Ongoing consolidation of magnets

Davide Tommasini

on behalf of the Norma Team

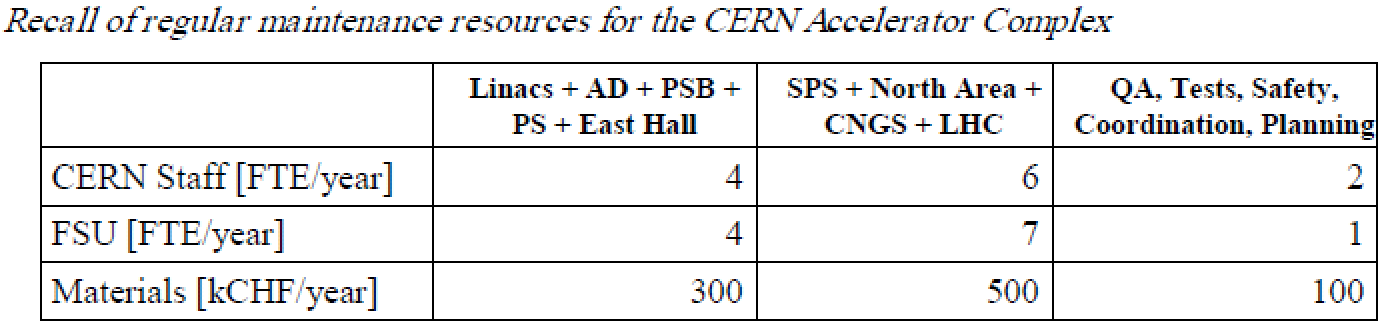
- What I will not detail further
- What we did last year
- The importance of spares
- Status of spares
- What still needs more understanding
- What we are going to do
- What may be needed to do after understanding
- What is needed now
- Importance of the yearly shut-down
- PSB energy increase
- NORMAWEB
- Conclusions

What I will not detail further

Recent reports:

- Present Status of the PS Magnets: IEFC 07-08-2009
- Urgent spares: integrated in P. Strubin EDMS 1020624
- Review of Resistive Magnets Situation : IEFC 13-11-2009
- Status of resistive magnets in the LHC injectors chain: MT-21, Hefei, China
- Quality Assurance for Normal Conducting Magnets: IEFC 22-01-2010
- The PS Booster, PS and SPS Magnets for the next 25 years : EDMS 1057909

Engagement of resources for a regular maintenance plan:



Recall of regular maintenance resources for the CERN Accelerator Complex

	Linacs + AD + PSB + PS + East Hall	**SPS + North Area + CNGS + LHC**	**QA, Tests, Safety, Coordination, Planning**
CERN Staff [FTE/year]	4	6	2
FSU [FTE/year]	4	7	1
Materials [kCHF/year]	300	500	100

What we did last year/are completing

- Piquet service, 24h/24, 7d/7
- Comprehensive magnet inventory, naming and labeling
- List of missing spares
- Completed the consolidation program of the PS (51+4 magnets)
- Completed the consolidation program of the SPS Lintott (254 magnets)
- Replacement of all main water hoses in the PSB
- Replacement of all main water hoses in the AD (under way)
- Reorganization of the magnet workshops (181-290-867)
- Many, many inspections and dedicated checks, at every machine technical stop
- Two major interventions during operation: one in the PS and one in the SPS
- Installation of flow meters in the LHC magnets
- Reconstruction and certification of magnets for all machines
- Fix the problem of missing spare NEA splitters
- Finalized the French contribution to provide 30 sets of PFWs for the PS main units
- AD consolidation, with approved manufacture of several spare magnets (under way)
- Home made spares, as the correctors for Linac 2 and for Linac 3
- Assessment of North Experimental Area status
- Validation of fix for the de-bonding of yoke laminations in the PS main units
- From last year, each individual intervention is tracked and documented (QA)

Major events during the 2009 run

Magnet failures during the year 2009 produced, in total, 83 hours of machine down-time.

The main failures were :

- a short circuit of the magnet bus bars in the PS
- a coil inter-turn short circuit in a SPS main dipole

In total only 5 of these failures stopped machine operation

An exercise

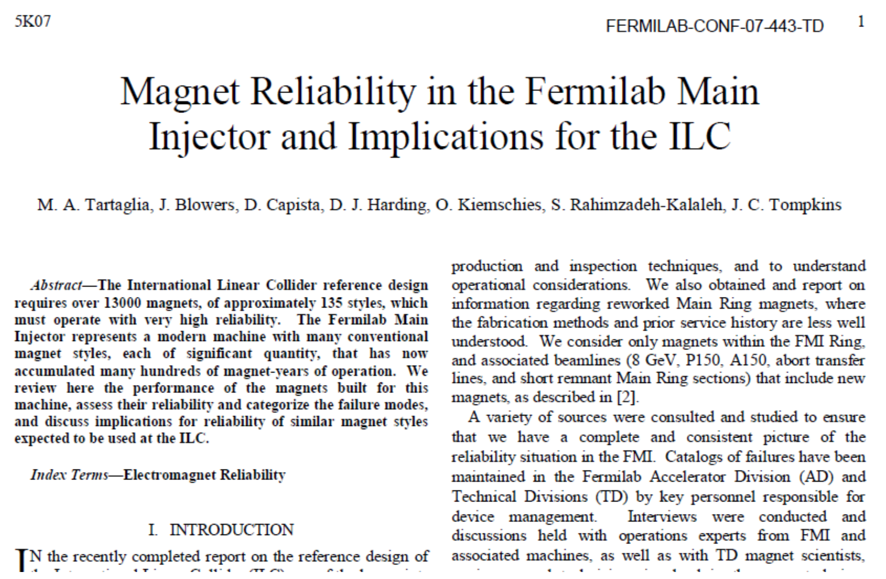
Reference year of operation	2009
Number of magnets	3000
Number of failures	5
Machine down-time [hours]	83
MTTR [hours]	17
MTBF [years of operation]	600

Statistically we may be happy … or not ?

