# FINAL TESTING, INSTALLATION AND COMMISSIONING OF THE HERA 52 MHz RF SYSTEMS

M.S. de Jong, P.J.P. Bunge, R.J. Burton, S.T. Craig, L.W. Funk and R.M. Hutcheon
Atomic Energy of Canada Limited
Chalk River Nuclear Laboratories
Chalk River, Ontario, Canada K0J 1J0

## Abstract

The HERA 52 MHz rf systems have been installed in the HERA tunnel, commissioned and turned over to DESY staff for routine operation. This paper will review the final commissioning, installation and testing experience. In addition, the development and performance of the higher order mode dampers and the coupling system between the driver and power amplifiers will be discussed. Development of the 3 kW broadband modular driver amplifier, implementation of rf and computer controls, and the preparation and conditioning of the evacuated aluminum cavity surfaces to overcome multipactor are the subject of companion papers at this conference.

## Introduction

Chalk River Nuclear Laboratories (CRNL) have recently finished the fabrication, testing and commissioning of the HERA 52 MHz rf systems for DESY. A detailed overview of the design was presented at an earlier conference[1]. Each of the 2 systems comprises an evacuated aluminum cavity[2], a final amplifier using a 4CW50000 tetrode, a 3 kW solid-state broad-band driver amplifier[3], low-level rf control circuitry[4], computer control system[5] and all ancillary power supplies. The basic specifications are listed in Table I.

| | |
|---|---|
| Rf frequency | 52.03-52.05 MHz |
| Total Circumferential Voltage | |
| - Capture | 30 kV |
| - Acceleration | 60-100 kV |
| - Compression | 290 kV |
| Harmonic Number | 1100 |
| Average Beam Current | 0.17 A |
| Number of Cavities | 2 |
| Voltage Stability | |
| - broad band | ±2%, ±5° |
| - 50 Hz to 300 Hz sidebands | ±0.2%, ±0.5° |
| Open Loop Feedback Gain | ≥ 50 |

**Table I** - HERA 52 MHz System Specification

## Final Testing at CRNL

Initial tests of the rf systems at CRNL have already been reported[6]. In addition, the cavity gap voltage monitors required calibration, the coupling between the 10:1 power combiner and the final amplifier had to be redesigned, and additional high-order mode (HOM) damping was required beyond that provided by the original damper.

### Cavity Gap Voltage Calibration

Two techniques were used to calibrate the gap voltage monitors. In the first technique, a 52 MHz rf drive was applied across a 50 Ω load placed across the gap. After ensuring that the load was matched to the rf drive, the gap voltage is deduced from the rf drive power in the load. The voltage induced in the pickup monitor probes accurately reflects probe-to-gap voltage ratio. This technique has proven reliable, but can only be performed conveniently at low power without the cavity under vacuum.

Gap voltage calibration at high power under vacuum using bremsstrahlung x-ray end-point measurement proved to be more difficult than anticipated. The number of high-energy photons was a very small fraction of the total number, necessitating long runs with less than ideal statistics. The very long gap, 300 mm, also reduced the number of electrons acquiring the full gap voltage, with most electrons following trajectories which took them to the inner surface of the intermediate cylinder at roughly half the gap voltage. The effect of the transit time factor was calculated, and contributes a further 3-5% reduction in the maximum voltage. In the end, the results were not conclusive, but were consistent with the calibrations performed earlier.

### Final Amplifier Input Coupling

The initial connection between the combiner and final amplifier was through a 5 Ω strip-line coupled into a quarter-wave resonant cavity, loaded by the cathode-grid impedance of approximately 35 Ω. When this was implemented, the 5 Ω line impedance loaded the cavity sufficiently to shift the frequency by almost 10 MHz. The voltage-standing-wave ratio (VSWR) on the 5 Ω line could not be reduced below 3. This high VSWR caused excessive power to be reflected into the solid-state driver amplifier, and resulted in frequent reverse-power trips from the driver amplifier protection circuitry. The high VSWR also caused the apparent gain of the solid-state amplifier to be reduced at the operating frequency. This reduction resulted in inadequate drive power for beam-loading compensation. All attempts at changing the strip-line coupling into the cavity to reduce the VSWR were unsuccessful, so a different approach was required.

