BNL-222166-2021-TECH

EIC-ADD-TN-020; C-A/AP/650

High current, high-temperature operation test of the superconducting magnets in the RHIC yellow ring

R. Than, S. Verdu-Andres

September 2021

Electron-Ion Collider

Brookhaven National Laboratory

U.S. Department of Energy

USDOE Office of Science (SC), Nuclear Physics (NP) (SC-26)

DISCLAIMER

EIC-ADD-TN-020
C-A/AP/650

High current, high-temperature operation test of the superconducting magnets in the RHIC yellow ring

R. Than, S. Verdú-Andrés, S. Berg, D. Bruno, R. Gupta,
G. Heppner, A. Marusic, C. Mi, J. Muratore, J. Sandberg
Brookhaven National Laboratory, Upton, NY 11973, USA

September 16, 2021

Abstract

We report on the tests conducted at the end of RHIC Run 21 to evaluate the operation of superconducting magnets in the RHIC yellow ring at higher currents – up to 5500 A for the arc dipoles and all other magnets on the dipole bus and the focusing arc quadrupoles, up to 5750 A for defocusing arc quadrupoles and up to 6000 A for the insertion quadrupoles Q1 through Q9 – and higher temperatures – up to 5.1 K – than routine. None of the magnets quenched. This is an encouraging finding as the superconducting magnet coils could reach up to 4.9 K during operation with the 275 GeV EIC hadron beams.

1 Introduction

The EIC hadron beams will feature shorter, higher charge bunches than the RHIC beams and, for selected energies, will circulate around the ring with a large radial offset for synchronized arrival at the interaction point with the relativistic electron bunches. That is the case of the 275 GeV EIC proton beam, with 290 short, 6 mm-long bunches each containing 1.98x10^11 protons and circulating with a radial offset that can be as large as 20 mm after including orbit errors [1]. The current vacuum chamber of the 4.55 K RHIC superconducting magnets is a round, stainless steel 316LN beam pipe where the beam-induced currents could deposit almost 8 W/m, far greater than the available 0.5 W/m dynamic heat load budget. The beam pipe of the RHIC superconducting magnets will be thereby updated with a beam screen that will reduce the beam-induced currents and will suppress electron cloud [2]; still, the dynamic heat load will be close to 0.5 W/m, bringing some sections of the arc dipole NbTi coils to almost 4.9 K [3]. Arc dipoles will also need to operate at 5676 A to steer the 275 GeV beams into orbit (value computed using measured transfer functions), higher than for any RHIC beam. Operation at both higher temperatures and higher currents reduce the margin to quench. For the RHIC arc dipoles, the maximum theoretical quench limit is 5.25 K at 5676 A with a 5% weak link, thus offering a limited margin of only 0.4 K [4]. In practice, the maximum attainable operating point before quench depends on the training followed by the magnets. The maximum currents at which RHIC SC magnets had been operated prior to this test were as high as 5177 A for arc dipoles; 5172 A for focusing arc quadrupoles; and 5356 A for defocusing arc quadrupoles. The IR quadrupoles are typically operated in a range from 4600 to 5200 A.

Figure 1 shows the quench performance of all the arc dipoles, arc quadrupoles and large aperture (130 mm) insertion quadrupoles tested and trained at 4.5 K prior to installation in RHIC based on the maximum current at which they were trained [5]. Both arc dipoles and arc quadrupoles attain higher currents than those necessary for the EIC after some training. In 2011 a study on the feasibility of operating RHIC with higher energy beams predicted the number of RHIC superconducting magnets to be trained for operation with higher energy beams by statistical methods [6]. That study employed the data reported in [5]. About 8 +/- 3 training quenches were expected to bring all the arc dipoles in the two RHIC rings to the current needed for operation with a 275 GeV beam and 4 +/- 2 for the triplet quadrupoles at the nominal operating temperature of 4.55 K. This finding, together with the fact that the coil of some magnets might reach temperatures above 4.55 K, motivated the design of a test program that would evaluate the operation of the magnets in the RHIC's Yellow ring at higher currents and temperatures comparable to those expected in the EIC. Both physical variables impact the available margin to quench. The EIC will also utilize three arcs of the RHIC's Blue ring. One of these arcs will be employed as the hadron transfer line and is not expected to see heat loads as large as in the rest of the arcs.

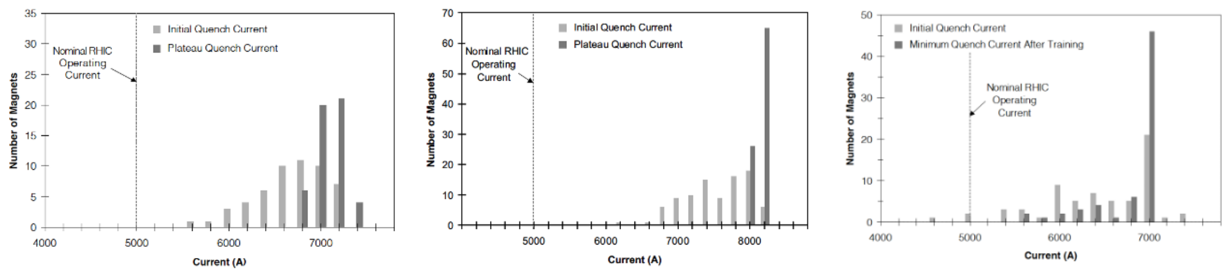


Fig. 3. Quench performance of 51 arc dipoles, tested at 4.5 K. The average plateau quench current of these 51 magnets was 7101 A; the field at this average quench current is 4.52 T.

Fig. 15. Quench performance of 91 arc quadrupoles, tested at 4.5 K. The average plateau quench current of these 91 magnets was 8152 A.

Fig. 31. Quench performance of 61 large aperture (130 mm) quadrupoles, tested at 4.5 K.

Fig. 1: Quench performance of the tested and trained arc dipoles, arc quadrupoles and large aperture (130 mm) insertion quadrupoles based on the maximum current at which they were trained [5].

Figure 2 shows the distribution of the tested and trained magnets in the different cryogenic sectors of the RHIC's Yellow ring. Not all the tested and trained magnets were installed in the Yellow ring.

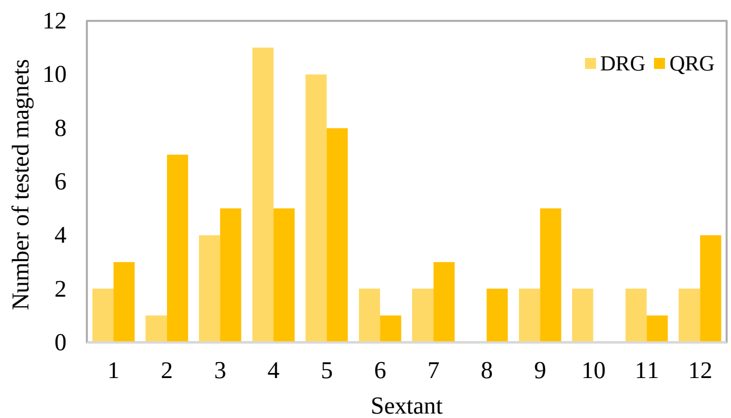


Fig. 2: Location of tested and trained arc dipoles and arc quadrupoles in the RHIC Yellow ring.

2 Method

The test took place over several days at the end of RHIC Run 21, on July 8-12, 2021, after the Blue ring was emptied to have a larger helium reserve available that would allow for a faster recovery in case of quench. Only the magnets of the Yellow ring were tested.

Test sequence

The test sequence was planned to explore first those magnets and operational scenarios that presented small chances for quench. Arc (main) quads were tested before dipoles given the reduced likelihood for arc quadrupoles to quench (based on data from [5]). The order in which sectors were tested was defined based on the number of tested and trained magnets that each sector contained. Table 1 has the settings for each step of the test sequence. Each setting was held for at least 30 minutes after the magnets had attained the maximum current.

Table 1: Test sequence

Setting	Sector	Temperature	Magnets	Ramp up to
I	All	Nominal 4.55K	Arc (main) focusing quads	5500 A
			Arc (main) defocusing quads	5750 A
II	All	Nominal 4.55K	Arc (main) dipoles	5500 A
III	All	Nominal 4.55K	Arc (main) focusing quads	5500 A
			Arc (main) defocusing quads	5750 A
			Insertion quads Q1-Q9	6000 A
IV	2/3	Elevated 4.7-4.9 K	Arc (main) dipoles	5500 A
V	4/5	Elevated 4.7-4.9 K	Arc (main) dipoles	5500 A
VI	12/1	Elevated 4.7-4.9 K	Arc (main) dipoles	5500 A
VII	12/1	Elevated 4.7-4.9 K	Arc (main) focusing quads	5500 A
			Arc (main) defocusing quads	5750 A
			Insertion quads Q1-Q9	6000 A
VIII	6/7	Elevated 4.7-4.9 K	Arc (main) dipoles	5500 A
IX	6/7	Elevated 4.7-4.9 K	Arc (main) focusing quads	5500 A
			Arc (main) defocusing quads	5750 A
			Insertion quads Q1-Q9	6000 A
X	10/11	Elevated 4.7-4.9 K	Arc (main) dipoles	5500 A
XI	10/11	Elevated 4.7-4.9 K	Arc (main) focusing quads	5500 A
			Arc (main) defocusing quads	5750 A
			Insertion quads Q1-Q9	6000 A
XII	8/9	Elevated 4.7-4.9 K	Arc (main) dipoles	5500 A
XIII	8/9	Elevated 4.7-4.9 K	Arc (main) focusing quads	5500 A
			Arc (main) defocusing quads	5750 A
			Insertion quads Q1-Q9	6000 A
XIV	4/5	Elevated 4.7-4.9 K	Arc (main) focusing quads	5500 A
			Arc (main) defocusing quads	5750 A
			Insertion quads Q1-Q9	6000 A
XV	2/3	Elevated 4.7-4.9 K	Arc (main) focusing quads	5500 A
			Arc (main) defocusing quads	5750 A
			Insertion quads Q1-Q9	6000 A

Powering of magnets

The maximum current available for testing the arc dipoles was slightly lower than what will be required for EIC operations due to limitations of the installed power supplies. The Q8/Q9 quads were powered by setting the Q8-Q9 shunt power supplies and the Qtrim power supplies to deliver 250 A each; the Q1 through Q7 were powered by setting the Q7 power supplies to 500 A. The current provided by the different supplies added on top of the main quad 5500 A power supply, as shown in Table 2. An example of the maximum current provided to the different insertion quadrupoles in a sector is shown in Fig. 3. Small variations are due to the settings of the unipolar power supplies (+2/-1 A) and measurement errors.

