Tsukuba Magnet Laboratory: Present status and future vision

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Abstract. The Tsukuba Magnet Laboratory (TML) has been a user facility for external users since April 1998 and contracted 91 collaborative studies with external research groups in the 2005 fiscal year. Internal and external researchers use high magnetic fields for magnetic processing as well as extreme-environment measurements. In 2006, two major changes were made to expand the experimental possibilities. One was the replacement of the helium liquefaction system, and the other was the remodelling of the 15 MW DC power supply. TML has also built an NMR complex including a 930 MHz and a 920 MHz NMR spectrometer. We have also started a collaborative study on high-field magnet development with the High Field Laboratory for Superconducting Materials. The projects include the development of a 30 T class superconducting magnet and a 50 T class hybrid magnet.

1. Introduction
The Tsukuba Magnet Laboratory (TML) is one of the departments of the National Institute for Materials Science (NIMS). Although the official name is High Magnetic Field Station, the name TML is commonly used for consistency and clarity.

TML has made a number of epoch-making achievements in high-field generation, such as a 17.5 T superconducting magnet in 1976 [1] and a 36.5 T hybrid magnet in 1995 [2]. The highest fields of a superconducting magnet have been maintained since 1993 [3]. TML became a user facility for external users in April 1998. Although the facilities in TML cover a wide range of research areas, such as solid-state physics, superconductor development, and magnetic processing, recent efforts in TML have focused on improving the facilities as a high-quality measurement tool. The formation of an NMR complex is one of the results. We report the present status at TML and our future vision.

2. User Facility
From 2001 to 2005, as a numerical target, more than 80 collaborative studies with external users per year (averaged value through the five years) were undertaken. The number of collaborative studies in those five years is shown in figure 1. The averaged number was 82, and we achieved the targeted value. The number of contracted collaborative studies in the 2005 fiscal year was 91. Although the ratio of machine time to external users is decreasing, as shown in figure 1, the total machine time to external users is increasing because the number of magnets at TML is increasing.
Figure 1. Numbers of collaborative studies and ratios of machine time to external users from 2001 to 2005.

3. Major recent topics

TML now consists of three buildings, as shown in figure 2. NMR laboratory I was built to house a 920 MHz NMR spectrometer in 2001. NMR laboratory II, where the 930 MHz NMR spectrometer was installed, was completed in 2003. As described later, all NMR magnets were installed in these two buildings in order to minimize the effects of background field perturbation caused by other magnets, such as the hybrid magnet.

Other magnets are installed in the main building. The hybrid magnet generated the highest fields of 37.9 T in a backup field of 14.02 T [4]. The bore diameter, operating current, and voltage of the resistive magnet are 32 mm, 34.45 kA, and 387.6 V, respectively. Using a resistive magnet with a 52 mm bore, 35.5 T was generated at the operating current of 34.88 kA and the operating voltage of 367.5 V [5]. This is the highest steady-state field in a room-temperature bore over 32 mm.

Those resistive magnets were made using a CuAg alloy developed at NIMS [6]. In 2005, Sakai et al. developed a new method to produce a high-performance Cu-Ag alloy [7]. Using this method, Cu-2 wt%Ag with 1200 MPa ultimate tensile strength and 81.7 % IACS and Cu-3 wt%Ag with 1400 MPa ultimate tensile strength and 76.4 % IACS were produced. New designs of resistive magnets using the new Cu-Ag alloy are in progress.

The field quality of the hybrid magnet has been evaluated [8] and improved [9]. For the improvement of the field stability, the 15 MW DC power supply was remodeled by the use of MOS-FET dropper circuits [9]. The resistive magnet has also been newly designed to improve the field homogeneity in a 10 mm DSV from 650 ppm to 10 ppm in a hybrid magnet [10].

