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WATER-COOLED THIN WALLED BEAM PIPES OF THE FAST RAMPING STORAGE RING ELSA

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Abstract

At the Electron Stretcher Facility ELSA of Bonn University thin walled beam pipes are in use to reduce eddy current loss to a minimum. The operation of the accelerator places high demands on the beam pipes like static stress because of the inner vacuum and additional one-sided thermal stress caused by synchrotron radiation. A first generation of thin walled beam pipes had been developed and manufactured during the construction of the stretcher ring in 1985. These pipes were successfully in operating stage the following ten years. The beam pipes had a wall thickness of 0.3 mm, a length of 3 m, and a bending radius of ca. 10.5 m. Special pipes with a sideway branch for synchrotron radiation experiments have been manufactured in the same assembly dimension. In the course of an intensity upgrade, a second generation of beam pipes has been developed in 1995. To reduce the thermal stress caused by the synchrotron radiation an internal water cooling was mounted. In this contribution the design and manufacturing principles of the thin walled beam pipes with water cooling are presented.

INTRODUCTION

The Electron Stretcher Accelerator ELSA [1] is a three-stage accelerator omprising two linacs, a booster synchrotron and a fast ramping pulse stretcher ring ($2\,\mathrm{T\,s^{-1}}$). To provide the fast ramping abilities of the stretcher ring it is essential to minimize the eddy current loss in the dipole gap. Since suitable radiation resistant non-conducting curved beam pipes are extremely difficult to manufacture this is most effectively achieved by building the vacuum chambers from stainless steel and reducing their wall thickness to a minimum. This reduction is mostly limited by the static stability of the beam pipe, the manufacturing possibilities, and the costs. First thin walled beam pipes had been constructed in 1985 and were in use from 1987 to 1995 when they have been replaced by a water-cooled version to enable an intensity upgrade at ELSA. The recent assembly of a new beam pipe by the university's workshops gave reason to rework the manufacturing process, especially those of beam pipes with a sideway branch and inner water cooling.

DIPOLE STANDARD BEAM PIPE

Setting up the Oval Shape of the Beam Pipe

Feedstock for all thin walled beam pipes at ELSA are round, welded pipes made of stainless steel with a wall thickness of 0.3 mm. This source material is as well used for the production of hydraulic formed vacuum bellows or metal bellow couplings. To form the round pipe into its oval shape it is pulled over a dedicated core at its full length of approx. 3 m. The core carries stainless steel balls which are positioned in wedge profile to expand the tube sideways. In contrast to cold-drawing or pultrusion the pipe is only bent and not stretched. Therefore, the circumference of the pipe remains constant throughout the entire processing operation and the required force can be performed by hand (see Fig. 1).

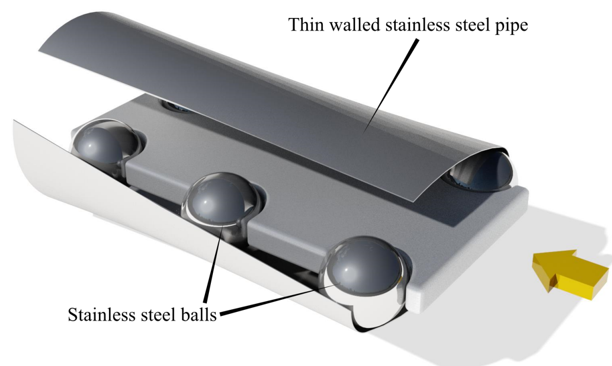

Figure 1: Schematic representation of the bending process to form the round feedstock into the required oval shape.

Mounting of the Reinforcing Ribs

In order to avoid further deformation caused by the ambient pressure on the evacuated oval pipe, it must be strengthened by additional reinforcing ribs. The design of the ribs is mostly influenced by their thickness, their maximum tolerable outer dimensions, and the distance between two adjacent ribs. Since the inner contour is determined by the oval shaped pipe and the height is limited by the size of the dipole gap, a careful minimization of the required amount of material resulted in a distance of ribs of 24 mm and a thickness of 1 mm. With an effective length of 3072 mm of each beam pipe, a considerably large number of in total 122 ribs are needed per pipe, taking into account the slightly different design of the beam pipe ends. To lower the production costs, the ribs were cut out of a stainless steel sheet using a water jet. The burr at the cut edges could be removed easily by vibratory grinding. This procedure turned out to be essential for later installation on the pipes since, in case of improper pre-treatment, burrs as well as any swarf clinging to the cut edges would cut deep marks in the thin walled pipe and could in worst case cause destruction of the entire pipe.

