Both superconducting and resistive magnets need a proper pre-cycling to have a reproducible behaviour, namely to provide the same field at the same level of current. Depending on the type of magnet, the type of pre-cycle stems from different physical phenomena, and reproducibility can be obtained through different pre-cycle strategies. For the Large Hadron Collider (LHC), the final goal is to have reproducibility within the tight beam dynamics requirements (of the order of $10^{-4}$) with a minimum pre-cycle time. Too long pre-cycle reduces the time available for the beam collisions, i.e. the integrated luminosity. In this report we give the pre-cycle strategy adopted for the LHC in 2009 and 2010.
1. Introduction

Both superconducting and resistive magnets need a proper pre-cycling to have a reproducible behaviour, namely to provide the same field at the same level of current. Depending on the type of magnet, the type of pre-cycle stems from different physical phenomena, and reproducibility can be obtained through different pre-cycle strategies. For the Large Hadron Collider (LHC), the final goal is to have reproducibility within the tight beam dynamics requirements (of the order of $10^{-4}$) with a minimum pre-cycle time. Too long pre-cycle reduces the time available for the beam collisions, i.e. the integrated luminosity. In this report we give the pre-cycle strategy adopted for the LHC in 2009 and 2010.

The accelerator is made up of several different types of magnets [1,2], that can be separated in the following categories.

1. For superconducting magnets based on Rutherford cables, one has two main issues.
   - **Memory - hysteresis branch.** A pre-cycle is needed to place the magnet on the correct hysteresis branch, i.e. with $\frac{dI}{dt}>0$ in usual cases (see Fig. 1). This ensures that during operation, when the current of the magnet is ramped up, the magnet is already placed on the ascending branch of the hysteresis. Such an hysteresis for superconducting magnets is mainly due to persistent currents in the superconductor. If the pre-cycle is skipped, the magnet at injection can be on the descending branch, thus giving a field that can differ of a few per mill, depending to the design and the operational current. This effect can be particularly strong when the injection current is very low, as is the case for some MQM and MQY. The cycle must be at a sufficiently high current to erase previous magnetizations.
   - **Decay amplitude.** The amplitude of the decay, and of its related snapback, is dependent on the pre-cycle ramp rate, flattop duration, flattop current, and pre-injection duration [3-7] (see Fig. 2). A correct pre-cycling ensures a reproducible decay and snapback. If the pre-cycle is skipped, one could have different decay and snapback amplitudes, and the trim deduced from previous runs could not work. Since a physics run normally terminated is the pre-cycle to the next run, and it involves a flattop duration of several hours, one should in principle need a flattop duration of several hours. Luckily, the decay amplitude has a dependence on the flattop duration which saturates after 1000 s to a maximum value. For this reason, magnets which have a non-negligible decay must have a pre-cycle with flattop duration of 1000 s (see Fig. 3).

![Fig. 1: Hysteresis of the transfer function (units w.r.t. the average value, main figure) during a pre-cycle (upper left part) to place the magnet on the ascending hysteresis branch.](image)
2. Superconducting magnets based on ribbons made of wires, as the correctors, have no decay and therefore the second issue is not relevant. In this case one just needs a cycle to reach the right hysteresis branch, with zero flattop duration.

3. Resistive magnets have the same issue with hysteresis as the superconducting ones, the difference being that hysteresis comes from the iron and not from the cable. Since the ferromagnetic domains have a certain viscosity, one needs several cycles to re-orient them. Therefore for resistive magnets we propose four cycles to stabilize the magnetic field versus current characteristics and to be on the right branch.

4. We also have two special cases:
   - Some superconducting correctors magnets are nested. In this case the prescription is to cycle only the outer magnet.
   - One family of magnets (the Landau octupoles MO) need to operate only at top energy. The magnet being at zero current at injection, the residual magnetization of the cable would strongly perturb the beam at injection: for this reason, they need a special cycle (degaussing) to cancel the residual magnetization. It is done with four cycles with decreasing amplitudes.

