LA-UR-96- 3686

CONF-9608132--13

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DEC 26 1996
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Submitted to: 7th International Conference on Megagauss Magnetic Field Generation and Related Topics - MGVII
Sarov, Russia
August 5-10, 1996

Los Alamos

NATIONAL LABORATORY

NEW DEVELOPMENTS IN PULSED FIELDS AT THE US NATIONAL HIGH MAGNETIC FIELD LABORATORY

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Introduction

Los Alamos National Laboratory is a member of a consortium (with Florida State University and the University of Florida) to operate the National High Magnetic Field Laboratory(NHMFL), with funding from the National Science Foundation and the State of Florida. Los Alamos provides unique resources for its component of NHMFL in the form of a 1.4 GW inertial storage motor-generator for high field pulsed magnets and infrastructure for fields generated by flux compression.

The NHMFL provides a user facility open to all qualified users, develops magnet technology in association with the private sector, and advances science and technology opportunities.

The magnets in service at Los Alamos are of three types. Starting with the pre-existing explosive flux compression capability in 1991, NHMFL added capacitor-driven magnets in December, 1992, and a 20 tesla superconducting magnet in January, 1993. The capacitor-driven magnets continue to grow in diversity and accessibility, with four magnet stations now available for several different magnet types.

Two magnets of unprecedented size and strength are nearing completion of assembly and design, respectively. Under final assembly is a quasi-continuous magnet that contains 90 MJ of magnetic energy at full field, and being designed is a non-destructive 100 T magnet containing 140 MJ.

Magnets, Present

A list of magnets now in use is given in Table 1. They are described in more detail below.

A. Capacitor-driven magnets

There are four experimental stations equipped with capacitor-driven magnets. Any of the various magnets can be installed in these stations as needed. One station has a dilution refrigerator that can reach a base temperature of 25 mK with a 24 mm od tail. All magnets are powered by a four-module, 10 kV, 1.5 MJ capacitor bank. Modules can be switched out when less capacitance is needed. Magnet lifetimes have varied from about 200 pulses to over 700. To date the magnet failures have been 'soft' in the sense that no mechanical disassembly occurred. Typically, a conductor break causes an arc which vaporizes liquid nitrogen and the resulting overpressure then crushes any experimental probe in the magnet's bore. All shots occur 'wet', i.e., with the magnet in a bath of liquid nitrogen.

The maximum field offered to users is about 8 T less than the field in which identical test magnets failed mechanically. That is, the advertised 50 T magnet will fail mechanically at about 58 T. Users who are willing to accept the risk of reduced magnet lifetime may request fields closer to the mechanical limit. All magnets are now constructed at NHMFL. The pulse shapes of the various magnets are given in Fig. 1. There is a continuing effort to upgrade both the magnets and instrumentation. Recently, improved measurement procedure reduced the noise level for transport measurements in 50 T pulsed fields to 1 micro-volt.

The 50 T pulsed magnets have bore diameters of 24 mm and an overall pulse width of about 20 ms. These are the most popular pulsed magnets and have the largest selection of experimental probes. Their design follows that of Prof. F. Herlach's group in Leuven, where NHMFL personnel wound some of the early magnets. This helpful collaboration enabled NHMFL to begin pulsed magnet operation in 1992. The 50 T magnets require about one hour to cool following a maximum field pulse.

The 40 T long-pulse magnet is based on a design by Prof. S. Askenazy in Toulouse and was constructed at NHMFL. It has the same bore diameter, 24 mm, as the 50 T but its overall pulse width is much greater, about 500 ms. The cool-down time between pulses for this larger magnet is close to 80 minutes.

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Finally, there are 60 T magnets with a bore diameter of 15 mm and a slightly shorter pulse width than the 50 T. Their design, like that of the 50 T magnets, employs the Leuven principle of varying the reinforcement (glass fiber) between conductor layers to match the local stress [1]. Because of the smaller bore the variety of experimental probes is more limited with the result that the 60 T magnets are in less demand in spite of their higher field. The cool-down time is less than one hour.

