Status quo of the Dresden High Magnetic Field Laboratory

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Abstract. We report on the recent progress made at the Dresden High Magnetic Field Laboratory (Hochfeld-Magnetlabor Dresden = HLD). This facility, under construction at the research center (Forschungszentrum) Rossendorf, is planned to open as user facility in 2007 offering access to various pulsed-field magnets. Besides the ultimate goal of constructing a multi-pulse magnet reaching 100 T in a bore of 20 mm with a peak-pulse duration of about 10 ms, further self-designed high-energy coils will be provided. For thermodynamic experiments, e.g., a pulsed coil for 60 T in 40 mm and 1 s is planned. The necessary energy of up to 50 MJ for coil operation recently became available through a world-unique capacitor bank working at 24 kV. First user-type magnets for fields up to 71 T for 100 ms in a bore of 24 mm have been tested successfully. As an outstanding feature of the laboratory, the bright light of a next-door free-electron-laser facility will allow dedicated high-field infrared spectroscopy. A broad range of experimental techniques is being developed both for user and in-house research in static and pulsed magnetic fields.

1. Introduction
One of the key parameters for top-level research is the access to high magnetic fields. Consequently, there is a growing demand for providing higher and higher magnetic fields with a reliable and sophisticated sample environment. There are nowadays worldwide activities to improve existing and build up new high-magnetic-field facilities that cope with these requests [1]. Beyond about 20 T, which is available by superconducting magnets, large-scale installations are needed to reach the highest possible magnetic fields. For field strengths above about 45 T, available in a hybrid-magnet system [1], only pulsed magnets are able to deal with the enormous stresses developing at these high fields in the conductor and reinforcement materials. Typical pulse lengths that can or may be reached in non-destructive coils with the currently available materials are in the range 10 – 1000 ms for magnetic fields between 60 and 100 T.

Here, we present the current status of our ongoing efforts to build, at the outskirts of Dresden, Germany, a new high magnetic field laboratory for pulsed non-destructive magnetic fields up to 100 T. Based on the initiative of five Dresden institutions this high-field project was evaluated successfully in 2002 and the first soil for the Dresden High Magnetic Field Laboratory (Hochfeld-Magnetlabor Dresden = HLD) was moved in mid 2003. Meanwhile the laboratory building is completed and equipped with a world-unique 50 MJ capacitive pulsed-power supply operating at 24 kV. First user-type magnets are available and being equipped with
cryogenic sample environments. The HLD is situated nearby a free-electron-laser facility that will enable unique infrared spectroscopy in high magnetic fields by supplying high-brilliance quasi-continuous infrared radiation [2, 3].

2. Infrastructure

The layout of the HLD laboratory building is shown in Fig. 1. In the center of the building the 50 MJ capacitor bank has been installed. The bank is split into 19 modules, with energies between 0.9 and 2.88 MJ, which are connected to four collectors. This allows a highly adaptable energy supply by charging only the desired modules to the needed voltage and very flexible energy distribution to a maximum of four nested coils which can be driven independently. This improves the design space in order to achieve maximum fields up to about 100 T and allows a large variety of coil designs adapted for special experimental needs. The capacitor bank has successfully been tested over shorts with pulsed maximum currents of up to 350 kA.

![Plan of the ground floor of the HLD](image)

**Figure 1.** Plan of the ground floor of the HLD. The pulsed magnets are located in pits (hatched areas). Maximum fields and pulse durations for the planned magnets are listed in the respective cells. The bold dotted lines are a sketch of the infrared beam which will be installed in a tunnel connecting the HLD and the free electron laser ELBE.

