Magnet Setup Cycling for LHC

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Contents

Aims of the magnet setup cycling:

- **To put the magnets in a known magnetic state described by the associated field descriptions.**
  - Only then we will be able to predict accurately the correction to apply for decay and snapback.
- **To assure magnetic reproducibility from run to run, in particular for injection. This is very important, in particular for the startup of LHC.**
- **Limit the field decay at injection**
- **Limit field errors due to hysteresis, coupling between magnets and other effects.**

- **Running in with beam up to 7 TeV, first 'year'**
  - All is done to assure magnetic reproducibility from run to run. Use a cycle giving a known magnetic state regardless of history. Try to keep changes small in necessary feed forward corrections for decay and snapback. Accept long setup cycle times.
- **Routine running for physics later 'years'**
  - Shorten setup cycling time by using the field model to predict corrector settings from the physics run history and by adjusting setup cycle.
  - *For example: if physics run takes more than 30 minutes, ramp down with 10A/s, go to preinjection plateau, adjust duration according with FIDEL according to history, go to injection (maybe apply small decay projection). The aim is again to get reproducible conditions.*
- **Finally arrive at the ideal shortest possible setup time.**

Interactions between magnets

- **Small field changes can occur in LHC by a variety of more or less well quantified effects.**
- **Sometimes magnets are so near to each other that their fields interact slightly. In addition these fields may depend on the sequence of cycling. Therefore cycling of these magnets may need to be synchronized.**
  - Two in one design of LHC. The two apertures have to be cycled simultaneously. Ex. MQ, MQM. MQY
  - MCS, MCDO spool pieces fixed on main dipole ends, MS and MCB in MSCB assembly.
  - Nested magnets. Examples: MCDO, MCBX(A), MCSOX
  - Magnets coupling with detector magnets.
- **All busbars in LHC are superconducting and in addition could magnetize slightly the magnet yokes. This may generate small fields at injection. These could depend on the sequence of cycling.**

Powering

- 1612 circuits in LHC.....
- For the setup cycling the maximum attainable ramprate, in particular when descending the field will set a lower limit to the setup duration.

Protection

- A quench during setup in the main circuits will give important delays.
- Therefore to limit the risk of quench, the maximum cycling current should not exceed considerably the maximum required operating current. (ex. MQM, arc MQT, MQTL).

The quench protection system may set limits to the ramprate, in particular to the gradual start and stop of a cycle. A parabolic slow stop/start of about 10s seems indicated.

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Exponential down ramp for monopolar PC circuits

- Except for MB and correctors all PC are monopolar. The maximum ramprate for decreasing the current is determined by the timeconstant of the circuit .
- Proposed time constants of exponential down ramps for magnets with field decay.
- The MQ circuits have very long time constant which will make their precycle longer than that of the dipole.

Magnet type	Circuit time constant (s)
MQ	240 - 400
MQM	22 - 63
MQML	25 - 51
MQY	90 - 224
MQXA	191 - 420
MQXB	33 - 55
MBR C/S/B	64 - 91

Models & Measurement

- **Very extensive magnetic measurement program made and still underway to understand influence of cycle details.**

- **Fidel modeling also applicable to the set up cycling, esp the preinjection plateau.**
  - Size of preinjection snapback

- **Choices to be made for numerous cycle details, can be guided by calculations with the CUDI program.**
  - Ramp down slowly to the pre-injection plateau and wait shortly or vice versa?

- **For no superconducting machine has the knowledge of the set up cycle influence on the field quality and decay been greater. But still not enough.**

Cycle types.

- **Two main cycle types for :** Magnets with field decay **and** Magnets without field decay
- **The magnets with field decay require a setup with long periods of defined waiting time and ramprates to limit the decay to small values and assure reproducibility. Time is a very important parameter.**
- **Magnets without field decay are not (less) dependent on cycle duration. These magnet types include all superconducting correctors and normal magnets of LHC. Similar to magnet cycling in LEP.**
  - Special case: nested superconducting corrector magnets.
- **A special part of the setup cycle can be the** demagnetization cycle **which sets the magnetization to very low values. This cycle can in addition set the decay to low values. The price to pay here is a large snapback.**

Cycle types, abnormal termination

- **How to setup when a main dipole quenches, when a orbit corrector went down and the beam was lost , the injector is down for 1 hour, etc ?**
  - Magnets with field decay may require a pre-cycle, which basically imitates a physics run.
  - Magnets without field decay will use the same cycle.

