Interlock requirements for TI 8 and TI 2

Input from Rüdiger, Helmut, Wim, Verena, Marcel, plus from AB/PO Denis Hundzinger & Roger Genand.

Assumptions

- The TCDI collimators will be set at ±5 σ
- The maximum shot-to-shot trajectory variation in the line is ±1σ
- The power supplies currents are interlocked via the ROCS and an inhibit is generated in 5ms if out of tolerance.

Power supply interlock levels

- All 37 quadrupole families : $\Delta I_{max}/I_{nom}$: 10^{-3}
- 20* Dipole families : $\Delta I_{max}/I_{nom}$: 1-5 x 10^{-3}

**including MST, MSE*

Assume that collimators protect LHC for most errors…

- Check the few (3 dipole, 4 quadrupole) families per line which are inside the downstream collimation regions (also look for any other obvious problems…)

- Possible maximum error given by interlock level + exponential decay of current over the 5ms.

- Typically ~4% for quads, ~1% for dipoles (L/R)

- Some 10-20% for the SPS extraction septa !

TI 8 dipole families

TI 8 Dipoles

Power Supply Number	Magnet Name Install	Magnet Name (Optics)	Number of magnets in series	Time constant L/R [ms]	Error in 5ms [2] (a) 5	P.S. precsion (+/-) [ ]	Interlock level (b)	Max error in worst failure case (a+b)
	MSE	MSE	6	23	0.194	2.5E-04	1.0E-03	**0.195**
1	MBHC400107	BH1	3	1010	0.005	1.0E-04	2.0E-03	0.007
3	MBHA400309	BH2	4	2607	0.002	1.0E-04	2.0E-03	0.004
8	MBI81607	MBI	236	894	0.006	2.0E-05	1.0E-03	0.007
11	MCIBH80407	BH3	1	391	0.013	1.0E-04	2.0E-03	0.015
12	MBIAH87833	BH4	7	2631	0.002	1.0E-04	1.0E-03	**0.003**
13	MSIB	BH5B	3	1209	0.004	1.0E-04	5.0E-03	**0.009**
13	MSIA	BH5A	2	618	0.008	1.0E-04	5.0E-03	**0.013**
14	MBIAV81107	BV1	12	2453	0.002	1.0E-04	3.0E-03	0.005
15	MBIBV87742	BV2	5	1296	0.004	1.0E-04	3.0E-03	0.007

TI 8 quadrupole families

TI 8 Quadrupoles

Power Supply Number	Magnet Name Install	Magnet Name (Optics)	Number of magnets in series	Time constant L/R [ms]	Error in 5ms [2] (a)	P.S. precsion (+/-) [ ]	Interlock level (b)	Max error in worst failure case (a+b)
4	QTMD400100	MQI1	1	157	0.031	1.0E-04	1.0E-03	0.032
5	QTRF400200	QTL2	1	1096	0.005	1.0E-04	1.0E-03	0.006
6	QTRD400300	QTL3	1	1032	0.005	1.0E-04	1.0E-03	0.006
7	QTLF400400	QTL4	1	1013	0.005	1.0E-04	1.0E-03	0.006
9	MQIF87000	MQIF	34	356	0.014	1.0E-04	1.0E-03	0.015
10	MQID87100	MQID	34	356	0.014	1.0E-04	1.0E-03	0.015
16	MQID80100	MQI5	1	123	0.040	1.0E-04	1.0E-03	0.041
17	MQIF80200	MQI6	1	118	0.042	1.0E-04	1.0E-03	0.043
18	MQID80300	Q7	1	113	0.043	1.0E-04	1.0E-03	0.044
19	MQIF87200	Q8	1	97	0.050	1.0E-04	1.0E-03	0.051
20	MQID87300	Q9	1	100	0.049	1.0E-04	1.0E-03	0.050
21	MQIF87404	Q10	2	162	0.030	1.0E-04	1.0E-03	0.031
22	MQID87500	Q11	1	106	0.046	1.0E-04	1.0E-03	0.047
23	MQIF87600	Q12	1	109	0.045	1.0E-04	1.0E-03	0.046
24	MQID87700	Q13	1	112	0.043	1.0E-04	1.0E-03	0.044
25	MQIF87800	Q14	1	116	0.042	1.0E-04	1.0E-03	**0.043**
26	MQID87900	Q15	1	125	0.039	1.0E-04	1.0E-03	**0.040**
27	MQIF88000	Q16	1	130	0.038	1.0E-04	1.0E-03	**0.039**
28	MQID88100	Q17	1	135	0.036	1.0E-04	1.0E-03	**0.037**