Table 2: Maximum current at which different magnets were tested

Arc Dipoles	Arc Quads Qf	Arc Quads Qd	Insertion Quads Q1-Q7	Insertion Quads Q8-Q9
5500 A	5500 A	5750 A (5500 A + 250 A)	6000 A (5500 A + 500 A)	6000 A (5500 A + 250 A + 250 A)

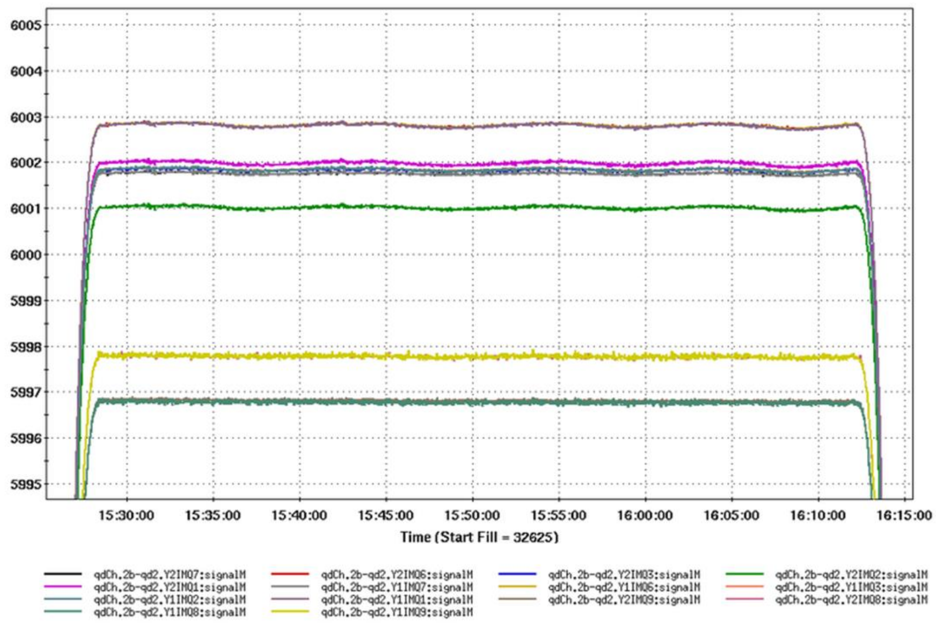


Fig. 3: Maximum currents employed to test the different insertion quadrupoles in a sector. Variations are due to the settings of the unipolar power supplies and measurement errors. (RHIC elog, July 11, 2021.)

Ramp Rate

To dissipate minimal heat in the magnet during ramp from Eddy current induced heating, the magnets were ramped up to 5040 A (dipoles) and 4640 A (quads) at roughly half of their normal rate (12 A/s and 10 A/s, respectively), and from there the ramp rate was reduced to 1 A/s for the final ramp to the target currents in Table 1. Given the short time available for these tests, the test program was designed to reduce the likeliness of early quenches that would jeopardize the completion of the program. Hence the use of a slow ramp rate and the testing of arc dipoles after arc quadrupoles. Figure 4 shows the current ramp up of arc dipoles and quadrupoles followed during this test.

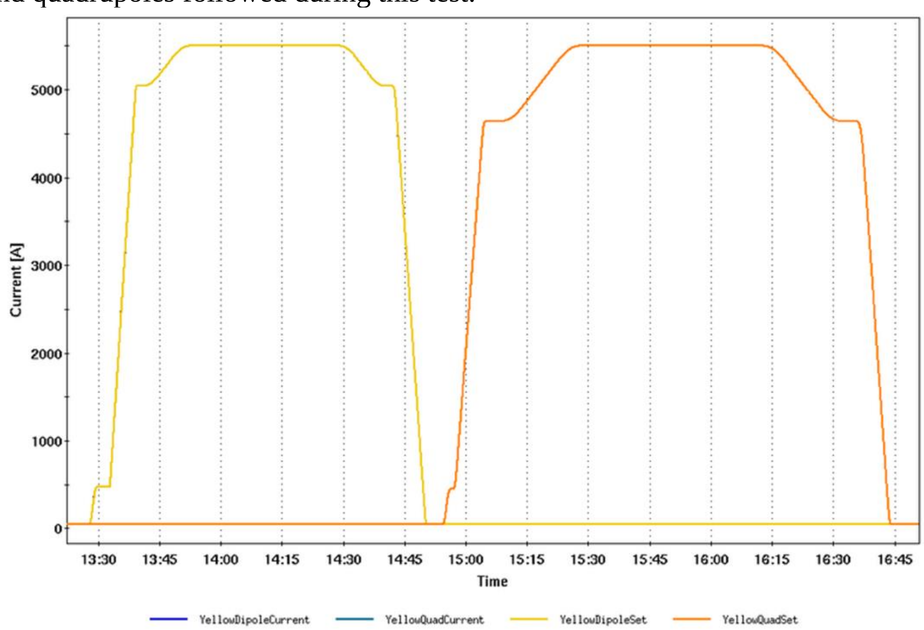


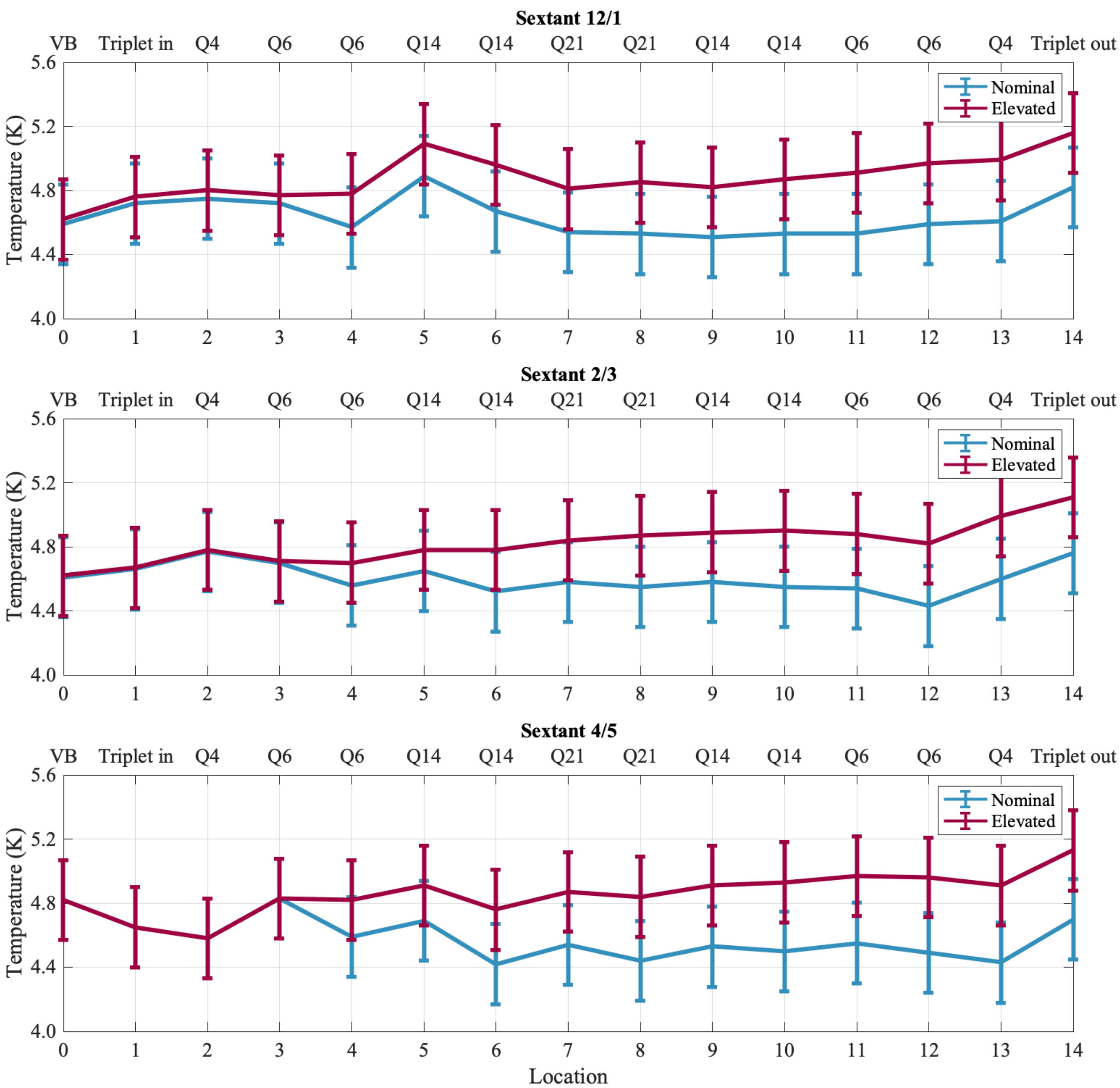
Fig. 4: Current ramp up for arc dipoles and arc quadrupoles during the test. Slower ramping rate implemented beyond the RHIC nominal currents for reduced Eddy current induced heating. (RHIC elog, July 9, 2021.)

Operation at Higher Temperature

The ring was operated at higher temperatures by switching off the 5 arc-recoolers in each sextant. Consequently, there was a temperature gradient from the beginning of the sector (cooler, around 4.55 K) to the end of the sector (warmer, around 4.9 K), with most of the magnets in a cryogenic arc (from Q4 through Q21 back to Q4) above 4.7 K. Figure 5 shows the temperature variation along each sextant during nominal (4.55 K) and elevated (4.7- 4.9 K) temperature operations. There are sensors before and after the recoolers at locations Q6 and Q14, hence the duplicated labels in Figure 5.

Temperature Sensors Accuracy

The cryogenic temperature sensors, which feature a 25 mK precision, do not have very accurate temperature calibration (standard curves can have a deviation as large as 250 mK), and each sextant has a slightly different heat load. Figure 6 shows the temperature difference between nominal and elevated temperature operations along each sextant.