- **Not always evident what to do. Standard setup cycle with precycle takes very long.**

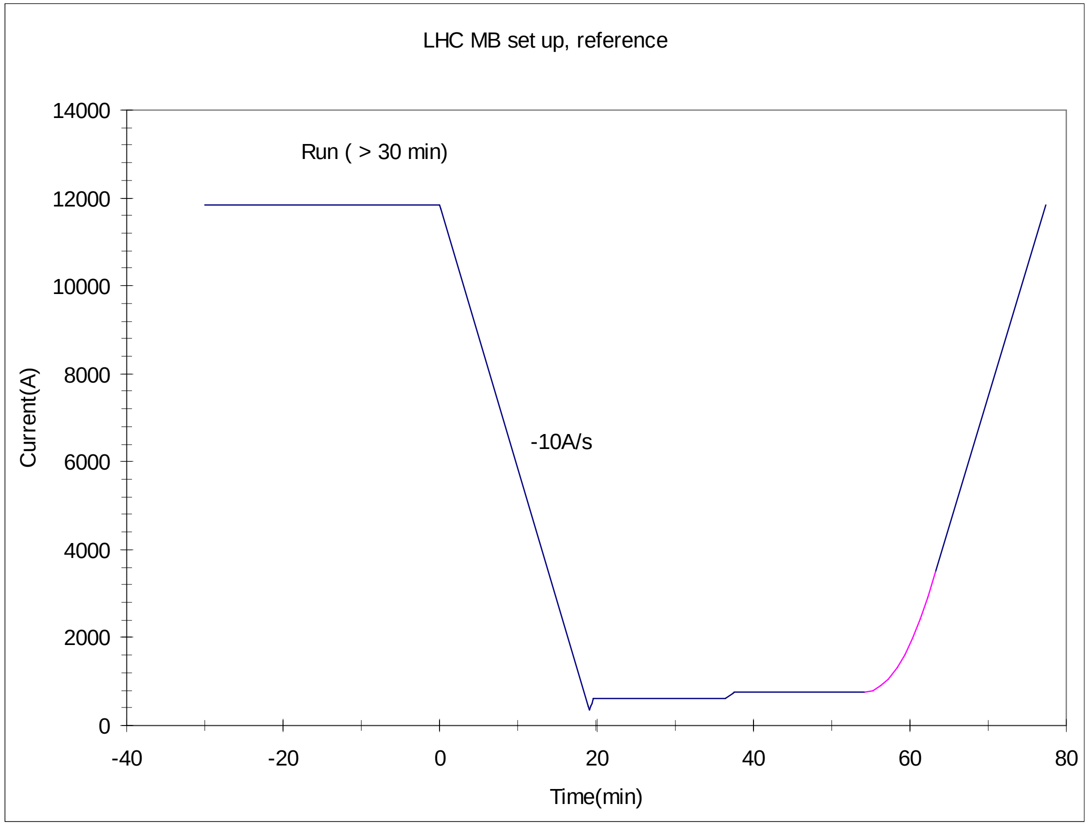
Reference cycles for magnets with field decay

- The LHC superconducting magnets whichh show a (small) time dependence in the field, particularly noticeable at injection. These are all superconducting magnets made with Rutherford cables.
- Magnet types with field decay are MB, MBRB, MBRC,MBRS, MBX, MQ, MQM, MQMC, MQML, MQXA, MQXB, MQY.

Magnet type	Multipole	measured μ (units)	measured σ (units)	Injection current	Minimum cycle current	Ramprate of precycle
MB	b_1	1.31	1.20	760	350	50
MB	b_3	2	0.60	760	350	50
MB	b_5	-0.33	0.12	760	350	50
MQ	b_2	-3.74	2.40	760	350	50
MQ	b_6	0.54	0.34	760	350	50
MQY	b_2	-6.00	2.00	176	50	20
MQY	b_6	0.45	0.12	176	50	20
MQM	b_2	-4.50	1.20	265	50	20
MQM	b_6	0.50	0.24	265	50	20

