Flow Restrictions in Water-Cooled Generator Stator Coils: Prevention, Diagnosis and Removal

Part 4: Chemical Cleaning of Water-Cooled Generator Stator Coils by the Cuproplex® Method

Robert Svoboda

Christoph Liehr

Hans-Günter Seipp

ABSTRACT

The Cuproplex process for removing copper oxides from generator cooling systems is characterized by the coordinated use of complexants, oxidants and auxiliary chemicals. The process can be performed off-line, as well as on-line with the generator in operation.

Off-line cleaning is usually done by injecting the dilute chemicals into the running pure-water system, sequentially over several cycles. On-line cleaning employs the continuous injection of chemicals at a sufficiently dilute concentration to keep conductivity below maximum allowed limits. On-line cleaning does not interfere with generator availability and provides real-time monitoring of the cleaning effects. However, on-line cleaning takes longer. The reagent and the dissolved copper are absorbed in the ion exchanger that is part of the system and disposed of as solid waste. The process thus offers the possibility of zero-liquid discharge.

INTRODUCTION

Flow restrictions in hollow conductors of water-cooled generators are most commonly caused by copper oxide deposits, but may also be caused by various debris that has entered the recirculating water, or even by mechanical deformation of the hollow conductors. The resulting load limitations and downtime required for repairs result in serious financial losses. It is therefore useful to have options for removing such restrictions.

This is the fourth part of a series of four papers to appear in this journal on the prevention, diagnosis and removal of flow restrictions in water-cooled generator coils [1–4]. This information has also been included in more detail in EPRI publications on this subject [5,6].

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BACKGROUND

In order to overcome the problems inherent with acid cleaning techniques [3], we developed a method which removes only oxides and can be applied to the whole cooling system under any operating condition – on- or off-line [7]. The method is based on complexing agents in combination with an oxidizer. First applied in 1980, it was subsequently patented and further developed into today's Cuproplex® method [8]. In 1996 the first Cuproplex on-line cleaning was carried out at the 1 350 MVA Seabrook generator; that was chemical cleaning while the generator was operating at full load [9].

Up to March 2004, we have applied this method in 121 generator cleanings, 22 of these on-line, on a total of 99 generators made by 8 different OEMs. At 10 generators, the water-cooled rotor has also been included in the cleaning.

CUPROPLEX®

The Cuproplex Process

This proprietary process by Alstom is characterized by the coordinated use of complexants, oxidants and auxiliary chemicals.

For practical reasons the complexing agent EDTA is mostly used (disodium salt of ethylene diamine tetra acetic acid). It is circulated through the whole system. It dissolves only copper oxides and does not react with copper metal. This agent is very efficient for dissolving CuO (cupric oxide), but not for Cu_2O (cuprous oxide), which is an important component of the oxide deposits. To increase the efficiency to remove Cu_2O, the process adds oxidizers, for example H_2O_2 (hydrogen peroxide). This also oxidizes and facilitates the removal of Cu-particles which could be present in the system.

Activators are added during some stages of the cleaning in order to initiate a prompt reaction with the oxides. Inhibitors are also added incrementally in order to delay the reaction of H_2O_2 with Cu so that H_2O_2 reaches all parts of the system. The chelation process prevents copper oxides from entering further reactions.

The art of such cleaning consists of choosing the right balance of chemicals at the various stages of the cleaning. Too much oxidizer, for example, may produce more oxides than the complexant can dissolve; too little oxidizer

makes the dissolution incomplete or may even leave conductive deposits on the isolating hoses. Some cases do not even require an oxidizer at all. If the balance of chemicals is not right, the generator may clog again within a short period of time [10].

The reagents and the dissolved copper are absorbed in the ion exchanger that is part of the system and disposed of as solid waste. Thus the process offers the possibility of zero-liquid discharge. However, the liquids used are neither toxic nor aggressive, so it is not efficient to avoid water losses entirely. The drain water has to be environmentally controlled but chemicals are so dilute that – in contrast to acid cleaning – no special precautions are necessary for handling.

