THE DELTA VACUUM SYSTEM

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ABSTRACT

DELTA, the **D**ortmund **EL**ectron **T**est **A**ccelerator, is a 3^{rd}-generation 1.5 GeV synchrotron light source dedicated to Free-Electron-Laser and accelerator-physics research. The storage ring is characterized by a flexible triplet-focussing optics and a beam of high brilliance and stability, optimized to obtain large FEL gain. Its ultra-high vacuum system is designed with very low impedance and for lifetimes far in excess of 10 hours, applying non-standard techniques. Electron-beam welded, uniform beam chambers with keyhole cross-section all along the 115 m circumference have been manufactured for the first time from 316 LN stainless steel. Other novelties are the sealing technique with keyhole-formed gaskets and the use of integrated pumps, both NEG and ion-sputter pumps, mounted side by side in the antechamber. An overview and first operational experience with this vacuum system is presented.

1 INTRODUCTION

The 1.5 GeV electron-storage-ring facility **DELTA** is a third-generation synchrotron-radiation source, [1] - [5]. In contrast to typical user machines, it represents a national test facility for R&D in radiation and accelerator physics and technology. Moreover, DELTA is dedicated to free-electron-laser (FEL) research in the VUV range [6] and to all kinds of new experiments utilising special beam characteristics and magnetic insertion devices to generate intense and polarized synchrotron radiation.

The DELTA facility comprises a 60-100 MeV electron S-band linac, a full-energy booster synchrotron of FODO structure with 54 m circumference and a 1.5 GeV low-emittance storage ring of 115 m circumference. The storage-ring lattice, based on triplet focussing cells and strong bending fields provides a very flexible optics and beams of high brilliance and stabilty. This optics represents the best compromise between small emittance (10 nm rad) and short damping time (about 4 msec). In order to obtain large FEL gains, high beam intensities, an energy spread of $<10^{-3}$ and short bunch lengths are anticipated. The DELTA lattice, which is characterized by two 20 m long dispersion-free straight sections with nearly constant beta functions, accomodates long insertion devices. Besides an electromagnetic undulator, already installed for the first FEL experiment, and a few synchrotron-radiation beam lines, construction of an asymmetric superconducting wiggler has started. After its delivery next spring, it will produce 1 Angström radiation with a high degree of polarization for various research applications.

Linac and booster are operating since a few months. Due to the particular design of the ultra-high-vacuum (UHV) system, the beam lifetime of the synchrotron is already much longer than originally anticipated. The storage ring is in the phase of commissioning with the aim to run the first storage-ring-FEL experiment up to the end of this year. After discussing some basic requirements and technical innovations, first experience with the ultra-high-vacuum system of DELTA will be presented.

2 BASIC REQUIREMENTS OF THE DELTA UHV SYSTEM

Several factors specific to the new generation of low-emittance, high-brilliance synchrotron radiation sources led to the following design requirements of the DELTA vacuum systems :

- Large beam lifetimes of 10 to 20 hours, demanding for a total pressure near 10^{-8} Pa with circulating beam.
- A beam tube with antechamber for integrated pumping to obtain a low and very uniform total pressure everywhere in the beam line.
- Very smooth and uniform vacuum tubes with a sufficiently large aperture and only a few, well-tapered changes of cross-section. By fulfilling this requirement of tapering for all vacuum parts, also for kickers, septa, bellows, valves and pumping ports, a very low total impedance of the beamline is guaranteed. It has been estimated for the DELTA storage ring to be of the order of $|Z/n| \cong 0.4\ \Omega$. A new kicker design of very low impedance [7] also contributes to this small value. A low impedance is particularly important for high-current beams of small emittance and short bunch length, which are essential for FEL operation.
- Stainless steel (sst) vacuum vessels. Low-magnetic 316 LN stainless steel has been chosen for the whole UHV system, because (i) it is cheaper for small machines like DELTA compared with aluminum or other materials, (ii) it has high strength and is very insensitive to corrosion, (iii) it permits to use thinner walls and needs less space than other materials; therefore, smaller magnet gaps and correspondigly lower operational costs are possible, (iv) it exhibits higher thermal resistance, allowing for a more efficient degassing heat treatment, for leak proof of weldings and stress release and for vacuum firing and

hydrogen degassing of vessels, (v) no welds between sst and other materials (like aluminum) are necessary; therefore standard components and sst flanges can be used and welding and repairing of vessels is much easier.

