Future Superconducting Magnet Technology

H2020-FETOPEN-2016-2017/H2020-FETOPEN-3-2017

Grant Agreement Number n° 766974

DELIVERABLE D 2.1

REPORT ON STATE OF THE ART SUPERCONDUCTING MAGNETS

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Date and visas	18/12/2018	18/12/2018		18/12/2018

HISTORY OF CHANGES					
Version	Publication date	Change	Edited by	Reviewed by	Approved by
0.1	17/12/2018	First version	Gijs DE RIJK	Sylvain Roux	Antoine Daël
1.0	18/12/2018	Final version	Gijs DE RIJK	Sylvain Roux	Antoine Daël

PROJECT DELIVERABLE INFORMATION SHEET		
FuSuMaTech Project	Project Reference	N° 766974
	Project Title	FuSuMaTech - Future Superconducting Magnet Technology
	Project website	http://fusumatech.web.cern.ch
	Deliverable No	2.1
	Deliverable type	Report
	Dissemination Level	Public
	Contractual Delivery Date	22/12/2018
	Actual Delivery Date	22/12/2018
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1. INTRODUCTION

Magnets are in use for a large variety of applications ranging from the study of basic properties of matter, the study of complex organic molecules, material testing, particle accelerators, particle spectrometers, medical diagnosis equipment and medical irradiation machines. Since a few decades more and more types of magnets are commercially available. Initially only resistive magnets were available but since the 1970-ies also an increasing number of superconducting magnet types can be procured off-the-shelf. This document presents a catalogue of most commercially available magnet types. Both off-the-shelf and build-to-drawing magnets are listed as in this field there is a close interaction between the suppliers and the clients in developing the products.

2. ORGANISATION OF THE MAGNET CATALOGUE

The catalogue is based on a 'mother' spread-sheet containing all the numerical and text data for each type of magnet. From this spread-sheet an individual page is generated for each entry into which diagrams, drawings and pictures can be added. The catalogue is not a final, complete, document but is intended to grow over time and gain in completeness. The catalogue should be published on a public web page and can be used by all interested parties as a source of data on magnets.

3. MILESTONE MS3 "AVAILABLE INVENTORY OF HIGHFIELD SUPERCONDUCTING MAGNETS"

The initially foreseen one day workshop to consult experts to make an inventory for the catalogue was replaced by a series of direct consultations of nearby experts at CERN and at TESLA. These discussions were sufficient to cover the need of expert consultations.

4. CONCLUSIONS

The latest developments in magnet technology are in two domains: pushing the high field limits using the Low Temperature Superconductors Nb-Ti and Nb_3Sn and very innovative developments with High Temperature Superconductors. With these LTS conductors new accelerator magnets, NMR and MRI magnets have recently been realised. Especially for the NMR and MRI magnets these have led and will lead on the short to medium term to new products in the medical and research magnet domain. With HTS conductor the translation to eg. commercial research magnets is imminent and risks to lead to a real breakthrough in the field.

