MAX IV STORAGE RING MAGNET INSTALLATION PROCEDURE

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Abstract

The MAX IV facility consists of a 3 GeV storage ring, a 1.5 GeV storage ring and a full energy injector linac. The storage ring magnets are based on an integrated "magnet block" concept. Each magnet block holds several consecutive magnet elements. The 3 GeV ring consists of 140 magnet blocks and 1.5 GeV ring has 12 magnet blocks. During the installation, procedures were developed to guarantee block straightness. This article discusses the installation procedure from a mechanical point of view and presents measurement data of block straightness and ring performance.

INTRODUCTION

The MAX IV 3 GeV storage ring consists of 20 achromats [1]. Each achromat consists of five unit cells and two matching cells. The cells consist of one magnet block with several magnet elements. The position of a single magnet element relies on the machined precision of the magnet block [2]. The magnet block is aligned by three vertical, two lateral and one longitudinal adjustment screw. During installation, the magnet block top half is lifted off to allow putting the vacuum chamber in place, but the magnet block bottom half by itself does not maintain its specified straightness. This deflection corresponds to magnet elements being displaced from their ideal locations, some quite far from the specifications.

A procedure for correcting the deflection was developed and implemented in the installation procedure.

INSTALLATION PROCEDURE

- Magnets for a full achromat are lifted to their positions on the concrete stand.
- Each block is aligned with laser tracker according to the global coordinate system.
- The top halves are removed and stored in the storage ring tunnel.
- Vacuum chamber installation starts. The bottom magnet halves are used as a reference for the installation table. Vacuum chambers for a full achromat are assembled and baked altogether and then lifted to position and mounted in the bottom magnet blocks.
- Magnet top halves re-assembled. This includes correction procedure if needed.
- Cooling water connection.
- Power and interlock cables connected.
- Cables connected at power supply.
- Alignment re-checked according to global coordinate system and magnet to magnet.

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Tool for Measuring Straightness

To measure the straightness of the magnet block, a special tool is used. It consists of a long aluminium beam with two struts at the ends and a dial gauge in the middle (see Fig. 1). Through holes in the top half magnet block the split surface is reached, with the dial gauge indicating straightness of three points (see Fig. 2). The tool is equipped with plastic handles and should be operated with gloves to minimize heat transfer. If the tool is touched with a bare hand it could show a reading of 20-30 microns.

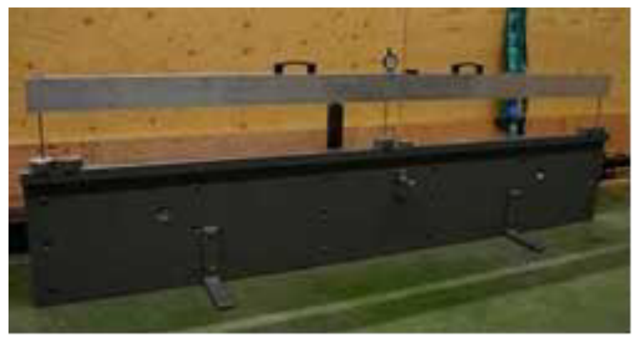

Figure 1: Measurement tool and reference beam.

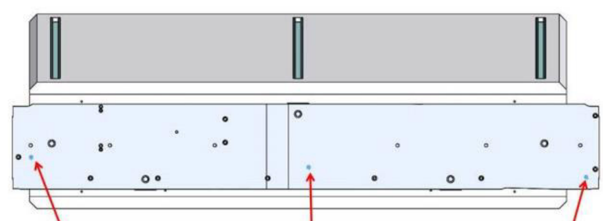

Figure 2: View from top, 3GeV U1 magnet block with points of measure.

Correction Procedure

This procedure corrects for unwanted deflections and it is performed when the bolts between the top and bottom block halves are loose. The correction is locked by tightening all bolts. The bottom magnet block is firmly attached by temporarily adding extra support and turnbuckles at the middle. Dial gauges are used to check that the magnet block is not lifted. This procedure is applied to 3 GeV ring and 1.5 GeV ring magnet blocks.

At both ends adjustable supports and turnbuckles are used to correct the magnet. Dial gauges are used to monitor the motion. The springback from the correction procedure is some 10-30 microns. Time for performing the correction procedure and achieving good results is 1-2h per magnet.

Figure 3 : Extra adjust on both left and right side so that the twist of the magnet block is controlled.

