EVALUATION OF BERGOZ INSTRUMENTATION NPCT*

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Abstract

The Bergoz Instrumentation (BI) New Parametric Current Transformer (NPCT) [1] has been evaluated at the SPEAR3 [2] synchrotron light source. The device was tested for vacuum performance and residual gas and was found suitable for installation in the storage ring. The NPCT was installed during August 2008 and has measured beam currents to 500 mA. Performance is compared to the earlier PCT design. The NPCT Sensor Head has been instrumented with thermal sensors for characterization of the internal operating temperature.

INTRODUCTION

The NPCT provides non-destructive measurement of average beam current. The NPCT functions on the principle of the zero-flux DC Current Transformer and is an evolution of the Unser transformer [3], commonly called a DCCT. A collaborative effort to evaluate the NPCT was proposed by J. Bergoz (BI) and R. Hettel (SSRL) in May 2008. The NPCT, part number NPCT-175-C036-HR, was installed during August 2008 and has measured electron currents up to 500 mA. Assessments of electrical performance, vacuum quality, and beam induced heating were made.

The NPCT construction is "in-flange" and no mechanical design effort was required at SSRL, except new mating spool pieces. To achieve the installation schedule, SSRL selected an already fabricated magnetics package and circular ceramic gap, with a 3.5 in. diameter beam bore. SSRL requested a modification to the Sensor Head flanges to accept radio frequency seals used in SPEAR3. Bergoz Instrumentation supplied a completed Sensor Head, consisting of the ferrite transformers, brazed ceramic break, vacuum body and mating Conflat flanges. In addition, a 19" 3U Euro-card chassis, two power supplies (one spare), two NPCT electronics modules (one spare), and a 36-meter interconnecting cable were supplied by Bergoz.

The Sensor Head was equipped with a PT-100 RTD (resistance temperature detector) for the purpose of this study. The RTD has been used to monitor internal beam induced heating. A thermocouple (TC) was installed on the outer-flange of the Sensor Head, and another thermocouple on a nearby vacuum chamber spool piece. Beam induced heating measurements were made with and without external low conductivity water (LCW) cooling loops installed near the Sensor Head.

*Work supported by the U.S. Department of Energy, contract DE-AC02-76-SF00515 and Office of Basic Energy Sciences.
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INSTALLATION

Mechanical

Schedule considerations influenced the selection of beam aperture size and shape. It was also desired that vacuum chamber adaptations be straightforward. This was achieved by locating the NPCT between two accelerating cavities. This location raised the concerns of strong radio frequency fields and vacuum performance.

Short drift tubes with 6 in. rotatable flanges were fabricated from stainless steel, with internal copper plating. External copper plating and cooling tubes for thermal conductivity were not used. The NPCT and drift tubes assembly is only 17.9 in. long, and the RF cavities on either side are stable thermal reservoirs. The assembly resides in an unfilled ion pump contingency space.

Vacuum

The instrument arrived at SSRL on 8/15/08. The Sensor Head was put on a vacuum test stand for processing. Initial measured pressure was 9.0 x 10^{-8} torr with a 150 l/s pump. The pressure decreased to 2.4 x 10^{-9} torr after nine days of room temperature pumping. An RGA measurement was made, indicating a clean vacuum device, with no significant gas species above 50 amu. Figure 1 shows the RGA spectrum after all vacuum processing was completed. The scan shows simple gasses common in vacuum systems [4]. Hydrogen $^{1}H_2$ is at 2 amu. Water produces peaks at 16, 17, and 18, due to the species $^{16}O^+$, HO^+, and H_2O^+. The peak at 19 amu is due to $^{18}OH^+$. Nitrogen $^{14}N^+$ produces a peak at 14. $^{14}N_2^{2+}$ is at 28, and CO_2 at 44 amu.

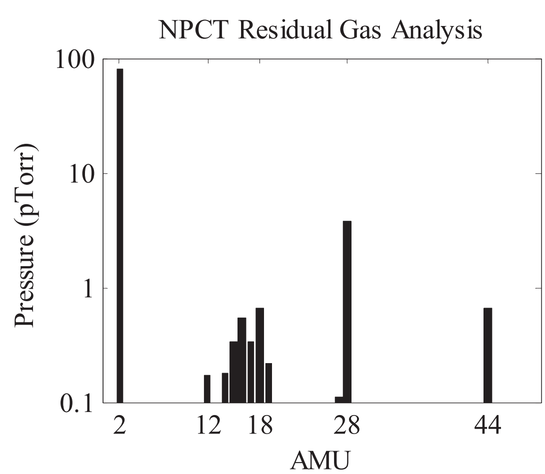

Figure 1: RGA after completion of all vacuum processing.

