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APPLICATION OF AMORPHOUS CORE TO DC BEAM MONITOR

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Summary

The dc beam monitor based on the second harmonic modulator-demodulator for the ion beam storage ring have been developed. The dc beam monitor consists of the Co-based amorphous core, lock-in amplifier and alternative current driver. To attain the superior signal to noise ratio, the core noise reduction has been examined. The beam test have been carried out with the RFQ linac 'TALL' at INS.

Introduction

The measurement of circulating beam in the TARN-II[1] is to be carried out for a long time because of the beam cooling experiments. One of the beam monitors for that experiments is dc beam transformer to measure the debunched beam current. The dc transformer is based on the magnetic modulator-demodulator developed by Williams and Noble[2]. The second harmonic of AC drive frequency which saturates the core with square B-H loop is measured and their phase difference in proportion to the dc beam current is detected.

The dc beam transformer developed by Unser[3] attained the current sensitivity of 1 μA of the storage beam in the ISR. They used the laminated troidal core with a high permeability and low coercivity. Recently, the alloy metal technology developed the magnetic core material without the crystalloid configuration such as a cobalt based amorphous alloy. To realize the high resolution of dc current measurement, the use of that alloy metal providing the capabilities of high permeability and low noise characteristics was proposed[4]. Then we have done the test of both the small core and the large core with geometry size of 1/2 model of TARN-II beam monitor to be constructed. The test of that core was made to evaluate the dB/dH and the gain of 10 $V/A\times cm^2$ was obtained.

The magnetic noise due to the Barkhousen noise was measured and noise reduction method was also investigated. The rms noise components are decreased in accordance with the increase of lamination density[6], AC drive frequency[7] and core temperature[8], respectively. We have examined temperature dependence of the noise with a point of view of the improvement of sensitivity of that monitor. However, the increase of drive frequency and lamination density are effectively served to decrease the noise, we have not tested because of strategic restriction of the measurement system.

Table 1. Design parameters of the dc beam monitor

Dimensions of large core(mm)	186 OD x 148 ID x 20 H
Maximum permeability	10^6 at dc
Coercivity (H_c	0.4 A/m at dc
Curie temperature	270 deg.
Crystallization temperature	540 deg.
Strip thickness	20 μm
Dimensions of vacuum chamber	4" x 500 L
Thickness of magnetic shield	2 mm
Temperature control	-20 deg to +70 deg

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The 1/2 model of the monitor system have been developed and tested with RFQ linac 'TALL' at INS[9]. The developed system aimed the current sensitivity of 1μA. The noise reduction tests above mentioned technics are being carried out, respectively.

dc transformer

The circuit diagram of measurement system and the cross sectional view of the dc beam monitor are shown in Figs.1 and 2. In Fig.1, the AC drive, sensing, feedback and calibration wires are wound around each troidal core and connected between them. The troidal core is a ferromagnetic material with square B-H loop and driven by the alternative current in order to produce the symmetrical polarizing field. The asymmetrical distortion of the flux wave caused by steady polarization H_0 (by passed beam) of the ferromagnetic core generates the phase shift of second harmonic components of the AC drive frequency.

For small phase shifts the amplitude of this resultant is proportional to the product of phase shift and amplitude of individual components of the second harmonic frequency. The phase shift of second harmonic component does not change unless H_0 reverses in sign, in which case the output changes in phase by 180 deg. This fact enables a phase-sensitive method of rectification to be employed after amplitude.

The phase sensitive amplifier was represented by the lock-in amplifier. In Fig.1, the band pass filter in the lock-in amplifier eliminates the fundamental and odd harmonics so that the phase sensitive rectifier do not produce errors. The AC drive signal was generated by the combination of the digital function generator for sinusoidal voltage source, 50 W AC amplifier and air cooled 50 ohm resistor. Then the AC drive current acts as a sinusoidal wave and can be viewed as a current source. The current was so chosen as to magnetize the troidal core sufficiently around the maximum signal to noise ratio of the second harmonic.

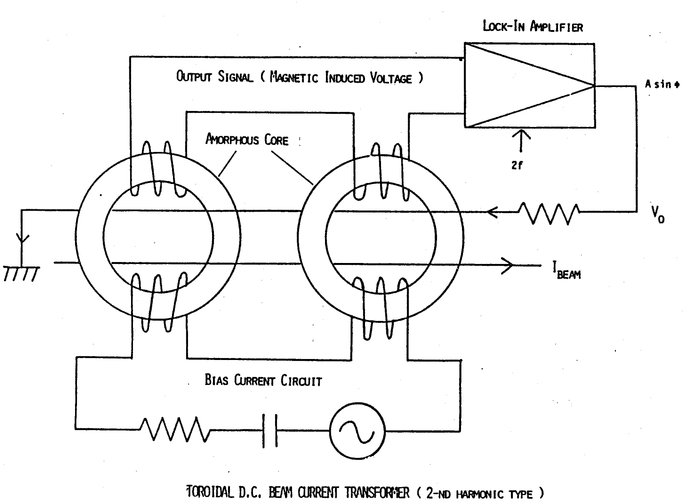

Fig.1 The block diagram of the dc beam monitor. The two cores for beam sensing are driven by the alternative current and their second harmonic components are detected by the lock-in amplifier.