Off-Line and On-Line Cleaning

Different to acids, complexants do not need a minimum strength for reacting with copper-oxides. The process can be done with a sufficient dilute solution so it does not interfere with any conductivity limits. The Cuproplex process can therefore be applied either during a generator shutdown (off-line) or when the generator is in operation (on-line). An off-line cleaning takes between three and seven days; an on-line cleaning two to three weeks.

Cuproplex Off-Line is performed by injecting the chemicals into the running pure-water system. The chemicals are applied in dilute form, sequentially over several cycles. The application of the chemicals is modified according to the response of the system to the chemical changes. The end of cleaning is usually not indicated before the reaction yield decreases, that is, when little or no additional oxides are dissolved as new chemicals are added.

Cuproplex On-Line employs the continuous injection of chemicals at a sufficiently dilute concentration to keep conductivity below maximum allowed limits. On-line cleaning does not interfere with generator availability and provides real-time monitoring of the cleaning effects. However, on-line cleaning takes longer and is more expensive.

Figures 1 and 2 give a process overview and show a typical set-up.

Materials Compatibility

It is important to consider the effects of chemical cleaning on all other involved materials and components. Especially the effects on the brazing material for the hollow conductors and the waterboxes need close attention.

Compared to acids, complexants are hardly aggressive to system materials. The process typically removes from 0.2 to 5 kg of copper as oxide during a cleaning. Only the oxides that have already formed in the system are removed, so the treatment does not promote any significant loss of wall thickness (< 1 µm). The process can be repeated as often as desired. The reagents do not attack either copper or steel, just the hydrogen peroxide oxidizes a small quantity of copper, which is subsequently dissolved by the EDTA.

Investigations have also been made into the effects on other system materials, especially brazing and solder [12]. It was found that materials attack (if any) is exceedingly less than with acid cleaning.

The reagents may, however, dissolve oxides which plug leaks. The few cases where this has happened were in system piping and all related to faulty welding joints. In addition, the pump seals have on some occasions started to leak during the cleaning.

We have also cleaned stators which suffered from active clip-to-strand leaks [5]. Close monitoring indicated that the leaks did not increase during the cleaning.

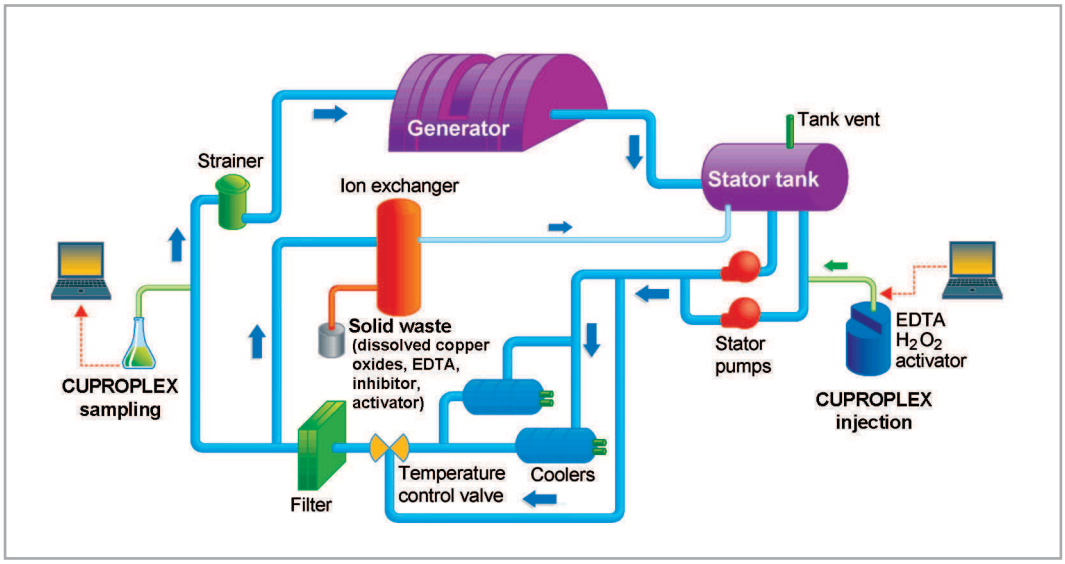


Figure 1: Application plan for the Cuproplex process.

