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CYCLOTRON LABORATORY

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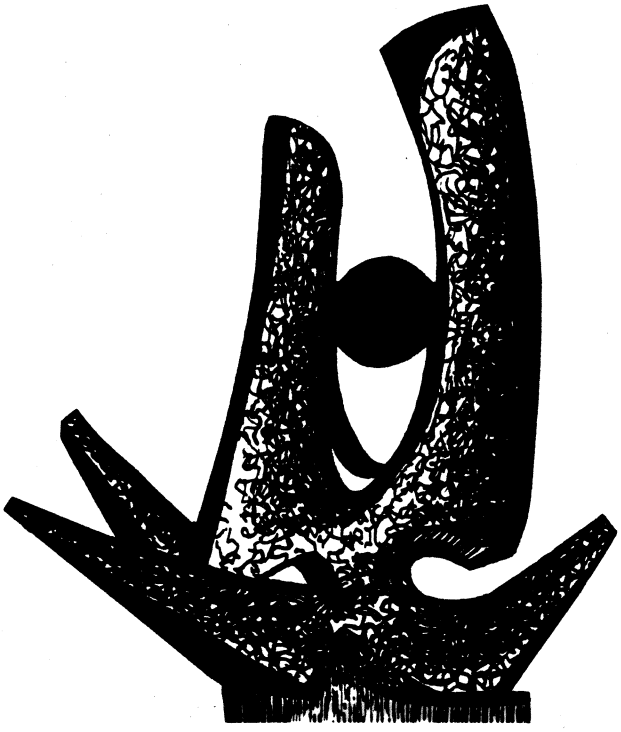

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Cryogenic Leak Test Procedure for a Large Superconducting Cyclotron Coil*

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ABSTRACT

A procedure for testing the vacuum integrity of very large stainless steel weldments used at cryogenic temperatures has been developed at Michigan State University. This development, which uses large quantities of liquid nitrogen, is a modified technique commonly applied to small devices and involves cooling the cryostat's liquid helium vessel (bobbin) to liquid nitrogen temperature, followed immediately by leak testing. This method, when applied to the K800 superconducting magnet coil, which tested leak tight at room temperature, easily detected a helium leak. After repairing the leak and retesting, with no apparent leak found, the K800 cryostat construction was completed; i.e. the bobbin wrapped with superinsulation, a liquid nitrogen radiation shield added, and then inserted into its vacuum jacket. The final leak test occurred when the cryostat was cooled to liquid helium temperature and found to be helium leak tight.

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Introduction

The successful leak tightness of large cryogenic vessels, now being commonly constructed for various nuclear physics accelerators[1] and experimental devices[2] has been designated as one of the difficult technological challenges[3] for large superconducting magnets. The various reasons for this technological problem are many and some are listed below.

1. The styles, size and the length of the welds used to form and enclose these large cryogenic vessels are complicated and long, thereby requiring a welding quality control that is extremely difficult to obtain.
2. The standard method of leak testing[4] (see figure 1), i.e. of pumping on the vessel and spraying helium on the suspected leak, becomes difficult since the inside of the vessel now contains many tons of outgassing contaminates (conductor, insulation, etc.) which makes using the leak detector at its maximum sensitivity an impossible task.
3. The process of cooling the coil down to cryogenic temperature produces large thermal stresses. These thermal stresses can cause the introduction of leaks, either by the cracking of a weld or more likely by the opening of a leak that was plugged with a contaminate (e.g. dirt, weld impurities, or water).
4. A measurement of the helium leak rate into the K500 cryostat coil vacuum space (a superconducting magnet coil built at MSU in the late 1970's) as a function of the cooldown temperature of the cryostat magnet coil is shown in figure 2. It indicates that a

leak rate level at the limit of leak detector sensitivity when the coil is at room temperature, increases by three magnitudes when the cryostat is cooled to liquid helium temperature. This leak then can become a heat load problem on the liquid helium refrigerator or at the minimum requires the continuous pumping of the cryostat vacuum jacket.