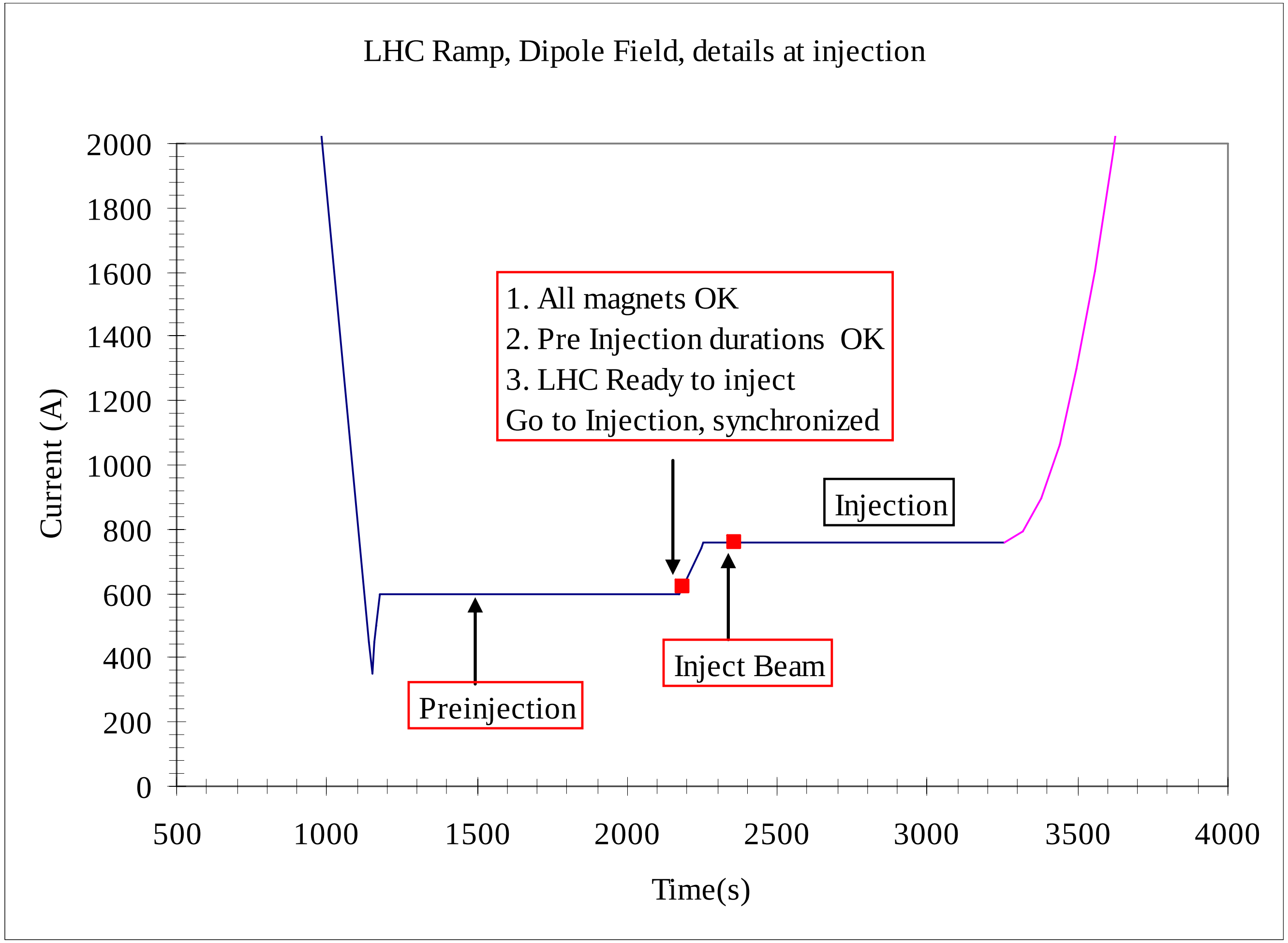
- Note that the precycle used for the standard measurements (S. Sanfilippo et al.) of the decay is not always realizable in the machine.

