LHC Machine Protection Panel meeting Geneva, 24th April 2009

Interlock Requirements for the Triplet Remote Alignment System

M. Acar, E. Blanco Vinuela, S. Redaelli, J. Wenninger

Acknowledgements: H. Mainaud-Durand, D. Missiaen, J.P. Quesnel











Introduction MQX alignment system **Controls** aspects **Interlock requirements Conclusions / Timeline**



Introduction



- Experimental regions will be highly radio-active after a few years of beam operation
- The super-conducting triplet of the LHC has the tightest alignment tolerance of the machine:
 - ~100 μm instead than the typical 300 μm of other components
 - Comparable to natural ground motion at frequencies \leq 0.1 Hz

Therefore, it was decided to equip the LHC triplets with:

- A fully remote control system of the magnet positions
- A sophisticated measurement system for the position survey
- Implications of LHC operations:
 - How do we use this system?
 - What are the implications for machine safety? → This meeting

Refs.: H. Mainuad at al., Remote alignment of low-beta quadrupoles with micrometric resolution, EPAC08 (Genova, Italy) M. Acar et al., The motorized alignment jacks of the LHc low-beta quadrupoles, IWAA2006 (SLAC-R-489)

How do we use the system from the CCC?



Date: 2009-03-26

Engineering Specifications

OPERATIONAL APPLICATIONS FOR THE ACTIVE ALIGNMENT SYSTEM OF THE LHC SUPERCONDUCTING LOW-BETA QUADRUPOLES

Abstract

This document describes the specifications for the applications to be used by the LHC operational team to control the active alignment system of the LHC superconducting lowbeta quadrupoles. The main focus of this document is on the monitoring of the magnet position, with particular emphasis on the operational displays and on the logging configuration. Machine protection aspects of the system are also discussed in detail.

Prepared by : Mikail Acar, Stefano Redaelli Checked by : G. Arduini, R. Bailey, S. Fartoukh, M. Lamont, H. Mainaud Durand, D. Missiaen, J.P. Quesnel, E. Vinuela Blanco, J. Wenninger Approved by : O. Brüning, R. Bailey, P. Collier, M. Lamont Functional specifications available in EDMS (being engineering checked) to address:

- Monitoring from the CCC
- Definition of beam units
- Logging
- Interlocks

New applications will be presented at the LHC commissioning meeting







Introduction MQX alignment system **Controls** aspects **Interlock requirements Conclusions / Timeline**



MQX measurement systems (I)





Stretched-wire system (WPS)

Hydrostatic levelling system (HLS)

WPS pick-ups



HLS pick-ups





MQX measurement systems (II)



Stretched-wire system (WPS)





Both based on capacitive position measurements

Resolution: 0.2 µm Range: 10 x 10 mm² Reproducibility: 1 µm Bandwidth: 10 Hz

Hydrostatic levelling system (HLS)





Resolution: 0.2 µm Range: 5 mm Reproducibility: 1 µm Bandwidth: 10 Hz



LHC installation layout





In ALL IPs: - 3-4 HLS sensors - 2 WPS sensors per cryostat



In IP1 and IP5: Additional stretched wire for relative offsets left/right + DOMS (differential offset measurement system)



Remote positioning system





S. Redaelli, MPP 24/04/2009



Some numbers...



Overall, the system includes:

- WPS (Wire Positioning System)
- HLS (Hydrostatic Leveling System)
- DOMS (Differential Offset Measurement System) 24
- Stepping motors for motorized jacks
- Temperature sensors

136=68x2 measurements (2 axes)

100 measurements (1 axis)

t System) **24** measurements (1 axis)

128 axes (16x2 per IP)

128 measurements

... big and distributed system!

Required appropriate controls infrastructure BUT enables a very complete set of measurement!





