ALBA SYNCHROTRON LIGHT SOURCE COMMISSIONING

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Abstract

ALBA is a 3rd generation Synchrotron Light Source build in Barcelona, Spain. It is a 3 GeV 3rd Generation Light Source with a circumference of roughly 270 m, an emittance of 4.4 nmrad and a design current of 400 mA. The storage ring has been optimized for a high photon flux density for the users. The 3 GeV booster synchrotron, with an emittance smaller than 10 nmrad is installed in the same tunnel. The pre injector is a 100 MeV Linac. The linac is operating since 2008, the booster since 2010 and the first commissioning phase for the storage ring has been finished in June 2011. Six insertion devices have been installed for the phase 1 beam lines. This paper gives an overview of the ALBA project with the emphasis on the results of the commissioning of the three accelerators Linac, booster synchrotron and storage ring.

INTRODUCTION

The first plans to get a 3rd Generation Synchrotron Light source in Spain, started in 1994, with the establishment of the design group 'Laboratori de Llum de Sincrotro' (LLS) for the preparation of a concept design report for a light source in Spain. The design project was finished in 1997 [1], and was approved in 2003 by the Spanish and Catalonia Government. The start up was in 2004 with the recruitment of the staff and a redesign of the machine. The main criteria's for the project are: a.) the energy should be 3 GeV, b.) the circumference has to be smaller as 270 m, c.) the booster should be in the same tunnel as the storage ring, d.) the pre accelerator should be a 100 MeV Linac, e.) the symmetry of the storage ring should be 4 fold with 4 long straight sections (8m) and 12 straights for insertion devices (4 m), f.) the lattice should be optimized for a high photon flux density. g.) the natural emittance should be smaller as 5 nmrad, h.) the nominal current should be larger as 250 mA., i.) topping up and single bunch operation should be possible.

The 100 MeV Linac was installed in 2008, the 3 GeV booster in 2009 and the storage ring in 2009 and 2010. Having the storage ring and the booster in the same tunnel had an influence upon the time schedule of 6 to 9 month.

THE PROJECT ALBA

Building

A picture of the ALBA - complex is given in Fig.1, with the main building housing the accelerator complex as well the experimental hall. Indicated in Fig. 1 are the locations of the warehouse, parking area, offices, workshop, electricity and cooling/HVAC. The size of the ALBA property is 250 * 450 m^2. The inner part of the building is an open (courtyard). Between the accelerator tunnel (with the storage ring and the booster) and the courtyard is the service area.

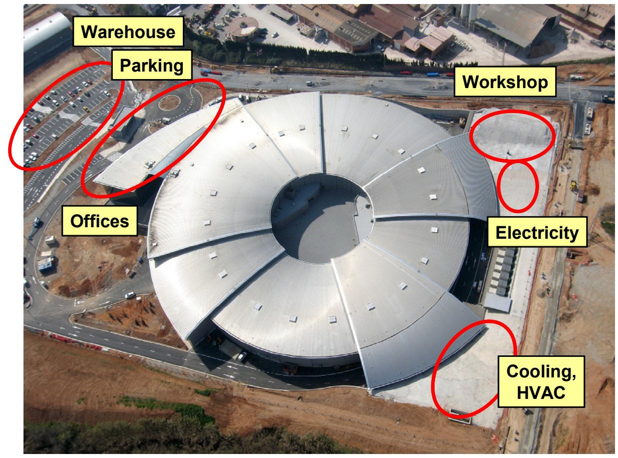

Figure 1: A picture of the ALBA-Building

All the equipment for the operation of the accelerator complex (RF-System, power supplies, racks for control system, etc.) is located in this area.

LINAC

An overview of the layout of the Linac is given in Fig.2. The thermionic gun delivers electrons with energy of 90 keV and a pulse length of roughly 1 nsec. The bunching systems consist of a 500 MHz and 3 GHz pre-buncher as well a 3 GHz buncher. The energy after the buncher is 16 MeV with a 3 GHz time structure.

