

CONSISTENCY IN MEASUREMENT OF BEAM PHASE AND INTENSITY USING LOCK-IN AMPLIFIER AND OSCILLOSCOPE SYSTEMS

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Abstract

The phase probes (PPs) are installed in all cyclotrons and beam transport lines of RIBF, and the beam-bunch signals that are detected nondestructively by these PPs are used for tuning of isochronism of cyclotrons and for monitoring the beam phase and beam intensity. We mainly use a newly developed system that incorporates a lock-in amplifier (LIA) for those tuning and monitoring; however, a conventional measurement method using an oscilloscope (OSC) system is also used. In this study, we investigated the consistency in the measurements carried out using LIA and OSC systems by FFT analyzing the observed data. Additionally, we investigated the measurement accuracy of LIA and OSC.

INTRODUCTION

The RIKEN RI beam factory (RIBF) consists of four ring cyclotrons (RRC, fRC, IRC, and SRC) and two injectors (RILAC and AVF) which are all connected in cascade. RILAC, AVF, and RRC began operation in the 1980s, and fRC, IRC, and SRC were installed in 2006. Phase probes (PPs) are installed in all cyclotrons and beam transport lines of RIBF, and the beam-bunch signals that are detected non-destructively by these PPs are used for tuning of isochronism of cyclotrons and for monitoring the beam phase and beam intensity (Fig. 1). We mainly use a newly developed system that incorporates a lock-in amplifier (LIA; SR844, SRS) for those tuning and monitoring; [1] however, in AVF and RRC, a conventional measurement method using an oscilloscope system (OSC; DSO6052A, Agilent) is used. In this study, we investigated the consistency in the measurements carried out using LIA and OSC systems.

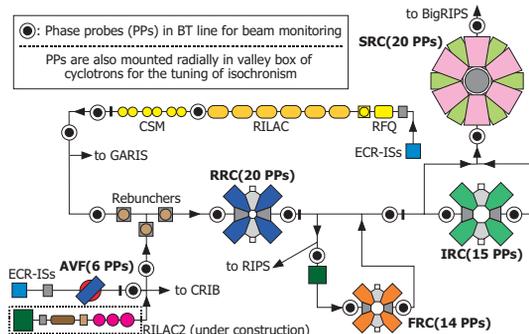


Figure 1: Schematic layout of RIBF.

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MEASUREMENT AND ANALYSIS

The block diagram of the measurement system is shown in Fig. 2. The beam-bunch signals from PPs are divided by a power divider and transported to the LIA and OSC and measured by them simultaneously. LIA use a technique known as phase-sensitive detection and outputs the beam phase and the beam intensity at a specific reference frequency. In order to investigate the consistency with OSC system, the phases and intensities for 1st to 10th frequency components (1f–10f) is calculated by performing FFT-analysis on the data from OSC. [2] These analysis were processed automatically by the LabVIEW program.

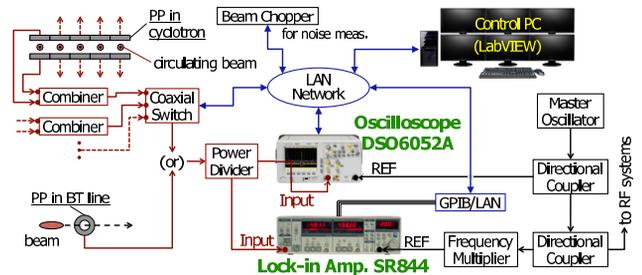


Figure 2: Block diagram of measurement system.

CONSISTENCY RESULTS

Consistency in isochronism of SRC

The comparison of the isochronism of SRC (¹⁴N⁷⁺ beam, Energy: 250 MeV/u, Frequency: 27.4 MHz) that was evaluated on the basis of the results of three measurement methods is shown in Fig. 3. This figure shows the relative beam phase observed by 20 PPs, which are radially mounted in the orbital region of SRC. Here, “LIA-3f” is the beam phase measured using LIA with the third harmonic of acceleration RF as its reference signal, “FFT-3f” is the third frequency component (3f) of FFT-analyzed phase of the beam-bunch signal measured using OSC, and “Zero cross” is the zero-cross points of the beam-bunch shape observed using OSC (conventional method). [2] We measured the 3f component of the beam-bunch signal because it had relatively good S/N ratio. It was observed that the phase differences between the three measurement methods are less than 0.2 ns (approximately 2° at fundamental acceleration RF).

Figure 4 shows the FFT-analyzed phase up to the 10f

component of the beam-bunch signal measured using OSC, together with “LIA-3f” and “Zero cross”. Since in the LIA system, we can basically measure only one frequency component of the beam-bunch signal,[2] we need to investigate the other frequency components. However, from the measurements carried out in our work, it was found that the phase differences between ten frequency components are less than 0.5 ns (approximately 5° at fundamental acceleration RF).

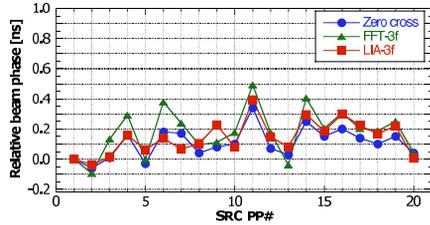


Figure 3: Comparison of isochronism of SRC on the basis of three measurement methods.

