ii. System Configuration

The total length of cold bore and insulating vacuum for both RHIC rings is ~6.4 km, divided into 12 arc sections and 24 triplet sections. Each 494m arc section consists of a continuous cryostat (without vacuum barriers), housing 64 super-conducting magnets interconnected to form a continuous cold beam tube. The two adjacent triplet magnet strings reside within a common cryostat due to their proximity. The total length of warm bore is approximately 1.2 km, making up roughly 16% of the RHIC circumference. It consists of the 24 Q3-Q4 insertion regions each 34m in length and located between each of the 494m arcs and the triplets, the 12 DX-D0 final focusing regions of 11m each (including the warm bore of the superconducting DX magnets) and the six interaction regions (called IR) of 17m each. There are also two short warm sections between Q7 and Q8 and between Q9 and D9 in each ring for injection lambertson and kicker magnets, respectively. Each warm section is isolatable from the adjacent cold bore sections with the RF-shielded all-metal gate valves mounted on the warm-to-cold transitions. Additional gate valves are also installed at some warm sections to isolate and protect special beam components, such as dump kickers, RF cavities and polarimeters. Figure 4-2 shows a vacuum hardware representation of one-twelfth of the entire ring, including the special beam injection sections at YO5 and BO6.

Warm-Bore Sections

Most warm sections have 12 cm φ beam pipes, made of 304L stainless steel. A list of various beam and diagnostic components residing in warm bore sections is given in Table 4-1. The warm sections are pumped by ion pumps and titanium sublimation pumps (TSP), and monitored with inverted magnetron type cold cathode gauges (CCG) at approximately 16 m interval. Partial pressure analyzers (PPA) are installed in selected warm bore sections, as listed in Table 4-2, to measure the residual gas compositions. Most warm sections are in-situ bake-able up to 250°C including the DX and DX-D0 beam pipes, and at somewhat lower temperature for the experimental region beam pipes. Most warm bore components have been degassed at 350^{o}C in a vacuum furnace prior to installation. Due to the proximity of the IR detectors, the DX beam pipes and sections of the DX-D0 chambers were vacuum fired at 950°C prior to assembly. This reduces the hydrogen content, thus the outgassing and the background to the detectors. The warm sections typically reach vacuum of low 10^{-9} Torr a few weeks after pump down from atmosphere. To achieve the designed vacuum of low 10^{-10} Torr, most warm bore sections have been in-situ baked up to 250^{o}C for 48 hours. In-situ bake is accomplished with custom heating blankets fitted around the pipes and other components, and monitored and controlled with integrated industrial temperature controllers. A local PC is used to down load the bakeout profile to the temperature controllers and to log the temperature data during bake. It usually takes 1-2 weeks, depending on the complexity of the section, to set up the bake and one week to execute the bake. Pressure of low 10^{-11} Torr has been routinely achieved after a successful in-situ bake.

Pressure rise of a few decades have been observed at all warm bore regions during recent high intensity operations with shorter bunch spacing, resulted from beam induced desorption and electron cloud induced desorption. This pressure rise has caused high beam loss as well as high detector background. To study and combat the pressure rise, electron detectors and solenoids have been designed and installed at selective locations as given in Table 4-2. The electron detectors consist of an anode shielded by two repelling/retarding grid electrodes to allow the measurement of the electron energy spectra. The detector is well shielded by a screen from beam image current. The overall efficiency of the detectors is measured to be 7 ± 2%. The solenoids consist of gage #10 PVC or Kapton insulated wire spirally wound around the bean pipes with ~ 200 turns per meter. Commercial DC power supplies of 40V x 30A are used to power each 4m long solenoid resulted in a 2.7 gauss/amp axial field. This field will confine the electrons near the pipe surface on a spiral orbit of a few mm in radii without hitting the pipe surface, thus reduce the secondary electrons and multi-pacting. Non-Evaporable-Getter (NEG) coated beam pipes have been installed at standard 12 cm φ insertion regions, with a total length of 250m, ~ 50% of the possible length of 500m. The location and length of the NEG coated warm bore pipes are listed in Table 4-2. The low activation temperature Zr-V-Ti alloy NEG coating developed by CERN is applied to the pipe surface using magnetron sputtering, by a vendor licensed by CERN. NEG coated surface has lower secondary electron emission as compared with stainless steel surface, therefore increases the electron cloud threshold. If properly activated, NEG surface has very low electron stimulated desorption and provides very large linear pumping speed, thus further reduces the pressure rise.

