SYSTEM OF NMR MEASUREMENT AND STABILIZATION OF MAGNETIC FIELD IN SUPERCONDUCTING WIGGLER AT BESSY II

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Abstract

The superconducting wiggler with operating field range of 3÷7T was designed at Budker Institute of Nuclear Physics (Novosibirsk) for BESSY II. The difficulty of the magnetic field measurements by NMR Magnetometer is connected with large field gradients (up to 50 Gs/mm), wide temperature range (4÷420 K) and small space for probe placing. Special solid-state probes were designed to meet this requirements. The accuracy of magnetic field measurements at probe locations is not worse than 20 ppm. For the wiggler field of 7 T the reproducibility of the magnetic field of 30 ppm has been achieved.

1 INTRODUCTION

One of the requirements for BESSY-2 superconducting 7T Wiggler is stability and reproducibility of the magnetic field better than 10^{-4}. For satisfying of this requirement NMR measurement and stabilization system is used. The main problem in using of the NMR probes in the Wiggler is large field gradients. Field gradients result in increasing of the resonans linewidth and decreasing of the signal-to-noise ratio and as a consequence in decreasing of the measurement accuracy. For very large field inhomogeneouty measurement of the magnetic field by means of NMR becomes impossible.

2 NMR PROBES: LOCATION AND PARAMETERS

The draft of the three pole Wiggler with one central and two secondary poles is presented in Fig.1. The values of magnetic field are to be measured in every pole of the Wiggler by the set of different NMR probes. Locations of the probes are shown in this figure as well.

There exists only a small region where NMR measurements of the central field are possible. This region is located within iron central pole at the vertical axis passed through its center. In some point of this region the vertical gradient becomes zero, thus allowing the use of NMR probes. Unfortunately this point shifts along the vertical axis when the field changes. In order to provide field measurements within the whole working range of the field from 3 to 7 T a pair of NMR probes shifted one from another along the vertical axis is used.

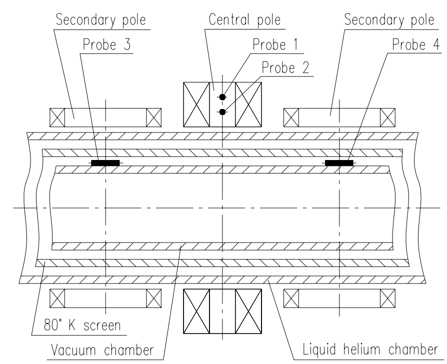

Fig. 1: The draft of the Wiggler and NMR probes locations.

The pair of NMR probes (probe 1 and probe 2) assembled in one body is placed in a hole of 6 mm diameter made in the center of the central Wiggler pole. Sensitive area of these probes is a cylinder of 1 mm diameter and 3 mm length. These probes work at a liquid helium temperature of 4.2 K. A working substance of aluminum dust consisting of very small particles with dimensions of 3÷5 μm is used. NMR resonans of aluminum nuclei is used in these probes. A vertical distance between the probes is 2.5 mm. Dependence of the resonans linewidth upon the Wiggler field value in the median plane is presented in the Fig.2. To optimize the measurement accuracy the whole field range is separated into two regions 2÷4 and 4÷7 T. The probe 2 operates in the first region and the probe 1 operates in the second region respectively.

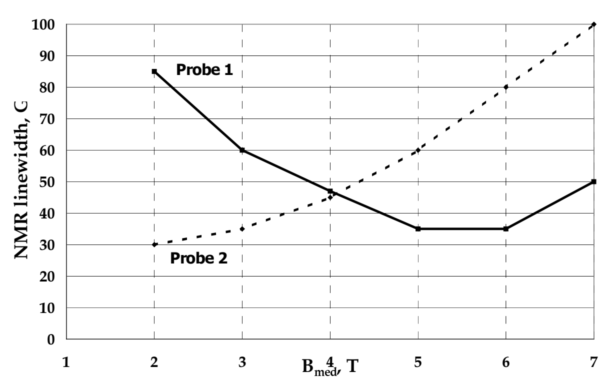

Fig. 2: Dependence of the resonance linewidth upon the Wiggler field value in the median plane.

One of the problems in using such a scheme of probes location is the difference between the fields in the median plane (plane of the beam) B_{med} and in the central pole B_{cp}. For the field in the median plane to be measured dependence of this field upon the field in the probe sites was experimentally obtained (Fig.3). This dependence was obtained with help of additional NMR probe placed in the median plane exactly at the center of the Wiggler. Accuracy of this dependence is defined by different contribution of iron influence in values B_{med} and B_{cp}. If one will measure a difference (B_{med} - B_{cp}) initially increasing the field from zero to maximum and then decreasing from maximum to zero one will get a hysteresis curve. A magnitude of this hysteresis achieve $(1\div2)\times10^{-4}$. But if one before setting of the field initially will raise it to maximal field (for example 7.1 T) and then will decrease it to zero reproducibility of the value (B_{med} - B_{cp}) will not be worse than (1.5÷2) Gs.

