

# THE WIRE ALIGNMENT METHOD IN A MAGNETIC FIELD MEASUREMENT SYSTEM

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## Abstract

In the magnetic field measurement system, a single-core CuZr wire is used in both the stretched-wire (SW) and pulsed wire measurement (PWM) systems. Before measuring the magnetic field of the magnets, the CuZr wire must be aligned with the center of the magnet mechanism. The SW system is then employed to locate the magnetic field center. The traditional method involves using a theodolite and level to align the CuZr wire with the center of the magnet mechanism. However, for superconducting magnets, or any magnets installed in a vacuum chamber, aligning the CuZr wire with the center of the mechanism using traditional methods presents challenges. In this paper, we propose a method that utilizes the wire's contact with the quadrupole magnet to observe changes in resistance for positioning purposes, thereby overcoming the limitations of center alignment in chamber-surrounded magnet mechanisms.

## INTRODUCTION

Since the Taiwan Photon Source (TPS) began operations, several types of magnets have been installed in the NSRRC storage ring. Before installation, it is crucial to fix the magnetic field and the first and second integral field within a specific range for each magnet. For magnetic field measurement, the most commonly used device is a Hall probe. For integral field measurement, several methods involving single wire or closed-loop wire [1] are well-known and applied based on the appropriate conditions of the magnet mechanisms. Generally, the theodolite and spirit level are commonly used to align with the mechanism's center before magnetic field measurement. After identifying the magnetic field center [2], an alloy wire is then aligned using the theodolite and spirit level, which are aligned with the magnetic field center plane. This alignment process is typically used for atmospheric magnets.

With the need for higher energy and the use of higher harmonics, in-vacuum type magnets are designed for installation in the storage ring to achieve the x-ray conditions required by users [3]. Due to the restrictions between the upper and lower permanent magnet arrays, the chamber and gap size make alignment using the theodolite and spirit level difficult before field measurement. Furthermore, after sealing the ends of the chamber with flanges and initiating a high vacuum state for measurement, checking the alignment condition with theodolite and spirit level becomes much more challenging.

In this paper, we apply a wire alignment method that utilizes resistance variation to check the magnet mechanism center position without relying on the theodolite and spirit level. This allows us to implement the alignment method

for in-vacuum type magnets, reducing the difficulty of achieving alignment in a vacuumed state.

## CIRCUIT DESIGN OF RESISTANCE VARIATION

In this experiment on wire alignment, we observe resistance variation by the wire contacting the edge of the magnet (see layout in Fig. 1). The resistance is measured and monitored using a resistance meter (RM, RM3545A, HIOKI). A 33 k $\Omega$  resistor ( $R_{Ref.}$ ) is design in the loop as a reference, which connected to the magnet ( $R_M$ ) in a series circuit to ensure that if the resistance of magnet is too low to be observed. Before alignment, when the wire ( $R_W$ ) is open in the loop, RM reads near 33 k $\Omega$  due to the sum of  $R_M$  and  $R_{Ref.}$  in circuit. When the wire contacts the magnet during alignment, the total resistance measurement changes significantly over a thousand times.

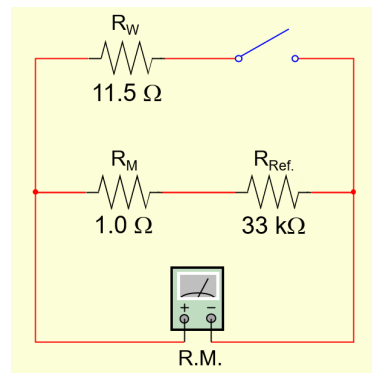


Figure 1: Layout of wire alignment with the RM.

This layout can be regarded as a parallel circuit (see Fig. 2) when the  $R_W$  loop is close (contacted). In a parallel circuit, the total resistance can be calculated and predicted by using the Eq. (1) below:

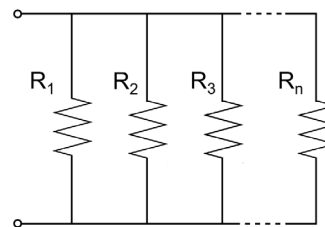


Figure 2: Example of parallel circuit loop.

$$R_{total} = \frac{1}{\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots + \frac{1}{R_n}\right)} \quad (1)$$

The total resistance is 33 k $\Omega$  before wire alignment; the total resistance decreases to about 11.5  $\Omega$  when the wire contacts the magnet. An obvious change in total resistance

allows the wire, which mounted on stages, to align with precision during the process. The measured resistant values of  $R_W$  and  $R_M$  are  $11.5 \Omega$  and  $1 \Omega$ , respectively.

