電磁石測定基準点校正のための固有振動数ワイヤアライメントシステム
EIGENFREQUENCY WIRE ALIGNMENT SYSTEM FOR MAGNET FIDUCIALIZATION

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Abstract

The SPring-8 storage ring magnets have critical alignment tolerances and in the phase of magnetic field measurement, the positions of the fiducial points on magnet need to be precisely calibrated relative to magnetic centre. We have used the laser CCD-camera system for this calibration. Recently, in renewing this system, an eigenfrequency wire alignment system is developed in view of followings. It can make continuous measurement and record the positional change due to the variation of current or temperature of the magnet. It measures all fiducial points simultaneously. The system is composed of four WPS (Wire Position Sensor), carbon wire, and wire eigenfrequency measurement devices. Aim of this alignment system is to calibrate the magnet fiducials with an accuracy of ±10 µm.

ABOUT WIRE ALIGNMENT SYSTEM

To renew existed laser alignment system we have used in the Magnetic Field Measurement Device (MFMD), the Iris Diaphragm Laser System [1] is one of the choices. While, considering the need to continuously measure the magnetic centre during magnet warm-up or variating current, we decide to use a wire alignment system.

Wire used in alignment is a historical method. At first, spring steel wire and microscope were used. The introduction of synthetic wire of Kevlar makes the distance of measurement over a hundred meters. Wire displacement measured with capacitance or optic sensor is well used nowadays. And, WPS (wire position sensor) combined with HLS (hydrostatic levelling system) makes it possible to measure both the horizontal and vertical.

We are developing an eigenfrequency wire alignment system (eWAS) for the MFMD. It is tested a very simple and accurate system.

ABOUT THE eWAS

The eWAS is composed of four WPS (FOGALE) assemblies, carbon wire, and wire vibration measurement devices. The features of this system are firstly, the sag of wire is calculated by measuring the eigenfrequency of wire. Secondly, the WPS sensors are embedded in balls made with ceramic. Figure 1 is schematic figure of this system.

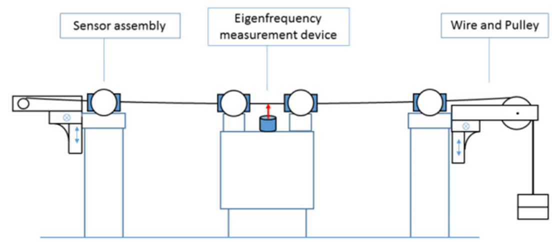

Figure 1: Schematic figure of the eigenfrequency wire alignment system (eWAS)

As an approximation, the equation of calculating maximum sag of a wire is known as

$$S = \frac{\rho g}{8T} L^2 \tag{1}$$

where, ρ is density (kg/m) of wire; T is tension (N); L is length (m), g is gravity acceleration.

And, for the wire with two fixed ends, vibration frequency of standing wave is indicated as

$$f_n = \frac{n}{2L}\sqrt{\frac{T}{\rho}} \tag{2}$$

Substituting eq. 2 for eq. 1, the sag of a wire is determined by the parameter of eigenfrequency only.

$$S = \frac{n^2 g}{32 f_n^2} \ \text{[m]} \tag{3}$$

The eWAS measures the fundamental frequency of a wire and calculates maximum sag with eq. 3.

The curve of wire is indicated by catenary. For a good approximation it is expressed with parabola.

$$y = \frac{4S}{L^2}x^2 - S \tag{4}$$

where, S is maximum sag; L is the length of wire. For simplification, the origin is defined at the middle of wire.

In the alignment the parabola is subtracted from the measurement in vertical direction. It needs not any compensation in horizontal.

As it is known, WPS sensor is well employed in position monitoring. It is usually fixed on ground or girder but rarely inserted in a ball, because of the uncertainty caused by tilts. However, we verified that embedding the WPS sensor in well machined ball makes the wire system more feasible for alignment, because it defines an actual 3-dimention reference point.

CURRENT PERFORMANCES OF THE eWAS

The eigenfrequency wire alignment system is tested for its resolution, repeatability and stability.

Resolution of the frequency and sag

From the resolution of frequency measurement, the resolution of wire sag can be deduced. According to eq. 3, resolution of sag depends on that of frequency as following.

$$\Delta S = \frac{g}{16 f_1^3} \Delta f_1$$

f_1: the fundamental frequency of wire, around 100 Hz in our case.