Waiting to test the leak tightness of the inner helium vessel after constructing the vacuum jacket around it, is not a good idea since it then poses the difficult question of localizing the possible leak location[5]. Also the task of fixing a leak requires the disassembly of the cryostat, a major undertaking for a large superconducting coil. Secondly, leak checking the helium vessel after a cooldown with helium is difficult, since a high helium background is encountered, which comes from outgassing of the various surfaces within the vessel that have been exposed to liquid helium. In the following section a cryogenic test procedure that solves many of these problems is described.

Cryogenic Leak Test Procedure

The leak testing techniques used on the K800 cyclotron coil are mainly the same as used on a small cryogenic device with several important modifications. All these cryogenic leak testing techniques involve using liquid nitrogen to cryoshock the devices. For small devices it is common to dunk the entire apparatus into a liquid nitrogen bath. Another technique is to use localized liquid nitrogen cooling. Both of these methods of cryoshocking and then leak checking become less practical as the size of the cryogenic device increases. For the K800 coil it was decided the helium container (bobbin) would be used as a vessel into which liquid nitrogen would be poured (this volume is also pumped on for leak checking).

This created the problem of large thermal stress during cooldown which potentially could cause overstressing of the coil and its banding. This problem was avoided by building a heat exchanger with multiple tap points. The liquid nitrogen enters the heat exchanger and is warmed by a counter flow of hot water before entering the K800 bobbin. The K800 coil temperature instrumentation was used to monitor the coil cooldown temperature. By adjusting the liquid nitrogen flow and the water tap points, the temperature difference between sections in the coil was kept at less than 100 K, (figure 3) thereby keeping the differential thermal stress in the design range of later normal coil cooling cycles.

Since the outer surface area of the coil (~ 15,000 cm^2) constitutes a large thermal load, the bobbin was insulated with 1" polyurethane foam between itself and it's support stand and 6" home type foil backed fiberglass insulation over the remaining surface. This insulation covering could be easily removed for leak checking.

The cryogenic cooling of the K800, 20 ton coil, (figure 4) required four days to reach liquid nitrogen temperature and the use of ~10,000 gallons of LN_2. After cryoshocking, the liquid nitrogen was allowed to boil from the coil and the bobbin was connected to the leak check system. The house insulation was removed and the coil surface sprayed with helium gas. A helium leak was easily detected and could be located to within 1 cm. Efforts at pinpointing the leak even closer failed because of problems with ice frost that had accumulated on the cold coil surface. In an attempt to remove the frost, the coil surface was heated with a heat gun and the frost then formed a frozen water surface which plugged the leak. Another advantage of leak checking at liquid nitrogen temperature was immediately apparent when tuning the leak detector. It was possible to tune the leak detector to its maximum sensitivity since the cold temperature of the coil had frozen out the gas contaminates from the coil insulation material.

The coil bobbin was warmed to room temperature (~4 days), the leak repaired, and the cooling process repeated. No leaks were detected on the second cryogenic cooling and leak testing.

A final test of the leak tightness of the coil occurred approximately two months later when it was cooled to liquid helium temperature. The cryostat vacuum jacket was isolated from its vacuum pumping system and the pressure was found to decrease with time: thereby, the leak testing result obtained at liquid nitrogen temperature were verified.

Conclusion

A method of cryogenic leak testing a large superconducting magnet liquid helium vessels before inserting into its vacuum jacket has been demonstrated. This method requires the useage of large quantities of liquid nitrogen and a heat exchanger to control the cooldown rate. The deposition of frost on the vessel while leak checking at very cold temperatures did not hinder the detection of a leak. A further refinement of the method would be to test in a low humidity room, thereby slowing down the frost deposition rate on the cold surfaces. Testing of the vessel at cold temperature also allowed the tuning of the leak detector to its maximum sensitivity, since most background gas contaminates were frozen out. We believe that using this procedure contributes significantly to the solution of the technological challenge of making large superconducting magnet helium vessels leak tight.

References

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Figure Captions

Figure 1.

A schematic drawing of the cryoshocking-leak test set up for the K800 coil bobbin. The turbomolecular pump on top of the bobbin was replaced with a nitrogen gas exhaust line during the cryoshocking phase of the leak test.

Figure 2.

The measured increase in the helium concentration in the cryostat vacuum jacket on the K500 coil as it is cooled to liquid helium temperature is shown. This large increase in helium leakage can then become a heat load problem.