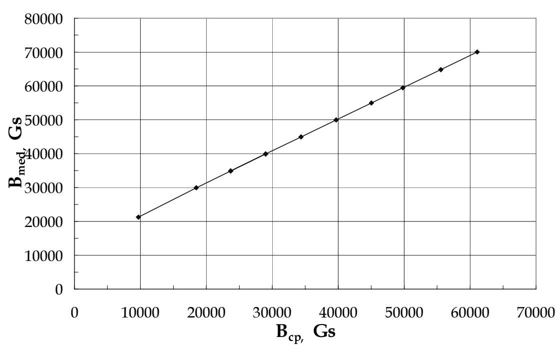

Fig. 3: Dependence of the field value in the median plane B_{med} upon the field value in the central pole B_{cp}.

Besides of the field stability in the Wiggler center which defines the stability of SR wavelenth it is necessary to keep an equality to zero of the Wiggler field integral along the beam trajectory. Equality to zero of the field integral is provided by correct relation between the currents I_1, I_2 of two independent Power Supplies. One of the ways to provide this is measurement with BPM of the beam position in a few points before and after the Wiggler with following correction of the currents. Another way is stabilization of the field B_{sp} on the side poles. For this purpose one more NMR probe on the vacuum chamber surface under one of the side poles is placed (probe 3 in Fig.1). Field range on the side poles is 0.55÷1.4 T. One of the problem in using of this probe is a small gap between vacuum chamber and 80°K screen where NMR probe is placed. Another problem is a wide temperature range. Nominal temperature at the site of location of the probe is about –50 ÷ -70 °C. But this probe must bear a heating up to +150°C when vacuum chamber will be warmed up. This probe is made with Teflon. Resonance of fluorine nuclei is used in this probe. Sensitive area dimensions are: 1.5×2×3 mm.

3 OPERATION PRINCIPLE AND CONSTRUCTION

A pulsed NMR technique is used in the system [1,2]. Nuclei of the sample in the probe are excited by short pulse of RF field with the frequency close to the NMR frequency, thus causing a signal of free induction decay (FID). A simplified scheme of the NMR System is shown in Fig.4.

Each probe is connected with NMR receiving and exciting electronics by receiving and exciting multiplexers correspondingly. The switch S commutates probe to receiving or exciting chaines. Low noise preamplifiers are placed near every NMR probe to decrease losses of the FID signal in RF cable between the probe and the receiving electronics. All electronics is made in VME standard. The amplified signal is shifted to a low frequency region by multiplying it by two orthogonal signals of precisely known Synthesizer frequency close to NMR frequency. Low frequency NMR signals are digitized by ADC and then processed by VME Controller. The Control circuit operates the measurement process.

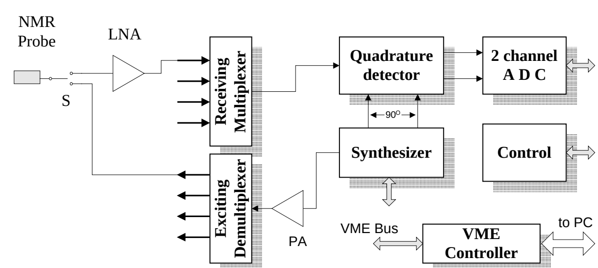

Fig. 4: A simplified scheme of the NMR System. PA - power amplifier, LNA - low noise amplifier, S - receiving/exciting switch.

4 FIELD STABILIZATION

After setting of the currents to specified values superconducting persistant keys PK1 and PK2 are closed (freeze) and currents I1 and I2 will flow on closed loops besides of Power Supplies (Fig.6). Then Power Supplies may be switched off. But presence of resistance of junctions between superconducting windings follows to

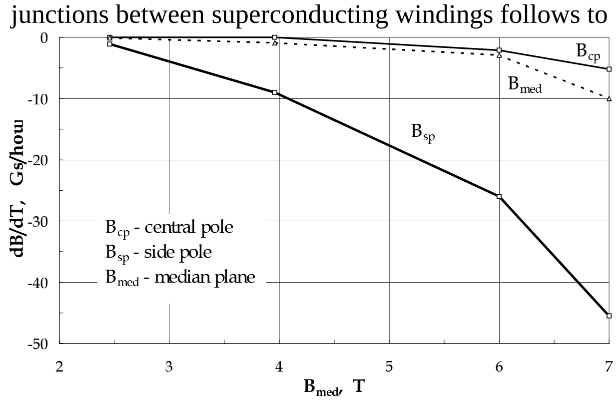

Fig. 5: Dependence of the rate of field degradation on the wiggler field value.

slow decreasing of the currents and as a consequence to wiggler field degradation.

