The Making of A Low Gauss Solenoid: The Legacy of 1936

Donald W. Matson
Electronics Engineer
Navy Primary Standards Laboratory
San Diego, California

In 1936 the National Bureau of Standards began construction on a primary standard low gauss solenoid. That solenoid now resides at the Navy Primary Standards Laboratory in San Diego, California, and through the cooperation of NIST and the U.S. Navy it is still being used as a primary standard.

Construction of a National Standard Solenoid

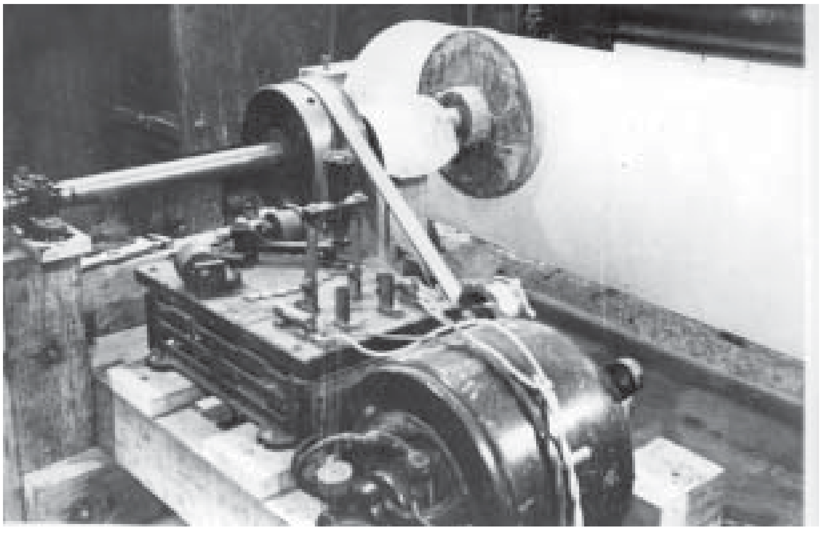
In the early 1930s the National Bureau of Standards (now the National Institute of Standards and Technology - NIST) embarked upon the development of a national self inductance standard – a solenoid. A solenoid is a cylinder with a layer of metal wiring wound around it to create a magnetic field. The proposed standard would serve as the ultimate reference for all inductance measurements within the United States. But the development of such a precision standard, while theoretically a very simple issue, in reality proved very difficult in its construction.

In order to use the theoretical equations and have a well characterized uncertainty, the machining had to be incredibly precise and approach the perfect solenoid as closely as the technology of the time would permit. Because of the unique nature of the task, some of the technology had to be developed especially for this project.

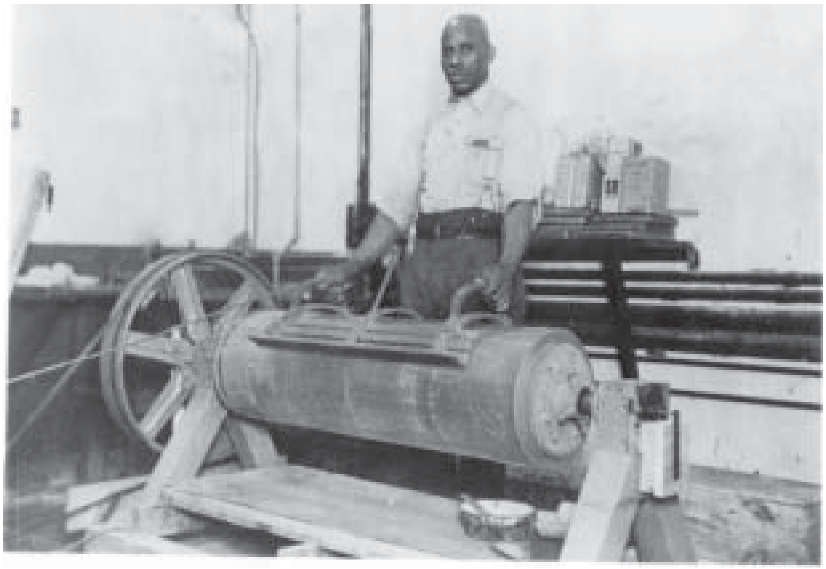
Because of its neutral magnetic nature, Pyrex glass provided an excellent material for the form of the solenoid. Another advantage was that its dimensions did not change much with temperature change, a critical point since the physical dimensions of the solenoid affect the value of self inductance.

