MAX IV AND SOLARIS LINAC MAGNETS PRODUCTION SERIES MEASUREMENT RESULTS

M. Johansson*, MAX IV Laboratory, Lund, Sweden
R. Nietubyc, NCBJ, Otwock, Poland

Abstract

The linacs of the MAX IV and Solaris synchrotron radiation light sources, currently in operation in Lund, Sweden, and Krakow, Poland, use various conventional magnet designs. The production series of totally more than 100 magnets of more than 10 types or variants, which were all outsourced to industry, with combined orders for the types that are common to both MAX IV and Solaris, were completed in 2013 with mechanical and magnetic quality assurance conforming to specifications. This article presents an overview of the different magnet types installed in these machines, and mechanical and magnetic measurement results of the full production series.

INTRODUCTION

The MAX IV Laboratory, located in Lund, Sweden, is a synchrotron radiation facility, consisting of two storage rings, 3 GeV and 1.5 GeV, and a full energy injector linac. A principle sketch of the linac is shown in Fig. 1. The choice of a linac to inject the storage rings also provides short pulse X-rays at the end the linac, and allows an upgrade path to an FEL. [1]

Whereas the MAX IV storage ring magnets are designed as “magnet blocks”, with many consecutive magnet elements machined out of a common iron block [2], all the linac and transfer line magnets are conventional designs. The different types are listed in Table 1 and some example photos are shown in Figures 3-5.

The Solaris National Synchrotron Radiation Centre, located in Krakow, Poland, consists of a 1.5 GeV storage ring identical to the MAX IV 1.5 GeV ring, and a 600 MeV injector linac using the same components as MAX IV [3]. A schematic of the facility is shown in Fig. 2.

SPECIFICATION AND PROCUREMENT

All magnets were purchased as fully assembled and tested units. Depending on whether they were new designs for MAX IV [4,5], or old re-used designs, and what material was provided from MAX-lab, the procurements can be categorized as follows,

a) New magnetic design and full set of manufacturing drawings from MAX-lab.
b) New magnetic design from MAX-lab. Manufacturing drawings made by supplier based on instructions in the technical specification from MAX-lab.
c) Existing MAX-lab design, including drawings.
d) Existing design from supplier.

Common for all cases was that the supplier was responsible for mechanical tolerances and for performing field measurements according to MAX-lab instructions, and MAX-lab was responsible for field measurement results.

The contracts were awarded to a total of five different suppliers, as listed in Table 2. All Solaris contracts were awarded to the same suppliers as chosen by MAX IV, so that each type constituted a common production series.

PRODUCTION SERIES RESULTS

Following the technical specifications/instructions that were given to the suppliers, all mechanical tolerances < 0.1 mm were verified for every yoke part of the whole series, for each magnet order, typically by 3D coordinate measurement machine. We have not made a statistical treatment of the mechanical data like for the storage ring magnets [6,7], but generally for each magnet type the tolerances listed in Table 1 were met.

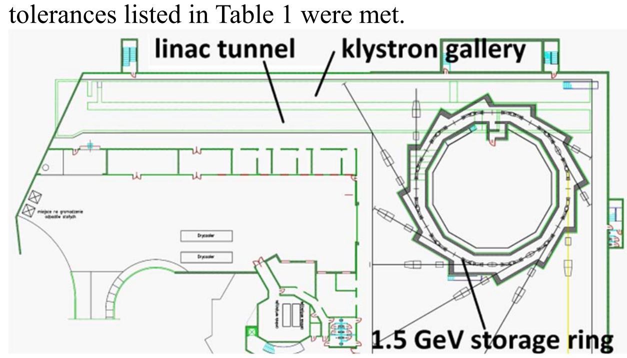

Figure 2: Solaris facility layout. The linac consists of six accelerator structures with a thermionic gun as source.