Experimental dependencies of the rate of field degradation on the wiggler field value are represented in Fig.5.

To compensate these field degradation and to stabilize wiggler fields both at central pole and at side poles the system of current pumping is used. Simplified scheme of this system is represented at Fig.6.

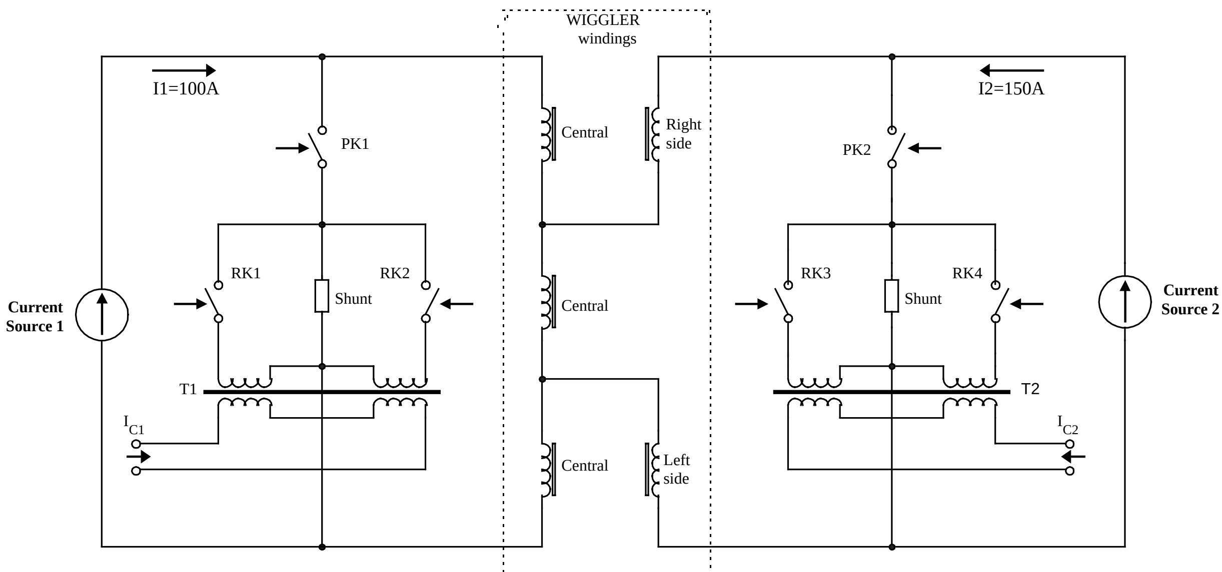

Fig. 6: A simplified scheme of current pumping system for field stabilization.

With help of transformers T_1, T_2 and superconducting keys RK_1-RK_4 this system adds current portions to each current loop.

After switching on the feedback the stabilization program operating in VME Controller takes the measured values of magnetic field B_{cp}, B_{sp}, found by another program and in case of deviation of these values from stabilized values more than one half of field step give the command to current pumping system to add one current portion to corresponding loop. An example of field stabilization for wiggler field value ~4T in the median plane is presented in Fig.7.

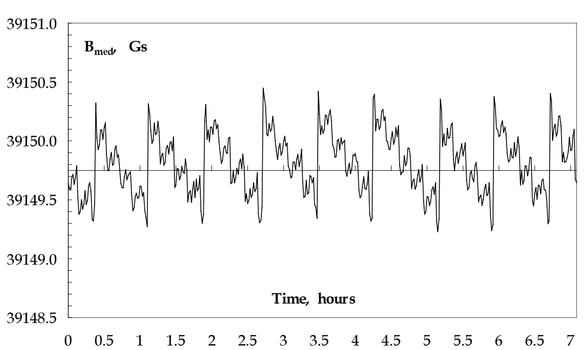

Fig. 7: Field stabilization for wiggler field value ~4T.

A current pumping operation has a consequence of the field ripples with the amplitude of 0.5÷0.7 Gs at the central pole and about 1 Gs at the side poles. Period of this ripples decreases from 10÷12 min at 4T to 1÷1.5 min at 7T. Long term field stability defined by relative accuracy of field measurements for Wiggler field 7T is 2 ÷3 Gs.

5 SUMMARY

At present the system of NMR measurement and stabilization of magnetic field is installed in superconducting wiggler at BESSY II. A relative accuracy of magnetic field stabilization about $3{\cdot}10^{-5}$ for the magnetic field strength 7T has been achieved.

REFERENCES

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