MB Nominal Cycle 1

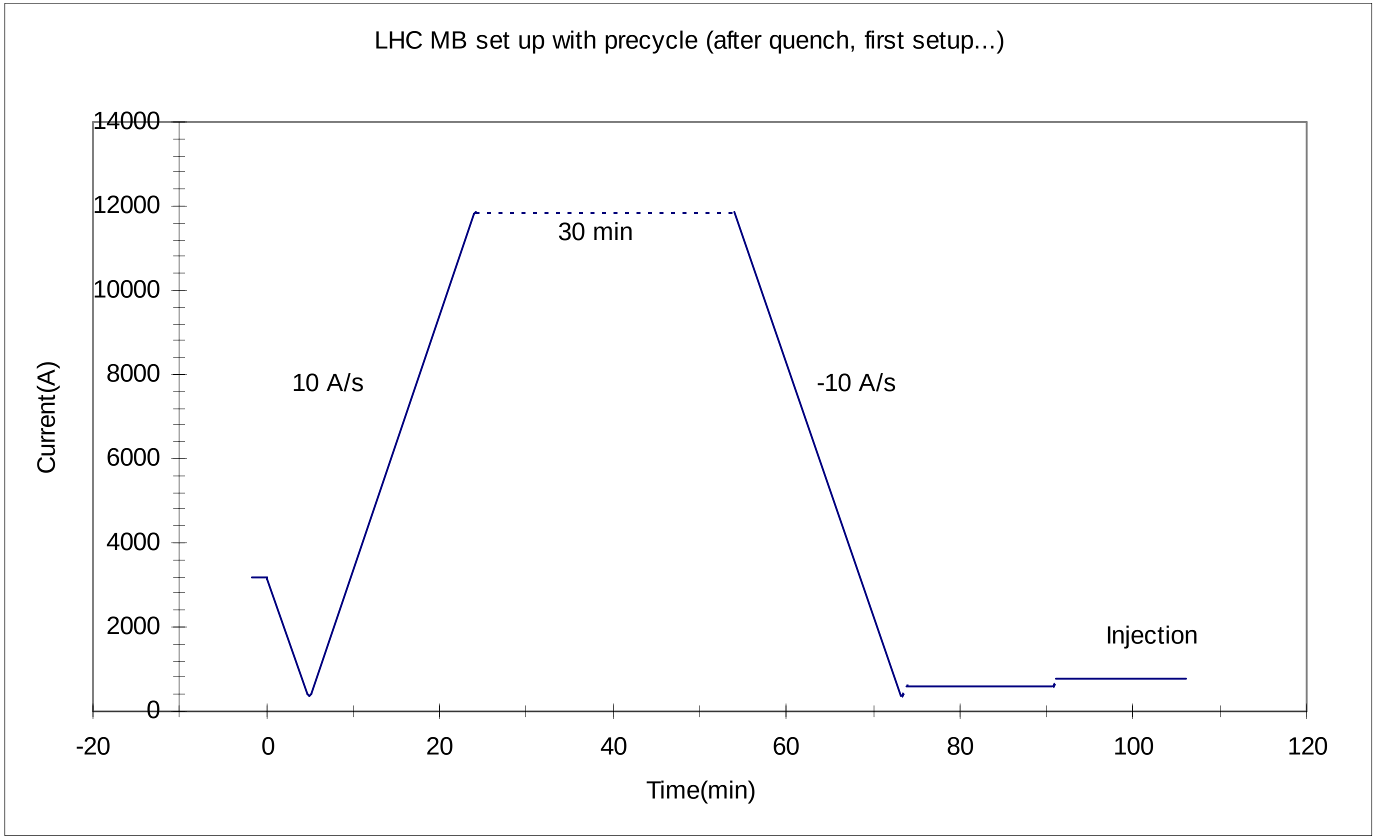


State	Duration (s)	Time (s)	Current
Ramp down, start: P	10	10	11750
Ramp down: L	1130	1140	450
Ramp down, stop: P	10	1150	350
Ramp to preinj, start:P	10	1160	450
Ramp to preinj: L	5	1165	500
Ramp to preinj, stop:P	10	1175	600
Preinjection	1000	2175	600
Ramp to injection, start:P	10	2185	620
Ramp to injection: L	60	2245	740
Ramp to injection, stop:P	10	2255	760
Injection, waiting for beam	100	2355	760