In 1936 the Corning Glass Company poured the solenoid from the same melt as the famous 200 inch mirror used in the California Institute of Technology's Mount Palomar telescope. The initial solenoid form was 120 centimeters long and had a diameter that varied from 36 cm to 37.5 cm The wall of the solenoid was 10 cm thick.

After taking delivery of the cylinder from Corning, the National Bureau of Standards (NBS) began rough grinding the solenoid's outer surface. To accomplish this, NBS used a motorized iron disk with carborundum grit, holding the solenoid on a spindle and rotating it slowly. After this process a lap was used to finish the surface uniformly. During this phase measurements of the diameter were checked frequently using a specially constructed micrometer. By using finer and finer grades of



The solenoid cylinder is rough ground to within a diameter variation of 2 mm by use of a metal disk fed with carborundum. (NIST photos, courtesy of NPSL).



A lap, constructed of wrought iron bars, is used to finish grind the outer surface to a precise cylindrical form using carborundum as an abrasive.

carborundum, the NBS artisans achieved a solenoid outer surface that only varied in diameter by five microns.

After the outside surface was finished, grinding began on the inside surface with the goal being to provide a uniform wall thickness. Two large iron rings held the solenoid on the outside of each end using paraffined wood clamps. The solenoid was rotated first by hand during the rough grinding and during the finish work using motorized gears. A large iron pipe and carborundum were used for the grinding. The rough grinding rotating the solenoid by hand took four days. The wall was ground to a thickness of seven centimeters.

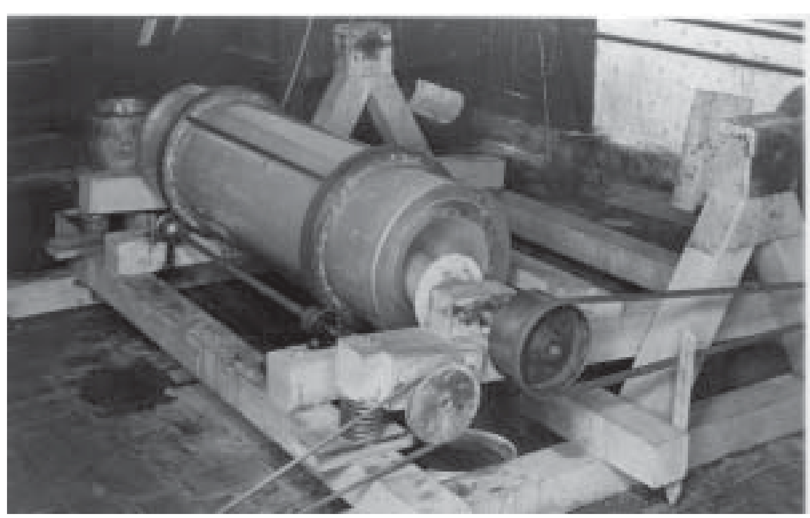
Grinding in the Thread

The heavy solenoid moved to another machine shop and work began on grinding a thread in the outer surface with a steel wheel using diamond dust for grit and kerosene as a lubricant. The craftsmen rigged a special microscope to view the threads and grinding wheel edge as they ground the nearly 1.5 kilometers of thread into the solenoid.