Controls architecture







Role-based access in PVSS





Possible roles available within the PVSS system: "ADMIN" / "EXPERT" / "OPERATOR" / "MONITOR"



Examples of expert tools



Control panel for one side of the IP (PVSS)





PVSS history buffer (raw data in mm)



TIMBER v2.1.0			
ata Source: Logging Database (PRO)		Elapsed: 219m	
🚴 Query Output 🚺 Query 📋 Variab	e Hierarchies 🔗 Variable Search 🗎 Variabl	le Lists 🕜 <u>A</u> bout	
ierarchy Variable Selection			
ROOT	Variable Filters		
- • ADE			_
• ATLAS	Name: %	Type: %	*
CNGS			
CRY0	Search Results		
► ● CTF3	Variable Name	Description Unit	Datatype
 Fundamental Data 	GISB.UX151L.HLS_LO:HEIGHTSTDDEV_MM	v1.0 HLS From S mm	NUMERIC A
• • LEIR	GISB.UX151L.HLS_LO:HEIGHT_MM	v1.0 HLS From S mm	NUMERIC
- • LHC	GISB.UX151L.HLS_LO:HEIGHT_RAW_MM	v1.0 HLS From S null	NUMERIC
 LHC HWC 	GISB.UX151L.HLS_LO:HEIGHT_V	v1.0 HLS From S V	NUMERIC
 LINAC2 	GISB.UX151L.HLS_LO:SENSORSTATUS	v1.0 HLS From S null	NUMERIC
 LINAC3 	GISB.UX151L.HLS_LO:TEMP_C	v1.0 HLS From S C	NUMERIC =
• • PS	GISB.UX151L.HLS_LO:TEMP_RAW_C	v1.0 HLS From S null	NUMERIC
PSB	GISB.UX151L.HLS_LO:TEMP_V	v1.0 HLS From S V	NUMERIC
• QPS	MQXA.1L1.A_HLS_LO:HEIGHTSTDDEV_MM	v1.0 HLS From S mm	NUMERIC
• • SM18	MQXA.1L1.A_HLS_LO:HEIGHT_MM	v1.0 HLS From S mm	NUMERIC
• SPS	MQXA.1L1.A_HLS_LO:HEIGHT_RAW_MM	v1.0 HLS From S null	NUMERIC
SPS-EA	MQXA.1L1.A_HLS_LO:HEIGHT_V	v1.0 HLS From S V	NUMERIC
	MQXA.1L1.A_HLS_LO:SENSORSTATUS	v1.0 HLS From S null	NUMERIC
	MQXA.1L1.A_HLS_LO:TEMP_C	v1.0 HLS From S C	NUMERIC
LUYYIIY	MQXA.1L1.A_HLS_LO:TEMP_RAW_C	v1.0 HLS From S null	NUMERIC
00 0	MQXA.1L1.A_HLS_LO:TEMP_V	v1.0 HLS From S V	NUMERIC
Variables	MQXA.1L1.B_HLS_LO:HEIGHTSTDDEV_MM	v1.0 HLS From S mm	NUMERIC
vanables	MQXA.1L1.B_HLS_LO:HEIGHT_MM	v1.0 HLS From S mm	NUMERIC
	MQXA.1L1.B_HLS_LO:HEIGHT_RAW_MM	v1.0 HLS From S null	NUMERIC
	MQXA.1L1.B_HLS_LO:HEIGHT_V	v1.0 HLS From S V	NUMERIC
availahla	MQXA.1L1.B_HLS_LO:SENSORSTATUS	v1.0 HLS From S null	NUMERIC
available	MQXA.1L1.B_HLS_LO:TEMP_C	v1.0 HLS From S C	NUMERIC
	MQXA.1L1.B_HLS_LO:TEMP_RAW_C	v1.0 HLS From S null	NUMERIC
in Timbor	MQXA.1L1.B_HLS_LO:TEMP_V	v1.0 HLS From S V	NUMERIC
	MQXA.1L1.D_HLS_LO:HEIGHTSTDDEV_MM	v1.0 HLS From S mm	NUMERIC -

14:43:53 = ...Found 64 Variables for Hierarchy 'SURVEY->LOW-BETA->IP1->L1->HLS-L1-Hi-network->HLS'



Example of measurements





S. Redaelli, MPP 24/04/2009







Introduction MQX alignment system **Controls** aspects **Interlock requirements Conclusions / Timeline**



Interlock requirements



Ø Background:

- No connection of this system to the LHC hardware interlock
 - → only SIS surveillance possible
- Baseline operational mode:

MQX should NOT be moved with beam in the machine!