Eigenfrequency measurement devices we used have a frequency resolution of 0.05 Hz. Consequently, the resolution of wire sag is estimated ~ 0.03 µm.

Resolutions of the frequency and sag are verified by following experiments. 6-kg initial weight was added a nut of 15 grams in average each time. Change of frequency versus tension is shown in fig. 2 (a). It is confirmed close to the calculation. Each step of frequency increment corresponds to 0.07 µm of the sag. Figure 2 (b) shows the increment of wire sag measured with the WPS versus that of tension. Because the resolution of WPS is ~0.2 µm, not enough to detect the change less than 0.1 µm, 50-time average was taken. As a result, changes of sag in ~0.2 µm step can be seen. And, 0.6-µm in total agrees with calculated value from the frequency measurement.

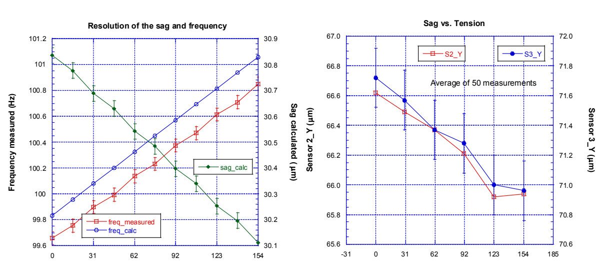

Figure 2: left (a): Verification of the resolution of frequency measurement and correspondent sag; right (b): wire sag measured with the WPS versus tension.

Centre repeatability of the sensor assembly

The repeatability of the centre of sensor assembly is important. Owing to symmetric structure of the WPS and careful adjustment of the sensor assembly, the repeatability is good even without precise levelling. With a 2mm/m round level to adjust rolling and pitching, and two indicators of slits to control the direction of yawing, the centre repeatability reaches 0.5 µm both of x and y directions (fig. 3). And, as a result of good repeatability, the centre of sensor can be adjusted within ±2µm with respect to that of ball (KYOCERA).

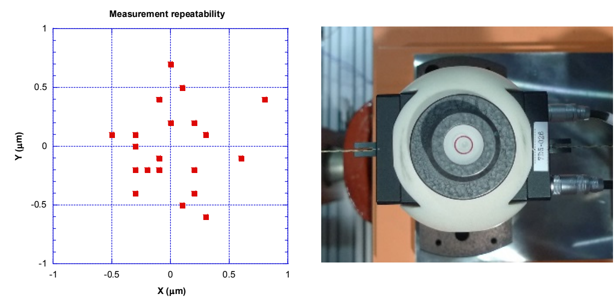

Figure 3: left (a): Centre repeatability when setting sensor; right (b): adjustment of the tilts around 3-rotation axes.

Measurement stability

Test of measurement stability of the system was taken on a 1.5-m table at the magnetic field measurement hall. Room temperature is not well controlled and varies 0.5-1 °C a day (fig. 4). Even so, measurement of the system is very stability. The noise level is 0.2 µm and the drift of measurement is about 1 µm/°C in vertical, which includes the variations of wire sag and thermal expansion of supports.

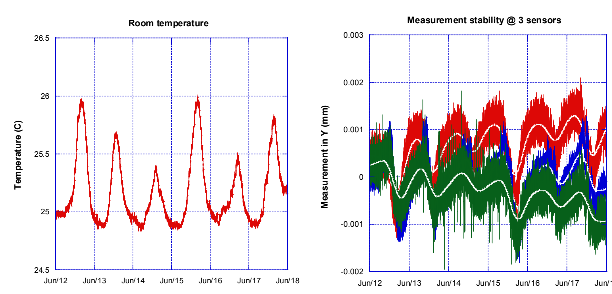

Figure 4: Measurement stability of the wire system.

APPLICATION OF eWAS TO MAGNET FIDUCIALIZATION

The advantages of wire system used in magnet fiducialization are the possibilities of measuring all fiducial points simultaneously and monitoring the position of magnet continuously.

Old laser CCD-camera system

About 820 pieces of magnets were measured for magnetic field centres before installation in 1995, including 480 quadrupoles and 336 sextupoles.

A laser CCD camera system [2] was used for the magnet fiducialization. The beam of He-Ne laser was expanded to 3-mm in diameter. Resolution of the CCD was 736 $\times$480 pixels and 8$\times$5 mm^2 in dimension. In the measurement the camera was moved manually among measurement points (fig. 5).

