Internal Report for JEDI

Investigation Beam Current and Position Monitoring Systems

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Introduction

Investigate Beam Current Transformers

First beam current transformer which we took to investigate was toroid coil. Size of this coil was smaller than it is required for COSY. But this small model is easy to test and also environmental conditions have less influence. We started investigation from calculation and software simulation to understand how flux behaves when single, thin wire, like beam, changes position inside the toroid. For this simulation and calculation we took the toroid with diameter 60 mm and 40 windings with diameter 5 mm. Current in single wire was 1 amp. By using the following formulas and calculation the software gave result (Figure 1).

$a = 60 * 10^{-3}, ra = 5 * 10^{-3}, n = 40, I = 1, u_0 = 4 * pi * 10^{-7}$

$$r(n,\varphi) := \begin{pmatrix} \cos(\varphi) & -\sin(\varphi) & 0 \\ \sin(\varphi) & \cos(\varphi) & 0 \\ 0 & 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} a + ra \cdot \cos(n \cdot \varphi) \\ 0 \\ ra \cdot \sin(n \cdot \varphi) \end{pmatrix} \qquad ex := \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix} \qquad ey := \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix} \qquad ez := \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix}$$

$$r(n,\varphi) \rightarrow \begin{bmatrix} \cos(\varphi) \cdot \left(\frac{\cos(40 \cdot \varphi)}{200} + \frac{3}{50} \right) \\ \sin(\varphi) \cdot \left(\frac{\cos(40 \cdot \varphi)}{200} + \frac{3}{50} \right) \\ \frac{\sin(40 \cdot \varphi)}{200} \end{bmatrix} \qquad dr(n,\varphi) := \frac{d}{d\varphi} r(n,\varphi) \qquad dr(n,\varphi) \cdot ez \rightarrow \frac{\cos(40 \cdot \varphi)}{5}$$

$$D(\varphi) := \begin{pmatrix} \cos(\varphi) & -\sin(\varphi) & 0 \\ \sin(\varphi) & \cos(\varphi) & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$$Az(rr, xs) := \frac{1}{2 \cdot \pi} \cdot I \cdot \ln\left[\sqrt{(rr - xs \cdot ex) \cdot (rr - xs \cdot ex)}\right]$$

$$\Phi(xs) := \mu 0 \cdot \int_0^{2 \cdot \pi} Az(r(n,\varphi), xs) \cdot \left(\frac{\cos(40 \cdot \varphi)}{5} \right) d\varphi$$

$$k := 1, 2 .. 100 \qquad d\Phi_k := \Phi\left[(a - 2 \cdot ra) \cdot \frac{k}{100}\right]$$