When mounting the ribs on the beam pipe, the pipe is fixed in a support structure to prevent it from crippling and to guide the ribs during their installation. Before mounting, fabrication tolerances of the inner rib contour have to be carefully controlled and, if necessary, adjusted. This turned out to be mandatory because only a tight fitting of the ribs

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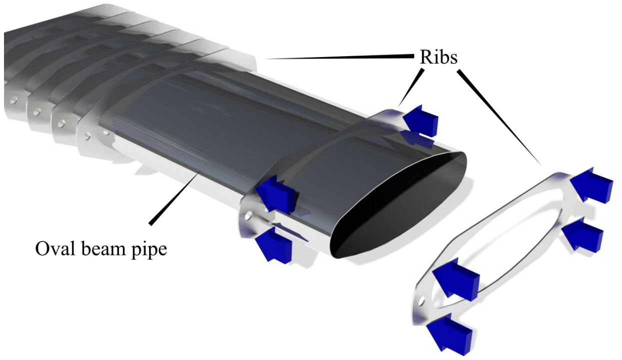

Figure 2: Mounting and positioning of the ribs.

ensures that they will hold their position during the later brazing process. Each rib is first attached to one end of the pipe and then moved slowly to its final position. Caused by many customisations and the complex geometry of the beam pipe the whole process is done by hand (see Fig. 2). Ribs that are too loose are sorted out and scrapped. A clearance of approx. 0.04 mm is ideal for mounting and fixing and causes a good capillary attraction during the brazing. The distance of ribs is controlled and adjusted by metal templates. After correct placing of all ribs, all parts are brazed together by vacuum brazing at 1040 °C using a nickel based brazing filler.

Bending the Beam Pipe to the Required Curvature

Until this point the beam pipe is still straight and has to be bent to fit the dipole-radius (approx. 10.85 m). It is not possible to bend such a filigree pipe in a classical way without crippling. So a steel rope is looped around the pipe between two ribs and a hydraulic system pulls the rope against one side of the fixed pipe (see Fig. 3). This causes a one-sided constriction of the pipe which is repeated for all rib gaps. The constrictions reduce the length of one side

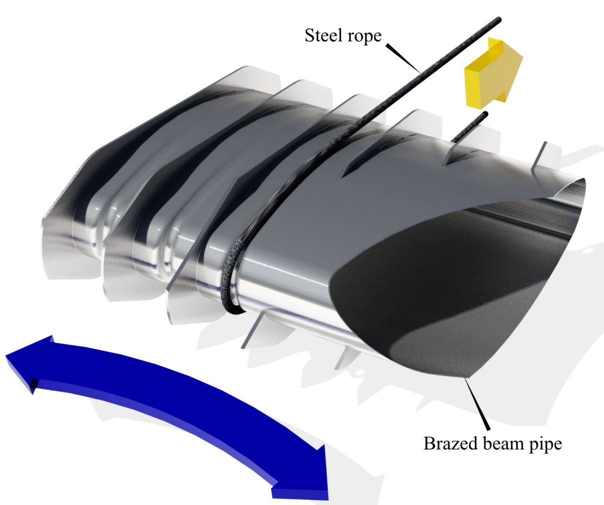

Figure 3: Pipe constriction and bending.

and cause a curvature of the beam pipe. This process has do be done slowly and carefully in several passages in order to achive a smooth curvature. Each time when starting on a new constriction the required traction is relatively small because after the brazing the stainless steel is completely soft annealed. Caused by cold work hardening the traction raises during the process. The depth of the constrictions is measured permanently by a dial indicator to prevent the pipe from overstretching. The correct radius is controlled by metal templates and full-scale drawings.

Final Assembly

The last step is the installation of the inner water cooling pipe (Fig. 4, D) and the bellows (B) and flanges (C) at both ends. The pipes for the water cooling are bent based on full-scale drawings, assembled with other parts like spacers and the feedthroughs and finally brazed together. At the beam outlet side of the beam pipe an additional copper heat sink (Fig. 4, F) is mounted to protect the metal bellow from the synchrotron radiation. The bending radius of the water cooling pipes is chosen slightly smaller than the radius in its later mounting position in the beam pipe. Because of this smaller radius it is possible to install the water cooling pipe with small pretension. After welding this pretension pushes the complete water cooling pipe towards the inner beam pipe wall. Round shaped spacers automatically center the water cooling pipe at the designed electron beam height. Length tolerances of the water cooling pipe can be compensated by excentric holes in the water feedthrough (Fig. 4, E). Finally, the water cooling pipe is welded to the feedthroughs by a laser or micro plasma to fix its position. The metal bellows and flanges at both ends are welded to the pipe as well (Fig. 4).

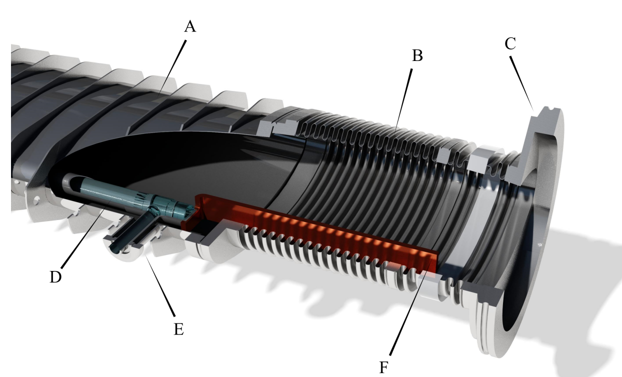

Figure 4: Outlet side of the beam pipe. A: Oval beam pipe, B: Metal bellow, C: Flange, D: Water cooling pipe, E: Water feedthrough, F: Copper heat sink

