**Hardware and Software Package for Fine Adjustment of the PETRA-III Damping Wiggles**


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Abstract—At the end of 2009, an extremely low horizontal emittance of 1 nm rad was achieved at the PETRA-III storage ring (Hamburg), a new third-generation SR source with an energy of 6 GeV, which offers new opportunities for SR experiments. Such an emittance was achieved through the efficient operation of a 4-m permanent magnet, with damping wiggles installed in long straight sections of the ring. The required final magnetic characteristics of the wiggles were achieved using the hardware and software package developed at the Budker Institute of Nuclear Physics (Novosibirsk). This paper briefly describes the magnetic measuring techniques, the equipment used and their parameters. A special section is devoted to the description of the programs for equipment control, data processing and presenting.

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1. INTRODUCTION

The third-generation PETRA-III SR source at the DESY center (Hamburg) is a result of the reconstruction of the PETRA-II storage ring, which served for many years as a booster of the HERA accelerator. The modernization consisted of the renewal of seven of the eight octants of the old storage ring and the construction of SR extraction beamlines and experimental station facilities in place of the eighth octant. Furthermore, two 100-meter sections were added to the ring for installing damping wiggles (Fig. 1) intended to increase radiation damping and reduce the emittance from 4 nm rad to the required 1 nm rad [1].

In 2005–2006, at the Budker Institute of Nuclear Physics in collaboration with DESY specialists, the design was developed and prototypes of the permanent magnet damping wiggles [2, 3] were manufactured. The main parameters of these devices are given in Table 1.

Over 2007–2008, at the Budker Institute of Nuclear Physics, 20 wiggles were manufactured, tested, and sent to Hamburg; towards the beginning of 2009, these devices were aligned and prepared for installation in the storage ring.

2. DAMPING WIGGLER ADJUSTMENT TECHNIQUE

Preliminary adjustment and testing of the wiggles was performed in Novosibirsk, and final adjustments were carried out in Hamburg, which made it possible to avoid any potential mechanical stresses of the device during its transportation of 5600 km. The optical system of the storage ring required careful adjustment of the magnetic parameters of the wiggles, since it was necessary to achieve a value for the first and second integrals of the vertical and horizontal fields of no more than ±100 Gs · cm and ±30 kGs · cm², respectively. Furthermore, DESY specialists formulated requirements for the “smoothness” of the transverse distributions of the field integrals for the purpose of minimizing multipole components.

Three methods were used during adjustment and alignment:

(i) Mapping of the vertical fields using Hall probes which were used to adjust wiggler poles to achieve a field of 1.52 T in the gap and to preliminarily estimate the first and second integrals of the vertical field. The carriage contained 11 probes perpendicular to the wiggler axis. Movement of such a carriage along the wiggler, in increments of 4 mm, made it possible to measure the transverse and longitudinal magnetic field distributions. The absolute measurement error at the field maximum was ±150 μT.

(ii) Measurements of the magnetic field integrals using a stretched wire. A string of 30 twisted wires was moved in a certain way in the horizontal or vertical direction in increments of 2 mm using an automatic slider according to the technique [4]. The voltage induced by the wire motion in the magnetic field was integrated at each step and was converted into code using an integrator. Depending on the motion...
method, the result was the transverse distribution of the first or second integrals of vertical or horizontal fields. The measurement error did not exceed 5 μT m. The data obtained were used to adjust the integrals using finger-type correctors mounted on the wiggler end faces. The final dependences were used to calculate the coefficients in the multipole expansion, which allows for a conclusion about curve “smoothness”.

(iii) Measurements of the dependence of the horizontal field on the longitudinal and transverse coordinates using λ-coils. The coil length is exactly equal to the wiggler period \( \lambda_U = 200 \text{ mm} \), and the coil plane is oriented in parallel to the vertical field. When moving such a coil along the wiggler, the effect of the strong vertical is weakened by a factor of hundreds, and it becomes possible to determine the dependence of the relatively weak horizontal field on the longitudinal coordinate with good accuracy. In addition, if several coils are arranged on a carriage, we will also obtain dependences on the transverse coordinate. The measurement error of the first integral at the final point is estimated as ±40 μT m.

The procedure of wiggler adjustment included three stages. At the first stage, the magnitude of the field in the gaps was adjusted using the Hall system. The second stage consisted of the measurement, using the stretched wire and subsequent adjustment of the first and second integrals, of the vertical and horizontal fields. At the same stage, the distribution of the first integral of the horizontal field along the wiggler was measured and, if required, poles were aligned, which significantly contribute to the integrals of horizontal fields. The third stage was performed at the DESY and included repeated measurements and alignments similar to those performed in Novosibirsk. The DESY testbed is shown in Fig. 2.

### Table 1. Characteristics of damping wigglers

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
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<tbody>
<tr>
<td>Maximum vertical field</td>
<td>1.52 T</td>
</tr>
<tr>
<td>Gap between poles;</td>
<td>24 mm</td>
</tr>
<tr>
<td>Period</td>
<td>200 mm</td>
</tr>
<tr>
<td>Number of poles</td>
<td>( 36 + 2(0.75) + 2(0.25) )</td>
</tr>
<tr>
<td>Full length</td>
<td>4 m</td>
</tr>
</tbody>
</table>

Fig. 1. Straight section with installed damping wigglers.

3. MEASUREMENT HARDWARE

Several years ago, a set of unified equipment was developed at the Budker Institute of Nuclear Physics, which made it possible to solve a wide range of problems in precision measurements of the characteristics of magnetic elements. In the VME standard, NMR magnetometers, multichannel devices for operation with the Hall probes, precision magnetic flux meters, and interfaces for the slider and power supply control were developed.

The construction of the entire apparatus for magnetic measurements in a single highway—module stan-