- Short vacuum conditioning and pump-down times, which are important for a test accelerator without in-situ bake-out installations.
- Because of lower costs, the same dipoles and quads and the same vacuum vessels are used for both rings.
- The DELTA booster was built to operate in two modes, namely as a slowly energy-ramped synchrotron and as a storage ring. Due to low-energy injection, the vessels of the booster are equipped near all ends of dipole fields with ion-clearing electrodes, using the distributed NEG strips as voltage supply.

3 TECHNICAL NOVELTIES OF THE DESIGN

To meet the described technical conditions encountered with modern light sources, the following innovations of vacuum technology were carried out at DELTA :

(1) For the first time, vacuum vessels of keyhole cross-section with beam channel and antechamber were totally manufactured of austenitic stainless steel of very low magnetic permeability ($\mu_r \leq 0.005$). Form and dimensions of the key-hole cross-section are determined by the gap width of dipoles of 50 mm and the pole distance of 70 mm of quadrupoles. As exhibited in Figure 1, beam tube of octagonal shape and rectangular antechamber are connected by a continuous slit of 8 mm height and 35 mm width. The dimensions of the slit were determined by computer calculations and represent an optimum between a low chamber impedance and maximum pumping conductance. The material chosen is electroslag refined (ESR) sst 316 LN. Whereas the chamber walls consist of cold-rolled sheets of 3 mm thick sst, all flanges were cut out of forged blocks of sst 316 LN (ESR). Bent dipole chambers as well as straight chambers, were fabricated in the same manner. With a heavy 600 tons press upper and lower half of each vessel were separately compress-formed in two steps by a deep-drawing process and cut in pieces of two meters length. Two different heavy tools of sst were built for bent and straight vessels, correspondingly. Transverse TIG welding from the inner side of the half shells was applied to obtain vessels of total lengths of more than 2 meters. Afterwards, upper and lower halves of vessels were electron-beam welded longitudinally in a 6 m long high-vacuum vessel. All beam chambers were subjected to careful chemical cleaning and a hydrogen-degassing heat treatment. This vacuum-firing processing has been performed at CERN in a big vacuum furnace for a period of two hours at a temperature and pressure of 950 ^{0}C and 10^{-3} Pa, respectively. After welding of the button electrodes of beam-position monitors and mounting of the distributed ion-getter pumps, each vessel was leak tested and finally baked for about 15 hours at 300 ^{0}C.

(2) Two different types of distributed ion-getter pumps are installed for the first time together and parallel to each other in the vacuum vessel of the storage ring. These are distributed NEG pumps of the low-temperature material St707 (DNEGP´s) and distributed ion pumps (DIP´s). For the latter about 4.5 kV high tension and the strong dipole fields of the storage ring are needed. The antechambers of all vacuum vessels of the booster and the straight ones of the storage ring contain two NEG strips. Each of them is folded and its ends connected to electrical feedthroughs at one end of the vessel. Thus two NEG strips are arranged as four in parallel. In each storage-ring dipole vessel one folded NEG strip (two in parallel) is mounted along the whole length, side by side with several DIP-modules. Each DIP-module of 300 mm length consists of two distributed ion pumps mounted on top of each other (see Figure 1). Their anode plates are connected with those of the next module or with the HV feedthrough. These DNEGP´s and DIP´s are reveted on ground plates and are electrically insulated by ceramic holders. Depending on the total length of the chamber, several such modules are connected with one another like a chain. These 2-fold DIP modules are equipped with two titanium cathodes, sharing a second one made of tantalum. Tantalum has been used because of its larger noble gas pumping speed compared with titanium. At both ends of each module a short spacer of 15 mm length is fixed. This spacers are fitting into the slot connecting antechamber and beam channel. Due to the reduced mechanical stability of the 3 mm thick wall, these spacers are necessary to ensure a constant slot size after evacuating the chamber. They also serve the purpose to keep the pump modules in position, thus any welding at vacuum surfaces is avoided. At the outside wall of the vessels a U-shaped sst channel for direct water cooling is welded, which is bridged at flanges by removable copper tubes. In addition to the distributed ion-getter pumps, all vacuum tanks of kickers, septa and pumping ports are equipped with lumped ion pumps. These lumped pumps consist of titanium-sublimation pums mounted in the same housing together with 120 or 240 ls^{-1} ion-sputter pumps of the diode type. The latter are also equipped with tantalum cathodes for increased noble-gas capacity.