TI 2 dipole families

TI 2 Dipoles

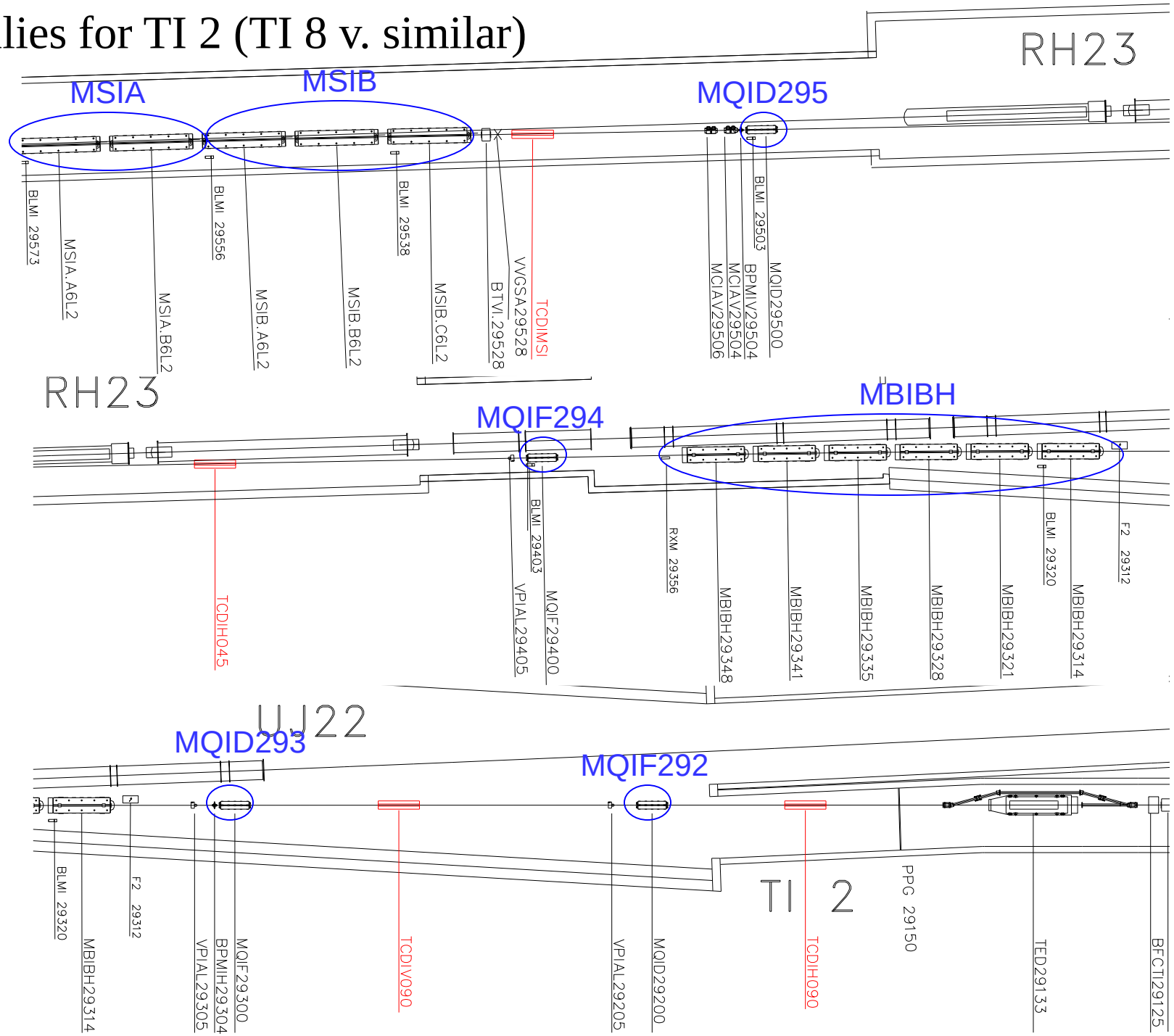
Power Supply Number	Magnet Name Install	Magnet Name (Optics)	Number of magnets in series	Time constant L/R [ms]	Error in 5ms [2] (a) 5	P.S. precsion (+/-) [ ]	Interlock level (b)	Max error in worst failure case (a+b)
	MSE	MSE	5	26	0.175	2.5E-04	1.0E-03	**0.176**
	MST	MST	2	41	0.114	2.5E-04	1.0E-03	**0.115**
8	MBI 22134	MBI	112	773	0.006	2.0E-05	1.0E-03	0.007
12	MBB 20150	BH1	2	1241	0.004	1.0E-04	2.0E-03	0.006
13	MBIBH 29314	BH2	6	1295	0.004	2.0E-05	2.0E-03	**0.006**
14	MSIB 29529	BH3B	3	1148	0.004	1.0E-04	5.0E-03	**0.009**
	MSIA 29556	BH3A	2	567	0.009	1.0E-04	5.0E-03	**0.014**
15	MBIAV 20637	BV1	17	2773	0.002	2.0E-05	3.0E-03	0.005
16	MBIAV 26853	BV2	12	2522	0.002	1.0E-04	3.0E-03	0.005
17	MBIAV 29116	BV3	4	1959	0.003	1.0E-04	3.0E-03	0.006

