BNL-105807-2014-TECH

EP&S No. 92;BNL-105807-2014-IR

Analysis of the cooldown time of the D bend superconducting magnets

W. L. Keith

July 1980

Collider Accelerator Department

Brookhaven National Laboratory

U.S. Department of Energy

USDOE Office of Science (SC)

DISCLAIMER

Accelerator Department

BROOKHAVEN NATIONAL LABORATORY
Associated Universities, Inc.

EP&S DIVISION TECHNICAL NOTE

NO. 92

W. L. Keith and G. Gulotta*

July 10, 1980

ANALYSIS OF THE COOLDOWN TIME OF THE D BEND SUPERCONDUCTING MAGNETS

ABSTRACT

A simple numerical technique accurately determined the time required to cool a D bend S.C. magnet from 290°K to 10°K using helium. The technique is described and the theoretical and experimental data are presented. Accuracy and limitations of the theoretical analysis are discussed.

*Gasper Gulotta was a visiting student in Nuclear Engineering from West Point Military Academy.

Analysis of the Cooldown Time for the D Bend S.C. Magnets

Introduction

Each D Bend magnet operates in a cryostat containing pool boiling liquid helium at 1.5 atm. and 4.5 °K. The magnets will be cooled from room temperature to 100°K using helium gas at approximately 80°K, and from 100°K to 4.5°K using two phase helium at 4.5°K. The time required for this cooling process was determined prior to the final design of the magnets in order to assess the need for a liquid nitrogen cooling jacket.

Theoretical Analysis

The masses of the components of one D Bend magnet are given below.

Component	Mass(lbs)
Iron	9393.43
Copper Superconductor	339.52
Aluminum	43.28
Epoxy Casting	81.50
Stainless Steel	929.74

The constant pressure specific heats (C_p) of the components are assumed to be linear functions of temperature over 20 degree temperature decrements from 290°K to 100°K, and over 10 degree decrements from 100°K to 10°K.

Using the relation,

(1) $$dQ = MC_p dt$$

and assuming,

(2) $$C_p = C_{po} + KT$$

one may integrate (1) from T_1 to T_2 to obtain

(3) $${}_1Q_2 = M\,[C_{po}\,(T_2-T_1) + \frac{K}{2}\,(T_2^2-T_1^2)]$$

Where ${}_1Q_2$ is the amount of energy to be removed from mass M to lower its temperature from T_1 to T_2. The energy to be removed from the magnet, ${}_1Q_{2\,\mathrm{TOTAL}}$ is the sum of the ${}_1Q_2$ for each component.

(4) $$ {}_1Q_{2\,\mathrm{TOTAL}} = \sum_{i=1}^{N} {}_1Q_2{}^{i} $$

N = No. of components.

Using the relation,

(5) $$ {}_1Q_{2\,\mathrm{TOTAL}} = \dot{m}t\,(h_{out}-h_{in}) $$

where $\dot{m}$ = mass flow of helium into the magnet (gms/sec)

h_{out} = enthalpy of the helium exiting the magnet (joules/gm)

h_{in} = enthalpy of the helium entering the magnet (joules/gm)

t = time required to remove ${}_1Q_2$ joules from the magnet.

the time (t) to lower the magnet temperature from T_1 to T_2 may be found. By repeating this procedure over the entire temperature range and summing, the total cooldown time is determined. This procedure is easily accomplished using a short Fortran program.

Correlation with Experimental Results

The following cooldown procedure was used during the first magnet test. One magnet was cooled from 290°K to 90°K using helium gas at 80°K flowing at 5 gms/sec, and from 90°K to 4.5°K using two phase helium at 4.5°K flowing at 3.8 gms/sec.

A time-temperature log was kept during the experiment, and this is shown in Figures 1 and 2 along with the theoretical calculations. For the temperature range from 290°K to 100°K, the theoretical results agreed with the experimental to within 8%. For the range from 90°K to 10°K, the theoretical agreed to within 20%. It should be noted that the changeover from gaseous to liquid cooling was made during the 100°K to 90°K decrement, so this data was not included.

Accuracy and Sources of Error

Since the theoretical solution is a linear function of flow rate, this is the greatest source of error. The experimental flow rates for gaseous helium were determined by noting a large volumetric change in time. This technique was repeated many times and the flow of 5 gms/sec was found to be constant. The flow of liquid helium was determined by noting the decrease in liquid level in the storage dewar.