MB Nominal Cycle 2

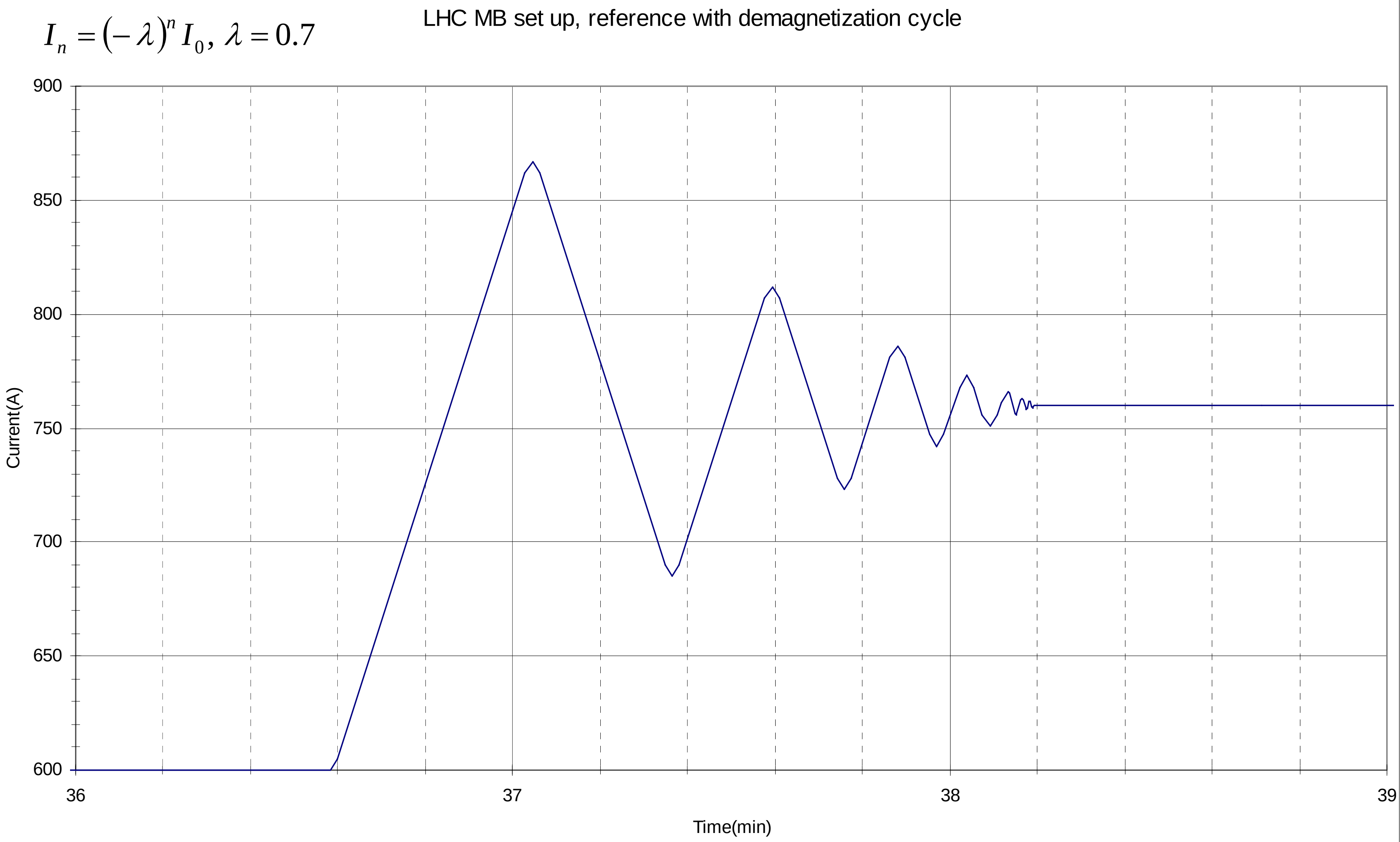


MB with precycle



MB with demagnetization cycle

$$I_n = (-\lambda)^n I_0,\ \lambda = 0.7$$



MQ nominal Cycle

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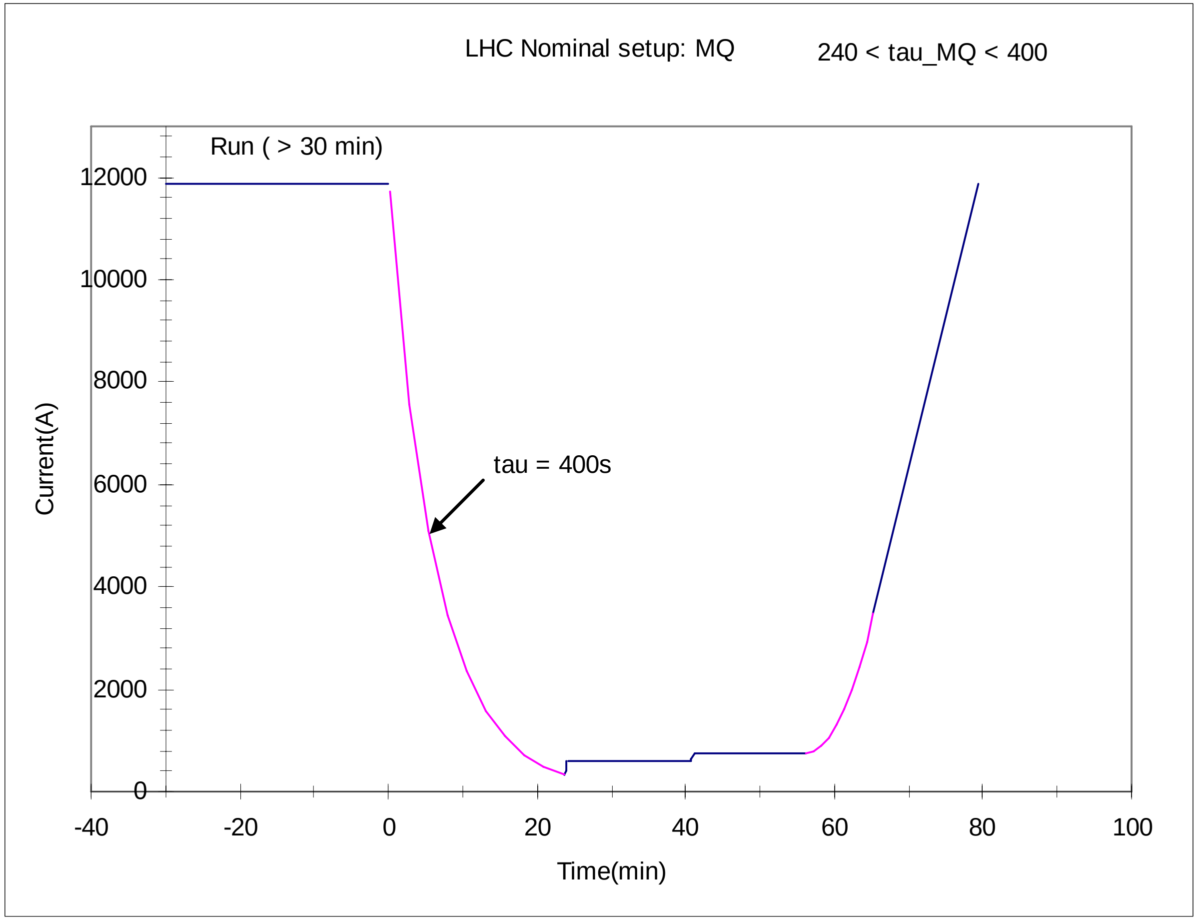
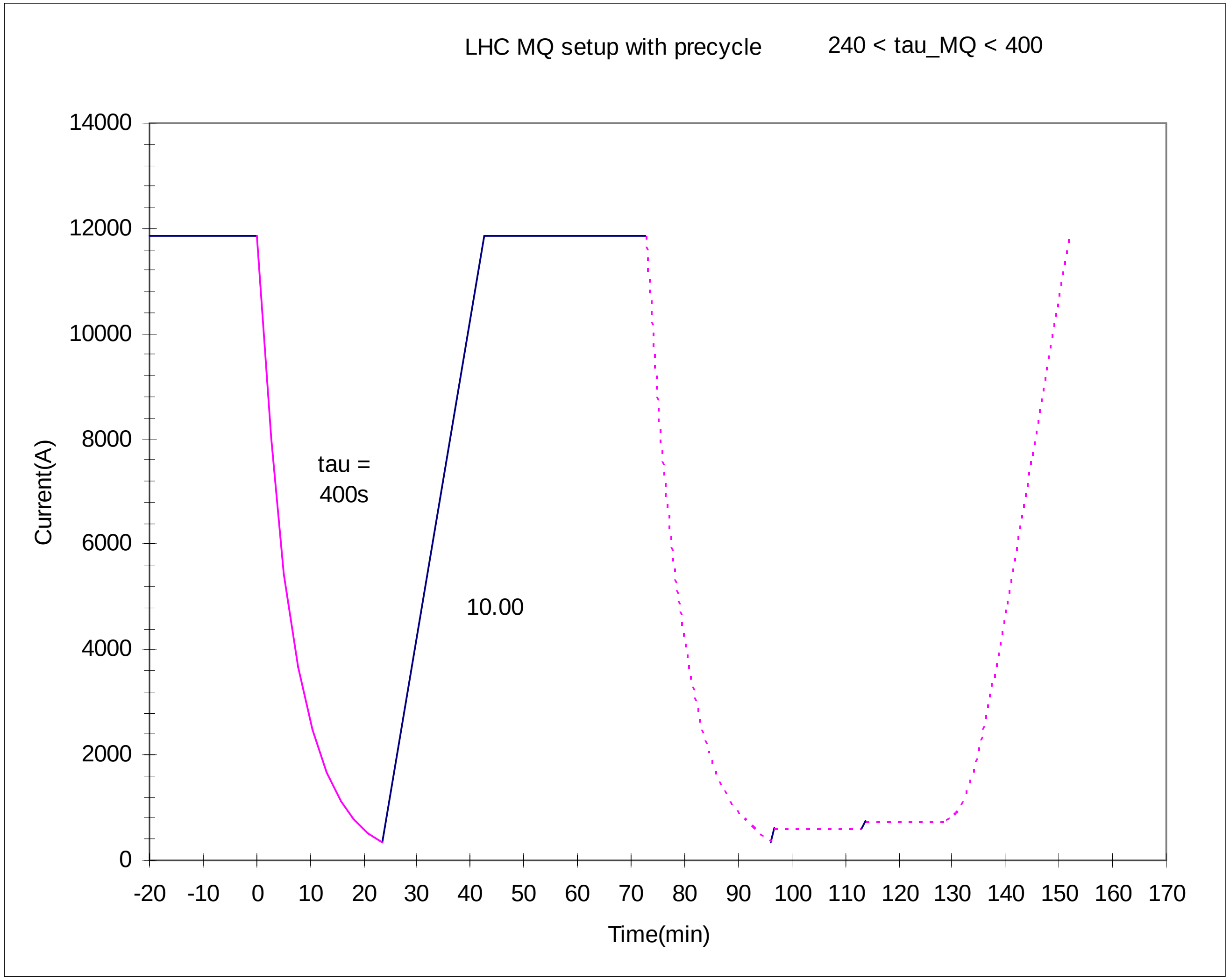