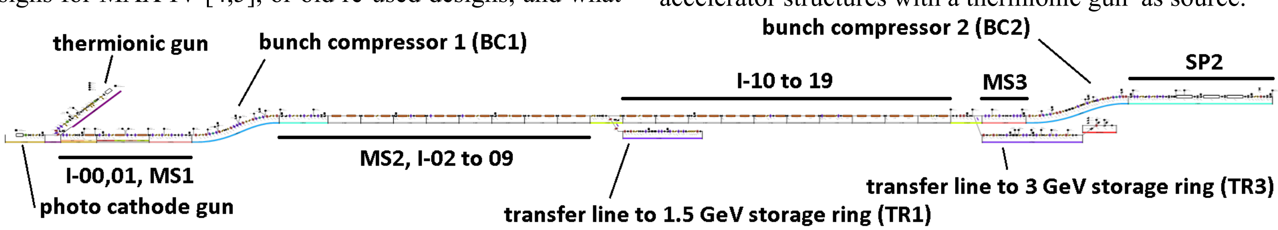

Figure 1: MAX IV linac schematic used in the control system “linac synoptic” application (illustration courtesy of J. Forsberg, MAX IV), with section names indicated. The schematic is not entirely to scale but it contains all essential features. Each “I-xx” section contains two 5 m S-band accelerator structures (except I-00 with one), giving a total of 39 S-band structures in the machine. The nominal beam path is 361.5 m from end of I-00 to entrance of SP2 beam dump.

* martin.johansson@maxiv.lu.se

Table 1: MAX IV and Solaris linac and transfer line magnet types. Locations are MAX IV (cf. Fig. 1) and numbers are MAX IV + Solaris.[1] For magnet types that are installed in many places, energy and field refer to the strongest location.

MAX IV name	No [pcs]	Location	T [2] [MeV]	l_{eff} [m]	Field	Design	Yoke Material	Coil Cooling	r_{pole} [mm]	Tolerance [mm]
DIA	8	BC1	260	0.1	0.667 T 2.607 T/m	Opera-3d	1010	water	7.5	±0.02 /half
DIB	8	BC2	3400	0.55	1.152 T 8.529 T/m	Opera-3d	Armco	water	7.5	±0.02 /half
DIC/D	2	TR3	3000	1.8	1.6 T	FEMM	1006	water	6	±0.05 /half
DIE/D	2+2	TR1	1500	0.93	1.6 T	FEMM	1006	water	7	±0.05 /half
DIH	4	TR1, TR3	3000	0.4	0.7 T	Opera-3d	laminated	water	12.5	±0.05 /half
DIPBD	1	SP2	3400	2.478	2.0 T	Opera-3d	1006/1020	water	5.5	±0.05 gap
DIPT	2+2	gun area	4	0.15	0.1 T	-	Armco	air	8	±0.01 /half
SM1A/B	2+2	TR1	1500	1.027	0.85 T	Radia	Armco/1006	water	g=5	[3]
SM3A/B	2	TR3	3000	1.027	0.85 T	Radia	Armco/1006	water	g=5	[3]
SOLA	1	gun area	4	0.16	0.4 T	-	unkn. steel	water	-	
SOLT	2+2	gun area	4	?	0.1 T	-	Armco	indirect	-	
QB	17+2	MS1–I-16	[4]	0.2	10 T/m	Opera-3d	Armco eq.	air	12.5	±0.025 assembled
QD	4	BC1	260	0.1	5.4 T/m	Opera-3d	Armco	water	25	±0.025 assembled
QE	4+4	I-01	[5]	0.07	10 T/m	-	Armco	air	20	±0.01 /quadrant
QF	30+6	TR1/3, MS3–SP2	3400	0.2	40 T/m	Opera-3d	Armco eq.	water	12.5	±0.025 assembled
QST	4+4	gun area	4	0.025	7.5 T/m	-	Armco	air	9.9	±0.01 /pole
QT	1+1	gun area	4	0.04	5.2 T/m	-	Armco	air	9.9	±0.01 /pole
SXH	2	BC2	3400	0.1	570 T/m^2	Opera-3d	Armco	water	12.5	±0.025 assembled
SXL	2	BC1	260	0.1	27.2 T/m^2	Opera-3d	Armco	water	25	±0.025 assembled
COB	1	gun area	-	0.13	5 mT	Opera-3d	1020	air	46.5	±0.1 gap
COD	45+7	TR1–SP2	≥ 1500	0.14	36 mT	Opera-3d	laminated	air	12.5	±0.1 /half
COE	21+9	I-00–I-07	< 1500	0.07	36 mT	Opera-3d	laminated	air	12.5	±0.1 /half
COH	2+2	gun area	4			-	1020	air	11.5	
COI	5+5	gun area	[6]				unkn. Steel	air	20	

Figure 3: energy filter magnets between thermionic gun and first accelerator structure at Solaris 2014.

