A PRECISION CALIBRATION SET-UP FOR AC MAGNETIC FLUX DENSITY MEASUREMENT IN THE RANGE OF 1 Hz TO 20 kHz

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Abstract – A precision generating and measurement system of AC magnetic flux density was developed by using a linear low-frequency AC magnetic field converter, a quartz Helmholtz coil, a voltage comparator, a multimeter, a standard resistor, and a computer with a program for automatic measurement. The expanded uncertainty ($k=2$) of the calibration system is less than 0.2 % over the frequency range of 1 Hz to 20 kHz.

Keywords: AC magnetic flux density, Calibration

1. INTRODUCTION

Recently, social interest is enormously stressed in the area of low-frequency electromagnetic field because of its harmfulness to people, particularly in the power line frequency[1]. In order to fulfill the increased demand for precise measurement of AC magnetic flux density(MFD), we developed a novel calibration set-up for precise generation and measurement of low-frequency AC MFD. Here we report on a precision calibration set-up newly developed for magnetic flux density measurement in the frequency range of 1 Hz to 20 kHz.

According to the well-known Faraday's law, the generated output voltage U_B of an induction sensor under application of sine-wave-shaped magnetic induction B can be expressed as follows:

$$U_B = 2\pi \cdot f \cdot k_{sw} \cdot B, \tag{1}$$

where f is the frequency and k_{sw} is the winding area of the induction coil.

However, in the practical realizations of the induction method, there is a trade-off between the necessity for a high k_{SW} value (a large number of windings or large winding geometrical size) for the expansion of the frequency range downwards and a high resonant frequency (a small number of turns or small geometrical sizes) for the expansion of the frequency range upwards. These trade-off effects are overcome in the developed linear low-frequency AC MFD converter (LFMFC), which consists of an electronic secondary converter and transforms frequency-dependent induction signal of the induction sensor to frequency-independent output voltage U_{out} (Fig. 1).
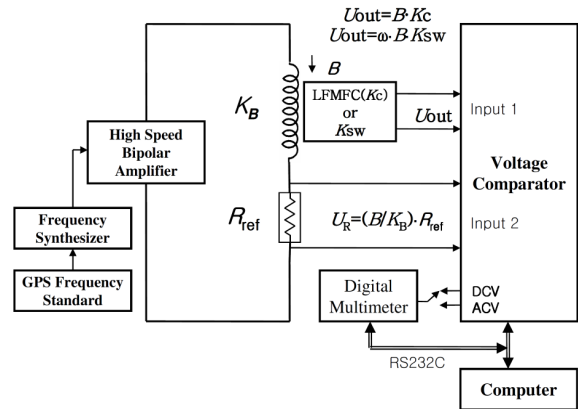

Fig. 1. Schematic block diagram of the AC magnetic flux density calibration system.

2. CONSTRUCTION OF A QUARTZ HELMHOLTZ COIL

A quartz tube is used to build a Helmholtz coil former. The former had a 234 mm length, 350 mm diameter, 35 mm thickness, and 1 mm pitch with a helical groove. The 54 number of turns in the each Helmholtz coil sections is equal (Fig. 2).

A former was fabricated by grinding and lapping processes. A rough cylindrical tube was mounted on a lathe between the head and tailstocks. The precision surface of the tube was obtained by a diamond-grinding wheel, mounted on the carriage. The helical groove of 1 mm pitch was machined by a diamond screw wheel in the same lathe. The temperature-controlled grinding fluid was showed on the surface of the former during the machining. The depth of the groove is estimated to 0.3 mm after final screw grinding(Fig. 3).

Several times the quartz cylinder was cleaned, and a measurement was taken of the radius and the pitch by a three-dimensional machine, equipped in the Length group at KRISS. This machine is able to measure the surface variations and the distance from the reference point, that is, radius and pitch, with a resolution of ± 0.2 μm. The variations of surface and pitch were measured to be within 1.0 μm.

We have wound the gold-plated wire along the groove of a former. The wire diameter is measured to be (810.0 ± 0.2) µm. After wire winding, there was no noticeable change in the dimensional variation between the former and Helmholtz coil. Figure 4 show photograph of the constructed a Helmholtz coil.
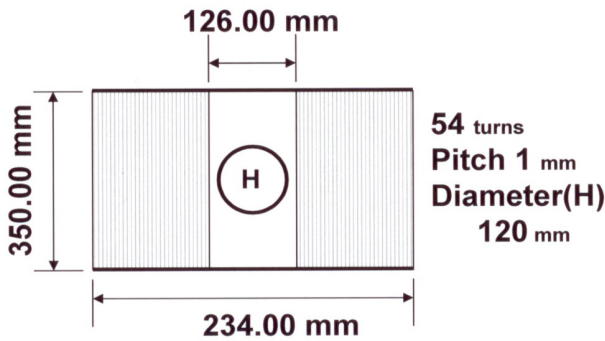

Fig. 2. Configuration of the designed a Helmholtz coil.

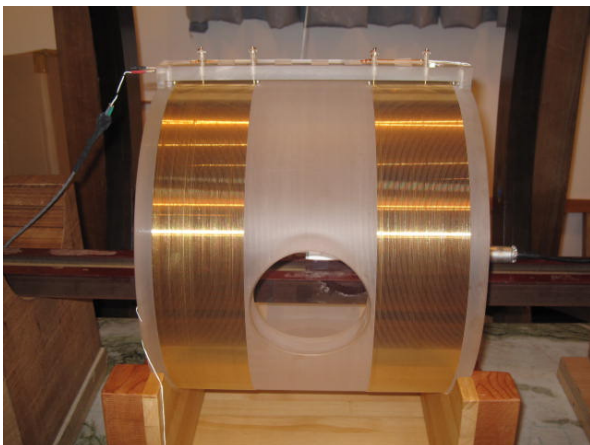Fig. 3. Photograph of pitch shape in Helmholtz coil former.

