Magnetic Calibration at the United States Navy Primary Standards Laboratory

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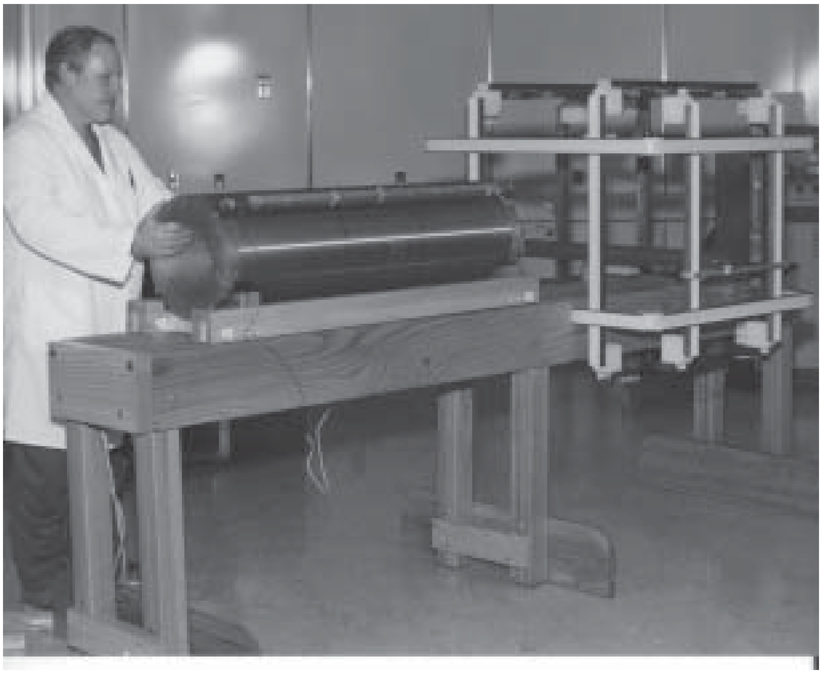
The Navy Primary Standards Laboratory in San Diego, California recently acquired the U.S. national standard magnetometer from the National Institute of Standards and Technology (NIST) to assist in their research and calibration program. As part of the agreement, NPSL will make the magnetometer available for use as a primary calibration standard to industry and assist NIST in providing calibration services.

A History of U.S. Navy Calibration

Throughout much of its history the U.S. Navy did not give much consideration to metrology, as the technology of the times did not require it. In this regard the Navy paralleled industry. During the early years of industrial development, measurements and metrology received little attention. Most measurement problems posed little challenge and common sense answers could be employed.

However, this often meant that differing standards arose depending upon who manufactured a particular item. A notable case of this problem occurred in the railroad industry with different track widths being laid. Even as late as the middle 1920s no commonly accepted electrical voltage standard existed in the U.S. forcing manufacturers to make items such as radios that could be adapted to different voltages in the various parts of the country.

Within the Navy not until the later part of World War II did the first significant organized effort occur to set up an independent system for disseminating standards throughout the fleet. In 1944, Naval leaders realized that the effectiveness of the war effort could be increased through a program to provide uniform standards throughout the Navy. To accomplish this, the Navy established the gauge program in the Washington D.C. Navy Shipyard, a manufacturing center for cannons at the time. The shipyard sent standardized gauges to all parts of the Navy as well as all naval suppliers. During this period the Navy also established the Assembly and Repair Department, Naval Air Station, North Island in San Diego, California. Its activity focused on designing and repairing test



The author makes adjustments to magnetometer at Navy Primary Standards Laboratory.

equipment used by the Navy's air corps. These and related efforts met the needs of the wartime situation.

However, the Navy realized that only a more systematic effort would meet its future, post war needs. In January 1946 the Navy Bureau of Aeronautics asked the Navy Research Laboratory (NRL) to investigate and report on the technical requirements and standards necessary to set up a calibration program. This marked the end of the earlier era in Navy metrology where separate facilities carried on their work independent of each other. In May 1947 the Navy Research Laboratory in Washington D.C. held a meeting to review its recommendations. From this conference came the decision to establish a Navy calibration program.

June of that year saw the establishment of a number of calibration laboratories, including the Test Equipment Standards Laboratory at North Island under the direction of Mr. K. W. Hedlund. From its inception the laboratory was staffed with civil service employees, resulting in a very low employee turnover throughout its history.