## EXPERIMENT SETUP AND METHOD

In this experiment (see Fig. 3), a copper zirconium wire (CuZr, Nano-fibrous Hypoeutectic Copper–Zirconium alloy, NGK INSULATORS, Ltd.) is mounted on motorized stages that consist of x-axis and y-axis (OSMS26 200-X/100-Z, OptoSigma). An integrator (PDI 5025, Metrolab) is connected in loop (L1) of the stretched wire measurement system, which can also be switched to the wire alignment loop (L2). The wire tension is adjusted to 6 N using a tension meter (LRK-100 N, NTS Technology Co., Ltd.) via a PEEK adaptor, which is mounted on a linear stage (TAMM100-50C, OptoSigma) via a PEEK adaptor, with the linear stage directly mounted on DS stage [4]. In a similar way, the other end of wire is mounted on US stage via a PEEK adaptor.

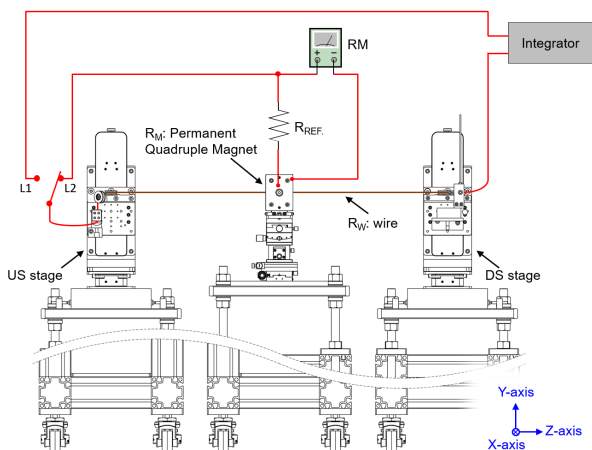


Figure 3: Experiment setup of (L1) stretched wire measurement system and (L2) wire alignment with resistance meter.

A permanent quadrupole magnet (PQM) [5] is settled between the US and DS stages. The CuZr wire is planned to contact the shim edge of pole tip region (shown in Fig. 4 A), which is suitable for implementing wire alignment due to the symmetry geometry around the magnetic field center. According to the four-pole structure, there are 16 contact positions (a to h and a' to h') that can construct the mechanical center position of the PQM, via stepping position of the US and DS stages. A real-time Labview program monitors resistance variation; the motorized stage stops moving when the resistance changes due to the wire contacting the magnet. With these 4 sets of coordinates of contact positions (see blue dash line in Fig. 4 B), a mechanical center line is determined through simultaneous linear equations calculation. However, the aligned mechanical center line requires at least one repetition of the contact alignment procedure to optimize the aligned position, approximating the actual mechanical center position. In our case, the difference is below  $10 \mu\text{m}$  from the center position to positions a-a' and b-b' after the last alignment.

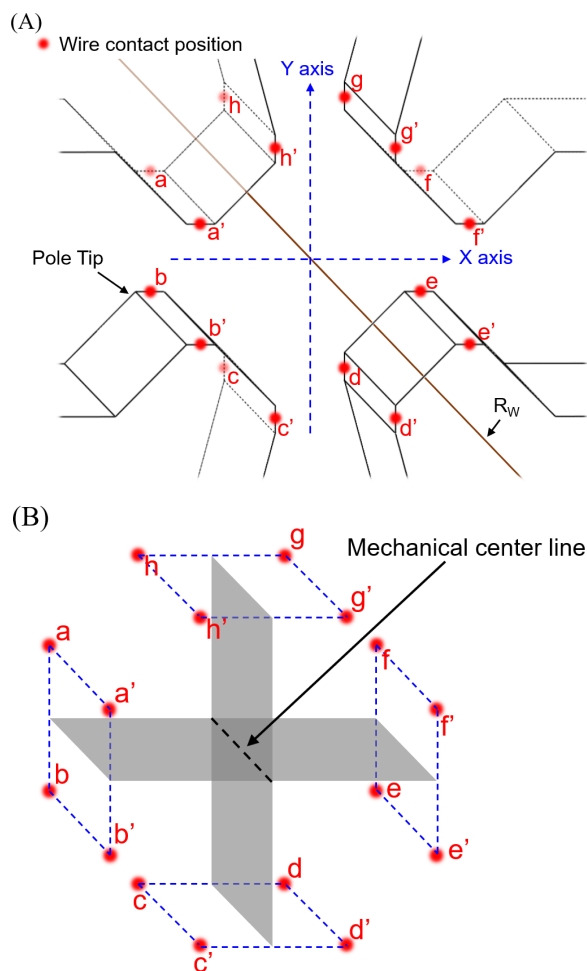


Figure 4: (A) Detail of the quadrupole magnet pole and contact position at the pole tip; the wire is ordered to touch the pole tip from a-a' to h-h'. (B) A simple schematic for collecting 16 contact positions (coordinates) to construct the mechanical center line (US and DS x/y position).

