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CORROSION OF COPPER COMPONENTS IN THE DEIONIZED WATER COOLING SYSTEM OF ALBA SYNCHROTRON LIGHT SOURCE: CURRENT RESEARCH STATUS AND CHALLENGES

M. Quispe†, E. Ayas, J.J. Casas, C. Colldelram, Ll. Fuentes, J. Iglesias, ALBA – CELLS Synchrotron, Cerdanyola del Vallès, Spain
A. Garcia, La Romanica, Sabadell, Spain

Abstract

Currently, the ALBA Synchrotron Light Source is carrying out studies on corrosion in copper components of the deionized water cooling circuit. The preliminary studies, based on Scanning Electron Microscopy (SEM), Energy Dispersive X-Ray Spectroscopy (EDS), and X-Ray Diffraction (XRD) have shown the presence of intergranular, pitting, and generalized corrosion in the analysed copper samples. The purpose of this paper is to present new advances in the field of this research, such as: the study of the influence of low velocity water flow in the cooling circuit on the current high dissolved oxygen content (> 6500 ppb), the results of corrosion products found in the cooling circuit, the description of the improper operation of the cooling circuit as a closed loop, and FEA studies of copper components in order to redefine the water flow velocity design criteria to values lower than 3 m/s and thus minimize corrosion by erosion. Finally, in order to attenuate the corrosion rate, preventive solutions are presented such as the viability to install an oxygen content degassing plant, new instrumentation for water quality monitorization, and installation of degassing equipment at strategic positions of the cooling circuit.

BACKGROUND

The requirement of deionized water (DIW) for cooling in Accelerators has brought an added problem: an increase in the rate of corrosion of the copper components. This particularity has an impact on the lifetime, as well as on the operation of the Accelerators. This problem has been extensively studied [1-7], and there is a consensus on the alternative to attenuate its effect, according to which, following the experimental correlation pH vs concentration of dissolved oxygen (DO) [8], it is advisable to fix the properties of the water in the "low-oxygen alkaline region" of regime 1 (see Fig. 1). Although the corrosion rate in regime 2 is similar to that of regime 1, however, to be in regime 2 it would be necessary to increase the pH above 7.6. On the other hand, for values of DO content < 10 ppb and with pH values from 7.2, we would easily be in regime 1. This last option is the most feasible technical solution, and has been applied by most of the Accelerators.

In the case of ALBA, the quality of the DIW has been very irregular. Based on the evolution of the pH reported since 2012 [9], our water quality has oscillated between regimes 3, 4 and 5. Currently our goal is to work in regime 1. This would allow reducing the corrosion rate to a range between 4 to 10 times lower compared to our current situation.

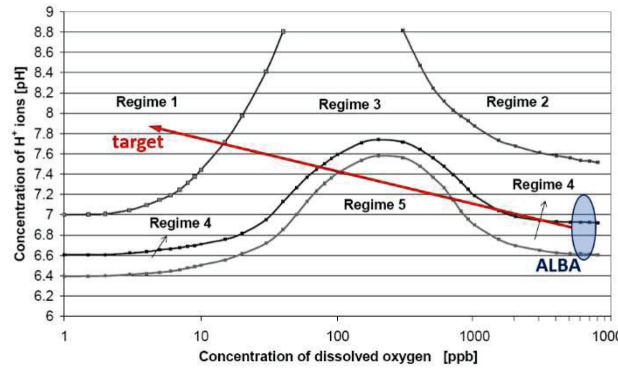

Figure 1: Copper corrosion rates. Regimes 1 and 2: < 0.1 μg/(cm^{2}y), regime 3: 0.1-0.4 μg/(cm^{2}y), regime 4: 0.4-1 μg/(cm^{2}y) and regime 5: > 1.0 μg/(cm^{2}y).