How does it compare

FNAL	
Reference year of operation	1999-2006
Number of magnets	1472
Number of failures	5
Machine down-time [hours]	83
MTTR [hours]	17
MTBF [years of operation]	600

SLAC	
Reference year of operation	
Number of magnets	
Number of failures	
Machine down-time [hours]	
MTTR [hours]	
MTBF [years of operation]	



5K07 FERMILAB-CONF-07-443-TD 1

Magnet Reliability in the Fermilab Main Injector and Implications for the ILC

M. A. Tartaglia, J. Blowers, D. Capista, D. J. Harding, O. Kiemschies, S. Rahimzadeh-Kalaleh, J. C. Tompkins

***Abstract*—The International Linear Collider reference design requires over 13000 magnets, of approximately 135 styles, which must operate with very high reliability. The Fermilab Main Injector represents a modern machine with many conventional magnet styles, each of significant quantity, that has now accumulated many hundreds of magnet-years of operation. We review here the performance of the magnets built for this machine, assess their reliability and categorize the failure modes, and discuss implications for reliability of similar magnet styles expected to be used at the ILC.**

***Index Terms*—Electromagnet Reliability**

I. INTRODUCTION

IN the recently completed report on the reference design of

production and inspection techniques, and to understand operational considerations. We also obtained and report on information regarding reworked Main Ring magnets, where the fabrication methods and prior service history are less well understood. We consider only magnets within the FMI Ring, and associated beamlines (8 GeV, P150, A150, abort transfer lines, and short remnant Main Ring sections) that include new magnets, as described in [2].

A variety of sources were consulted and studied to ensure that we have a complete and consistent picture of the reliability situation in the FMI. Catalogs of failures have been maintained in the Fermilab Accelerator Division (AD) and Technical Divisions (TD) by key personnel responsible for device management. Interviews were conducted and discussions held with operations experts from FMI and associated machines, as well as with TD magnet scientists,

Improving the Availability of Accelerator Magnets

Cherrill Spencer
SLAC & ILC Magnet Systems Group
Talk for the Accelerator Reliability Workshop
27th January 2009, Vancouver

Fault to ground of PS bus bar #22-23

Incident

Insulation failure to ground and between two bus bars, induced by a water leak from a cooling pipe

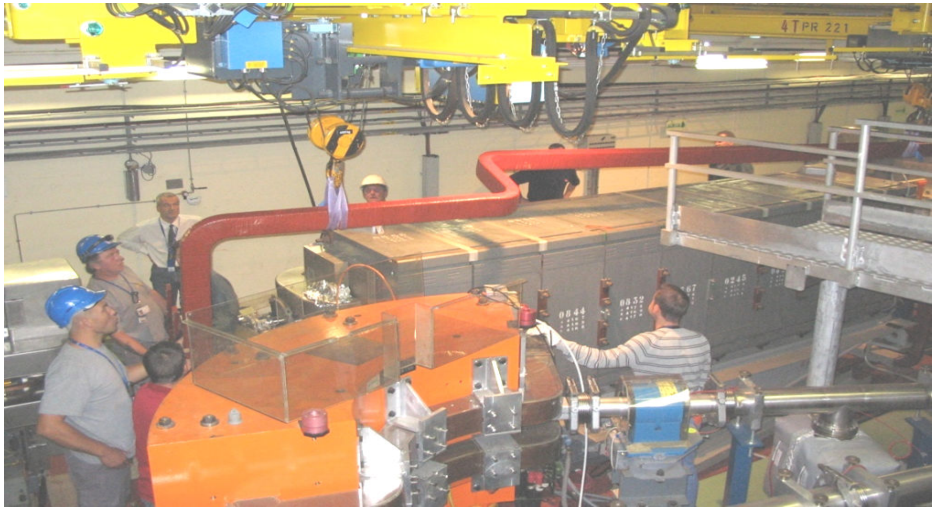
Temporary fix

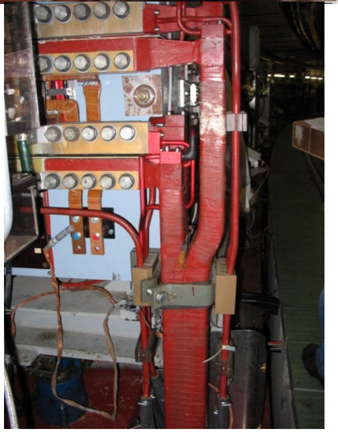
Removal of the adjacent ground shield and wrapping of the bus bars in insulating sheets (polyimide)

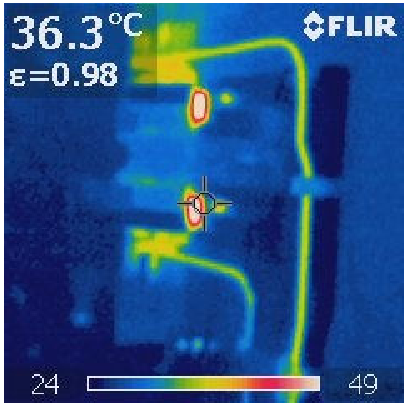
Definitive fix

Was performed during a technical stop by replacing the defective bus-bar with a reinforced spare one

Warning : we are missing two types of spare bus bar s !