Since SPEAR3 vacuum pressure averages 4.7 x 10^{-10} torr, a low temperature bake was considered. Although the Sensor Head specification allows baking at 100°C, we were cautious with this new instrument and limited the bake temperature to 50°C. The bake continued at 50°C for an additional nine days. A final pressure of 1.4 x 10^{-9} torr was measured at 22°C. This small pressure "bump" has improved with beam processing.

Radio Frequency (RF) Fields

The fundamental RF field generated in the cavities by the klystron, and higher order modes (HOM) generated by the beam, are strongly attenuated [5] in the drift tubes adjacent to the NPCT. The *e*-folding length of the 476 MHz longitudinal accelerating field, the lowest transverse magnetic (TM) mode of the cavity, is 1.880 cm. With drift tubes and spool pieces totaling 49.15 cm, the 476 MHz cavity field of 4.7 MV m^{-1} is attenuated to 21 µV m^{-1} at the edge of the NPCT flange.

Attenuation of HOMs is less severe, but the source fields are weaker. At 500 mA, the strongest induced HOM is a dipole mode estimated at 311 V m^{-1} at 1.67 GHz. The corresponding *e*-folding length is 4.502 cm over 49.15 cm. This field is attenuated to 5.6 mV m^{-1}. Both fields are well below any level of concern for the NPCT. No change in the NPCT signal was observed during on/off testing of the 476 MHz field.

RTD Instrumentation

The PT-100 RTD is attached to a ferrite toroid and connected through the DB 15 plug. Pin#1 is one terminal of the resistor; the second terminal is the connector shell. All electrical connections to the Sensor Head, including the PT-100, are made through a single 36-meter long cable, Belden 9508NH, terminating at the processor chassis. Because the PT-100 is non-standard to the instrument, a cable "breakout" box was added. The breakout box included a common mode choke and filtering capacitors. Temperature measurements were made using an Allen Bradley ControlLogix 1756-IR6I module.

The arrangement introduced an error (13.2°C) because the roundtrip resistance of the cable (5.1 Ω) is not compensated in a 2-wire connection. The actual correction applied was empirically established at 10.0°C. This was determined by wrapping the Sensor Head with heat tapes under no-beam conditions and comparing the RTD output to several TC outputs. A second source of errors was ground currents, which were correlated to their sources. These errors were less than 1.5°C.

Output Instrumentation

The NPCT output signal was measured using a Keithley 2002 8-1/2 Digit Voltmeter, sampling 90 points per second. This data was averaged and recorded at 1 Hz. The existing PCT signal is processed with a separate Keithley 2002. An error was introduced into calculation of the difference (PCT – NPCT) because the two voltmeters were not synchronized. As the accelerator filled, the voltmeters sampled at slightly different times, reading different currents. The PCT – NPCT difference is less than ± 0.02% over the 500 mA range, including the voltmeter introduced error.

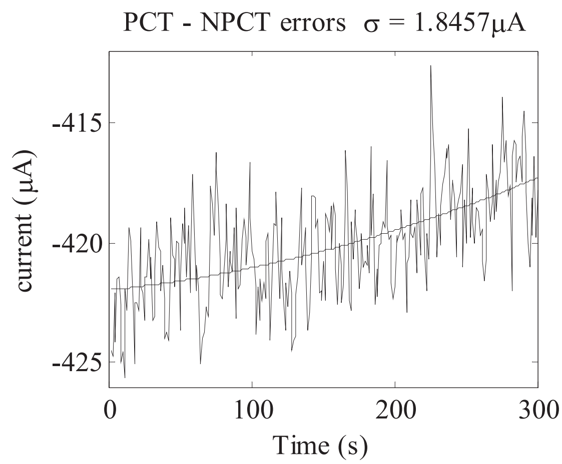

Figure 2: Difference between PCT and NPCT with 500 mA stored. The 420 µA offset can be zeroed out.

TESTING

Beam

The NPCT was tested with 100 mA and 500 mA beam currents. The standard fill pattern, 280 bunches and a 93 bunch gap, with a camshaft bunch in the gap, was used. The typical bunch length in SPEAR3 is 20 psec rms. The beam was unconditionally stable against betatron and synchrotron oscillations with the NPCT installed. The NPCT had no negative effect on beam quality.

Electrical

The NPCT was bench tested. It was beam tested during several 500 mA experiments, the first on 12/08/08. Electrical test results are summarized in Table 1.

Table 1: Output Measurements

Parameter	Measured	Specification
Current Accuracy	± 0.04% (20°C)	± 0.1% ± 0.1 µA/K
Resolution	0.87 µA rms (1 Hz)	< 1 µA/√Hz
Resolution 500 mA Beam	1.19 µA rms NPCT 1.56 µA rms PCT	< 1 µA/√Hz
PCT - NPCT	< ± 0.02%	N/A

Current accuracy was bench measured using a precision DC source and measured ± 0.04% over the 500 mA range. The resolution was bench measured using an SR785 Dynamic Signal Analyzer [6], 0.87 µA rms in 1 Hz bandwidth, and with 500 mA beam, 1.19 µA rms.