The laboratory worked out of temporary quarters until 1952 when it moved into a remodeled facility costing $186,000 in the back of an aircraft hanger building. In 1949 the Test Equipment Standards Laboratory changed its name to the Electronics Standards Laboratory. A similarly named laboratory was established at Norfolk Naval Air Station, Virginia.

In 1957 the first formal Navy calibration program instruction was issued establishing a number of laboratories for avionics calibration. By 1960 the Navy had four Bureau of Aeronautics Primary Standards Laboratories heading the metrology program and interacting directly with the National Bureau of Standards (later renamed the National Institute of Standards and Technology). The four Navy laboratories disseminated the national standards of measurement within the Navy.

Later that year the Navy designated the Navy Quality Assurance Office in the Washington Navy Shipyard and the laboratory at North Island, San Diego, as its two top standards laboratories. The other laboratories became known at the time as type two and type three laboratories.

The North Island facility again changed its name, this time to the Western Standards Laboratory at the same time the Eastern Standards Laboratory, Washington D.C. Navy Shipyard was renamed. In 1979 the Navy merged the eastern laboratory with the Western Standards Laboratory, with the western branch serving as the administrative headquarters for the new combined laboratory. At this time the two labs changed their name to the Navy Primary Standards Laboratory East and West.[6]

During the 1960s the Eastern Standards Laboratory decided that the growing use of magnetic equipment within the Navy required calibration support and began to develop a magnetic calibration facility. Fortunately, their laboratory's close location to the National Institute of Standards and Technology (NIST) provided them with some important advantage. NIST allowed the Navy to perform calibrations below the ten gauss level at its facilities at Gaithersburg, Maryland. (A gauss equals one ten-thousandth of a Tesla and is used as the unit of magnetic induction in the centimeter-gram-second system. The Tesla is the correct metric unit.)

In 1989 the Navy Primary Standards Laboratory West moved into a new facility. This new building, unlike its home in the back of the airplane hangar, had been carefully designed from the beginning to serve as a standards laboratory. Within its 25,000 square feet the new building accommodated a number of specially designed environmentally controlled modules, as well as other unique facilities such as an anechoic chamber for microwave work. The laboratory also gained the use of several other buildings at North Island.[6]

After the dissolution of the Soviet Union, the military needs of the United States changed. In a period of reassessing its military needs and the urgencies of serious domestic problems, the government decided the military services had to suffer important cuts in their funding. This resulted in the closure of the Navy Primary Standards Laboratory, East in September 1993.

With the closure of its eastern branch the western laboratory (now called simply the Navy Primary Standards Laboratory or NPSL) transferred the magnetic calibration capability to North Island. NPSL immediately realized that for calibrations below ten gauss a new system would be needed. With its location in San Diego, California, NPSL could not easily go to NIST on a frequent basis for its low gauss calibrations.

Development of a Low Gauss Calibration System

In 1994 the Navy Primary Standards Laboratory asked the National Institute of Standards and Technology to design and build a low gauss calibration system that would serve as a standard for this type of work. NIST eagerly joined in this effort, as it had stopped offering a calibration service for magnetometers and wanted to ensure that the country's need for magnetic calibrations directly traceable to NIST could be met.[3] Furthermore, such a magnetic laboratory could assist in the National Voluntary Laboratory Accreditation Program (NVLAP). Dr. Edwin R. Williams at NIST began a close collaboration with the Navy to develop the Navy's magnetic calibration program.

Navy Primary Standards Laboratory Capabilities

Currently the Navy Primary Standards Laboratory receives a wide range of items requiring magnetic calibration. As one would expect, the largest number are gaussmeters of various types. At one end are very inexpensive and relatively low accuracy (within 0.5 gauss) meters used to make only rough readings. At the other end are precision gaussmeters designed to provide very accurate readings at low as well as high gauss levels. Meter construction varies from mechanical types using magnets and springs to those using Hall effect or fluxgate probes. The Hall effect probes can be made very small, but usually suffer from more noise during low level measurements than the fluxgate probes.

The standard or reference magnet is also frequently encountered at NPSL. Made from special alloys, these precision magnets come in a variety of values. They are used to calibrate and act as check standards on gaussmeters. With a set of such magnets a gaussmeter can be checked at a number of values. But, as with common magnets, if not treated carefully, the reference magnet can change in value. Any type of trauma can cause a change in value without leaving any visible sign. Therefore they require careful calibration to insure that they remain accurate.