Figure 2: Typical set-up for off-line (top) and for on-line cleaning (bottom).

Follow-up Treatment after Chemical Cleaning

After thorough chemical cleaning, the copper surface is blank metal which is stable in water and does not require a passivation. If the water then contains oxygen, an oxide layer is again formed. Experience has shown that – depending on water chemistry – this oxide layer may, however, not always be stable. It may dissolve, migrate and redeposit, thus clogging the generator within a short period. This can be avoided by applying a directed reoxidation.

We have developed a process for reoxidation based on the fact that better results are obtained when this is done in an alkaline environment [6,9]. The process is optimized by the use of inhibitors. It is especially useful in machines that will be returned to high-oxygen water treatment [10,11].

Limitations

Hollow conductors that are completely blocked and do not have any water flow cannot be cleaned by any type of chemical cleaning. They require a preceding mechanical cleaning.

With all the cleaning methods available, one important point should be kept in mind: the cause of the clogging is not eliminated by the cleaning; reoccurrence of clogging cannot be excluded. Thus cleaning is not the final solution to the problem.

EXPERIENCE

The 121 cleanings we have carried out so far were implemented for one or more of the following reasons:

- Diagnosis:
  To determine the amount of oxides accumulated in the system in order to assess past and expected future performance of the generator.
- Maintenance:
  To remove oxides and reestablish the original cooling capabilities.
- Prevention:
  For routine cleaning of the system to ensure cooling system efficiency. This is of special interest for generators with many years of operation.

In most maintenance cleanings, Cuproplex provided the desired effect. Only in a few cases was there no improvement in flow or in temperatures. These cases may have been due either to very compact oxides or metallic copper, or other material not accessible to the cleaning agents, like debris, or to some conductors in the hot bars being completely blocked (and inaccessible to any chemical cleaning) or mechanically deformed.

In no case did a Cuproplex cleaning do any damage to the generator or components of the cooling system.

Sometimes the question arises of whether (any type of) chemical cleaning makes a generator more susceptible to renewed plugging that necessitates another cleaning. If a cleaning is done properly, no such susceptibility occurs. Cuproplex reference shows that of the total of 99 generators so far cleaned, only 13 had another cleaning later on. These were for various reasons, including preventative cleanings, or generators where it was not possible to eliminate the root cause of plugging.

Figures 3 to 8 give some practical results from Cuproplex cleaning.

On-Line Cleaning of a 1 160 MW Generator with Design High-Oxygen Chemistry

Figure 3 displays the results of the on-line cleaning of a generator with a design high-oxygen chemistry. Due to insufficient feed of air into the system, the water had in fact a low-oxygen content for many years. At the point when

large amounts of air entered the system, the stator water flow started to decrease substantially (Figure 3). In consequence, the load of this 1 160 MW nuclear power plant had to be reduced in peak demand season. On-line cleaning brought back the plant to full cooling capacity, permitting full power operation within a few days. As a special feature, this generator had active clip-to-strand leaks [5]. They did not increase with cleaning.

The generator then was returned to controlled low-oxygen chemistry and has been operating successfully like this for the last 8 years.

It should be mentioned that we also have cleaned other generators with oxygenated water treatment that have subsequently successfully been returned to high-oxygen conditions. These generators have now been operating up to 5 years without recurrence of plugging.