In this paper we give the prescriptions for pre-cycling adopted in 2009 and 2010 for the LHC, i.e. for the 1.2 and 3.5 TeV runs. A similar strategy can be applied to higher energies, the only main change being the time needed for pre-cycling. The 2008 run used previous settings which were not completely coherent. The variations in the pre-cycle strategy adopted during operation w.r.t. the prescription of the FiDeL team are marked in italics.

2. Pre-cycles for superconducting magnets with non-negligible decay: MB, MQY, MQM

These three families of magnets have a non-negligible decay. According to what outlined in the introduction, their standard pre-cycle should include a flattop with a duration of 1000 s. Measurements have shown that the decay decreases for larger flattop duration, reaching an asymptotic value at 1000 s [6,7]. A flattop of 1000 s is adopted in all magnets with non-negligible decay.
2.1 MAIN DIPOLES - MB

The MB pre-cycle (8 circuits) starts at 350 A and reaches flattop current with 10 A/s, stays at flattop 1000 s and ramps down linearly with 10 A/s back to 350 A. Then it immediately ramps up to the pre-injection plateau at 500 A (see Fig. 3). For the 3.5 TeV operation, it takes about 2300 s (limited at 2000 A in 2009, duration of 1500 s).

At the beginning of 2010, a ramp rate of 2 A/s has been used to cope with issues related the quench detection system. At the time of writing (July 2010), this ramp rate is still used. In order to speed up the pre-cycle, a ramp up to 2000 A with a plateau of 600 s has been done in March-May 2010. Since May 2010, the plateau has been increased to 4000 A to better match the usual conditions of run after a successful run (i.e. previous cycle at 6000 A). This cycle (see Fig. 4) takes about 4500 s.

![MB pre-cycle used for 3.5 TeV operation since 21st May 2010.](image)

2.2 IR QUADRUPOLES – MQY (Q4, Q5, Q6)

The MQY pre-cycle (36 circuits) is similar to the MB one, with two exceptions: (i) there is no pre-injection plateau, i.e. the pre-cycles end at the minimum current and stay there, and (ii) the ramp down is exponential according to the circuit properties: each circuit has a different time constant. The receipt for the flattop duration is 1000 s. Indeed, since these magnets have a very long time to discharge (the longest of the LHC), we decided to reduce the flattop to 300 s. The impact on the decay should not be important. In these conditions, the total time needed for pre-cycling is between 1700 s and 4000 s. The flattop current has been limited at 1000 A in 2009, with a duration of 1500-3500 s.

![MQY pre-cycle used for 3.5 TeV operation since 21st May 2010.](image)
2.3 IR QUADRUPOLES – MQM AT 4.5 K (Q5, Q6)

The MQM at 4.5 K pre-cycle (28 circuits) is as the MQY: linear ramp up with 10 A/s, flattop duration of 1000 s, exponential ramp down to minimum current. At 3.5 TeV, the pre-cycle takes about 1800-2300 s. The flattop current has been limited at 2000 A in 2009, with a pre-cycle duration of 2000-2300 s.

2.4 IR QUADRUPOLES – MQM AT 1.9 K (Q7, Q8, Q9, Q10)

The MQM at 1.9 K pre-cycle (92 circuits) is as the in the MQY: linear ramp up with 10 A/s, flattop duration of 1000 s, exponential ramp down to minimum current. At 3.5 TeV, the pre-cycle takes about 1800-2500 s. The flattop current has been limited at 2000 A in 2009, with a pre-cycle duration of 1500-2500 s.
3. Pre-cycles for main superconducting magnets with negligible decay: MBX, MBRB, MBRC, MBRS, MQ, MQXA, MQXB

3.1 COMMON FEATURES
These magnets have a negligible decay, therefore the flattop duration is not critical: we have reduced it to 300 s (5 minutes). All these magnets have a one quadrant power converter and therefore the ramp down is exponential.

3.2 SEPARATION DIPOLES – MBX (SUPERCONDUCTING D1)
The MBX pre-cycle (4 circuits) has a duration of 1000-1200 s. Current has been limited at 2000 A in 2009, with a pre-cycle duration of 1000 s.
3.3 SEPARATION DIPOLES – MBRC (D2)

The MBRC pre-cycle (8 circuits) has a duration of 1400-1600 s, with two different injection currents. Current has been limited at 2000 A in 2009, with a pre-cycle duration of 1450 s.