5. SPREAD SHEET

code	pict / xsect	application	Basic type	type	grading	conductor material 1	conductor material 2	conductor material 3	cooling	Maximum nominal field	Global Annual Volume	Installed number	Introduced	Manufacurer	comment
SA-R-1	p/x	synchrotron accelerator	resistive	H dipole	-	Cu	-	-	water	2T	Medium	>1000	1960	many	A basic particle accelereator bending magnet, the length can vary between 0,5 and 6m
SA-R-2		synchrotron accelerator	resistive	H dipole	-	Al	-	-	water	2T	Low	few 100	1960	many	
SA-R-3		synchrotron accelerator	resistive	C dipole	-	Cu	-	-	water	1.6T	Medium	>1000	1960	many	
SA-R-4		synchrotron accelerator	resistive	C dipole	-	Al	-	-	water	1.6T	Low	few 100	1960	many	
SA-R-5		synchrotron accelerator	resistive	combined function dipole	-	Cu	-	-	water	1.6T	Low	few 100	1959	many	
SA-R-6	p	synchrotron accelerator	resistive	combined function dipole	-	Al	-	-	water	1.6T	Low	few 100	1959	many	
SA-R-7	x	synchrotron accelerator	resistive	quadrupole	-	Cu	-	-	water	1.5T on the pole	Medium	>1000	1960	many	
SA-R-8	p/x	synchrotron accelerator	resistive	double aperture quadrupole	-	Cu	-	-	water	1.5T on the pole	Low	few10	1960	many	
SA-R-9		synchrotron accelerator	resistive	quadrupole	-	Al	-	-	water	1.5T on the pole	Low	few 10	1960	many	
SA-R-10	p	synchrotron accelerator	resistive	sextupole	-	Cu	-	-	water	1T on the pole	Low	few 10	1960	many	
SA-R-11		synchrotron accelerator	resistive	octupole	-	Cu	-	-	water	1T on the pole	Low	few 10	1960	many	
SA-R-12		synchrotron accelerator	resistive	low field C dipole	-	Cu	-	-	water	0.5T	Low	few 10	1960	many	
SA-R-13		synchrotron accelerator	resistive	corrector dipole	-	Cu	-	-	air	0.5T	Low	few 100	1960	many	
SA-R-14		synchrotron accelerator	resistive	corrector quadupole	-	Cu	-	-	air	0.5T on the pole	Low	few 10	1960	many	
SA-R-15		synchrotron accelerator	resistive	HO corrector	-	Cu	-	-	air	0.5T on the pole	Low	few 10	1960	many	
SA-R-16		synchrotron accelerator	resistive	focusing solenoid	-	Cu	-	-	air	1T	Low	few 100		many	
SA-R-17		synchrotron accelerator	resistive	focusing solenoid	-	Cu	-	-	water	2T	Low	few 100		many	
SA-R-18		synchrotron accelerator	resistive	lambertson septum	-	Cu	-	-	water	1.2T	Low	few 10		many	
SA-R-19		synchrotron accelerator	resistive	pulsed septum	-	Cu	-	-	water	1T	Low	few 10		many	
SA-R-20		synchrotron accelerator	resistive	wiggler	-	Cu/Al	-	-	water	2T	Medium	few 100	1966	many	
SA-P-1		synchrotron accelerator	permanent	undulator	-		-	-	none	0.5T	Medium	few 100	1953	many	
SA-P-2		synchrotron accelerator	permanent	sextupole	-		-	-	none	2T on the pole					
SA-S-1	p/x	synchrotron accelerator	Superconducting	dipole	no	Nb-Ti	-	-	He	6T	Low				
SA-S-2		synchrotron accelerator	Superconducting	double aperture dipole	no	Nb-Ti	-	-	He	6T	Low				
SA-S-3		synchrotron accelerator	Superconducting	dipole	yes	Nb-Ti	Nb-Ti	-	He	9T	Low				
SA-S-4	p/x	synchrotron accelerator	Superconducting	double aperture dipole	yes	Nb-Ti	Nb-Ti	-	He	9T	Low				
SA-S-5	p/x	synchrotron accelerator	Superconducting	quadrupole	yes	Nb-Ti	Nb-Ti	-	He	9T on the pole	Low				
SA-S-6	p/x	synchrotron accelerator	Superconducting	double aperture quadrupole	yes	Nb-Ti	Nb-Ti	-	He	9T on the pole	Low				
SA-S-7		synchrotron accelerator	Superconducting	sextupole	no	Nb-Ti	-	-	He	3,5T on the pole	Low				
SA-S-8	p	synchrotron accelerator	Superconducting	octupole	no	Nb-Ti	-	-	He	1.4T on the pole	Low				
SA-S-9	p	synchrotron accelerator	Superconducting	HO corrector	no	Nb-Ti	-	-	He	1.4T on the pole	Low				
SA-S-10	p/x	synchrotron accelerator	Superconducting	dipole	no	Nb_3Sn	-	-	He	14,6T	Low				
SA-S-11	p/x	synchrotron accelerator	Superconducting	quadrupole	no	Nb_3Sn	-	-	He	12T on the pole	Low				
SA-S-12		synchrotron accelerator	Superconducting	focusing solenoid	no	Nb-Ti	-	-	He	4T	Low				
SA-S-13		synchrotron accelerator	Superconducting	focusing solenoid	no	Nb_3Sn	-	-	He	12T	Low				
SA-S-14		synchrotron accelerator	Superconducting	Pipetron dipole	no	Nb-Ti	-	-	He	1.8T	Low				
SA-S-15		synchrotron accelerator	Superconducting	wiggler	-	Nb-Ti	-	-	He	6T	Low	few 100		many	
LA-P-1		Linear Accelerator	permanent	quadrupole	-		-	-	none	2T on the pole	Low	few 100		many	
LA-R-1		Linear Accelerator	resistive	solenoid	-	Cu	-	-	water	2T	Medium	>1000		many	
LA-S-1		Linear Accelerator	Superconducting	solenoid	-	Nb-Ti	-	-	He	4T	Low	few 10		many	
PS-R-1	p	particle spectrometer	resistive	spectrometer dipole	-	Cu	-	-	water	2T					
PS-R-2		particle spectrometer	resistive	spectrometer solenoid	-	Cu	-	-	water	2T					
PS-S-1	p	particle spectrometer	Superconducting	spectrometer dipole	no	Nb-Ti	-	-	He	2T					
PS-S-2	p	particle spectrometer	Superconducting	spectrometer solenoid	no	Nb-Ti	-	-	He	4T					
PS-R-3		particle spectrometer	resistive	spectrometer toroid	-	Cu	-	-	water	1T					
PS-S-3	p/x	particle spectrometer	Superconducting	spectrometer toroid	no	Nb-Ti	-	-	He	4.4T					
NM-R-1		NMR	resistive	solenoid	-	Cu	-	-	water	0.6T	Low	500	1950	>5	Desk top NMR for food testing, teaching etc
NM-S-1		NMR	Superconducting	nested solenoid	no	Nb-Ti	-	-	He	4.7T -9.4T (200-400MHz)	High	>5000	1962	4	Bruker, Jeol, Varian, Wuhan
NM-S-2		NMR	Superconducting	nested solenoid	yes	Nb_3Sn	Nb-Ti	-	He	11,7T - 19T (500-800MHz)	High	>5000	1977	3	Bruker Jeol, Varian
NM-S-3		NMR	Superconducting	nested solenoid	yes	Nb_3Sn	Nb-Ti	-	He	21T (900MHz)	Low	50	2000	3	Bruker, Jeol , Varian
NM-S-4		NMR	Superconducting	nested solenoid	yes	Nb_3Sn	Nb-Ti	-	He 2K	23,5T (1GHz)	Low	5	2009	2	Bruker, Jeol (1)
NM-S-5		NMR	Superconducting	nested solenoid	yes	YBCO	Nb_3Sn	Nb-Ti	He 2K	28,2T (1,2GHz)	Low	<5		1	Bruker
MR-R-1		MRI	resistive	solenoid multicoil	no	Cu			water	0.35T	Low	few 10	1977		Generally obsolete as s/n very low
MR-P-1		MRI	Permanent	axial field	-		-	-	none	2T		100			Mostly in China
MR-S-1		MRI	Superconducting	Split multicoil	no	Nb-Ti	-	-	He	0.35T	Medium	30		1	Viewray MR guided RT
MR-S-2		MRI	Superconducting	Split pair	no	MgB_2	-	-	conduction	0.5T	Medium	5			
MR-S-3		MRI	Superconducting	solenoid multicoil	yes	Nb-Ti	Nb-Ti	-	He	1.5T	High	>20000	1985	10+	Standard MRI system now manufactured in Europe, North America, China, Japan and Kore
MR-S-4		MRI	Superconducting	solenoid multicoil	yes	Nb-Ti	Nb-Ti	-	conduction	1.5T	Low	10	2013	4	Very recently developed
MR-S-5		MRI	Superconducting	solenoid multicoil	yes	Nb-Ti	Nb-Ti	-	He	3,0T	High	>3000	1990	5+	Approx 20% of systems sold now 3T (High Field)
MR-S-6		MRI	Superconducting	solenoid multicoil	yes	Nb-Ti	Nb-Ti	-	He	7.0T	Medium	75	2000	3	GE, Siemens,Agilent, Tesla
MR-S-7		MRI	Superconducting	nested solenoid	yes	Nb-Ti	Nb-Ti	-	He	9,4T	Low	5	2005	3	GE, Agilent, Tesla
MR-S-8		MRI	Superconducting	nested solenoid	yes	Nb-Ti	Nb-Ti	-	He 2K	10,5T	Low	1	2013	1	Agilent
MR-S-9		MRI	Superconducting	nested solenoid	yes	Nb-Ti	Nb-Ti	-	He 2K	11,7T	Low	2	2013	2	Agilent, CEA
MR-S-10		MRI	Superconducting	nested solenoid	yes	Nb_3Sn	Nb-Ti	-	He	14T	Low	0		1	No whole body only small bore
MR-S-11		MRI	Superconducting	nested solenoid	yes	Nb_3Sn	Nb-Ti	-	He 2K	16,4T	Low	0		1	No whole body only small bore
CA-R-1		Cyclotron accelerator	resistive	sector dipole	-	Cu	-	-	water		Medium	100			
CA-S-1		Cyclotron accelerator	Superconducting	sector dipole	no	Nb-Ti	-	-	conduction	4.6T	Medium	5			Ionetix (supercompact)
CA-S-2		Cyclotron accelerator	Superconducting	sector dipole	no	Nb-Ti	-	-	conduction	5,74T	Medium				
CA-S-3		Cyclotron accelerator	Superconducting	sector dipole	no	Nb_3Sn	-	-	He	8T	Low	10			Mevion
FT-S-1		FTMS	Superconducting	nested solenoid	no	Nb-Ti	-	-	He	7T	Medium	20			
FT-S-2		FTMS	Superconducting	nested solenoid	yes	Nb_3Sn	Nb-Ti	-	He	12T	Low	10			
FT-S-3		FTMS	Superconducting	nested solenoid	yes	Nb_3Sn	Nb-Ti	-	He 2K	15T	Low	<5			