In Fig.2, the dc beam monitor is composed of 4" vacuum chamber with insulating ring, troidal cores, Cu-plates, electro-magnetic shield and signal feedthroughs. The geometry size of the troidal core are 186 mm in outer diameter, 148 mm in inner diameter and 20 mm in thickness, respectively.

The troidal core was housed in the black-phenole case and sealed with the silicon compound. The troidal core is Co-based type amorphous alloy. Degree of the fluctuations of B-H loop in Co-based amorphous core is about one tenth of that in Fe-Ni based type and the magnitude is reduced at high frequencies of excitation current[10]. We chosen the drive frequency of 490 Hz because the second harmonic frequency of 980 Hz coincides with the spot of frequency spectrum of the thyristor noise generated by the bending magnet power supply.

The sensing wires are combined inversely so as to cancel the fundamental or odd frequency components of the higher harmonics. The magnetic shield was composed of the permalloy (Tokin-TMC-V) with 2 mm thickness and attenuates the external magnetic noise such as the terrestrial magnetism and strangeness magnetism and so on. The insulation ring cuts the one turn loop composed of vacuum chamber and electro-magnetic shield. The vacuum chamber is to be used under the pressure of lower than 10^{-8} Torr.

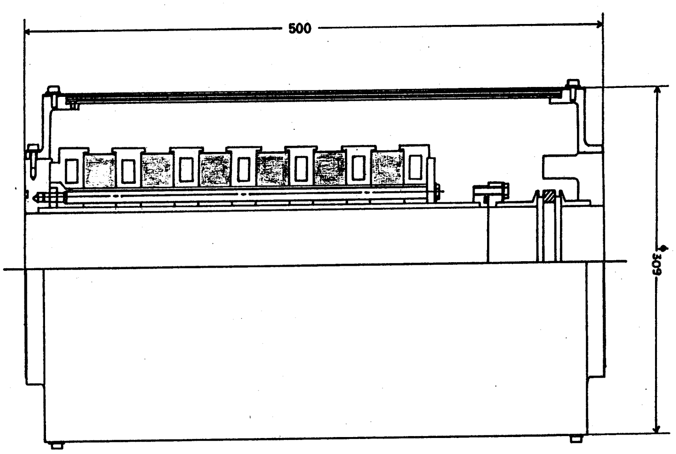

Fig.2 Cross sectional view of the dc beam monitor. The beam detection cores are mounted around the 4" vacuum chamber and piled up together with the copper plates alternatively.

Evaluation of noise and gain

The calculation of Barkhousen noise presents a very difficult and usual problem. The noise arises from the random timing of the events which are regarded as statistical fluctuations. Then the core noise caused by fluctuations in every cycle of the dynamic B-H loop has been measured for the change of magnetizing force and core temperature of the small core. On the other hand, the two second harmonics shown in Fig.1 are not perfect sinusoids but have both phase and amplitude flatter. They do not cancel exactly and a residual noise-spectrum remains. The residual noise-spectrum is passed by the band pass filter to the lock-in amplifier and results in an output-noise spectrum near zero frequency. The Figure 3 shows the resultant of noise measurement as a function of magnetizing force.

The small core test concerning noise evaluation is described below.

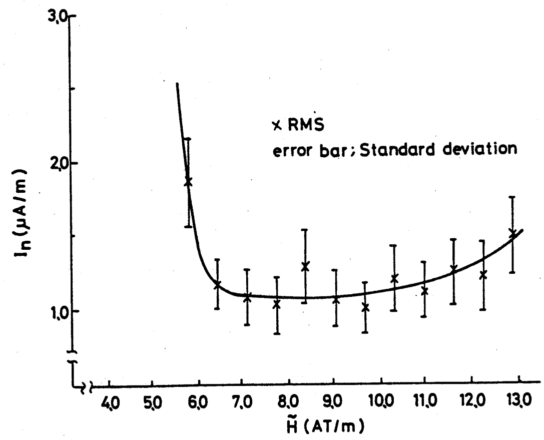

Fig.3 Magnetic core noise of large core as a function of magnetizing force.

In Fig.4, the measurement system of temperature dependence of the noise and gain is shown. The sample (Toshiba MA26) was heated in the silicon oil bath (Toray SH705). The temperature dependence of the current gain is shown in Fig.5. The peak of the gain is concentrated around the H_{peak}/H_{sat} = 1.45. The rms core noise was also measured as a function of the core temperature. The core temperature was increased up to 213 ℃. The measurement result shows that the core noise at maximum temperature was one tenth of room temperature.