3.4 SEPARATION DIPOLES – MBRS (SUPERCONDUCTING D3)

The MBRS pre-cycle (2 circuits) has a duration of 1400 s. Current has been limited at 2000 A in 2009, with a pre-cycle duration of 1250 s.

3.5 SEPARATION DIPOLES – MBRB (SUPERCONDUCTING D4)

The MBRB pre-cycle (2 circuits) has a duration of 1500 s. Current has been limited at 2000 A in 2009, with a pre-cycle duration of 1350 s.
3.6 MAIN QUADRUPOLES - MQ

The MQ pre-cycle (16 circuits) has a duration of 2300-3200 s. Flattop current has been limited at 2000 A in 2009, with a pre-cycle duration of 1500-2300 s. During 2010 the limitation to 2000 A has been kept, with the nominal 10 A/s ramp rate.

3.7 INNER TRIPLET QUADRUPOLES - MQXA

The MQXA pre-cycle (16 circuits) has a duration of 3500 s. The plateau is set at 1000 s to synchronize it with the MQXB (nested power converters); it could be probably made shorter (same cycle made in 2009).
3.8 INNER TRIPLET QUADRUPOLES - MQXB

The MQXB pre-cycle (8 circuits) has a duration of 3200 s (same cycle made in 2009).

A summary of the pre-cycles of the main circuits used in the machine is given in Fig. 16.
4. Pre-cycles for superconducting magnets based on ribbons (no decay)

4.1 COMMON FEATURES

These magnets have no decay. There is no need of flattop, which is set at 10 s. According to unipolar or bipolar power converter, and to the optical function, one has different cycles.

4.2 ORBIT CORRECTORS – MCBCH/V

These magnets (156 circuits) have bipolar power converter, with an up-down pre-cycle that takes about 500 s. Some circuits have been limited to currents lower than nominal.

![Fig. 15: MCBCH/V pre-cycle.](image)

4.3 ORBIT CORRECTORS – MCBH/V

These magnets (752 circuits) have bipolar power converter, with an up-down cycle that takes about 500 s.
4.4 WIDE APERTURE ORBIT CORRECTOR - MCBY

These magnets (88 circuits) have bipolar power converter, with an up-down pre-cycle that takes about 700 s. Some circuits have been limited to currents lower than nominal.
4.5 TUNING QUADRUPOLES - MQT

These magnets (32 circuits) have bipolar power converter, with an up-down pre-cycle that takes about 1200 s. Maximum current has been limited to 200 A at the beginning of 2010.

4.6 “LONG TUNING” QUADRUPOLES - MQTL

These magnets (136 circuits) have bipolar power converter, with an up-down cycle that takes about 1200 s. These magnets are not correctors but they have fixed settings to build the optics in the dispersion suppressor and matching section regions. Some circuits have been limited to currents lower than nominal. Please note that the Q6 MQTL placed left and right of IR3 and IR7 (8 circuits) have not been pre-cycled in 2009. Maximum current has been limited to 200-300 A, according to the circuit, at the beginning of 2010.
Fig. 19: MQTL pre-cycle.
4.7 SKEW QUADRUPOLES - MQS
These magnets (24 circuits) have bipolar power converter, with an up-down pre-cycle that takes about 1200 s. *Limited at 400 A in 2009, limited at 200 A in 2010.* RQS.R3B1 has no pre-cycle since it is not powered.

4.8 LATTICE SEXTUPOLES - MS
These magnets (64 circuits) have bipolar power converter, with an up-down pre-cycle that takes about 1200 s. *Limited at 400 A in 2009, limited at 200 A in 2010.*

4.9 SKEW SEXTUPOLES - MSS
These magnets (16 circuits) have bipolar power converter, with an up-down pre-cycle that takes about 1200 s. *Limited at 400 A in 2009, limited at 200 A in 2010.*
4.10 SPOOL PIECES SEXTUPOLES - MCS

These magnets (16 circuits) have bipolar power converter, with an up-down pre-cycle that takes about 1500 s. *Limited at 300 A in 2010.*

![MCS pre-cycle](image)

Fig. 23: MCS pre-cycle.

