BROOKHAVEN NATIONAL LABORATORY

**Superconducting Magnet Division**

# Magnet Note

**Author:** K.C. Wu

**Date:** November 8, 2001

**Topic No:** 608-12 (AM-MD-309)

**Topic:** Cryogenics for Magnet Testing and Measuring

**Title:** Cryogenic Test Results for DESY GG Magnet

M. Anerella
A. Blake
J. Cozzolino
J. Escallier
G. Ganetis
M. Garber
A. Ghosh
R. Gupta
H. Hahn
M. Harrison
J. Herrera
A. Jain
P. Joshi
S. Kahn
W. Louie
J. Muratore
S. Ozaki
B. Parker
S. Peggs
F. Pilat
S. Plate
C. Porretto
W. Sampson
J. Schmalzle
J. Sondericker
S. Tepikian
R. Thomas
D. Trbojevic
P. Wanderer
J. Wei
T. Wild
E. Willen

# Cryogenic Test Results for DESY GG Magnet

Force flow cooling of the DESY GG magnet QHG101 was carried out in the MAGCOOL horizontal facility from February 5th through $8^{th}$, 2001. Cooldown began on Saturday, February $3^{rd}$. The magnet reached 4.7 K on Sunday, February 4th. In the following four days, the magnet is cooled by three groups of flow rate (75, 50 and 30 g/s). Magnetic measurements are carried out during the day with various lead flows (with a maximum total of 0.25 g/s). The lead flows are shut off during the night. Whenever the lead flows are on, a reduction of heat load in the Lead Tower is seen. The pressure drop and heat load of QHG101 are evaluated. As expected, the heat load of QHG101 is less than that of the $1^{st}$ GO magnet due to its smaller size. However, the pressure drop characteristic is identical.

## Flow Diagram

QHG101 is tested in the same facility as that for the $1^{st}$ GO magnet. The flow diagram is given in Figure 1. To improve thermal evaluation from the first GO test, three sets of redundant temperature sensors are installed at the inlet to the magnet, the exit of the magnet, and the exit of the Lead Tower. Eight flow controllers are installed to control lead flow through leads for the dipole, the quadrupole, the skew dipole and the skew quadrupole. There is a flowmeter installed downstream of each flow controller for flow reading. Lead flow through the sextupole is controlled manually.

The magnet is connected to the lead tower and the feed can. Three flexible transfer lines are used to provide connections for the supply helium, return helium and liquid nitrogen flow. The magnet is cooled by helium from the MAGCOOL supply header. After cooling the magnet and lead tower, helium returns to feed can. In the feed can, a by-pass valve is installed to divert portion of the flow to the return line and control helium flow through the magnet.

In this test, the beam tube is cooled by liquid nitrogen from the feed can. The nitrogen also flows through the connecting tube and the lead tower as heat shield.

A venturi flowmeter with a differential pressure transducer is installed for measuring the flow through the magnet. A second differential pressure transducer is used to determine the overall pressure drop. Temperature sensor, Tee, is installed near the venturi for determining the supply temperature. Temperature sensors, TCA and TCB, are installed at the inlet to QHG101. Temperature sensors, TC1 and TC2, are installed in the exit of QHG101. Temperature sensors, TCD and TCE, are installed at the exit of the Lead Tower. Eight flow controllers and nine flowmeters are installed for the current leads and instrumentation feed through. In this test, all temperature sensors behave properly except Tee which gives a slightly higher temperature. Data from Tee is not used.

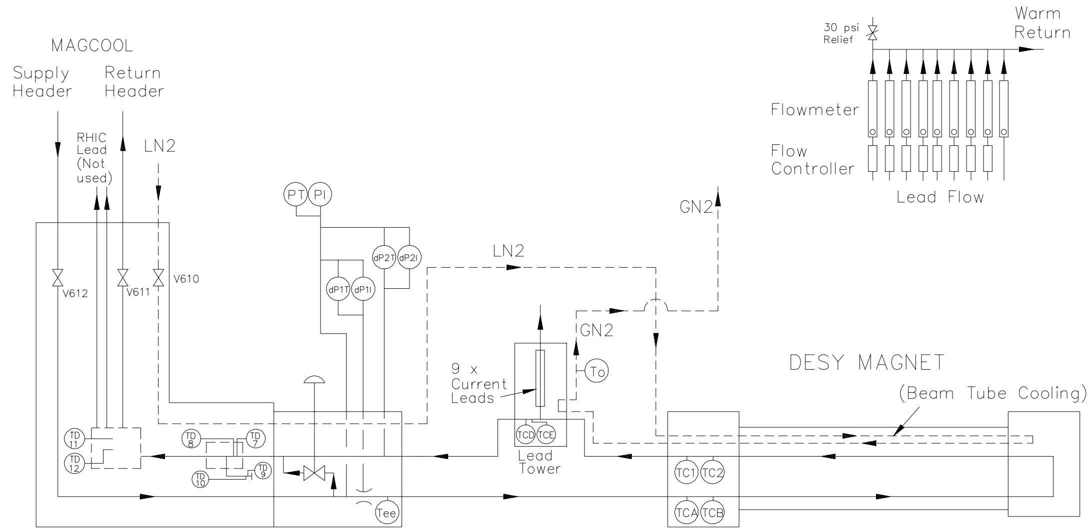


**Figure 1 Flow diagram for testing DESY magnet QHG101**

## Test Conditions

In the four-day period (Feb. 5 – 8), the cryogenic system provides stable temperature helium to cool the magnet. The by-pass valve is used to create three groups of flows through the magnet as shown in Figure 2. In Figure 2, helium density is assumed to be 0.13 g/cc. These three groups are approximately 36 - 84, 84 - 108 and 108 – 128 hours. Data are taken at ten minutes interval. The time coordinate for 0 - 24 hour is Saturday, 24 – 48 is Sunday, 48 – 72 is Monday, 72 – 96 is Tuesday, 96 – 120 is Wednesday. The system is shut down Thursday 8 am or the 128th hour.