6. CATALOGUE

H dipole

basic type	resistive
Maximum Fieled strength	2T
grading	-
conductor material(s)	Cu - -
Cooling	water
used for	synchrotron accelerator
Manufacturer	many
Installed number	>1000
global annual volume	Medium
Introduced	1960

A basic particle accelereator bending magnet, the length can vary between 0,5 and 6m

Cross section

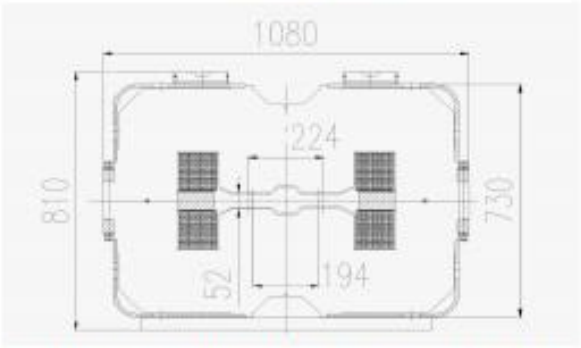


Figure 8.14: Cross-section of the normal conducting separation dipole MBW.

Photo

H dipole

basic type	resistive
Maximum Fieled strength	2T
grading	-
conductor material(s)	Al - -
Cooling	water
used for	synchrotron accelerator
Manufacturer	many
Installed number	few 100
global annual volume	Low
Introduced	1960

0

Cross section

Photo

C dipole

basic type	resistive
Maximum Fieled strength	1.6T
grading	-
conductor material(s)	Cu - -
Cooling	water
used for	synchrotron accelerator
Manufacturer	many
Installed number	>1000
global annual volume	Medium
Introduced	1960

0

Cross section

Photo

C dipole

basic type	resistive
Maximum Fieled strength	1.6T
grading	-
conductor material(s)	Al - -
Cooling	water
used for	synchrotron accelerator
Manufacturer	many
Installed number	few 100
global annual volume	Low
Introduced	1960

0

Cross section

Photo

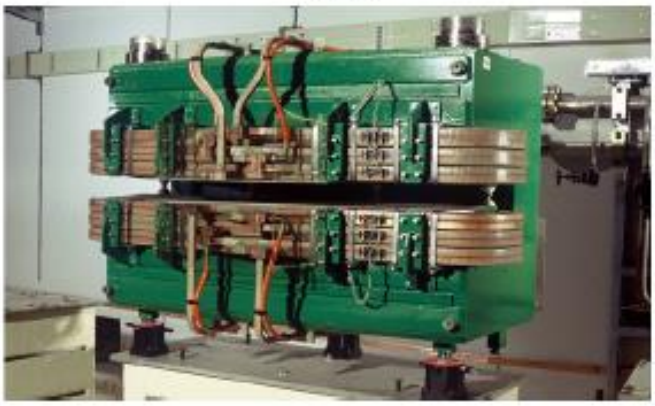
combined function dipole

basic type	resistive
Maximum Fieled strength	1.6T
grading	-
conductor material(s)	Cu - -
Cooling	water
used for	synchrotron accelerator
Manufacturer	many
Installed number	few 100
global annual volume	Low
Introduced	1959

0

Cross section

Photo



combined function dipole

basic type	resistive
Maximum Fieled strength	1.6T
grading	-
conductor material(s)	Al - -
Cooling	water
used for	synchrotron accelerator
Manufacturer	many
Installed number	few 100
global annual volume	Low
Introduced	1959

0

Cross section

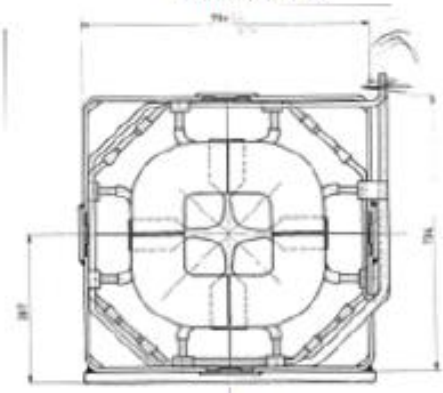
Photo

quadrupole

basic type	resistive
Maximum Fieled strength	1.5T on the pole
grading	-
conductor material(s)	Cu - -
Cooling	water
used for	synchrotron accelerator
Manufacturer	many
Installed number	>1000
global annual volume	Medium
Introduced	1960

0

Cross section



Photo

double aperture quadrupole

basic type	resistive
Maximum Fieled strength	1.5T on the pole
grading	-
conductor material(s)	Cu - -
Cooling	water
used for	synchrotron accelerator
Manufacturer	many
Installed number	few10
global annual volume	Low
Introduced	1960

0

Cross section

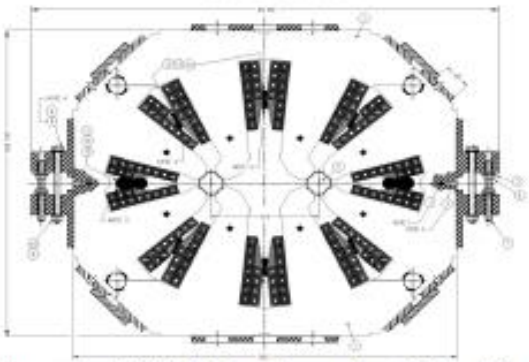


Figure 8.7: Cross-section of the MQW twin aperture normal conducting matching quadrupole.