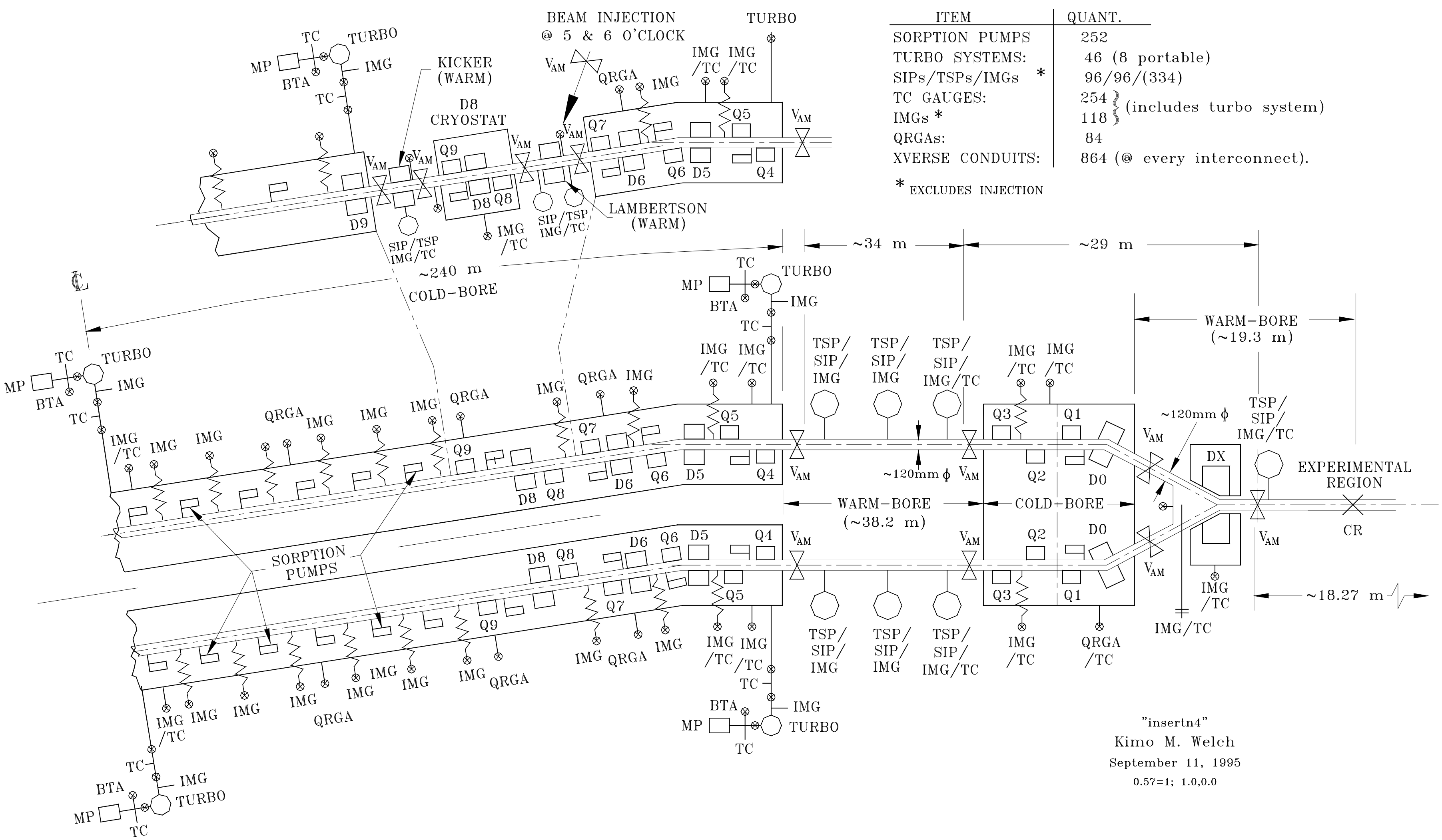

Fig. 4-2. Vacuum instrumentation and pumping for one twelfth of RHIC machine.

