

EXPERIENCE WITH LONG TERM OPERATION WITH DEMINERALIZED WATER SYSTEMS AT DAANE

L. Pellegrino, LNF – INFN, Frascati (Roma) - Italia

Abstract

During eight years operation of the DAANE water cooling system some critical situations have been successfully managed by upgrading the demineralized water system. The collected data and the experience gained in the field of copper corrosion and related water treatment are critically revised.

INTRODUCTION

The water cooling system for the Daane complex has been operated successfully since mid nineties.

More than 1200 meters of piping convey low conductivity cooled water from pumping stations to end users in the accelerator buildings. The piping is made of AISI 316 stainless steel, jointed in place with high quality TIG welding. The end users are magnets and the RF structures. All their cooling passages are OFHC copper channels with stainless steel fittings, with no other metals included. A treatment system maintains the characteristics of the water, mainly the conductivity and the dissolved oxygen contents.

Some crucial improvements have been done during the early functioning period, sometimes following failure episodes, as reported in the next chapters.

First, a short review of the topic of low conductivity water cooling in accelerators is presented.

CORROSION IN ACCELERATORS

In the accelerator cooling systems the copper corrosion in demineralised water is an unavoidable drawback but can be limited to a sustainable level.

The corrosion rate depends on conductivity, dissolved O₂ and CO₂, pH, temperature, flow velocity and conditions, imposed electrical potential difference, galvanic potential difference (due to different metallurgy). The conductivity and other parameters can be maintained in set by polishing on line and controlled make up.

In addition, the oxygen inlet should be limited by adopting closed water circuit (sealed or inert gas cushioned, yet taking advantage by O₂ pumping away with inert gas flow). Any possible depression in the piping should be checked. As a rule, it should be avoided any unnecessary stop and opening of circuits, as well as allowing dead leg in piping with differential aeration. Furthermore recommendable are vacuum deaeration and UV hygienization technologies, both on-line and on the make-up.

Finally, it should be reminded that employing different metals and allowing unwanted electric potential difference are both possible cause of corrosion intake.

Several papers deal with the problem of managing low conductivity water plant in accelerators [1,2], but outside of this field, only electric power generation plants (cooling of high voltage stator windings) seems to suffer from similar troubles.

Typical values of water characteristics are: conductivity < 0.2 σ S/cm, dissolved oxygen <20 ppb, 6.8 < pH < 7.2.

In the specific case of accelerator magnets, the leading corrosion process could be the electrochemical one. The Coulomb law (1) gives an estimation of the rate of metal mass (m) loss, knowing the expected current I through the electrolyte and the Faraday constant F:

$$\frac{dm}{dt} = \frac{M}{Fn} I \quad (M \text{ atomic weight, } n \text{ ion charge}) \quad (1)$$

Loss of copper of some mg to some 10 mg per year could be expected in good operating conditions.

THE DAANE COOLING SYSTEM

In figure 1 is represented the Main Rings cooling system. Note the position of the cushioned expansion tank, affecting the pressurization level of the whole secondary circuit, as well as the polishing on-line, whose insertion point plays a crucial role in its effectiveness.

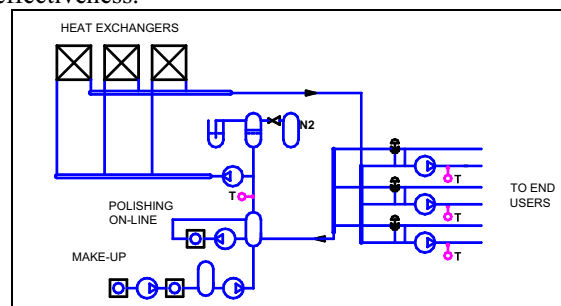


Figure 1: Cooling system (secondary circuit) design.

A simple hydrostatic device is employed to guarantee a stable and safe nitrogen pressure level.

The polishing system, as well as the final stage of the make-up one, consists in a row of mixed-bed ion exchanger resin bottles, with micrometric filtration stages against resin pollution and loss of containment of the sand-like resin particles.

The make-up system has in series: mechanical pre-filters, chlorine- and iron- removing units, micrometric filters, reverse osmosis membrane units, again micrometric filters, a buffer tank, a booster/recirculating pump and mixed bed ion exchanger stage. All the components are redundant. Timers make self polishing of reverse osmosis

membranes as well as of the water stored in the buffer tank through the ion exchanger stage.