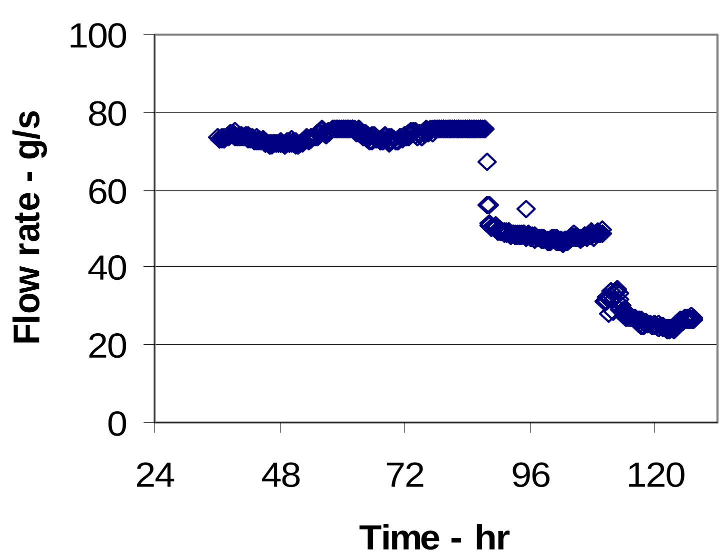


**Figure 2 Flow rate through QHG101**

The pressure in the magnet is between 3.3 and 4.7 atm as given in Figure 3. In the cryogenic test facility, the return pressure is maintained steady. Pressure in the magnet is higher at higher flow due to a larger pressure drop. For 70 g/s, the pressure is between 4.2 and 4.7 atm. At 50 g/s, the pressure is between 3.5 and 4 atm. At 30 g/s, the pressure is between 3.3 and 3.5 atm.

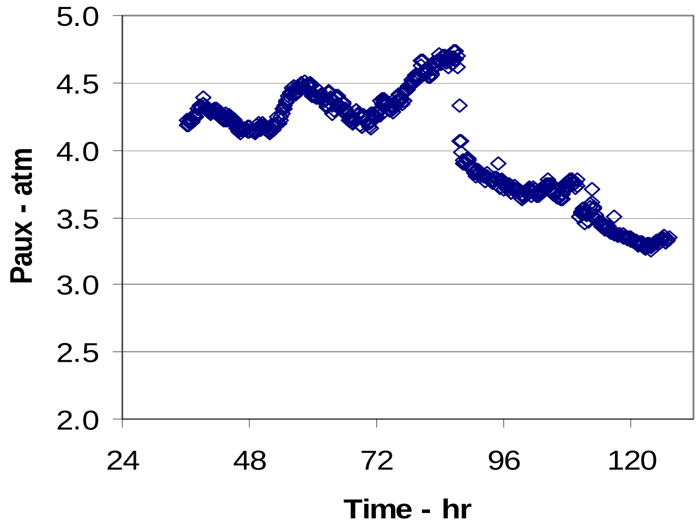


**Figure 3 Pressure as a function of time**

The temperature as a function of time is given in Figure 4. The magnet supply temperature is kept at approximately 4.65 K. The temperature at the exit of the magnet is a function of flow and varies between 4.75 and 4.9 K. The temperature at the Lead Tower is a function of both cooling flow and lead flow. Without lead flow (during the night), the Lead Tower is between 4.9 and 5.25 K. With lead flow, the temperature decreases to 4.8 K.

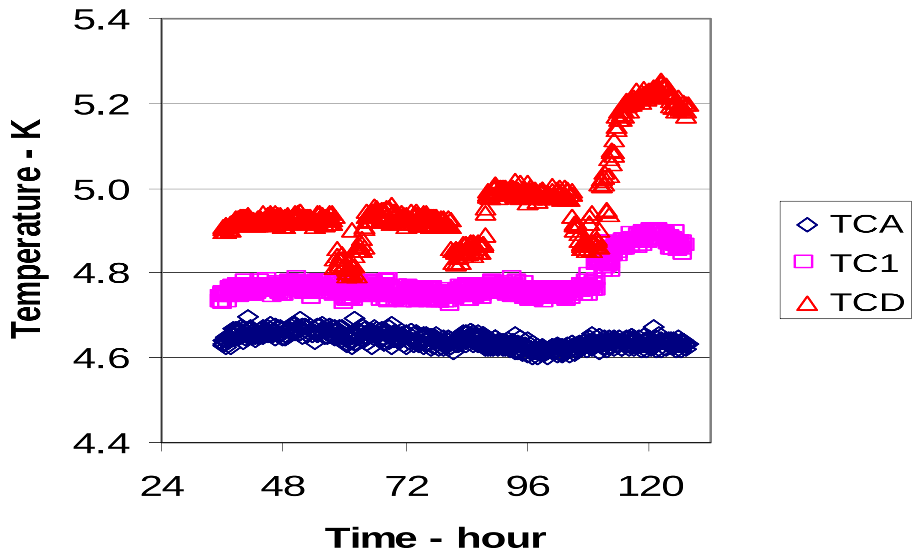


**Figure 4 Temperature as a function of time**

The differential pressure (dPT1) of the venturi flowmeter as a function of time is given in Figure 5. The accuracy of this differential pressure transducer was verified prior to the test. However, the maximum cooling flow exceeds its maximum range of 60-inch water. Fortunately, the transducer is able to provide sensible reading to about 85-inch water. A small period during the test did exceed the maximum range. During that period, flow rate is slightly more than that given in Fig. 2.

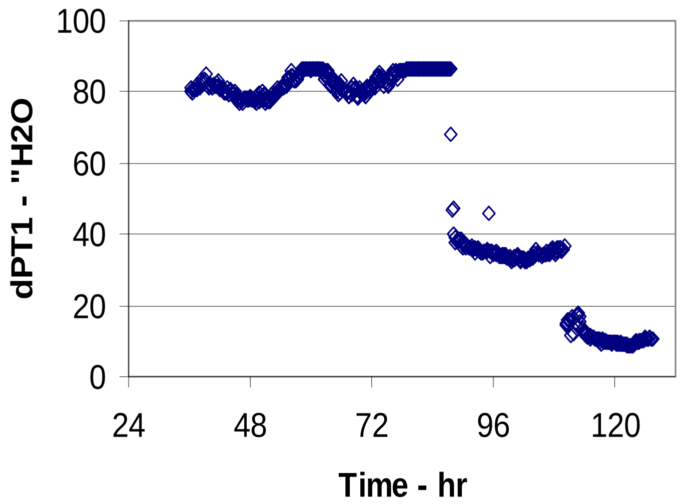


**Figure 5 Differential pressure dP1 for the flowmeter**

Temperature in the beam tube is between 90 and 100 K. The insulating vacuum is in the $10^{-5}$ Torr range through out the test. Temperature on the outer surface of the cryostat is normal and no icy spots were observed.