## EXPERIMENTAL RESULT

In wire alignment, we compare the stretched wire measurement [1] results from two alignment methods: (a) the traditional method using theodolite and spirit level (T-method), and (b) the resistance variation method (R-method). After wire alignment, we measured the horizontal ( $I_{1x}$ ) and vertical ( $I_{1y}$ ) first integral fields in the y-scan and x-scan directions, respectively. The range for each scan procedure is  $\pm 3.6 \text{ mm}$  from aligned center position, constrained by the magnet structure. With linear fit analysis of the integral field measurement, the center position of the magnetic field (defined as 0 gauss) can be obtained through the fitting line condition. In Fig. 5 (A), the 0-gauss position is  $0.025 \text{ mm}$  and  $0.015 \text{ mm}$  away from the mechanical center with T-method and R-method, respectively; and in Fig. 5 (B), the 0-gauss position is  $0.042 \text{ mm}$  and  $0.008 \text{ mm}$  away from mechanical center with T-method and R-method, respectively. The linear fitting range is  $\pm 2 \text{ mm}$ , which represents an ideal fitting line with the  $R^2$  value above 99.9%. The tolerance of T-method represents the limit of theodolite and spirit level, with a

precision of about 20-50  $\mu\text{m}$ ; the R-method shows lower deviation (under 20  $\mu\text{m}$ ) in the aligned center position to 0-gauss position.

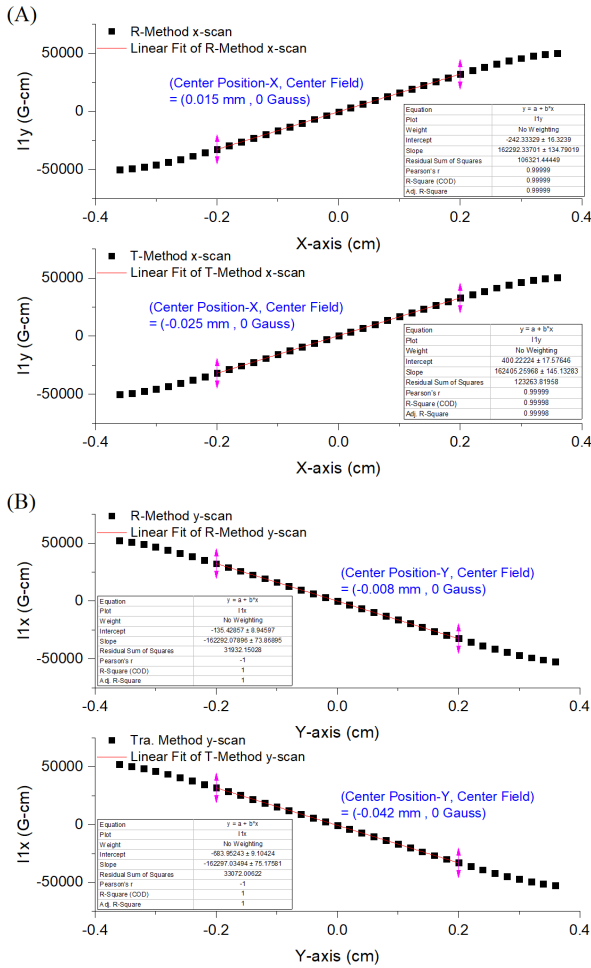


Figure 5: First integral measurement by the stretched wire measurement system; and linear fitting conditions for each measurement. Comparison of T-method and R-method with measurement (A)  $Ily$  in x-scan and (B)  $Ilx$  in y-scan.

## CONCLUSION

A wire alignment method based on resistance variation has been verified as feasible in stretched wire measurement with a permanent quadrupole magnet. The precision of this alignment method appears to be better than that of traditional methods using theodolite and spirit level. During the entire alignment process, we observed that this is a non-subjective method, as the resistance changes sensitively when the wire comes into contact.

Basing on this alignment method and experimental experience, we can apply it to magnetic field measurements of in-vacuum undulators (e.g., cryogenic permanent magnet undulators) in the future to overcome the difficulties posed by chamber-surrounded magnets (or undulators).

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