Water Treatment design

While the process characteristics of the make-up water treatment depends mainly on the quality of the available water, its sizing rely on the foreseeable rate of spilling in the users and in the piping, and finally on the volume of the water circuit.

On the other hand, the sizing of the polishing on-line system could be related basically to the rate of users' corrosion and to the total recirculating flow. In addition, it affects the velocity of recovery after a scheduled shut-down or a failure. Typical values adopted in Dałne are reported in the table below.

Table 1: Sizing of water treatment systems

| | | |
|--------------|---------------|-----------------------|
| Main circuit | flow | 400 m ³ /h |
| | Total volume | 110 m ³ |
| Polishing | flow | 4 m ³ /h |
| Make-up | flow | 0.5 m ³ /h |
| | Buffer volume | 0.5 m ³ |

DEMINERALIZED SYSTEMS OPERATION

From the operation experience, the capacity of systems above mentioned has revealed adequate.

The use of mixed bed resins bottles allowed safe, clean and fast maintenance operation. The make-up buffer was extremely useful to constantly maintain the proper level in the expansion tank in case of little spilling due for example to the maintenance of pumps.

With the best operating conditions, the polishing leads to reduce the circulating water conductivity to less than 0.2 µS/cm. The total mean per year consumption of resins between 1997 and 2003 has been of 483 kg compared to 420 kg installed.

Reduced polishing stage efficiency during accelerator operation produces a fast increase of the circulating water conductivity, some 0.1 µS/cm in few days. Because we experienced failure as those reported in the next chapter when conductivity rise towards 1 µS/cm, the main maintenance threshold is set to 0.5 µS/cm. Before reaching this stage, the replacement of bottles has to be done.

A further early warning is the pressure lowering in the polishing circuit, meaning the clogging of micrometric filters upstream of the bottles. This requires a weekly (or little more frequent) light maintenance. The same threshold of 0.5 µS/cm is applied when recovering from a prolonged shut-down of the plant, to set the start of accelerator operation.

The time of recovery is quite long, as reported in figure 2, so the full stop, leading in few days to conductivity of more than 2 µS/cm, is limited only to

the case of scheduled long pauses for major accelerator improvements or new experiments set up.

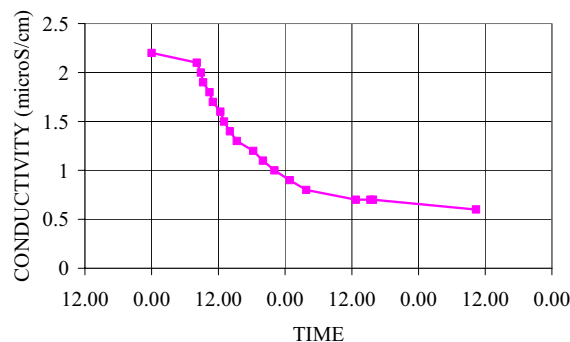


Figure 2: water conductivity vs. time after a shut-down.

THE DAANE WIGGLERS: A CASE STUDY

At the end of nineties we experienced repeated failures due to obstruction of the coolant passages in the Wiggler magnets of the Dałne Main Rings.

All the coils of a magnet are in hydraulic parallel. The inlet water temperature is 32°C, the outlet reaches 65°C maximum. The coils are made of OFHC copper; they are joined to the manifolds in AISI 304L SS by EPDM rubber hoses.

The rubber hose between the manifold spigot and the coil end forms a flow section enlargement, with internal diameter going from 4 to 6 and again to 4 mm, as a little "chamber". Solid pebbles (D>5 mm) formed in some of these "chambers" inside the hoses and, there, moved back and forth, obstructing sometime the flow in one or more coils. Therefore the coils, no more cooled, heated until safety thermal device switched down the whole chain of four wiggler magnets.



Figure 3: copper oxide pebbles.

After a while, the pebble moved and the flow went right making impossible to find the cause of the failure.

Only once a persistent obstruction permitted us to catch the problem and start finding a solution.

The material of obstruction was analysed by the CSM of Pomezia, Italy, (SEM microscopy with EDS spectrometer), showing copper and copper oxides as

the only component, as well as the water at inlet and outlet of the polishing system, as in table 2. In figure 3 is the micrographic picture of a pebble.

The surface of pieces of copper conductor with some months of operating life, as well as the pebbles and the powder were checked with micrographic imaging and "energy dispersion" X-ray surface analysis.