## Overall Pressure Drop

In this test, we measure the overall pressure drop (dPT2) including a supply line from the feed can, QHG101, transfer tube to Lead Tower, Lead Tower and a return line to the feed can. The pressure drop as a function of time is given in Figure 6. The overall pressure drop is proportion to the differential pressure developed in the venturi. As shown in Figure 7, the ratio for dPT2/dPT1 is between 4.7 and 5.2. The pressure drop as a function of flow rate is given in Figure 8. At the largest pressure drop corresponding to the highest flow of 78 g/s, the results certainly indicate dPT1 of the venturi reaches the maximum. The pressure drop of the 1$^{st}$ GO magnet is also given in Figure 8. As seen, the pressure drop characteristic of the two magnets are identical. Overall pressure drops are about 0.17 and 0.43 atm for 30 and 50 g/s flow respectively. Pressure drop through QHG101 equals overall pressure drop minus that from the transfer tube, the lead tower and the two flexible transfer lines.

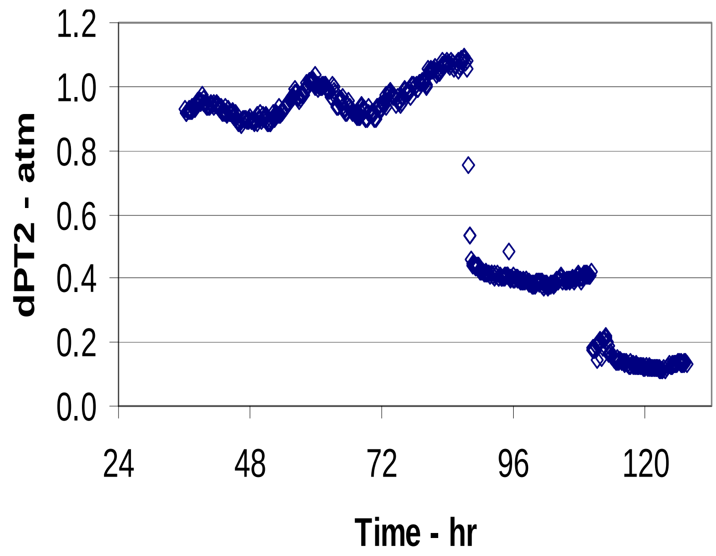


**Figure 6 Overall pressure drop dPT2 as a function of time**

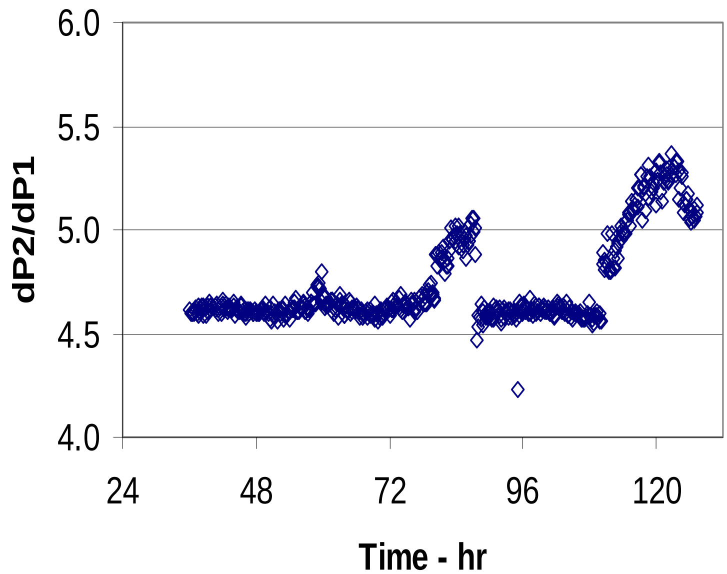


**Figure 7 Ratio of dPT2 to dPT1**

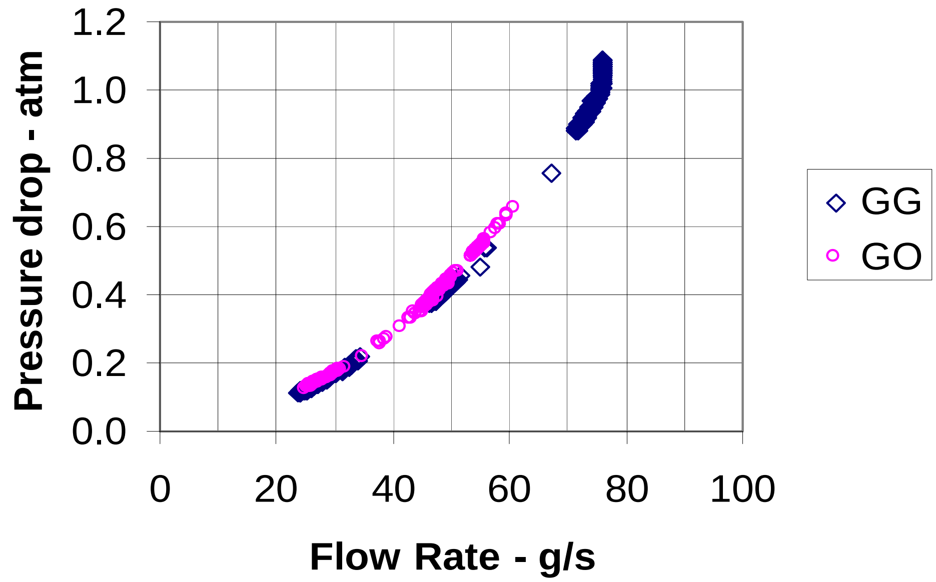


**Figure 8 Overall pressure drop as a function of flow rate**

## Heat Load

The heat load of a system cooled by a steady flow is given by equation 1. The temperature difference across QHG101 is given in Figure 9. The increase in temperature difference is due to change of flow rate through the magnet. Heat load for QHG101 is calculated using a mean specific heat of 5 J/g-K and is given in Figure 10. The heat load for QHG101 is between 40 and 30 watts. Temperature rise of 0.1 K at large flow (75 g/s) probably is not accurate enough for heat load evaluation. However, the cryogenic system for the 30 g/s flow is not as stable as those days operating flow at 50 and 75 g/s. For practical purpose, heat load is somewhere between 30 and 40 W with beam tube operating at 100 K.