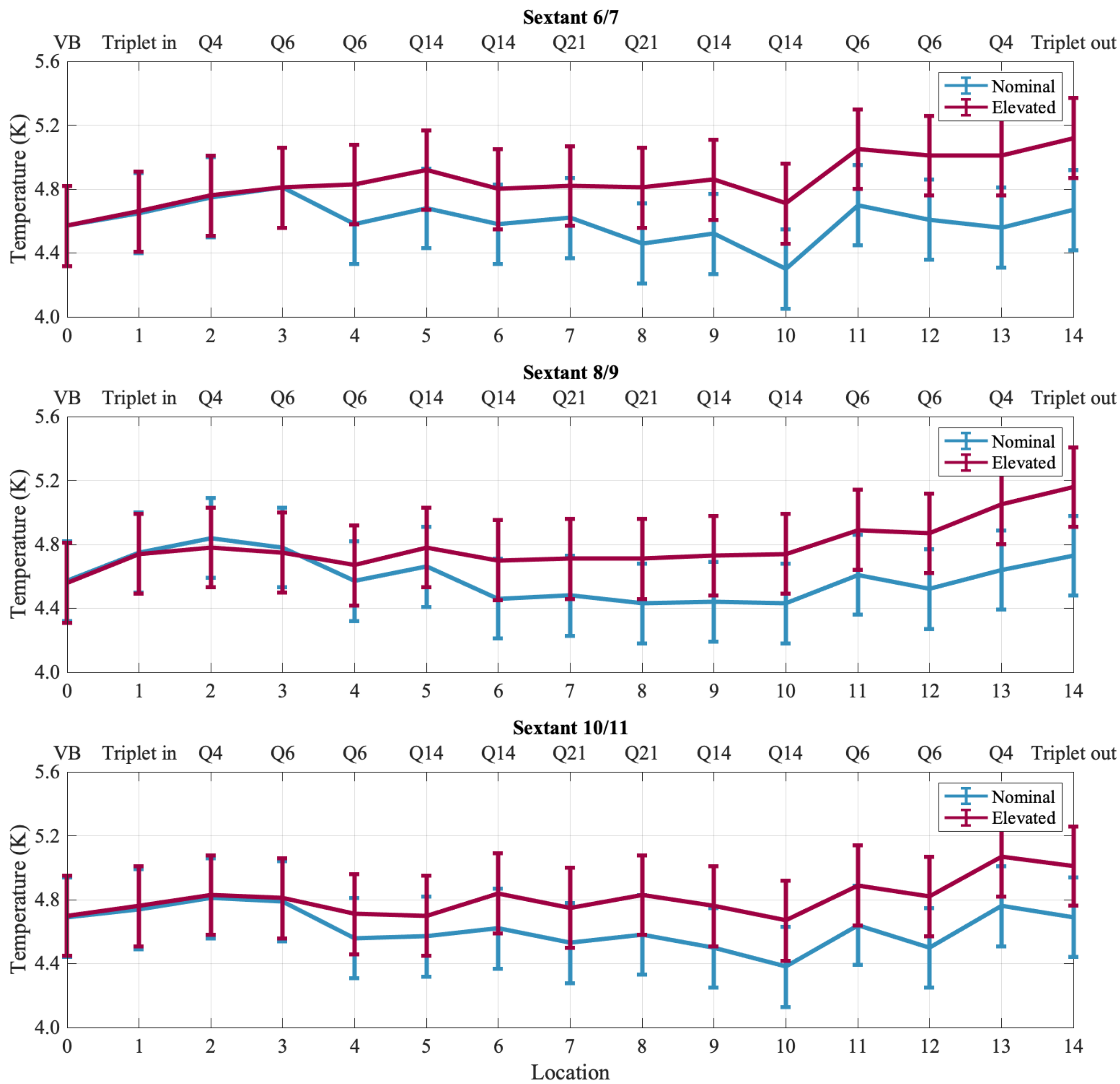


Fig. 5: Temperature along each sextant during nominal (4.55 K) and elevated (4.7 – 4.9 K) temperature operations. VB stands for valve box.

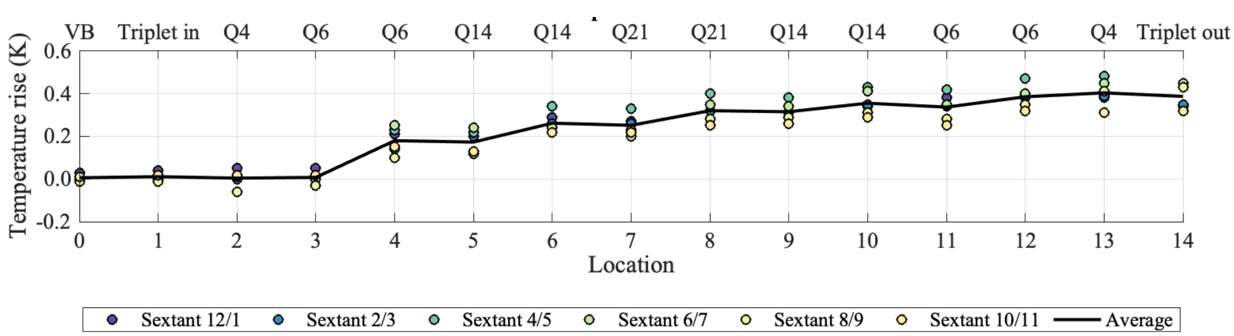


Fig. 6: Temperature rise relative to nominal (4.55 K) temperatures along each sextant.

3 Results

None of the magnets tested quenched over a period of 30 minutes or more of sustained operation at nominal (4.55 K) or elevated temperatures (4.7 – 4.9 K) at the maximum currents listed in Table 2. Table 3 summarizes the test results.

Table 3. Test results

RHIC Yellow ring magnets tested	Maximum current tested	Normal temperature 4.55 K	Elevated temperatures 4.7 - 4.9 K
All arc (main) dipoles	5500 A	No quenches	No quenches
All arc (main) focusing quads	5500 A	No quenches	No quenches
All arc (main) defocusing quads	5750 A	No quenches	No quenches
All insertion quads Q9-Q1	6000 A	No quenches	No quenches

4 Discussion and Outlook

At the end of RHIC Run 21, the arc dipoles and focusing arc quadrupoles in the RHIC Yellow ring were brought to a maximum current of 5500 A, the defocusing arc quadrupoles to 5750 A and the insertion quadrupoles Q1-Q9 to 6000 A. None of the magnets quenched after sustained operation over a period of 30 minutes or longer at these currents. The temperature of each cryogenic sextant (12/1, 2/3, 4/5, 6/7, 8/9, 10/11) was later increased by switching off the cryocoolers installed along the arcs. The temperature gradient along a cryogenic sextant varied from 4.55 to 5.15 K, with most of the arc magnets being above 4.7 K. The magnet currents were ramped again to the maximum values specified above, finding no quenches after sustained operation at these higher currents and temperatures. There is a possible different method to obtain a more uniform temperature test by turning off the valvebox recooler and controlling the arc recoolers to provide just enough cooling to keep a temperature uniformity of 0.1 K. This can be done at the end of the following run.

The successful operation at temperatures and currents comparable to those expected for the EIC suggests that the magnets might have sufficient mechanical margin for operation with EIC beams. Still, the installation of a beam screen will be needed to ensure low dynamic heat load and suppress electron cloud. The proven reliable operation of the RHIC arc dipoles at 5500 A is sufficient to steer the 268 GeV proton beams. Performance at the maximum required current of 5676 A – not possible due to power supply limitations – remains to be tested to fully prove the reliable operation with 275 GeV EIC beams and the existing cooling system. Further studies should inspect the feasibility of ramping to the maximum required currents at higher, more practical rates.

Acknowledgements

Thanks to the C-AD Power Supply group and the C-AD Cryo-Operations group for their support to conduct this test, as well as to Wolfram Fischer, Bob Lambiase, Michiko Minty and Steve Peggs (EIC, C-AD); Vadim Ptitsyn and Joe Tuozzolo (EIC); and John Escalier and George Ganetis (NSLS-II) for useful discussions.

References

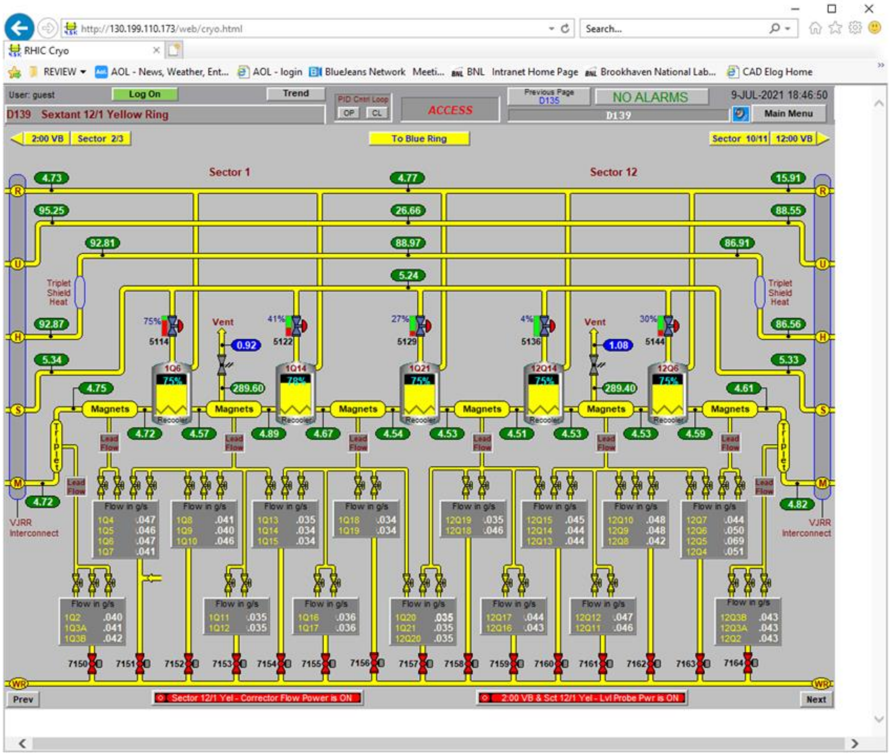
[1] F. Willeke *et al.*, "Electron-Ion Collider Conceptual Design Report". Unpublished (Feb. 2021).
[2] S. Verdú-Andrés *et al.*, "A beam screen to prepare the RHIC vacuum chamber for EIC hadron beams: conceptual design and requirements". Proc. of IPAC'2021, Campinas, Brazil (2021).
[3] S. Nayak *et al.*, "Thermal analysis of the RHIC arc dipole magnet cold mass with the EIC beam screen". Proc. of IPAC'2021, Campinas, Brazil (2021).
[4] R. Gupta, "Evaluation of RHIC magnets for EIC: higher energy and higher temperature. RHIC arc dipole (80 mm)". Unpublished (Sept. 17, 2020).
[5] M. Anerella *et al.*, "The RHIC magnet system", NIM A 499 (2003) 280-315.
[6] W. MacKey and S. Tepikian, "Energy upgrade as regards quench performance". Rep. BNL-94637-2011-TECH, Brookhaven National Laboratory, Upton, NY (2011).

