Online monitoring of beam phase and intensity using lock-in amplifiers†

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We developed a monitoring system dedicated for RIBF that incorporates lock-in amplifiers (LIAs) that can measure the beam phase and intensity of signals from the phase probe (PP) with an amplitude of a few hundred nanovolts. The configuration of the LIA system is schematically shown in Fig. 1. The rf is also monitored using the LIA system. We compared the performance of the LIA system with that of a conventional system that incorporates oscilloscopes (OSCs). It was confirmed that LIA has much higher precision and smaller deviation than the OSC; LIA has a resolution of 0.02° for a 1.0 V standard signal and can measure a signal as small as 200 nV, which corresponds to 10 electric nA of beam current.

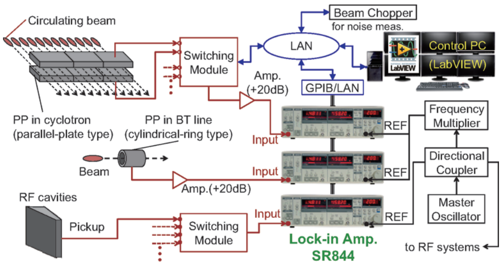

Fig. 1. Configuration of the LIA system.

Since the PPs are placed at relevant positions along the beam lines of the RIBF, we can easily find the instability or decrease of beam intensity caused by the variation of rf or magnetic field by using the LIA system. The correlations between rf, beam phase, beam intensity, and environmental factors such as the ambient temperature and cooling water temperature have also been revealed.[1,2] In addition, we can clearly observe the deterioration of a solid-state charge stripper and the pressure variation of a gas charge stripper.[3]

The isochronism measurement results for the SRC, which has a low velocity gain of 1.5, showed excellent agreement between the three measurement methods (OSC zero-corss, OSC FFT, and LIA) with a discrepancy less than 0.2 ns (≃2 rf degree), as shown in Fig. 2(a). The isochronism measured for 10 frequency components ($1f$–$10f$) was also in good agreement with an accuracy discrepancy less than 0.5 ns (≃5 rf degree). However, in the RRC, which has a high velocity gain of 4.0, a phase difference of up to 0.7 ns (≃7 rf degree) was observed between the three measurement methods. The phase difference was improved to a discrepancy of less than 0.4 ns (≃4 rf degree) when we corrected for the radial variation of the observed bunch width, as shown in Fig. 2(b).

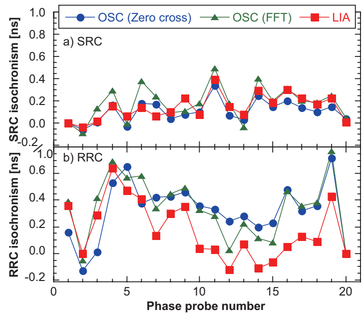

Fig. 2. Comparison of isochronism in a) the SRC and b) the RRC on the basis of three measurement methods.

The remaining phase difference between LIA and OSC is considered to be the effect of the cable dispersion. In fact, it was observed that the cable dispersion via 80 m increases asymmetric distortion of the bunch shape, and it produces a timing advance of 0.14 ns relative to the actual timing, as shown in Fig. 3. Because we measure the single-frequency component of the beam-bunch signal in the LIA system, such cable dispersion does not disturb the beam-phase measurement, and it is concluded that the LIA system gives a more accurate beam phase if the measurement is performed at the control room.

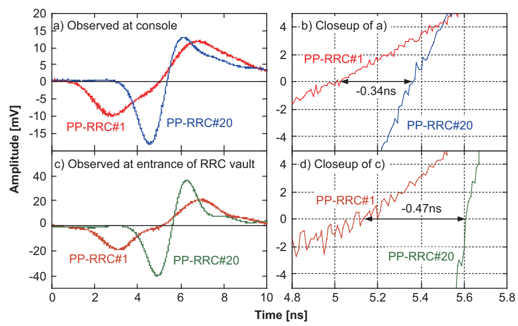

Fig. 3. Bunch shapes observed at the console 90 m downstream of PP-RRC (a) and at the entrance of the RRC vault 10 m downstream of PP-RRC (c).

References

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2) K. Suda et al.: Proc. of CYCLOTRONS 2010, Lanzhou, China, MOPCP068, pp.186–188.
3) R. Koyama et al.: Proc. of PASJ10, Nagoya, Aichi, August 2013, SAP013, in press.

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