DESIGN AND CONSTRUCTION OF INDUCTIVE BPM

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Abstract

To have a controllable Electron machine, that is required to be able to control beam orbits by knowing the beam position. The basic requirements for detecting the position of electron are calibrating and testing the BPMs. For this purpose wire method is used. Due to restrictions in access to accelerator, to have an experience in Beam diagnostics, this method was used to test the constructed inductive BPMs including 4 cm square polyethylene coil with 10 turn coil in each side. BPM was tested by a pulsed current (as an electron bunch) produced by a pulse generator. At first Tektronix 2235A oscilloscope was calibrated and used to measure the induced voltage of each coil, then by using a microcontroller, protocol RS232 and GUI, induced voltages were monitored. The electrical center was measured with respect to the mechanical center and wire position was detected with 2mm Resolution. Conversion between the BPM signals and the actual wire position were done. Results were compared and presented.

INTRODUCTION

Since inductive BPMs use magnetic properties of beam and mount around the vacuum chamber without any vacuum considerations count as low-disturbance device.

Based on limited existing facilities at our lab we decided to design and make this kind of BPM as first experience without any accessing to accelerator. The idea for making inductive BPM was gotten of CT circuits.

Constructed BPM has a 4 cm square polyethylene core with 10 turns coil at each side. Using bone board which was machined and had 1mm intervals between holes, we displaced the stretched wire with 20mA and 1MHz pulsed current.

All steps were calculated theoretically and simulated by CST and Proteus. Finally, practical results were compared with them at each step. At first Tektronix2235A was used for measuring induced voltage, then electrical setups designed and constructed as readout device for this purpose.

At electrical setup, 60dB logarithmic amplifier, LPF with 9.54MHz cut off frequency, BPF with 1MHz central frequency and 1 KHz bandwidth were used. According to different induced voltages based on different wire places, one linear equation was chosen and then by using of microcontroller ATMEGA32, RS232 as interface, and GUI Matlab as simulation and readout software we could monitor wire position. The general form of this way is shown at Fig.1 along with belongings.

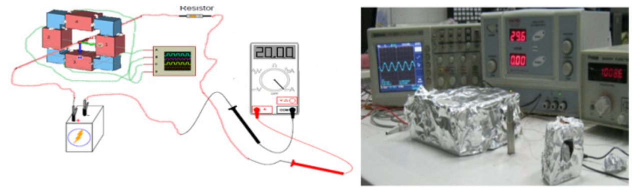

Figure 1: General schematic of setups.

DESIGN AND CONSTRUCTION CONSIDERATIONS

The windings parameters measured by LCR meter is shown at Fig. 2 as an equal circuit modelled for each coil [1].

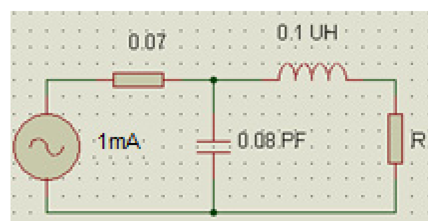

Figure 2: Measured parameters of each coil.

Due to the measured parameters and taking R=47 Ω, equivalent impedance is obtained from Eq. 1. Based on this equation, resonance frequency will be 70 KHz and impedance at 1MHz will be 45.3113∟-15.72 Ω so 1 MHz is away from resonance frequency and the results are reliable.

$$Z = \frac{R + Ls}{LC\,s^2 + CRs + 1} + 0.07 = 45.3113\angle -15.72\Omega \qquad (1)$$

Fig. 3 exhibits impedance versus different frequencies. As one can see, circuit is equivalent to LPF.

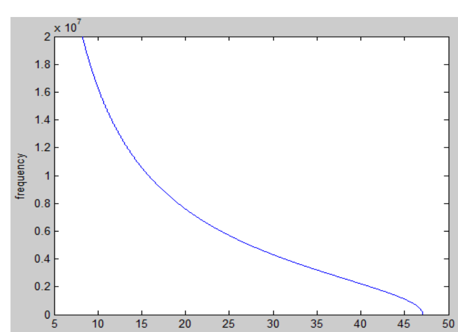

Figure 3: Equal impedance of each coil versus frequency.