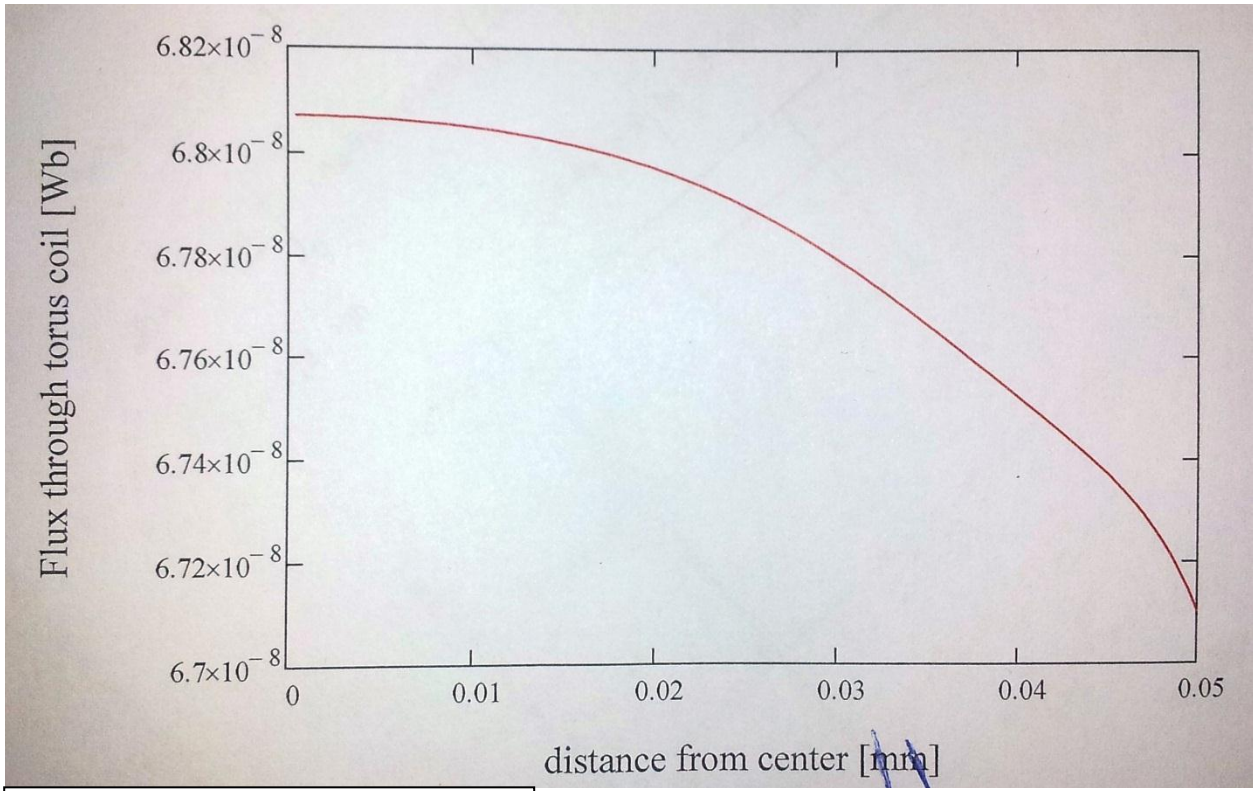


Figure 1. Magnetic flux through a toroid.

After analyzing this graph and comparing to the practical experiments we found that software made mistake in calculating of integral. This was caused by small numbers. After that we took out u_0 from integral (figure 2).

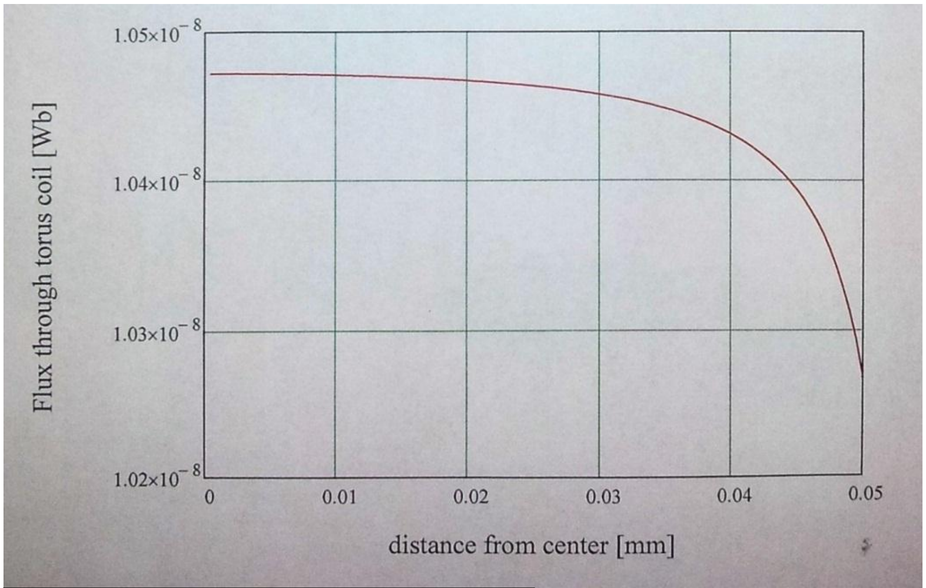


Figure 2. Magnetic flux through a toroid, u_0 is out of integral

At this graph we can see that flux through torus coil keeps stability at 80% of radius from center and after this it starts decreasing slightly. The main reason of this can be low number of windings. But if we increase turns it also will cause to decrease the resonance frequency and voltage amplitude.