$$\dot{Q} = \dot{m} \times C_p \times (T_o - T_{in}) \qquad (1)$$

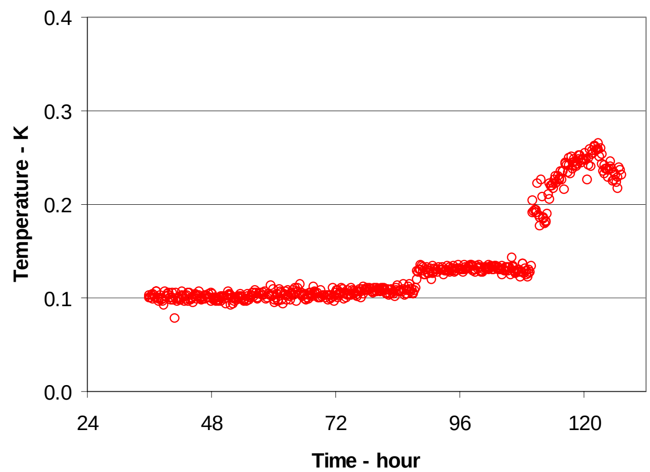


**Figure 9 Temperature increase through QHG101**

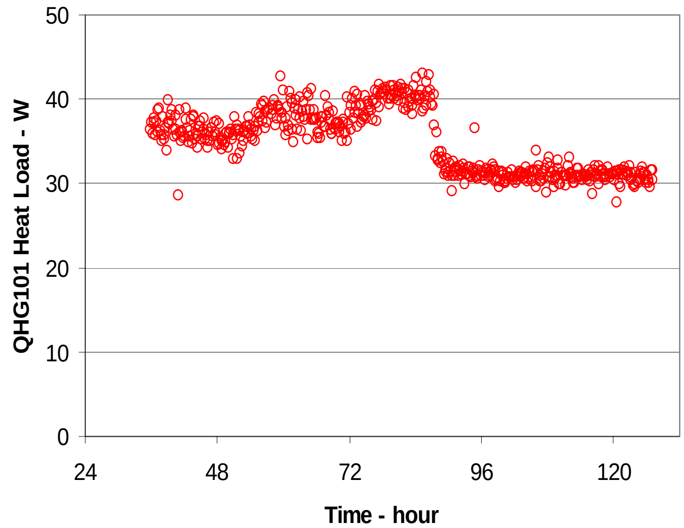


**Figure 10 Heat load of QHG101**

The temperature difference between QHG101 and the Lead Tower as a function of time is given in Figure 11. The temperature difference increases due to a decrease of cooling flow. The three sets of dip in temperature difference are due to lead flow. As current leads being fed with lead flows, heat load for the Lead Tower decreases. Heat load for Lead Tower and the connecting tube is calculated using a mean specific heat of 5 J/g-K and is given in Figure 12. Without lead flow, the heat load is between 40 and 70 watts. With full lead flow, the heat load is between 20 and 30 watts.

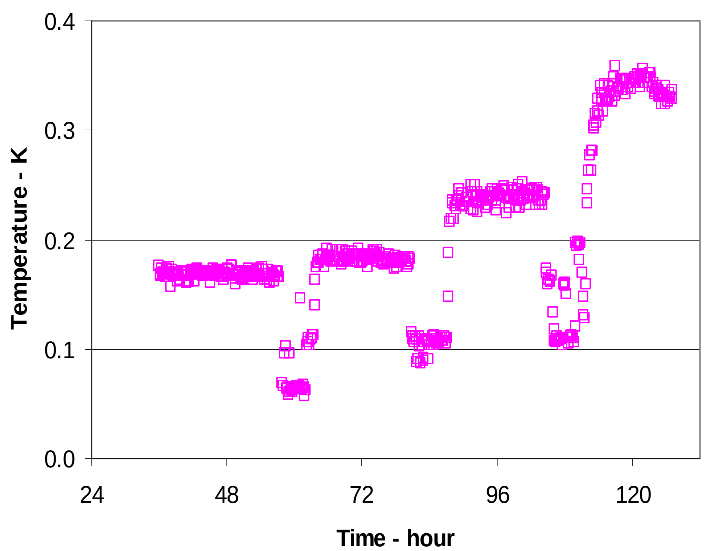


**Figure 11 Temperature increase from QHG101 to Lead Tower**

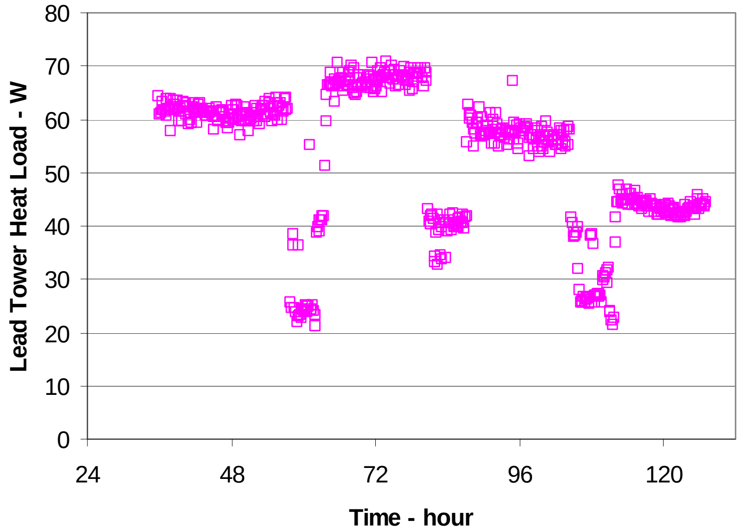


**Figure 12 Heat load for Lead Tower**

To further investigate the heat load, temperature as a function of flow is given in Figure 13. As one can see, temperature at the inlet to QHG101 is fairly steady at 4.65 K for all flow. Temperatures at the exit of the magnet and Lead Tower decrease with flow.