Photo

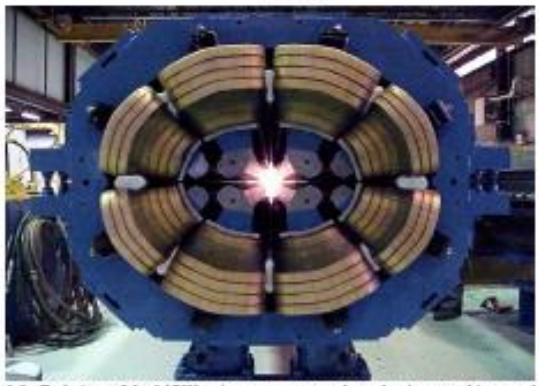


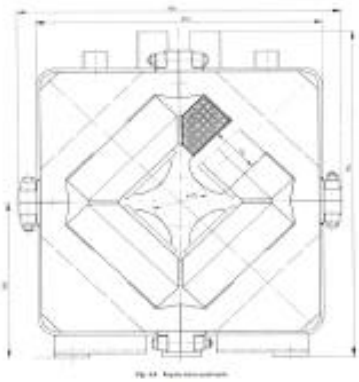
Figure 8.8: End view of the MQW twin aperture normal conducting matching quadrupole.

quadrupole

basic type	resistive
Maximum Fieled strength	1.5T on the pole
grading	-
conductor material(s)	Al - -
Cooling	water
used for	synchrotron accelerator
Manufacturer	many
Installed number	few 10
global annual volume	Low
Introduced	1960

0

Cross section



Photo

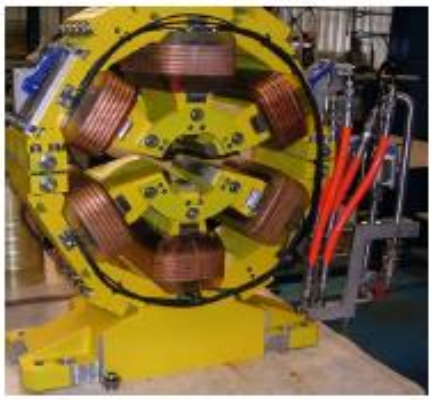
sextupole

basic type	resistive
Maximum Fieled strength	1T on the pole
grading	-
conductor material(s)	Cu - -
Cooling	water
used for	synchrotron accelerator
Manufacturer	many
Installed number	few 10
global annual volume	Low
Introduced	1960

0

Cross section

Photo



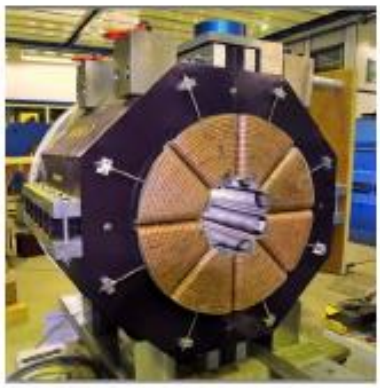
octupole

basic type	resistive
Maximum Fieled strength	1T on the pole
grading	-
conductor material(s)	Cu - -
Cooling	water
used for	synchrotron accelerator
Manufacturer	many
Installed number	few 10
global annual volume	Low
Introduced	1960

0

Cross section

Photo

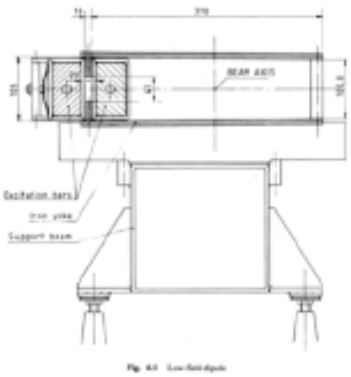


low field C dipole

basic type	resistive
Maximum Fieled strength	0.5T
grading	-
conductor material(s)	Cu - -
Cooling	water
used for	synchrotron accelerator
Manufacturer	many
Installed number	few 10
global annual volume	Low
Introduced	1960

0

Cross section



Photo

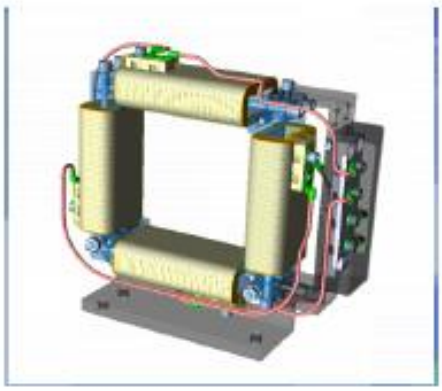
corrector dipole

basic type	resistive
Maximum Fieled strength	0.5T
grading	-
conductor material(s)	Cu - -
Cooling	air
used for	synchrotron accelerator
Manufacturer	many
Installed number	few 100
global annual volume	Low
Introduced	1960

0

Cross section

Photo



corrector quadupole

basic type	resistive
Maximum Fieled strength	0.5T on the pole
grading	-
conductor material(s)	Cu - -
Cooling	air
used for	synchrotron accelerator
Manufacturer	many
Installed number	few 10
global annual volume	Low
Introduced	1960

0

Cross section

Photo

HO corrector

basic type	resistive
Maximum Fieled strength	0.5T on the pole
grading	-
conductor material(s)	Cu - -
Cooling	air
used for	synchrotron accelerator
Manufacturer	many
Installed number	few 10
global annual volume	Low
Introduced	1960

0

Cross section

Photo

focusing solenoid

basic type	resistive
Maximum Fieled strength	1T
grading	-
conductor material(s)	Cu - -
Cooling	air
used for	synchrotron accelerator
Manufacturer	many
Installed number	few 100
global annual volume	Low
Introduced	0

0

Cross section

Photo

focusing solenoid

basic type	resistive
Maximum Fieled strength	2T
grading	-
conductor material(s)	Cu - -
Cooling	water
used for	synchrotron accelerator
Manufacturer	many
Installed number	few 100
global annual volume	Low
Introduced	0

0

Cross section

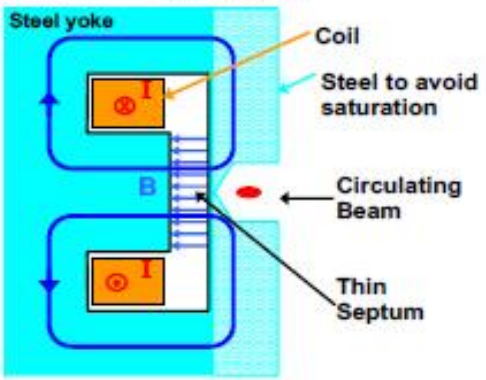
Photo

lambertson septum

basic type	resistive
Maximum Fieled strength	1.2T
grading	-
conductor material(s)	Cu - -
Cooling	water
used for	synchrotron accelerator
Manufacturer	many
Installed number	few 10
global annual volume	Low
Introduced	0

0

Cross section



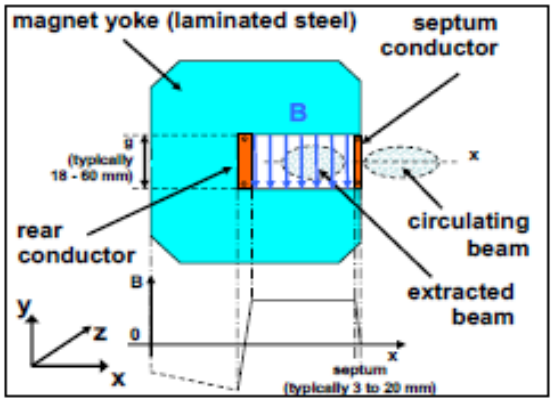
Photo

pulsed septum

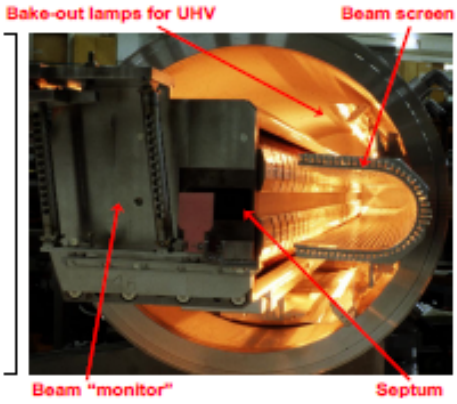
basic type	resistive
Maximum Fieled strength	1T
grading	-
conductor material(s)	Cu - -
Cooling	water
used for	synchrotron accelerator
Manufacturer	many
Installed number	few 10
global annual volume	Low
Introduced	0