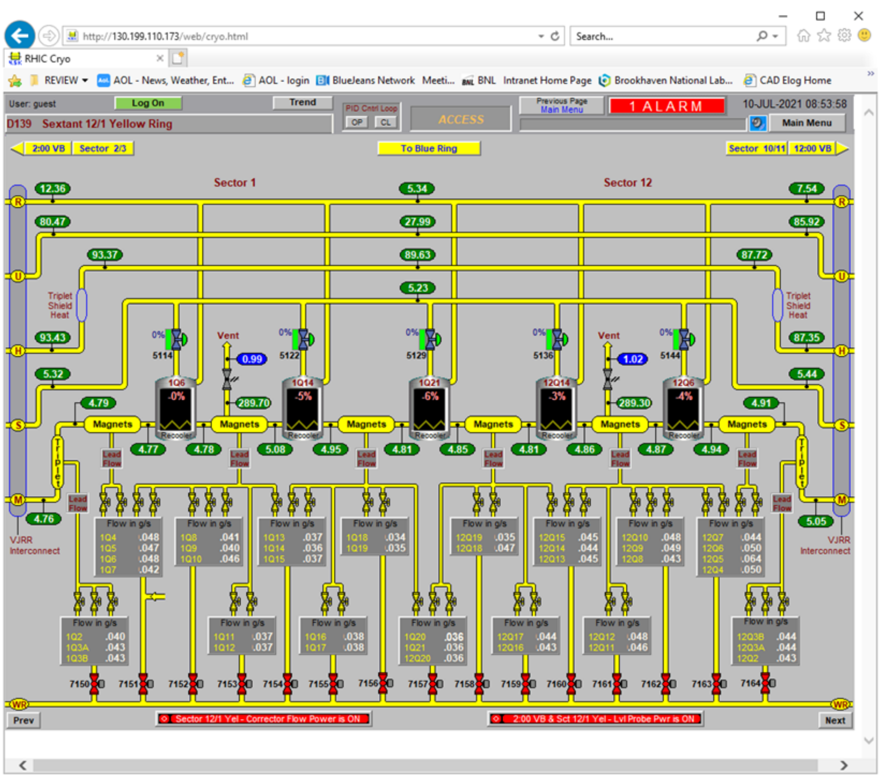
APPENDIX A: Magnet Sextant Temperature Data

Table 4: Average temperature at different locations of each sextant during operation at nominal temperatures (4.55 K) and elevated temperatures (4.7 – 4.9 K)

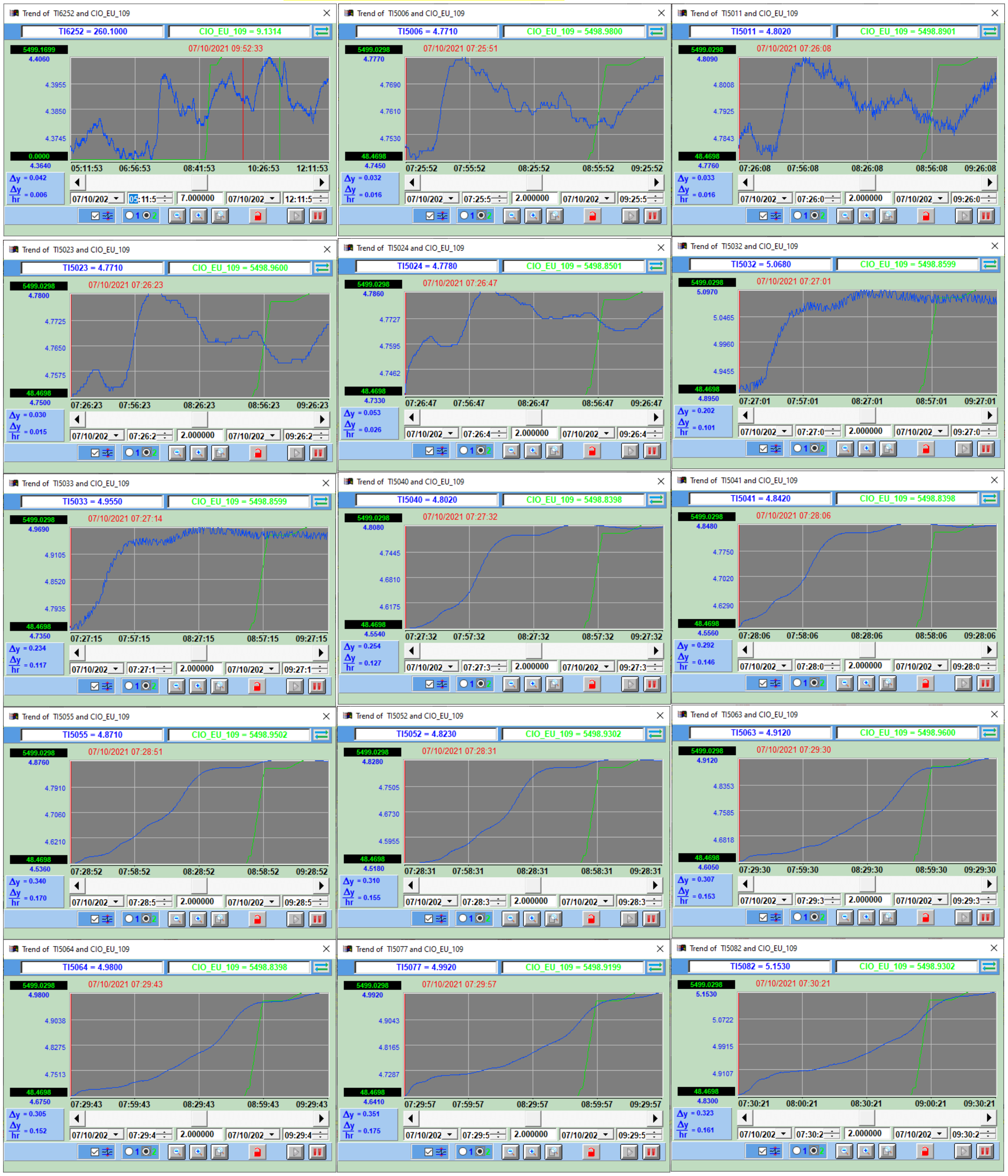
	Nominal (4.55 K)						Elevated (4.7 – 4.9 K)					
Sextant / Location	12/1	2/3	4/5	6/7	8/9	10/11	12/1	2/3	4/5	6/7	8/9	10/11
0	4.59	4.61	4.82	4.57	4.57	4.69	4.62	4.62	4.82	4.57	4.56	4.70
1	4.72	4.66	4.65	4.65	4.75	4.74	4.76	4.67	4.65	4.66	4.74	4.76
2	4.75	4.77	4.58	4.75	4.84	4.81	4.8	4.78	4.58	4.76	4.78	4.83
3	4.72	4.70	4.83	4.81	4.78	4.79	4.77	4.71	4.83	4.81	4.75	4.81
4	4.57	4.56	4.59	4.58	4.57	4.56	4.78	4.70	4.82	4.83	4.67	4.71
5	4.89	4.65	4.69	4.68	4.66	4.57	5.09	4.78	4.91	4.92	4.78	4.70
6	4.67	4.52	4.42	4.58	4.46	4.62	4.96	4.78	4.76	4.8	4.70	4.84
7	4.54	4.58	4.54	4.62	4.48	4.53	4.81	4.84	4.87	4.82	4.71	4.75
8	4.53	4.55	4.44	4.46	4.43	4.58	4.85	4.87	4.84	4.81	4.71	4.83
9	4.51	4.58	4.53	4.52	4.44	4.5	4.82	4.89	4.91	4.86	4.73	4.76
10	4.53	4.55	4.50	4.30	4.43	4.38	4.87	4.90	4.93	4.71	4.74	4.67
11	4.53	4.54	4.55	4.7	4.61	4.64	4.91	4.88	4.97	5.05	4.89	4.89
12	4.59	4.43	4.49	4.61	4.52	4.50	4.97	4.82	4.96	5.01	4.87	4.82
13	4.61	4.60	4.43	4.56	4.64	4.76	4.99	4.99	4.91	5.01	5.05	5.07
14	4.82	4.76	4.70	4.67	4.73	4.69	5.16	5.11	5.13	5.12	5.16	5.01