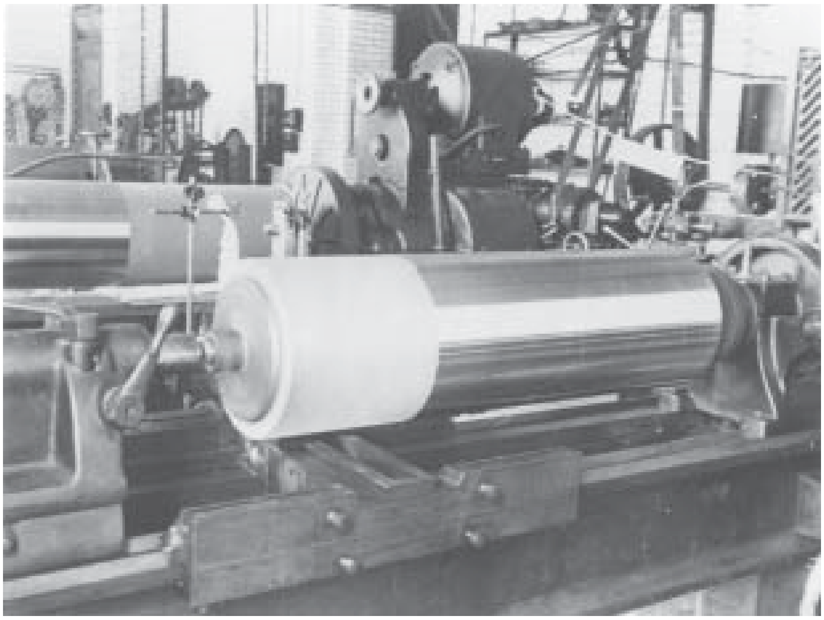
Thread lapping was done using two simultaneous laps. To form the laps, the workers cut threads on the inside surface of an iron tube with an inner diameter approximately the same as the outer diameter of the solenoid. Cut into sections, the metal functioned as the grinding element in the laps. The lapping was done to form a constant diameter over the length of the solenoid and to provide a non-varying thread pitch. As the solenoid rotated, driven by an electric motor, the lap rode over the surface from end to end, extending some distance out from the solenoid. After each pass the lap was rotated and the process repeated.

During this procedure a new challenge arose. In those days one could not make a large Pyrex glass casting without the formation of bubbles below the surface. The grinding process exposed some of the bubbles and threads passing over open bubbles would fall two to three microns lower than threads on each side. The workers discovered that a bubble allowed fresh grit to flow under the lap, causing increased localized grinding in these areas. In order to combat the problem, they reduced the grinding pressure by attaching a counter balance. Although this slowed the process, it did solve the problem.

In order to assure that the windings had the same diameter, the NBS workers placed test windings on sections of the solenoid and then lightly moved a very flat oilstone over the surface. The form of the polished marks indicated the inequalities in winding diameters. To evaluate the pitch of the thread a special micrometer was constructed



The center of the solenoid is finish ground using a long bar and motorized gears. Rough grinding of the center was done by hand.



Winding the wire on the cylinder.

that could measure to within 0.1 micron. The micrometer proved so sensitive that the pressure applied by the fingers on the ends of the solenoid could be detected!

Developing Uniform Wiring

The wire selected for the final windings had to be very uniform with a desired wire diameter of 0.7 mm. To better control the uniformity of the wire, NBS purchased 1 mm wire and reduced it down to the desired 0.7 mm. NBS experimented with different dies to draw down the wire and found that sapphire dies worked better than the harder diamond or tungsten carbide dies.

As the wire was moved from a wooden cylinder to a brass one, it was passed through a die that reduced its diameter by 0.05 mm. The process was repeated several times until the target diameter was obtained. In the final stage, the wire was passed through the die and then wound under constant tension onto the solenoid. The windings were examined closely for uniformity of diameter and pitch. Precise, delicate rulings were made into the wires to facilitate measuring the length of the wire wound.

The solenoid was completed in December 1936 and careful examination confirmed that it followed the form of a true helix with no deviation greater than one micron.

From 1937 until 1994, the solenoid was used as the U.S. national primary standard for magnetic calibration.

The NIST Solenoid Moves to San Diego

During the 1990s the United States Navy Primary Standards Laboratory began establishing a magnetic calibration laboratory. Because of the need to calibrate precision, low gauss gaussmeters, the Navy needed a consistent method for creating well characterized, low gauss magnetic fields. The National Institute of Standards and Technology, actively assisting the Navy in this effort, decided that the precision solenoid (no longer serving as a self inductance standard) would provide an ideal device for this purpose.

In order to make the magnetic field in the solenoid's center even more uniform, extra windings were added at the Navy Primary Standards Laboratory. Two seven-turn windings of insulated 0.8 mm wire centered at 172 mm on each side of the solenoid's center (like a Helmholtz coil) were added and wired in series with the solenoid.

Today this historic primary standard solenoid resides at North Island in San Diego, California, at the Navy Primary Standards Laboratory. Housed in an environmentally controlled module, it functions as the Navy's low gauss standard, still actively serving as a valuable metrology standard.