0

Cross section



Photo



wiggler

basic type	resistive
Maximum Fieled strength	2T
grading	-
conductor material(s)	Cu/Al - -
Cooling	water
used for	synchrotron accelerator
Manufacturer	many
Installed number	few 100
global annual volume	Medium
Introduced	1966

0

Cross section

Photo

undulator

basic type	permanent
Maximum Fieled strength	0.5T
grading	-
conductor material(s)	0 - -
Cooling	none
used for	synchrotron accelerator
Manufacturer	many
Installed number	few 100
global annual volume	Medium
Introduced	1953

0

Cross section

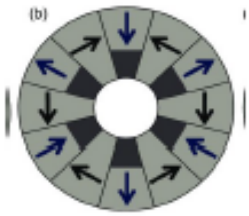
Photo

sextupole

basic type	permanent		
Maximum Fieled strength	2T on the pole		
grading	-		
conductor material(s)		0 -	-
Cooling	none		
used for	synchrotron accelerator		
Manufacturer		0	
Installed number		0	
global annual volume		0	
Introduced	0		

0

Cross section

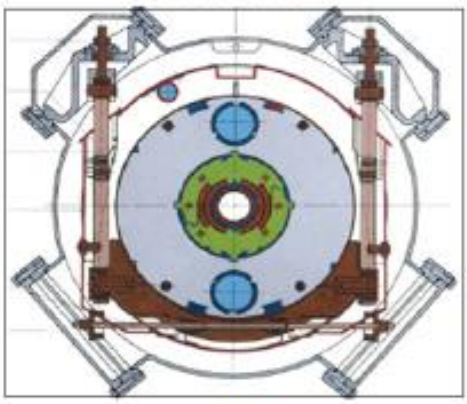


Photo

dipole

basic type	Superconducting		
Maximum Fieled strength	6T		
grading	no		
conductor material(s)	Nb-Ti	-	-
Cooling	He		
used for	synchrotron accelerator		
Manufacturer		0	
Installed number		0	
global annual volume	Low		
Introduced	0		
0			

Cross section



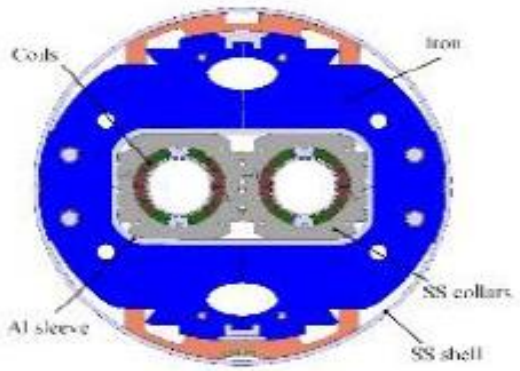
Photo

double aperture dipole

basic type	Superconducting
Maximum Fieled strength	6T
grading	no
conductor material(s)	Nb-Ti - -
Cooling	He
used for	synchrotron accelerator
Manufacturer	0
Installed number	0
global annual volume	Low
Introduced	0

0

Cross section



Photo

dipole

basic type	Superconducting		
Maximum Fieled strength	9T		
grading	yes		
conductor material(s)	Nb-Ti	Nb-Ti	-
Cooling	He		
used for	synchrotron accelerator		
Manufacturer		0	
Installed number		0	
global annual volume	Low		
Introduced	0		

0

Cross section

Photo

double aperture dipole

basic type	Superconducting		
Maximum Fieled strength	9T		
grading	yes		
conductor material(s)	Nb-Ti	Nb-Ti	-
Cooling	He		
used for	synchrotron accelerator		
Manufacturer		0	
Installed number		0	
global annual volume	Low		
Introduced	0		
0			

Cross section

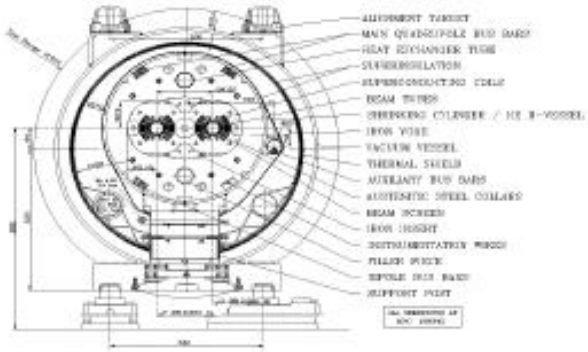


Figure 7.3: Cross-section of cryodipole

Photo

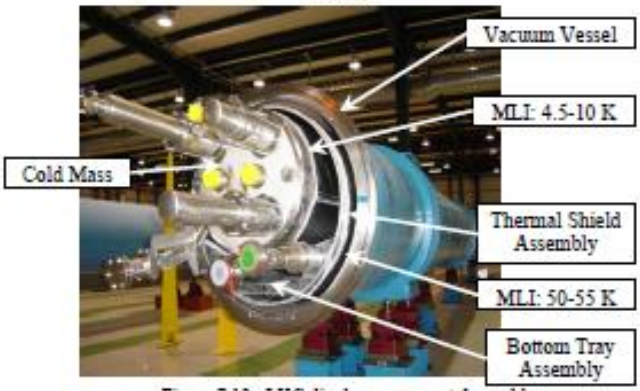


Figure 7.12: LHC dipole cryomagnet Assembly

quadrupole

basic type	Superconducting		
Maximum Fieled strength	9T on the pole		
grading	yes		
conductor material(s)	Nb-Ti	Nb-Ti	-
Cooling	He		
used for	synchrotron accelerator		
Manufacturer		0	
Installed number		0	
global annual volume	Low		
Introduced	0		

0

Cross section

Photo

Figure 8.18: (Left) Cross-section of the MQXA low-β quadrupole. (Right) MQXA quadrupole ready for tests in the vertical cryostat in KEK.

double aperture quadrupole

basic type	Superconducting		
Maximum Fieled strength	9T on the pole		
grading	yes		
conductor material(s)	Nb-Ti	Nb-Ti	-
Cooling	He		
used for	synchrotron accelerator		
Manufacturer		0	
Installed number		0	
global annual volume	Low		
Introduced	0		