(3) A special flange technique has been applied for sealing of DELTA vessels. Silver-plated (20 μm) OF-copper gaskets of 0.50 mm thickness made by chemically etching are inserted between each pair of DELTA flanges. The flanges are cut out of sst with the typical keyhole aperture of DELTA vessels and with plane and smooth surfaces of 0.1 to 0.2 μm roughness. A thin lip on both sides of the gasket of 0.15 mm thickness and 0.7 mm width, which runs around the circumference of the key-hole aperture at 1 mm distance, forms the sealing when compressed between the flanges. Due to this particular sealing, the flange size is considerably reduced, and there are no vacuum problems caused by slits between flanges and no need for rf bridging of slits. In case of scratches or damage of the sealing surface, DELTA flanges are much easier and faster to repair than

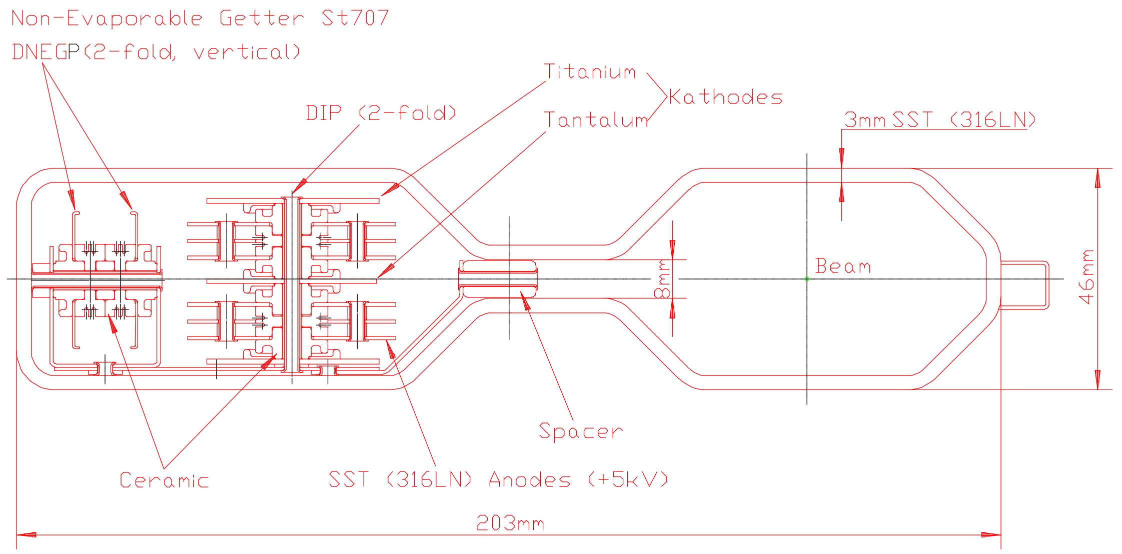

Figure: 1 Keyhole cross-section of the DELTA vacuum vessel made of 316 LN stainless steel with beam channel (on the right side) and antechamber (left) connected by a continuous slit of 8 mm height and about 35 mm width. Compact distributed DNEGP´s and DIP´s are mounted side by side inside the antechamber of dipole vessels.

Conflat (CF) flanges. Also fixing of flanges with screws and gaskets is easier, the only drawback being somewhat higher cost of production of these particular gaskets.

4 FIRST EXPERIENCE WITH THE UHV SYSTEM

The present status of the DELTA UHV system is that the vacuum chambers of both rings with those of LINAC and transfer beam channels are assembled. Whereas LINAC and booster are in operation since more than one year, all six sectors of the storage-ring beam lines are at ultra-high vacuum since a few weeks and first beam has been injected.

The mechanical dimensions of all sst vacuum vessels and flanges were found to be highly accurate and according to specifications, inspite of the demanding thermal treatment described above. No leaks of welds or of the carefully preselected chamber material were found. It turned out that the tightness of DELTA flanges with the special sealings is very reliable and even better than that of CF side-flanges, in particular after baking.

An average total pressure of close to 10^{-9} mbar has been obtained in all sectors of both ring systems after pump-down times of only very few days and without fully activating the distributed NEG pumps. So far, all DNEGP´s of both rings have been activated only for about two hours at a maximum temperature of ~ 200 ^{0}C, instead of applying an activation temperature of at least 350 ^{0}C, necessary for full activation. All DIP´s of the storage ring are operating fully successfully without short-circuits.

At injection energy of 68 MeV with low beam currents and without voltage at the ion-clearing electrodes beam lifetimes of 7 minutes have been observed and of > 3 hours at 1 GeV, which exceed design values by far.

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