Another source of error is the enthalpy of the helium entering the magnet (h_{in}). During the gaseous cooling phase, the temperature of the helium exiting the LN_2 heat exchanger was assumed to be 77°K and the temperature indicated in the magnet cryostat near the inlet was 85°K. The assumption that the inlet temperature of the gas was 80°K seems reasonable. If the inlet temperature is assumed to be 85°K, the theoretical solution increases by 8%. During the liquid cooling phase, the quality of the mixture entering the magnet was determined by considering the steady state heat load in the transfer line from the storage dewar to the magnet and assuming this heat vaporized a portion of the liquid.

Over the range from 10°K to 4.5°K, the helium exit enthalpy approaches the inlet enthalpy and (h_{out}-h_{in}) becomes very small and long time values are found which do not agree with experimental values. In addition, the cryostat starts to fill with liquid and the heat transfer is no longer simply forced convection.

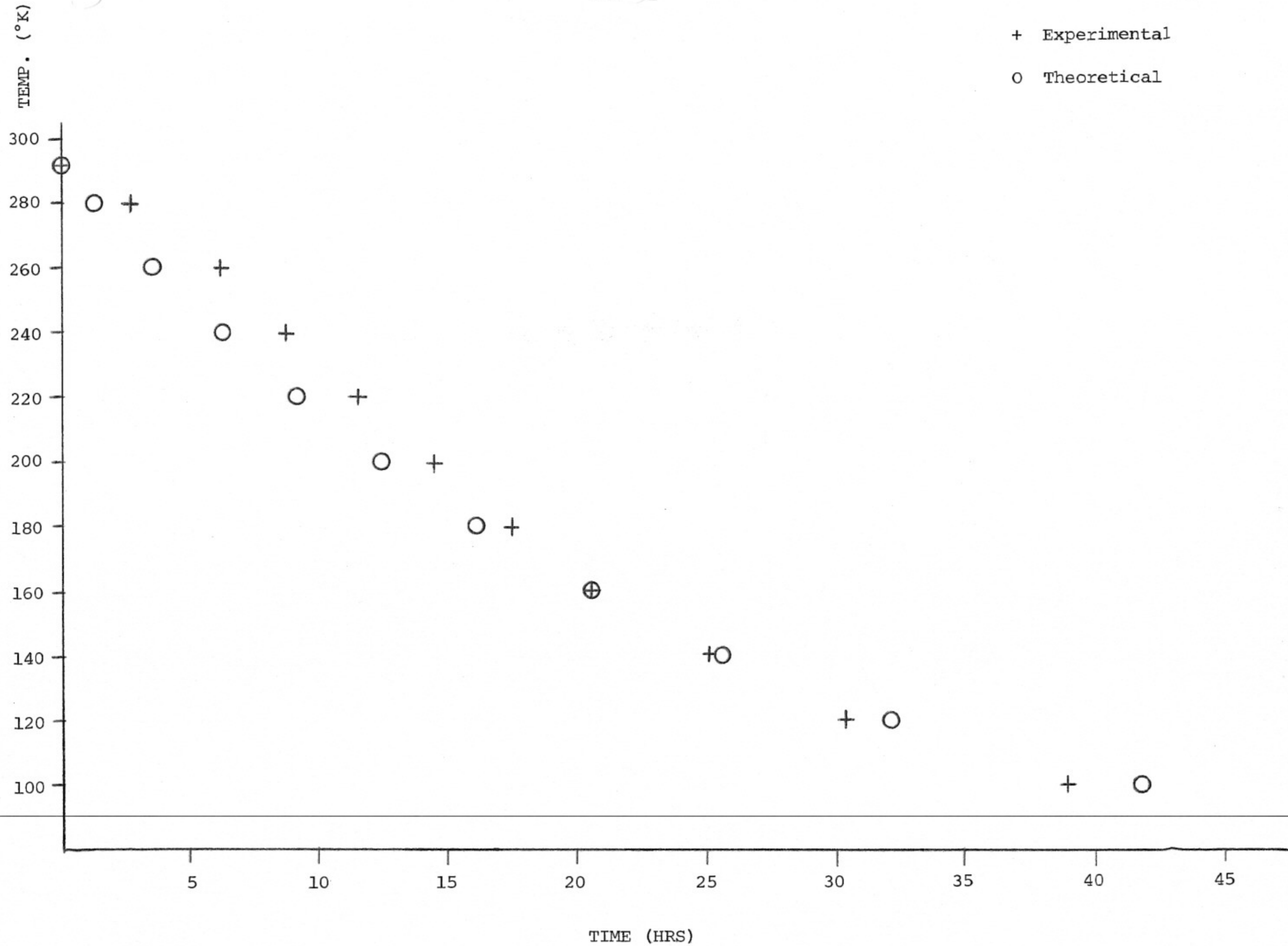
The steady state external heat load on the magnet is small enough so as to be ignored.