The importance of spares

Two functions:

- replace defective magnets
- allow routine checks

we need enough spares for affording both tasks

how many ?

Most faults can be repaired, except:

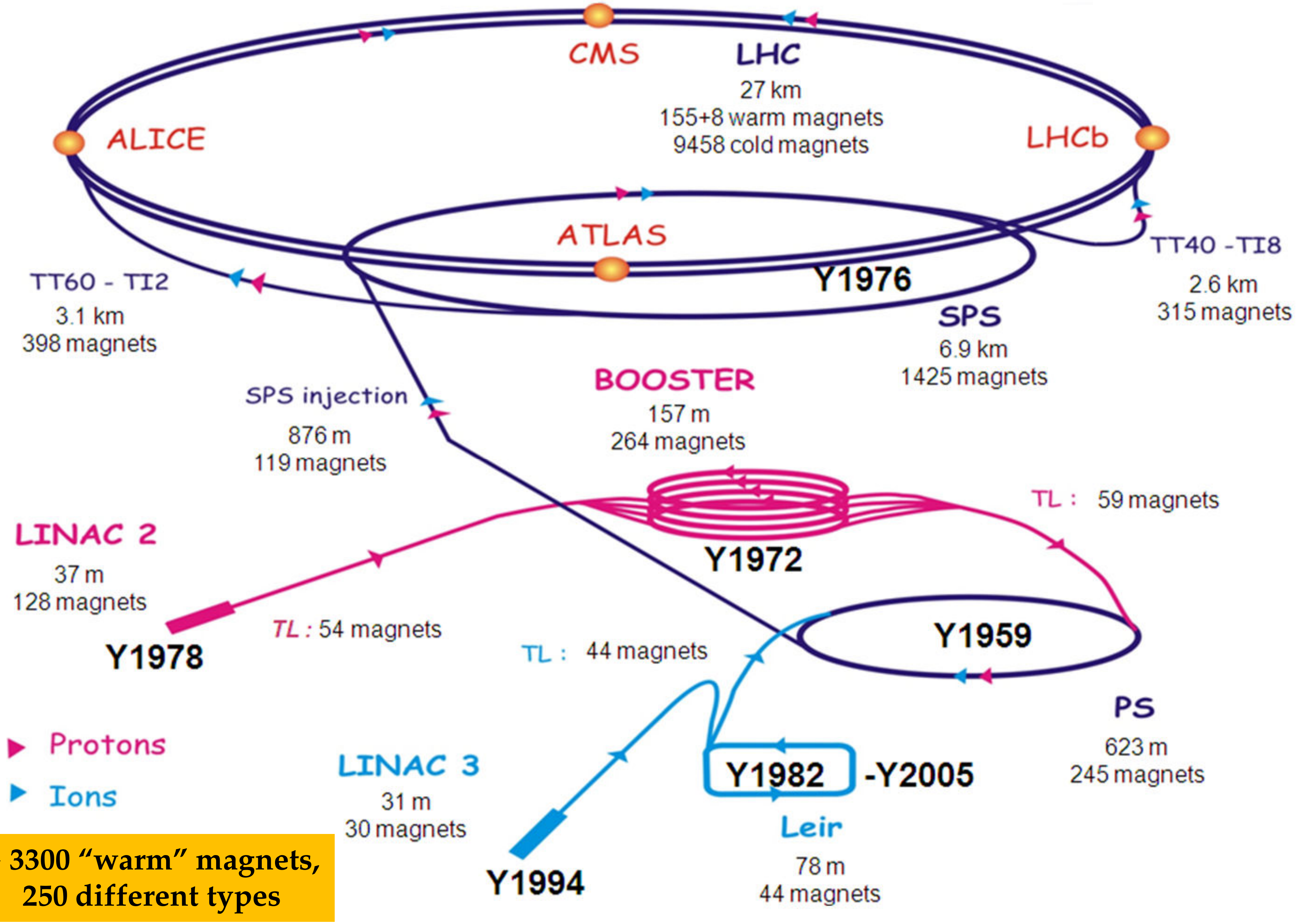
- coil inter-turn short circuits
- too radioactive magnets/components

the number of spares, at least one, depends on:

- regular maintenance plan (ex : SPS)
- the HV test policy (no spares → no tests → more risk)