FIRST STUDIES

The visual inspections of the first samples taken during the years 2018, 2019 and 2020, have confirmed the first evidences of corrosion in ALBA after more than 10 years of operation. A common pattern has been found in all the samples: surfaces with moderate to high roughness, such as the examples of cases (b), (c) and (d) of Fig. 2, corresponding to pieces of the masks of the Front Ends BL11 and BL13 and the radiofrequency cavity of the Storage Ring (SR), respectively.

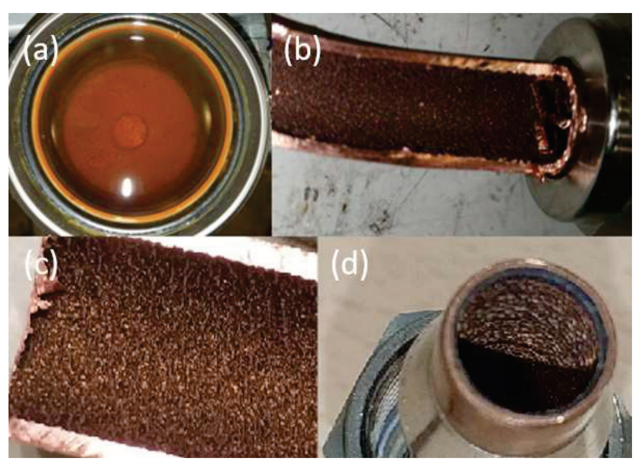

Figure 2: Visual signs of corrosion in ALBA. (a) Copper oxide particles; (b, c, and d) Pieces of the masks in BL11 and BL13 and of the radiofrequency cavity of the SR.

†mquispe@cells.es

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On the other hand, we have found accumulation of particles similar to copper oxide in some cavities where the flow circulates at low pressure and velocity, such as the capsule that houses the pH sensor in the common return (Fig. 2a).

During 2020 and 2021 we have also carried out more detailed studies, based on Scanning Electron Microscopy (SEM), Energy Dispersive X-Ray Spectroscopy (EDS) and X-Ray Diffraction (XRD) [9]. Samples from the four main rings were evaluated; five samples in the SR: Glidcop Al-15 Crotch Absorber, OFHC Copper Crotch Absorber, Copper Masks of the Front Ends BL11 and BL13, and Copper Radio Frequency Cavity; a sample at the Experimental Area (EA): Copper Mask in Beam Line BOREAS; a sample of Service Area (SA): Copper Circulator; and two Booster (BO) samples: Copper straight and bent pipes of a Quadrupole. Fig. 3 shows an example of these studies; the case corresponds to the sample of copper tubes of the masks of the Front Ends BL11 and BL13, where the EDS analysis has confirmed the presence of Copper, Oxygen, Carbon, Chlorine, Titanium and Calcium. The SEM results show surface oxides with different morphologies and a combined action of generalized corrosion with the presence of pitting phenomena.

As a main conclusion, this research shows that generalized, pitting and intergranular corrosion are present in the studied samples. The depth values in the pits are less than 119.4 µm. From the point of view of mass loss, this value is not critical for masks and crotch absorbers, but pits are the sources for crack initiation.

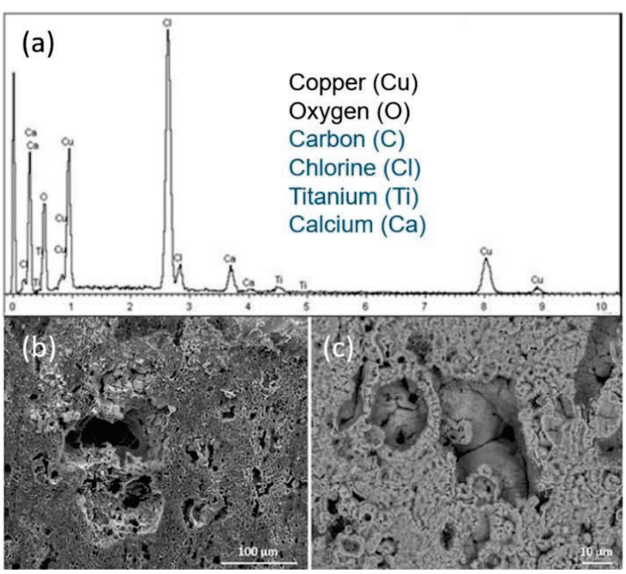

Figure 3: Results of the studies (a) EDS and (b, c) SEM in the samples of the component tubes of the masks of the Front Ends BL11 and BL13.