Conclusions

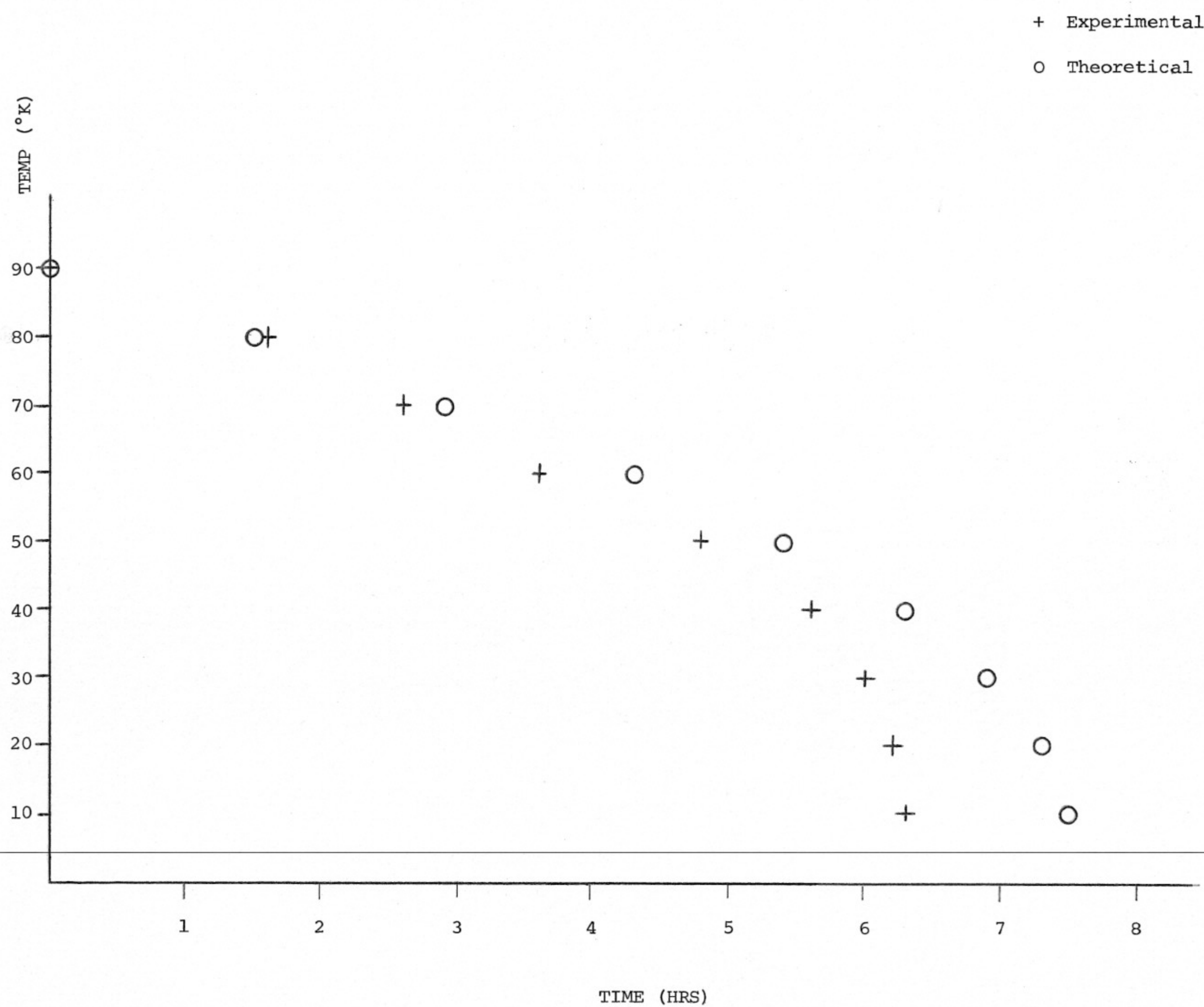
The value of this technique is the ease with which one may predict the cooldown times of large masses from room temperatures to cryogenic temperatures using forced convection. The temperature decrements to be used should be determined from the linearity of the specific heats of the major components. The accuracy over the 90°K to 10°K range was found to increase by 10% if 4 degree temperature decrements rather than 10 degree ones were used. If the specific heats are fairly linear, larger temperature decrements may be used and fewer C_p values are input to the program.

Dist.: Dept. S&P

FIG 1


TEMP. (°K)
+ Experimental
O Theoretical
300
280
260
240
220
200
180
160
140
120
100
5
10
15
20
25
30
35
40
45
TIME (HRS)

FIC 2


+ Experimental
o Theoretical
TEMP (°K)
90
80
70
60
50
40
30
20
10
1
2
3
4
5
6
7
8
TIME (HRS)