B. Superconducting magnets

There are two superconducting magnets, a 20 T, with 52 mm bore, and a smaller 9 T magnet. Both are used for calibration, set-up, and staging experiments. A field cancellation coil in the 20 T magnet permits accurate low temperature thermometers to be placed in a region 35 cm from the principal field where the field is reduced to 0.1% of the main field. The 20 T magnet is in high demand for dedicated experiments and is well equipped with experimental probes, including a dilution refrigerator that reaches 20 mK.

C. Flux compression generators

From the beginning, NHMFL provided outside users with access to flux compression experiments built on the long experience of scientists (Dr. Max Fowler, in particular) and technicians at Los Alamos [2]. Currently, these experiments are performed in collaboration with or on a shared-space basis with other Los Alamos programs. They can also be provided on a full cost recovery basis. Flux compression experiments up to 1,000 T are possible in cooperation with Laboratory programs and international collaborations, in particular, VNIIEF [3]. The most recent series, code-named 'Dirac', began in April and concluded in July 1996. (The results are described elsewhere in these proceedings.) NHMFL is a liaison between outside users and the explosive flux compression capabilities at Los Alamos and thereby promotes general user access to this technique for producing ultra high fields.

The NHMFL capacitor-driven magnets are frequently used to conduct staging experiments for the flux compression shots. Other infrastructure can be provided. For example, a disposable plastic He-4 cryostat was designed that can maintain a temperature of 1.8K for almost 2 hours. Several were built by NHMFL and successfully used for the Dirac series. It is described elsewhere in these proceedings.

Magnets, Future

The new magnets now under assembly or being designed are listed in Table 2.

A. Quasi-continuous magnet

A quasi-continuous, or controlled power, magnet can maintain a field longer by an order of magnitude than a traditional capacitor-driven pulsed magnet and can reach a higher field than a hybrid magnet. Because it is not actively cooled its mass must be sufficient to absorb the resistive heating, and the power and energy supplied must be substantial. For a convenient bore size of 32 mm the energy needed is of order 100 MJ, which requires an ac power source. Programmable pulse shapes such as ramps, steps, and flat-tops are then possible. Of course, a disadvantage of ac power is the intrinsic ripple resulting from rectification.

The NHMFL quasi-continuous magnet consists of nine mechanically independent coils, each with steel reinforcing [4]. These coils are nested with radial separations of about 4 mm to permit efficient cooling by liquid nitrogen. Cooling time is expected to be one hour or less. Unlike the case for capacitor-driven magnets the liquid nitrogen will be drained from the quasi-continuous magnet just before the pulse. A drawing of this magnet is given in Fig. 2.

The ac power will be furnished by a synchronous motor-generator, which can convert its inertial energy to 600 MJ of electrical energy within approximately one second. Its duty cycle is about 10 minutes.

The quasi-continuous magnet will be brought into service in two steps. The first step will be to operate the magnet at 45 T using three power converters rated at 80 MVA each. This will occur in the latter part of 1996 and will allow low power testing of all control functions under experimental conditions. Four additional power converters of the same rating will arrive in the summer of 1997 and will allow the next step of operation at the full 60 T with a 100 ms flat-top [5]. This operation will only require five of the seven power converters; the remaining two converters will permit enhanced operation to 65 T by decreasing the time needed to reach and return from peak field. The most effective use of the seven power converters for the quasi-continuous magnet is still being studied. It is technically possible to replace the inner cluster of five coils with stronger versions to achieve 70 T in a quasi-continuous mode.

It is also technically possible to replace the five inner coils with a capacitor-driven magnet to reach 85 T. This would test design concepts for the non-destructive 100 T magnet, but the user demand for quasi-continuous experiments may have higher priority.

B. Non-destructive 100 T magnet

A non-destructive 100 tesla magnet system is now being designed for installation at Los Alamos [6]. This system, consisting of a capacitor-driven magnet that is surrounded by outer coils similar to the quasi-continuous magnet discussed above, is jointly funded by the US Department of Energy and the US National Science Foundation, and is being developed in cooperation between LANL and NHMFL. Because of its extensive coverage elsewhere in these proceedings it will not be discussed further here.