0

Cross section

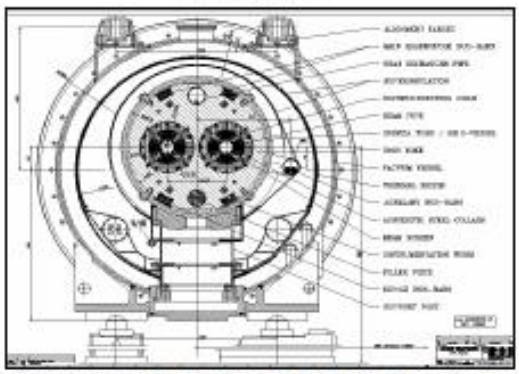


Figure 7.16: Cross-section of short straight section with quadrupole cold mass inside cryostat

Photo

sextupole

basic type	Superconducting		
Maximum Fieled strength	3.5T on the pole		
grading	no		
conductor material(s)	Nb-Ti	-	-
Cooling	He		
used for	synchrotron accelerator		
Manufacturer		0	
Installed number		0	
global annual volume	Low		
Introduced	0		

0

Cross section

Photo

octupole

basic type	Superconducting		
Maximum Fieled strength	1.4T on the pole		
grading	no		
conductor material(s)	Nb-Ti	-	-
Cooling	He		
used for	synchrotron accelerator		
Manufacturer	0		
Installed number	0		
global annual volume	Low		
Introduced	0		

0

Cross section

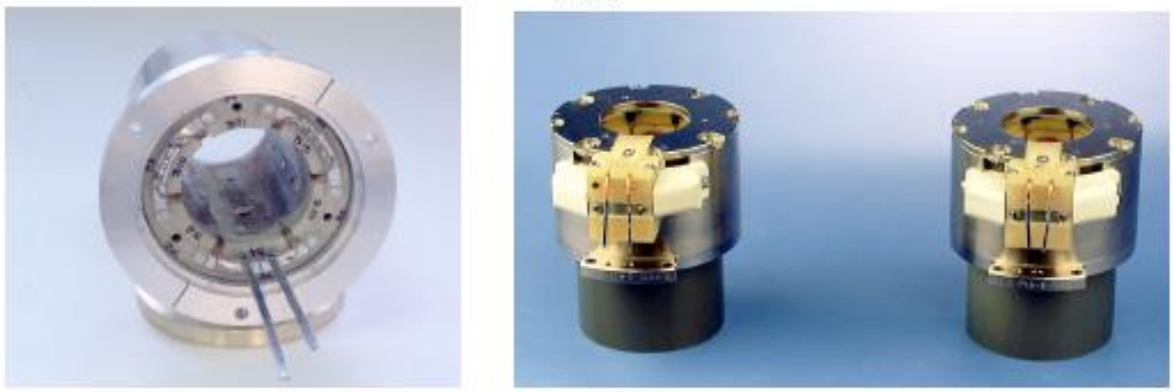
Photo

HO corrector

basic type	Superconducting		
Maximum Fieled strength	1.4T on the pole		
grading	no		
conductor material(s)	Nb-Ti	-	-
Cooling	He		
used for	synchrotron accelerator		
Manufacturer	0		
Installed number	0		
global annual volume	Low		
Introduced	0		
0			

Cross section

Photo

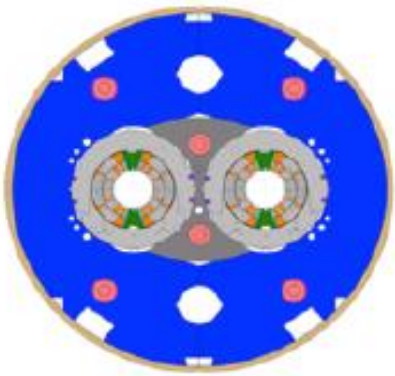


dipole

basic type	Superconducting
Maximum Fieled strength	14.6T
grading	no
conductor material(s)	Nb3Sn - -
Cooling	He
used for	synchrotron accelerator
Manufacturer	0
Installed number	0
global annual volume	Low
Introduced	0

0

Cross section

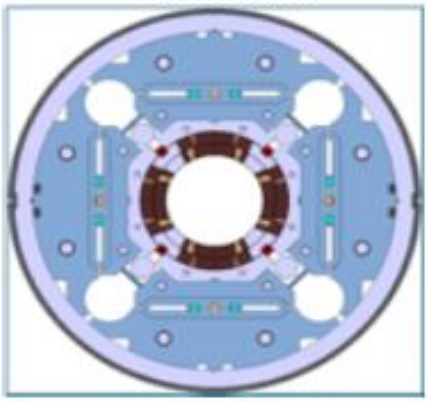


Photo

quadrupole

basic type	Superconducting		
Maximum Fieled strength	12T on the pole		
grading	no		
conductor material(s)	Nb3Sn	-	-
Cooling	He		
used for	synchrotron accelerator		
Manufacturer		0	
Installed number		0	
global annual volume	Low		
introduced	0		
0			

Cross section



Photo

focusing solenoid

basic type	Superconducting		
Maximum Fieled strength	4T		
grading	no		
conductor material(s)	Nb-Ti	-	-
Cooling	He		
used for	synchrotron accelerator		
Manufacturer	0		
Installed number	0		
global annual volume	Low		
Introduced	0		

0

Cross section

Photo

focusing solenoid

basic type	Superconducting		
Maximum Fieled strength	12T		
grading	no		
conductor material(s)	Nb3Sn	-	-
Cooling	He		
used for	synchrotron accelerator		
Manufacturer	0		
Installed number	0		
global annual volume	Low		
Introduced	0		

0

Cross section

Photo

Pipetron dipole

basic type	Superconducting		
Maximum Fieled strength	1.8T		
grading	no		
conductor material(s)	Nb-Ti	-	-
Cooling	He		
used for	synchrotron accelerator		
Manufacturer		0	
Installed number		0	
global annual volume	Low		
Introduced	0		

0

Cross section

Photo

wiggler

basic type	Superconducting
Maximum Fieled strength	6T
grading	-
conductor material(s)	Nb-Ti - -
Cooling	He
used for	synchrotron accelerator
Manufacturer	many
Installed number	few 100
global annual volume	Low
Introduced	0

0

Cross section

Photo

quadrupole

basic type	permanent
Maximum Fieled strength	2T on the pole
grading	-
conductor material(s)	0 - -
Cooling	none
used for	Linear Accelerator
Manufacturer	many
Installed number	few 100
global annual volume	Low
Introduced	0

0

Cross section

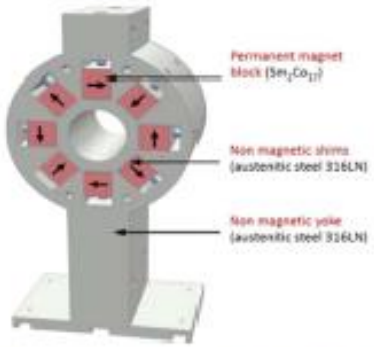


Fig. 1. Schematic layout of the Linac4 permanent-magnet quadrupole.

