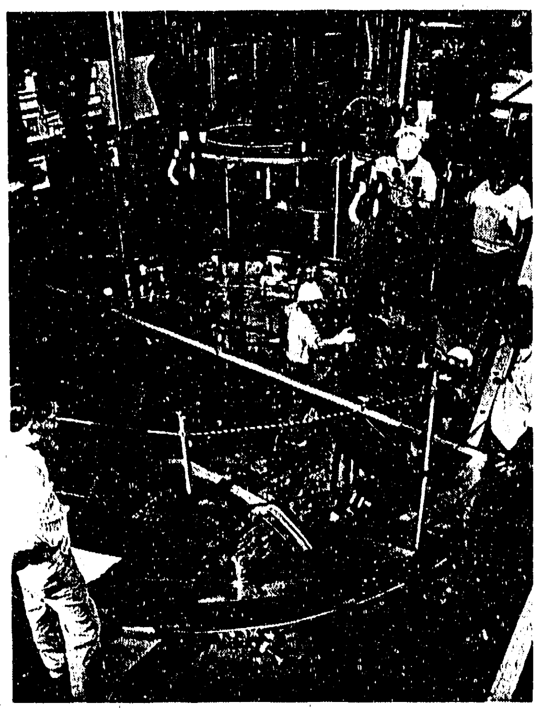

Figure 1. Magnets in Place

As previously used, the magnets developed fields of 12 T. A field of 14-T will be achieved in FENIX by using iron cores in the magnet bores and bringing the two magnet sets close together. A 60-mm gap between the magnet pairs permits insertion of conductors to be tested in the 14-T transverse field. The aluminum spacer plates that maintain this gap and the notch where test conductors are inserted can be seen in Fig. 2.

Forced-flow helium at adjustable temperatures, pressures, and flows will be provided to sample conductors being tested. Samples can be from one to several meters in length, with about 0.15 m being in the uniform, high-field region. Power supplies are available to provide currents up to 40 kA.

The cost of constructing FENIX is minimized by the use of pre-existing equipment. The cryogenic equipment, cryostat, magnet, and sample power supplies, are in place. The only major expense is the relocation and integration of the MFTF A_{2o} and A_{2i} magnets. The total cost for setup of

Manuscript received September 24, 1990.

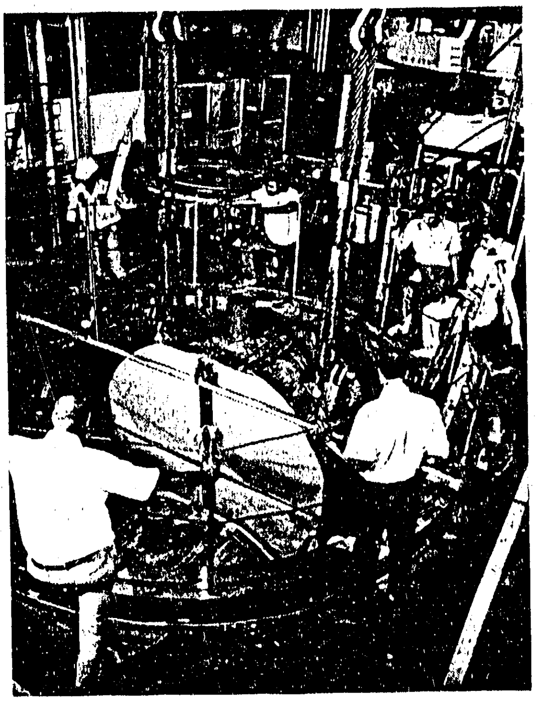

Figure 2. Magnet Installation

FENIX is about $1M. This compares favorably with an estimated cost of $20M for construction of a comparable, all new facility.

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Work on FENIX is well underway with a target completion date of December 1990. As of August 1990 the magnets are installed and plumbing is completed in the 4-m vessel. Vacuum and cryogenic systems are being installed. The facility will be available for use by researchers internationally.

Services installed in FENIX to support the sample conductors are described in the following sections. Helium flows, temperature control, etc. provided are intended to satisfy most test programs. However, modifications to these services can be made if required.