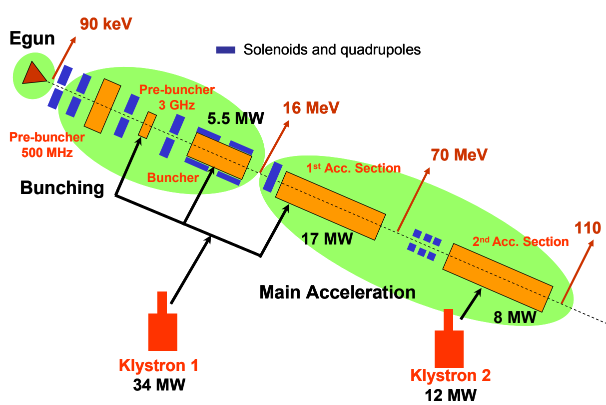

Figure 2: Layout of the 100 MeV Linac

Within the bunching system there are 5 solenoids for focussing the beam. The first accelerating structure (travelling wave, constant gradient) accelerates the beam up to energy of 70 MeV and the 2nd one to 110 MeV. The 110 MeV Linac was build by Thales. The acceptance test of the Linac took place in October 2008, with the results that all specifications were fulfilled and some exceed. More details of the Linac are described in [2].

Boster Synchrotron

The Booster-Synchrotron with a circumference of 249.6 m has fourfold symmetry, with 4 long straight sections of 2.46 m. Two of them are used for the injection and the RF-System. The layout of the lattice for one quadrant is given in Fig.3

The lattice consists of the matching cells at the beginning and end of the arc as well 8 unit cells between them. The bending magnet in the matching cells makes a deflection angle of 5 degrees and that one in the unit cells of 10 degrees; both magnets are defocusing ones and they have the same gradient. The tunes are mainly determined by the quadrupoles QH02 (Q_x) and by the gradient in the bendings (Q_y). The bending magnets and the quadrupole QH02 have an integrated sextupole component to compensate the natural chromaticity to (+1/+1). The characteristics of the booster are: emittance = 9.0 nmrad, tunes Q_x = 12.42 and Q_y = 7.38, chromaticities ξ_x = -17.0 and ξ_y = -9.6, momentum compaction factor α_p = 0.0036 and energy loss per turn U_0 = 625 keV. [2], [3]

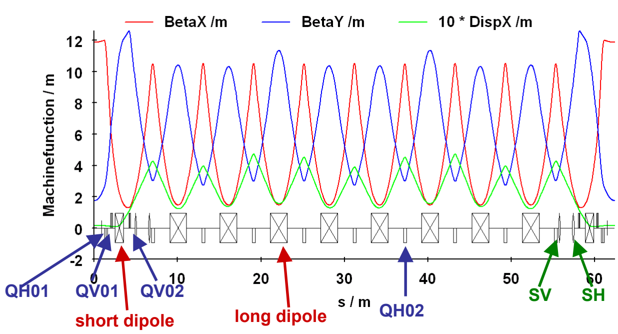

Figure 3: Lattice of the 4 fold symmetry ALBA - Booster Synchrotron

Storage Ring

The storage ring with a circumference of 268.8 m, has fourfold symmetry (as in the case of the booster synchrotron) with 4 long straight sections (8.0 m), 12 medium straights (4.2 m) and 8 short (2.6m). The lattice within one quadrant is given in Fig.4. The lattice consists of two matching sections and two unit cells. The design of the matching sections is given by the requirement of the injection system (high horizontal beta functions) and the one of the unit cells by the requirement of the users, in particular the need of high flux density and therefore low beta values and beam sizes at the medium straights, dedicated for insertion devices. The short straight section are mainly used for accelerator systems (3 for the RF and 1 for diagnostics and 2 for feedback systems). The storage ring has the following characteristics: emittance = 4.3 nmrad, tunes Q_x = 18.18 and Q_y = 8.37, the chromaticity's are: ξ_x = -40.0 and ξ_y = -25.6, momentum compactions factor $\alpha_1 = 8.8*10^{-4}$ with $\alpha_2 = 2*10^{-3}$,energy spread $\delta E/E = 1.05*10^{-3}$ and energy loss per turn (including insertion device) U_0 = 1.4 MeV. The details about the design of the storage ring and its components are given in [4] to [14].

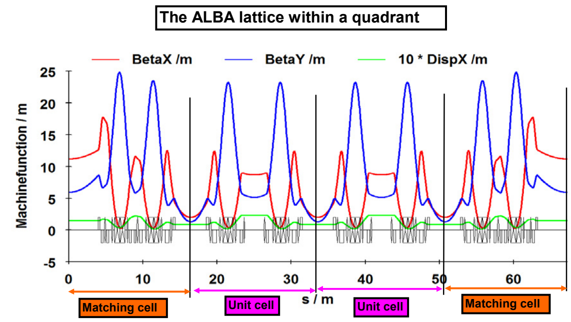

Figure 4: Lattice of one Quadrant of the ALBA Storage Ring

COMMISSIONING RESULTS

LINAC

The installation of the Linac took place during spring and summer 2008 and the commissioning was done in September and October 2008 together with the final acceptance test. All parameters are within specification; the emittance was a factor of 1.5 smaller as specified.