In spite of this, such stability is totally satisfactory for beam current monitoring. After software simulation we made experiment at small coil, with diameter 20 mm and 30 windings, which resonates at 1 MHz (Figure 3).

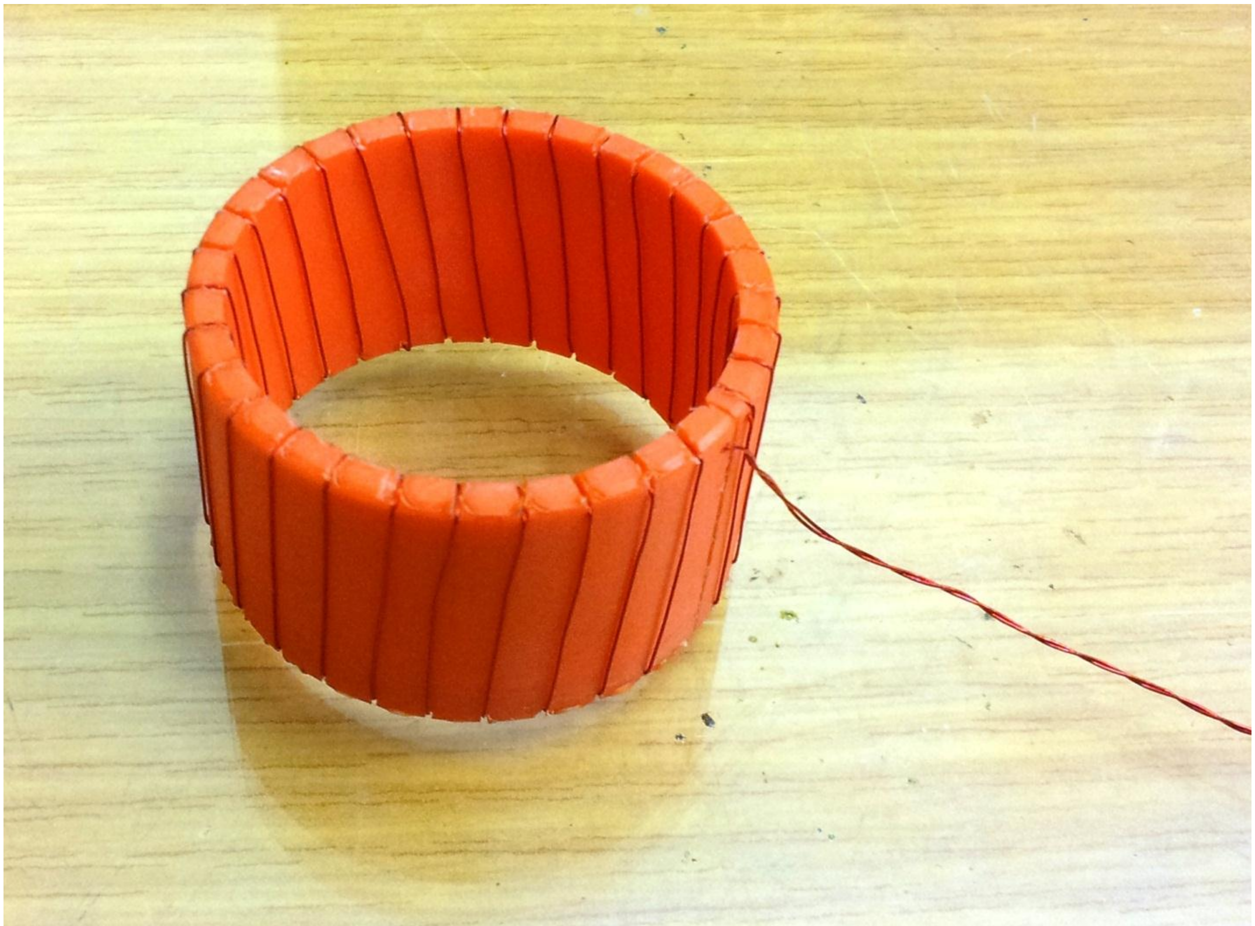


Figure 3. Experiments on handmade torus coil

For this experiment we put single copper wire inside the coil with the current approximately equal to beam current (0.16mA) and made measurements using the Lock-in Amplifier. This device also has internal signal generator and noise filters (Figure 4).