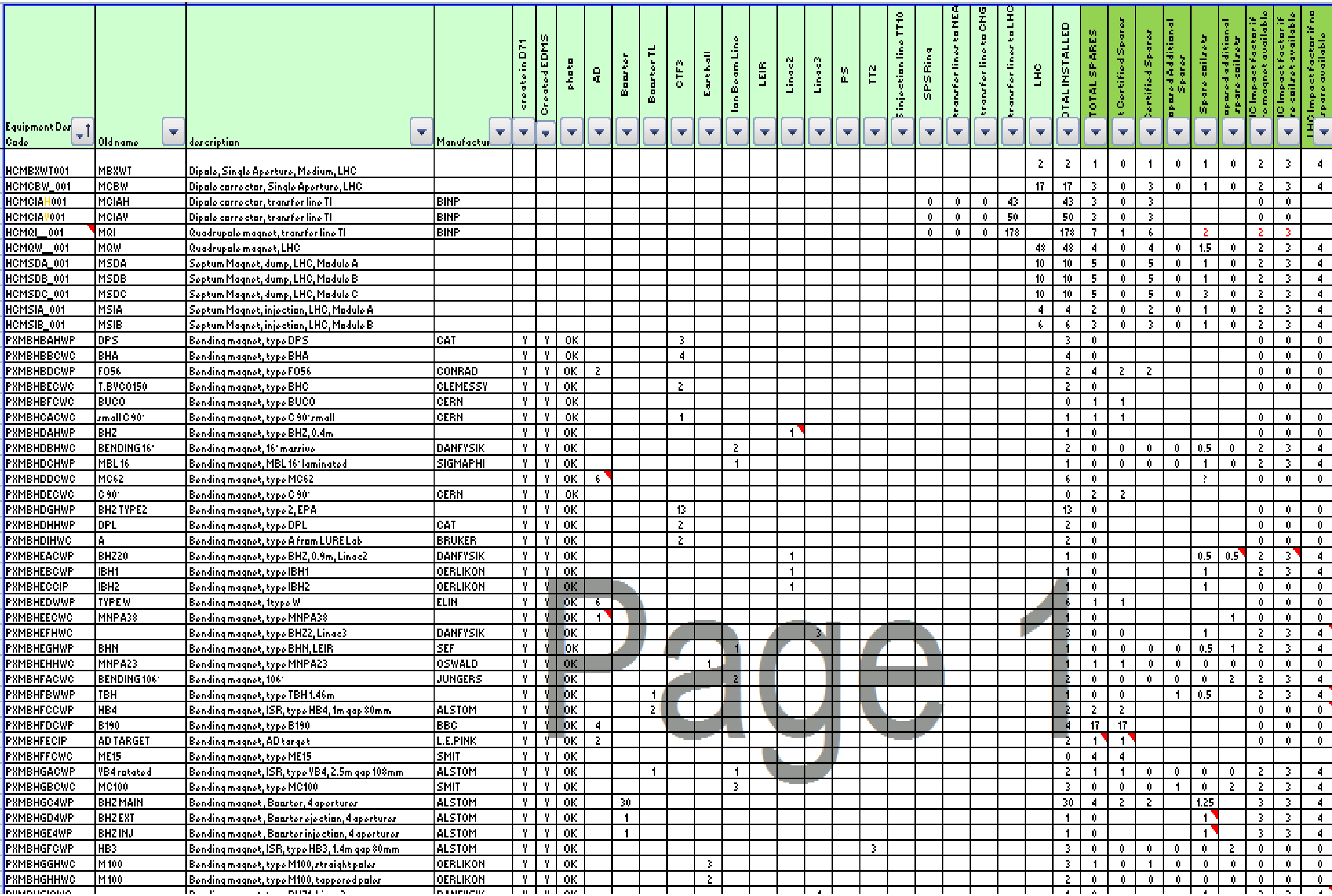
this merits more thoughts

Status of Spares : LHC Injectors



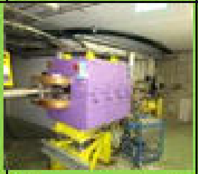
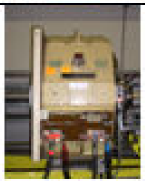
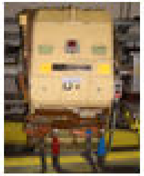
~ 3300 "warm" magnets,
250 different types

Status of Spares : inventory

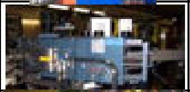
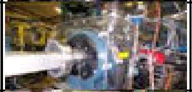
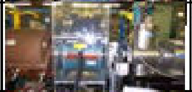
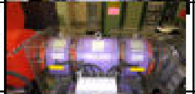
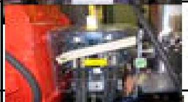
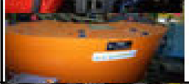
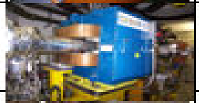
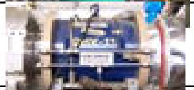
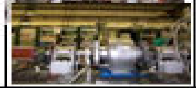


