# RHIC SEXTANT TEST: ACCELERATOR SYSTEMS AND PERFORMANCE*

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*Abstract*

One sextant of the RHIC Collider was commissioned in early 1997 with beam. We describe here the performance of the accelerator systems during the test, such as the mag-net and power supply systems, instrumentation subsystems and application software. We also describe a ramping test without beam that took place after the commissioning with beam. Finally, we analyze the implications of accelerator systems performance and their impact on the planning for RHIC installation and commissioning.

## 1 INTRODUCTION

A gold ion beam was transported through one sextant of RHIC on January 26, marking the successful beginning of the Sextant Test, the effective commissioning of one sixth of the RHIC accelerator. The commissioning milestones and the main physics results are discussed elsewhere in these proceedings [1][2]. The focus of this presentation is the performance of the various accelerator systems during the beam tests, from the point of view of the system commissioner. A description of the design of the systems and the planning for system integration can, again, be found elsewhere [3]. We will discuss the highlights of the beam systems one by one but will necessarily refer to individual papers for the details. We will also discuss some of the power supply tests that took place after the beam shutdown, in the areas that are closer to the physicist's concern such as ramping and stability. Finally we will analyze the experience gained from the sextant test in terms of system performance and its extrapolation to the full RHIC commissioning, and concern ourselves especially with system integration and application software.

## 2 SYSTEM PERFORMANCE WITH BEAM

We will now review the individual beam systems performance during the test. The AtR (AGS to RHIC transfer line [4]) or, more specifically the U and W line, was first commissioned in fall 1995 and the analysis of that test resulted in guidelines for modification and improvement of the application software. It was decided that each application for a system should consist of: a Manager, running on a Console level Computer (CLC), a Graphical User Interface, also running on a CLC and Accelerator Device Objects (ADOs) running on a Front End Computer (FEC)[5]. Managers provide global functionality, such as data handling, global commands, high level functionality such as physics algorithms and administration of resources. Managers are implemented as "virtual front end computers" and code is written in ADO style. The GUI is separated from the Manager so that the application can be operated as a building block in a sequencer program. ADO's are C++ class instances that provide interface to the hardware, device specific basic operations, and real time functionality.

### *2.1 Magnets and Power Supplies (PS)*

All magnets performed flawlessly during the beam test. Once injected into RHIC, the beam hit the dump at the end of the sextant without need for corrections, validating the dipole integral transfer function measurements and magnet polarities. Phase advance measurements confirmed the quadrupole transfer functions and polarities. The sextant test power supply systems consisted of the PS for the main dipole bus (main quadrupole PS for RHIC), a 1000 A PS for the main quadrupole bus, a H/V quadrupole trim PS and 33 10 A PS for the independently powered dipole correctors.[3][6][7]. The power supplies delivered the required current of 550 A in the dipole and quadrupole buses. The power supplies worked very reliably in operations. Problem areas were a lack of precise current calibration between the DCCT, WFG and MADC readbacks, and occasional false power supply cutoffs and quench detection trips. These were caused by a sudden spurious increase in the set point on the current regulator, not requested by the WFG. The new ADO style manager for power supply control worked well, but improvements will be necessary in the low level communication software, as will be discussed later.

### *2.2 Instrumentation*

#### *2.2.1 Beam Loss Monitors (BLM)*

The BLM system [3][8] was commissioned as a beamline system in single pass mode and the electronics for the Ring operation mode was also tested. During the beam test the hardware worked together with the low level software without problems. A new ADO style BLM Manager was developed for the test as well as a new BLM user interface. The BLM Manager and interface, a prototype of the way controls and user interface will be developed for RHIC commissioning, worked reliably during the run.

#### *2.2.2 Beam Position Monitors (BPM)*

The BPM system [3][8] worked satisfactorily in the U and W subsections of the AtR line. Orbit and difference orbit data were taken, and the orbit was flattened by the

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orbit correction application. However, BPMs in the Sextant did not work reliably and that reduced the physics output of the test since precise and fast optics measurements require BPM data. During beam operations the BPM system was troubled by low level hardware and software problems, which manifested themselves as unreliable and inconsistent gain settings, orbit readings, etc. The ADO style BPM manager, after some initial configuration problems, worked but most of its functionality were rarely exercised because of the system problems.