Figure 3.

The coil temperature sensors were used to monitor the liquid nitrogen cryoshocking. The temperature difference between various coil sections (numbers) were less than 100 K. The steps in cooling rate coincide with changing the water tap points in the LN_2 heat exchanger. Liquid nitrogen completely filled the coil after four days of cooling.

Figure 4.

A photograph of the K800 during the cryoshocking cooldown. The coil is wrapped in house insulation which reduces the thermal ambient load and also keeps water frost from the coil surface. After reaching liquid nitrogen temperature, the insulation was removed and helium gas sprayed on the coil surface while leak checking.

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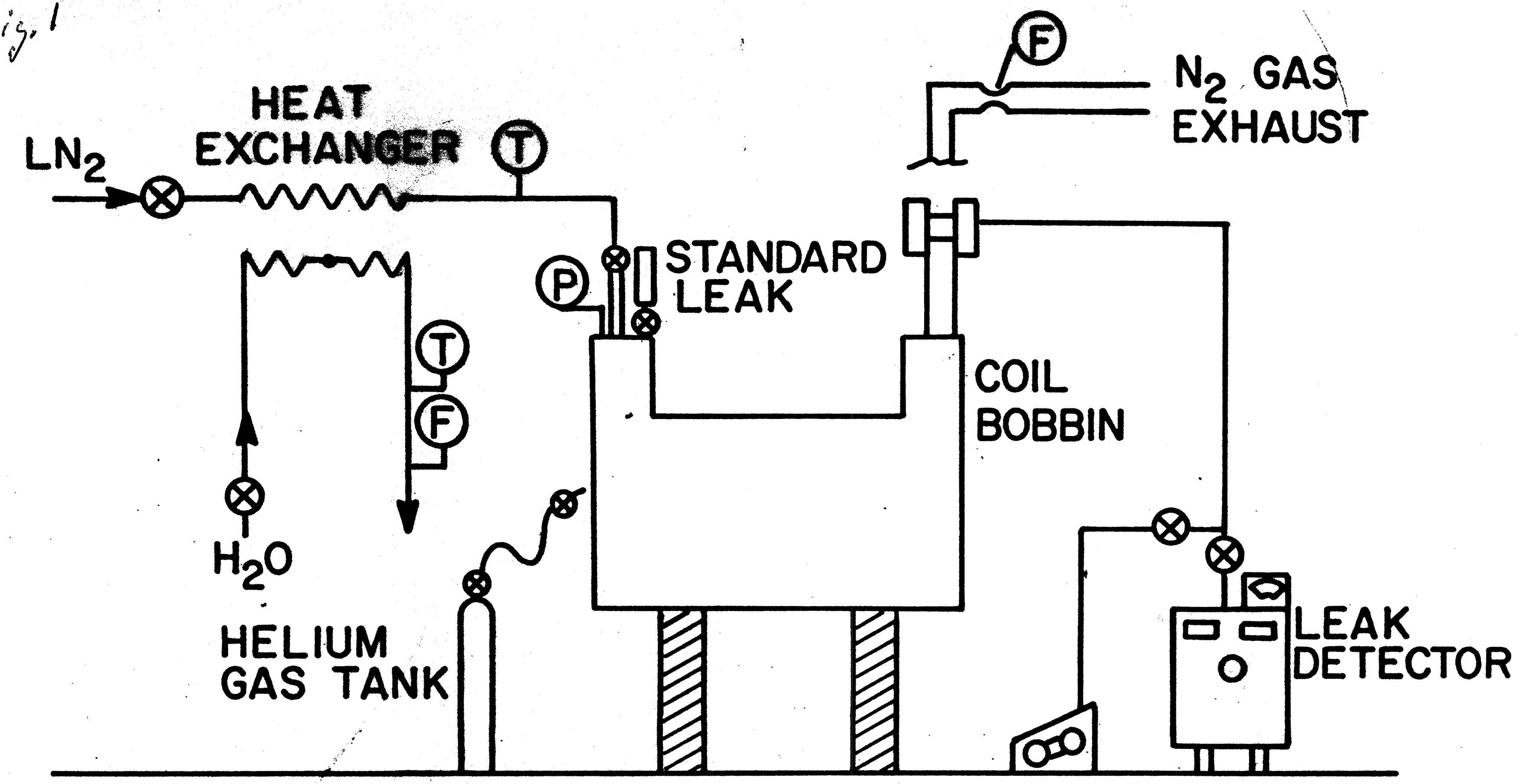
Fig. 1