MQ with precycle



Parameters of magnets with field decay 1

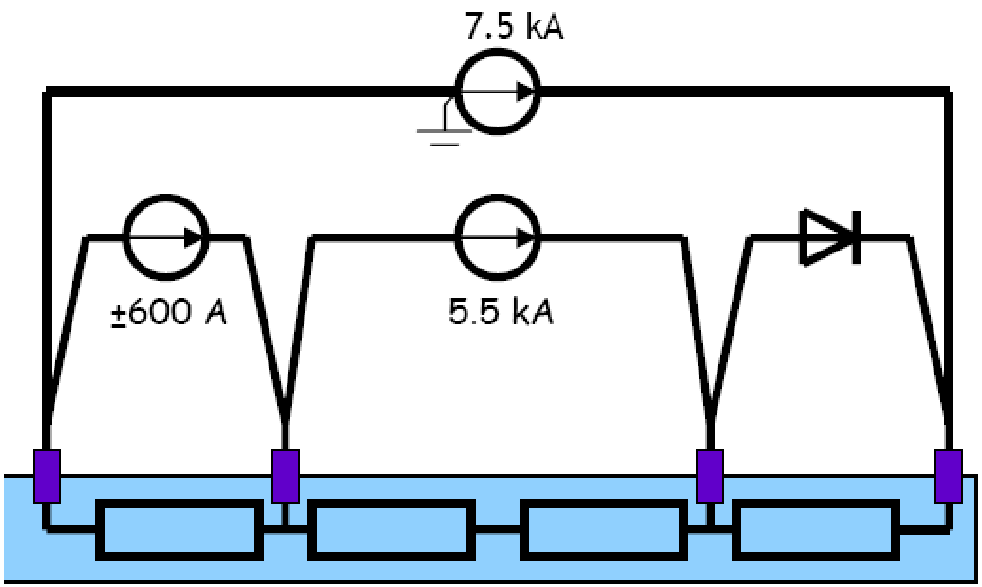
Magnet type	Ramp rate up (A/s)	Parabolic roundoffs (s)	Nominal, Layout DB (A)	Max Expected Operation Current	Proposed max Current	Flattop duration (min)	Exponential Down Ramp τ (s)
MB	*10*	*10*	*11870*	*18870*	*11870*	*30*	*-10A/s, lineair*
MBRB	10	10	5520	6175	5520	30	100
MBRC	10	10	4400 6000	4405 5979	4400 6000	30	100
MBRS	10	10	5520	5865	5520	30	100
MBX	10	10	5800	5650	5800	30	100
MQ	10	10	11870	11870	11870	30	400
MQM	10	10	4310(Q5,6) 5390	2746-4312 3281-5390	3000-5390	30	100
MQMC	10	10	5390	3439-5192	3500-5390	30	100
MQML	10	10	4310 (Q5,6) 5390	3109-4312 2102-5387	3000-5390	30	100
MQY	10	10	3610	2132-3556	2200-3610	30	300