4.11 SPOOL PIECES OCTUPOLES – MCO (NESTED WITH MCD)

These magnets (16 circuits) have bipolar power converter. Since they are nested with MCD, and MCO is the inner one, it is not cycled.

![MCO pre-cycle](image)

Fig. 24: MCO pre-cycle.

4.12 SPOOL PIECES DECAPOLES – MCD (NESTED WITH MCO)

These magnets (16 circuits) have bipolar power converter, with an up-down cycle that takes about 500 s. *Limited at 200 A in 2010.*

![MCD pre-cycle](image)

Fig. 25: MCD pre-cycle.
4.13 LATTICE OCTUPOLES – MO

These magnets (32 circuits) have bipolar power converter. They need a special degaussing cycle, with four up-down cycles with decreasing top current, which takes about 1700 s. Limited at 200 A in 2010.

![Diagram](image)

Fig. 26: MO pre-cycle.

A summary of the pre-cycles of the arc corrector circuits (plus MQTL) is given in Fig. 27.

![Diagram](image)

Fig. 27: Pre-cycle used on May 21st for the arc corrector circuits.
4.14 TRIPLET ORBIT CORRECTORS – MCBXV/H

These magnets (24 circuits H and 24 circuits V) have bipolar power converter. Since MCBXV is nested with MCBXH (MCBXH is the outer one), no pre-cycle is done for the V, and a pre-cycle is done for the H, which takes about 1200 s. *MCBXH has been limited at 250 A in 2010.*

![Fig. 28: MCBXV and MCBXH pre-cycle.](image)

4.15 TRIPLET SEXTUPOLE CORRECTORS – MCSX (NESTED WITH MCBX AND MCTX)

These magnets (8 circuits) have bipolar power converter. Since MCSX is nested with MCSTX and MCBXH/V (MCBXH/V is the outer one), no pre-cycle is done.

![Fig. 29: MCSX pre-cycle.](image)

4.16 TRIPLET DODECAPOLE CORRECTORS – MCTX (NESTED WITH MCSSX AND MCBX)

These magnets (8 circuits) have bipolar power converter. Since MCTX is nested with MCSX and MCBX (MCBX is the outer one), no pre-cycle is done.
4.17 TRIPLET SKEW QUADRUPOLE CORRECTORS – MQSX

These magnets (8 circuits) have bipolar power converter, with an up-down cycle that takes about 1200 s. Limited at 190 A in 2010.

4.18 TRIPLET SKEW SEXTUPOLE CORRECTORS – MCSSX (NESTED WITH MCOX AND MCOSX)

These magnets (8 circuits) have bipolar power converter, with an up-down cycle that takes about 850 s. No pre-cycle has been done in 2010 since these correctors are not used below $\beta^* = m$.

4.19 TRIPLET SKEW SEXTUPOLE CORRECTORS – MCOX (NESTED WITH MCSSX AND MCOSX)

These magnets (8 circuits) have bipolar power converter. Since MCOX is nested with MCSSX and MCOSX (MCSSX is the outer one), no pre-cycle is done.
4.20 TRIPLET SKEW SEXTUPOLE CORRECTORS – MCOSX (NESTED WITH MCSSX AND MCOX)

These magnets (8 circuits) have bipolar power converter. Since MCOSX is nested with MCSSX and MCOSX (MCSSX is the outer one), no pre-cycle is done.
5. Pre-cycles for resistive magnets

5.1 COMMON FEATURES

These magnets have no decay. There is no need of flattop, which is set at 10 s. One does not need to define different cycles for 3.5 or 5 TeV. According to unipolar or bipolar power converter one has different cycles.

5.2 SEPARATION DIPOLES – MBXW (RESISTIVE D1)

These magnets (2 circuits) have a stabilizing pre-cycle with 4 oscillations between minimum and maximum current, which takes about 3000 s.

5.3 SEPARATION DIPOLES – MBW (RESISTIVE D3-4)

These magnets (2 circuits) have a stabilizing pre-cycle with 4 oscillations between minimum and maximum current, which takes about 3000 s.