General Description

Figure 3 shows a pictorial cutaway. The A_2 magnet sets were removed from the MFTF facility in June 1989. The various components (including magnet supports, helium reservoir, and test well) are installed. A Koch, model 2800, helium refrigerator is in place at the FENIX site

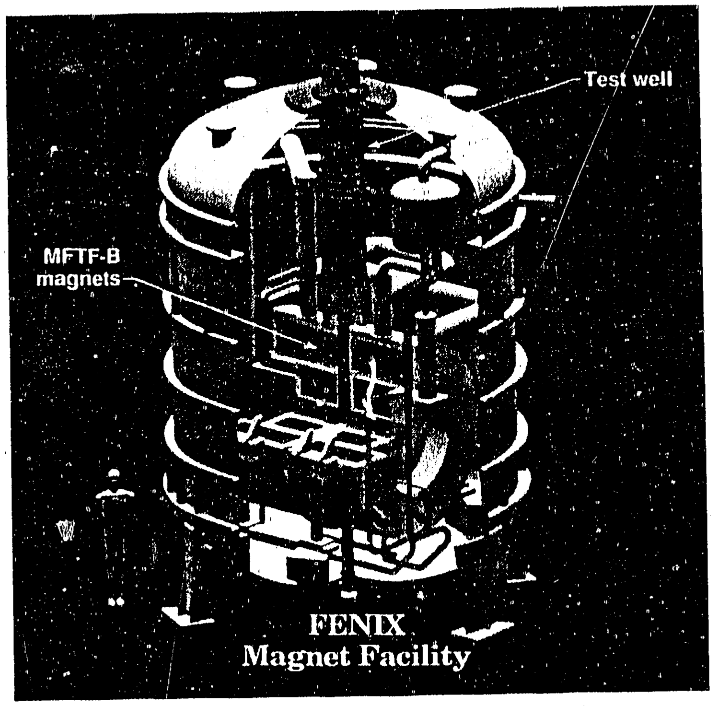

Figure 3. FENIX Magnet Facility

and will be used to provide refrigeration to the facility's A_2 magnet sets, their vapor-cooled supports, and current leads. An Airco 400-W helium refrigerator also exists at the test site. The Airco refrigerator will be used to provide liquid helium to the test well, thus providing refrigeration for the test conductor leads and the forced flow through the test conductor.

Figure 4 shows the test-well, magnetic-field plot at the magnet centerline, where the field is greatest. The plot is dimensioned so future users can determine field conditions for test conductors.

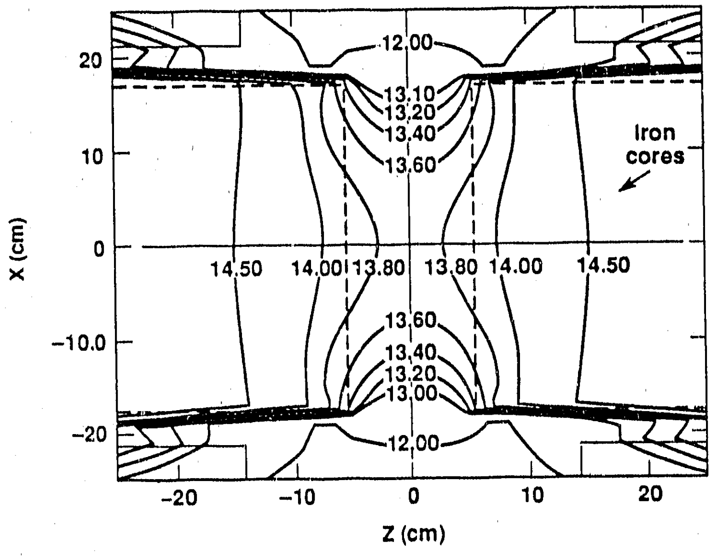

Figure 4. Magnetic Field Plot

Figure 5 shows the the existing building, crane, and 4-m cryostat. The dotted lines above the 4-m cryostat depict the test conductor and its supporting structure. The cold-sink and heat-exchanger coils used to provide cryogens to the test conductor are within the upper dotted lines. The

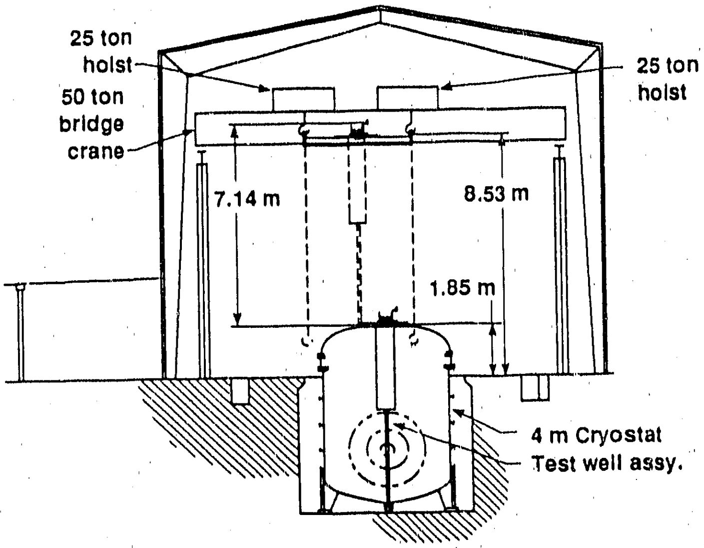

Figure 5. Building Elevation

test conductor can be removed from the test well without warming the facility.