Equipment Des Code	Old name	description	Manufactur	create in DT1	Created EDMS	photo	AD	Booster	Booster TL	CTF3	East hall	Ion Beam Line	LEIR	Linac2	Linac3	PS	TT2	S injection line TT10	SPS Ring	transfer lines to NEA	transfer line to CNG	transfer lines to LHC	LHC	OTAL INSTALLED	TOTAL SPARES	t Certified Spares	Certified Spares	pared Additional Spares	Spare coilsets	prepared additional spare coilsets	IC Impact factor if o magnet available	IC Impact factor if re coilset available	LHC Impact factor if no spare available
HCMBXWT001	MBXWT	Dipole, Single Aperture, Medium, LHC																					2	2	1	0	1	0	1	0	2	3	4
HCMCBW_001	MCBW	Dipole corrector, Single Aperture, LHC																					17	17	3	0	3	0	1	0	2	3	4
HCMCIAH001	MCIAH	Dipole corrector, transfer line TI	BINP																0	0	0	43		43	3	0	3				0	0	
HCMCIAV001	MCIAV	Dipole corrector, transfer line TI	BINP																0	0	0	50		50	3	0	3				0	0	
HCMQI__001	MQI	Quadrupole magnet, transfer line TI	BINP																0	0	0	178		178	7	1	6		2		2	3	
HCMQW__001	MQW	Quadrupole magnet, LHC																					48	48	4	0	4	0	1.5	0	2	3	4
HCMSDA_001	MSDA	Septum Magnet, dump, LHC, Module A																					10	10	5	0	5	0	1	0	2	3	4
HCMSDB_001	MSDB	Septum Magnet, dump, LHC, Module B																					10	10	5	0	5	0	1	0	2	3	4
HCMSDC_001	MSDC	Septum Magnet, dump, LHC, Module C																					10	10	5	0	5	0	3	0	2	3	4
HCMSIA_001	MSIA	Septum Magnet, injection, LHC, Module A																					4	4	2	0	2	0	1	0	2	3	4
HCMSIB_001	MSIB	Septum Magnet, injection, LHC, Module B																					6	6	3	0	3	0	1	0	2	3	4
PXMBHBAHWP	DPS	Bending magnet, type DPS	CAT	Y	Y	OK				3														3	0						0	0	0
PXMBHBBCWC	BHA	Bending magnet, type BHA		Y	Y	OK				4														4	0						0	0	0
PXMBHBDCWP	F056	Bending magnet, type F056	CONRAD	Y	Y	OK	2																	2	4	2	2				0	0	0
PXMBHBECWC	T.BVC0150	Bending magnet, type BHC	CLEMESSY	Y	Y	OK				2														2	0						0	0	0
PXMBHBFCWC	BUCO	Bending magnet, type BUCO	CERN	Y	Y	OK																		0	1	1							
PXMBHCACWC	small C 90°	Bending magnet, type C 90° small	CERN	Y	Y	OK				1														1	1	1					0	0	0
PXMBHDAHWP	BHZ	Bending magnet, type BHZ, 0.4m		Y	Y	OK								1										1	0						0	0	0
PXMBHDBHWC	BENDING 16°	Bending magnet, 16° massive	DANFYSIK	Y	Y	OK						2												2	0	0	0	0	0.5	0	2	3	4
PXMBHDCHWP	MBL 16	Bending magnet, MBL 16° laminated	SIGMAPHI	Y	Y	OK						1												1	0	0	0	0	1	0	2	3	4
PXMBHDDCWC	MC62	Bending magnet, type MC62		Y	Y	OK	6																	6	0				?		0	0	0
PXMBHDECWC	C 90°	Bending magnet, type C 90°	CERN	Y	Y	OK																		0	2	2							
PXMBHDGHWP	BHZ TYPE2	Bending magnet, type 2, EPA		Y	Y	OK				13														13	0						0	0	0
PXMBHDHHWP	DPL	Bending magnet, type DPL	CAT	Y	Y	OK				2														2	0						0	0	0
PXMBHDIHWC	A	Bending magnet, type A from LURE Lab	BRUKER	Y	Y	OK				2														2	0						0	0	0
PXMBHEACWP	BHZ20	Bending magnet, type BHZ, 0.9m, Linac2	DANFYSIK	Y	Y	OK								1										1	0				0.5	0.5	2	3	4
PXMBHEBCWP	IBH1	Bending magnet, type IBH1	OERLIKON	Y	Y	OK								1										1	0				1		2	3	4
PXMBHECCIP	IBH2	Bending magnet, type IBH2	OERLIKON	Y	Y	OK								1										1	0				1		0	0	0
PXMBHEDWWP	TYPE W	Bending magnet, 1type W	ELIN	Y	Y	OK	6																	6	1	1					0	0	0
PXMBHEECWC	MNPA38	Bending magnet, type MNPA38		Y	Y	OK	1																	1	0					1	0	0	0
PXMBHEFHWC		Bending magnet, type BHZ2, Linac3	DANFYSIK	Y	Y	OK									3									3	0	0			1		2	3	4
PXMBHEGHWP	BHN	Bending magnet, type BHN, LEIR	SEF	Y	Y	OK						1												1	0	0	0	0	0.5	1	2	3	4
PXMBHEHHWC	MNPA23	Bending magnet, type MNPA23	OSWALD	Y	Y	OK					1													1	1	1	0	0	0	0	0	0	0
PXMBHFACWC	BENDING 106°	Bending magnet, 106°	JUNGERS	Y	Y	OK						2												2	0	0	0	0	0	2	2	3	4
PXMBHFBWWP	TBH	Bending magnet, type TBH 1.46m		Y	Y	OK			1															1	0	0		1	0.5		2	3	4
PXMBHFCCWP	HB4	Bending magnet, ISR, type HB4, 1m gap 80mm	ALSTOM	Y	Y	OK			2															2	2	2					0	0	0
PXMBHFDCWP	B190	Bending magnet, type B190	BBC	Y	Y	OK	4																	4	17	17					0	0	0
PXMBHFECIP	AD TARGET	Bending magnet, AD target	L.E.PINK	Y	Y	OK	2																	2	1	1					0	0	0
PXMBHFFCWC	ME15	Bending magnet, type ME15	SMIT	Y	Y	OK																		0	4	4							
PXMBHGACWP	VB4 rotated	Bending magnet, ISR, type VB4, 2.5m gap 108mm	ALSTOM	Y	Y	OK			1			1												2	1	1	0	0	0	0	2	3	4
PXMBHGBCWC	MC100	Bending magnet, type MC100	SMIT	Y	Y	OK						3												3	0	0	0	1	0	2	2	3	4
PXMBHGC4WP	BHZ MAIN	Bending magnet , Booster, 4 apertures	ALSTOM	Y	Y	OK		30																30	4	2	2		1.25		3	3	4
PXMBHGD4WP	BHZ EXT	Bending magnet , Booster ejection, 4 apertures	ALSTOM	Y	Y	OK		1																1	0				1		3	3	4
PXMBHGE4WP	BHZ INJ	Bending magnet , Booster injection, 4 apertures	ALSTOM	Y	Y	OK		1																1	0				1		3	3	4
PXMBHGFCWP	HB3	Bending magnet, ISR, type HB3, 1.4m gap 80mm	ALSTOM	Y	Y	OK											3							3	0	0	0	0	0	2	0	0	0
PXMBHGGHWC	M 100	Bending magnet, type M100, straight poles	OERLIKON	Y	Y	OK					3													3	1	0	1	0	0	0	0	0	0
PXMBHGHHWC	M 100	Bending magnet, type M100, tappered poles	OERLIKON	Y	Y	OK					2													2	0	0	0	0	0	0	0	0	0