For a system with constant heat load and steady inlet temperature, the heat load can be calculated from the slope of temperature and the reciprocal of flow as shown in equation 2. The exit temperature should vary linearly with the reciprocal of mass flow. The slope is Q/Cp and the intersect equals Tin. The temperature as a function of reciprocal of flow for QHG101 is given in Figure 14.

$$T_o = T_{in} + \frac{\dot{Q}}{C_p} \times \frac{1}{\dot{m}} \qquad (2)$$

In Figure 14, the slope for the magnet exit temperature is about 6 K-g/s. The heat load is estimated at 30 watts assuming Cp is 5 J/g-K. Note the 1$^{st}$ GO has 50 watt heat load using the same calculating procedure. The magnet heat load will decrease when the beam tube is operated at 40 K instead of 100 K.

For temperature at the exit of the Lead Tower, the trend is not as clear. The data does not intersect with the supply temperature when extrapolating to very large flow (reciprocal of flow approaches zero). Using values obtained at the 75 g/s region, the heat load without lead flow is about 73 W. From all temperature data, it is possible to fit a line with a smaller slope and a heat load about 60 W is possible. Since there will be lead flow during operation, the heat load without lead flow is not as critical to the operation.

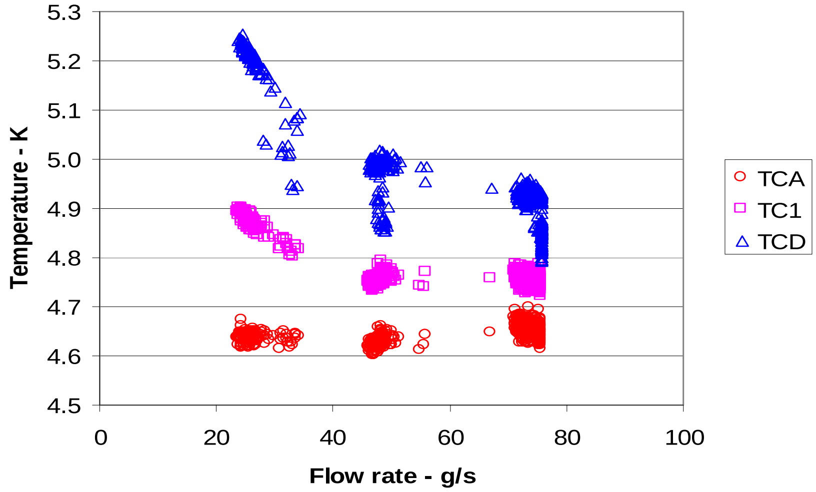


**Figure 13 Temperature of QHG101as a function of cooling flow**

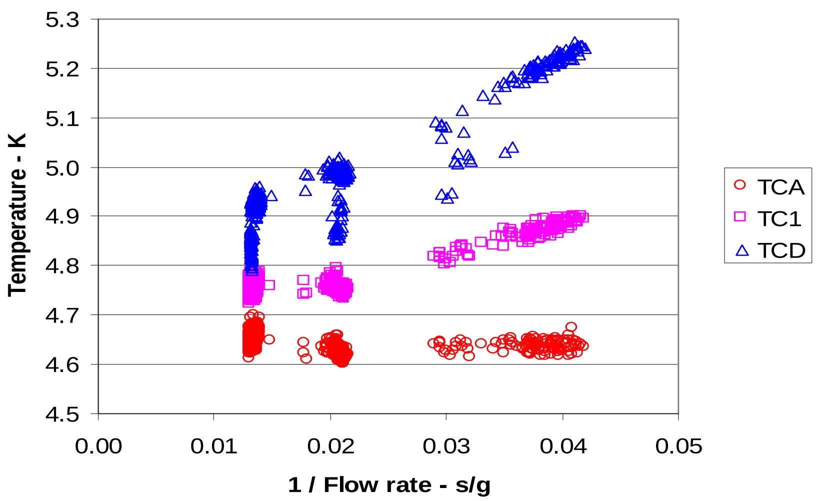


**Figure 14 Temperature of QHG101 vs reciprocal of cooling flow**

## Lead Flow

Total lead flow as a function of time is given in Figure 15. When the magnet is powered, the lead flow increases from its tare value to operating condition. Total maximum operating flow for eight leads is about 250 mg/s (0.25 g/s). In Figure 15, those periods associated with small lead flows are due to signal off set at zero flow condition. Since all flow control valves on the flowmeters are shut off during the night, there is no lead flows during those period. Zero lead flow during the night shall be used for all results given in Figure 15 – 24.

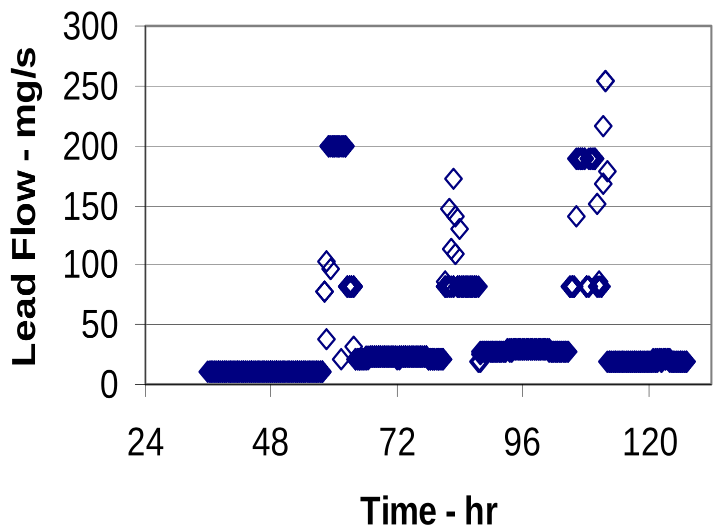


**Figure 15 Total lead flow as a function of time**

## Lead Flow and Heat Load

Total lead flow and temperature of Lead Tower (TCD) as a function of time are given in Figure 16. Each time the lead flow is turned on, the temperature at the exit of the Lead Tower decreases. Portions of Figure 16, between 48 – 72 hour, 72 – 96 hour and 96 – 120 hours, are given in Figure 17 - 19 for better readability.

