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# THE MAX-LAB STORY; FROM MICROTRON TO MAX IV

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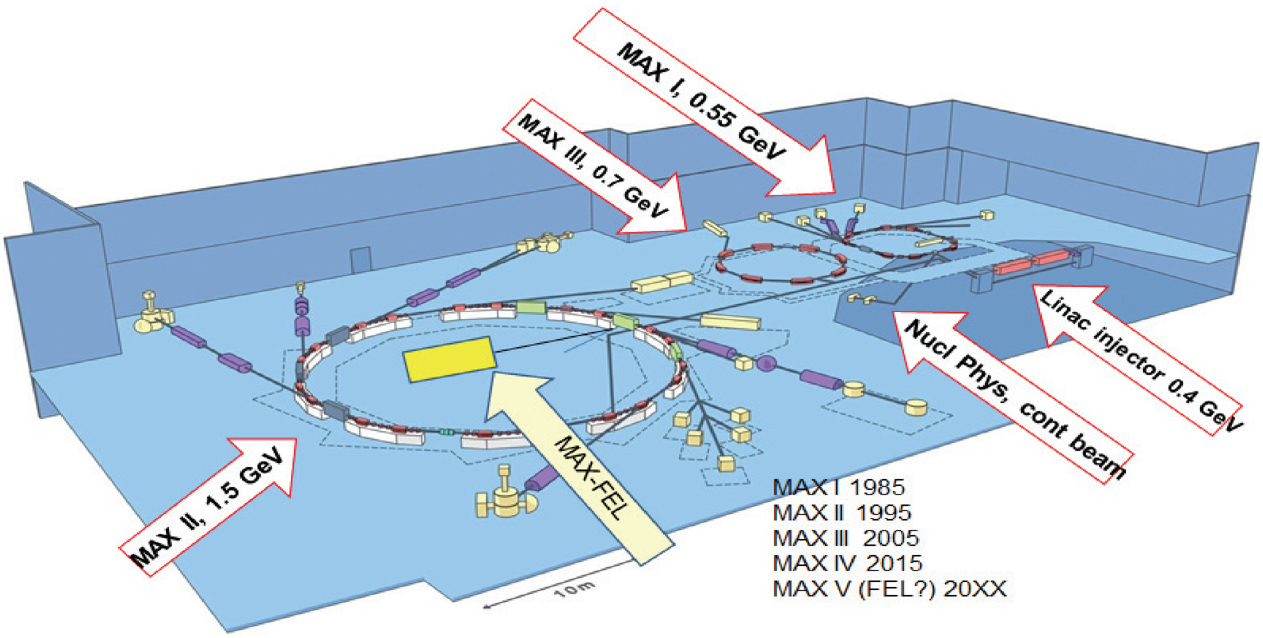


Figure 1: The MAX-lab facility.


*Abstract*

The MAX story started with the design and construction of a small Race-Track Microtron 1973-1979. This microtron was later followed by the synchrotron radiation storage rings MAX I, MAX II, MAX III and the MAX IV facility, the latter consisting of two storage rings operated at 1.5 and 3 Gev respectively and also including a full energy injector linac.

It was quite clear from the very beginning that conventional accelerator technology not was matching the boundary conditions in terms of the staff size and limited economical resources at MAX. We had to find new technical solutions based on mass-produced industrial components and an extensive usage of CNC machining to match the turbulent development of synchrotron radiation sources.

This article describes some of the most important features of the accelerators developed at MAX-lab and covers also the design philosophy behind the early ideas for designing a close to Diffraction Limited Storage Ring.


Finally, the author and MAX staff wants to thank the prize committee for the prestigious Wideröe prize and thank all our international colleagues world-wide.

## THE MAX I FACILITY

The 1.2 GeV synchrotron LUSY, one of the first strong-focusing synchrotrons and aimed for research in nuclear and particle physics was closed 1972. The national funding of the laboratory seized but to preserve some of the accelerator activity in Lund, the university and faculty of science supported the construction of a smaller machine meant for nuclear physics research [1].