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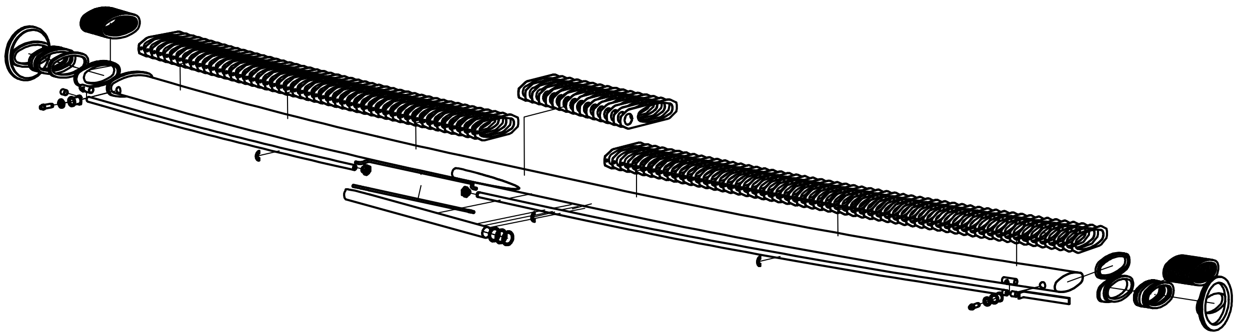

Figure 5: Exploded drawing of a beam pipe with sideway branch and all single parts.

DIPOLE BEAM PIPE WITH SIDEWAY BRANCH

To enable synchroton radiation experiments and Compton polarimetry, special beam pipes with a sideway branch are required. The position of the branch can be individually customized to its later function or the available installation space. Usually the branch is positioned near the center of the beam pipe being tangent to the electron beam trajectory, but other positions and orientations are possible as well. The basic manufacturing of a thin walled beam pipe with sideway branch is similar to the standard procedure. Setting up the thin walled feedstock in the needed oval shape it is just the same course of action as done by the standard beam pipe. Mounting of the ribs on the oval pipe is performed in the same way except for the area of the planned sideway branch. In this section 16 special ribs hold the branch pipe in place at the right angle. The thin walled branch pipe has to be cut sideways to fit the shape of the oval beam pipe with right clearance for later brazing. The cutting is done by milling while a wooden core stabilizes the branch pipe and prevents it from crippling.

To cut out the side of the oval beam pipe originally a copper stamp was used to erode the notch. At this stage the pipe was fully assembled with ribs which already had been brazed to the pipe. The copper stamp had to be fed through the complete branch pipe and needed to be aligned and held very accurately. This technique increases the risk of eroding flashovers which could cut through the outside wall and ruin the entire beam pipe. Nowadays, a test set-up is used for cutting the notch by a water jet before brazing to reduce risk and cost. During this process an oval-shaped aluminium core and wide aluminium clamping claws stabilize the beam pipe during the water jet cutting. After removing the clamping claws and the core all ribs are mounted in the same manner as for the standard beam pipe. First results with short pipe segments are auspicious and further upcoming tests will show the process stability at brazing.

In the area where the branch ribs are mounted the beam pipe cannot be bent because the branch pipe segment would be bent as well. That would cause a malposition of the branch. To compensate the straight section in the beam pipe the bending radius before and after the branch is chosen slightly smaller. In this way the effective length of the beam pipe remains similar (3070 mm with and 3072 mm without sideway branch). This makes both beam pipe types interchangeable and eases the planning for attachable components. The formed tilt at the flanges caused by the smaller bending radius (approx. 2.5°) will be compensated by the two bellows at the pipe ends.

The water cooling has to be guided around the sideway branch. This is done by stainless steel splitters which allow to bypass vertically the branch along its full length. Special designed rims at the splitters shield the inner wall of the beam pipe and the branch pipe from synchrotron radiation, especially the brazed seam (Fig. 6).

The remainig steps for completion of the beam pipe, positioning of the ribs, vacuum brazing, assembling and fixation of the water cooling and the flanges, are performed similar to the procedure for the standard beam pipes.

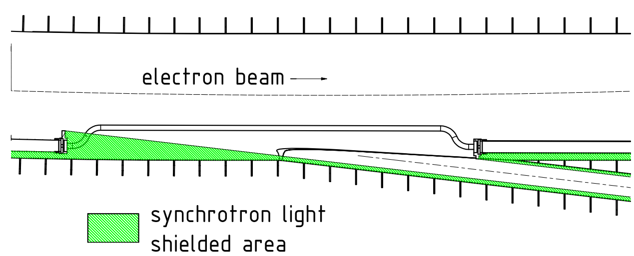

Figure 6: Sectional view of the sideway branch with synchrotron radiation shielding.

CONCLUSION

Thin walled beam pipes have been manufactured for many years in the workshops of the University of Bonn. New developments and manufacturing technologies make it possible further simplify the renewal and manufactoring of new beam-lines for accelerator diagnostics and experiments at ELSA.

REFERENCES

[1] W. Hillert, "The Bonn Electron Stretcher Accelerator ELSA: Past and Future", Europ. Phys. Jour. A28 (2006) 139.