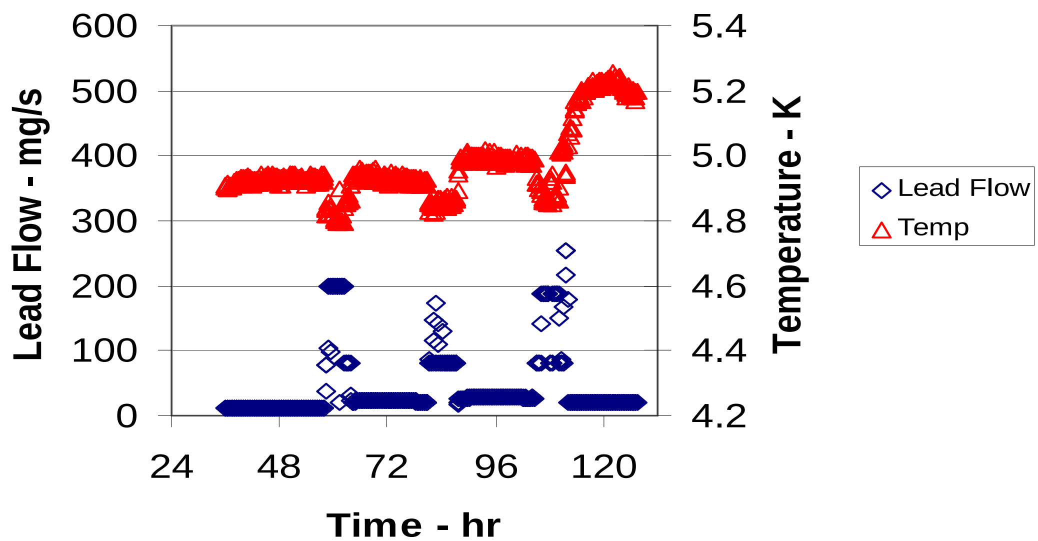


**Figure 16 Total lead flow and Tower temperature for QHG101**

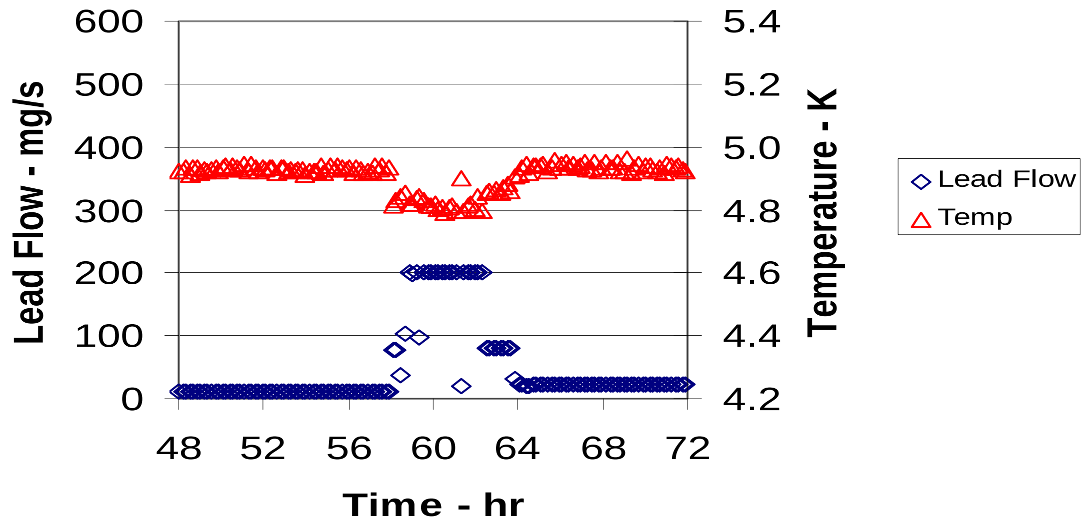


**Figure 17 Total lead flow and Tower temperature between 48th and 72nd**

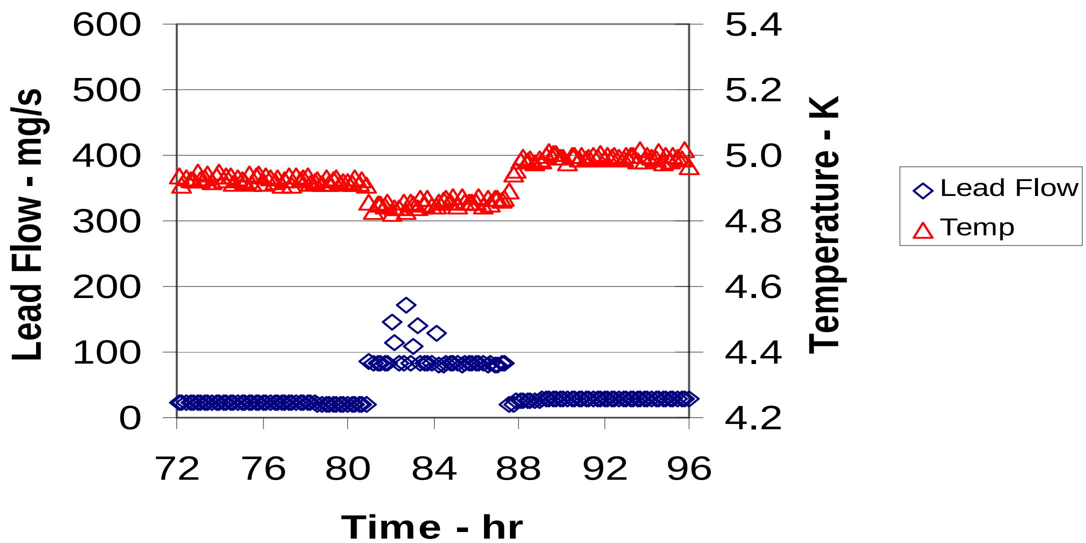


**Figure 18 Total lead flow and Tower temperature between 72nd and 96th hour**

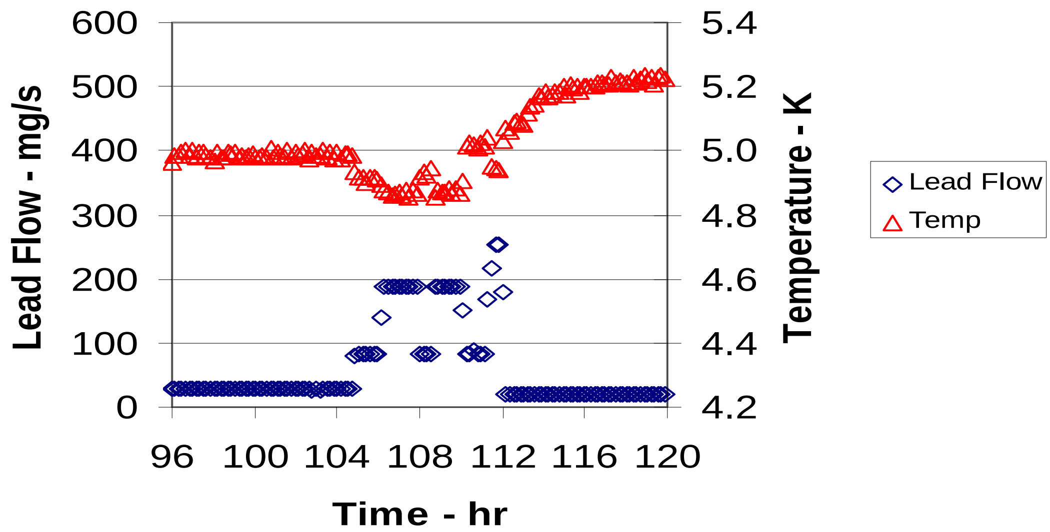


**Figure 19 Total lead flow and Tower temperature between 96th and 120th hour**

Total lead flow and heat load for Lead Tower as a function of time are given in Figure 20. Portions of Figure 20, between 48 – 72 hour, 72 – 96 hour and 96 – 120 hours, are given in Figure 21 - 23 for better readability. Heat load as a function of total lead flow is given in Figure 24. From these figures, the heat load reduces approximately 20 W for 0.1 g/s lead flow.