APPENDIX B.1: Magnet Sextant 12/1 Temperature Data

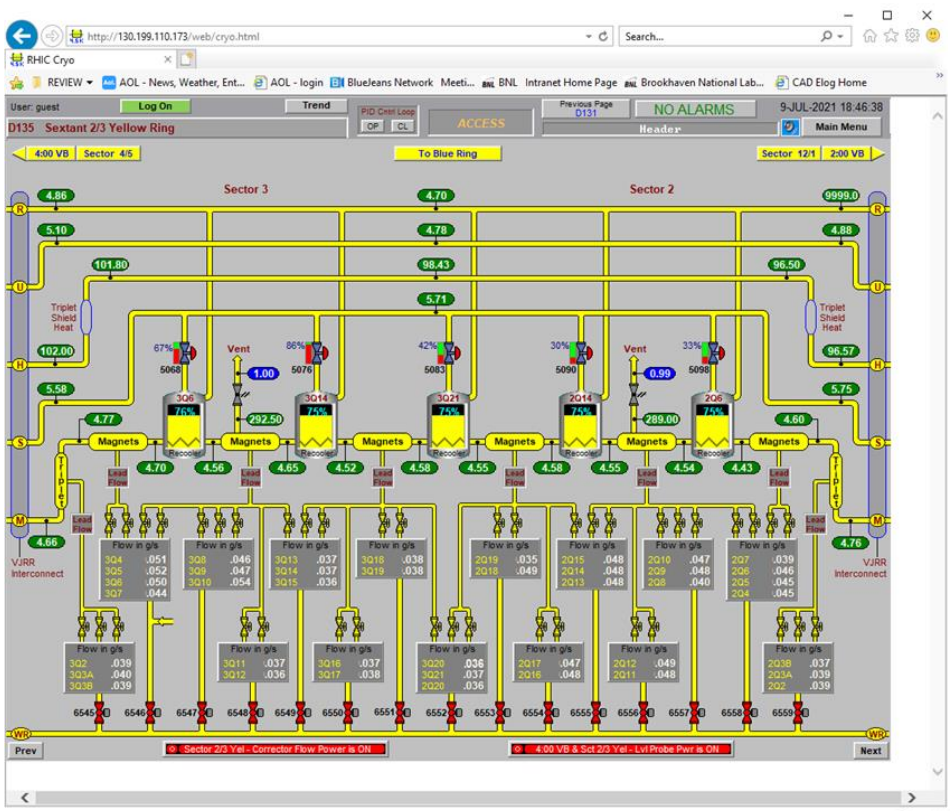


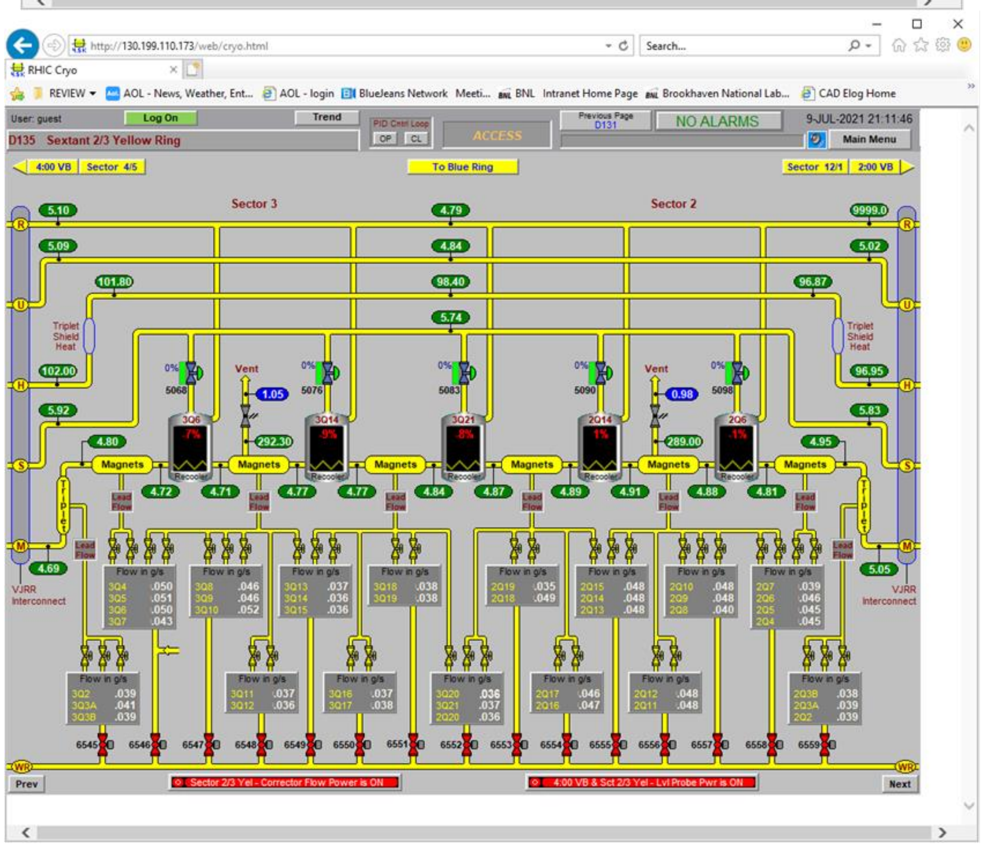


SEXTANT 12/1

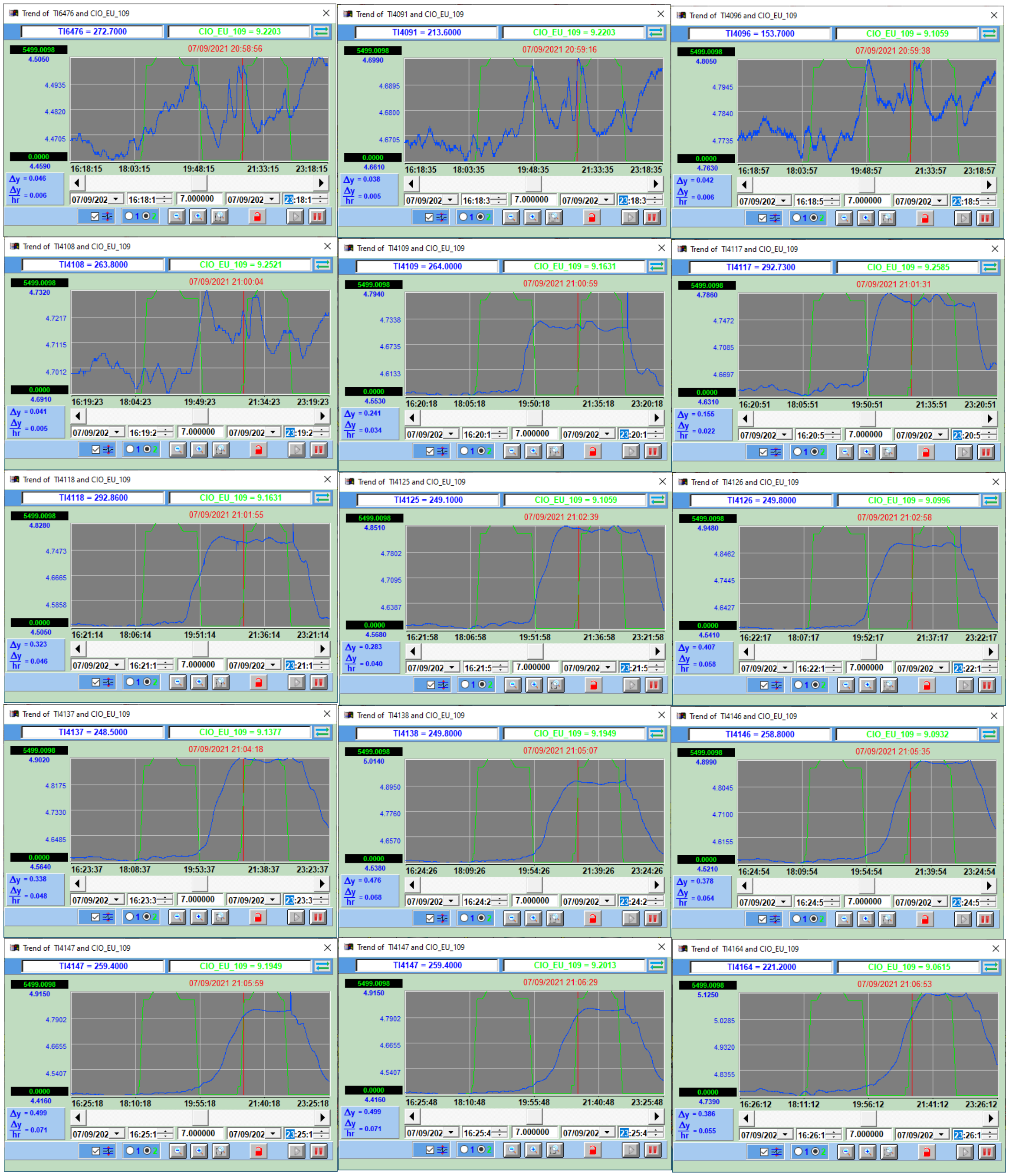

Trend of TI6252 and CIO_EU_109
TI6252 = 260.1000
CIO_EU_109 = 9.1314
07/10/2021 09:52:33
Trend of TI5006 and CIO_EU_109
TI5006 = 4.7710
CIO_EU_109 = 5498.9800
07/10/2021 07:25:51
Trend of TI5011 and CIO_EU_109
TI5011 = 4.8020
CIO_EU_109 = 5498.8901
07/10/2021 07:26:08
Trend of TI5023 and CIO_EU_109
TI5023 = 4.7710
CIO_EU_109 = 5498.9600
07/10/2021 07:26:23
Trend of TI5024 and CIO_EU_109
TI5024 = 4.7780
CIO_EU_109 = 5498.8501
07/10/2021 07:26:47
Trend of TI5032 and CIO_EU_109
TI5032 = 5.0680
CIO_EU_109 = 5498.8599
07/10/2021 07:27:01
Trend of TI5033 and CIO_EU_109
TI5033 = 4.9550
CIO_EU_109 = 5498.8599
07/10/2021 07:27:14
Trend of TI5040 and CIO_EU_109
TI5040 = 4.8020
CIO_EU_109 = 5498.8398
07/10/2021 07:27:32
Trend of TI5041 and CIO_EU_109
TI5041 = 4.8420
CIO_EU_109 = 5498.8398
07/10/2021 07:28:06
Trend of TI5055 and CIO_EU_109
TI5055 = 4.8710
CIO_EU_109 = 5498.9502
07/10/2021 07:28:51
Trend of TI5052 and CIO_EU_109
TI5052 = 4.8230
CIO_EU_109 = 5498.9302
07/10/2021 07:28:31
Trend of TI5063 and CIO_EU_109
TI5063 = 4.9120
CIO_EU_109 = 5498.9600
07/10/2021 07:29:30
Trend of TI5064 and CIO_EU_109
TI5064 = 4.9800
CIO_EU_109 = 5498.8398
07/10/2021 07:29:43
Trend of TI5077 and CIO_EU_109
TI5077 = 4.9920
CIO_EU_109 = 5498.9199
07/10/2021 07:29:57
Trend of TI5082 and CIO_EU_109
TI5082 = 5.1530
CIO_EU_109 = 5498.9302
07/10/2021 07:30:21