- Movements with beam shall be possible with safe beams during special studies (MDs, alignment optics)
- ✓ Three main critical aspects were identified:
 - (1) Protection against movements by unauthorized people
 - (2) In standard operation, dump the beams if the magnets are being moved
 - (3) Inhibit injection in case of "large" position drifts with respect to the positions of the previous store

(1) Implementation of access control

- Protect the FESA properties related to motor positions with RBAC
- Same roles presently available in PVSS will be configured: MONITOR / OPERATOR / EXPERT
- Only expert will have rights to move magnets not an operational tool!
- Development of RBAC functionality in PVSS is in progress (Enrique B.V.)
 Foreseen delivery for tests: **1.5 months** Only DOMAIN (by machine) restriction available
- No machine-mode dependent configuration for the moment
- MD mode will be possible by logging-in as EXPERT and by masking SW interlock **RBAC**







(2) Interlock on motor status

With the present architecture, it is not easy to detect motor movements...

A **summary status** property will be added in the FESA class of the motor controller to identify the "**MOVING**" status

One status per IP side, calculated for the class that controls 16 motor axes \rightarrow 8 statuses Implementation detail:

The "MOVING" status of each degree of freedom will be identified by looking simultaneously at command execution flag, motor step counter and resolver counter.

At the SIS level, a **beam dump** for both circulating beams will be triggered if the magnets are moved with beam in the machine.

Motor control panel (16 axes per IP side)

ES	M9 ES <09V0804S5000L0M1H0CMS0E0000 PC:6
2 ES <02H0809S2003L0M1H0CMS0E0000 PC:6	M10 ES <10V0809S5008L0M1H0CMS0E0000 PC:6
ES <03V0808S5010L0M1H0CMS0E0000 PC:6	M11 ES <11H0802S2005L0M1H0CMS0E0000 PC:6
4 ES <04V0808S5010L0M1H0CMS0E0000 PC:6	M12 ES <12V0806S5000L0M1H0CMS0E0000 PC:6
5 ES <05H0802S2000L0M1H0CMS0E0000 PC:6	M13 ES <13H0807S2010L0M1H0CMS0E0000 PC:6
5 ES <06V0808S5006L0M1H0CMS0E0000 PC:6	M14 ES <14V080CS5010L0M1H0CMS0E0000 PC:6
ES <07H0802S2004L0M1H0CMS0E0000 PC:6	M15 ES <15V07F9S4980L0M1H0CMS0E0000 PC:6
ES <08V0800S5000L0M1H0CMS0E0000 PC:6	M16 ES <16H07FFS1985L0M1H0CMS0E0000 PC:6

Selection of command types

	Channel	Single message	Command
	ΟŪ		C CALH
	01	Emergency Stop Motor Stop	C CALR
	C 2		C CALV
	C 3	Normal mode	C CHMC
_	04		C CLST
_	0.6		C EMST
	00	Command selection:	C GOAH
	0.6	CALH: CALibration as Horizontal	C GOAS
	07	,	C GOMA
	0.8	Parameter 1: 0	C GOMD
	C 9		C GOME
	C 10	Parameter 2: 0	C GOMF
	C 11		C GOMR
	C 12	Command:	C GOMU
	C 13	>00CALH*	C GOOR
	C 14	Journal	C GORE
	C 15	Const Circle Const L. Addate Line L.	C IGMC
	0.10	Sena Single Cma Add to List	C MOOF
	0.16		C MOON
			C MOST
		-List of messages	C MPSR
			CRADE
_			CSACE
			C SAOP
			C SDAS
			C SDCE
			C SDCP
			C SDSP
_			C SDSS
			C SESC
		Send List Remove Remove List	C SESL
_	_		C SPRE
			C SPST
_			



Select



(3) Fill-to-fill magnet stability



- <u>All WPS sensors</u> attached to the magnets will be used as input for the software interlock 136 sensor readings for horizontal and vertical!
- Interlocks will be set on the "raw" position measurements in millimetres Published by the FESA (direct connection to the middleware, no PVSS)
- Zero reading after magnet survey need to be stored in the database as SIS references
- Tolerances window of 0.5-1.0 mm set around readings.