Usage

Even though the principal magnet (the quasi-continuous) is still under construction the existing magnets are attracting approximately 50 different principal investigators for user experiments annually. In the past 12 months, 114 different experiments were recorded, ranging in duration from one day to two weeks.

The user activity is summarized below for the one-year period August 1, 1995, through July 31, 1996. These include only experiments with NHMFL magnets, not flux compression experiments.

Number of experiments		110	
Number of distinct Principal Investigators		58	
Total number of magnet-days used		477	(20 T: 309 magnet days)
Number of magnet-days used for testing		19	
Number of Principal Investigator-days		694	(20 T: 456 PI days)
University PI-days	361		52%
NHMFL PI-days	152		22%
Government Laboratory PI-days	176		25%
Industry PI-days	5		1%
Total	694		100%

Summary

Since the first magnet was installed less than four years ago the variety of magnets and scientific infrastructure of the NHMFL Pulsed Field Facility at Los Alamos have grown to accommodate over a hundred user experiments a year.

In late 1996 the NHMFL will provide a quasi-continuous magnet, the first of its type in the US and the strongest of its class in the world. When fully powered, this magnet will sustain a constant 60 tesla for 100 ms in a 32 mm bore and produce a wide variety of other pulse shapes, such as ramps, steps, long decays, etc. It will be equipped with advanced probes to conduct experiments at low temperature and high pressure.

In less than three years from now the NHMFL will offer, in a joint project with the US Department of Energy, a non-destructive 100 tesla magnet, with a bore size and pulse period similar to today's capacitor-driven magnets.

Acknowledgements

This work was carried out under the sponsorship of both the US DoE Office of Basic Energy Sciences and the National Science Foundation, Cooperative Agreement DMR-9527035.

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Table 1. Magnets in Service at NHMFL, Los Alamos (August, 1996)

FIELD & BORE	FIRST USE	PULSE rise-duration (ms)	SUPPORTED RESEARCH
PULSED, GENERAL PURPOSE			
52 T, 24 mm	12/92	6-30	Magneto-Optics, ultra-violet through far infrared; Magnetization; Mechanical Properties; Thermal expansion; Specific heat; Transport; Temperatures from 25 mK to 550 K; Pressure from ambient to 3 GPa; low resolution NMR in highest fields for solid state.
62 T, 14 mm	3/93	7-35	
45 T, 24[1] mm	2/95	9-60	
40 T, 24 mm	3/96	10-500	
SUPERCONDUCTING			
20 T, 52 mm	12/92	continuous	Same as pulsed fields
9 T, 32 mm	11/95	continuous	Magneto-Optics, ultraviolet to near infrared
FLUX COMPRESSION			100 T - 1,000 T available through LANL programs