APPENDIX B.2: Magnet Sextant 2/3 Temperature Data



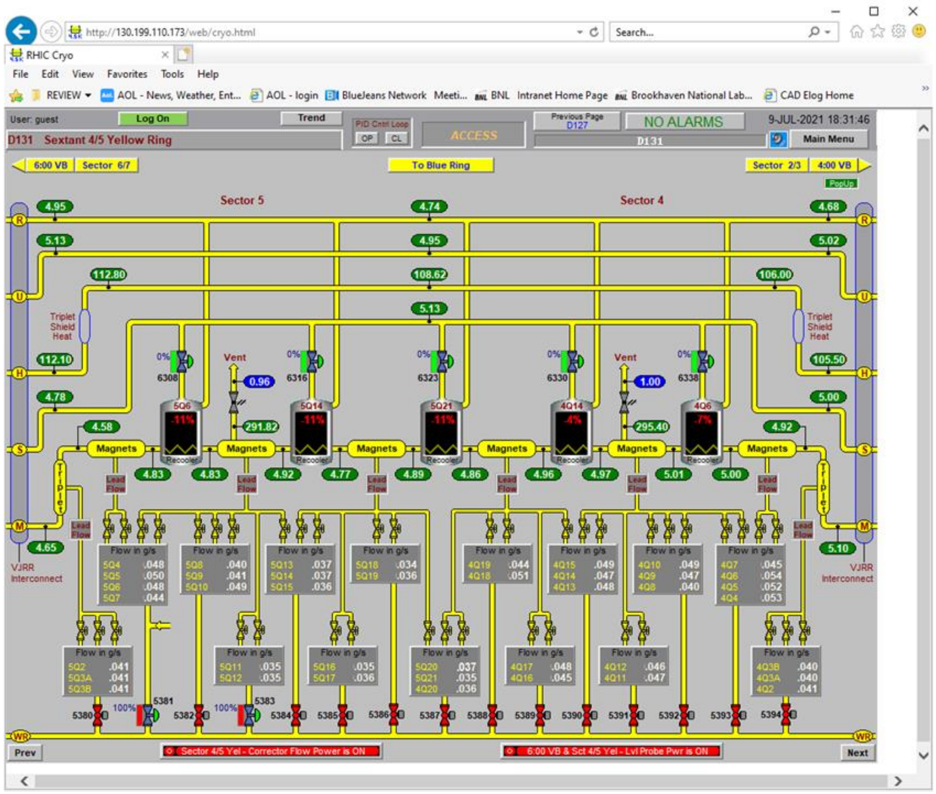


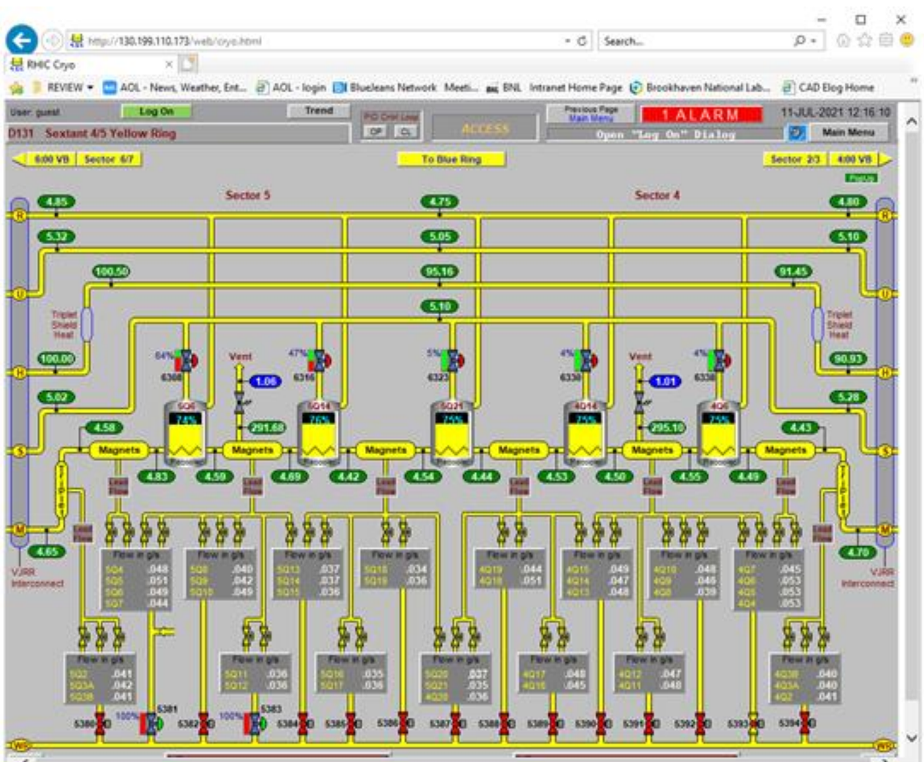
SEXTANT 2/3



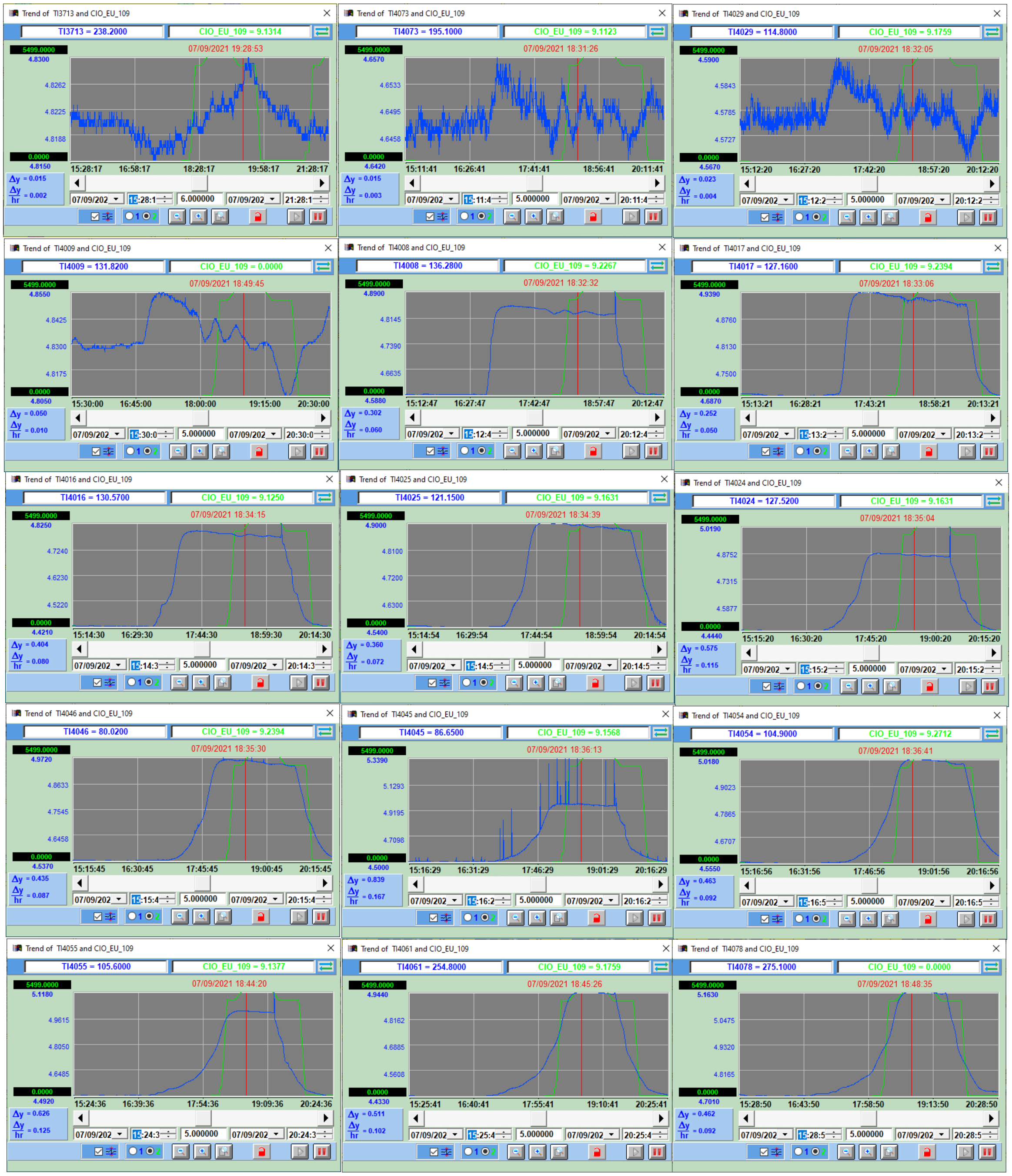
Trend of TI6476 and CIO_EU_109
TI6476 = 272.7000
CIO_EU_109 = 9.2203
Trend of TI4091 and CIO_EU_109
TI4091 = 213.6000
CIO_EU_109 = 9.2203
Trend of TI4096 and CIO_EU_109
TI4096 = 153.7000
CIO_EU_109 = 9.1059
Trend of TI4108 and CIO_EU_109
TI4108 = 263.8000
CIO_EU_109 = 9.2521
Trend of TI4109 and CIO_EU_109
TI4109 = 264.0000
CIO_EU_109 = 9.1631
Trend of TI4117 and CIO_EU_109
TI4117 = 292.7300
CIO_EU_109 = 9.2585
Trend of TI4118 and CIO_EU_109
TI4118 = 292.8600
CIO_EU_109 = 9.1631
Trend of TI4125 and CIO_EU_109
TI4125 = 249.1000
CIO_EU_109 = 9.1059
Trend of TI4126 and CIO_EU_109
TI4126 = 249.8000
CIO_EU_109 = 9.0996
Trend of TI4137 and CIO_EU_109
TI4137 = 248.5000
CIO_EU_109 = 9.1377
Trend of TI4138 and CIO_EU_109
TI4138 = 249.8000
CIO_EU_109 = 9.1949
Trend of TI4146 and CIO_EU_109
TI4146 = 258.8000
CIO_EU_109 = 9.0932
Trend of TI4147 and CIO_EU_109
TI4147 = 259.4000
CIO_EU_109 = 9.1949
Trend of TI4147 and CIO_EU_109
TI4147 = 259.4000
CIO_EU_109 = 9.2013
Trend of TI4164 and CIO_EU_109
TI4164 = 221.2000
CIO_EU_109 = 9.0615