Photo

z. 1. (a) 45mm long PMQ for Tank 1;

solenoid

basic type	resistive
Maximum Fieled strength	2T
grading	-
conductor material(s)	Cu - -
Cooling	water
used for	Linear Accelerator
Manufacturer	many
Installed number	>1000
global annual volume	Medium
Introduced	0

0

Cross section

Photo

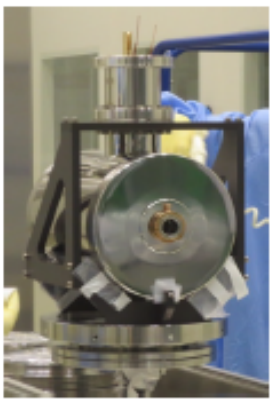
solenoid

basic type	Superconducting		
Maximum Fieled strength	4T		
grading	-		
conductor material(s)	Nb-Ti	-	-
Cooling	He		
used for	Linear Accelerator		
Manufacturer	many		
Installed number	few 10		
global annual volume	Low		
Introduced	0		

0

Cross section

Photo



spectrometer dipole

basic type	resistive		
Maximum Fieled strength	2T		
grading	-		
conductor material(s)	Cu	-	-
Cooling	water		
used for	particle spectrometer		
Manufacturer		0	
Installed number		0	
global annual volume		0	
Introduced	0		
0			

Cross section

Photo

spectrometer solenoid

basic type	resistive		
Maximum Fieled strength	2T		
grading	-		
conductor material(s)	Cu	-	-
Cooling	water		
used for	particle spectrometer		
Manufacturer		0	
Installed number		0	
global annual volume		0	
Introduced	0		

0

Cross section

Photo

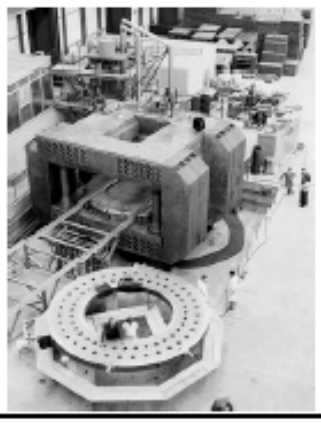
spectrometer dipole

basic type	Superconducting		
Maximum Fieled strength	2T		
grading	no		
conductor material(s)	Nb-Ti	-	-
Cooling	He		
used for	particle spectrometer		
Manufacturer		0	
Installed number		0	
global annual volume		0	
Introduced	0		

0

Cross section

Photo



spectrometer solenoid

basic type	Superconducting		
Maximum Fieled strength	4T		
grading	no		
conductor material(s)	Nb-Ti	-	-
Cooling	He		
used for	particle spectrometer		
Manufacturer		0	
Installed number		0	
global annual volume		0	
Introduced	0		

0

Cross section

Photo

spectrometer toroid

basic type	resistive		
Maximum Fieled strength	1T		
grading	-		
conductor material(s)	Cu	-	-
Cooling	water		
used for	particle spectrometer		
Manufacturer		0	
Installed number		0	
global annual volume		0	
Introduced	0		

0

Cross section

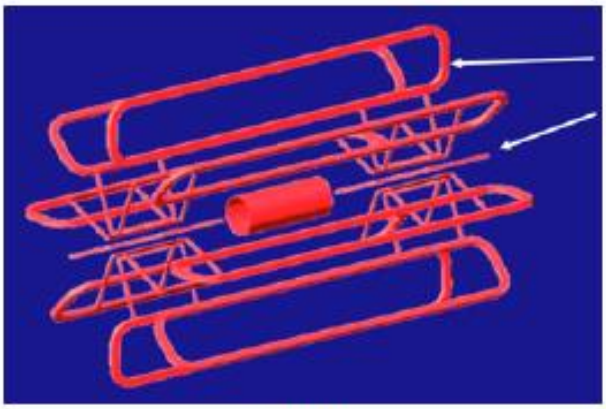
Photo

spectrometer toroid

basic type	Superconducting		
Maximum Fieled strength	4.4T		
grading	no		
conductor material(s)	Nb-Ti	-	-
Cooling	He		
used for	particle spectrometer		
Manufacturer		0	
Installed number		0	
global annual volume		0	
Introduced	0		

0

Cross section



Photo

solenoid

basic type	resistive		
Maximum Fieled strength	0.6T		
grading	-		
conductor material(s)	Cu	-	-
Cooling	water		
used for	NMR		
Manufacturer	>5		
Installed number		500	
global annual volume	Low		
Introduced	1950		

Desk top NMR for food testing, teaching etc

Cross section

Photo

nested solenoid

basic type	Superconducting		
Maximum Fieled strength	4.7T -9.4T (200-400MHz)		
grading	no		
conductor material(s)	Nb-Ti	-	-
Cooling	He		
used for	NMR		
Manufacturer		4	
Installed number	>5000		
global annual volume	High		
Introduced	1962		

Bruker, Jeol, Varian, Wuhan

Cross section

Photo

nested solenoid

basic type	Superconducting		
Maximum Fieled strength	11.7T - 19T (500-800MHz)		
grading	yes		
conductor material(s)	Nb3Sn	Nb-Ti	-
Cooling	He		
used for	NMR		
Manufacturer		3	
Installed number	>5000		
global annual volume	High		
Introduced	1977		

Bruker Jeol, Varian

Cross section

Photo

nested solenoid

basic type	Superconducting		
Maximum Fieled strength	21T (900MHz)		
grading	yes		
conductor material(s)	Nb3Sn	Nb-Ti	-
Cooling	He		
used for	NMR		
Manufacturer		3	
Installed number		50	
global annual volume	Low		
Introduced	2000		

Bruker, Jeol , Varian

Cross section

Photo

nested solenoid

basic type	Superconducting		
Maximum Fieled strength	23.5T (1GHz)		
grading	yes		
conductor material(s)	Nb3Sn	Nb-Ti	-
Cooling	He 2K		
used for	NMR		
Manufacturer		2	
Installed number		5	
global annual volume	Low		
Introduced	2009		

Bruker, Jeol (1)

Cross section

Photo

nested solenoid

basic type	Superconducting		
Maximum Fieled strength	28.2T (1.2GHz)		
grading	yes		
conductor material(s)	YBCO	Nb3Sn	Nb-Ti
Cooling	He 2K		
used for	NMR		
Manufacturer		1	
Installed number	<5		
global annual volume	Low		
Introduced	0		

