ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-MOPRO081

RESONANCE FREQUENCY FEEDBACK SYSTEM FOR A PRECISE MAGNET ALIGNMENT USING MULTI-VIBRATING WIRES

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Abstract

Magnet alignment is one of most critical issues for realizing next generation light source. A vibrating wire method has been regarded as the promising scheme, however, environment changes, especially temperature drift causes not only the drift of a magnetic center, but also the drift of a resonance frequency of the wire. These drifts are all mixed in a signal of wire vibration, and not separable for an ordinary method. We have developed a frequency feedback system for the vibrating wire method. A magnetic center can stably be measured using the system, and the resolution of the measurement was better than 1 [μm] for a typical quadrupole magnet. A possibility to apply it for future light source have been discussed.

INTRODUCTION

Low emittance storage rings are being constructed at synchrotron radiation facilities in the world [1]– [3]. Because an alignment tolerance is one of most important issues, high alignment precision of micro-meter order enhances flexibility in the design of the low emittance ring. A vibrating wire method (VWM) has been used for such a high precision alignment [4]. A tensioned wire is placed along a longitudinal direction. An error field of multi-pole magnet is estimated by detecting a vibration of the wire excited with AC current. The wire position, where no vibration is excited, is defined as the magnetic center. If a time fluctuation in the resonance frequency is negligibly small, a magnetic field is estimated by an amplitude of only one wire vibration at the resonance frequency.

However, the resonance frequency easily drifts due to temperature change, etc. To trace the resonance frequency at all times, we developed a frequency feedback system. It is necessary to trace the resonance, even when the wire is set in the vicinity of the magnetic center where the magnetic field is nearly zero. Here we propose to install one or two additional wires tensioned by same weight parallel to the original wire. We discuss the effectiveness of it for quick and reliable alignment.

METHOD

Amplitude and phase of a wire vibration A(ω), and $\phi(\omega)$ near its resonance frequency are shown as [5],

$$A(\omega) = \frac{a}{\sqrt{(\omega^2 - b^2)^2 + c^2\omega^2}} \tag{1}$$

$$\phi(\omega) = \tan^{-1}\frac{c\omega}{\omega^2 - b^2} \tag{2}$$

where b, and c are resonance frequency [rad/s] and damping constant [s^{-1}], respectively. Magnetic field at the wire is estimated by coefficient a [m/s^2] [6]. Change in the resonance frequency can be estimated by measuring the phase of the wire vibration because the phase is $\pi/2$ [rad] at the resonance. From Eq. 2, the change in the resonance frequency $\Delta\omega$ [rad/s] is expressed as following equation.

$$\Delta\omega \cong \frac{c}{2\tan\phi(\omega)} \tag{3}$$

Set frequency of the supplied current was traced to the resonance frequency by controlling the phase of itself using Eq. 3. We shall call this process "primary feedback".

A 1.95-m length Be-Cu wire with 0.2-mm diameter was prepared as a field signal wire. One end of the wire was fixed, and a weight of 2 [kg] was hanged at the other end of it. Nominal fundamental resonance frequency is $2\pi\times70$ [rad/s]. Supplied current of the wire was generated by an arbitrary waveform generator. Wire positions in horizontal and vertical directions were measured by laser sensors (KEYENCE Ltd, IB-05) placed at the longitudinal position of 0.33 [m] from the fixed end. The amplitude and the phase of the wire vibration at the set frequency were picked up by a lock-in-amplifier. A test dipole magnet was placed at the center of the wire in longitudinal direction. Maximum integrated field of the magnet is 2×10^{-3} [T] $\times$ 0.15 [m].

When the wire is set in the vicinity of the magnetic center, the signal strength is not enough for the primary feedback. In addition, a polarity of the phase is frequently changed in the quadrupole field. Second wire was installed in parallel to the above the signal wire as designated wire for the feedback, which we shall call "feedback wire". Distances between the signal wire and the feedback wire are 5 [mm] in horizontal and vertical directions (Fig. 1). The set frequency of the supplied current of the signal wire was traced to the resonance frequency by controlling the phase of the feedback wire. We shall call this process "secondary feedback". A magnetic field excited by the feedback wire is superimposed. Although the extra field is supposed to be in the order of 1×10^{-6} [T] at the signal wire, we here propose a possibility to install the third wire, which we shall call "counter wire", to cancel the extra field in case the field is not negligibly small. We discuss the necessity in the following.

Five or more quadrupole and sextupole magnets are placed between neighboring two bending magnets at typical low emittance ring [1]. When magnetic centers of these magnets are measured by one wire system, it is necessary to select a

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higher order resonance to get high S/N ratio since sensitivity of the vibration measurement depends on the longitudinal position of both the sensor and the magnet. Hence, above two kinds of feedback were tested at the 1st, 3rd, 5th, and 7th resonance frequencies.