Fig. 4. Photograph of the constructed a Helmholtz coil.

3. APPARATUS

For precise measurements of AC MFD and convenient use of the calibration system, a LFMFC and a voltage comparator were designed and developed.

Figure 1 shows a schematic block diagram of the AC MFD calibration system. The apparatus consists of a Helmholtz coil, a LFMFC, a standard resistor, a voltage comparator, a digital multimeter, a synthesizer, and a power amplifier. Here the following symbols are used: B is the magnetic flux density of standard coil, R_{ref} represents the standard resistor, k_C denotes the conversion coefficient of the LFMFT.

The main application of the LFMFC is precise conversion of an AC MFD to AC voltage and precise measurements of an AC MFD together with a AC voltmeter [2][3]. The total conversion coefficient becomes close to the value of 100 µV/nT, which allows a direct readout of a MFD in using the indications of the voltmeter.

The DC coil constant was measured by Cs-He atomic magnetic resonance(AMR) magnetometer, standard resistor, Zener voltage standard, and current source. The coil constant at the center was 272.7115 µT/A in agreement with the calculation result within 0.1 %.

The voltage comparator is used to improve the accuracy and to automate the calibration process of AC MFD measurement instruments. It contains a switchboard with channels, a differential preamplifier, a precision rectifier, second- and fourth-order Butterworth low frequency filters, a built-in voltmeter and a RS232C interface. The second- and fourth order filters can be used to form a sixth-order filter.

The operation principle of the voltage comparator is a combination of the LFMFC output voltage U_{out} and voltage U_R of a standard resistor R_{ref}. Thus, if the value of the resistance R_{ref} is selected so as to satisfy equality $R_{ref} = k_C \cdot k_B$, the result will be $U_R = U_{out}$, i. e., the two output voltages will be equal, where the error of the voltmeter is excluded from the results of the measurements. For the calibration of the measuring coil to ensure that $U_R = U_{out}$, the value of R_{ref} should be found according to the condition: $R_{ref} = \omega \cdot k_{sw} \cdot k_B$.

The voltage comparator has also a manual mode that can be used for low accuracy measurements with the built-in voltmeter. The basic operating mode of the voltage comparator is comparison to that of the voltmeter in mode of the DCV.

The digital multimeter is used to measure the AC or DC voltage and also for measurement of frequency of the AC voltage. Therefore, at frequencies above 10 Hz, the ACV mode of the voltmeter is typically used.

Operation of the voltage comparator and the voltmeter is controlled by a personal computer (PC) over a RS232C interface. A PC program allows the execution of the following operations: measuring the voltage from the output of the LFMFC or the measuring coil, measuring the voltage across the standard resistor, and measuring the AC MFD frequency. It is also used to calculate the coil constant k_B or the constant k_{sw} of the measuring coil at the chosen frequency. Fig. 5 shows photograph of coil constant measurement.

Figure 6 reveals the measured coil constant of the Helmholtz coil as a function of frequency (a) and standard deviation of the 10 measurements (b) in the range of 1 kHz to 20 kHz.

Fig. 5. Photograph of coil constant measurement.

Fig. 6. Measured coil constant of the Helmholtz coil (a) and standard deviation of the 10 measurements (b).

4. CONCLUSIONS

The precision low-frequency AC MFD measurement system was developed by KRISS in collaboration with VNIIM to setup for the primary standards of magnetic units [4][5]. The non-linearity of the k_C in the frequency characteristic was less than 0.05% in a range of 1 Hz to 20 kHz. An extended measurement uncertainty($k=2$) of the calibration system was less than 0.2 % obtained through the application of a LFMFC, a voltage comparator and standard AC MFD measuring coils in conjunction with standard AC resistors and a voltmeter.

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[5] Po Gyu Park et al., "Construction of AC-DC Magnetic Field Standard Systems and Results of International Key Comparison", *J. of Korean Magnet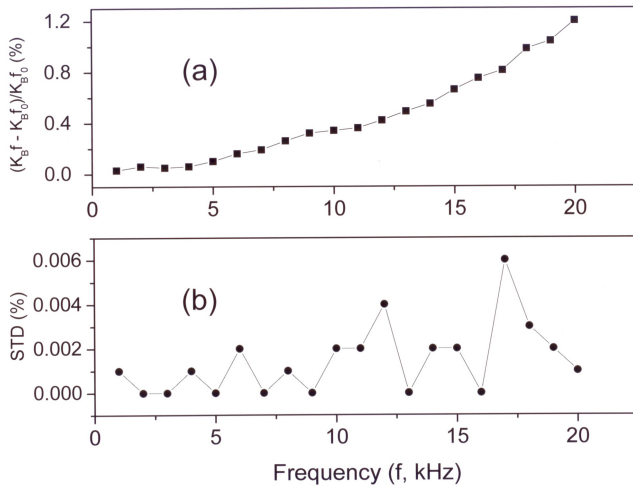ic Society,* vol.14, no.3, pp.201-206, Dec. 2004, (Kor).