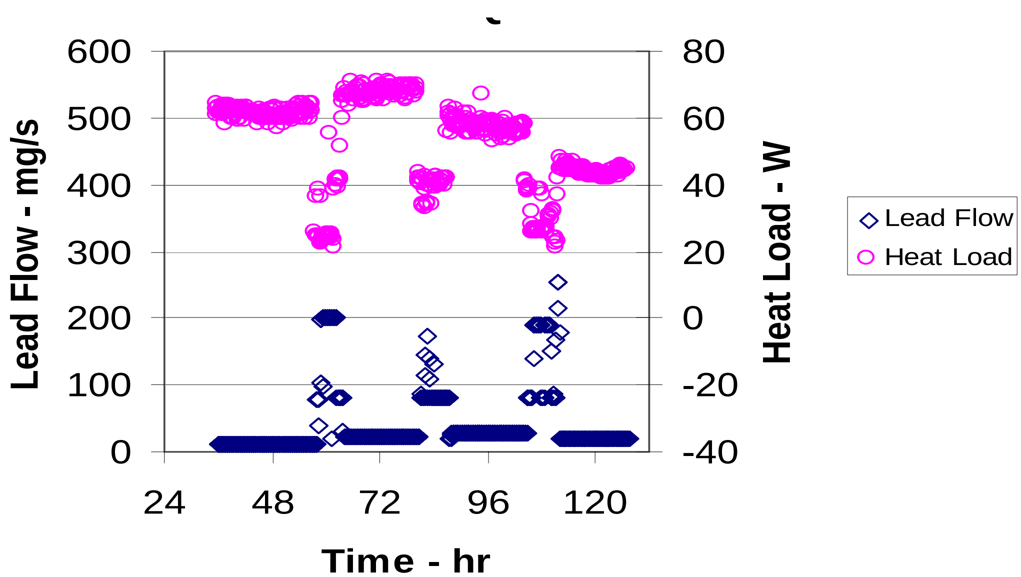


**Figure 20 Total lead flow and heat load for QHG101**

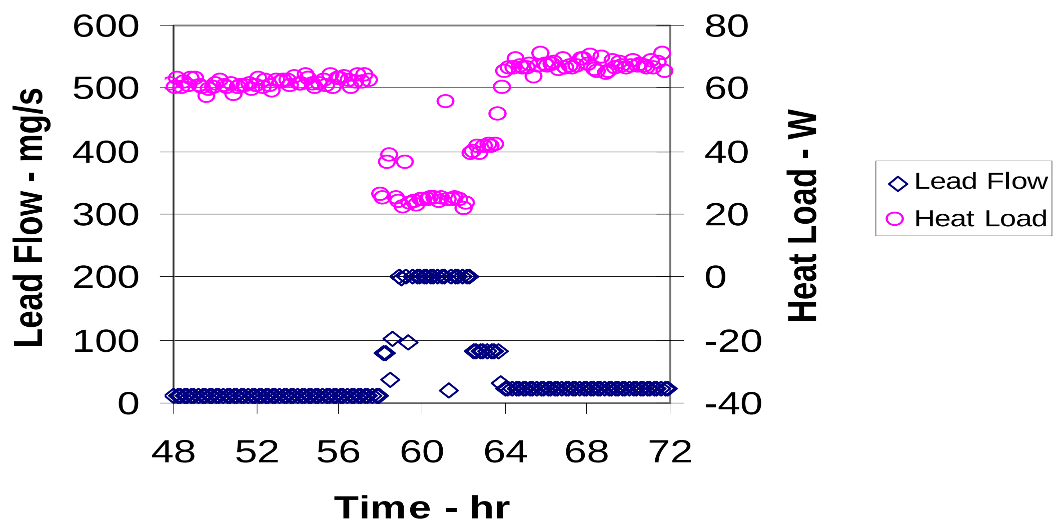


**Figure 21 Total lead flow and heat load between 48th and 72nd hour**

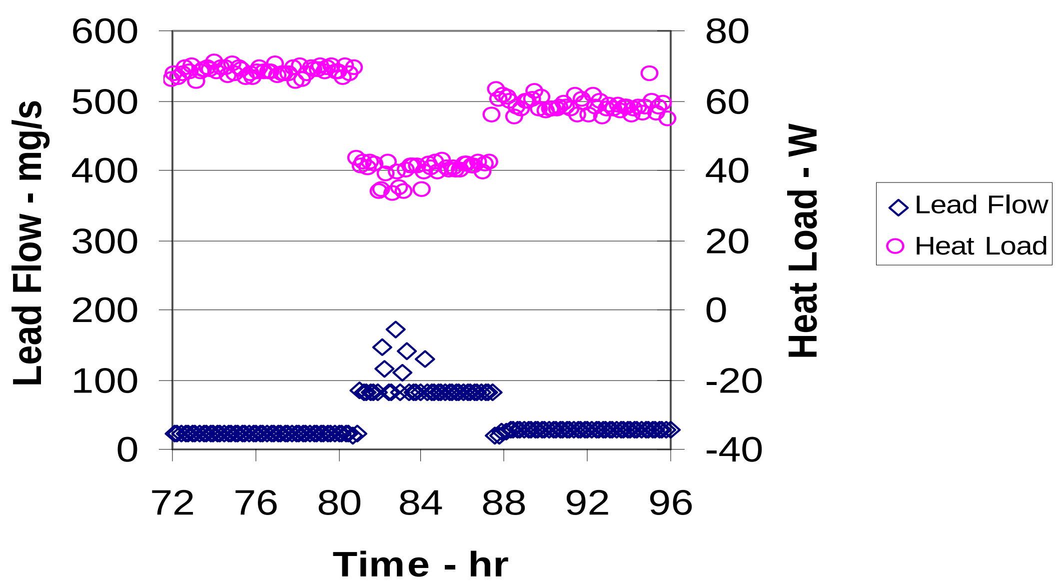


**Figure 22 Lead flow and heat load between 72nd and 96th hour**

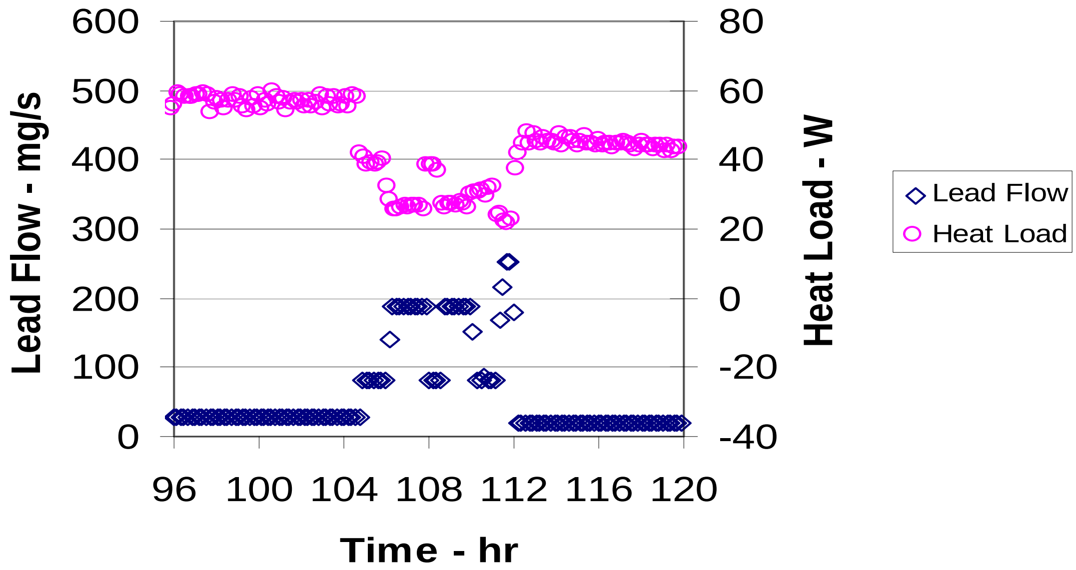


**Figure 23 Lead flow and heat load between 96th and 120th hour**

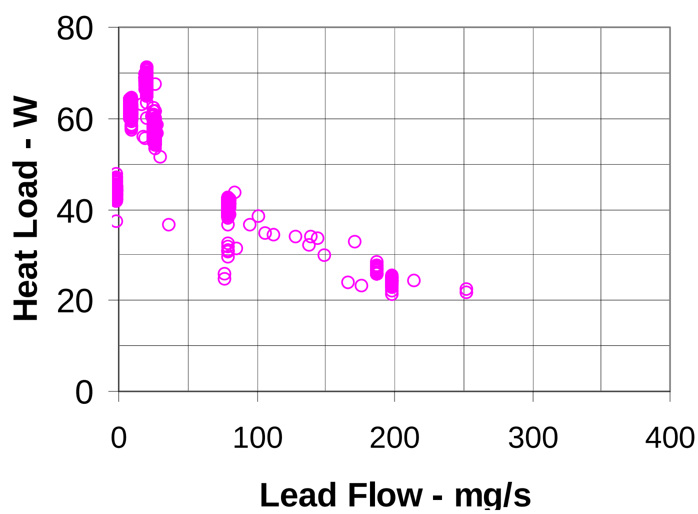


**Figure 24 Heat load of Lead Tower as a function of total lead flow**

## Lead Quench and Lead Flow

During the test, a correlation is used to control flow rate through the current lead. The original correlation gives satisfactory results when cooling flows are at 75 and 50 g/s. The same correlation produce quench in the lead when the cooling flow is 30 g/s. Increase tare flow provides better cooling and the lead can be powered to full current without quench. This phenomenon is consistent with the experience of DESY.

## Flow Calculation

The flow rate is calculated according to the following simplified formula for venturi flowmeter

$$\dot{m} = 22.6 \times \sqrt{Density \times dP_1} \qquad (3)$$

In equation 3, the units are g/s for mass flow, g/cc for density and inch of water for dP1. Density of helium is assumed to be 0.13 g/cc for all cases.