Figure 4. Electronic, Lock-in amplifier

Summary of these measurements is given on this plot below (Figure 5).

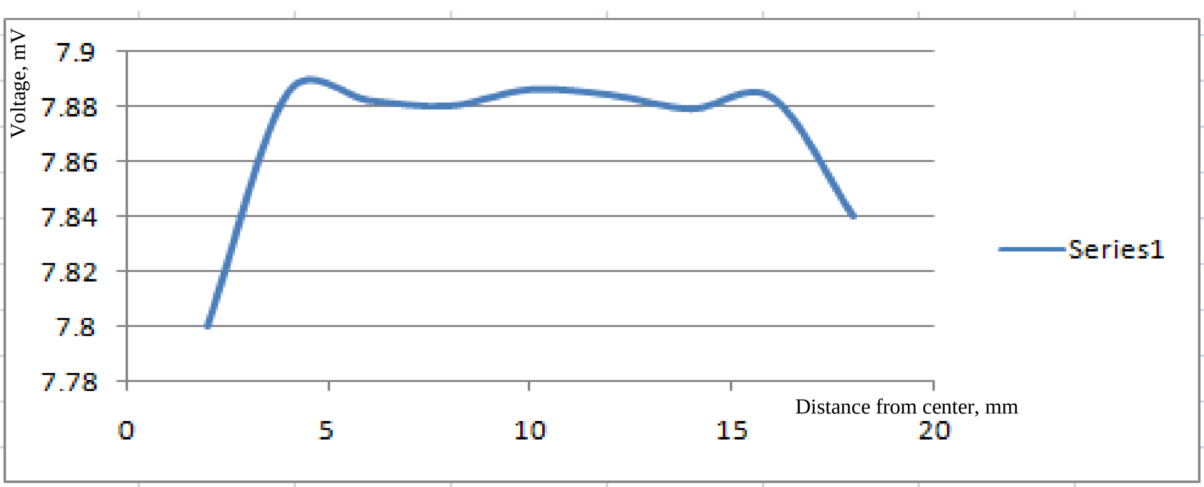


Figure 5. Experimental result

This graph shows the same that we got from software analyzing. Low voltage at start and end points was caused by uneven distribution of wire. During investigation of BCT we also made software simulation and physical experiments on double helix dipole. Double helix dipole creates homogenous field inside the coil. The idea was if it works on the contrary. For checking that, we made double helix dipole on plastic tube, 50 windings with angle 45^{o} to tube and put the copper wire inside this tube. The needed information was voltage amplitude dependence on wire position. The software simulation result is fully different from the toroid simulation result. Exactly if we have double helix dipole in x, y, z planes, x plane movement has linear face (flux though coil to distance) and not linear graph when single wire moves in y plane (figure 6).

