# THE DANISH SYNCHROTRON RADIATION LIGHT SOURCE ASTRID2

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*Abstract*

The ASTRID2 synchrotron light source has now been in user operation for more than 3 years, and most of the initially unresolved minor issues have been dealt with. This paper will report on the solutions and give an overview of the current status. The problem of the fast injection bumpers, which overheated at high currents, has been solved. The 3rd harmonic Landau cavity has been installed and it has resulted in a much better lifetime and a more stable beam. We observe vertically unstable beams above a given threshold beam current. Initially this threshold was quite low, but with time, as the vacuum chambers have been conditioned more and more, the threshold has increased steadily, and is now close to the design current of 200 mA.

It is planned to add 3 more power supplies to each of the pole-face windings, which are found in all 12 dipoles. These three supplies will, in addition to the original quadrupole correctors, give a vertical corrector, a horizontal corrector and a skew quadrupole corrector. Furthermore, we are presently producing a new timing system, which will allow us to run single-bunch operation and a fast orbit feedback system.

## INTRODUCTION

The new Danish light source ASTRID2 [1-4], which replaced the more than 20 years old ASTRID light source, [5] has now been in regular user operation for more than 3 years. ASTRID2 operates in top-up mode at a beam energy of 580 MeV, using ASTRID as a full-energy injector. Figure 1 shows an overview of the laboratory. The ASTRID2 lattice is a 6-fold symmetric DBA with combined-function main dipole magnets. The circumference is 45.7 m. For further lattice details see [1-2].

The ring currently serves seven beam lines and an eighth (AU-SGM4), which will share the light from the old ASTRID undulator with AU-SGM3/ARPES, is under construction. Presently the user-mode beam current is 180 mA, limited by an increase in vertical beam size (see below).

## OPERATIONAL STATUS

In normal user mode, ASTRID2 operates autonomously 24/7 in top-up mode. In case of injection failures, top-up is disabled and operators are alerted by SMS. For known failures, software routines will try an automatic recovery. The failure rate is low, with complete beam loss in ASTRID2 only happening once every month or less, and injection failures happening less than once a week. Usually, user beam periods are 4 weeks, followed by one week of machine physics and development.

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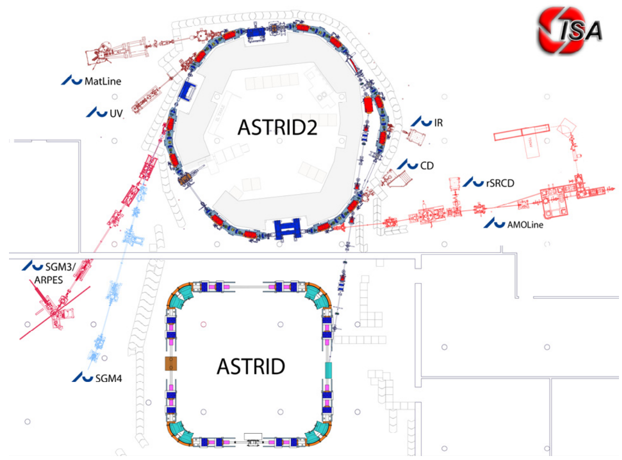


Figure 1: Overview of the ASTRID2 laboratory.

### Bumper Modifications

It has earlier been reported [3-4] that the original ASTRID2 injection bumpers prevented top-up operation at the design current for extended periods of time, due to heating of the in-vacuum ferrites above their Curie temperature. The modification suggested in [4] with titanium-coated ceramic shells inside the ferrites has been effective, since the ring now can run top-up at a beam current of 250 mA indefinitely. The limit of 250 mA, which is well above the design current of 200 mA, is not set by the bumpers, but by concerns for heating other parts of the vacuum chambers.

### 3rd Harmonic Landau Cavity

A 3rd harmonic Landau cavity was installed in March 2015, and has resulted in roughly a doubling of the beam lifetime. Furthermore, it has resulted in a more stable beam at frequencies up to the synchrotron frequency. ASTRID2 is plagued with strong longitudinal coupled bunch instabilities and before the Landau cavity was installed mode #9 was dominating, resulting in a strong horizontal quadrupole motion at the synchrotron frequency in dispersive sections as observed on a synchrotron light monitor. With the Landau cavity the coupled-bunch instability is damped somewhat and the mode spectrum is changed. In a small range of cavity detuning the dominant mode is #15 and the beam movement at the synchrotron frequency and its harmonics is strongly reduced. The beam is therefore more stable for the users, who do not see high frequency variations. However, the high frequency oscillations lead to an apparent emittance increase (in the dispersive sections).