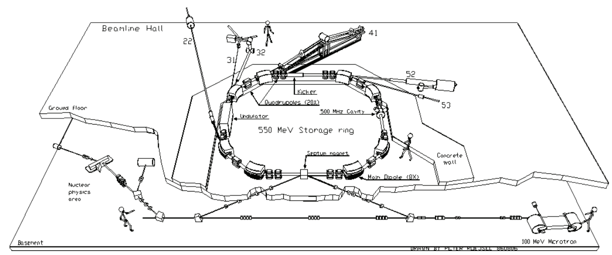

Figure 2: The MAX I accelerator. (Graphics from 1985).

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The goal was then to construct a 100 MeV Race-Track Microtron and a 100 MeV pulse-stretcher ring to deliver a continuous electron beam for research in the giant resonance energy region.

At this time, a 50 MeV Race-Track Microtron was under construction at the Royal Institute of Technology (RIT) in Stockholm. A cooperation between MAX- RIT was inevitable, especially since the professor at RIT, Olle Wernholm, was the constructor of the LUSY synchrotron.

The MAX facility was never financed in an orderly way, consultant work for accelerator industry and smaller bits and pieces from different funders finally made way for the microtron, which finally accelerated electron in 1979.

This microtron was later reproduced in some 10-20 copies (with some modifications) for cancer therapy, material research and injectors at a few synchrotron radiation laboratories.

The construction of the MAX I ring (originally called the MAX ring) started after the completion of the microtron when the facility (staff some 7 persons) moved to a new hall from the Institute of Physics.

The MAX I ring was, as the microtron, completely home-built. The major power supplies consisted of welding machines donated by a ship-yard, the laminated magnets were glued together using a wringler. (It never could be used for its original task afterwards.)

During the early construction, the idea of utilizing synchrotron radiation capability popped up, so the ring energy was raised to 550 MeV, implying low energy injection from the microtron.

To everyone's surprise, including our own, the MAX ring went into operation in 1986. Although the accelerators were far from world-leading, a vivid experimental programme started up immediately pushed by a strong scientific community.

A ring-based Free Electron Laser (FEL) utilizing harmonic generation started up 1988 and a small-gap undulator with squeezable vacuum chamber was installed as early as 1992.

## THE MAX II STORAGE RING

Already at the start-up of the MAX I ring, it was quite clear, that this dual purpose ring (pulse-stretcher and synchrotron radiation source) not could be regarded as a long-lasting solution. A third generation light source operated at 1.5 GeV was the natural candidate for the continuation of the facility.

Backed up by a growing user society, a MAX II application was sent in to the Swedish Research Council a few years after the MAX I completion. The application was well taken, but the Research Council funding was simply not sufficient for a conventionally constructed third generation light source. Thus, the following (at that time) novelties were introduced to lower the construction and installation cost:

- One common big steel girder for a full achromat was introduced. Each of the 9 magnets in each achromat was rigidly positioned on discs (3 per magnet). These discs were first welded on the girders and then precisely machined to the proper dimensions. After commissioning, the magnet centres were measured with the electron beam and the RMS deviation of the magnet centres turned out to be 0.025 mm, which was quite sufficient.
- The sextupole magnets necessary for chromaticity correction were integrated into the quadrupole magnets. Some fine-tuning of the sextupole strengths could be done with back-leg windings on the magnets.
- As an injector, the MAX I storage ring should be used operating in a booster synchrotron mode. The injection energy should then be 500 MeV and the injection rep rate was 1 shot/minute.

With the measures described above, a relatively compact strorage ring could be designed [2] matching the economical and staff size conditions. The MAX II application was approved 1989 and the first electrons were stored 1995.