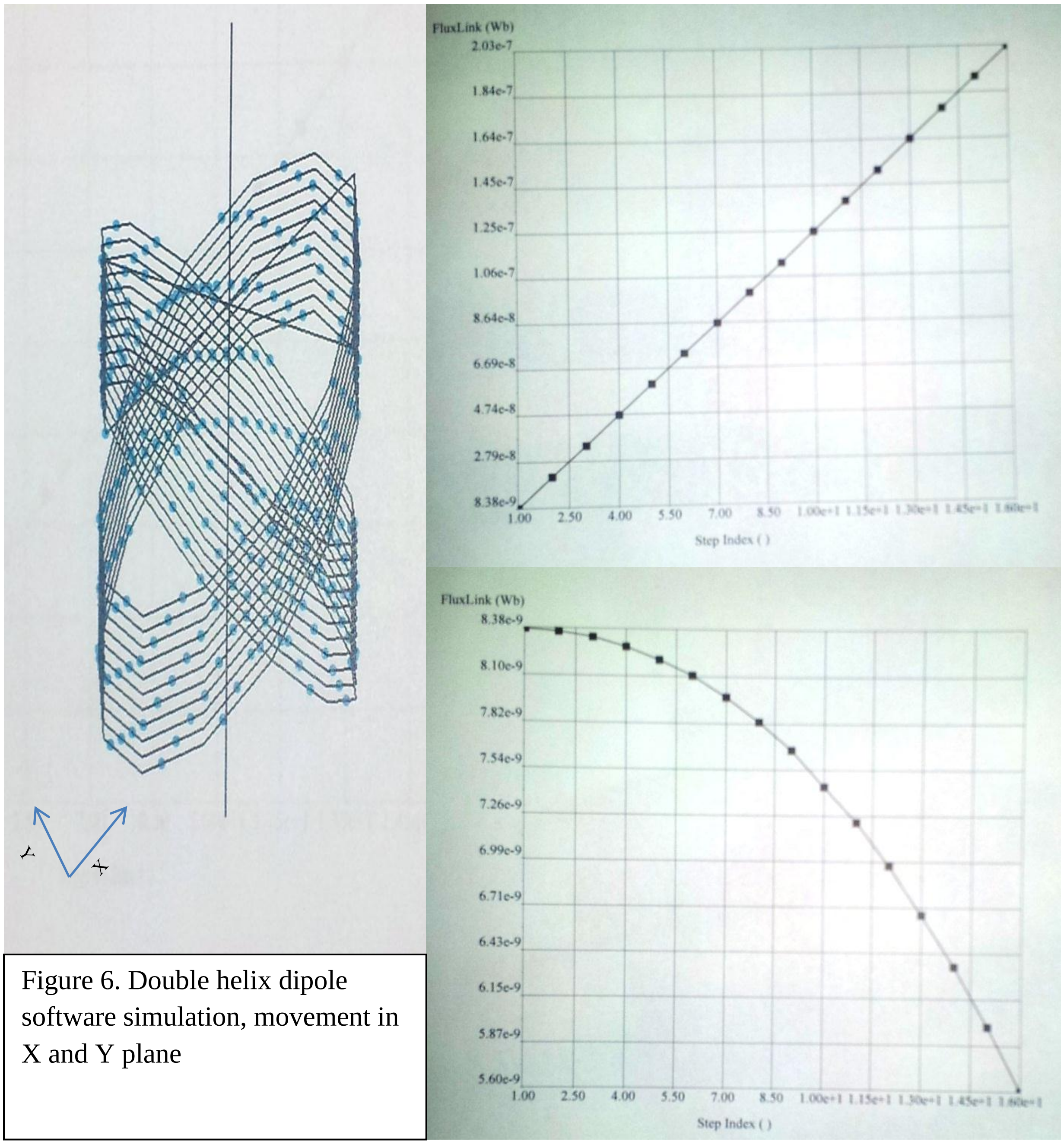
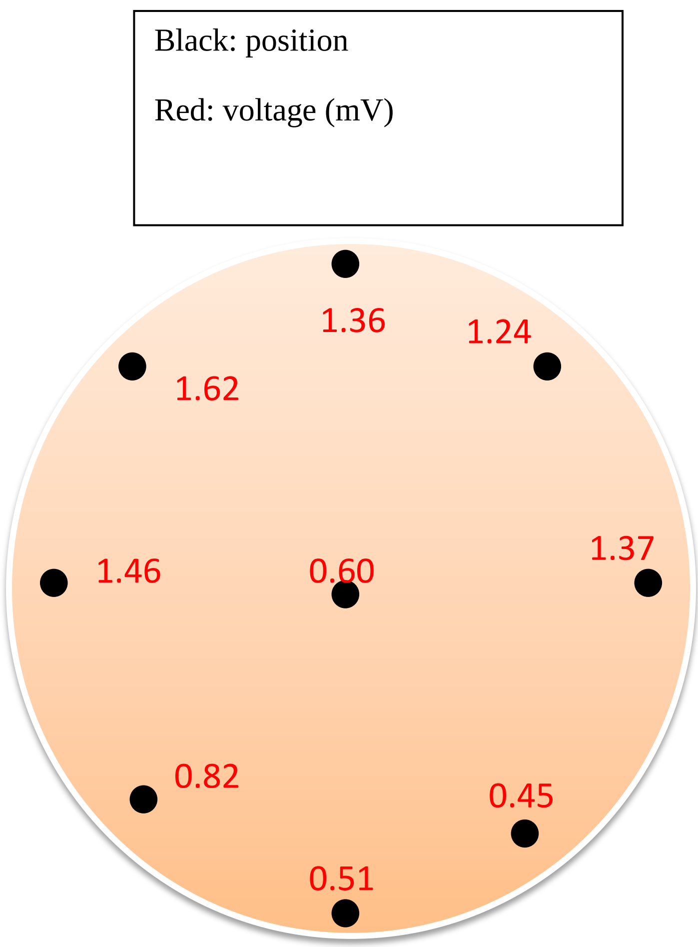