Thermal

Beginning with 100 mA stored on 12/08/08, the PT-100 indicated a temperature of 28°C, and began to rise in temperature 7 min. after increasing the stored current toward 500 mA. The PT-100 indicated a continual temperature rise, marked by 0.5°C amplitude oscillations. Because of instrumentation uncertainty and the rising temperature, it was decided to end the experiment and add cooling loops and an additional TC to the Sensor Head before another high current run. Data taken was fit to an exponential function. The maximum measured temperature was 46°C after 62 minutes at 500 mA, and the final (extrapolated) temperature was 54°C, with a time constant of 68 minutes.

After instrumentation improvements, the NPCT was again tested with 500 mA beam, for a 6-hour period. The internal temperature rise over the period is shown in Figure 3.

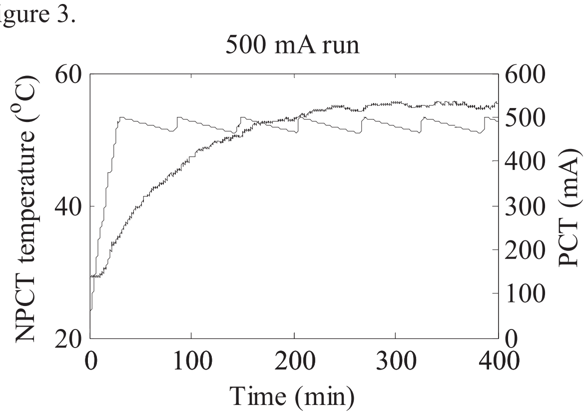

Figure 3: NPCT internal temperature rise with 500 mA

For reference, the temperature of a typical vacuum chamber, located between cavities B and C, was also measured. Temperature measurements are summarized in Table 2.

Table 2: Measured Maximum Temperatures

Beam Current	Typical Vacuum Chamber	NPCT w/ LCW		NPCT Ferrite w/o LCW
		Ferrite	Flange	
100 mA	33°C	31°C	31°C	28°C
500 mA	41°C	55°C	50°C	54°C

The operating temperature of the Sensor Head was reasonable under all test conditions. The 100 mA data reflects the LCW supply temperature at 31°C. The internal NPCT temperature rises expectedly above the reference chamber temperature. The chamber is a simple, entirely metallic structure, having a smooth heat flow path. The measurements indicate that the extra cooling loops made little difference, probably because good conduction already existed between the NPCT, drift tubes, and cavities. However, their addition is conservative.

SUMMARY

A Bergoz NPCT was installed and evaluated in SPEAR3. As part of the evaluation process, vacuum and electrical measurements were made before installation. Vacuum chamber installation was completed in four hours. Ancillary components were two drift chambers. The NPCT was installed in the RF Straight, a region of particular sensitivity to vacuum quality. The instrument was sufficiently clean after room temperature pump-down to be installed there. Vacuum has improved with beam.

Operating continuously at 500 mA, the internal temperature did not exceed 55°C, a 24°C temperature rise. Current accuracy measured ± 0.04% over the 500 mA range, within specification. Measured beam current agreed with the PCT within ± 0.02% over the same range. The resolution (option-HR) was 0.87 μA rms, within specification. Magnetic field interference has not been witnessed. The RTD is potentially useful to the end user as a diagnostic device and temperature interlock. Possibly it could be incorporated into the NPCT design.

A planned upgrade is installation of an ion pump adjacent to the NPCT. Since we could not bake-out the NPCT to standard bake-out temperatures (~200°C), the pump will compensate for any out-gassing. LCW lines will be added as a conservative measure.

ACKNOWLEDGEMENTS

The support of several accelerator specialists was essential to the production of this data. The authors wish to thank Julien Bergoz (BI) for loaning the NPCT instrument. This included customizing the Sensor Head to allow installation of RF gaskets, supplying drawings and documentation, and answering a variety of queries. Brian Richter of GMW Associates, Inc. provided assistance with the loan agreement and logistics. At SSRL, the support, encouragement, and technical expertise of Bob Hettel were invaluable to the project.

Vacuum testing and installation were performed by M. Nalls, R. Pak, and R. Bach. T. Neal calibrated the thermocouples. Mechanical work and installation were performed by M. Swanson, R. DiMattia, J. Guerra, and G. Woodcock. L. Lessard instrumented the RTD. W. Zangara negotiated the collaboration agreement.

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