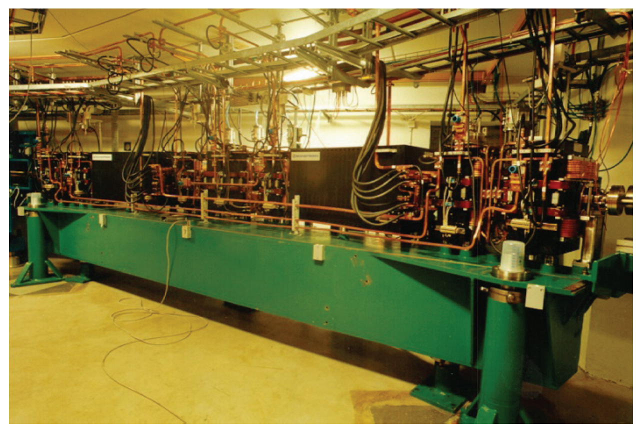

Figure 3: A MAX II achromat.

The early operation was however hampered by coupled bunch instabilities and a pretty short beam life-time. We then started to look for a way to elongate the electron bunches in the ring to increase the Touschek life-time and also to introduce more Landau-damping. At that time, harmonic bunch-lengthening cavities were suspected to introduce Robinson instabilities, but it was found that this instability could be counteracted by a proper parameter choice. The 3$^{rd}$ harmonic cavities introduced in the MAX II ring improved the operation considerably.

The electron energy of the MAX II storage ring was a bit low for hard X-ray production. To mitigate this, 2 super-conducting multi-pole wigglers were built which opened up this photon spectral region.

With the introduction of these wigglers, the RF power of our 75 kW 500 MHz klystron was not sufficient. We also needed to increase the bucket height to further increase the Touschek life-time. To overcome these issues, a shift to lower RF frequencies was inevitable since FM transmitters are commercially available and offered a cheaper way to reach these goals.

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The introduction of the 100 MHz RF system was far from problem-free but once carried out, we were quite rewarded in terms of an increased beam life-time and sufficient RF power.

## THE MAX INJECTOR

After some 25 years of service, the Race-Track injector microtron showed clear signs of aging. Moreover, the multiple tasks of the MAX I ring as pulse stretcher, light source and injector, implied a complex scheduling. Injection into the MAX II ring was also hampered by the low rep rate of the MAX I ring operated in the booster mode.

The new MAX injector [3] was then constructed. Neither funding nor space available allowed a conventional 500 MeV linac solution. A recirculated SLEDed linac was thus constructed. The compact $180^0$ bend isochronous (to second order) achromats ($2*1\ m^2$) were designed as solid iron blocks where all magnets were machined out. The commissioning was exciting, to say the least. There were few knobs to be turned since all magnet properties were fixed in the form of precisely machined magnet surfaces. After fixing the usual trivial problems (magnet miss-wiring, cooling problems etc), commissioning was however due in a few days.

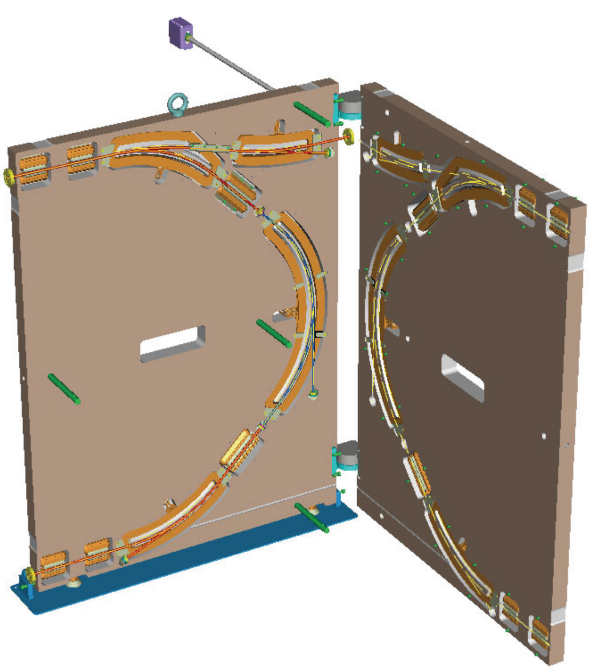

Figure 4: A MAX-injector isochronous achromat.