Table 2: Water analysis after the failure.

| sample 1 | O ₂ (mg/l) | $\omega\#\sigma S/cm$ | pH | T (°C) | Cu# $\sigma g/l$ |
|----------|-----------------------|-----------------------|------|--------|------------------|
| before | 12.50 | 0.8 | 7.55 | 23.1 | 92.0 |
| after | 12.40 | 0.3 | 7.87 | 23.0 | 4.0 |

The conclusion was that the relatively high conductivity, the relevant dissolved oxygen contents of cooling water and the high electric potential of some coils with respect to the grounded piping yield the production of copper oxides and their migration according to the potential difference. Probably, sulphide-reducing bacteria catalysed the agglomeration process of the oxide, starting on the lips of the inlet copper spigots, in a slower flow region.

The deposits grew until detached and continued growing, probably without leaving the "chamber".

The successful corrective actions

We modified the polishing circuit and its location in the plant, to assure a continuous treatment of the whole water mass with the proper flow in the mixed bed bottles, and added new instruments and a data logger; the N₂ cushion system was reviewed and frequently checked; the whole plant pressurization scheme was reviewed, to ensure a positive pressure everywhere, avoiding unwanted air intakes.

As soon as a stable operating condition was reached, the failure did not present anymore.

A mock-up with the same dimensions of a wiggler magnet coil was installed, without any applied electrical potential, to further investigate the phenomenon. After four years of operation, recently the mock-up was sampled and sectioned. The internal surface was uniformly black, denoting copper oxidation to CuO, but no evidence of material loss or deposition was detected. This fact probably endorses the electrochemical origin of the corrosion described in the preceding paragraphs.

THE DAANE SYNCHROTRON LIGHT ABSORBERS: A SECOND CASE STUDY

In the vacuum chambers of Daane Main Rings are mounted 88 synchrotron light absorbers, with different sizes. They are made of copper, and are water cooled from the same circuit of magnets. The cooling of the absorber is realized by two parallel channels drilled in the body, connected each other by a transversal hole grooved with a long tool through the channels itself.

The synchrotron light hits the absorber far from the channels, avoiding any direct thermal stress

concentration in a potentially harmful area for spilling water into vacuum.

Nevertheless, after some year of operation, a tiny crack opened a way to the water. The alarm was early on, so the damage was limited, but the probability of other occurrences of a similar failure was high, due to the large number of absorbers installed.

A visual endoscopic inspection revealed a pitted area downstream of the hole between the inlet and the outlet channels (figure 4). Moreover, the water flow was measured as more than twice the design one.

Because of the local narrowing of the water passage, a very high velocity was reached in the water flow, leading to cavitation that damaged the internal surface of the outlet channel. This phenomenon was surely enhanced by corrosion, until the opening of the crack. Some similar cases are reported in literature.

Following this analysis, a proper flow velocity was restored, with no further consequences.

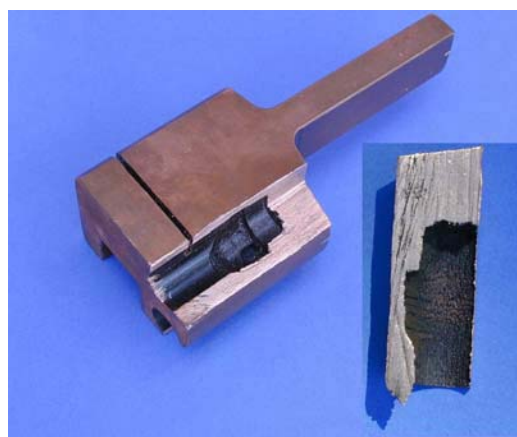


Figure 4: the tip of an absorber and a section showing the internal of the crack area.

CONCLUSIONS

The commissioning and the improvements done on the Daane cooling plant have been effective in yielding a long period of stable operation.

Nevertheless, there is evidence that any interruption in and maintenance of the water cooling system could cause severe failures and shutdown. This is especially true in the field of corrosion, where silent or hiding phenomena could produce sudden unexpected damages.

REFERENCES

- [1] R. Dortwegt, E.V. Maughan, "The chemistry of copper in water and related studies planned in the Advanced Photon Source", PAC'01, Chicago, 2001.
- [2] H. Poggensee, "Korrosionsursachen und korrosionverhinderung in kupferkühlleitungen im LINAC II", internal report DESY M-93-04, DESY, Hamburg, June 1994.