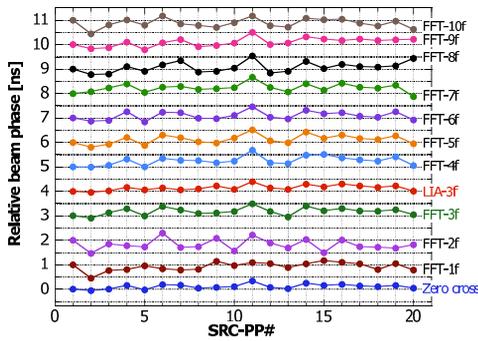


Figure 4: Comparison of isochronism of SRC for 1f–10f of FFT-analyzed phase.

Consistency in isochronism of RRC

On the other hand, relatively large discrepancy among three methods for RRC was observed especially in inner PPs. The results of measurement of RRC (⁴⁰Ar¹⁷⁺ beam, Energy: 95 MeV/u, Frequency: 28.1 MHz) are presented in Fig. 5. This inconsistency is considered to depend on observed-bunch width on the beam orbital. Using OSC, different signal shapes were observed for PPs#1, #10 and #20 as shown in Fig. 6. For RRC, the inner-bunch width is narrower than the outer one unlike in the case of SRC. Figure 7 shows the FFT-analyzed phase of RRC-original data from OSC after the zero-cross points of all PPs of RRC are aligned at the same phase (for more detail, see [2]). The inconsistency between FFT-2f and zero cross is improved if the correction phase is subtracted from original phase as shown in Figure 8. However, the correction is still insufficient especially for PPs#1 and #3. The reason is considered to be the effect of 9f component. As shown in Figure 9, relatively large 9f component is observed in PPs#1 and #3 and is considered to affect the determination of zero-cross points.

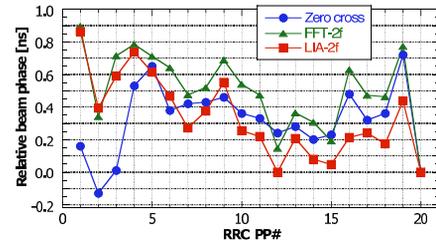


Figure 5: Comparison of isochronism of RRC on the basis of three measurement methods.

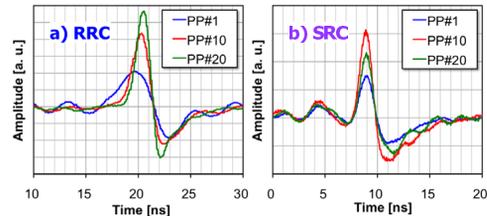


Figure 6: Bunch shape of RRC (a) and SRC (b).

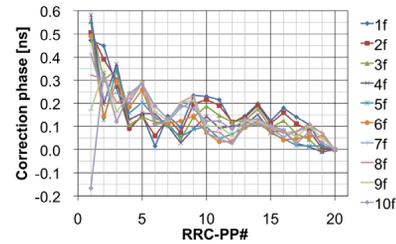


Figure 7: Correction phase depend on bunch width.

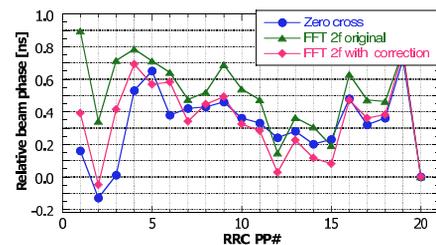


Figure 8: Comparison of isochronism of RRC before and after phase correction.

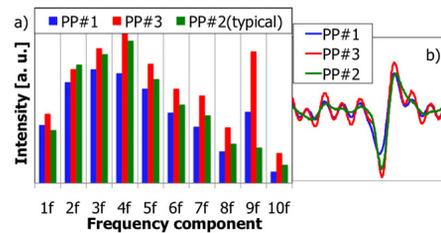


Figure 9: Frequency spectrum (a) and bunch shape (b) of PPs#1, #2 and #3 of RRC

Consistency in variation of beam-phase and intensity

Figure 10 shows the beam phase and the beam intensity of a 0.669-MeV/u ¹³⁶Xe²⁰⁺ beam (RF: 18.25 MHz) de-

tected by PP-S71 (see Fig. 1) over a 4-h period. In this case, the 5f component of the beam-bunch signal had relatively good S/N ratio. The correlation diagrams of the LIA and OSC data presented in Fig. 10 are shown in Fig. 11, and a certain degree of linearity is observed between them.