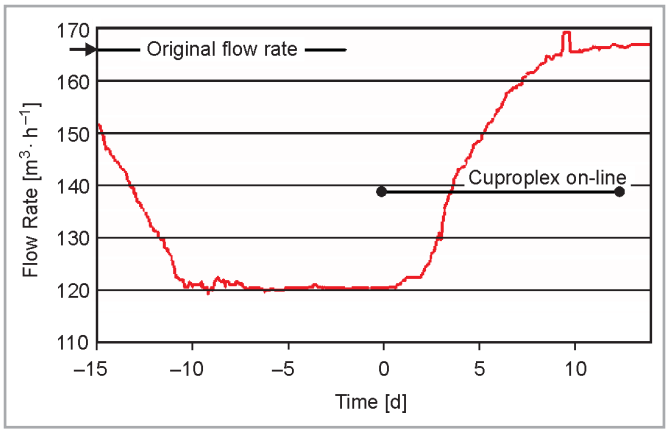
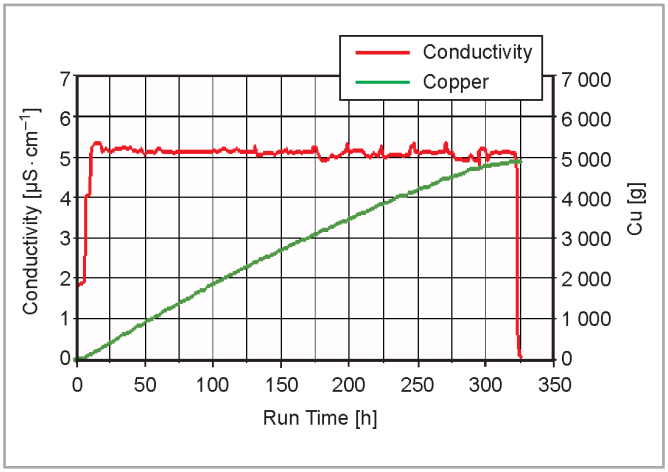


Figure 3: Plant S: Improvement in cooling water flow by chemical cleaning.
Date zero indicated the start of on-line cleaning. The data before show the deterioration of cooling water flow as the result of continuous oxygen injection. Cooling was fully restored by Cuproplex on-line cleaning. The generator was on-line all the time.

On-Line Cleaning of a 540 MW Generator with Parsons Waterbox Design

Figures 4 and 5 give results from the on-line cleaning of a 540 MW generator in another nuclear power plant. As a special feature, this generator employs the Parsons waterbox design. The background of the cleaning as well as additional information has been published in another paper [12]. Cooling also had deteriorated in such a way that the plant load had to be reduced.

Figure 4 shows that the conductivity could be kept stable at the nominal value throughout the cleaning. Higher conductivity would have tripped the generator. It can also be seen that the reaction yield decreased to low levels towards the end of the cleaning, indicating that further cleaning would remove only a small (but possibly still important) quantity of oxides.



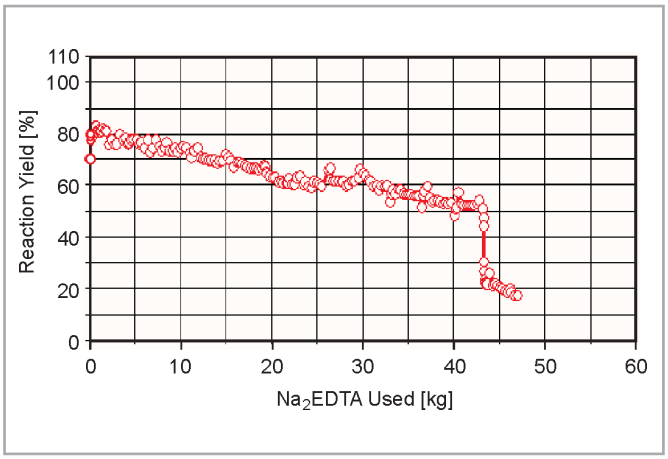


Figure 4: Plant P6: Conductivity, copper removal (top), and process reaction yield (bottom) during the on-line cleaning.