From time to time the Navy magnetic laboratory also receives Helmholtz coils and solenoids. These devices are used to generate fairly uniform magnetic fields, which in turn can be used to calibrate other items. The fields they generate come directly from the amount of current supplied to them, which allows the magnetic field to be set at the desired level.

Because of the demand for the traceability of magnetic calibrations to NIST, the Navy Primary Standards Laboratory will be assisting NIST by providing primary magnetic calibration to companies requesting it. The demand for this service has actually been increasing with the growing implementation of ISO 9000.

At the Navy Primary Standards Laboratory, magnetic fields from 0.1 μT (1 mG) to 1.4 T (14,000 G) can be generated using a series of three coils and an electromagnet. For calibrations of less than a gauss that require no greater than 0.05% uncertainty, a three-axis set of computer controlled Helmholtz coils is used. If a smaller uncertainty is required, a precision glass solenoid can produce a well controlled field from 0 mT to 1.2 mT (12 gauss). This solenoid allows for an uncertainty of 0.002% and can be placed within the triaxial system of Helmholtz coils in order to allow the coils to reduce the earth's and other magnetic fields. Another Helmholtz coil produces magnetic fields from 1 mT (10 G) to 10 mT (100 G) with 0.1% uncertainty. Larger fields come from a commercial electromagnet that can be adjusted to give fields from 40 mT (400 G) to 1.4 T (14,000 G).

The low gauss system is currently based on the precision solenoid that NIST validated through nuclear magnetic resonance measurements. The higher gauss measurements come from the electromagnet using generated fields monitored with a commercial nuclear magnetic resonance proton magnetometer. This allows us to know with great accuracy the field strength the magnet generates. Items calibrated in this magnetic field are calibrated by the nuclear magnetic resonance magnetometer which provides our intrinsic standard.[3]

The low gauss solenoid is of particular interest as it represents a very unique piece of equipment. From basic physics we know that a solenoid tends to have a very uniform field at its center, especially if it is much longer than its diameter. In a physics text many assumptions are made, such as a uniform diameter for the windings, even spacing of the windings, etc. The text book problems for a solenoid are very simple, however, the real life creation of a very uniform magnetic field for calibration using a precise solenoid is much more difficult.

The Navy Primary Standards Laboratory had the very good fortune to be given the NIST precision solenoid for its magnetic work. This solenoid has quite a history, having served as the inductance standard for the nation since 1936. Recently two seven-turn windings of insulated 0.8 mm wire were added as a second layer (like a Helmholtz coil) 172 mm on each side of the center in order to make the solenoid interior field more even. These proved necessary because, unlike the classic physics text solenoid, this one has a finite length.

In magnetic calibrations the NIST defined standard derives from nuclear magnetic resonance (NMR). If a carefully prepared sample of select material is subjected to a magnetic field, as explained by quantum mechanics, it will absorb a radio wave if the signal possesses the right frequency as shown in equation 1.

$$\omega = 2\pi f = [(2\,\mu_p)/\hbar]\,B = \gamma B \qquad (1)$$

In the above equation f represents the frequency in Hertz of the radio wave (ω the radian frequency), μ_p symbolizes the proton's magnetic moment, B stands for the magnetic field being measured, $\hbar$ is Plank's famous constant divided by 2 p, and γ the gyromagnetic ratio of the proton (the British call this the magnetogyric ratio).

For this type of NMR measurement, the uncertainty varies with the physical geometry and chemical composition of the sample. For various reasons water is a very commonly used substance. When referring to a spherical sample of water (at 25°C) γ'_p symbolizes the gyromagnetic ratio of the proton. The currently accepted value for this important physical constant as determined by Dr. Williams as:

$$\gamma'_p = 2.67515427(28)\, 10^8\ \mathrm{T}^{-1}\,\mathrm{s}^{-1}$$

with the experiment having been conducted in terms of the SI 90 definition for the volt and ohm.[3] Nuclear magnetic resonance measurements can when carried out correctly have an accuracy of about 1 ppm.[8]

Conclusion

Looking toward the future, it is not hard to anticipate that the Navy's need for magnetic calibration work will increase in the demand for precision as newer and better measuring devices become available and older equipment is replaced. Recently the laboratory undertook a program to develop its capabilities. One major project already underway is to work with the National Institute of Standards and Technology to establish a low gauss nuclear magnetic resonance system that will provide the intrinsic standard for lower gauss measurements and future reliance on intrinsic standards.

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Editor’s note: An article on the making of the U.S. national standard solenoid, also by Don Matson, follows this.