Bruker

Cross section

Photo

solenoid multicoil

basic type	resistive			
Maximum Fieled strength	0.35T			
grading	no			
conductor material(s)	Cu		0	0
Cooling	water			
used for	MRI			
Manufacturer		0		
Installed number	few 10			
global annual volume	Low			
Introduced	1977			

Generally obsolete as s/n very low

Cross section

Photo

axial field

basic type	Permanent		
Maximum Fieled strength	2T		
grading	-		
conductor material(s)		0 -	-
Cooling	none		
used for	MRI		
Manufacturer		0	
Installed number		100	
global annual volume		0	
Introduced	0		

Mostly in China

Cross section

Photo

Split multicoil

basic type	Superconducting		
Maximum Fieled strength	0.35T		
grading	no		
conductor material(s)	Nb-Ti	-	-
Cooling	He		
used for	MRI		
Manufacturer		1	
Installed number		30	
global annual volume	Medium		
Introduced	0		

Viewray MR guided RT

Cross section

Photo

Split pair

basic type	Superconducting		
Maximum Fieled strength	0.5T		
grading	no		
conductor material(s)	MgB2	-	-
Cooling	conduction		
used for	MRI		
Manufacturer		0	
Installed number		5	
global annual volume	Medium		
Introduced	0		
0			

Cross section

Photo

solenoid multicoil

basic type	Superconducting		
Maximum Fieled strength	1.5T		
grading	yes		
conductor material(s)	Nb-Ti	Nb-Ti	-
Cooling	He		
used for	MRI		
Manufacturer	10+		
Installed number	>20000		
global annual volume	High		
Introduced	1985		

Standard MRI system now manufactured in Europe, North America, China, Japan and Korea

Cross section

Photo

solenoid multicoil

basic type	Superconducting		
Maximum Fieled strength	1.5T		
grading	yes		
conductor material(s)	Nb-Ti	Nb-Ti	-
Cooling	conduction		
used for	MRI		
Manufacturer		4	
Installed number		10	
global annual volume	Low		
Introduced	2013		

Very recently developed

Cross section

Photo

solenoid multicoil

basic type	Superconducting		
Maximum Fieled strength	3.0T		
grading	yes		
conductor material(s)	Nb-Ti	Nb-Ti	-
Cooling	He		
used for	MRI		
Manufacturer	5+		
Installed number	>3000		
global annual volume	High		
Introduced	1990		

Approx 20% of systems sold now 3T (High Field)

Cross section

Photo

solenoid multicoil

basic type	Superconducting		
Maximum Fieled strength	7.0T		
grading	yes		
conductor material(s)	Nb-Ti	Nb-Ti	-
Cooling	He		
used for	MRI		
Manufacturer		3	
Installed number		75	
global annual volume	Medium		
Introduced	2000		

GE, Siemens,Agilent, Tesla

Cross section

Photo

nested solenoid

basic type	Superconducting		
Maximum Fieled strength	9.4T		
grading	yes		
conductor material(s)	Nb-Ti	Nb-Ti	-
Cooling	He		
used for	MRI		
Manufacturer		3	
Installed number		5	
global annual volume	Low		
Introduced	2005		

GE, Agilent, Tesla

Cross section

Photo

nested solenoid

basic type	Superconducting		
Maximum Fieled strength	10.5T		
grading	yes		
conductor material(s)	Nb-Ti	Nb-Ti	-
Cooling	He 2K		
used for	MRI		
Manufacturer		1	
Installed number		1	
global annual volume	Low		
Introduced	2013		

Agilent

Cross section

Photo

nested solenoid

basic type	Superconducting		
Maximum Fieled strength	11.7T		
grading	yes		
conductor material(s)	Nb-Ti	Nb-Ti	-
Cooling	He 2K		
used for	MRI		
Manufacturer		2	
Installed number		2	
global annual volume	Low		
Introduced	2013		

Agilent, CEA

Cross section

Photo

nested solenoid

basic type	Superconducting		
Maximum Fieled strength	14T		
grading	yes		
conductor material(s)	Nb3Sn	Nb-Ti	-
Cooling	He		
used for	MRI		
Manufacturer		1	
Installed number		0	
global annual volume	Low		
Introduced	0		

No whole body only small bore

Cross section

Photo

nested solenoid

basic type	Superconducting		
Maximum Fieled strength	16.4T		
grading	yes		
conductor material(s)	Nb3Sn	Nb-Ti	-
Cooling	He 2K		
used for	MRI		
Manufacturer		1	
Installed number		0	
global annual volume	Low		
Introduced	0		

No whole body only small bore

Cross section

Photo

sector dipole

basic type	resistive		
Maximum Fieled strength		0	
grading	-		
conductor material(s)	Cu	-	-
Cooling	water		
used for	Cyclotron accelerator		
Manufacturer		0	
Installed number		100	
global annual volume	Medium		
Introduced	0		

0

Cross section

Photo

PSI= 590 MeV proton

sector dipole

basic type	Superconducting		
Maximum Fieled strength	4.6T		
grading	no		
conductor material(s)	Nb-Ti	-	-
Cooling	conduction		
used for	Cyclotron accelerator		
Manufacturer		0	
Installed number		5	
global annual volume	Medium		
Introduced	0		

Ionetix (supercompact)

Cross section

Photo

sector dipole

basic type	Superconducting		
Maximum Fieled strength	5.74T		
grading	no		
conductor material(s)	Nb-Ti	-	-
Cooling	conduction		
used for	Cyclotron accelerator		
Manufacturer		0	
Installed number		0	
global annual volume	Medium		
Introduced	0		

0

Cross section

Photo

sector dipole

basic type	Superconducting		
Maximum Fieled strength	8T		
grading	no		
conductor material(s)	Nb3Sn	-	-
Cooling	He		
used for	Cyclotron accelerator		
Manufacturer		0	
Installed number		10	
global annual volume	Low		
Introduced	0		

Mevion

Cross section

Photo

nested solenoid

basic type	Superconducting		
Maximum Fieled strength	7T		
grading	no		
conductor material(s)	Nb-Ti	-	-
Cooling	He		
used for	FTMS		
Manufacturer		0	
Installed number		20	
global annual volume	Medium		
Introduced	0		

0

Cross section

Photo

nested solenoid

basic type	Superconducting		
Maximum Fieled strength	12T		
grading	yes		
conductor material(s)	Nb3Sn	Nb-Ti	-
Cooling	He		
used for	FTMS		
Manufacturer		0	
Installed number		10	
global annual volume	Low		
Introduced	0		

0

Cross section

Photo

nested solenoid

basic type	Superconducting		
Maximum Fieled strength	15T		
grading	yes		
conductor material(s)	Nb3Sn	Nb-Ti	-
Cooling	He 2K		
used for	FTMS		
Manufacturer		0	
Installed number	<5		
global annual volume	Low		
Introduced	0		

0

Cross section

Photo