APPENDIX B.3: Magnet Sextant 4/5 Temperature Data



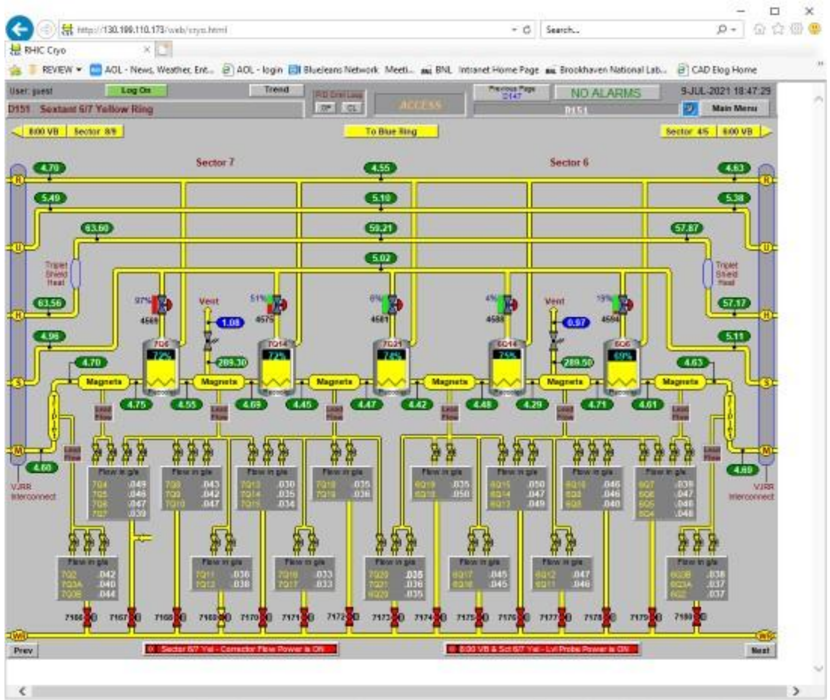


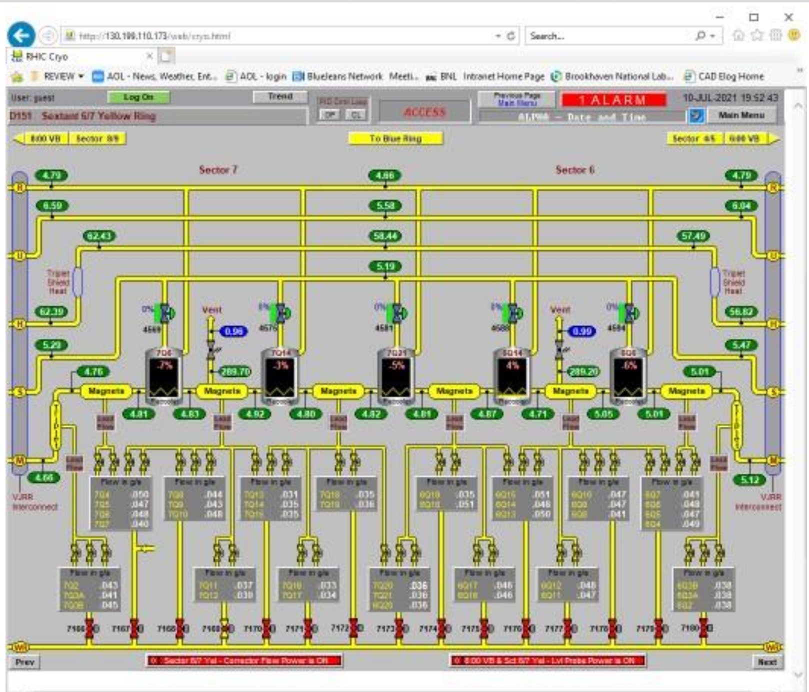
SEXTANT 4/5



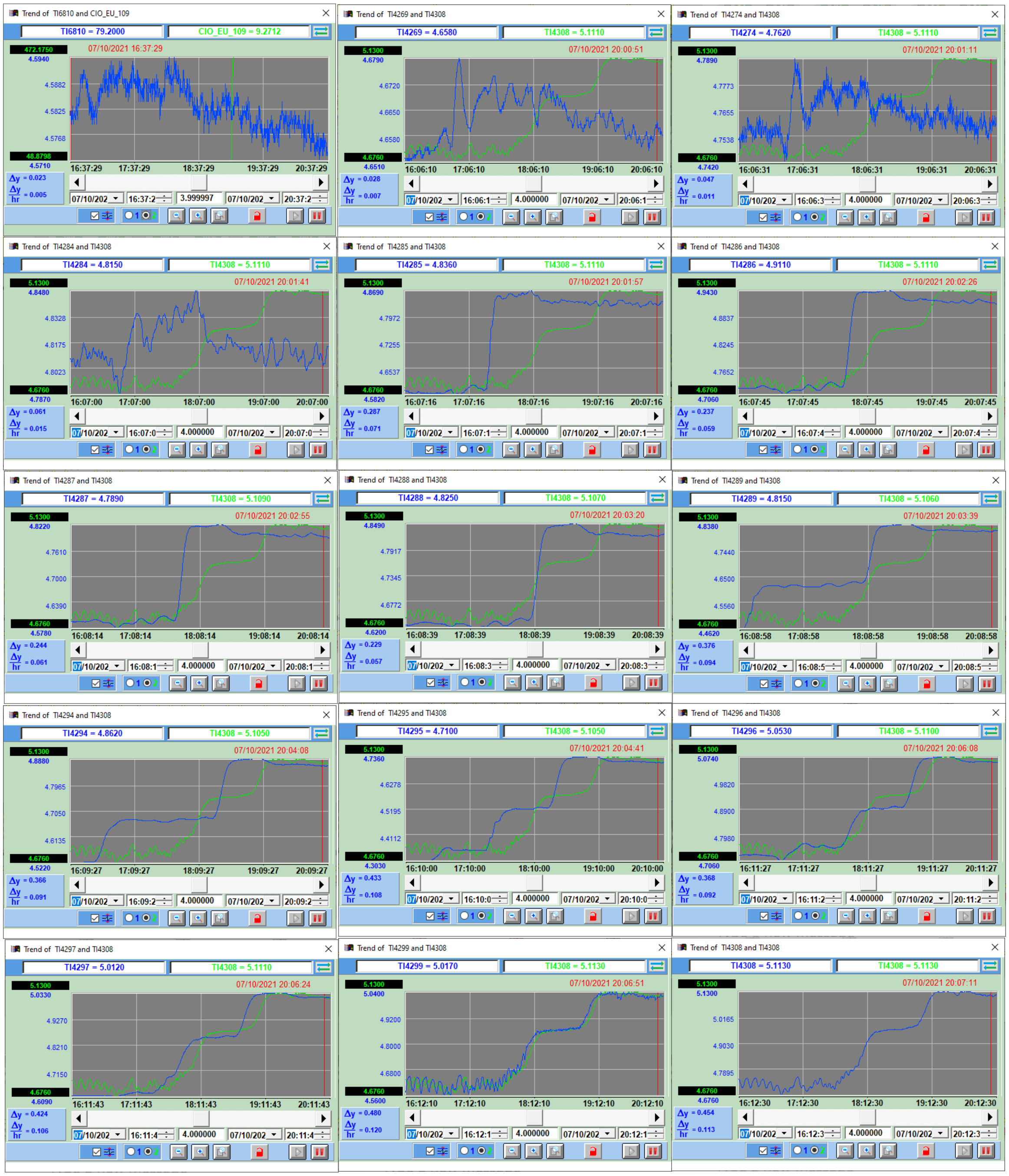
Trend of TI3713 and CIO_EU_109
TI3713 = 238.2000
CIO_EU_109 = 9.1314
07/09/2021 19:28:53
Trend of TI4073 and CIO_EU_109
TI4073 = 195.1000
CIO_EU_109 = 9.1123
07/09/2021 18:31:26
Trend of TI4029 and CIO_EU_109
TI4029 = 114.8000
CIO_EU_109 = 9.1759
07/09/2021 18:32:05
Trend of TI4009 and CIO_EU_109
TI4009 = 131.8200
CIO_EU_109 = 0.0000
07/09/2021 18:49:45
Trend of TI4008 and CIO_EU_109
TI4008 = 136.2800
CIO_EU_109 = 9.2267
07/09/2021 18:32:32
Trend of TI4017 and CIO_EU_109
TI4017 = 127.1600
CIO_EU_109 = 9.2394
07/09/2021 18:33:06
Trend of TI4016 and CIO_EU_109
TI4016 = 130.5700
CIO_EU_109 = 9.1250
07/09/2021 18:34:15
Trend of TI4025 and CIO_EU_109
TI4025 = 121.1500
CIO_EU_109 = 9.1631
07/09/2021 18:34:39
Trend of TI4024 and CIO_EU_109
TI4024 = 127.5200
CIO_EU_109 = 9.1631
07/09/2021 18:35:04
Trend of TI4046 and CIO_EU_109
TI4046 = 80.0200
CIO_EU_109 = 9.2394
07/09/2021 18:35:30
Trend of TI4045 and CIO_EU_109
TI4045 = 86.6500
CIO_EU_109 = 9.1568
07/09/2021 18:36:13
Trend of TI4054 and CIO_EU_109
TI4054 = 104.9000
CIO_EU_109 = 9.2712
07/09/2021 18:36:41
Trend of TI4055 and CIO_EU_109
TI4055 = 105.6000
CIO_EU_109 = 9.1377
07/09/2021 18:44:20
Trend of TI4061 and CIO_EU_109
TI4061 = 254.8000
CIO_EU_109 = 9.1759
07/09/2021 18:45:26
Trend of TI4078 and CIO_EU_109
TI4078 = 275.1000
CIO_EU_109 = 0.0000
07/09/2021 18:48:35