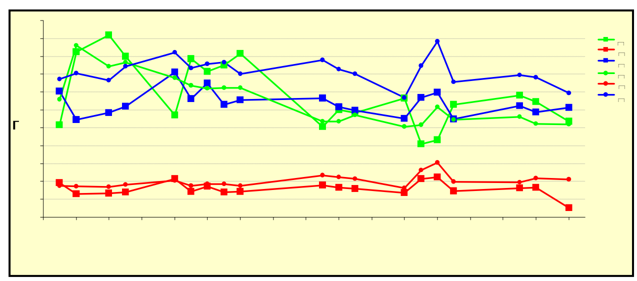

Figure 5: The measured machine functions over roughly one month from the 26th September to the 28th of October 2010.

According to the time schedule of the building we had to shut down the Linac for one year and started again in autumn 2009. In Fig.5 are given the data for the machine functions at the end of the Linac along September and October 2010.

In general, the Linac operation is very reliable for the different modes: long bunch, small bunch, single bunch, large (4 nC), and small charge (0.5 nC),

BOOSTER SYNCHROTRON

Commissioning of the Booster took place in 3 phases:

Phase 1: 10th to 24th of January 2010, with two shifts per day and working over the weekend. The goal was to check all the sub-systems, characterise the booster at injection energy and start the ramp to higher energies. On the 17th of January 2010, the first beam was stored at injection energy and on the 24th of January the beam was ramped up to 2.8 GeV. The first characterisation (tunes, chromaticity, closed orbit deviations, etc) of the booster has also been done during this phase.

Phase 2: July 2010, with two shifts per day and working over the weekend. However, due to problems with the Linac, the failing of booster power supplies and the injection elements, the commission was suspended with no further progress.

Phase 3: September - October 2010, with a single shift per day from 14:00 to 22:00, as due to storage ring installation the tunnel had to be open in the morning. This was a successful period and the following results are from this period.

A 3 GeV beam could be reached at the 4th of October, at the 28th of October the beam was extracted into the booster to storage ring transfer line. Since October 2010 the booster synchrotrons runs reliable. The behaviour is pretty well understood and it is ready, working as an injector for the storage ring, but some optimisation has still to be done. Some results are given in Fig. 6 and 7.

At the beginning of the ramp (few turns) there are some beam losses of 15 to 30%, but for the rest of the ramp, there aren't any beam losses (see Fig.6). The overall transmission from the Linac to the end of the BTS transfer line is 50 to 60 %. By using the correctors in DC mode, the closed orbit deviations in the ramp blow up to +/- 8 mm, this could be decreased to +/- 2 mm with the ramping of the correctors. The movement of the tunes during ramping is given in Fig.7. The variation of the tunes is minimized by the modification of the ramping curve of the quadrupoles; the bendings are ramped with a sinusoidal curve. The variation of the tunes are ΔQ_x = +/- 0.05 and ΔQ_x = +/- 0.03. The agreement with the model is pretty good, although there are some deviations at the beginning of the ramping.

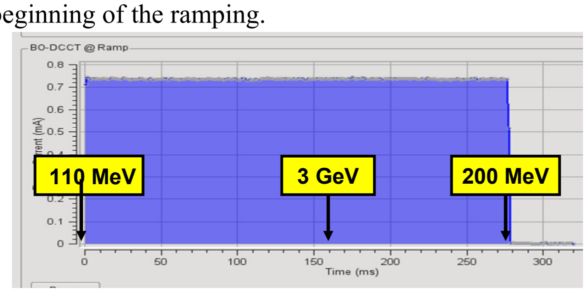

Figure 6: The accelerated beam from 110 MeV to 3 GeV and the de-accelerated beam from 3 GeV to 200 MeV.