Figure 6. Double helix dipole software simulation, movement in X and Y plane

Also practical experimets gave same result, which is given below:



Foreseen our aim it’s not comfortable and suitable to use double helix dipole for beam current monitoring. In this situation the toroid coil is better with resonance frequency which has protons’ beam. The computer simulation and small experiments show that toroid is satisfactory as BCT.

Investigate of BPM systems

Beam position monitoring is one of the most important thing for the future researches at COSY and it requires approximately thousand times better resolution than it is now. Following the experiments on BCT, we decided to use the toroid again with different type of windings for position determination. For this we took torus and made two maximally identical coils with opposite direction of windings (Figure 7).

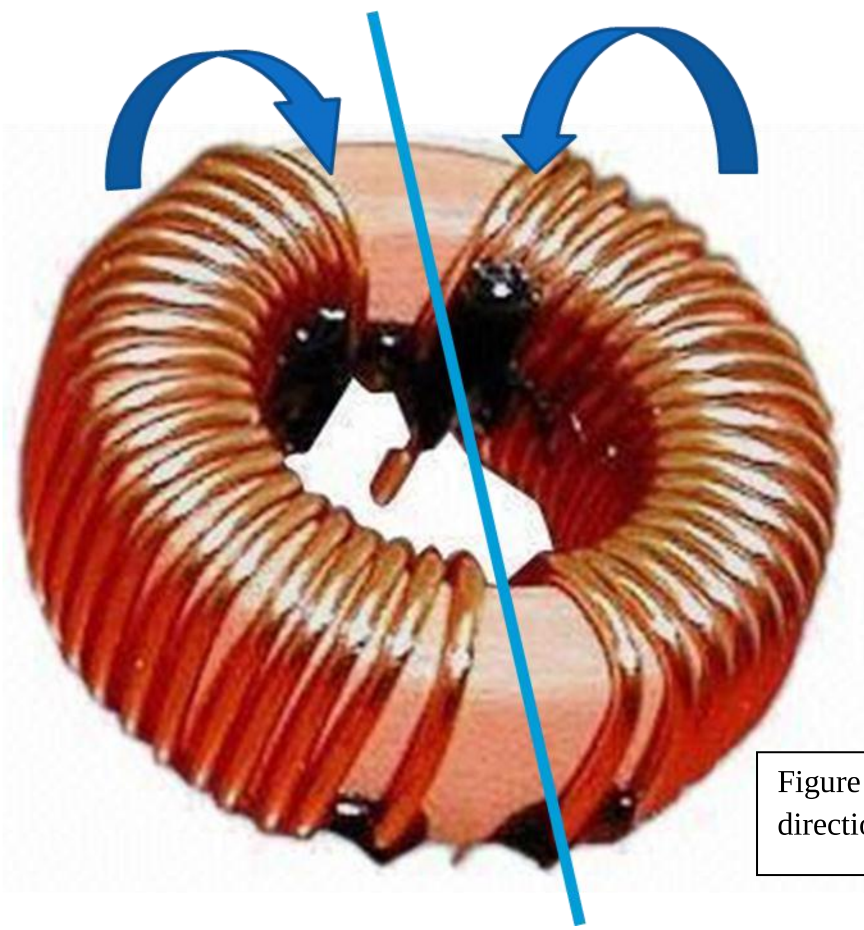


Figure 7. Toroid with opposite direction of winding