Status of Spares for protons : priorities

Type	Photo	Old Name	Used in	Function	Number Installed	Proposed spare magnets	Proposed spare coil sets	Estimated Magnet cost [kCHF]	Estimated Coil cost [kCHF]	Priority	Total cost [kCHF]
					LHC PROTON BEAM						
PXMBHFBWWP		TBH	PSBooster TL	Switch ISOLDE/PS, beam goes in the middle when off	1	1	1	140	50	1	190
PXMBHEACWP		BHZ20	Linac 2	Switch DUMP/PSB, beam goes to dump when off	1	1	1	70	10	2	80
SPQI__NWP		QI	TT10 injection line	Lattice quadrupole	30		1		30	2	30
SPLSFN_FWP		LSFN	SPS ring	Chromaticity sextupole, focussing	54		1		50	2	50
SPLSDN_FWP		LSDN	SPS ring	Chromaticity sextupole, defocussing	54		1		50	2	50
								Total LHC Proton Beam:			270

Status of Spares for ions : priorities

Type	Photo	Old Name	Used in	Function	Number Installed	Proposed spare magnets	Proposed spare coil sets	Estimated Magnet cost [kCHF]	Estimated Coil cost [kCHF]	Priority	Total cost [kCHF]
PXMU2HACWP		Main bending	LEIR	Main Bending	4		1		190	1	190
PXMQNEKFWP		QDN/QFN	LEIR	Main Quadrupole	20	1	1	90	20	2	110
PXMDSCAHWC		BENDING 67.5°	Linac 3	Bending after source (ITL BHZ01 &02)	2		1		40	3	40
PXMQNAJPWC		B-Q120/150-2	Linac 3	ITL (Low Energy Transfer) - Focusing & Defocusing Quadrupole	4	1	1	35	20	3	55
PXMLNAAIWP		SOLENOID S	Linac 3	ITL (Low Energy Transfer) Solenoid	2	1	1	35	20	3	55
PXMQNAOPWC		TRIPLET TYPE D	Linac 3	ITF (Transfer Filter) Focusing Quadrupoles	2 (short)	1	1	35	20	3	55
PXMQNAPPWC		TRIPLET TYPE D	Linac 3	ITF (Transfer Filter) Defocusing Quadrupoles	1 (long)	1	1	35	20	3	55
PXMQNANPWC		Doublet	Linac 3	ITM () Focusing & Defocusing Quadrupoles	2	1	1	30	15	3	45
PXMBHFACWC		BENDING 106°	Ion Beam Line	Main bending in the transfer line from linac 3 to LEIR (1/2 turn loop)	2		1	0	70	3	70
PXMBHEGHWP		BHN	Ion Beam Line	Bending in the transfer line from linac 3 to LEIR (1/2 turn loop)	2		0.5	0	20	3	10
PXMBHGBCWC		MC100	Ion Beam Line	Injection & ejection bending magnets for LEIR ring	3		1	0	40	3	40
PXMCCARWIP		DHV	LEIR	Extraction bumper & corrector magnet in the LEIR ring	4	1	1	25	5	3	30
PXMQNAQFAP		LINAC 9	Linac 3	ITF (Transfer Filter) Defocusing Quadrupoles	3	2		15	0	4	30
								Total LHC Ion Beam:			785

What still needs more understanding

- Why regular inter-turn short circuits in the SPS?
- How many PS bus bars are wet/potentially weak?
- How critical is water erosion in the SPS magnets?
- Where else we have water erosion?
- Can we monitor water erosion?
- How critical is mechanical fatigue, in particular in the SPS?
- Can we identify the weakest magnets?
- Till which point shall we test?
- What are the magnets requiring the development of tools to speed-up their possible replacement in case of failure?
- How dealing with very radioactive magnets (LHC points 3-7)?

What we are going to do

- Analyze the mechanisms of SPS inter-turn short circuits
- Experiment new dielectric tests for the PS bus bars
- Perform more detailed analysis on water erosion in the SPS
- Design and set-up endoscopic tools to check water erosion
- Design and implement inter-turn coil dielectric checks
- Redefine test criteria capable of identify faults, to be performed compatibly with available time and number of available spares
- Keep in mind any fault can be repaired, except (typically) inter-turn short circuits or too radioactive magnets/components
- Continue the analysis of spares
- Reinforce contacts with experts in other large research institutes

What may be needed after understanding

- Replace all (or most) PS bus bars
- Replace all PFWs in the PS main units, eventually reinforce GI
- Initiate a massive, general consolidation of the SPS magnets
- Purchase more spares

unlikely we may need to

- replace the PS main coils (no inter-turn short circuits so far)
- consolidate the PSB magnets (they are very robust)
- deal with generalized water erosion elasewhere than in the SPS

however

Failures of electrical machines

Failures of electrical machines is a complex science
Ageing is only one of the mechanisms triggering failures
Not always failures have precursors during normal operation

monitoring

analyze

test … test … test

analyze

understand

decide

What is needed now

PS

Complete and reinforce all spare bus bars sets (2 sets are missing, give priority).