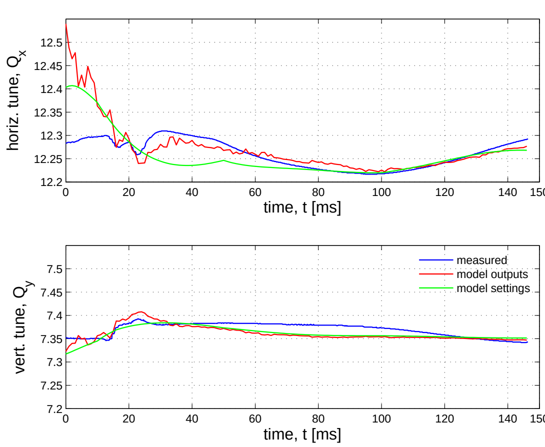

Figure 7: Movement of the working point during ramping. Outputs are the measured currents and models are the current set points.

Concerning the chromaticity, there isn't a good agreement between the measured and calculated values for energies up to 1 GeV. These deviations are not understood and they have to be investigated. The measured emittance according to the cross section of the beam in the BTS transfer line are ε_x = 13 nmrad and ε_y = 2.6 nmrad; which results in a coupling factor of 20% and a deviation from the nominal value of a factor 1.3

Storage Ring: Phase 1

The commissioning of the storage ring started at the 8th of March 2011 with a special slot for the injection into the storage ring, over the weekend at the 12/13 February. This weekend was not successful because of a miss-positioning of a quadrupole in the BTS-transfer line and some problems with the extraction kicker of the booster synchrotron. At the end the beam could be injected into the storage ring but passed only one bending magnet.

With the start of the real commissioning at the 8th of March it was realized that also at ALBA there was the typical "polarity failure", with all the quadrupoles having the wrong polarity. After fixing it, the beam immediately made one turn, with the on axis injection scheme and the sextupole off. The on-axis injection was done in order to make the energy adjustment of the storage ring to the booster synchrotron.

Normal injection was reached the same day with only 1 corrector in each plane. By switching on the RF-system and the optimization of the kickers and septum settings for the multi turn injection, the beam could be stored on the 13th of March over one second and already some characterisation of the storage ring could be done (measurements of the integer of the tunes, etc). The measurement of the dispersion function showed a large un-symmetry of the machine. With a further optimisation of the kicker settings (in particular the timing for closing the injection bump), as well the quadrupoles and bendings, on the 16th of March a beam 20 mA were accumulated. This was a historical day for project, showing that there is no "show stopper" for the correct operation of the storage ring.

Characterisation of the storage ring was done at 20 mA. With the measurement of the beta functions with the $\Delta Q/\Delta I$ method it was found a mis-cabling between the quadrupoles QF1 and QD1 in sector 8. By fixing this the symmetry in the dispersion function could more or less be restored. On the 30th of March, with the adjustment of the chromaticity a beam of 50 mA could be stored and at the 1st of April one of 100 mA.

Over the eastern period from the 15th of April to the 9th of May there was a shutdown. With a further optimisation of the closed orbit, optimisation of the BPM readings, fixation of the RF-frequency, etc, a beam of 170 mA could be stored at the 7th of June (see Fig. 11), with an injection efficiency of roughly 95 % (see Fig.8). Phase 1 of the storage ring commissioning finished the 10th of June.

At the beginning of the commissioning period the tunes were: Q_x = 18.1 and Q_y = 8.2. During the commissioning period, tunes changes by ±0.1 in both planes were observed day by day. After the results of the "Beam – Base –Alignment", fixation of the RF-Frequency, closed orbit correction and cycling procedure for the magnets, final tunes are Q_x = 18.22 and Q_y = 8.37 were fixed, only ΔQ_x = 0.03 and ΔQ_y = 0.04 away from the design ones.

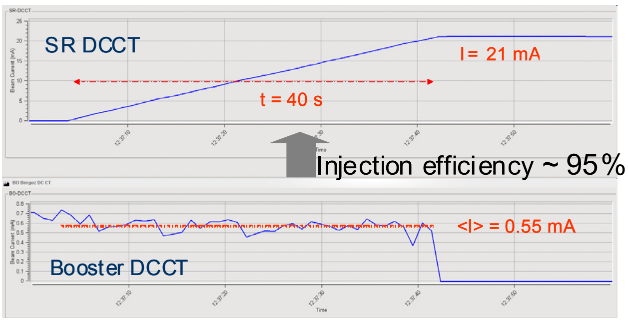

Figure 8: Measurement of the injection efficiency.