Assuming the stretched wire is placed in the middle of the core and each winding as a transformer, with 20mA

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(pick-pick) stretch wire current as primary current with 1 turn, it is expected to induce 2mA (pick-pick) at the end of each coil with 10 turns as secondary, so induced voltage at the end of resistance R will be approximately 45mV (see Eq. 2)

$$V = I.Z = (1mA).45.3113\angle -15.72 \approx 45mV \qquad (2)$$

But for calculating induced voltages, one must consider dimensions of the core including $r_{in} = 15mm, r_{out} = 25mm, r_{avr} = 20mm$. Based on that and considering stretched wire current including $i(t) = 10\sin(2\pi ft)$, magnetic flux and related voltage can be calculated by Eq. 3.

$$\varphi = A.\frac{(4\pi.10^{-7})(i)}{2\pi\, r_{avr}} = 10^{-11}\sin(2\pi ft) \qquad (3)$$

$$v = \frac{Nd\varphi}{dt} = N.2\pi f.10^{-11}\cos(2\pi ft)$$

Fig. 4 shows calculated voltage versus different frequency and different turn number of windings [2].

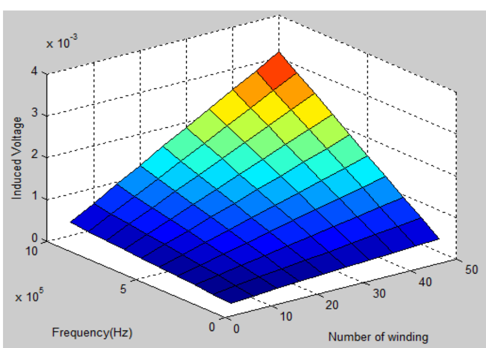

Figure 4: Expected final voltage respect different turns and frequency.

As can be seen at Fig. 4, the expected voltage at the end of windings with 10 turns and 1MHz frequency should be less than 1mV. For detecting it by electrical readout voltage must be amplified in addition to omit unwanted signals. Before installing electrical set up, results of theory with simulation by CST for all wire locations were compared and one of them is randomly given at table 1. It shows CST with less than 7% differences with respect to theory, is reliable simulation software for this purpose [3].

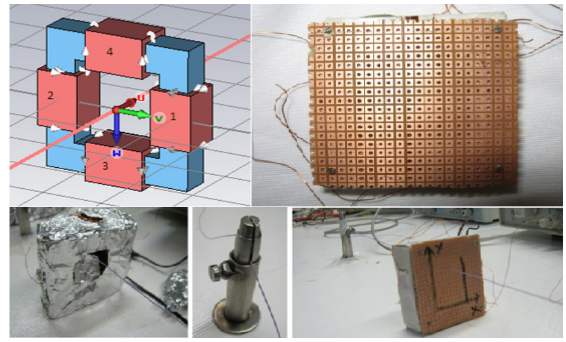

Figure 5: Simulated core and winding by CST addition to bone board installed to core and related wire bracket.

Table 1: Induced Voltage of CST and Theory at (25, 5)

Wire position at (25,5)			
Coil number	**CST result(mV)**	**Theoretical result (mV)**	**Error Percentage**
Coil (1)	1.172	1.124	4.27
Coil (2)	0.505	0.466	8.58
Coil (3)	1.23	1.124	9.43
Coil (4)	0.490	0.466	5.31
			6.215

The designed electrical set up was installed at the end of each coil which is shown in Fig.6 including one LPF with 9.54 MHz cut-off frequency for eliminating noises, one BPF with central frequency on 1 MHz and bandwidth 1 KHz to eliminate other harmonics and then one amplifier (AD8306) for amplifying voltage up to 60dB. Terminals of these electrical set ups were connected to each channel of Tektronix 2235A then voltages at different places were measured.

As simulation, Output voltage of CST entered as an input voltage of circuit simulated by Proteus. The result of simulation versus scope's output at different positions was compared which one of them randomly is given in table 2.