At one side of the laboratory building five cells for pulsed magnets are situated. Three of the cells, designated for large high-energy magnets, are reinforced with non-magnetic steel and designed to withstand the full energy of 50 MJ. The two remaining cells can house pulsed magnets for energies up to about 2 MJ, sufficient for magnetic fields of up to about 65 T for some 10 ms. The capacitor bank and the experiments in the cells are remotely operated over glass-fibre cables from the control room. For a safe operation the facility is equipped with an interlock and a personnel-transponder system, photo electric guards, as well as video cameras. Opposite to the pulsed-magnet cells laboratory space for versatile experimental installations in superconducting dc magnets as well as for sample preparation is available.
The HLD is built next to a mid-infrared free electron laser (FEL) situated in a neighboring building, called ELBE. After completion of the second FEL in 2006, quasi-continuous infrared light from 5 μm up to about 150-200 μm of high intensity and brilliance will be at hand. This wavelength range fills the energy region (THz gap) of other available radiation sources and fits comfortably well with the Zeeman energy at fields above 60 T (see left panel in Fig. 2). The laser beam will run through a vacuum tube in a tunnel to the HLD where it will be distributed to the different pulsed-field cells (dashed line in Fig. 1). The distance between the holes in the resonator mirrors of the FEL, where the beam is coupled out, and the refocussed beam at the experiment in the pulsed magnet is about 50 m. The calculated envelopes for the various beams from ELBE to the HLD are shown in the right panels of Fig. 2 for different wavelengths. By use of different deflecting and focussing mirrors (M92a, M93, and M95) the beam width (4w contains 99.9% of the Gaussian wave packets) can be kept below about 200 mm. All design steps as well as the engineering of the beamline have been or will be done at the FZ Rossendorf.

Figure 2. Left panel: Zeeman splitting for a spin-1/2 system with g = 2 as a function of magnetic field and the corresponding wavelength of the energy difference between the split states. Typical available magnetic fields as well as infrared sources are indicated. Right panels: Calculated beam shapes for different wavelengths, λ, and coupling-hole diameters, D, of the infrared-beam envelopes along the beamline between the ELBE source and the HLD.

3. Pulsed-magnet design

The magnet design for very high magnetic fields is a challenging task. Especially the pressures created by the Lorentz forces (about 4 GPa at 100 T) are beyond the tensile strength of the strongest steels. Only by use of high-strength conductors reinforced by special fibers, such as Zylon, the highest magnetic fields may be reached in non-destructive pulsed magnets. Within an optimization procedure one has to take into account a large number of design parameters, such as available energy, maximum field, magnetic force, highest allowed temperature, or conductivity of the conductor just to name a few. Pulsed magnets for a comparably short pulse duration (less than 20 ms) and magnetic fields up to approximately 70 T are traditionally designed as reinforced...
single coils. For longer pulses and higher fields one has to choose a multi-coil configuration. Extensive computer simulations are thus an integral part of all pulsed-magnet design. These are based on analytical approximations and numerical methods like finite-element analysis.

The design, simulation, manufacture, and testing of pulsed magnets have been established entirely at the HLD. Up to date, two differently designed low-energy (1.4 MJ) coils using copper wire have repeatedly reached magnetic fields up to 65 T for 15 to 30 ms in 20 to 24 mm bores. A first high-energy (8.5 MJ) coil has successfully reached 71.4 T with a pulse duration of about 100 ms in a 24 mm bore [4]. A two-coil 46 MJ magnet for fields above 85 T in a bore of 20 mm is under construction and first tests are planned for this fall. A 60 T long-pulse (about 1000 ms) magnet with 40 mm bore has been designed. More details on the HLD pulsed-magnet design program can be found in Refs. [4, 5].

4. Experimental techniques

In the HLD pilot laboratory at the IFW (Institute for Solid State and Materials Research) Dresden, electrical transport and magnetization measurements are running routinely in pulsed fields up to about 50 T / 10 ms [6]. In addition, the feasibility of NMR experiments in pulsed-field environments has been proven [7]. The modular design of the 50 MJ power supply at the HLD in Rossendorf allows a large variety of pulsed-field coils with respect to pulse height and duration, enabling a diverse set of experimental techniques. Besides the above mentioned techniques, HLD plans to offer among others heat capacity, thermal conductivity, ultrasound, magnetic-resonance methods, and optical spectroscopy over a wide temperature range from mK to above room temperature.

5. Summary

The HLD is planned to open as a user facility in 2007. First scientific experiments have been performed routinely by in-house experimentalists as well as external users in the HLD pilot laboratory at the IFW Dresden. The new laboratory is aiming at the highest possible non-destructive pulsed fields offering to date already 70 T in 24 mm with a pulse duration of about 100 ms. As a unique feature, the facility will enable infrared spectroscopy at highest pulsed magnetic fields. The pulsed magnets are complemented by superconducting dc magnets reaching fields up to 20 T.

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