We have also analysed the content of the particles in the water for each cooling ring. So far, according to the values in Table 1, the values obtained in terms of copper and iron particles do not follow a defined pattern. A significant fact is that the value of the copper particles in the SR and SA rings are higher, compared to the other rings. Precisely both rings have agglutinated the maximum number of components made of copper.

Table 1: Content of Cu and Fe Particles in the DIW

Ring	**Cu (ppb)**			**Fe (ppb)**		
	Aug 2021	Nov 2021	Apr 2022	Aug 2021	Nov 2021	Apr 2022
EA		43	29		8	5
SR	53	333	42	5	84	5
BO		53	15		5.5	5
SA		181	26		9	5

Regarding to the appropriate technology for the future installation of an oxygen content degassing plant, we have found a consensus on the model applied by other Accelerators, which is the technology based on the hydrophobic membrane principle. The reason is that this model does not require chemical additives, the membrane keeps the two phases separate (water and N2 gas in our case) and its efficiency has been demonstrated to achieve DO content less than 10 ppb. In this technology (see Fig. 4), the water is flowing around the hydrophobic membrane, but it cannot flow through the porous. The water ingress is prevented by surface tension effect, even when the water is a high pressure. Then, the sweep N2 gas inside the membrane creates a driven force for O2 gas transport. The O2 gas molecules will diffuse from both water into the water-gas interface and the molecules gas immediate spread off into the N2 gas phase.

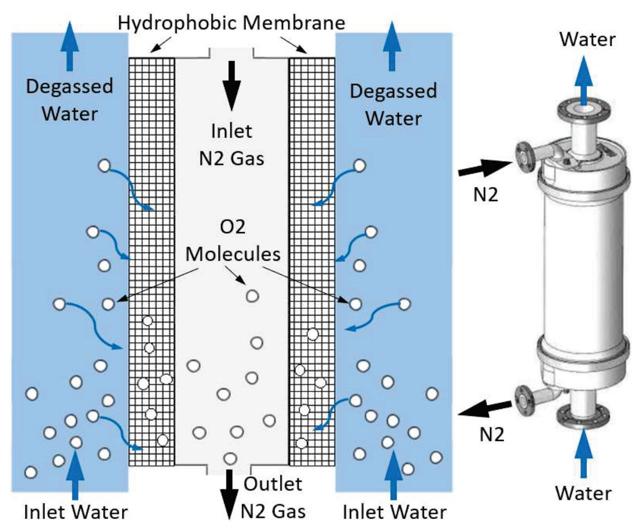

Figure 4: Operating principle of a DO content degassing system.

WEAK POINT OF THE PROJECT

The DO content in our system is the weak point of this project. Its value is very high (> 6500 ppb). This value is typical for an open hydraulic system. Our hydraulic system is closed by definition. In a closed hydraulic system, with signs of corrosion, the DO content would be consumed over time and its theoretical trend would be towards zero. For this reason, our research has focused on these two

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questions: (i) in a closed hydraulic system, with characteristics similar to ALBA, what is the value of the DO content by default that we should have? and (ii) what are the possible causes that originate this high value in the DO content?