Figure 5 shows the improvement in stator water flow and in the slot temperatures. Stator water flow improved substantially, from 25 $kg \cdot s^{-1}$ to 35 $kg \cdot s^{-1}$ within 4 days of cleaning. The rise in temperatures before the begin of the cleaning is clearly seen, indicating a quick rise towards overheat within a few weeks. On-line cleaning brought temperatures back to normal within a few days.

It is interesting to note that the hottest slot cooled much faster than the rest. It seems that this bar did not require much oxide to plug it up, in other words it may be especially sensitive to clogging and may be at special risk of plugging again. Such behavior is indicated, for example, if a bar has mechanical flow restrictions, e.g., due to pinched or dented hollow conductors. For long-term stabilization, such bars may need a repair other than chemical cleaning, or a replacement.

The temperature decrease at 205 hours run time was caused by changes in hydrogen cooling and is not related to the cleaning.

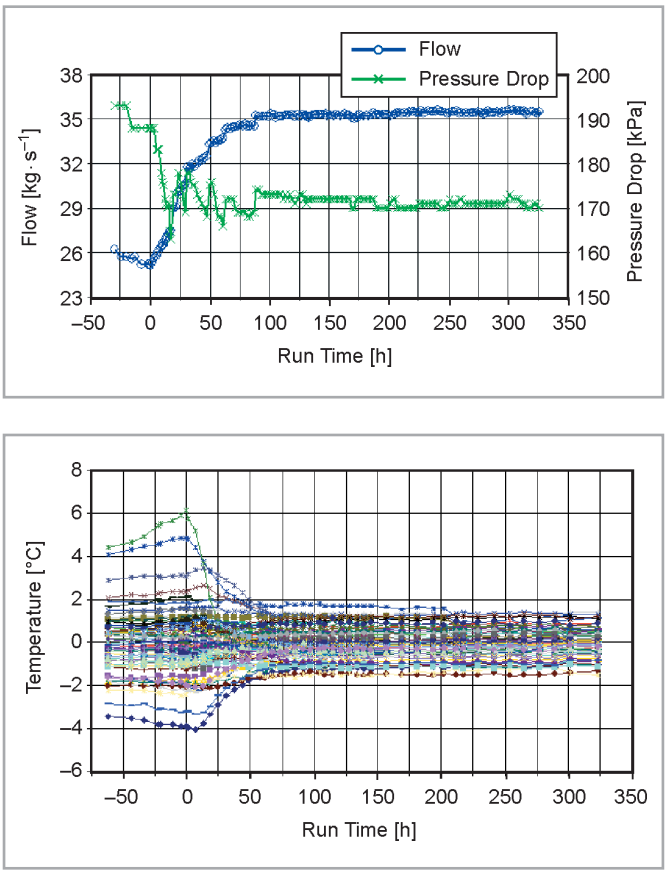


Figure 5: Plant P6: Improvement in stator water flow, stator pressure drop (top), and slot temperatures (bottom) during the on-line cleaning.

Off-Line Cleaning

Figure 6 shows process control data for off-line cleanings at generators in a hydroelectric (T4) and two coal-fired power plants (S3, TH3). It is interesting to note that the generator with the least copper oxides had serious plugging problems, while the one with the most oxides was cleaned only as a preventive measure.

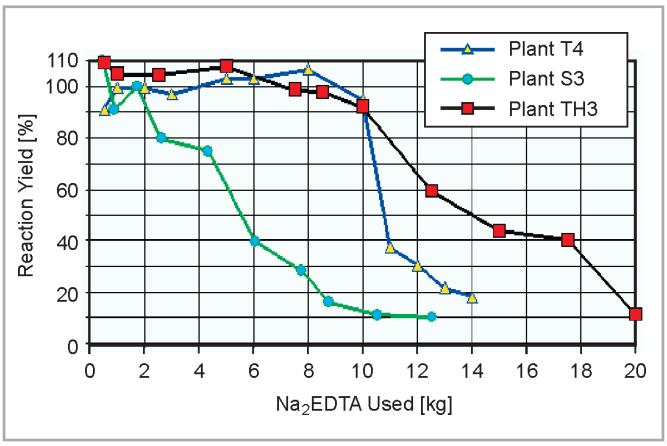


Figure 6: Cuproplex off-line cleaning. Process reaction yield in three different generators. Generator S3 had serious plugging problems; T4 and TH3 were preventive cleanings.