Experience on the stability of measurements needs to be gained in order to fine tune the system (usual compromise between protection and efficiency).

- From magnet strength, "standard" tolerance for COD is equivalent to ~ 1 mm MQX error.
- First implementation by Joerg available and under test. Need further tests with larger loads

Permits Tree	
E [AND] INJ_B1_PERMIT	
🗄 💥 Р [AND] INJ_B2_PERMIT	
🖻 💥 Р [AND] INJ_PERMIT	
BEAM_MODE_INJECTION	
🗉 💥 📘 [AND] EXPERIMENTS_INJ	
💷 💥 📘 [AND] PC-CURRENTS	
🖻 💥 📙 [AND] WPS_IT	100
WP5_IT_L1	
WP5_IT_L5	
WP5_IT_L8	
WP5_IT_R1	
WP5_IT_R2	
💥 📔 WP5_IT_R5	
WP5_IT_R8	
🛱 💥 P [AND] RING ALARM	-
Depth: 1 Show Font size: +1 -1 Reset	
Expand All Collapse all	

Patamet, et a	MPS MOY	A 11.2	A ACO 1	MPS MOXA	1L2 B 4	CO MPS	MOXA 312	A ACO MPS '
Dediel weeks	wro_ngr		0.020	1 700		0.011	2 520	1 605
Radial positio	ons [mm]		0.329	-1.703	-0.626	-0.911	2.526	1.695
Radial ref	[mm]		0.230	-1.567	-1.517	-1.946	2.448	1.726
Radial tol	[mm]	1	1.000	1.000	1.000	1.000	1.000	1.000
Height positio	ons [mm]		0.258	0.265	0.596	1.094	-0.582	-0.385
Height ref	[mm]	5	0.233	0.249	-0.419	-0.263	-0.563	-0.409
Height tol	[mm]	:	1.000	1.000	1.000	1.000	1.000	1.000
14-31-03 - 2009-0	14-21 14	- 31 - 02	775 U	MultiQue	eEvecut	or-thre	ad-41 RRI	OR MnsPosi
								-
** WPS check for L1		1 8 800	MPS MO					
Parameters : WPS	NUXA IL.	1 6 600	WE & 1191		LCQ WPS M	QXA 3L1 J	ACQ WPS I	MQXA 3L1 B ACQ
Parameters : WPS Radial positions	[nm] :	0.781	-0.312	2 -1.472	CQ WPS_M -3.049	QXA_3L1_4 -0.691	ACQ WPS_1 -0.362	MQXA_3L1_B_ACQ
Parameters : WPS Radial positions Radial ref	[nm] : [nm] :	0.781	-0.31	2 -1.472 5 -1.461	CQ WPS_M -3.049 -3.036	QXA_3L1_i -0.691 -0.669	L_ACQ_WPS_1 -0.362 -0.341	MQXA_3L1_B_ACQ
Parameters : WPS Radial positions Radial ref Radial tol	[nm] : [nm] : [nm] :	0.781 0.786 1.000	-0.312	2 -1.472 5 -1.461 0 1.000	-3.049 -3.036 -3.036 1.000	QXA_3L1_4 -0.691 -0.669 1.000	ACQ WPS_1 -0.362 -0.341 1.000	MQXA_3L1_B_ACQ
Parameters : WPS Radial positions Radial ref Radial tol Height positions	[mm] : [mm] : [mm] : [mm] :	0.781 0.786 1.000 -0.572	-0.312 -0.366 1.000 -0.613	2 -1.472 5 -1.461 0 1.000 7 -0.852	.CQ WPS_M -3.049 -3.036 1.000 -0.673	QXA_3L1_i -0.691 -0.669 1.000 -1.043	A_ACQ WPS_1 -0.362 -0.341 1.000 -1.254	MQXA_3L1_B_ACQ
Parameters : WPS Radial positions Radial ref Radial tol Height positions Height ref	[mm] : [mm] : [mm] : [mm] : [mm] : [mm] :	0.781 0.786 1.000 -0.572 -0.581	-0.310 -0.360 1.000 -0.617 -0.580	2 -1.472 5 -1.461 0 1.000 7 -0.852 5 -0.859	-3.049 -3.036 1.000 -0.673 -0.679	QXA_3L1_4 -0.691 -0.669 1.000 -1.043 -1.082	A_ACQ WPS_1 -0.362 -0.341 1.000 -1.254 -1.249	MQXA_3L1_B_ACQ