With the final settings of all components and without using any corrector the closed orbit deviations are Δx = < 3 mm and Δy = < 2 mm, showing a very good alignment of the machine, consistent with positions of all magnets in the range of +/- 30 μm. The closed orbit correction system was able to reduce this deviation down to values under 200 μm peak to peak. With the settings of the 11 sextupole families to the nominal chromaticity of 1 in both planes, the measured chromaticity's are ξ_x=2.1 and ξ_y=0.4, close to the nominal one. The "Beam-Based-Alignment" procedure has been done during the commission period 4 times, with the result that deviations of up to +/- 1.5 mm could be observed in a few BPMs in both planes. These deviations have to be investigated. LOCO measurements and corresponding corrections have been routinely performed (see Fig.9 and 10). The beta beating to the model is less than 0.01 m/rad in both directions, fore the optimal settings of the magnets. The horizontal dispersion also shows an excellent agreement to the model, with deviations smaller than 3 mm. The vertical dispersion is smaller than 1 mm (see Fig.10). The beam size measurements from the middle of the bending magnet (σ_x=71 μm, σ_y= 31 μm) results an emittance of ε_x= 5.5 nmrad and ε_y= 0.03 nmrad, corresponding to a coupling of 0.7%. Taking into account the tolerances of this measurement, it means also a good agreement with the model. The coupling also agrees with the measured vertical dispersion and preliminary results from lifetime data analysis.

Most of the commissioning was done with 3 to 4 cavities, because there were vacuum leaks problems with the pick up loop in the cavities. This results in an overvoltage factor of 1.3 or an overall cavity voltage of 1.35 MV. The maximum currents with these data's are around 200 mA. With these settings a bunch length σ(s) = 31 ps has been measured with the Streak camera. This is exact the theoretical value.

As the RF conditions were not optimum and vacuum improving day to day (see Fig.13) it is difficult to provide a clear analysis of the measured lifetime. A few hours of lifetime (up to 5) at 100 mA have been reached.

The influence of the multipole wiggler as well as the two elliptical undulators have been investigated and the measured tune shifts do agree very well with the theoretical results. The radiation from these insertion devices passed through the front ends and went into the optical hutches of the beam lines (see Fig.12).

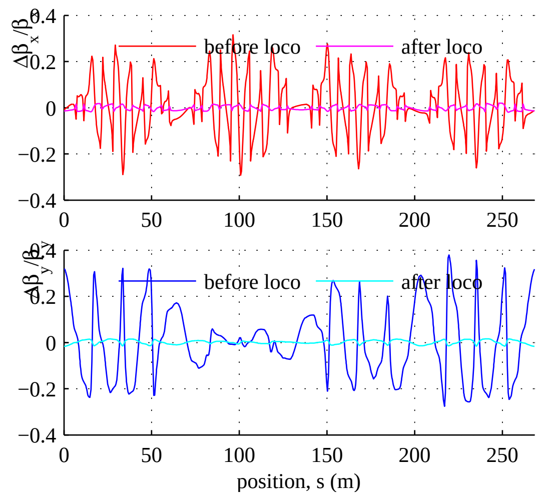

Figure 9: Differences between measurements of the beta function with LOCO and the model. The maximum differences of Δβ/β are 2 %.

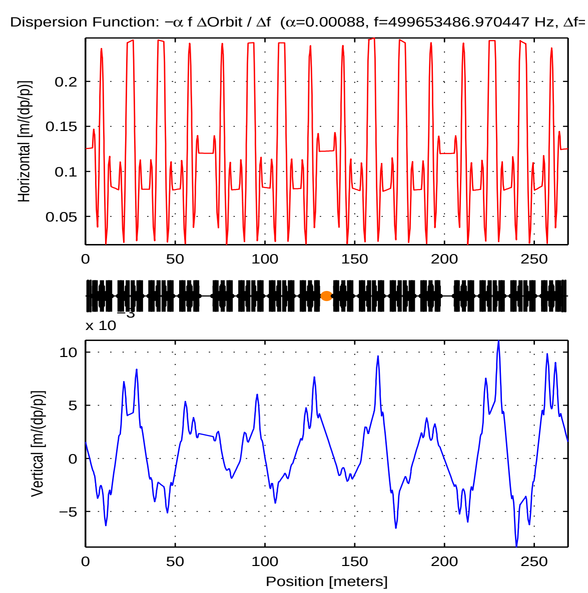

Figure 10: Measurements of the horizontal and vertical dispersion function. The deviations in the horizontal directions are: long straight 0.003 m, medium straight 0.002 m, short straight 0.002 m.