The revised coupling scheme uses a quarter-wave transformer, where the impedance of the transformer is the geometric mean of the input and output impedances. In this case, the geometric mean of 5 and 35 Ω is approximately 13 Ω, so the transformer was made from four 50 Ω coaxial lines in parallel for an effective impedance of 12.5 Ω. The lines connect the strip-line directly to a short 15 Ω coaxial section in the tube input. The length of the coaxial lines was adjusted to minimize the VSWR on the strip-line. Under normal operating conditions, the VSWR is now typically 1.1 to 1.2. When heavy beam loading is simulated, the VSWR increases to only 1.4, well within acceptable limits. The result was higher net gain from the solid-state amplifier and far fewer reverse power trips.

### HOM Damper Modifications

Initial measurements of the effectiveness of the main HOM damper showed that the first HOM at 140 MHz was damped, albeit insufficiently. Most other HOM's were not significantly damped. This led to the development of additional small HOM dampers shown in Fig. 1. The length and shape of the copper antenna were adjusted to maximize the damping of the modes at 140 and 238 MHz. The ferrite, Fair-Rite Products type No. 67, was selected because of its low loss below 100 MHz, which increases by about 7 dB per octave at higher frequencies. Thus the ferrite losses at the cavity fundamental are reduced. We estimate that less than 50 W of power at 52 MHz is absorbed in each auxiliary damper when the cavity is run at maximum voltage.

The effective longitudinal shunt impedances were calculated from the measured Q-values of each of the modes and R/Q determined by URMEL[7]. The final HOM impedances for the HERA cavities are given in Table II.

| URMEL | | CAVITY 1 | CAVITY 2 |
|---|---|---|---|
| f (MHz) | R/Q | R (kΩ) | R (kΩ) |
| 52.43 | 123.5 | 1118. | 1161. |
| 142.43 | 70.5 | 14.8 | 21.1 |
| 238.83 | 12.9 | 14.4 | 5.8 |
| 338.58 | 35.7 | 31.1 | 26.1 |
| 418.24 | 2.23 | 2.9 | 1.5 |
| 506.52 | 15.5 | 12.2 | 55.8 |
| 519.80 | 8.29 | - | 60.1 |
| 568.39 | 1.45 | - | 7.3 |
| 610.02 | 0.94 | - | 0.97 |
| 648.73 | 6.88 | - | 26.5 |
| 683.60 | 2.65 | - | 4.97 |

**Table II** - HERA 52 MHz HOM Damper Performance

While these impedances do not meet the stringent 4 kΩ maximum value specified, they are certainly acceptable for early operation of the HERA proton ring, and may well be acceptable for full current operation. Only detailed examination of accelerator operation with beam will permit an exact determination of acceptable impedances. The 4 kΩ level was chosen to provide a guarantee of trouble-free operation.

The acceptance tests at CRNL were completed in 1990 January. These tests included 24-hours operation, spark-free, at cavity gap voltages in excess of 145 kV, 8-hours operation with a simulated maximum beam loading on the amplifier, and measurements of the fast feed-back open loop gain. Electron multipactor at low gap voltages caused a reduction in the apparent cavity Q and, hence, the open loop gain of the feedback system. The feedback gain was adjusted so that, even with multipactor, the gain was larger than 50 over the entire gap voltage range, as required.