## THE MAX III STORAGE RING

It became clear at the beginning of 2000 that the MAX II ring started getting overloaded with beamlines and the MAX I ring needed a replacement.

The solution was the design of a 700 MeV new ring, the MAX III ring. This could be fed from the MAX injector and squeezed in between MAX I and MAX II.

At this time, the first plans of a MAX IV facility had emerged, but a project of this size needed proto-typing, especially for the magnet technology.

The integrated magnet solid steel block concept, which could solve many of the production and installation issues, was thus introduced in the MAX III ring. (The same concept as used for the MAX injector.)

The same RF concept as used in MAX is used in the MAX III ring; 100 MHz RF + Harmonic Cavities).

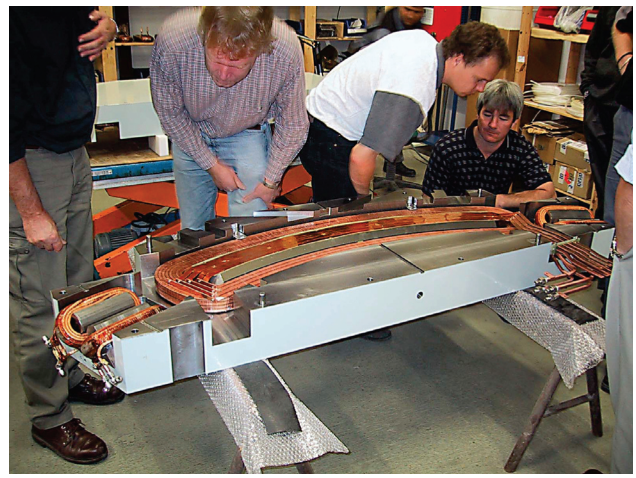

Figure 5: Half of a MAX III magnet block.

## THE MAX IV FACILTY

Armed with the experience and proto-typing of the existing MAX accelerators, a conceptual MAX IV design report was released in 2008.

The MAX IV facility (under construction) consists of two storage rings operated at 1.5 and 3 GeV respectively. As injector, a full energy linac will be used [5].

This concept allows us to cover a broad spectral range of high-quality synchrotron radiation from optimized Insertion Devices (ID). The linac injector will also feed a Short Pulse Facility (SPF) with short, high-current electron bunches for X-ray production. It is also designed to allow for a Free Electron Laser (FEL) extension.

The leading idea for the 3 GeV ring is to construct a very small emittance light source. A very powerful parameter defining the ring emittance is the number of lattice cells, the horizontal emittance is inversely proportional to the number of cells cubed. The MAX IV 3 GeV ring utilizes the Multi-Bend Achromat (MBA) lattice for this purpose.

Miniaturisation of the magnet elements, a mechanically rigid system and an easy way to install the magnets are important factors to reduce the cost of a small emittance ring. The integrated magnet block concept, developed earlier at the MAX injector and the MAX III ring, fits very well in this scheme. Paired with a fully Non Evaporable Getter (NEG) coated vacuum system, a