Table 4-1. Locations of Warm Space Beam Components in RHIC Rings

Sector #	S(m)	L(m)
YO1		
Quad Pickup	40.00	0.25
PLL Kicker	40.63	1.00
Head-Tail Pickup	41.96	1.00
Pickup	42.58	0.25
PLL Kicker	43.21	1.00
Tune Kicker - H	45.15	2.00
Tune Kicker - H	47.15	2.00
Lum. Monitor	52.94	0.33
IPM - V	54.45	1.17
Roman Pot	56.66	0.51
Roman Pot	59.54	0.51
IPM - H	70.74	1.17
BI1		
Movable BPM(2)	40.91	0.38
Kicker	43.42	0.25
ANL Electron Detector	45.64	
TuneK-V+Gap Cleaning K.	52.26	2.00
TuneK-V+Gap Cleaning K.	54.26	2.00
YI2		
Movable BPM(2)	40.94	0.38
Kicker	43.45	0.25
TuneK-V+Gap Cleaning K.	52.16	2.00
TuneK-V+Gap Cleaning K.	54.16	2.00
Button BPM	66.88	0.50
WCM	67.63	1.00
DCCT	68.38	0.50
m Schottky	69.13	1.00

Sector #	S(m)	L(m)
BO2		
ANL Electron Det	39.57	
Quad Pickup	40.00	0.25
PLL Kicker	40.63	1.00
Head-Tail Pickup	41.96	1.00
Pickup	42.58	0.25
PLL Kicker	43.21	1.00
Tune Kicker - H	45.15	2.00
Tune Kicker - H	47.15	2.00
Lum. Monitor	52.94	0.33
IPM - V	54.45	1.17
Roman Pot	56.66	0.51
Roman Pot	59.54	0.51
Button BPM	66.88	0.50
WCM	67.63	1.00
DCCT	68.38	0.50
m Schottky	69.13	1.00
IPM - H	70.83	1.17
IR4		
AC Dipole	4.36	1.35
AC Dipole	2.86	1.35
AC Quad	1.14	1.56
WCM	0.00	0.50
Comm Cavities	5.43	0.74

Sector #	S(m)	L(m)
YO4		
WCM	40.30	0.50
Accel Cavity	46.69	2.93
Accel Cavity	49.93	2.93
Sto Cavities (3)	53.50	0.74
Landau Cavity	60.83	0.74
BPM	69.17	0.42
Cooling Pickup-LF	69.76	0.60
Cooling Kicker- HF	70.64	0.60
BPM	71.24	0.42
BI4		
WCM	38.98	0.50
Accel Cavity	41.42	2.93
Accel Cavity	44.66	2.93
Sto Cavities (3)	56.40	0.74
Landau Cavity	61.74	0.74
YO5		
Warm Dipoles	52, 55	0.6
Lambertson	121.90	
Injection Kickers	146.60	5.70
YI6		
Collimator - V	44.2	0.53
BO6		
Lambertson	121.90	
Injection Kickers	146.60	5.70

Sector #	S(m)	L(m)
YI7		
Collimator-H+V	41.32	0.53
Collimator - H	51.09	0.53
Collimator - V	57.26	0.53
Collimator - H	58.28	0.53
BI8		
Collimator-H+V	41.32	0.53
Collimator - H	51.09	0.53
Collimator - V	57.26	0.53
Collimator - H	58.28	0.53
YO9		
Dump Kicker	42.45	7.24
BPM	51.75	0.38
Dump	69.06	4.87
BO10		
Dump Kicker	42.45	7.24
BPM	51.75	0.38
Collimator - V	63.14	0.53
Dump	69.06	4.87
YI11		
Cooling Pickup	70.96	0.60
IR12		
Gas Jet	0.00	0.62
Shutter-1	6.23	0.07
Shutter-2	6.56	0.07
Shutter-2	6.89	0.07
YO12		
Polarimeter	70.68	1.60
BI12		
Polarimeter	71.19	1.60

S: distance to nearby IP

L: chamber length

Table 4-2. Locations of RHIC NEG Coated Pipes, Solenoids, Electron Detectors, PPAs,….