No need to decide now about a generalized replacement

No need to decide now about a systematic replacement of PFWs or other parts in the main units

SPS Main Units

Design a definitive fix for the weakening pole shims

Spares

TBH and BHZ20 are essential and have been funded

Proton lines : desirable manufacture of TT10 lattice quadrupoles and SPS sextupoles

Ion lines : many spares missing, a decision about spares policy is needed

New projects: attention to keep enough spares when operational magnets are used

North Experimental Area

Continue in the consolidation of the documentation

Situation of signal and power cables to be assessed

East Experimental Area

A layout with reliable magnets has been identified, do not wait !

profit of other's experience

Autumn 2010 : international review of the LHC injectors magnets

Importance of the yearly shutdown

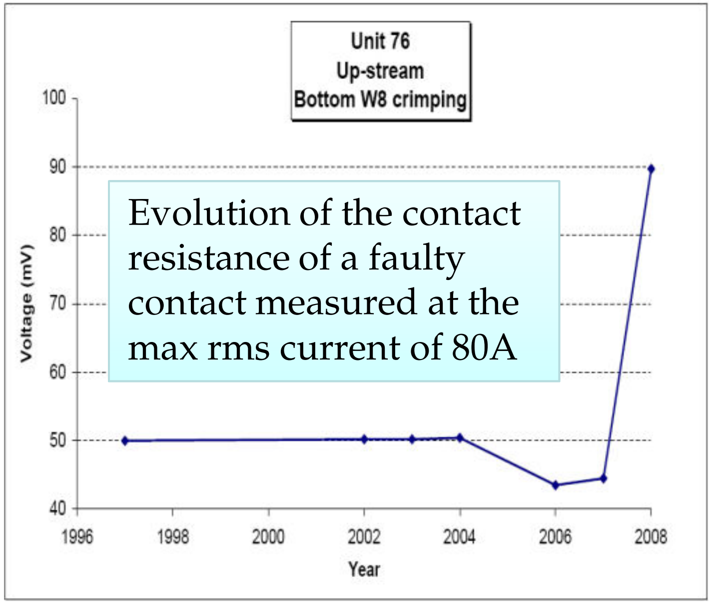
Example in the PS

Visual inspection (on all machines):

What was found:
Water leaks on TT2 magnets: QFO.215, PS aux. Magnets: 205 in SS13 and SS14
PS Auxiliary Magnets: Magnet type 210 in SS35 equipped with soft plumbing !
Oxydised connection on Magnet type 205 in SS25
Soldered hydraulic connection magnet type 206 in SS53 !
Degraded interlock wire insulation on magnet 802-409-802
No interlocks of the fast pulsed magnets

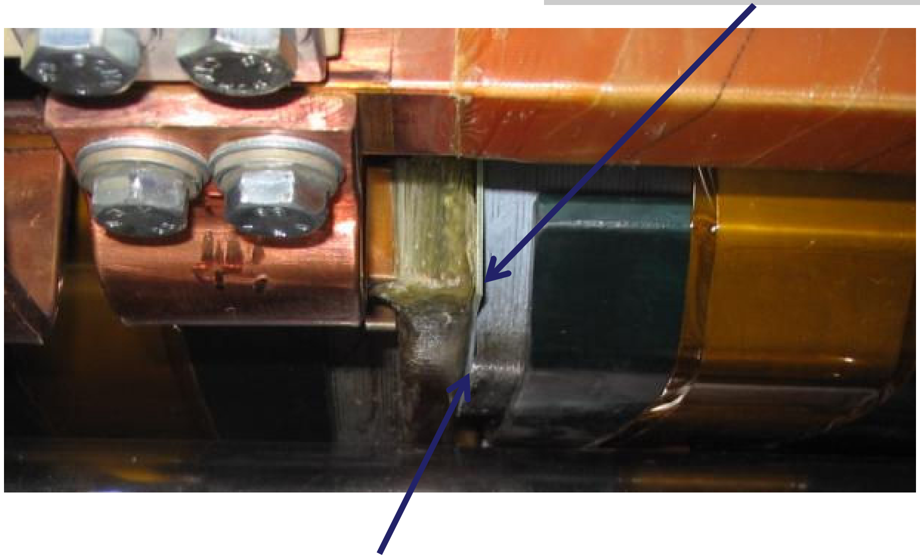
Measurements:

HV tests on the PS Main Magnets (Main coils 7 kV, PFW 3 kV + coil to coil 2 kV, F8W 3 kV)
Contact resistance of the old PFW (25 units)
Circuit resistance of the F8W on all magnets



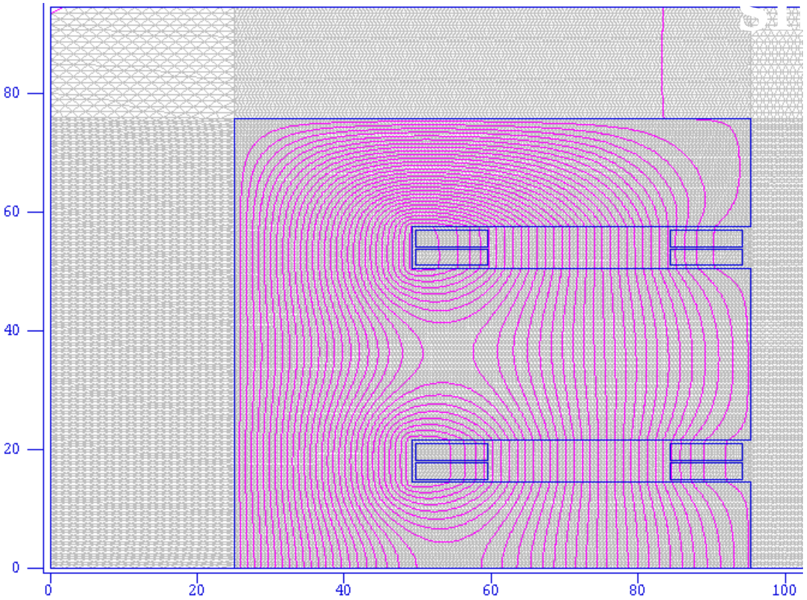
Evolution of the contact resistance of a faulty contact measured at the max rms current of 80A