Our final optimization step, which would be the installation of a DO content degassing plant, depends on the answers to the previous two questions. Regarding the second question, which is linked to the problem of the air that enters in our system, we are working on the following hypotheses, as causes of the high DO content:

- Cavitation problems in the main pumping system. In particular, the group of pumps that are responsible for driving the total hot water (around 450 m^3h) is a candidate for air entrance, due to the low pressures that would be generated in its suction area. This problem is being studied and the first results have been published in the reference [10].
- The main expansion tank is another candidate. The system operates with a membrane that separates DIW from a zone of pressurized air. The presence of porosities in the membrane could facilitate the entry of air into the hydraulic system.
- Inadequate design of the general distribution network, mainly in the four main rings. Its geometry is the cause that the water is distributed at velocities below the design criteria. This fact worsens our capacity to evacuate the air that enters in the system. If the velocity is below the specified minimum value, then it is not possible to move the air in the pipes. This fact affected ALBA's operation for approximately 2 months in 2013 [11].
- Two laboratories consume DIW to carry out experiments. Although there is no constant use and the control is adequate, these two consumptions break the concept of a closed hydraulic system.
- Degassing due to material type of flexible hoses.
- Protocols for maintenance and intervention of the hydraulic system, as well as in the consumption of the experimental lines.

IMPROVEMENT ACTIONS UNDERWAY

We are currently upgrading our diagnostic capability. Between 2022 and 2023 we are going to install new equipment for measuring conductivity, pH and DO content. We are also going to improve our air purging capacity, with degassing systems based on vacuum principles. The installation of copper corrosion meters is also part of this optimization.

We are also studying the feasibility of modifying the design criteria that we have defined in ALBA for the maximum velocity of the water. Currently for the design of optical components we have set a maximum velocity of 2 m/s and for the family of absorbers 3 m/s. The effect of erosion would be attenuated if the maximum velocities set for the design are reduced. This research has two parts: in the first part, using CFD (Computational Fluid Dynamic), we are going to quantify the conservative factor that we are introducing when we apply the experimental correlations provided by the literature [12]. In the second part we are reviewing our design considerations. The criterion of the maximum velocity for the crotch absorbers in the SR, could be relaxed for the absorbers type 1 and 2 (together they are about a hundred units). The feasibility of this new proposal is demonstrated by the new FEA results, as the example of the absorber type 2 (Fig. 5). According to the results obtained, working in the range of 1.6 to 3 m/s, the values of temperature, stress and strain remain within the accepted design limits for copper. In particular, the sensitivity of stress and strain is negligible to velocity variation. On the other hand, this calculation has been reproduced for a machine current of 400 mA, however, after more than 10 years of operation, we currently are working at 250 mA, which would imply a second conservative margin not considered at the beginning of the ALBA project.

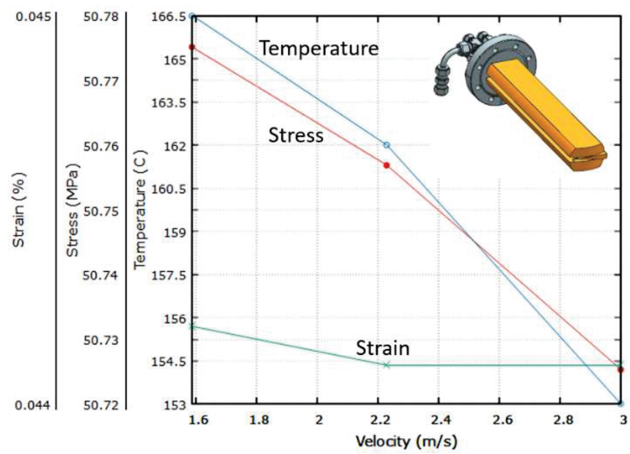

Figure 5: FEA results of the absorber type 2 in the SR.

CONCLUSION

To reduce the current rate of copper corrosion in ALBA's cooling system, it is necessary to install a degassing plant to remove the DO content in the water. At the moment this step is not feasible, due to the high value of DO content, greater than 6500 ppb. This value would correspond to an open hydraulic system, when in reality our hydraulic system is closed by definition. This paper presents the investigations that ALBA has launched to determine the cause of this problem.