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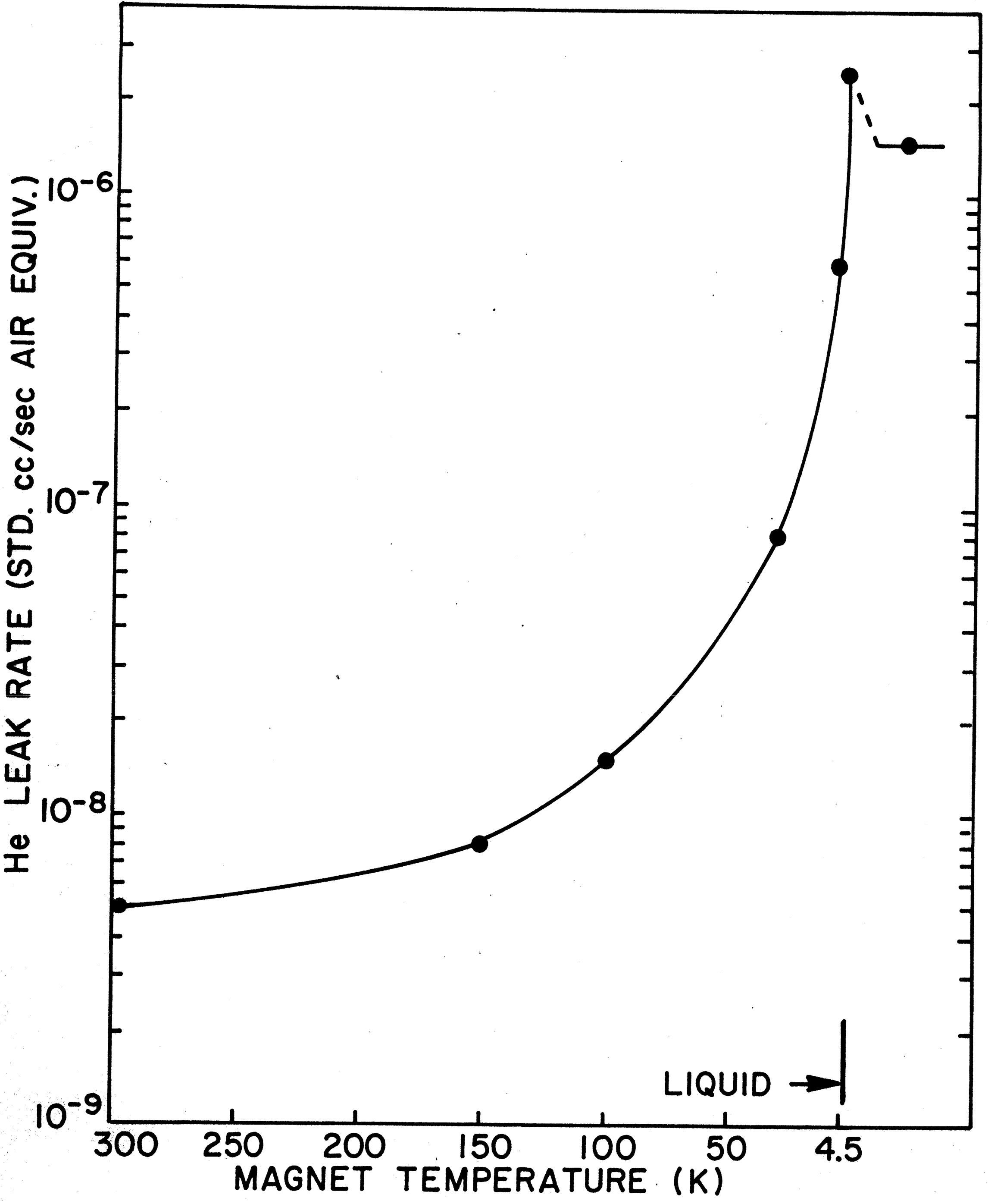
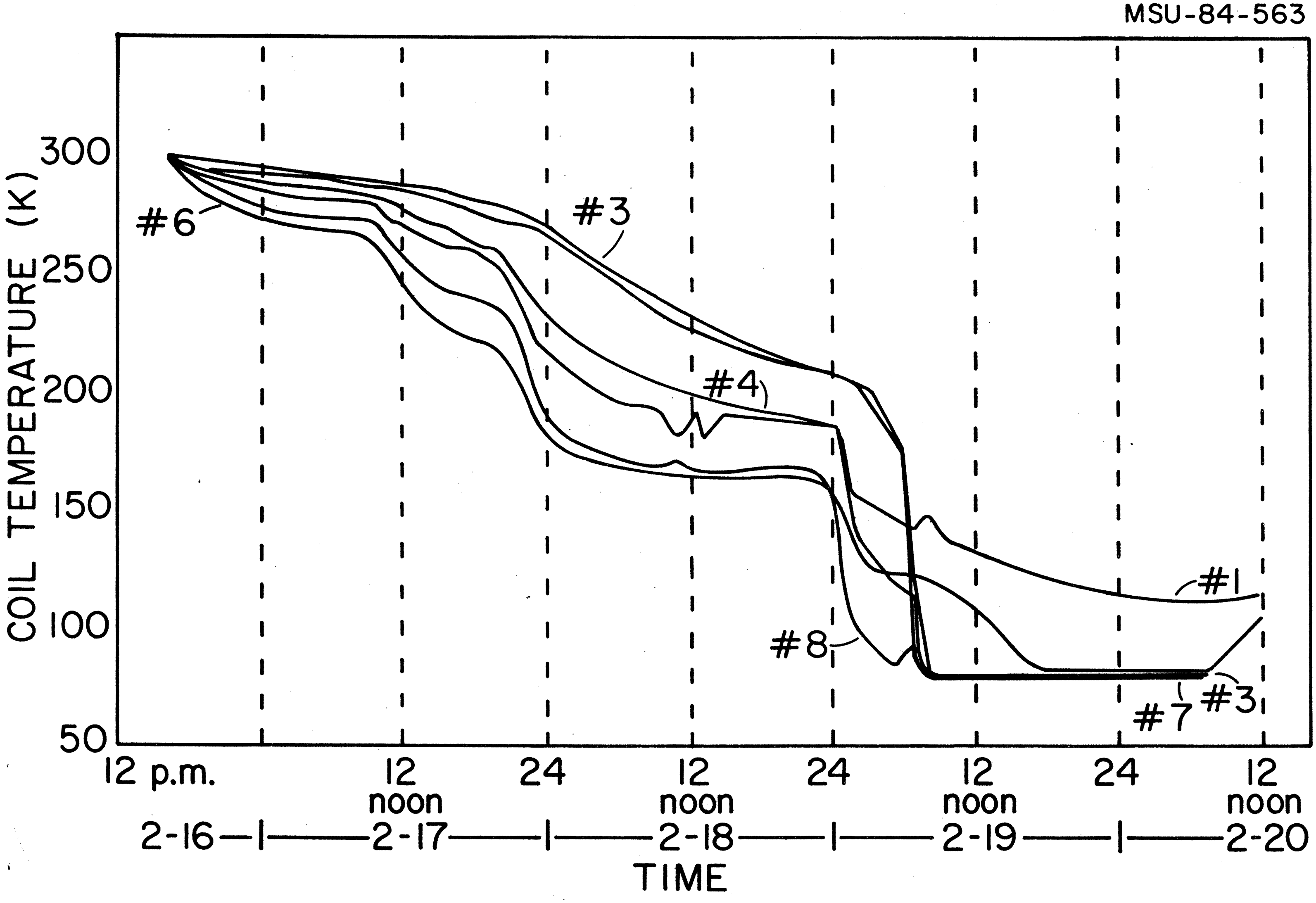


Fig. 2

Fig. 3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COIL TEMPERATURE (K)
300
250
200
150
100
50
12 p.m.
12
noon
24
12
noon
24
12
noon
24
12
noon
2-16
2-17
2-18
2-19
2-20
TIME
#6
#3
#4
#1
#8
#7
#3