*2.2.3 Beam Current Monitors (BCM)*

The current transformers were the same design and used the same application software as during the 1995 AtR test. Two additional transformers installed in the Y line and the Sextant performed reliably.

*2.2.4 Beam Profile Monitors (Flags)*

The flag hardware system, described in [3][9], was also already validated during the AtR test and the additional units installed in the sextant were essential to the successful outcome of the test. The high level software was completely rewritten, although not in ADO style, and provided 2 and 3 dimensional imaging (see Figure 1 for an picture of the beam on the last flag) as well as very useful online image fitting capabilities.

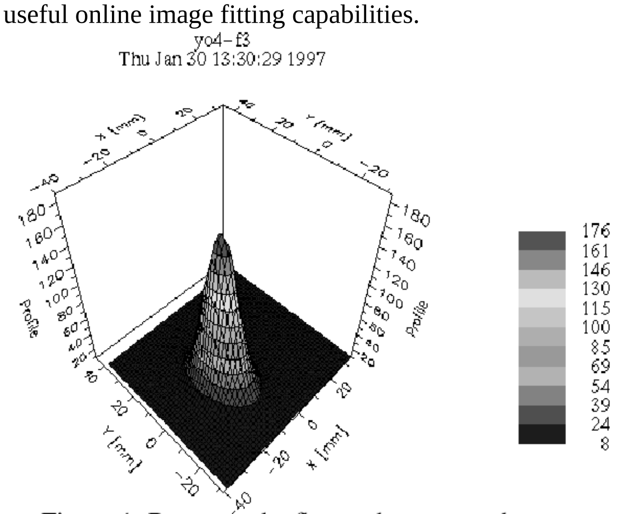


Figure 1: Beam on the flag at the sextant dump

*2.2.5 Ionization Profile Monitor (IPM)*

An IPM was commissioned that collects the electrons resulting from residual gas ionization during bunch passage. The prototype IPM measured vertical profiles of single bunches of Au nuclei containing 0.6 to 1 × $10^8$ particles. These profiles were compared to those measured on a closeby flag and found to be in excellent agreement.[10]

*2.3 Beam Permit*

The goal of the beam permit link, which is described in more detail in [3], is to protect the cryogenic devices from the beam by preventing injection in RHIC and aborting the beam from storage. Only the first capability was commissioned during the sextant test. The system, which was tested before beam operations by simulating false inputs at the modules, performed well with beam. Three times the permit link disabled beam injection into the sextant because of closed vacuum valves.

*2.4 Injection*

The injection system into RHIC consists of a Lambertson septum magnet and 4 kicker modules, as described in [11]. At the beginning of the test a vertical corrector magnet, powered at 30 A, replaced the kickers by providing the requisite 1.86 mrad vertical deflection. Once good injection conditions were established, the kickers were brought on line. The kicker commissioning was very successful and all established goal were met: determining kicker timing and strength, measuring rise time and shot-to-shot stability for multi-bunch extraction. All requirements for RHIC injection were met [12]. A high-level application program to guide the beam into the sextant was only partially tested, because of lack of availability of BPM data.

*2.5 RF*

The RF contributions to the Sextant Test consisted of the preparation of ‘RHIC like’ bunches in the AGS and the high power operation of the 197 MHz storage RF system in the RHIC tunnel at the 4 o’clock area [13]. The final bunch coalescing of 8 to 4 bunches was implemented in the AGS. To perform this the AGS had to run 3 harmonic numbers in one cycle, with eight cavities running on harmonic 8 and two cavities running on harmonic 16 at injection, switching to harmonic 4 for the last coalescing. An intensity of 0.4 × $10^9$ ions per bunch was attained. The RHIC low level RF Direct Digital Synthesizer (DDS) board successfully synchronized the AGS bunches to the RHIC 28 MHz bucket and provided the kicker triggers for beam extraction for the four successive bunches. The 28 MHz digital reference was sent back to RHIC via fiber optic link and, after bandpass filtering, used to drive the Step Recovery Diode (SRD) harmonic generator to derive the 197 MHz reference. This board also generated the bunch fiducial for triggering the BPM system. A single 197 MHz storage system cavity was successfully run at 1.1 MV gap volts after approximately 2 hours of RF conditioning, fully demonstrating the driver amplifier, power amplifier and cavity chain.