Parameters of magnets with field decay 2

Magnet type	Min. current (A)	Injection (range)	Preinjection level, consistent with MB	Proposed Preinjection level	Ramprate to injection (A/s)	Wait before injection, approx. (s)
MB	*350*	*763*	*-200*	*560*	*2*	*100*
MBRB	200	397	-212	300	1	100
MBRC	120 160 (200)	283,P1,5 384,P2,8	-212	180 270	1	100
MBRS	200	377	-212	280	1	100
MBX	200	363	-205	260	1	100
MQ	350	763	-256	560	2	100
MQM	120	145-222 162-309	-126	120-240	1	100
MQMC	120	221-309	-126	160-210	1	100
MQML	120	145-229 135-304	-126	120-240	1	100
MQY	80	133-229	-84	80-150	1	100

Insertions

Magnet type	Ramp rate up (A/s)	Nominal, Layout DB (A)	Max Expected Operation Current	Flattop duration (min)	Exponential Down Ramp τ (s)	Min. current (A)	Preinjection level, consistent with MB	Injection (range)	Parabolic roundoffs (s)
MQXA	5	6450	6738-7343	30	?	200	-116	415-472	10
MQXB	8	10630	11289-12305	30	?	350	-214	695-791	10



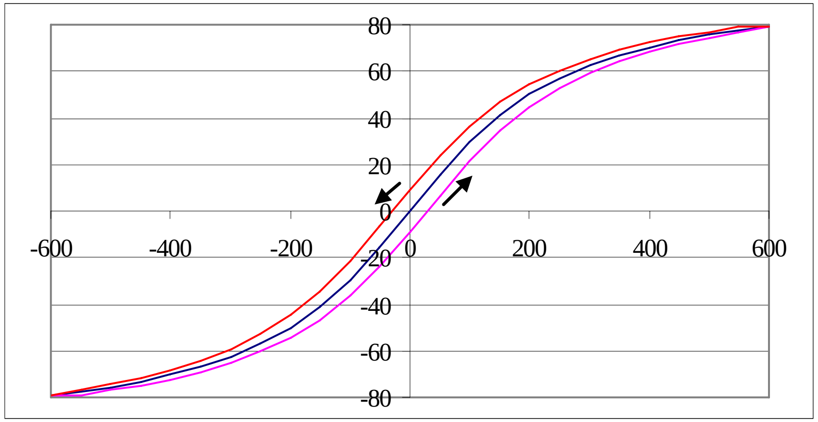
MQXA MQXB MQXB MQXA (from EDMS 531773)

- The Workshop on Test facilities and Measurement Equipment (Dec, 2006) felt that additional magnet magnetic measurement will be required even after initial commissioning, for studying the influence of practical machine cycles on the field description.

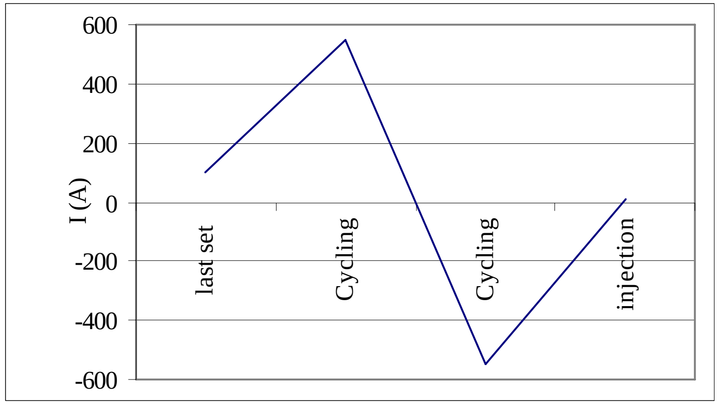
- Study influence of the LHC ramprate of 10A/s on the main dipole.

- FQWG should define necessary program until 2008 startup and beyond now. Ressources may be low..

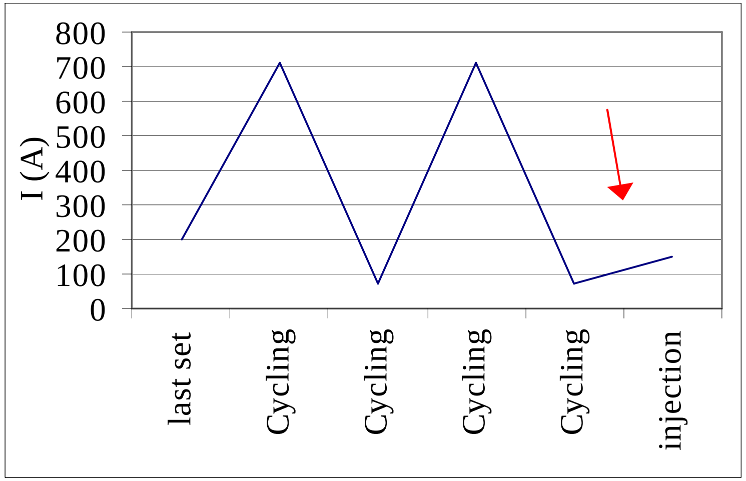
Typical cycles for magnets with no field decay.