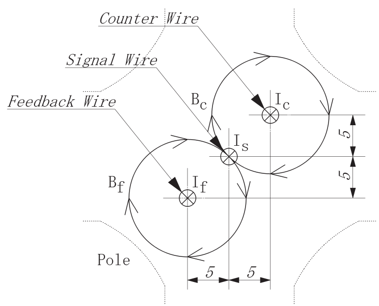

Figure 1: Cross sectional view of multi wires. I_s, I_f, and I_c indicate supplied currents for the signal wire, for the feedback wire, and for the counter wire, respectively. B_f, and B_c indicate magnetic fields by I_f, and I_c, respectively.

MEASUREMENTS

Frequency responses of the amplitude and the phase for both the signal wire and the feedback wire were separately measured near their resonance frequencies. To estimate an influence of the field excited by the feedback wire, the responses for the signal wire were also measured when the supplied current of the feedback wire was turned on at its resonance frequency.

To observe a time fluctuation, the amplitude and the phase were measured every 1 [s] at the original resonance frequency without the feedback for both the signal wire and the feedback wire. An moving average values in 100 [s] was recorded for 6 hours. Next, same measurement was performed with the primary feedback every 200 [s] using the averaged phase. Based on the result, a correlation coefficient between the resonance frequency of the signal wire and that of the feedback wire was calculated. Finally, same measurement was performed with the secondary feedback using the coefficient.

RESULTS

Influence of the Feedback Wire

The frequency responses of the amplitude and the phase for the signal wire are shown in Fig. 2 near the 1st resonance frequency. Upper figure shows the responses when the supplied current of the feedback wire was turned on with its resonance frequency. Result of a least squires fitting, the coefficients a, b, and c in Eq. 1 were (2.02±0.03)×10^{-3} [m/s^2], 2π(70.641±0.002) [rad/s], and 0.89±0.02 [s^{-1}], respectively. The coefficient c in Eq. 3 was 0.80±0.01 [s^{-1}].

Lower figure shows the responses when the supplied current of the feedback wire was turned off. The coefficients a, and c in Eq. 1 were (2.07±0.03)×10^{-3} [m/s^2], and 0.87±0.02 [s^{-1}], respectively. These values were agreed with the upper values within the fitting error. For the higher order resonance of 3rd, 5th and 7th, any differences over the fitting error were also not observed between above two conditions. Since the field excited by the feedback wire were negligibly small, the counter wire was not installed here.

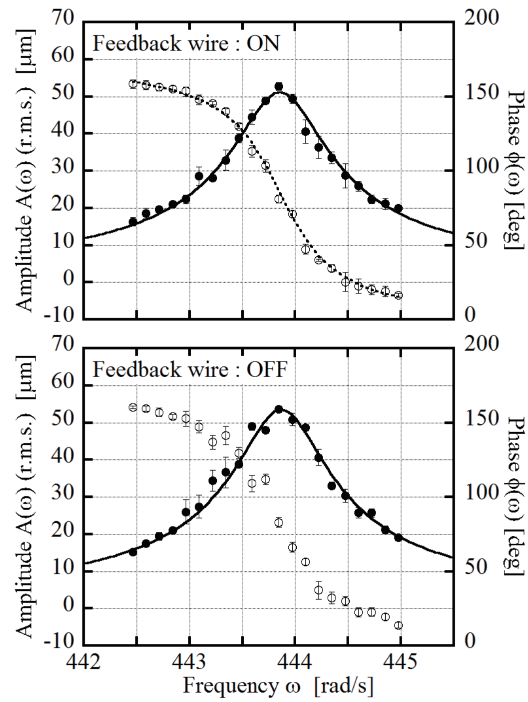

Figure 2: Frequency responses of the amplitude and the phase for the signal wire vibration near the 1st resonance frequency. Error bars indicate one standard deviation of ten measurements. Solid and broken lines indicate results of the least squires fitting with Eq. 1, and Eq. 3, respectively

Frequency Feedback of Supplied Current

An example of the time fluctuations in the amplitude and the phase for the signal wire are shown in Fig. 3 at the 3rd resonance frequency. Upper figure shows the fluctuations without the feedback. The amplitude decreased to 1/2 in 1.8 hours. Lower figure shows the fluctuations with the primary feedback. The phase was -91±12 [deg] and the amplitude fluctuation was suppressed to 4 [%] in 6 hours.

Correlation between the resonance frequency of the signal wire and that of the feedback wire is shown in Fig. 4. The correlation coefficient was 0.996. In case of the secondary feedback, the phase was -96±13 [deg] and the amplitude fluctuation was 4 [%] in 6 hours.