Parameters : WPS Radial positions Radial ref Radial tol Height positions Height ref Height tol	[nn] : [nn] : [nn] : [nn] : [nn] : [nn] :	0.781 0.786 1.000 -0.572 -0.581 1.000	-0.312 -0.366 1.000 -0.617 -0.586 1.000	2 -1.472 5 -1.461 0 1.000 7 -0.852 5 -0.859 0 1.000	-3.049 -3.036 1.000 -0.673 -0.679 1.000	QXA_3L1_4 -0.691 -0.669 1.000 -1.043 -1.082 1.000	ACQ WPS_1 -0.362 -0.341 1.000 -1.254 -1.249 1.000	MQXA_3L1_B_ACQ
Parameters : WPS Radial positions Radial ref Radial tol Height positions Height ref Height tol 4:31:03 - 2009-04-2	[nn] : [nn] : [nn] : [nn] : [nn] : [nn] : [nn] : 1 14:31:0	0.781 0.786 1.000 -0.572 -0.581 1.000 02,775	-0.312 -0.366 1.000 -0.617 -0.586 1.000 [MultiQu	2 -1.472 5 -1.461 0 1.000 7 -0.852 5 -0.859 0 1.000 aeueExecut	-3.049 -3.036 1.000 -0.673 -0.679 1.000 cor-threa	QXA_3L1_4 -0.691 -0.669 1.000 -1.043 -1.082 1.000 d-4] INF(<pre>A_ACQ WPS_1 -0.362 -0.341 1.000 -1.254 -1.249 1.000) WpsPosi;</pre>	MQXA_3L1_B_ACQ tionValueCondi
Parameters : WPS Radial positions Radial ref Radial tol Height positions Height ref Height tol 4:31:03 - 2009-04-2	[mm] : [mm] : [mm] : [mm] : [mm] : [mm] : [1 14:31:)	0.781 0.786 1.000 -0.572 -0.581 1.000 02,775	-0.313 -0.366 1.000 -0.617 -0.586 1.000 [MultiQu	2 -1.472 5 -1.461 0 1.000 7 -0.852 5 -0.859 0 1.000 aeueExecut	-3.049 -3.036 1.000 -0.673 -0.679 1.000	QXA_3L1_4 -0.691 -0.669 1.000 -1.043 -1.082 1.000 d-4] INF(A_ACQ WPS_1 -0.362 -0.341 1.000 -1.254 -1.249 1.000 WpsPosit	MQXA_3L1_B_ACQ tionValueCondi



Additional aspects



Maximum motor speed:

Present settings: $v_{vertical} = 25 \ \mu m/s$; $V_{horizontal} = 80 \ \mu m/s$ Seems okay for a SIS acquisition at 0.5-1.0 Hz Can reduce further v_{max} if necessary.

Switch OFF the motor power during beam operation? Possible (AUG), should be done! Remote ON is possible. Can do that as a default before beam operation

Direct connection to **BIC** for hard interlock? No feasible before 2009-2010 operation. 2 year experience with beam + SW interlock will tell if it is really needed...



Conclusions / Outlook



- The MQX alignment system is the first example of dynamic alignment in colliders of the LHC scale State of the art survey and remote control systems
- This system will need to be operated CAREFULLY!
- Critical interlock requirements have been identified and are being addressed
- **Timeline** for tests:

1.5 months to start testing RBAC Deployment of operational applications from July Interlock tests in August Second report to MPP at the beginning of September