TI 2 quadrupole families

TI 2 Quadrupoles

Power Supply Number	Magnet Name Install	Magnet Name (Optics)	Number of magnets in series	Time constant L/R [ms]	Error in 5ms [2] (a) 5	P.S. precsion (+/-) [ ]	Interlock level (b)	Max error in worst failure case (a+b)
9	MQIF 25800	MQIF	26	287	0.017	1.0E-04	1.0E-03	0.018
10	MQIF 28400	MQIF	13	298	0.017	1.0E-04	1.0E-03	0.018
11	MQID 28500	MQID	40	313	0.016	1.0E-04	1.0E-03	0.017
18	MQID 20100	Q1	1	137	0.036	1.0E-04	1.0E-03	0.037
19	MQIF 20200	Q2	1	145	0.034	1.0E-04	1.0E-03	0.035
20	MQID 20300	Q3	1	153	0.032	1.0E-04	1.0E-03	0.033
21	MQIF 20400	Q4	1	162	0.030	1.0E-04	1.0E-03	0.031
22	MQID 20500	Q5	1	178	0.028	1.0E-04	1.0E-03	0.029
23	MQIF 20600	Q6	1	167	0.029	1.0E-04	1.0E-03	0.030
24	MQIF 28600	Q7	1	95	0.051	1.0E-04	1.0E-03	0.052
25	MQID 28700	Q8	1	98	0.050	1.0E-04	1.0E-03	0.051
26	MQIF 28800	Q9	1	100	0.049	1.0E-04	1.0E-03	0.050
27	MQID 28900	Q10	1	103	0.047	1.0E-04	1.0E-03	0.048
28	MQIF 29000	Q11	1	107	0.046	1.0E-04	1.0E-03	0.047
29	MQID 29100	Q12	1	110	0.044	1.0E-04	1.0E-03	0.045
30	MQIF 29200	Q13	1	115	0.042	1.0E-04	1.0E-03	**0.043**
31	MQID 29300	Q14	1	117	0.042	1.0E-04	1.0E-03	**0.043**
32	MQIF 29400	Q15	1	124	0.040	1.0E-04	1.0E-03	**0.041**
33	MQID 29500	Q16	1	129	0.038	1.0E-04	1.0E-03	**0.039**