5.4 QUADRUPOLES - MQWA

These magnets (4 circuits) have a stabilizing pre-cycle with 4 oscillations between minimum and maximum current, which takes about 2800 s.
5.5 QUADRUPOLES - MQWB

These magnets (8 circuits) have a stabilizing pre-cycle with 4 oscillations between minimum and maximum current (bipolar power converter), which takes about 2000 s.

5.6 ORBIT CORRECTORS – MCBWH/V

These magnets (16 circuits) have a stabilizing pre-cycle with 4 oscillations between minimum and maximum current (bipolar power converter), which takes about 2100 s.
5.7 SPECTROMETERS COMPENSATORS – MBXWTV, MBXWSH, MBXWH, MBWMD

These magnets (6 circuits) should have a stabilizing cycle with 4 oscillations between minimum and maximum current, which takes about 3000 s. No pre-cycle has been done in 2009, neither in the first half of 2010.

Fig. 41: Pre-cycle used on May 21st for the resistive magnets circuits (excluded spectrometers compensators).

Fig. 41: MBXWTV and MBXWSH pre-cycle implemented in 2010.

Fig. 42: MBXWH pre-cycle implemented in 2010.
6. Pre-cycles for failures during operation

Here we give the prescriptions in different scenario that one can imagine during machine operation.

- **Beam lost on injection plateau**: No need of pre-cycle, since one usually injects in an asymptotic condition.
- **Power trip on injection plateau of a corrector**:
- **Power trip on injection plateau of a main circuit with decay**: A full pre-cycle is needed. One can reduce the flattop time to zero if one does not plan to have a ramp.
- **Power trip on injection plateau of a main circuit with negligible decay**: A full pre-cycle is needed.
- **Any power trip or beam loss during the ramp**: All magnets should be pre-cycled.
- **What to do after a successful trial ramp and successive flattop**: The magnets should be brought down to the minimum values of the currents, and then to back injection. If the magnets were brought down not to the minimal values, but straight to injection, they would be on the wrong side of the hysteresis branch, thus inducing large errors. If the flattop duration is smaller than 1000 s one has to expect a larger decay (up to 50%) in b3 of the dipoles.

7. Summary

The summary table containing the magnet types, circuit, and the type of pre-cycle is given below. For the magnets which belong to the optics, i.e. with given settings, we compare the minimum current of the pre-cycle with the minimum operational current at injection. The second value must be well above the first one to be sure to be on the ascending branch of the hysteresis at injection.

The following magnets have not been pre-cycled in 2009:

- MQTL in Q6 left and right of IR3 and IR7 (4 circuits)
- Spectrometer compensators: MBXWT, MBXWS, MBXW, MBWMD.

All pre-cycles should have a minimum current well below the injection current. This was not the case in 2009 for the following cases: MQXA, MQXB, MQWA, MBW. This has been corrected in 2010. Both settings are given in Table II.
Table I: main features of the pre-cycles implemented in 2010.