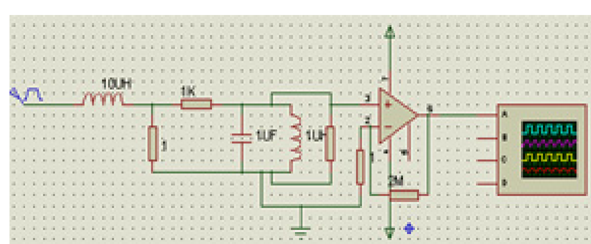

Figure 6: Designed circuit for amplifying and filtering.

Table 2: Induced Voltage of Simulation and Practice

Wire position at (5,15)			
Coil number	**Output of CST and Proteus (V)**	**Scope's output (V)**	**Error percentage (%)**
Coil (1)	0.3	0.299	3.5
Coil (2)	2.8	2.95	5.08
Coil (3)	1.3	1.22	6.15
Coil (4)	1.1	1.049	4.63
			4.84

By attention to results, was tried to find relations between wire position and induced signals by helping of delta over sum theory. Different equations were evaluated. Among them one established more linear between induced voltages and wire position. At last by linear fitting, Eq. 4 was acquired [4].

$$x(pos) = ((\log(\frac{v_1}{v_2}) - \log(v_1 \cdot v_2 \cdot v_3 \cdot v_4)) - 9.531) / 0.1226$$
$$y(pos) = -((\log(\frac{v_4}{v_3}) - \log(v_1 \cdot v_2 \cdot v_3 \cdot v_4)) - 9.693) / 0.1125 \quad (4)$$

According to this equation, the output of amplifier was connected to S&H and then ATMEGA32 and finally by RS232 transferred to PC. Fig. 7 shows block diagrams of final designed circuits.

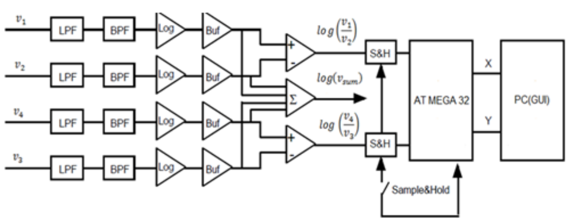

Figure 7: Schematic of electrical circuit for position measuring.

Transferred data to PC were monitored by GUI (Matlab). Fig 8 shows comparisons between real position of the wire (mechanical position) to position which detected by GUI (electrical position) according to displacing 5mm by considering right and down corner of the core as the origin of the coordinates. Results show less than roughly 7% differences between electrical and mechanical positions.

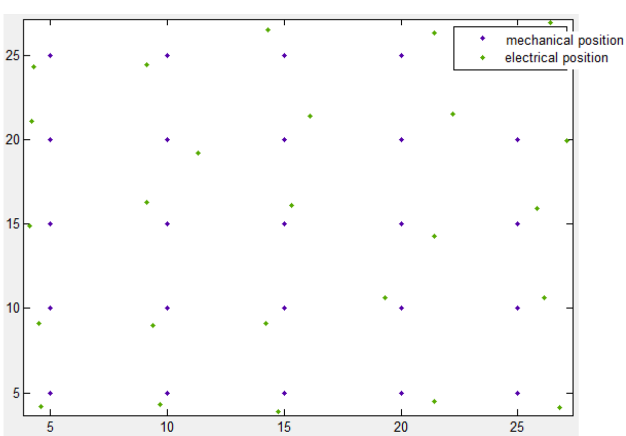

Figure 8: Blue dots are representative of mechanical Position and green dots show electrical position.

CONCLUSION

According to less than 7% differences between CST results and theory, it was deduced that CST is reliable software for simulation at this part. Electrical circuits designed by Proteus then CST outputs entered as input to Proteus, results showed less than 5% differences versus practical results by oscilloscope. Established linear formula was obtained and used as a basic equation for coding to monitor wire displacement according to induced voltages. Using ATMEGA 32 as interference and protocol RS232, data were transferred to PC and GUI (MATLAB) used as software for monitoring wire places. Finally results of this portion were compared with the real data which showed that electrical position varies less than 7% error than mechanical position. Constructed prototype inductive BPM has a 2mm resolution, more than 93% accuracy that can be used for electrostatic small accelerators where 2mm resolution and mentioned accuracy is sufficient.

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