Forced-Flow Helium Available For Test Conductor

Figure 6 shows a schematic of the system used to provide cryogens to the test conductor. The heat exchanger is a coiled tube-in-tube unit located in the upper part of the test well. The liquid-helium bath is maintained by the Airco refrigerator and supports both lead cooling and conductor forced-flow cooling. Room-temperature helium flows from high-pressure storage through the heat exchanger, where it is cooled to near liquid-helium temperature. It then passes through a cold-sink coil where it is cooled to the liquid-helium-bath temperature. The flow then branches into four paths which can be separately controlled. Temperature to each path can be controlled by the heaters shown, as well as the bypass valve that bypasses the cold sink. Flow rate to each path can be controlled by the flow meters and valving shown in the upper right on Fig. 6.

The use of four paths provides the user with flexibility. For example, three paths might be paralleled to provide high flow to the main test conductor, and the fourth path used to provide flow to a conductor joint. Another possibility is providing flow to two different test conductors at the same time, with the ability to monitor conditions in each conductor separately.

The heaters can be used to provide pulsed or steady-state heat to the test conductors. Longer term testing with warmer inlets will probably be accomplished by using the bypass valve to avoid the heat load introduced by the heaters.

As shown, inlet and outlet temperatures, pressures, and flows to each path can be monitored. One limitation of the present design is that the same inlet pressure is provided to all paths. Pressure-dropping valves could be used to vary inlet pressures, but these are not planned unless users indicate a need for them.

The extended lip on the smaller test conductor portion of the well permits operating it dry. Here a slight amount of heat will be added at the bottom of the test well to boil off any helium spillover from the upper test well. Pool-boiling conductors can also be tested by flooding the entire test well.