APPENDIX B.4: Magnet Sextant 6/7 Temperature Data

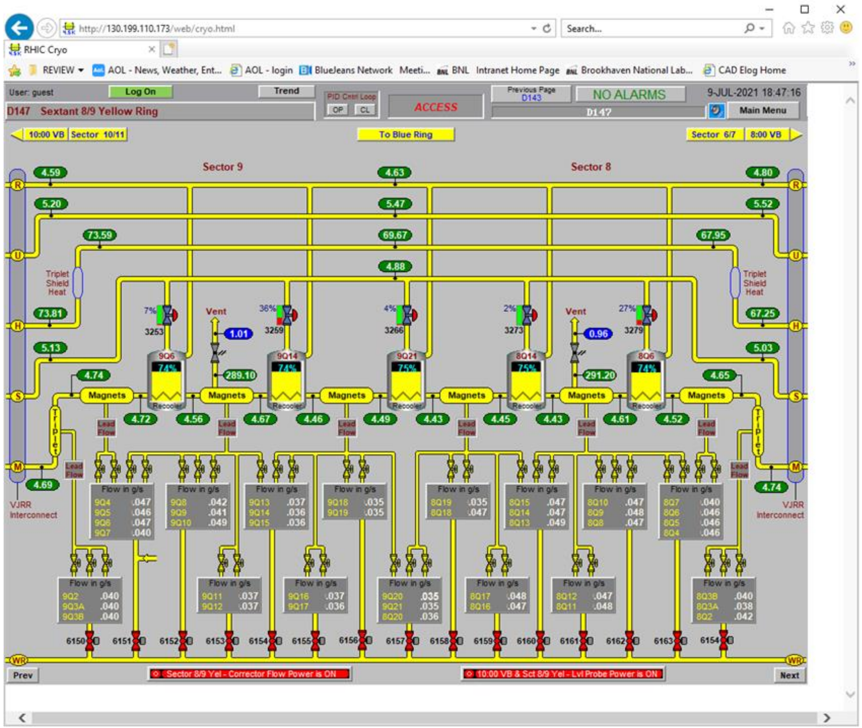


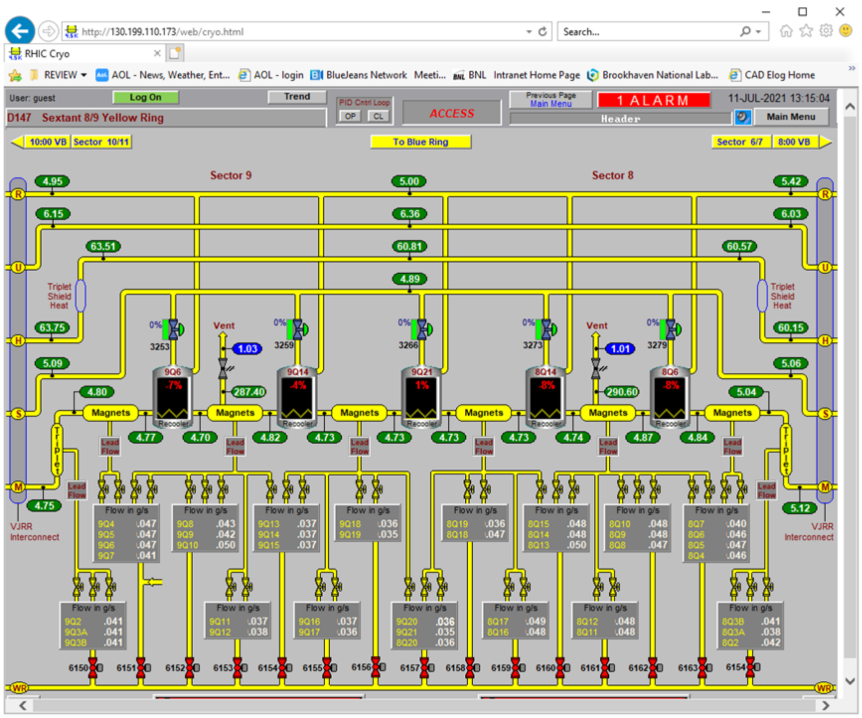


SEXTANT 6/7

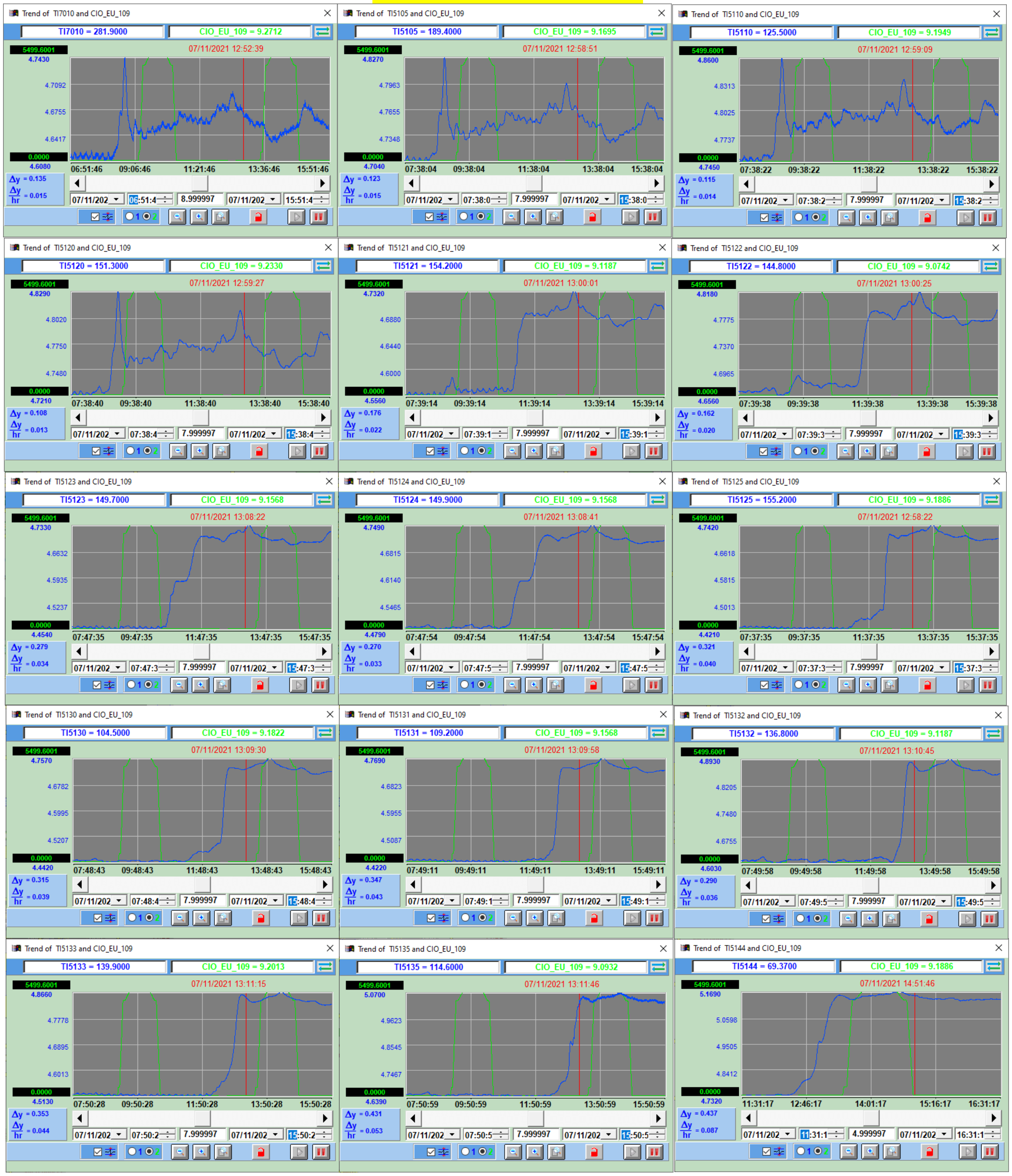

Trend of TI6810 and CIO_EU_109
Trend of TI4269 and TI4308
Trend of TI4274 and TI4308
Trend of TI4284 and TI4308
Trend of TI4285 and TI4308
Trend of TI4286 and TI4308
Trend of TI4287 and TI4308
Trend of TI4288 and TI4308
Trend of TI4289 and TI4308
Trend of TI4294 and TI4308
Trend of TI4295 and TI4308
Trend of TI4296 and TI4308
Trend of TI4297 and TI4308
Trend of TI4299 and TI4308
Trend of TI4308 and TI4308

APPENDIX B.5: Magnet Sextant 8/9 Temperature Data



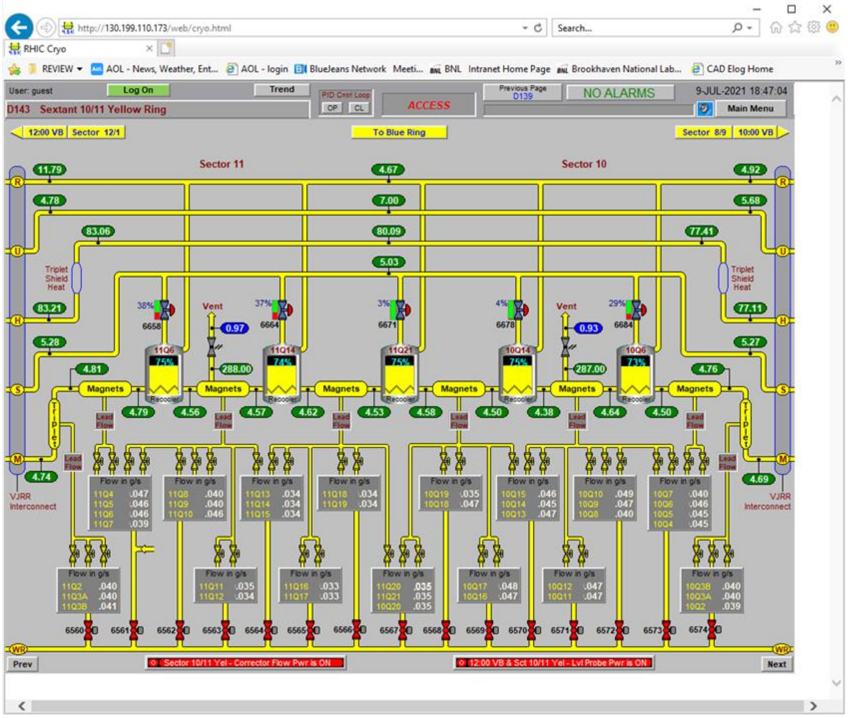


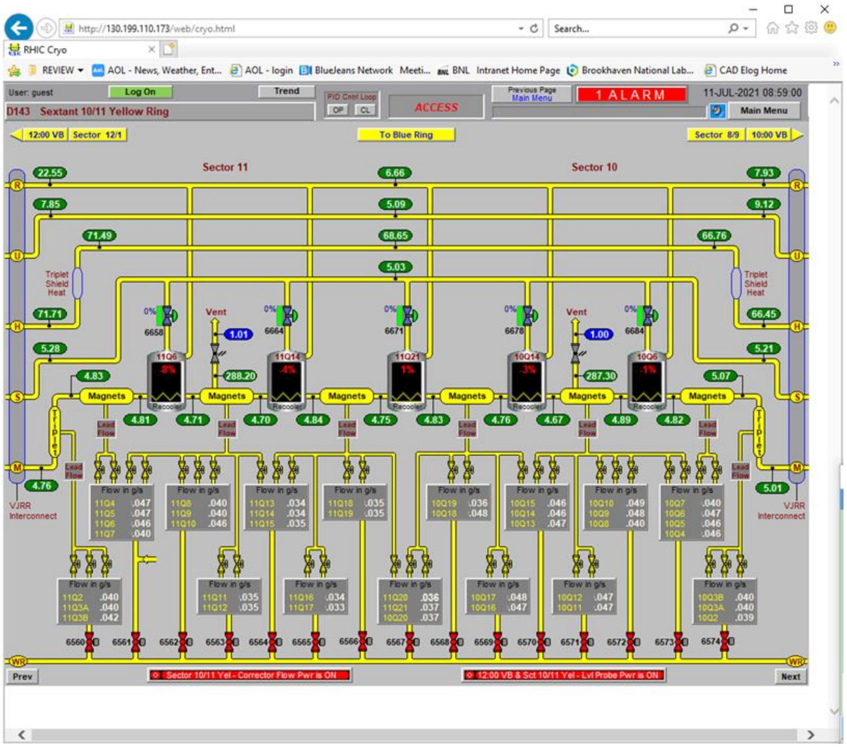
SEXTANT 8/9



Trend of TI7010 and CIO_EU_109
TI7010 = 281.9000
CIO_EU_109 = 9.2712
07/11/2021 12:52:39
Trend of TI5105 and CIO_EU_109
TI5105 = 189.4000
CIO_EU_109 = 9.1695
07/11/2021 12:58:51
Trend of TI5110 and CIO_EU_109
TI5110 = 125.5000
CIO_EU_109 = 9.1949
07/11/2021 12:59:09
Trend of TI5120 and CIO_EU_109
TI5120 = 151.3000
CIO_EU_109 = 9.2330
07/11/2021 12:59:27
Trend of TI5121 and CIO_EU_109
TI5121 = 154.2000
CIO_EU_109 = 9.1187
07/11/2021 13:00:01
Trend of TI5122 and CIO_EU_109
TI5122 = 144.8000
CIO_EU_109 = 9.0742
07/11/2021 13:00:25
Trend of TI5123 and CIO_EU_109
TI5123 = 149.7000
CIO_EU_109 = 9.1568
07/11/2021 13:08:22
Trend of TI5124 and CIO_EU_109
TI5124 = 149.9000
CIO_EU_109 = 9.1568
07/11/2021 13:08:41
Trend of TI5125 and CIO_EU_109
TI5125 = 155.2000
CIO_EU_109 = 9.1886
07/11/2021 12:58:22
Trend of TI5130 and CIO_EU_109
TI5130 = 104.5000
CIO_EU_109 = 9.1822
07/11/2021 13:09:30
Trend of TI5131 and CIO_EU_109
TI5131 = 109.2000
CIO_EU_109 = 9.1568
07/11/2021 13:09:58
Trend of TI5132 and CIO_EU_109
TI5132 = 136.8000
CIO_EU_109 = 9.1187
07/11/2021 13:10:45
Trend of TI5133 and CIO_EU_109
TI5133 = 139.9000
CIO_EU_109 = 9.2013
07/11/2021 13:11:15
Trend of TI5135 and CIO_EU_109
TI5135 = 114.6000
CIO_EU_109 = 9.0932
07/11/2021 13:11:46
Trend of TI5144 and CIO_EU_109
TI5144 = 69.3700
CIO_EU_109 = 9.1886
07/11/2021 14:51:46

APPENDIX B.6: Magnet Sextant 10/11 Temperature Data





SEXTANT 10/11