Shimming of the laminations

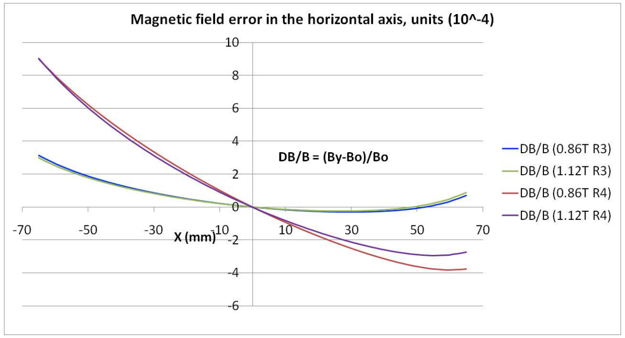


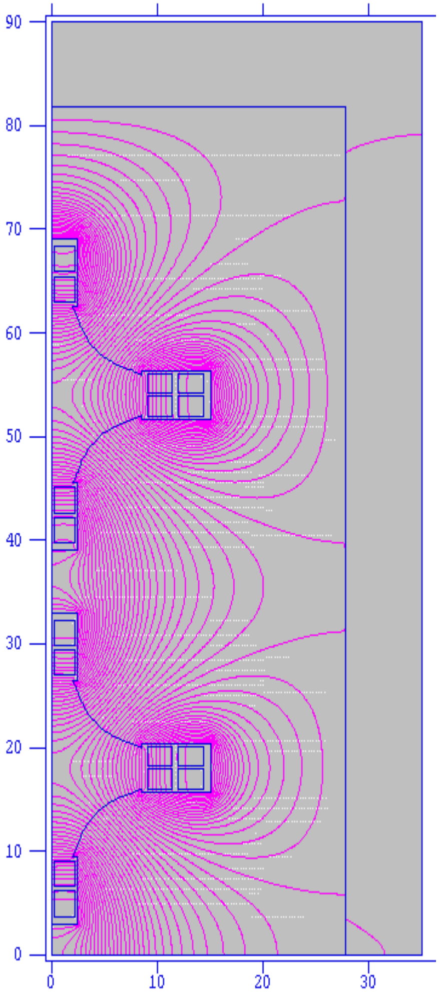
Inspection of moving laminations shimmed by glued vetresite plates

PSB Magnets 30% field increase

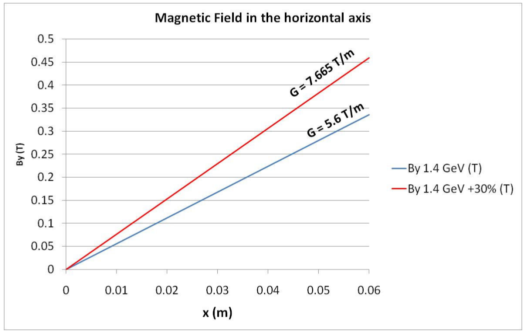


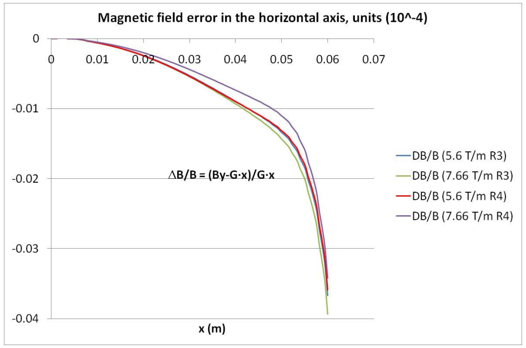
BR.BHZ Normal configuration	Present	+30%
FIELD STRENGTH (T)	0.86	1.12
PEAK CURRENT (A)		
Inner Rings	4032	5255
Outer Rings	4065	5515
POWER COMSUMPTION (kW)	49	83
Q (@ ΔT= 28 K) (l/min)	26	44
ΔT (@ Q = 26 l/min) (K)	28	47





study performed by Antony Newborough





BR.QF	PRESENT	+%30
FIELD GRADIENT (T/m)	5.60	7.66
PEAK CURRENT (A)	4032	5255
POWER COMS. (kW)	16	27
Q (@ ΔT= 20 K) (l/min)	12	20
ΔT (@ Q = 12l/min) (K)	20	34

BR.QD	PRESENT	+%30
FIELD GRADIENT (T/m)	5.60	7.66
PEAK CURRENT (A)	4032	5255
POWER COMS. (kW)	11	19
Q (@ ΔT= 20 K) (l/min)	8	14
ΔT (@ Q = 8.3l/min) (K)	20	34

NORMAWEB

http://norma-db.web.cern.ch/cern_norma/general/

Conclusions

- Magnets in the CERN accelerators are impressively reliable
- The PSB and the PS are the most reliable accelerators at CERN
- No reasons to think the oldest accelerators are close to end of life
- We need to ensure we have a sufficient number of spares
- We need to ensure we can effectively treat any magnet at any location
- We need more understanding of the real status of these magnets
- Do not forget to define responsibility for the main supply cables

Keep regular maintenance

Improve diagnostics

Be careful with spare policy

4-weeks of shutdown needed