Our investigations have concluded that the analysed samples show intergranular, generalized and pitting corrosion. Pit depths are below 119.4 µm.

This paper also presents a group of optimization actions, in the context of the copper corrosion problem. Some of them are the improvement of our capacity to diagnose water quality with new instrumentation; optimization of the air purge system; and studies to reduce the value of the maximum water velocity imposed for the design of the components in Accelerators, with the aim of attenuating the erosion effect.

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REFERENCES

[1] D. Katonak, J. Bernardin, and S. Hopkins, "Water Purity Development for the Coupled Cavity LINAL (CCL) and Drift Tube LINAC (DTL) Structures of the Spallation Neutron Source (SNS) LINAC", in *Proc. 2001 Particle Accelerator Conference,* Chicago, IL, USA, June 2001, pp. 1432-1434.

[2] J.C. Chang *et al.*, "Current Status of the De-Ionized Cooling Water System and Improvement at TLS", in *Proc. MEDSI04*, ESRF, Grenoble, France, May 2002.

[3] R. Dortwegt *et al.*, "Mitigation of Copper Corrosion and Agglomeration in APS Process Water Systems", in *Proc. MEDSI02*, APS, Argonne, Illinois U.S.A, September 2002, pp. 462-468.

[4] S. Suhring, "Accelerator Availability and Reliability Issues", in *Proc. 2003 Particle Accelerator Conference*, Portland, OR, USA, May 2003, paper ROPB007, pp. 625-629.

[5] B. Adak, "Copper Corrosion and Clogging in APS Deionized Water Cooling System", Doctoral Thesis, Illinois Institute of Technology, Chicago, Illinois, May 2009.

[6] N. Hammond, "Cooling Water Chemistry, Corrosion Products and their effect on Accelerator Operation at the Diamond Light Source", in *Proc. MEDSI 2012*, SSRF, Shanghai, China, October 2012.

[7] P. Czernecki *et al.*, "Technical Overview of the SOLARIS Low-Conductivity Water Cooling System", in *Proc. IPAC2017*, Copenhagen, Denmark, May 2017, paper WEPVA082, pp. 3449-3451. doi:10.18429/JACoW-IPAC2017-WEPVA082

[8] H. Reist and D. George, "Accelerator Magnet Plugging by Metal Oxides", PSI Scientific and Technical Report 2004, Volume VI, pp. 142-145.

[9] M. Quispe *et al.*, "Assessment of the Corrosion of Copper Components in the Water Cooling System of ALBA Synchrotron Light Source; Presentation of a Proposal to Mitigate the Corrosion Rate of Copper", in *Proc. MEDSI 2020*, Chicago, IL, USA, July 2021, paper TUPB12, pp. 171-174. doi:10.18429/JACoW-MEDSI2020-TUPB12

[10] A. González *et al.*, "CFD Predictions of Water Flow Through Impellers of the ALBA Centrifugal Pumps and Their Aspiration Zone. An Investigation of Fluid Dynamics Effects on Cavitation Problems", in *Proc. MEDSI 2020*, Chicago, IL, USA, July 2021, paper WEPB16, pp. 299-302. doi:10.18429/JACoW-MEDSI2020-WEPB16

[11] M. Quispe, "Cooling System Operation", 21st Meeting of the ALBA Scientific Advisory Committee, Barcelona, Spain, December 2015.

[12] S. Grozavu *et al.*, "CFD Studies of the Convective Heat Transfer Coefficients and Pressure Drops in Geometries Applied to Water Cooling Channels of the Crotch Absorbers of ALBA Synchrotron Light Source", presented at the 13th International Particle Accelerator Conf. (IPAC'22), Bangkok, Thailand, Jun. 2022, paper THPOTK050, this conference.