At this case when we have single wire with the current inside the coil it induces voltage in both coils, but the voltage we are measuring is subscription of these voltages. Using this principle it is possible to measure the voltage when “beam” changes position from the center of toroid. Further the beam goes from the center the bigger voltage is induced. Such coil gives the information about position only in one dimension.

For the experiment we took 30 mm diameter torus with copper wire as it was described. Measurement was done by lock-in amplifier. The experiments’ results were 18mV different per 30 mm and because the linearity it means 0.6 nV different per 10 nm. This resolution is the best in our case but it is difficult to get such result from the big size coil, which is needed at COSY case. Also after other experiments we developed this toroid and made four coils on one torus (Figure 8).

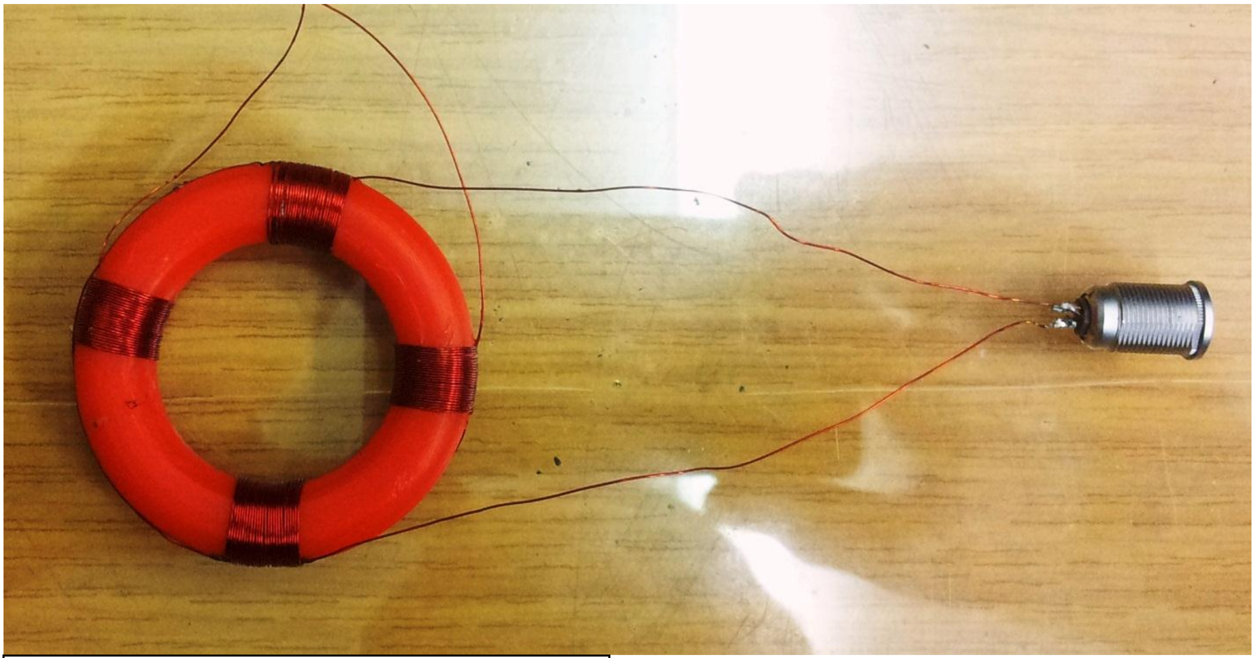


Figure 8. Two dimensional BPM toroid

Resolution and stability of position data are the same as in previous case.

Conclusion and Outlook