NEG Coated Pipes

Sect #	L(m)	S(m) to IP
YO1	3.95	48 - 52
	1.7	57 - 59
	5.2	60 - 65
	4.05	66 - 70
YI2	1.23	39 - 40
	1.61	41 - 43
	5.2	44 - 49
	1.45	49 - 51
	4.93	56 - 61
	5.2	61 - 66
	1.9	70 - 72
BO2	3.95	48 - 52
	1.7	57 - 59
	5.2	61 - 66
YO4	5.2	62 - 67
	1.94	67 - 69
BI5	5.2	39 - 44
	3.1	44 - 47
	5.2	49 - 54
	5.2	54 - 59
YI6	4.14	39 - 43
	2.77	45 - 48
	5.2	49 - 54
	5.2	54 - 59
IP6	2.79	4 - 7
	2.79	4 - 7
BO7	5.2	39 - 44
	3.1	44 - 47
	5.2	49 - 54
	5.2	54 - 59

Sect #	L(m)	S(m) to IP
YO8	5.2	39 - 44
	3.1	44 - 47
	5.2	49 - 54
	5.2	54 - 59
BI8	1.24	39 - 40
	5.2	42 - 47
	1.78	48 - 50
	4.17	52 - 56
BI9	5.2	40 - 45
	5.2	45 - 50
	5.2	50 - 55
	5.2	56 - 61
	5.2	61 - 66
	5.2	66 - 71
BO10	3.41	59 - 62
YI10	5.2	40 - 45
	5.2	45 - 50
	5.2	50 - 55
	5.2	56 - 61
	5.2	61 - 66
	5.2	66 - 71
BO11	5.2	40 - 45
	5.2	45 - 50
	5.2	50 - 55
	5.2	56 - 61
	5.2	61 - 66
	5.2	66 - 71
IP12	5.2	2 - 7
	3.7	2 - 5

Solenoids

SL ADO	S(m) to IP	L(m)
yo1-sl-pw3.1	49.7	2.5
yo1-sl-pw3.2	65.6	2 + 2
bi1-sl-pw3.1	46.8	4
bi1-sl-pw3.2	69.0	4.2
yi2-sl-pw3.1	48.2	3 + 1
bo2-sl-pw3.1	50.3	3
g1-sl-pwx	5.3	2.3
g2-sl-pwx	5.3	2.3
yo4-sl-pw3.3	66.6	4.2
g9-sl-pwx	7.0	~1
g10-sl-pwx	7.0	~1
yo12-sl-pw3.1	50.0	2 + 2
bi12-sl-pw3.1.1	42.4	4
bi12-sl-pw3.1.2	48.1	3.2
bi12-sl-pw3.1.3	52.1	4
bi12-sl-pw3.2.1	58.1	4
bi12-sl-pw3.2.2	63.6	4
bi12-sl-pw3.2.3	67.8	3
g11-sl-pwx.2	3.4	4
g12-sl-pwx	3.5	3

Anti-Grazing Ridges

Sector #	S(m) to IP	ID(cm)
BI5, YO5	39.4	11
	44.5	10
	47.6	10
	53.8	10
	59	10

Electron Detectors

ED ADO	S(m) to IP
yo1-eld-pw3.1.v	48.3
yo1-eld-pw3.2-.v	65.6
bi1-eld-pw3.1.h	45.2
bi1-eld-pw3.1.v	45.4
bi1-ANL ED.h	45.6
bi1-eld-pw3.2.v	71.3
yi2-eld-pw3.1.v	49.3
bo2-ANL ED.v	39.6
bo2-eld-pw3.1.v	48.3
yo12-eld-pw3.1.v	49.9
bi12-eld-pw3.1.v	49.9
g12-eld-pwx.v	1.7
g12-eld-pwx.h	1.8