<table>
<thead>
<tr>
<th>Magnet</th>
<th>N. of circuits</th>
<th>Magnet</th>
<th>Decay</th>
<th>Flattop current</th>
<th>Flattop duration</th>
<th>N. cycles</th>
<th>Duration</th>
<th>Ramp rate</th>
<th>Ramp down</th>
<th>Cycle type</th>
</tr>
</thead>
<tbody>
<tr>
<td>MB</td>
<td>8</td>
<td>SC-Rutherford</td>
<td>Yes</td>
<td>6000</td>
<td>1000</td>
<td>1</td>
<td>2400</td>
<td>10</td>
<td>Linear</td>
<td>Up-down unipolar</td>
</tr>
<tr>
<td>MQY</td>
<td>40</td>
<td>SC-Rutherford</td>
<td>Yes</td>
<td>1800</td>
<td>1000</td>
<td>1</td>
<td>4500</td>
<td>10</td>
<td>Linear</td>
<td>Up-down unipolar</td>
</tr>
<tr>
<td>MQM 4.5 K</td>
<td>20</td>
<td>SC-Rutherford</td>
<td>Yes</td>
<td>2200</td>
<td>1000</td>
<td>1</td>
<td>2300</td>
<td>10</td>
<td>Exponential</td>
<td>Up-down unipolar</td>
</tr>
<tr>
<td>MQM 1.9 K</td>
<td>92</td>
<td>SC-Rutherford</td>
<td>Yes</td>
<td>2700</td>
<td>1000</td>
<td>1</td>
<td>2500</td>
<td>10</td>
<td>Exponential</td>
<td>Up-down unipolar</td>
</tr>
<tr>
<td>MBX</td>
<td>4</td>
<td>SC-Rutherford</td>
<td>Negligible</td>
<td>2700</td>
<td>300</td>
<td>1</td>
<td>1200</td>
<td>10</td>
<td>Exponential</td>
<td>Up-down unipolar</td>
</tr>
<tr>
<td>MBRC</td>
<td>8</td>
<td>SC-Rutherford</td>
<td>Negligible</td>
<td>3050</td>
<td>300</td>
<td>1</td>
<td>1500</td>
<td>10</td>
<td>Exponential</td>
<td>Up-down unipolar</td>
</tr>
<tr>
<td>MBRS</td>
<td>2</td>
<td>SC-Rutherford</td>
<td>Negligible</td>
<td>2850</td>
<td>300</td>
<td>1</td>
<td>1500</td>
<td>10</td>
<td>Exponential</td>
<td>Up-down unipolar</td>
</tr>
<tr>
<td>MBRB</td>
<td>2</td>
<td>SC-Rutherford</td>
<td>Negligible</td>
<td>3050</td>
<td>300</td>
<td>1</td>
<td>1500</td>
<td>10</td>
<td>Exponential</td>
<td>Up-down unipolar</td>
</tr>
<tr>
<td>MQ</td>
<td>16</td>
<td>SC-Rutherford</td>
<td>Negligible</td>
<td>6000</td>
<td>300</td>
<td>1</td>
<td>3200</td>
<td>10</td>
<td>Exponential</td>
<td>Up-down unipolar</td>
</tr>
<tr>
<td>MQXA</td>
<td>16</td>
<td>SC-Rutherford</td>
<td>Negligible</td>
<td>3500</td>
<td>1000</td>
<td>1</td>
<td>3200</td>
<td>4.0</td>
<td>Exponential</td>
<td>Up-down unipolar</td>
</tr>
<tr>
<td>MQXB</td>
<td>8</td>
<td>SC-Rutherford</td>
<td>Negligible</td>
<td>5500</td>
<td>300</td>
<td>1</td>
<td>3200</td>
<td>6.1</td>
<td>Exponential</td>
<td>Up-down unipolar</td>
</tr>
<tr>
<td>MCBH/V</td>
<td>752</td>
<td>SC-ribbon</td>
<td>No</td>
<td>±54</td>
<td>10</td>
<td>1</td>
<td>500</td>
<td>0.45</td>
<td>Linear</td>
<td>Up-down bipolar</td>
</tr>
<tr>
<td>MCBCH/V</td>
<td>156</td>
<td>SC-ribbon</td>
<td>No</td>
<td>±100</td>
<td>10</td>
<td>1</td>
<td>650</td>
<td>0.61</td>
<td>Linear</td>
<td>Up-down bipolar</td>
</tr>
<tr>
<td>MCBY</td>
<td>88</td>
<td>SC-ribbon</td>
<td>No</td>
<td>±72</td>
<td>10</td>
<td>1</td>
<td>760</td>
<td>0.38</td>
<td>Linear</td>
<td>Up-down bipolar</td>
</tr>
<tr>
<td>MQT</td>
<td>32</td>
<td>SC-ribbon</td>
<td>No</td>
<td>±400</td>
<td>10</td>
<td>1</td>
<td>2500</td>
<td>0.64</td>
<td>Linear</td>
<td>Up-down bipolar</td>
</tr>
<tr>
<td>MQL</td>
<td>136</td>
<td>SC-ribbon</td>
<td>No</td>
<td>±550</td>
<td>10</td>
<td>1</td>
<td>1500</td>
<td>1.46</td>
<td>Linear</td>
<td>Up-down bipolar</td>
</tr>
<tr>
<td>MQS</td>
<td>24</td>
<td>SC-ribbon</td>
<td>No</td>
<td>±500</td>
<td>10</td>
<td>1</td>
<td>2500</td>
<td>0.64</td>
<td>Linear</td>
<td>Up-down bipolar</td>
</tr>
<tr>
<td>MFS</td>
<td>64</td>
<td>SC-ribbon</td>
<td>No</td>
<td>±400</td>
<td>10</td>
<td>1</td>
<td>2500</td>
<td>0.64</td>