Families for TI 2 (TI 8 v. similar)

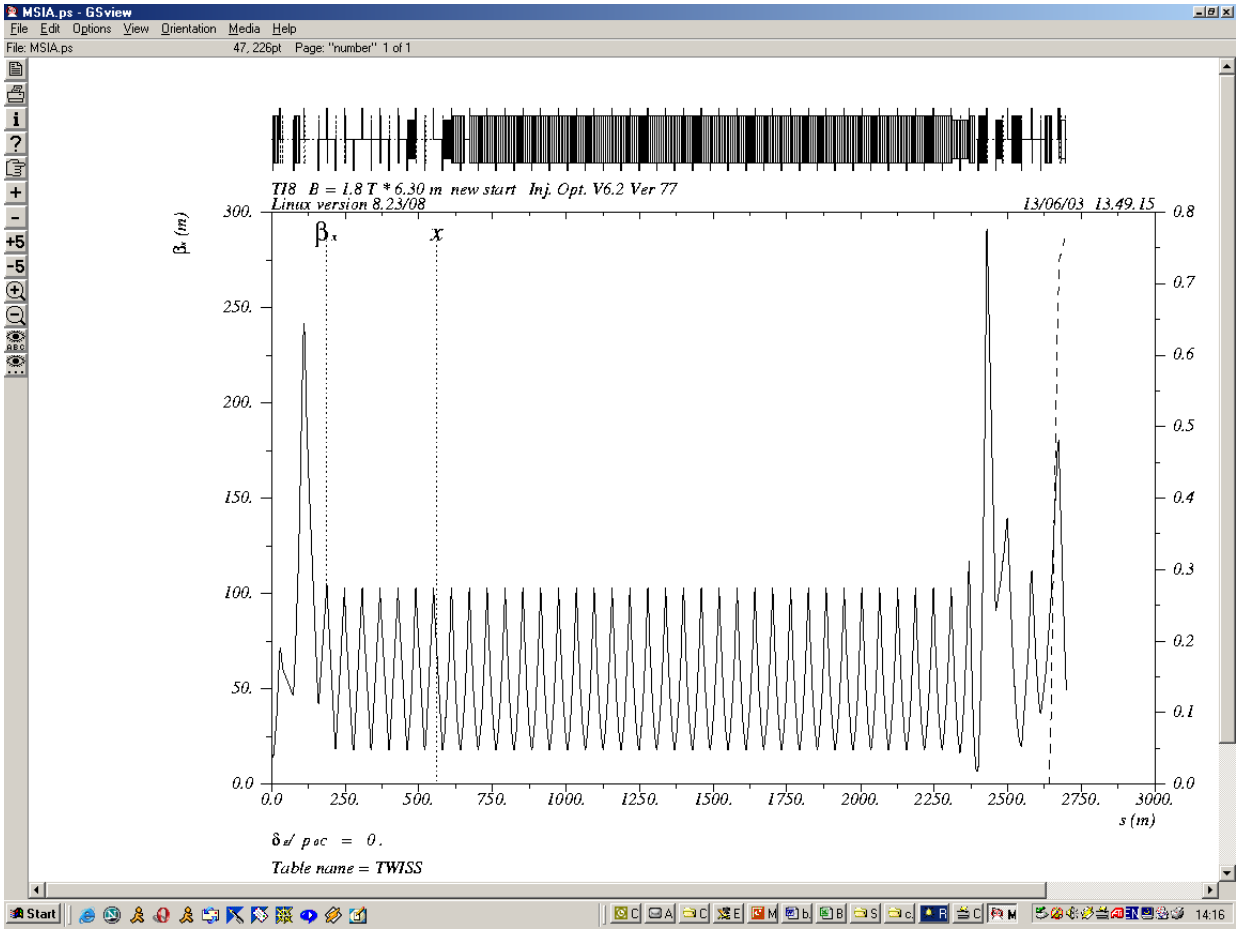


Used these errors in MAD to produce orbit offsets/angles x/x’ at observation point (known $\alpha\beta\gamma$), then translated into offset $\Delta X/\sigma$

$$\Delta X/\sigma = \sqrt{([\gamma x^2 + 2\alpha x x' + \beta x'^2] / \varepsilon)}$$

Dipoles – easy

Quadrupoles – messy (made 4mm h. bump at the quad using orbit correctors then introduced error and compared x x’).