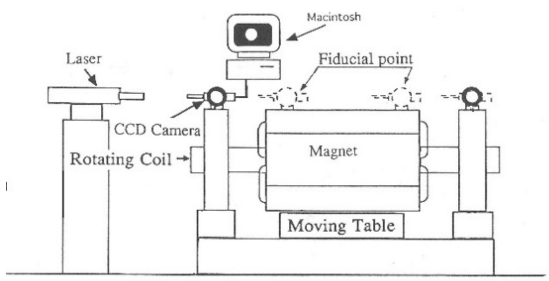

Figure 5: Old laser CCD-camera system used in magnet fiducialization.

Measurement of the eWAS in MFMD

After setting magnet on the stage of the MFMD, the wire and four sensor-embedded balls are set up on two reference points and two measurement points. The positions of magnet fiducials are measured continuously. To measure wire eigenfrequencies, the wire is pulled and then freed with hand. Forced vibration is measured with a laser displacement sensor (KEYENCE) and an oscilloscope (KEYSIGHT). Maximum sag at the middle of the wire is calculated with eq. 3. Consequently, curve of parabola of eq. 4 is obtained and used to compensate the sag of wire.

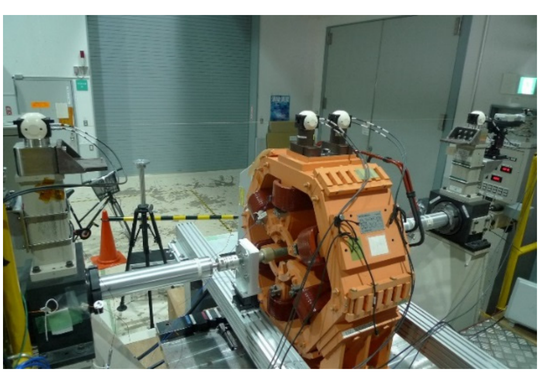

Figure 6: Set up of the eWAS on the MFMD.

Owing to the precise measurement of the eWAS, we found some facts we didn't know before.

For examples, figure 7 shows that there exist a relative positon movement between magnet and reference poles, about 5 μm (p-p) a day. It is considered coming from their different thermal expansions because of different thermal capacities. Figure 8 shows that during magnetic field measurement of the sextupole, the fiducial points drifted about 2 μm. It is because of the extension of a pole which has a coil driving motor inside.

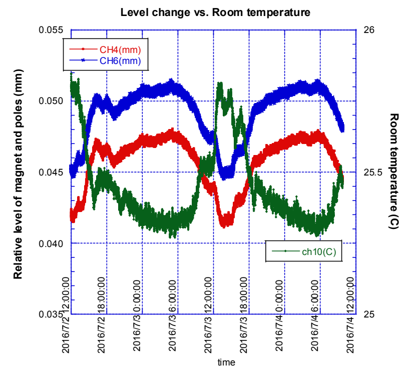

Figure 7: Without power on, the magnet is observed a daily change of height relative to reference poles.

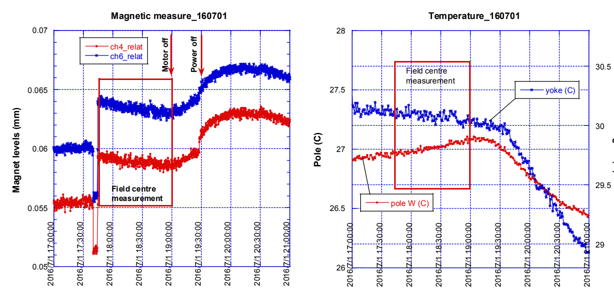

Figure 8: Magnetic measurement drifts in relation to the temperature of one of the poles.

Problem remained

The straightness of carbon wire still remained a problem. It is found that changing the wires or shifting the position of wire along longitudinal direction will lead a little difference in measurement. It is about 10μm. Other experiment [3] convinces that the nonlinearity of carbon wire is not good comparing to Cu-Be metal wire.

CONCLUSION

We have been developing an eigenfrequency wire alignment system (eWAS) for the MFMD. It is tested a very simple and accurate system. Measurement stability is about 1 μm/day and centre repeatability is ~0.5 μm. Wire sag is compensated by measuring the eigenfrequency of the wire and resolution is estimated better than 0.1 μm. Further work should be done about the straightness of the wire.

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