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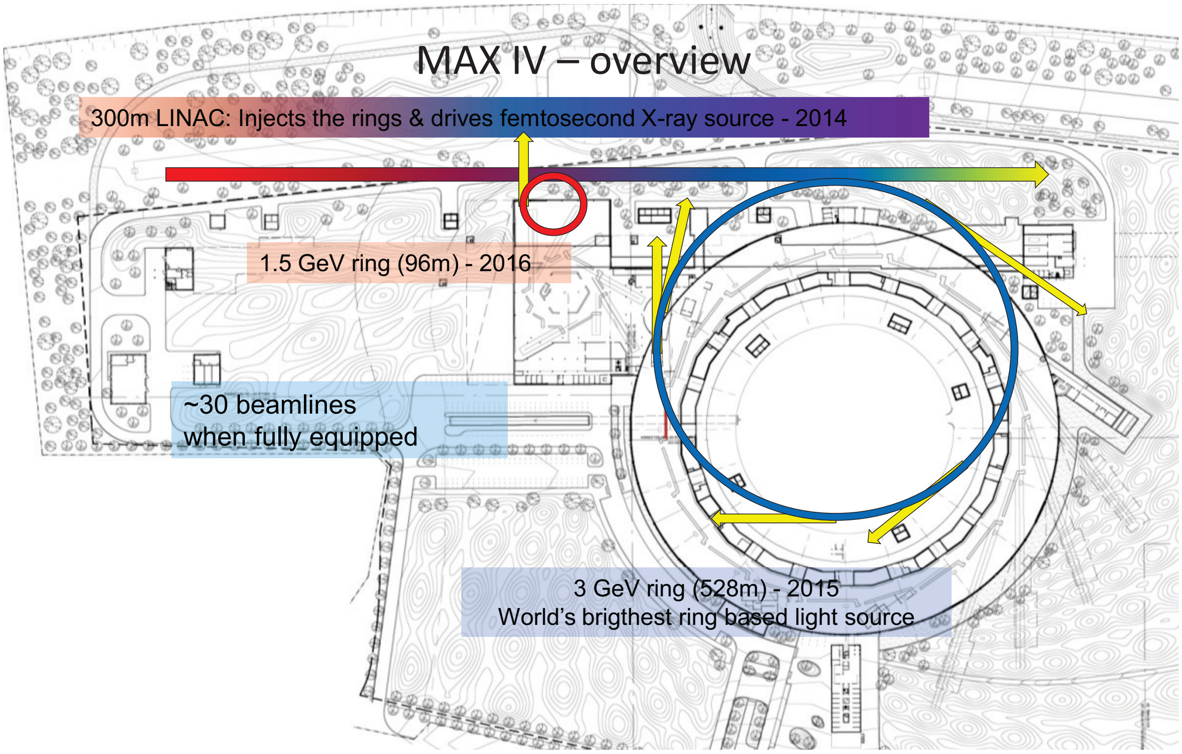


Figure 6: The MAX IV facility.

complete concept for the 3 GeV ring was designed.

To mitigate the Intra-Beam Scattering, coupled bunch and resistive wall effects and also to increase the Touschek life-time, a 100 MHz + HC RF system will be used in the MAX IV rings.

The 1.5 GeV ring is built in two copies. One will stay in Lund, the other will be the light source at Solaris in Krakow.

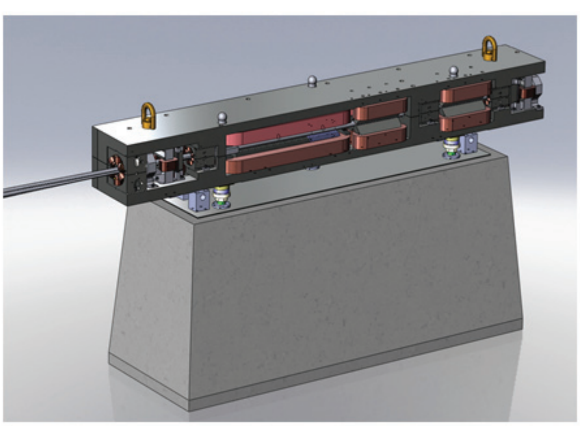

Figure 7: A MAX IV 3 GeV magnet block.

The MAX IV project is scheduled to go into operation in 2016. We can now see how several light-sources plan for construction or upgrading using the MBA concept. Since the emittances of these sources will be a factor 10-100 smaller than the earlier, we can look forward to new exciting science applications.

## ACKNOWLEDGMENT

The MAX accelerators have been designed, constructed, installed and commissioned by a skilful and dedicated staff in tight cooperation with industry. Hat off for all of them!

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