Basically what is happening is that the ends of the magnet are pulled down or pushed up in order to pre-stress the magnet to a desired shape. It is done so that the twist of the magnet is controlled (see Fig. 3). If the magnet is out of tolerance it can have two shapes. The shape of the deflection is either convex or concave. If it is convex the ends are pushed up and pulled down if concave (see Fig. 4).

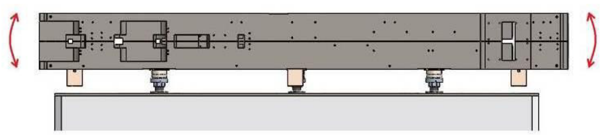

Figure 4 : Correction procedure.

MECHANICAL BEHAVIOUR OF MAGNET BLOCK

Displacement Due to Gravity

When the magnet is closed and tightened it can be considered as relatively stiff. The top and bottom half by themselves are weaker and has significant displacement due to gravity when placed on three points. This has to be handled when the top half is to be re-installed. When put on the bottom half, the top half gets more or less the same shape as the lower half, and the straightness does not change considerably when the bolts are tightened.

Temperature Variation

It has been found that the top and bottom half need to be stored at the same location or temperature. If the top and bottom halves are of different temperature when bolted together the overall deflection will change over time until the inner temperature of both magnet half settles.

Internal Stress

Though the iron blocks have been heat treated and should be free of stresses it seems that they still hold some internal stresses. The reason to believe that is irregular behaviour during the installation. Some blocks need concave correction and some convex. (If the deflection had been caused by gravity only it would have been the same correction for all blocks.) Each magnet block can be seen as an individual.

Internal stresses seem therefore to be one cause of the behaviour. It might be so that these stresses aren't revealed until the magnet block is put on three support points or flipped 90deg. in order to change the gravitational affect.

The result is that they bend more easily in one way than the other.

FEA

The FEA shows a max deflection of 28µm at the very end of the magnet block for U1 magnet block (see Fig. 5). As a complete unit with the top and bottom half assembled the magnet can be seen as a stiff unit. The FEA was performed on the iron blocks standing on spherical bearings, not including the coils, cables etc.

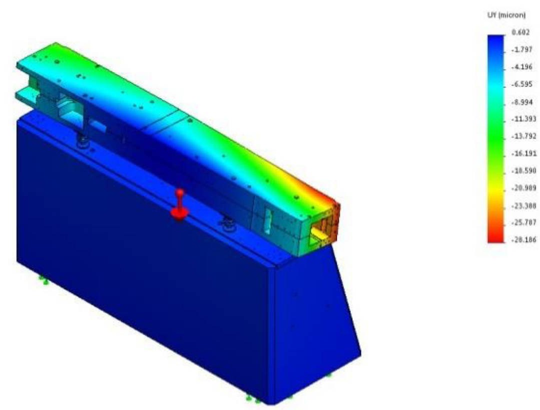

Figure 5 : FEA of gravity sag(U1), colour scale goes from 0µm(blue) to -28µm(red).

MEASUREMENT

Two sets of complete straightness measurements of the magnets when installed in the ring have been performed in June 2015, before start of commissioning and in August 2016(see Table 1). This reveals the change over time(see Table 2). The low change of mean value over one year indicates that the effect from gravity on the correction procedure is small.

Table 1 : Current Straightness of 3 GeV Ring Magnet Blocks (140pcs)

Cell	RMS(µm)	Mean value(µm)
M1	20,2	-14,8
U1	19,4	-9,4
U2	19,6	-8,8
U3	15,2	-11,8
U4	15,4	-4,3
U5	16,9	0,5
M2	18,4	-8,2
	18,9	**-8,1**