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### *Skew Quadrupole for Lifetime Improvement*

Since the users of ASTRID2 do not need a very small vertical emittance, a single skew quadrupole in an available straight section is used to increase the coupling. The vertical beam size is increased by ~20%, resulting in a beam lifetime increase of roughly 60% to become a little less than 2 h at a beam current of 180 mA. The inherent coupling is a few percent. Reversing the sign of the skew quadrupole field reduces the observed beam size and beam lifetime.

The design of the skew quadrupole is inspired by the Pole-Face Windings used in the main bends (see below), and is made with 4x5 wires arranged on the sides of the circular vacuum chamber at angles of ±45°. The gradient is 7.1 mT/m/A with a maximum current of 15 A and the length is 0.55 m. See Fig. 2 for a plot of the calculated field distribution.

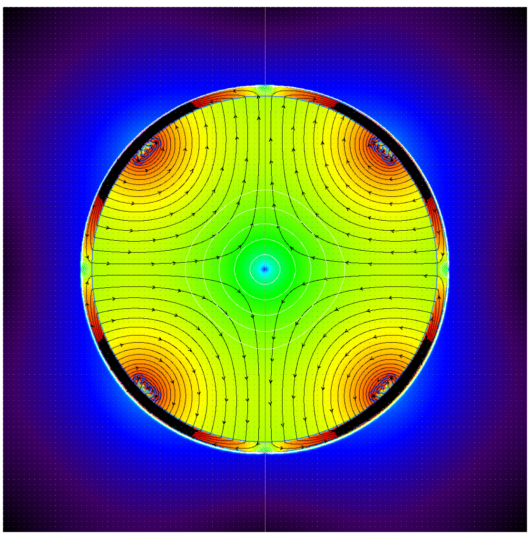

Figure 2: Field distribution for the home-made skew quadrupole.

### *Vertical Emittance Blow-up*

In the early part of commissioning of ASTRID2, we saw a strong instability in the vertical emittance already at low beam currents. When crossing a certain beam current threshold the vertical beam size would start to grow. At a second threshold, the vertical beam size would become unstable, and jump between a small beam size and a very large beam size. The collapse of beam size was exponential with a decay time of roughly the transverse damping time. Operation with a gap of ~5 bunches (~30% empty buckets) increased the thresholds somewhat.

With time the ring has been conditioned more and more and these thresholds have steadily increased. Today we can run top-up at 180 mA beam current (with uniform bunch filling) without any increase in vertical beam size, but at around 200 mA the vertical beam size begins to increase. Today the threshold for the very unstable vertical beam is well above 250 mA. Figure 3 shows the beam current threshold for vertical beam size growth, together with the nominal user beam current as function of time. As can be seen from the figure, over the last ~3 years we have been operating quite close to the threshold. We believe the reason for the increase in vertical beam size is capture of ions generated from the residual gas.

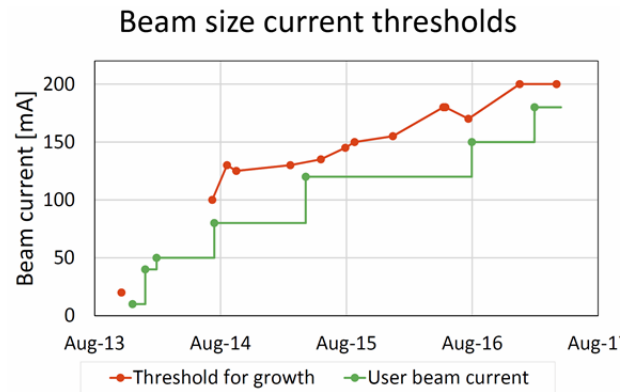


Figure 3: Beam current threshold for vertical beam size growth together with user beam current as function of time.

## PLANNED IMPROVEMENTS

### *New Timing System*

A new timing system is presently undergoing last final changes and should soon be ready for installation. The system is based on a National Instruments CompactRIO platform. The clock for the cRIO is locked to the RF frequency of 105 MHz, and the system contains counters to keep track of (single) bunch revolutions in both ASTRID (booster) and ASTRID2. With triggers synchronous with the counters, a single bunch can be prepared in ASTRID and transferred to a specific bunch in ASTRID2. This allows single-bunch operation of ASTRID2, a feature requested by the users. The resolution in trigger delays and widths are ~1 ns.