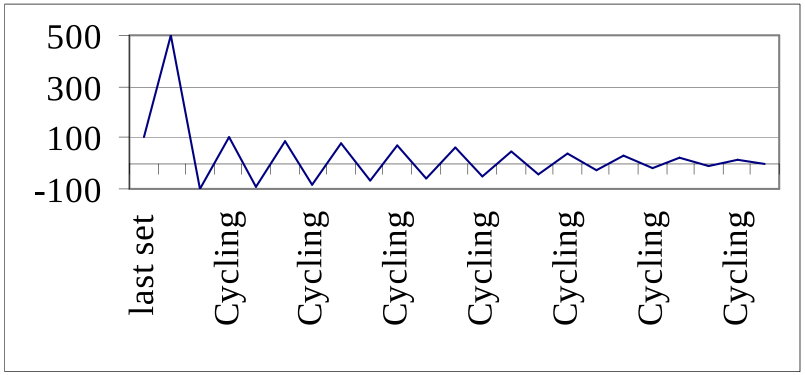
Qualitative excitation curve for bipolar magnets



Setup cycle for bipolar corrector, n=1



Setup cycle for monopolar warm magnet, n=2



Demagnetization cycle (for bipolar circuits)

Setup Cycle Synchronization and Timing.

- **The interactions between magnets will require synchronization of groups of magnets.**
  - Ex. Nom ramp for MQ to be synchronized (start downramp at same time after run).
- **All magnets with field decay to be are to be set reproducibly from the preinjection plateau to injection. For these magnets 'the ramp starts at the end of preinjection'.**
- **Magnets without field decay can in be set to injection immediately**
  - however two and four aperture magnet assemblies do require to be synchronized (ex. MQTL, MSCB, MQW)
- **For best reproducibility of LHC synchronization of the setup cycles of all LHC is recommendable. *This however is not always practical or necessary. (corrector power converter failure of one MQT circuit during pre-injection plateau).***

Nested correctors

- **The residual field of nested corrector magnets depends on the way of how they are cycled. Not only the magnitude can change but also the multipole content can be change.**
- **Only one of the correctors of each nested assembly is pre-cycled, such that only normal residual fields are generated.**
- **The principle of the Reference Setup sequence for MCDO, MCBX and MCBXA nested corrector magnets is:**
  - First set the inner correctors to their injection setting.
  - Then with the outer corrector perform a specified cycle and set to injection level
- **For the MCSOX corrector**
  - First set the outer MCSSX and inner MCOSX corrector to their injection setting.
  - Then with the MCOSX perform a specified cycle and set to injection level.

Conclusions

➔ **EDMS engineering specification in preparation.**

– Contains details for each circuit

➔ **More magnetic measurements still to be done**

– But: can't measure everything. Have to setup with best judgement and using Fidel & Cudi modelling.

➔ **LHC requires considerable synchronization during set-up.**

Task Summary

- ➔ **Agree on general setup strategy.**
- ➔ **Define the precise setup cycle for magnets with field decay.**
- ➔ **Define cycles for all magnet types, including 450GeV run**
- ➔ **For each circuit in LHC define which cycles (and field model) are to be used.**
- ➔ **Define cycling sequences for magnets, define synchronization.**
- ➔ **Study setup cycling for exceptional operation events.**
- ➔ **Define magnetic measurement program for startup 2008.**

Cycle and Field Model allocation to circuits

FAMILY_NAME	Magnet Type	Cycle_ID	Field Model ID	DESCRIPTION
MB78	MB	MB_setup0	MB_Average	
RSD1.L4.B1	MSD	MS550	MS_Average	
MCBH.20R7.B2	MCBH	MCB55	MCB_2	
MQTLxyz	MQTL	MQTL350	MQTL_Average	Max. cycling current limited to 350A due to performance problems.

- ➔ Family name (circuit) from the Layout DB.
- ➔ Added magnet type for convenience.
- ➔ Split : Field Model id = Static FM + Dynamic FM ?

Cycle Tables

			"goto"	"with ramprate	"stay there for
(Magnet Type)	Cycle_id	Sequence	I (A)	dI/dt (A/s)	dt (s)
MB	MB_nom	1	350	-10	0
MB	MB_nom	2	500	10	1000
MB	MB_nom	3	760	2	100
MB	MB_pre	1	350	-10	0
MB	MB_pre	2	13000	10	1000
MB	MB_pre	3	350	-10	0
MB	MB_pre	4	500	10	1000
MB	MB_pre	5	760	2	100
MCBH	CH50	1	50	0.5	0
MCBH	CH50	2	-50	-0.5	0
MCBH	CH50	3	0	0.5	0

Cycle group		
Group_nam	Cycle_id	Order
MCBXA	MCBXH	2
MCBXA	MCBXV	1
MCBXA	MCSX	1
MCBXA	MCTX	1
MCDO	MCD550	2
MCDO	MCO100	0

- ➔ Added magnet type for convenience.
- ➔ Polarity for bipolar cycling to be verified.
  - – Positive of PC not always connected to the ‘A’ terminal, for example for the MCS spool pieces.
- ➔ Naming to be defined
- ➔ Last setting sequence to injection?