DISCUSSION

With the primary feedback, a magnetic center position was measured using a typical quadrupole magnet (30 [T/m] × 0.1 [m]) installed on a remote-controlled stage. The quadrupole magnet was placed instead of the test dipole magnet. The supplied current was 115.9 [mArms] at the 1st resonance frequency. The magnet position was separately scanned in

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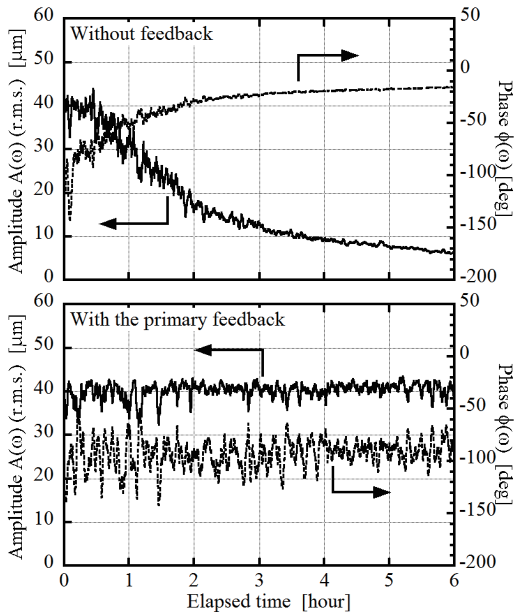

Figure 3: Example of the time fluctuations in the amplitude and the phase for the signal wire at the 3rd resonance frequency.

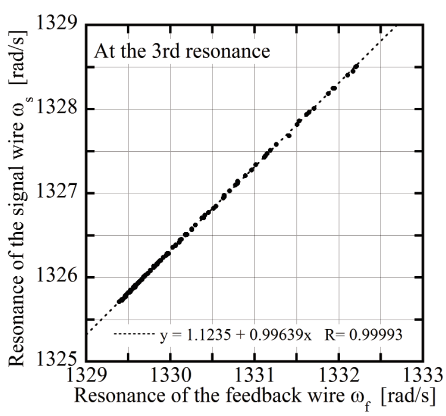

Figure 4: Correlation between the resonance frequency of the signal wire ω_s and that of the feedback wire ω_f. Broken line indicates result of least squires fitting with a linear function.

horizontal and vertical directions with 1-μm step. Position dependences on the vibration amplitude for the signal wire were obtained. To estimate a repeatability, the scan was repeated three times every 20 [min] for each directions.

Figure 5 shows the vertical position dependence on the vertical vibration amplitude of the wire. Amount of the amplitude change was 2.8 [μm] per 1-μm step of the magnet position. Because one standard deviation of the measurement was 0.2 [μm], a position resolution was estimated to be 0.1 [μm], which is equivalent to the field of 3×10^{-6} [T]. Same result was obtained by the horizontal position dependence. Furthermore, the detection limit can be improved since the maximum supplied current was 1.7 [Arms] if the temperature rise was limited up to 20 [K].

The vertical magnetic center was changed 0.7 [μm] in three measurement. Drifts of the magnetic center in horizontal and vertical directions were observed with the secondary feedback for 24 hours. An air temperature variation was ±0.25 [K] in this period. The amount of the drifts in horizontal and vertical directions were ±3.0 [μm], and ±2.5 [μm], respectively. Since only the secondary feedback can measure the drift, it is expected that important specifications, i.e. materials of the girder, stability of the air temperature, etc, for future light sources are determined using this system.

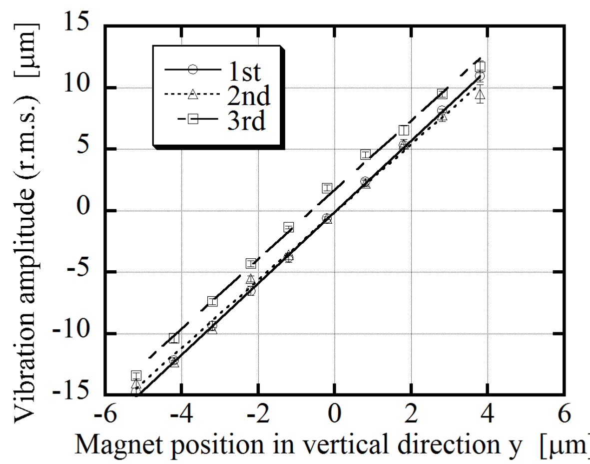

Figure 5: Vertical position dependence on the vertical vibration amplitude of the signal wire. Position of the magnetic center of the 1st turn is defined as the origin in horizontal axis. Error bars indicate one standard deviations of ten measurements, but invisibly small. Lines indicate results of least squires fitting with a linear function.

SUMMARY

The vibration amplitude of the wire drifts in the constant field because the resonance frequency is changed. It was shown that the drift was effectively suppressed by the frequency feedback. Second wire, installed in parallel to the signal wire, enable the feedback even if the signal wire is set in the vicinity of the magnetic center. Position of a magnetic center and a drift of it were measured for a typical quadrupole magnet. The resolution of the position and the detection limit of the field were discussed.

REFERENCES

[1] NSLS-II preliminary design report, http://www.bnl.gov/nsls2/project/PDR/.

[2] The MAX IV Detailed Design Report, http://www.maxlab.lu.se/maxlab/max4/DDR_public/index.html.

[3] L. Liu et. al., Proc. of IPAC2013, (2013) 1874-1876, Shanghai, China.

[4] A. Jain et. al., Proc, of IWAA2008, (2008) 1-6, Tsukuba, Japan.

[5] A. Temnykh et. al., Nucl. Inst. and Meth. A399 (1997) 185-194.

[6] S. Kashiwagi et. al., Proc. of IPAC2012, (2012) 732-734, New