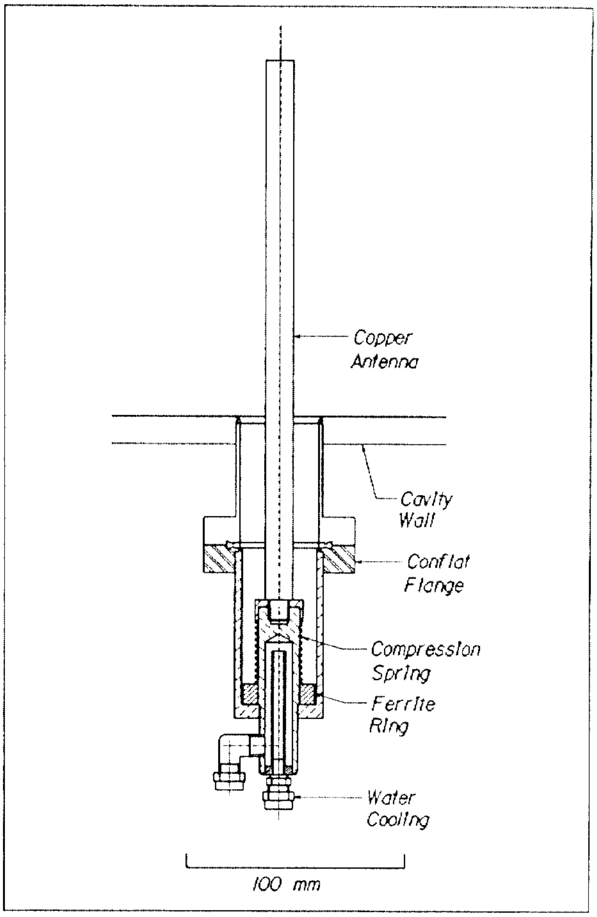

**Fig. 1** Auxiliary HOM Damper Design.

Disassembly of the rf systems for crating and shipping took 10 days in 1990 February. Most crates had been fabricated in advance and were packed as disassembly proceeded. In preparation for shipment, the cavities were filled with dry nitrogen and the auxiliary dampers removed for examination. Both ferrite rings were found to be broken, but the pieces maintained the ring configuration, and no reduction in damper effectiveness was anticipated. The rings were a very tight fit on the centre conductor of the damper, leading to an initial hoop stress on the ferrites, in a direction in which the rings are not mechanically strong. Alternative rings with slightly larger IDs were chosen for the final installation.

### Installation at DESY

The cavities and all associated equipment were air-freighted to DESY, arriving at the lab site on February 20. The high-voltage power supplies and equipment racks were immediately unpacked and installed in the equipment room by DESY staff. CRNL staff arrived at DESY on February 26 and immediately began the process of installation. Space constraints were very tight, and care had to be taken to schedule activities so that the various groups could all work effectively. By the end of the first week, mechanical assembly was complete, installation of the water distribution system was about 50% complete, installation of equipment in the shielded tunnel electronics trench was about to start, and leak-testing by the DESY vacuum group had begun.

The only major problem was a vacuum leak found in a feedback pickup loop feedthrough that was damaged during shipping. A replacement was fabricated within one day with the assistance of the DESY proton rf group and the DESY mechanical shop, and rf tests showed its electrical characteristics were very close to those of the original.

By the end of the second week, both cavities were under vacuum, one system was operating cw and the second system was ready to begin rf pulse conditioning.

## Final Commissioning

During the third week, acceptance tests that had been performed at CRNL were repeated. Although both systems were capable of running cw, the cavity rf conditioning was not adequate to permit 24-hour runs at gap voltages in excess of 145 kV (the design maximum operating voltage). Both systems ran, spark-free, at 145 kV for more than 16 hours with a simulated worst-case beam loading 50% greater than design.

The small amount of rf conditioning resulted in considerable outgassing and low-level multipactor during operation. Consequently, the vacuum pressure was significantly higher than the design limit. It was clear during the operation that more rf conditioning was required before the ultimate pressure would be achieved. A small leak around one of the drive loop feedthroughs was also found later by DESY staff.

The rf system computer software was debugged and modified to permit remote operation by the main DESY control computers. The final software was then burned in EPROMs and remote operation was checked out. By the end of the third week, both systems had passed the acceptance tests, and the handover to DESY was complete.

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