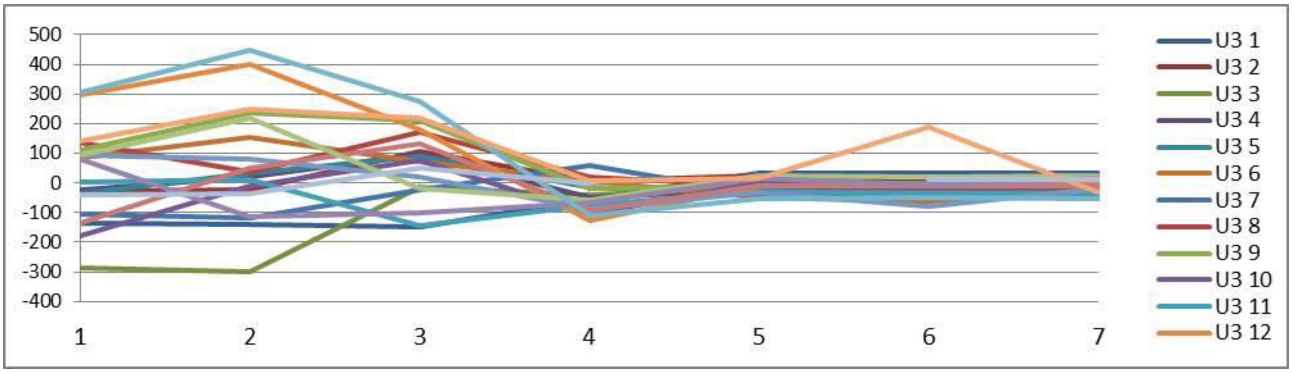

Figure 6: Straightness in microns of U3 magnets during the different stages in the process.

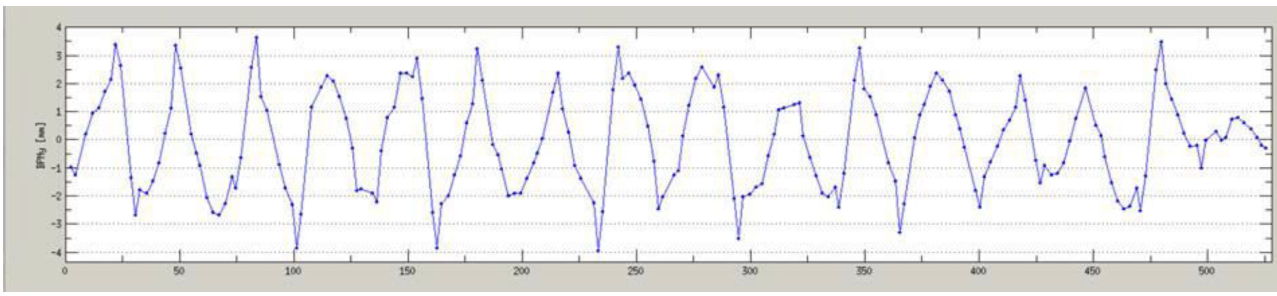

Figure 7 : Vertical closed orbit with all vertical correctors set to zero in the 3 GeV ring.

Table 2 : Straightness of 3 GeV Ring Magnet Blocks (140 pcs), Change over Time (June 2015 to August 2016)

Cell	RMS(µm)	Mean value(µm)
M1	15,8	-3,6
U1	13,2	-8,9
U2	13,3	-6,3
U3	43,1(15,2*)	4,3(-1,3*)
U4	10,9	-3,1
U5	18,2	-0,3
M2	11,4	2,8
	18,0(14,0*)	**-2,2(-3,0*)**

*after straightness correction

Three U3 magnet blocks were out of tolerance during the second measurement. One of them showed a change of 172µm.

The straightness was also checked several times before and during the installation, from arrival to its final destination (see Fig. 6).

1. Magnet closed and placed on a flat table
2. Magnet closed and placed on three points
3. Magnet with all bolts loose and placed on three points
4. Magnet with all bolts loose and placed on a flat table. Bolts tightened
5. June 2015, after installation of vacuum chamber. This includes the correction procedure
6. August 2016. One year of operation and the straightness is measured again.
7. Correction procedure was performed on magnets that were out of tolerance.

Performance

An indication that good internal alignment of the individual magnets in each block was indeed achieved was the fact [3] that the first turns around the ring could be obtained without firing a single corrector magnet(see Fig. 7). Moreover, measurement of the vertical bare closed orbit shows on the order +/ 4 mm peak to peak deviations well in accordance with design calculations [DDR].

CONCLUSION

Issues with gravity sag and other deflections were handled well. The developed procedure for correcting the straightness works. Machine performance confirms that the position of the magnet blocks and the magnet elements is according to specification.

Three magnets moved out of tolerance during one year of operation. Measurement of the straightness will be performed once per year to identify and correct magnets that move out of tolerance.

REFERENCES

[1] M. Eriksson *et al.*, "The MAX IV Synchrotron Light Source", in *Proc. IPAC 2011*, San Sebastián, Spain, paper THPC058.

[2] M. Johansson, B. Anderberg, L-J. Lindgren, "Magnet Design for a Low-Emittance Storage Ring" J. Synchrotron Rad. 21, 884-903, 2014.

[3] Pedro F. Tavares *et al.*, Commissioning of the MAX IV Light Source", presented at NAPAC 2016, Chicago, IL, USA, paper TUB3IO01, unpublished.