At TML, 124,217 liters of liquid helium was consumed from April 2004 to March 2005. The former helium liquefaction system (Sulzer TCF-250) was installed in 1988. Recently, a remarkable decrease of the liquefaction rate has been observed. In order to deal with such an amount of helium effectively, a new helium liquefaction system (Linde L-280) was installed in 2006. The volume of the liquid helium vessel was increased from 2000 to 5000 liters. The liquefaction rate was more than 190 liters/h with liquid nitrogen at the pre-cooling stage.
4. NMR complex

As shown in figure 2, eight NMR magnets are in operation and make up the NMR complex. They are installed in two buildings. For solid-state NMR measurements, five spectrometers (one, 930 MHz; two, 500 MHz; one, 400 MHz; and one, 270 MHz) are in operation. All spectrometers have a room temperature bore of 89 mm\(^{\phi}\), except for the 930 MHz NMR spectrometer, whose bore diameter is 54 mm. Although almost all high-field NMR spectrometers are mainly used for solution NMR measurements, the 930 MHz NMR spectrometer is used for solid-state NMR measurements. MQMAS probes for \(^{11}B\), \(^{17}O\), \(^{23}Na\), \(^{27}Al\), and \(^{43}Ca\) have been developed. They are operated with a 2 kW power amplifier. CPMAS probes for H-X (X = \(^2D\), \(^{13}C\), \(^{15}N\), and \(^{17}O\)), H-X-Y, and \(^{19}F\)-\(^{13}C\) operated with a 500 W power amplifier are also available. The maximum spinning frequency of the probes is 20 kHz.

Two narrow-bore (54 mm\(^{\phi}\)) NMR spectrometers, one of 920 MHz and one of 600 MHz, are used for solution NMR measurements using \(^1H\)-\(^{13}C\)-\(^{15}N\) triple-resonance probes. The stereoscopic structure of protein molecules has been determined in the course of a collaboration study with the Genomic Sciences Center of the Institute of Physical and Chemical Research (RIKEN) [11].

One 600 MHz NMR magnet is used for magnet technology. For a drastic increase of the magnetic fields using superconducting NMR magnets, the use of high-\(T_c\) superconductors (HTS) is necessary. In order to realize a high-resolution HTS NMR magnet operated with a power supply, fundamental studies have been performed with the magnet. Its cryostat was improved using a cryocooler and HTS power leads so that long-term operations in a driven mode could be performed without liquid helium consumption. We have evaluated the field stabilities in a driven-mode operation using a highly stabilized power supply. Field compensation using a flux pumping circuit was also carried out. The replacement of the innermost coil to an HTS double-pancake coil is planned in order to evaluate the performance of HTS NMR. Such an evaluation will yield useful information for obtaining high-resolution NMR spectra using the 1.2 GHz NMR magnet described below.

5. Collaborative developments with HFLSM

In March 2006, High Field Laboratory for Superconducting Materials (HFLSM), Tohoku University, and TML agreed on the collaborative developments of high-field magnets [12]. The projects include
the development of a 30 T class superconducting magnet and a 50 T class hybrid magnet. The
construction of a new high-field facility with a Sendai branch and a Tsukuba branch is also included in
the long-term vision.

The design of 30 T class superconducting magnets is in progress on the basis of a design for a 1.2
GHz NMR magnet [13]. The peak fields of HTS, Nb, Sn, and NbTi are 28.2 T, 22.5 T, and 12.0 T,
respectively. The 1.2 GHz NMR magnet is designed with a hoop stress criteria of 200 MPa. The
magnet will operate in superfluid helium with a highly stabilized power supply. The increase of the
stress criteria can result in drastic compacting of the magnet. The development of a high-strength
conductor was included in the project because it is one of the key technologies for developing a large
superconducting magnet.

6. Conclusion
High magnetic fields are commonly used as two different tools. One is for measurement, and the other
is for processing. In research fields of solid-state physics or superconductor development, magnetic
fields are mainly used as a measurement tool. For magnetic separation or magnetic levitation,
magnetic fields are used as a processing tool. Many research communities have been built for every
research field and every objective. Unfortunately, interaction among these communities rarely occurs.
User facilities such as TML are expected to organize these communities and play a catalytic role for
triggering effective interaction that will result in new progress.

Recent efforts in TML, such as the formation of the NMR complex, have been made to improve the
quality and quantity of our laboratory as a measurement tool. However, its function as a processing
tool is also important. TML will cover all kinds of magnetic field communities by its own efforts and
through cooperation with other facilities.

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