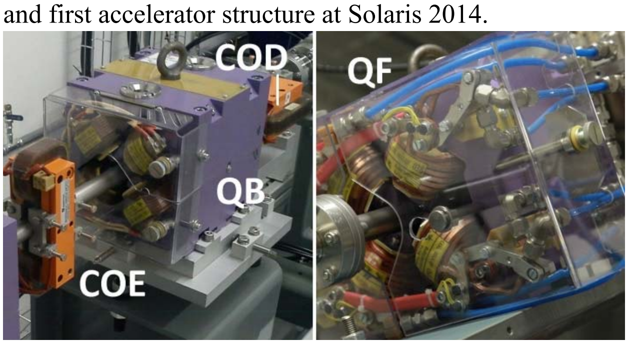

Figure 4: QB/QF are air/water cooled variants with the same yoke. COD/COE are variants with different lengths.

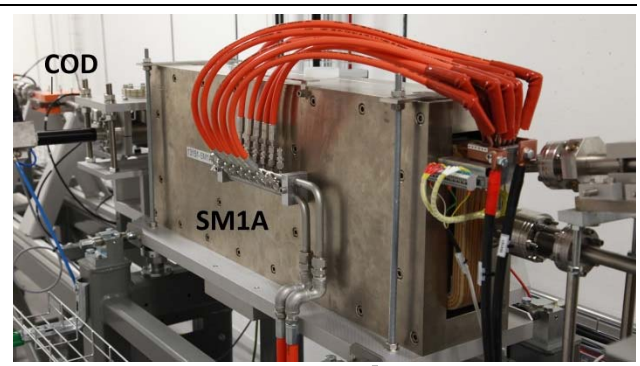

Figure 5: The septum magnets[7] are Lambertson type, bending the beam upward from the linac into the transfer lines (SM1A, SM3A), and downward to emerge parallel with stored beam in the rings (SM1B, SM3B). This photo is from Solaris 2015, where SM1A is used simply as a bending magnet. At MAX IV, SM1A and SM3A are each preceded by a pair of dipoles (DIH) shifting the beam sideways into the septum pole gap, selecting if the beam is taken up into the transfer line or straight through the septum channel.

[1] Single numbers are MAX IV only types.
[2] Max beam energy assumed for magnet design at each location.
[3] Tolerance chain of many parts.
[4] Quadrupole type B has 10 T/m at its design current, but its strongest location in the nominal lattice only has -5.3 T/m.
[5] Quadrupole type E has 10 T/m at its design current, but its strongest location in the nominal lattice only has 2.7 T/m.
[6] Corrector type I drawings = type H with larger pole gap.
[7] The MAX IV septum designs [4] are conceptually identical to the previous MAX I and MAX III septa [8].

Table 2: MAX IV and Solaris Linac and Transfer Line Magnet Production Series Results

MAX IV name	No [pcs]	Procure. Case	Supplier	Ordered	Delivered	Field Meas. For All Magnets in Series	Outcome/Comment
DIA	8	b	SigmaPhi[8]	2012 Q1	2013 Q3	Hall probe full map	Integrated B'/B verified.
DIB	8	b	Scanditronix[9]	2013 Q1	2013 Q4	Hall probe full map	Integrated B'/B verified.
DIC/D	2	a	Scanditronix	2012 Q2	2013 Q2	Hall probe long. and	
DIE/D	2+2	a	Scanditronix	-||-	-||-	transverse lines	
DIH	4	b	Danfysik[10]	2012 Q3	2013 Q4	Hall probe full map	
DIPBD	1	b	Danfysik	2013 Q1	2013 Q4	Hall probe entr/exit field maps	
DIPT	2+2	c	Scanditronix	2012 Q1	2012 Q4	Hall pr. single point[13]	
SM1A/B	2+2	a	Danfysik	2012 Q2	2014 Q1	Hall probe entr/exit	residual field in septum channel
SM3A/B	2	a	Danfysik	-||-	-||-	field maps	verified
SOLA	1	d	RadiaBeam[11]				
SOLT	2+2	c	Scanditronix	2012 Q1	2012 Q4	Hall probe single point	
QB	17+2	b	BINP[12]	2012 Q1	2013 Q3	rotating coil	
QD	4	b	Danfysik	2012 Q1	2013 Q3	rotating coil	
QE	4+4	d	Scanditronix	2010 Q4	2011 Q3	rotating coil	
QF	30+6	b	BINP	2012 Q1	2013 Q3	rotating coil	
QST	4+4	c	Scanditronix	2012 Q1	2012 Q4	Hall pr. long. lines[13]	l_{eff} = 33.5 mm (cf. Table 1)
QT	1+1	c	Scanditronix	-||-	-||-	Hall pr. long. lines[13]	l_{eff} = 48.5 mm (cf. Table 1)
SXH	2	b	Scanditronix	2013 Q1	2013 Q4	rotating coil	
SXL	2	b	Danfysik	2012 Q1	2013 Q3	rotating coil	
COB	1	b	Scanditronix	2011 Q1	2011 Q2	Hall probe single point	
COD	45+7	b	Danfysik	2012 Q3	2013 Q4	Hall probe single point	plus field map for a few individuals
COE	21+9	b	Danfysik	-||-	-||-	-||-	
COH	2+2	c	Scanditronix	2012 Q1	2012 Q4	Hall probe single point	
COI	5+5	-	MAX-lab				