<td>Linear</td>
<td>Up-down bipolar</td>
</tr>
<tr>
<td>MSS</td>
<td>16</td>
<td>SC-ribbon</td>
<td>No</td>
<td>±400</td>
<td>10</td>
<td>1</td>
<td>2500</td>
<td>0.64</td>
<td>Linear</td>
<td>Up-down bipolar</td>
</tr>
<tr>
<td>MCS</td>
<td>16</td>
<td>SC-ribbon</td>
<td>No</td>
<td>±550</td>
<td>10</td>
<td>1</td>
<td>1500</td>
<td>1.46</td>
<td>Linear</td>
<td>Up-down bipolar</td>
</tr>
<tr>
<td>MCO</td>
<td>16</td>
<td>SC-ribbon</td>
<td>No</td>
<td>±550</td>
<td>10</td>
<td>1</td>
<td>500</td>
<td>4.4</td>
<td>Linear</td>
<td>Up-down bipolar</td>
</tr>
<tr>
<td>MCD</td>
<td>16</td>
<td>SC-ribbon</td>
<td>No</td>
<td>±550</td>
<td>10</td>
<td>1</td>
<td>500</td>
<td>5.0</td>
<td>Linear</td>
<td>Degaussing</td>
</tr>
<tr>
<td>MBX</td>
<td>24</td>
<td>SC-ribbon</td>
<td>No</td>
<td>±550</td>
<td>10</td>
<td>1</td>
<td>2200</td>
<td>0.64</td>
<td>Linear</td>
<td>Up-down bipolar</td>
</tr>
<tr>
<td>MCBXV</td>
<td>24</td>
<td>SC-ribbon</td>
<td>No</td>
<td>±550</td>
<td>10</td>
<td>1</td>
<td>2200</td>
<td>0.64</td>
<td>Linear</td>
<td>Up-down bipolar</td>
</tr>
<tr>
<td>MCSX</td>
<td>8</td>
<td>SC-ribbon</td>
<td>No</td>
<td>±550</td>
<td>10</td>
<td>1</td>
<td>2200</td>
<td>0.64</td>
<td>Linear</td>
<td>Up-down bipolar</td>
</tr>
<tr>
<td>MCTX</td>
<td>8</td>
<td>SC-ribbon</td>
<td>No</td>
<td>±550</td>
<td>10</td>
<td>1</td>
<td>2200</td>
<td>0.64</td>
<td>Linear</td>
<td>Up-down bipolar</td>
</tr>
<tr>
<td>MQSX</td>
<td>8</td>
<td>SC-ribbon</td>
<td>No</td>
<td>±550</td>
<td>10</td>
<td>1</td>
<td>2200</td>
<td>0.64</td>
<td>Linear</td>
<td>Up-down bipolar</td>
</tr>
<tr>
<td>MCSSX</td>
<td>8</td>
<td>SC-ribbon</td>
<td>No</td>
<td>±550</td>
<td>10</td>
<td>1</td>
<td>2200</td>
<td>0.64</td>
<td>Linear</td>
<td>Up-down bipolar</td>
</tr>
<tr>
<td>MCOX</td>
<td>8</td>
<td>SC-ribbon</td>
<td>No</td>
<td>±550</td>
<td>10</td>
<td>1</td>
<td>2200</td>
<td>0.64</td>
<td>Linear</td>
<td>Up-down bipolar</td>
</tr>
<tr>
<td>MBXW</td>
<td>2</td>
<td>Resistive</td>
<td>-</td>
<td>750</td>
<td>10</td>
<td>4</td>
<td>3000</td>
<td>2</td>
<td>Linear</td>
<td>Up-down unipolar</td>
</tr>
<tr>
<td>MBW</td>
<td>2</td>
<td>Resistive</td>
<td>-</td>
<td>720</td>
<td>10</td>
<td>4</td>
<td>2900</td>
<td>2</td>
<td>Linear</td>
<td>Up-down unipolar</td>
</tr>
<tr>
<td>MQWA</td>
<td>4</td>
<td>Resistive</td>
<td>-</td>
<td>710</td>
<td>10</td>
<td>4</td>
<td>2800</td>
<td>2</td>
<td>Linear</td>
<td>Up-down unipolar</td>
</tr>
<tr>
<td>MQWB</td>
<td>8</td>
<td>Resistive</td>
<td>-</td>
<td>±600</td>
<td>10</td>
<td>4</td>
<td>2000</td>
<td>4.8</td>
<td>Linear</td>
<td>Up-down bipolar</td>
</tr>
<tr>
<td>MCBWH/V</td>
<td>16</td>
<td>Resistive</td>
<td>-</td>
<td>±500</td>
<td>10</td>
<td>4</td>
<td>2100</td>
<td>3.8</td>
<td>Linear</td>
<td>Up-down bipolar</td>
</tr>
<tr>
<td>MBXWT</td>
<td>2</td>
<td>Resistive</td>
<td>-</td>
<td>600</td>
<td>10</td>
<td>4</td>
<td>500</td>
<td>8.0</td>
<td>Linear</td>
<td>Up-down unipolar</td>
</tr>
<tr>
<td>MBXWS</td>
<td>2</td>
<td>Resistive</td>
<td>-</td>
<td>780</td>
<td>10</td>
<td>4</td>
<td>780</td>
<td>4</td>
<td>Linear</td>
<td>Up-down unipolar</td>
</tr>
<tr>
<td>MBXWH</td>
<td>1</td>
<td>Resistive</td>
<td>-</td>
<td>750</td>
<td>10</td>
<td>4</td>
<td>750</td>
<td>4</td>
<td>Linear</td>
<td>Up-down unipolar</td>
</tr>
<tr>
<td>MBWMD</td>
<td>1</td>
<td>Resistive</td>
<td>-</td>
<td>550</td>
<td>10</td>
<td>4</td>
<td>550</td>
<td>4</td>
<td>Linear</td>
<td>Up-down unipolar</td>
</tr>
</tbody>
</table>