### *New Fast Orbit Feed-Back System*

Another upgrade soon to be ready is a fast orbit feedback system (FOFB). The system will use the original window frame ±3 mrad horizontal and vertical corrector magnets, which have been verified to have a bandwidth in excess of 1 kHz. The original ±15 A slow power supplies have been upgraded with a fast analogue input, with a current range of ±0.5 A for ±10 V input. The combined system of power supply and magnet has been verified to have a bandwidth in excess of 1 kHz. Beam positions are generated at a rate of 10 kHz from our 24 *Libera Electrons*, and through a dedicated Ethernet segment are acquired by a LabVIEW real-time program running on a standard PC. Orbit correction values can be calculated by the LabVIEW program and fed to the power supplies at a rate of up to 10 kHz. All hardware has been produced and tested. Only the software to close the loop is missing, and is expected to be finished during the coming summer.

The FOFB is expected, among other things, to fully cure the problem with the stray magnetic field from

ASTRID [4], which was not solved by the iron plates on the wall between ASTRID and ASTRID2. The FOFB system is also expected to eliminate the orbit disturbance of up to ~5 µm seen from the cars on the parking lot, which is above the basement housing the ASTRID2 ring.

### *More Power Supplies for Pole-Face Windings*

ASTRID2 has from the start been equipped with Pole-Face Windings (PFWs) in all main bends [2], which are used to compensate the (vertical) tune and beta changes caused by insertion device gap changes [4]. With the same current in all (central) windings, a pure quadrupole field centred in the mid plane is generated. The central 7 wires carry the current generating the desired field, whereas the outer 3+4 wires carry the return current. Having different currents (individual power supplies) in the four quadrants (A-D) allows any combination of regular and skew quadrupoles and vertical and horizontal dipoles to be created. Small dipole components can also be seen as shifts in the quadrupole centre.

Figure 4 shows the resulting field for a current of ±4.2 A in the right windings (A and D) and ±5.5 A in the left windings (B and C). These currents generate a pure skew quadrupole in the centre of the PFW. Having equal (magnitude) currents in all quadrants would generate a skew quadrupole with a centre shifted to the left. The reason the wire positions are at an angle is to follow the poles of the combined-function dipole magnet. Computer software will be used to calculate individual currents based on the requested field components.

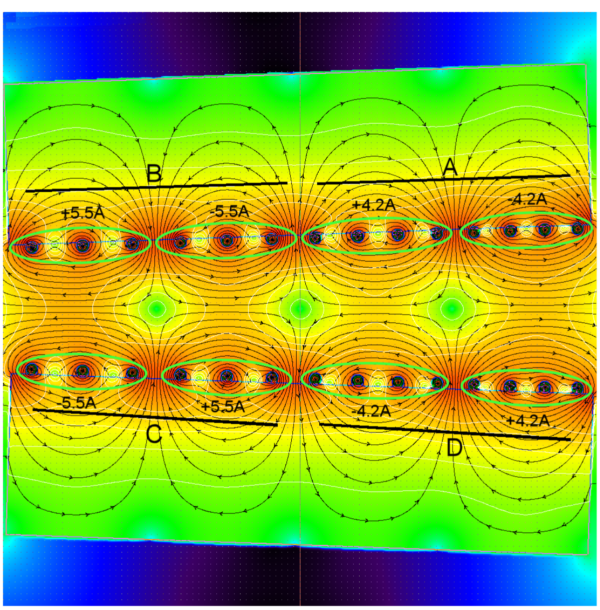


Figure 4: Layout of PFW and resulting field for the indicated currents. The currents have been chosen to generate a pure skew quadrupole in the centre of the PFW.

The vertical dipoles will be used to compensate for vertical misplacements which we have in the combined function dipole magnets. The ability to move the centre of the quadrupoles will be used to compensate for inaccuracies in the positioning of the PFW foils. Presently, we observe movements of beam when changing the PFW (quadrupole) strength.

As a future project we are contemplating to use the skew quadrupole components in the PFW's to vary the coupling around the ring, to increase the beam size at positions around the ring, where no beam line is using the light, and in this way improve beam lifetime [6].

Our electronics workshop are presently manufacturing the necessary additional 36 power supplies to allow individual currents in the four quadrants, and we expect installation during the autumn.

## UNRESOLVED ISSUES

### *Strong LCBI*

As mentioned in the section about the 3rd harmonic Landau cavity, ASTRID2 suffers from strong longitudinal coupled bunch instability (LCBI). The threshold for the LCBI is only a few mA, and even though the Landau cavity is providing some damping, the threshold is still very low. The reasons for the strong LCBI are not understood, but an obvious candidate is non-smooth vacuum chambers. Temperature tuning of the RF cavity has been performed, but does not change the LCBI spectra much. This excludes cavity higher order modes as a major source for the LCBI. A longitudinal bunch-by-bunch feedback system is being considered, but would be a major project for us.

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