Field Measurements

For almost all magnet types, there was some level of field measurements required in the specifications to the suppliers. Brief descriptions are given in Table 2, together with comments on some results. For all the new magnet types there was a good level of agreement between design and field measurement results. It can be noted that all these magnets were purchased without any intermediate prototyping.

STATUS

The MAX IV linac installation was completed in the spring of 2014. Before start of beam commissioning [9], a comprehensive test program was carried out for all linac and transfer line magnets, consisting of polarity check by hand held Hall probe for each individual magnet, and logged steady state temperature rise at full current for each individual water cooled magnet.

At present, the MAX IV linac is used routinely to inject the two storage rings at full energy, using the thermionic gun, and as a high brightness driver for the Short Pulse Facility, using the photo cathode gun.

Solaris linac installation was completed late 2014 and had achieved 300 MeV by February 2015 [10]. At present the Solaris linac is used routinely to inject the storage ring at 525 MeV, which is then ramped to full energy.

[8] SigmaPhi, Vannes, France.
[9] Scanditronix Magnet AB, Vislanda, Sweden.
[10] Danfysik A/S, Taastrup, Denmark.
[11] RadiaBeam Technologies LLC, Santa Monica, CA, USA
[12] Budker Institute of Nuclear Physics, Novosibirsk, Russia

REFERENCES

[1] M. Eriksson *et al.*, "The MAX IV Synchrotron Light Source", in *Proc. IPAC2011*, San Sebastián, Spain, paper THPC058, pp. 3026-3028.

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

[3] C.J. Bocchetta *et al.*, "Project Status of the Polish Synchrotron Radiation Facility Solaris", in *Proc. IPAC2011*, San Sebastián, Spain, paper THPC054, pp. 3014-3016.

[4] B. Anderberg and L.-J. Lindgren, chapter 2.7 of MAX IV Detailed Design Report. Technical Report. MAX-Lab, Lund, Sweden, 2010, https://www.maxiv.lu.se/publications/

[5] M. Johansson, MAX-lab Internal Note 20121017, available at https://www.maxiv.lu.se/publications/

[6] M. Johansson, L-J. Lindgren, M. Sjöström, P. F. Tavares, "MAX IV 3 GeV Storage Ring Magnet Block Measurement Results", in *Proc. IPAC2015*, Richmond, VA, USA, paper WEPMN062, pp. 3069-3071.

[7] M. Johansson, K. Karas, R. Nietubyc, "MAX IV and Solaris 1.5 GeV Storage Rings Magnet Block Measurement Results", these proceedings.

[8] B. Anderberg and L.-J. Lindgren, "The New Septum Magnets", Nucl. Instr. and Meth. A 547, 2005, pp. 686–689.

[9] S. Thorin *et al.*, "Beam Commissioning and Initial Measurements on the MAX IV 3 GeV Linac", in Proc. FEL2015, Daejeon, Korea, paper TUP014, pp. 375-378.

[10] A. I. Wawrzyniak *et al.*, "First Results of Solaris Synchrotron Commissioning", in *Proc. IBIC2015*, Melbourne, Australia, paper WEDLA01, pp. 602-605.

[13] For one magnet in series.