Commissioning of the Slow Orbit Feedback System has started, with the system running for some hours at a time. The present configuration is running using the Matlab MiddleLayer package, at a frequency of 0.5 Hz. It can compensate the changes in the orbit created by the (uncompensated) multipole wiggler, and keeps the beam stable at the level of the noise of the BPMs.

Average pressure before injecting the first beam was 4.10^{-10} mbar. With the first stored beam in the machine (beam current = 0.1 mA), the average pressure increased to 2.10^{-8} mbar. With accumulated beam dose of 4.5 A.h, 80 mA stored beam current, the average pressure of the SR is 3.10-9 mbar, which is very good. Fig. 13 shows the normalised average pressure to the beam current (mbar/mA) vs. accumulated beam dose (A.h.).

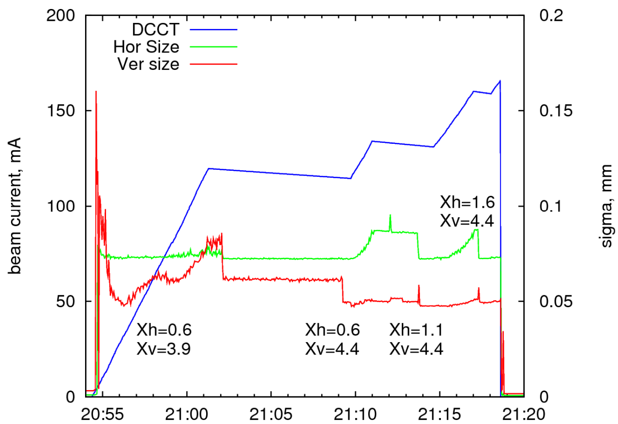

Figure 11: Beam current and cross section of the beam by accumulating 170 mA. The blowing up of the beam could be compensating by increasing the chromaticity. Xh and Xv are the chromaticities in the horizontal and vertical directions.

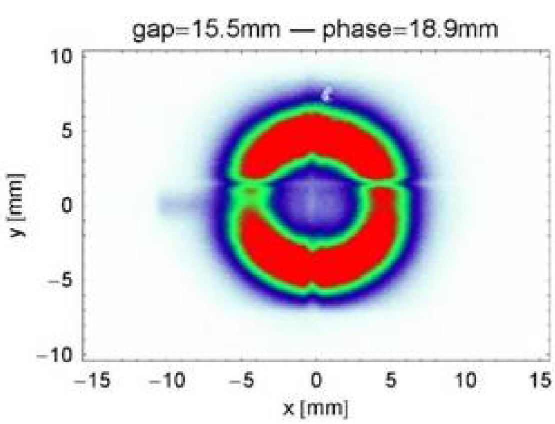

Figure 12: Light from an Apple II Undulator

NEXT STEPS

In the summer shutdown from July to September, the super conducting wiggler and the two in-vacuum undulators have been installed and the 2nd phase of commissioning will start in October this year. From November 2011 it is planned to start the commissioning of the phase 1 beam-lines. The operation with users should start in spring 2012.

Concerning improvements to the accelerator, the next main objectives are: implementation of the filling pattern control, commissioning of the orbit feedback (slow and afterwards fast), commissioning of the transverse bunch-by-bunch feedback and better control of the coupling.

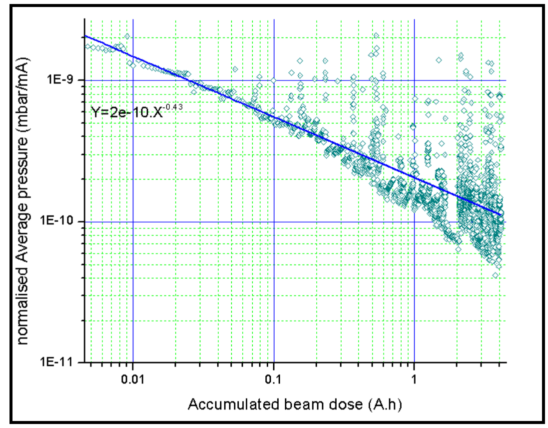

Figure 13: average pressure normalised to the beam current (mbar/mA) vs. accumulated beam dose (A.h).

ACKNOWLEDGMENTS

It is a pleasure to acknowledge the continued support received from the ALBA staff during the detailed design, construction and commissioning phases.

CELLS also want to thank our colleagues from other laboratories, and in special the members of our Machine Advisory Committee, for all the help provided.

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