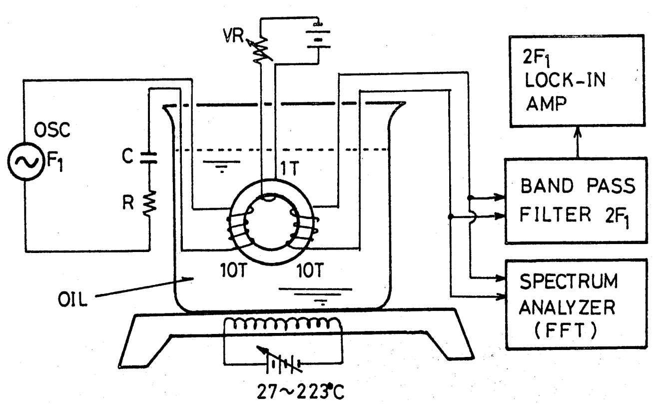

Fig.4 Measurements of temperature dependence of the noise and gain.

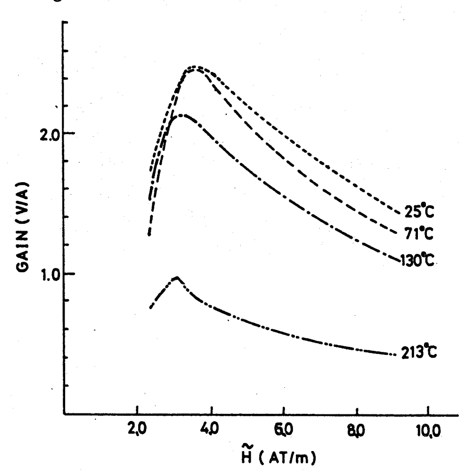

Fig.5 Temperature dependence of the gain as a function of magnetizing force.

Beam test

The 1/2 model dc transformer have been tested with an ion beam from the RFQ linac 'TALL' at INS. The TALL can accelerates the 8 keV/u light ion beam such as protons, H_2^+ and Li up to 800 keV/u. The Fig.6 shows set up of the dc beam monitor at the down stream of TALL. The beam bunch frequency is 100 MHz and measured beam bunch width is 160 deg. The beam spot width is 13.4 mm and average output current is 10 μA at H_2^+.

The dc beam monitor was calibrated with the dummy signal flowing through the straight wire which was set along the virtual center of the dc transformer. The dummy signal source is chosen either dc or pulse signal generator. The average current of the pulsed dummy signal was calibrated with the dc signal. The straight wire of 1 mm diameter is fixed and terminated with the series resister of 50 ohm. On the other hand, each troidal core have calibration winding of 2 turns in order to test the dc transformer. For sensitivity test, direct current was applied through the pair of 2 turns wiring and compared with the current flowing through the straight wire.

The effect of secondary emission from the faradey cup monitor is estimated as 1 % of measured current. The stainless beam pipe of 70 cm length was used as the faradey cup monitor. To calibrate the dc beam monitor, the linac beam intensity was adjusted with an einzel lens in front of the entrance of TALL. The fluctuation of beam intensity was few % during the whole process. The beam ON and OFF are carried out with the RF voltage for beam acceleration. The low level RF signal for an RF amplifier was cut or fed to manipulate the RF voltage. The measurement result is shown in Fig.7.

Conclusion

The measurement of magnetic noise and current gain of the Co-based amorphous core have been carried out. The maximum point of signal to noise ratio was searched and evaluated. We had done the measurement of temperature dependence of the magnetic noise and the decrease of noise was recognized. The 1/2 model of the dc beam monitor have been developed and tested with RFQ linac 'TALL'. The current sensitivity of 1 μA was attained with the averaging method.

Acknowledgements

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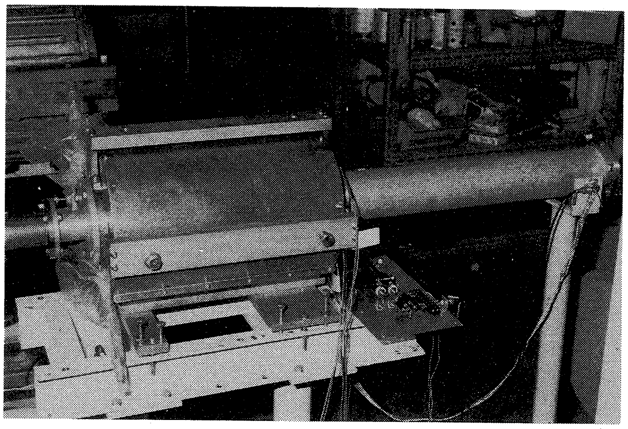

Fig.6 Set up of the beam test. The dc transformer is set at down stream of the TALL.

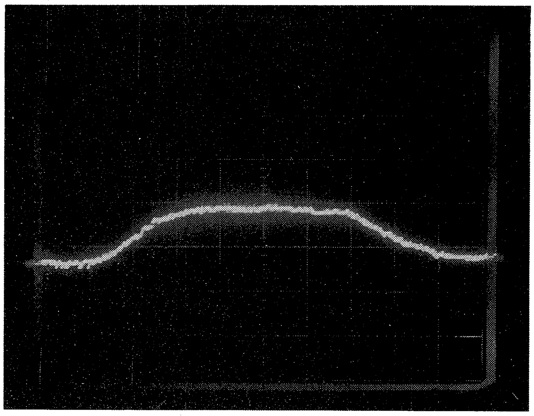

Fig.7 Result of beam test. The protons of 16 μA was measured. H ; 5 sec/div.