Results

TI 8

Family	t ms	Dk/k	x	x'	alpha	beta	e mm mrad	dx/s
MBIAH	2631	0.003	0.1804	-0.071	1.689	49.13	0.0078	5.15
MSIA	618	0.013	-1.5225	-0.007	1.689	49.13	0.0078	5.31
MSIB	1209	0.009	-2.5087	0.016	1.689	49.13	0.0078	6.88
MQIF878	116	0.043	0.1226	-0.002	1.689	49.13	0.0078	0.26
MQID879	125	0.040	-0.048	0.004	1.689	49.13	0.0078	0.20
MQIF880	130	0.039	0.4380	-0.015	1.689	49.13	0.0078	0.71
MQID881	135	0.037	-0.1524	0.003	1.689	49.13	0.0078	0.27

TI 2

Family	t ms	Dk/k	x	x'	alpha	beta	e mm mrad	dx/s
MBIBH	1295	0.006	8.9754	-0.396	2.028	52.203	0.0078	**14.57**
MSIA	567	0.014	1.5656	0.004	2.028	52.203	0.0078	5.84
MSIB	1148	0.009	2.3605	-0.021	2.028	52.203	0.0078	6.86
MQIF292	2220	0.043	-0.1990	0.01	2.028	52.203	0.0078	0.36
MQID293	2179	0.043	0.4492	-0.02	2.028	52.203	0.0078	0.72
MQIF294	2004	0.041	0.1349	-0.006	2.028	52.203	0.0078	0.20
MQID295	1881	0.039	-0.1665	-0.004	2.028	52.203	0.0078	0.25

Cross-check using

$$\Delta X/\sigma \approx 11.7\,\Delta k\sqrt{\beta_{av}}$$

k	n magnets	beta av m	dx/s
3.5	7	38	5.33
1.86	2	94	5.48
2.76	3	71	7.36

k	n magnets	beta av m	dx/s
3.0	6	140	14.58
1.86	2	106	6.18
2.76	3	71	7.63

Note that:

- these are all in the horizontal plane (v. plane for quads not checked but magnitude will be similar)
- all mean the full batch impacting in one spot (ignoring sweep from kicker waveforms).

MBIBH failure…

- In fact $\Delta\phi$ MBIBH $\Rightarrow$ TCDIMSI is about 66°…

- So at the TCDIMSI the maximum offset from the MBIBH trip can only be 3.6mm, which corresponds to a total of about 6.4 σ in the LHC, so comparable to the others.

Expected occurrence rate

- Identified 6 families (all the dipoles considered) where trips might be dangerous for LHC.
- Power supply trip rate : worst case 1 per supply/y
- Supply pulses for ~300ms
- *Assuming random distribution of trip time within this 300ms* (tbc!), with 5ms dead time the rate of dangerous trips per year is just

$$6 \times 5/300 = 0.1$$

And now…?

- Can this (somewhat pessimistic) once per 10 years be accepted?
- If not, can we improve on it, by better surveillance /interlocks (i.e. <5ms loop, tighter limits) on these 6 power convertors? A 1 ms response time would make these failures inconsequential…
- In any case, the basic interlock on the current for all the families is needed to protect the transfer lines themselves and the LHC machine

A word on the SPS extraction septa…

- 20% current drop will mean that the septa or the immediately downstream elements will be damaged.
- 3 families, so occurrence rate for trips is

  $$3 \times 5 / 300 = 0.05\ldots$$

- Seems negligible… but other failure modes…?
- Can the surveillance be improved to reduce the 5ms response time? Being investigated…