*2.6 Cryogenics*

The RHIC cryogenic system [14], which consists of the modified Isabelle refrigerator and new cryogenic components, was completed for the test from the refrigerator through 1 sextant up to the 4 o’clock valve box. The system performed very well during beam test: with a cold refrigerator, a helium delivery to load of about 4.5 K and mass flow of 50 g/s, cooldown was achieved in 48 h and cryogenics condition were stable throughout operations. After the beam test, a warmup time of only 24 h was achieved with the magnet warm-up heaters. During tests with beam and without beam several measurements were successfully done such as heat load measurements, warm pressure drop measurements, and the effect of an induced magnet quench on the system. Performance of cryogenics subsystems were found to be as per manufacturers specifications. Functional tests of existing and new equipment proved very valuable to improve future performance of the system.

### *2.7 Vacuum*

Large helium leaks were observed in the insulating vacuum volumes when the cold mass and helium lines were first pressurized. These leaks were located using helium profiling and repaired. A few smaller helium leaks were found and temporarily handled with additional turbopump stations. After cooldown the pressures in the insulating vacuum ranged from $10^{-7}$ to $10^{-3}$ Torr (at the leaks), adequate to maintain a low heat load to the cold surfaces. The warm bore beam vacuum sections were pumped down and maintained at $10^{-9}$ Torr with the ion sputter pumps. Neither an *in situ* bake nor titanium sublimation pumps were deployed for the first sextant. After cooldown the pressure readings at the cold cathode gauges of the cold bore beam vacuum sections ranged from $10^{-10}$ to $10^{-9}$ Torr, mostly due to the local outgassing of the gauge trees. The real pressure inside the cold bore was less than $10^{-11}$ Tor[15].

### *2.8 Controls and Database*

The RHIC Control System [5] is the system that naturally integrates all others and as such benefited greatly from the beam test to validate its design. Design improvements from the analysis of the 1995 AtR run were included and overall the system performed well during beam operations. From the commissioner's point of view, the ADO programming environment proved to be a good framework for software development and high level applications worked reliably. Identified areas for future improvement include the low level asynchronous communication software, and the reliability of the FECs. A problem that will require attention is the scaling of the control system performance to the whole RHIC. A configuration database was developed for the Sextant Test to handle low and high level data requirements. High level applications relied directly on this database while at the low level configuration data for the FECs were handled via a networked file system. The latter functionality will be moved to the configuration database in the next phase of the project.

## 3 TESTS WITHOUT BEAM

After the test with beam was completed, the sextant was kept cold for 3 additional weeks in order to allow system tests without beam. The cryogenic system ran one additional full thermal cycle, the power supplies went through an extensive series of tests and some aspects of the high level software, such as the ramping manager and the sequencer, were exercised. During beam tests the main dipole bus was powered only by the flat-top power module, and the current was limited to less than 800 A. The goals of the power supply testing without beam [5][6] were to ramp the magnets to 5500 A with both the ramp and flat-top modules, to perform ramping cycles at the nominal ramp rate of 80 A/sec, to power the interaction region quadrupole shunts, to power all correction systems that were not used during beam tests (such as sextupoles and gamma-T quadrupoles) and to test thoroughly the quench protection system. All goals were accomplished. Dipole and quadrupole magnets were powered in series to 5500 A, 10% above nominal storage energy, and kept at full current for 12 hours, the time scale of a RHIC store. Over 200 ramp cycles were performed with ramp and flat-top modules run together from 500 to 5500 A at a rate of 80A/sec, also 10% above nominal. This allowed the high level ramping application software to be exercised together with the prototype sequencer for RHIC operations. All superconducting shunt buses in interaction regions 4 and 5 and the trim quadrupole circuits were powered to their maximum currents. The quench detection system was balanced for ramps to a threshold level of 0.025 volts, and was able to detect a dipole bus quench caused by a spot heater during ramping. Four magnet quenches were induced by warm-up heaters and the quench protection system performed as required by bringing the current down before any other magnet quenched. Problem areas identified included the poor performance of SCR switches, excessive noise on the current RTDL signal, and instability of the current set-point interface on the current regulator.

## 4 ANALYSIS AND CONCLUSIONS

Overall the Sextant test was a great success. From the systems point of view all fundamental design concepts of RHIC were validated: components, mechanical aspects, electrical systems, cryogenics, beam systems. Problem areas were discovered but nothing of the magnitude to impact the overall scope and plans for RHIC.

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