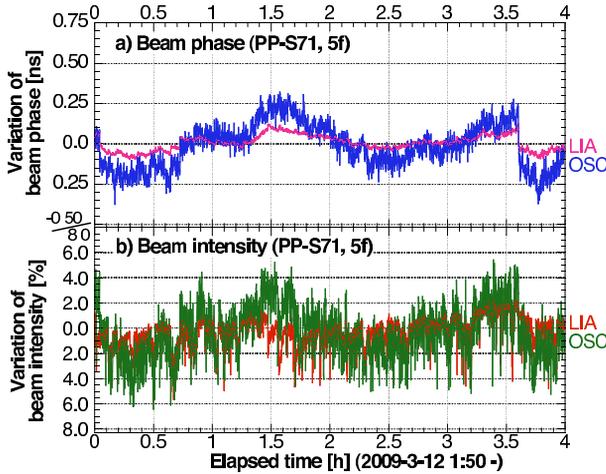


Figure 10: Beam phase and beam Intensity at PP-S71 measured using LIA and OSC systems.

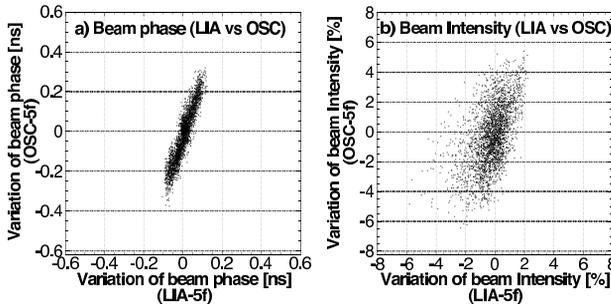


Figure 11: Correlation diagrams for LIA and OSC data presented in Fig. 10.

MEASUREMENT ACCURACY

Since the fluctuation ranges of both the beam phase and the beam intensity measured using OSC are larger than those of the beam phase and the beam intensity measured using LIA, we investigated the voltage and phase resolution of the LIA and OSC using a function generator (AFG3252, Tektronix). Figure 12a shows the phase and voltage variation measured using the LIA and OSC when the input phase and voltage from AFG3252 to them are varied by 0.01–0.10° and 0.01–0.10%, respectively, after 90 s (frequency: 18.25 MHz). Figure 12b shows 90-s average of the phase and voltage variations plotted in Fig. 12a as a function of the total increment in the input phase and voltage from AFG3252. Here, the error bars in Fig. 12b are standard deviation for measurements performed after 90 s each ($\pm 1\sigma$), and they represent the measurement uncertainty. We consider the voltage and phase variations, which are obtained irrespective of the error bars, as the resolution. The error margins for LIA in Fig. 12b are insignificant (smaller than the symbols), indicating high measurement accuracy in the

case of LIA. The resolution and measurement uncertainty of LIA and OSC are summarized in Table 1.

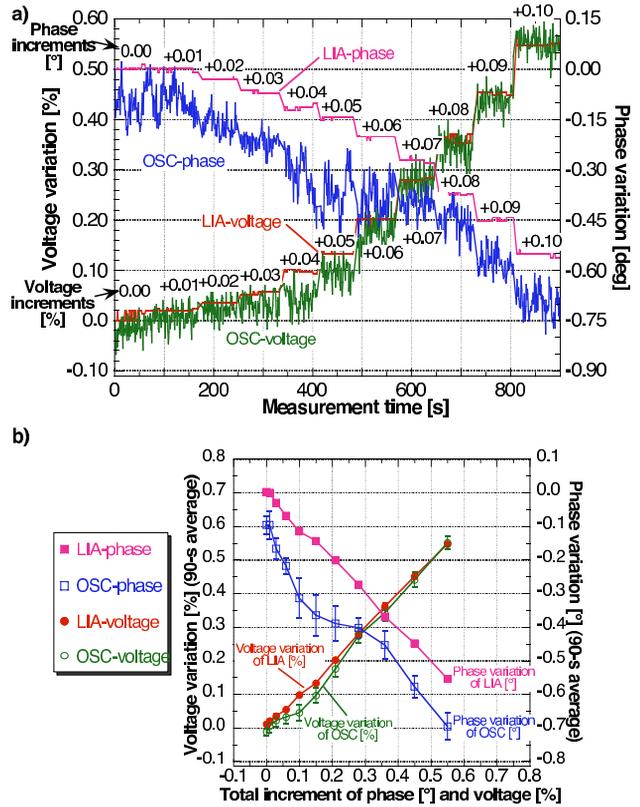


Figure 12: Phase and voltage resolution of LIA and OSC using AFG3252.

Table 1: Estimated measurement accuracy of LIA and OSC systems.

system	phase [°] ([ps])		voltage [%]	
	resolution	uncertainty	resolution	uncertainty
LIA	0.02 (3)	± 0.007 (1)	0.02	± 0.009
OSC	0.09 (14)	± 0.06 (9)	0.05	± 0.025

SUMMARY

The consistency in the isochronism measured using LIA and OSC systems is confirmed. However, it was found that some phase correction is needed when the bunch width is different on the beam orbital or some higher frequency components are superimposed on the bunch signal as in the case of RRC. Further investigation for this problem is required. The consistency in the variation of beam phase and beam intensity is also confirmed, and it was observed that LIA has a higher measurement accuracy than OSC.

REFERENCES

- [1] R. Koyama et al.: RIKEN Accel. Prog. Rep. **42**, pp. xviii–xix (2009).
- [2] R. Koyama et al.: Proc. of PASJ6, Tokai-mura, Ibaraki, August 2009, WOOPB03, pp. 25–29.