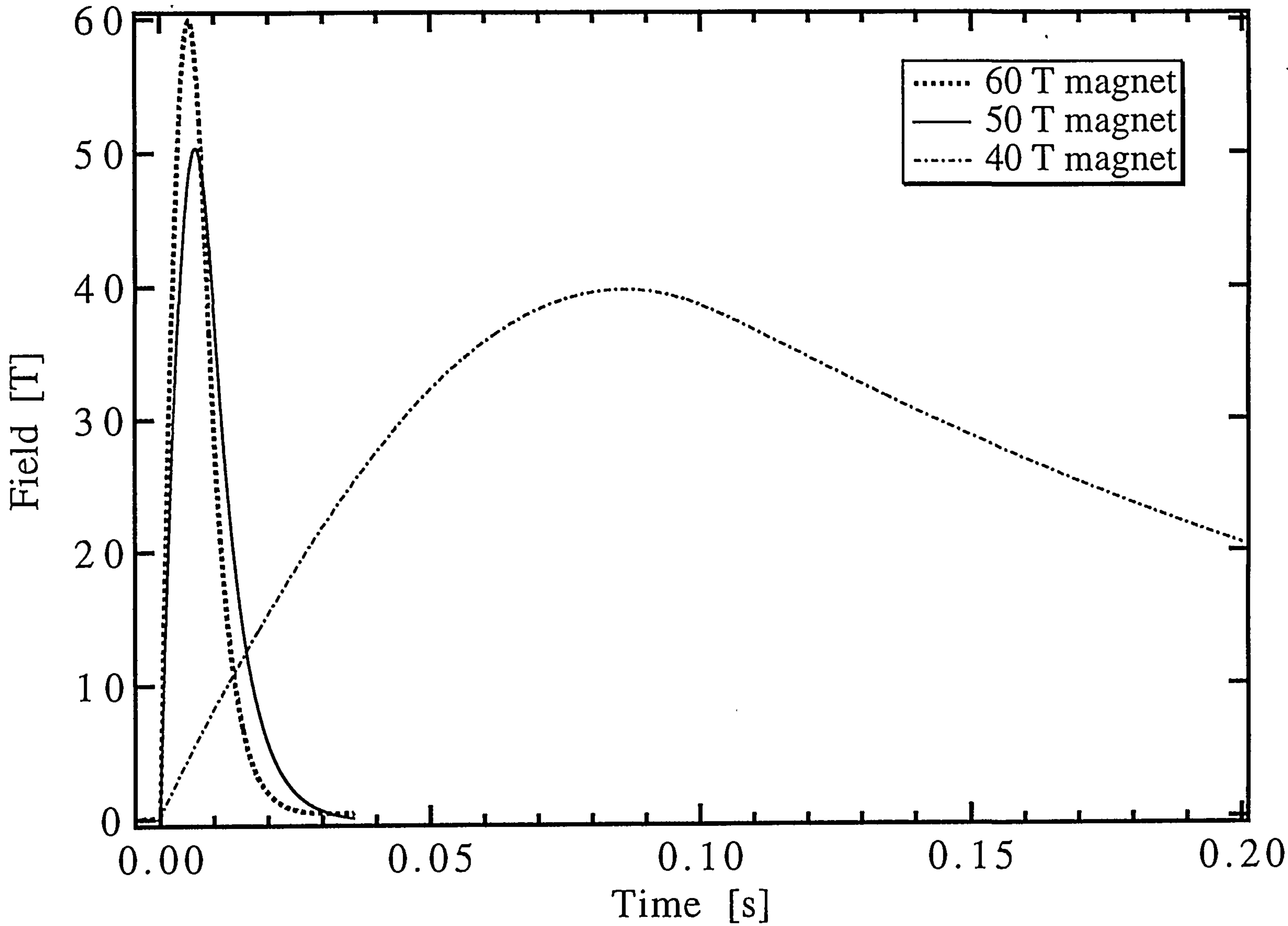
[1] Higher homogeneity

Table 2. Magnets in Final Assembly or Design for NHMFL, Los Alamos

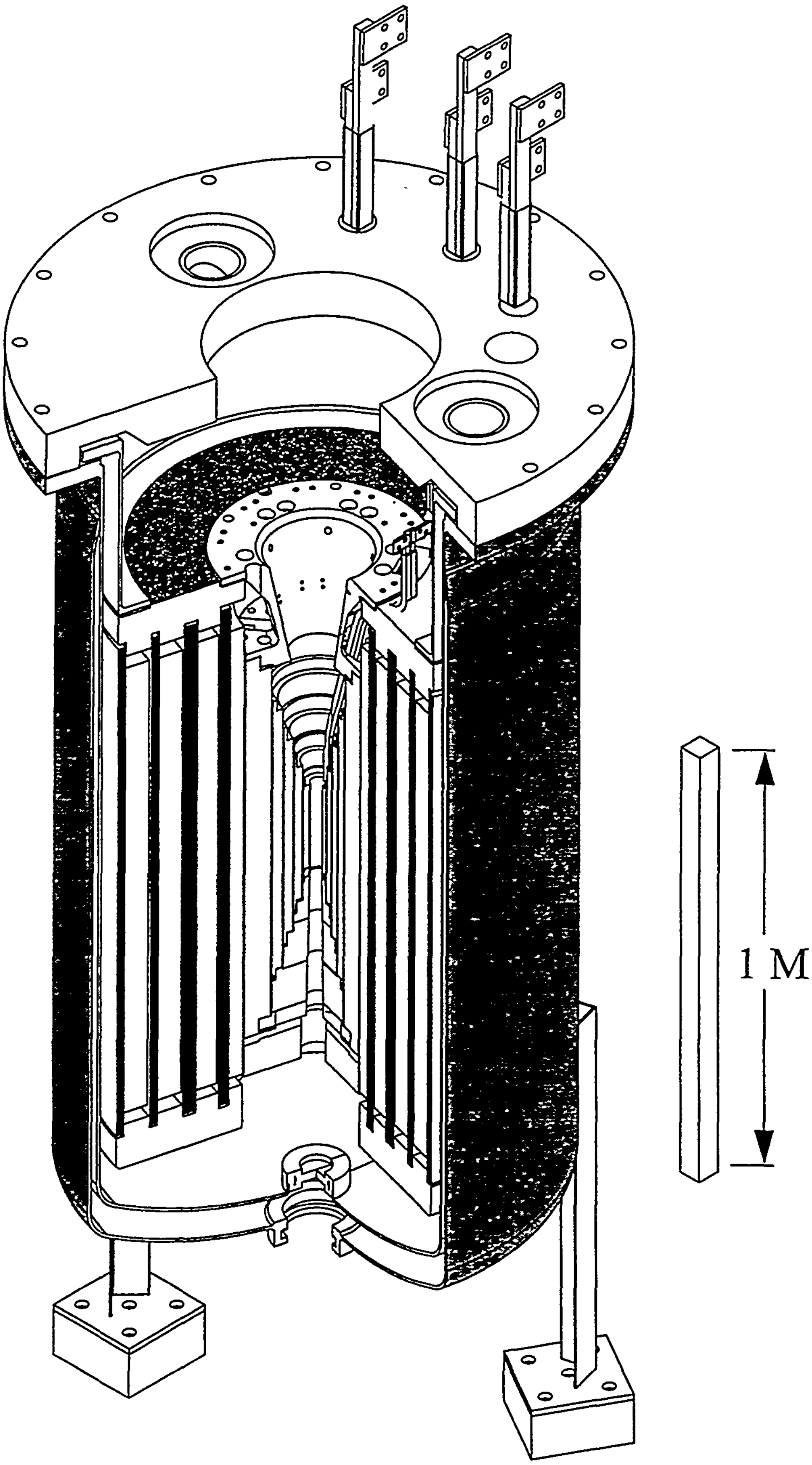
FIELD & BORE	TARGET DATE	PULSE rise-duration (ms)	COMMENTS
QUASI-CONTINUOUS; POWERED BY MOTOR-GENERATOR			
45 T, 32 mm	12/96	programmable	This is the same magnet attached to a different number of 80 MVA power converters. Three power converters produce 45 T for 100 ms, five produce 60 T for 100 ms, and seven produce 65 T for 50-80 ms. The cool-down time is about 1 hour following a maximum pulse.
60 T, 32 mm	8/97	programmable	
65 T, 32 mm	10/97	programmable	
NON-DESTRUCTIVE 100 T; POWERED BY MOTOR-GENERATOR AND CAPACITOR BANK			
100 T, 24 mm	12/98	5-25 (approx.)	With standard capacitor-driven insert.
to be decided	??/99	to be decided	Many possibilities exist with speciality inserts.

Figure Captions

Fig. 1. Pulse shapes of 40, 50, and 60 tesla capacitor-driven magnets.
Fig. 2. The quasi-continuous magnet containing nine mechanically independent coils.



60 T magnet
50 T magnet
40 T magnet
Field [T]
0
10
20
30
40
50
60
0.00
0.05
0.10
0.15
0.20
Time [s]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