Table II: Minimum pre-cycle current versus injection current as implemented in 2010.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>MB</td>
<td>350/500</td>
<td>350/500</td>
<td>757</td>
</tr>
<tr>
<td>MQY</td>
<td>100</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>MQM 4.5 K</td>
<td>200</td>
<td>200</td>
<td></td>
</tr>
<tr>
<td>MQM 1.9 K</td>
<td>200</td>
<td>200</td>
<td></td>
</tr>
<tr>
<td>MBX</td>
<td>350</td>
<td>350</td>
<td>345</td>
</tr>
<tr>
<td>MBRC</td>
<td>200</td>
<td>200</td>
<td>284/385</td>
</tr>
<tr>
<td>MBRS</td>
<td>200</td>
<td>200</td>
<td>353</td>
</tr>
<tr>
<td>MBRB</td>
<td>200</td>
<td>200</td>
<td>395</td>
</tr>
<tr>
<td>MG</td>
<td>350</td>
<td>350</td>
<td>686</td>
</tr>
<tr>
<td>MQX</td>
<td>400</td>
<td>200</td>
<td>408/452</td>
</tr>
<tr>
<td>MQXB</td>
<td>700</td>
<td>350</td>
<td>700/776</td>
</tr>
<tr>
<td>MBXW</td>
<td>18.1</td>
<td>18.1</td>
<td>43.7</td>
</tr>
<tr>
<td>MBW</td>
<td>41.1</td>
<td>18.1</td>
<td>40.9</td>
</tr>
<tr>
<td>MQWA</td>
<td>35.1</td>
<td>20.1</td>
<td>35.3/38.0</td>
</tr>
</tbody>
</table>
References