Flow available for Test Conductors

Inlet pressure: 0.5 to 2.5 MPa, adjustable

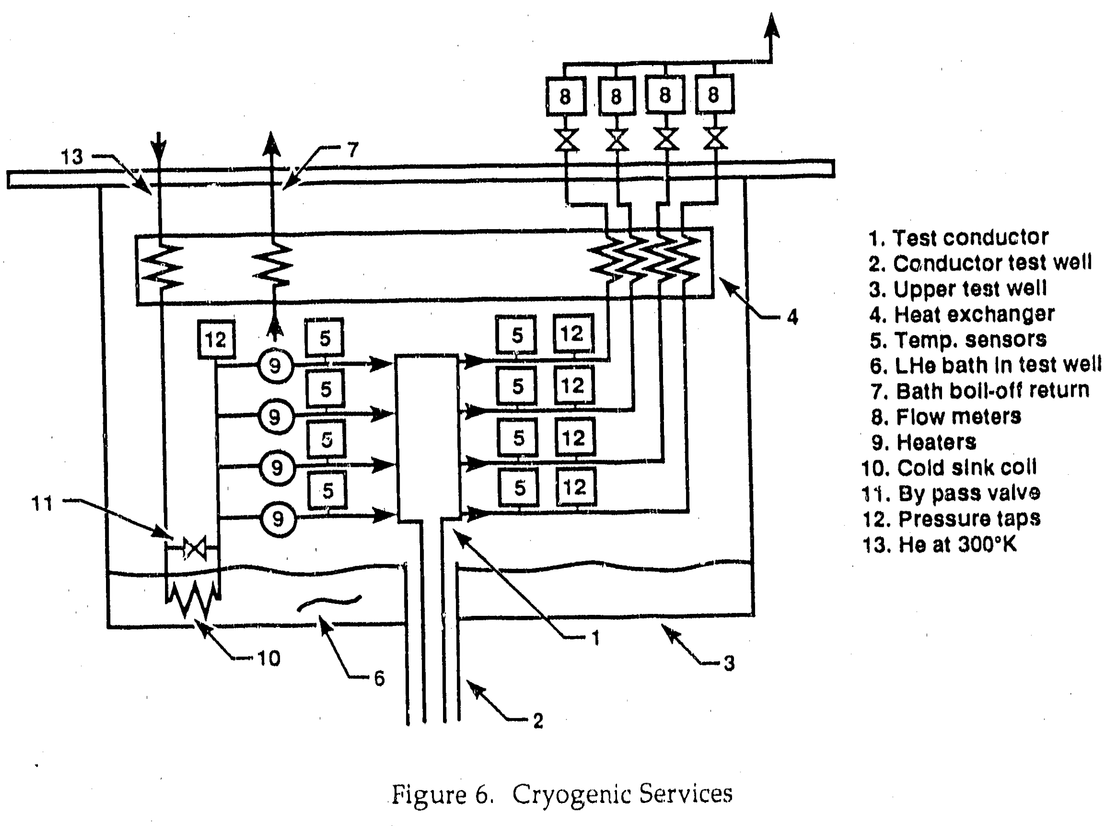

Figure 6. Cryogenic Services

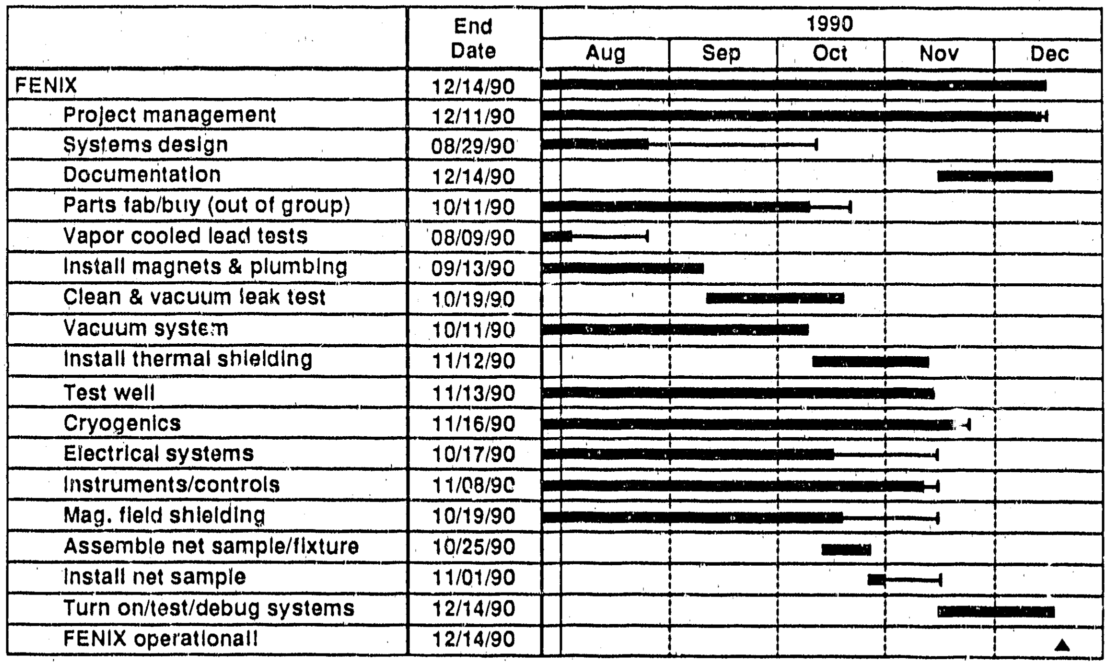

Figure 7. Schedule

Inlet temperature: 3.5 K to >10 K — 3.5 K by pumping on test well, 4.3 K by use of atmospheric test well, higher temperatures using heaters and by-pass.

Flow rate: 30 g/s total for all paths with 0.5-MPa pressure at the test coil outlet. Maximum flow is proportional to pressure.

Duty cycle: Continuous with 40-kA test conductors for several hours — here an existing 10-kL dewar will supplement the liquid-helium supply to the test conductor and its leads.

Test Conductor Power Supply, Controls, and Diagnostics

A NWL 6-V, 40-kA power supply is used as the test conductor current source. The voltage available to the sample at full current, 40 kA, is about 0.5 – 0.75 V. Water-cooled leads are used to deliver the current from the power supply, located outside the building, to the sample in the FENIX test well. The power supply will be controlled by a Hewlett Packard 9000/300 series computer with user-programmable ramping.

The diagnostics will consist of the following systems:

1. HP 9000/300 series computer at the FENIX/HFTF building with an EtherNet link to the LLL VAX 8600 on the NMFECC Network. Data will be archived on the LLL VAX in data files for the IDL data analysis/plotting software. We are planning to make the data available in WKS spreadsheet files, also for use in PC/MAC applications. This data can be available to the client/customer via the NMFECC network.

2. HP 3852 Data Acquisition Units with two multi-channel, analog, sampling modules. One is a low-speed (up to 20 samples/second with 20 channels available) Integrating DVM with high resolution and high accuracy. The second is a high-speed (up to 10,000 samples/second with 50 channels available), 13-bit, analog-to-digital converter.

3. Several miscellaneous signal conditioners are available for pressure transducers, strain gages, temperature sensors, hall probes, etc.

Schedule

Anticipated completion of the FENIX facility is about December 1990. Figure 7 is a project schedule.

Acknowledgments

This work was performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

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