PPA

Sector #	S(m) to IP
G1, G2, G4	16.5
G5, G6, G7, G8	16.5
G12	7.6
BI1, YI2	55.6
YO4, BI4	60.0
YO9, BO10	58.6
YI10	55.4

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10/15/2004

Cold-Bore Sections

The cold-bore comprises a seamless, austenitic stainless steel tube, extending beyond the end-plates of the magnets, to which it is welded and interconnected with formed rf-shielded bellows. No welded, brazed or bolted vacuum joints serve as barriers between superfluid helium and UHV environments. This is to eliminate the possibility of helium leaks from cold mass, through these joints into the cold bore. The leak rate of 4.5 K, 5 atm helium will be ~ 10^3 times greater than that of a RT 1atm gaseous helium, in terms of molecules per second, through the same leaky passage. The only other means whereby He can leak into the cold-bore UHV system is through metallurgical flaws in the seamless pipe or from the circumstance of gaseous He, in the cryostat insulating vacuum, leaking through a catastrophic failure in the interconnect piping or bellows. For these reasons, cryosorption pumps of activated charcoal are installed at magnet interconnects every 30m to pump helium (and hydrogen). The cold bore is monitored at 30m intervals with cold cathode gauges (CCGs) installed on the cryostat wall. Each CCG is connected to the cold bore through a 1.5m long 1" diameter gauge conduit thermally anchored at RT cryostat wall and at 55K heat shield, and terminated at a port on the rf-shielded bellows adaptor in magnet interconnects. The gauges provide a means of monitoring possible pressure rise in the cold-bore.

Prior to the magnet cool down, the cold bore is pumped down to ~10^{-3} Torr with a turbomolecular pump. After cool down to 4.5K, the CCGs read mid-10^{-10} Torr range when the true pressure, in the absence of helium, in the cold bore is <10^{-11}Torr. The high readings are due to the localized outgassing of the room temperature gauge conduits. The usefulness of the CCGs in monitoring the cold bore pressure was studied during RHIC first sextant test and found to be capable of detecting He pressure changes down to ~10^{-11} Torr.

Pressure rise of a few decades has been observed at a few locations in the cold bore during recent high intensity studies and thought to be caused by electron cloud induced desorption. The real gas density inside the cold bore during this pressure rise could be 10 – 100 times higher than that indicated by the RT CCG, due to the correction to thermal transpiration. Further studies of the relation between surface condensation during cool down and the pressure rise as well as heat load to the cold mass are needed to understand the impact of the cold bore pressure rise.

Cryostat Vacuum Systems

All gases in the cryostat insulating vacuum except helium are effectively pumped by the magnet cold masses. Helium leaking into the cryostats originate from two sources: 1) leaks in welds in the magnet cold mass or He interconnect plumbing; or 2) leaks from the He conduits or interconnecting bellows running along the full length of the cryostats. To locate serious He leaks to within one magnet interconnect and to institute provisions for local pumping until repairs are implemented, a high conductance transverse vacuum conduit is used at every magnet interconnect to couple the interconnect region to pumping ports located on the magnet cryostats. Most of these ports are capped off with inexpensive manual valves. Initially, one turbopump is mounted at the center of each arc and triplet cryostat to maintain pressure prior to, and during cool down. There are a total of 28 turbopump stations permanently installed in the tunnel for the 28 insulating vacuum volumes. Each insulating volume has one or more cold cathode gauges to measure the pressure levels. Partial pressure analyzers (PPA) are also installed along the cryostats to distinguish air leaks from helium leaks after cool down. Helium pressure gradients, as measured with PPA and portable leak detector through the pumping ports, will facilitate longitudinal location of leaks stemming from interconnect plumbing or magnet cold-masses. Additional turbopumps may be installed to pump on particularly troublesome leaks. Permanent turbopump stations are installed at each of the twelve valve boxes to pump and maintain the insulating vacuum. No permanent pump stations are installed at one hundred plus Vacuum-Jacketed-Refrigerator (VJR) lines. They are pumped periodically with portable pumps before cool down and during operation.