Figure 7 shows the improvement in the stator pressure drop at a 400 MW generator in a gas-fired power plant with off-line cleaning.

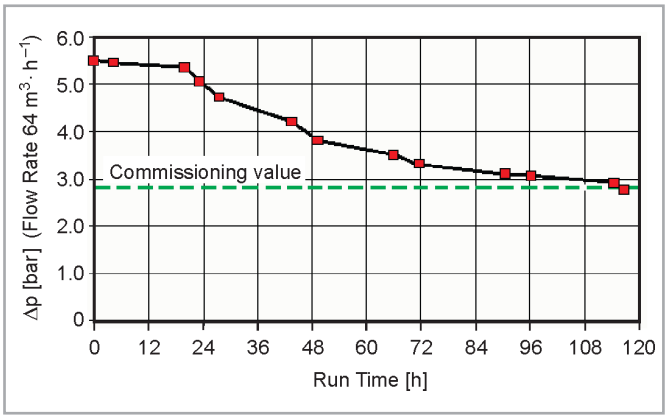


Figure 7: Improvement in stator pressure drop with off-line Cuproplex cleaning (plant GF).

Figure 8 shows photos of the same water chamber of a 750 MW hydroelectric generator before and after off-line cleaning. The cleaning effect is evident.

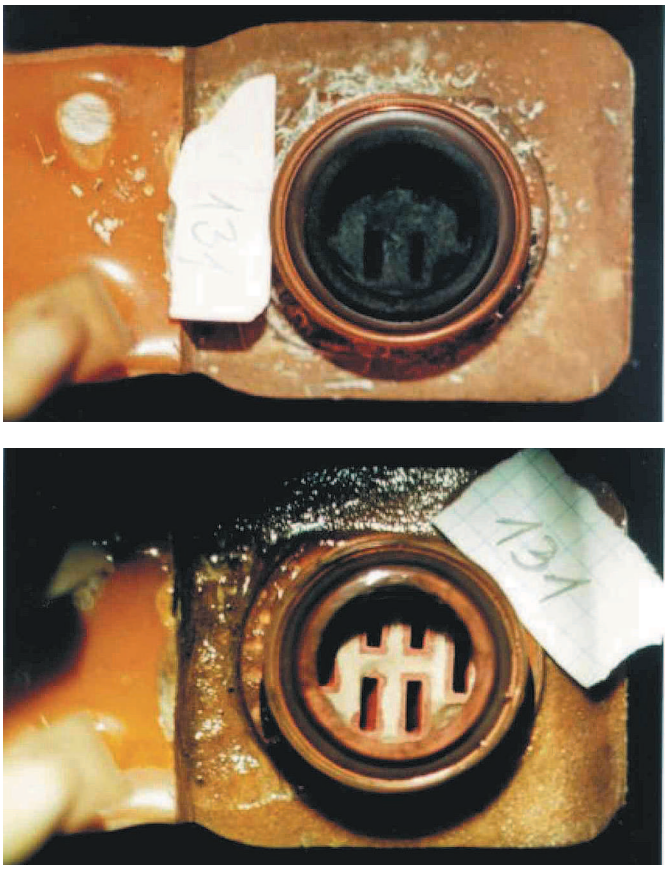


Figure 8: Plant I14: Removal of deposits by chemical cleaning.
Condition of the inlet water chambers of the same stator bar before (top) and after (bottom) Cuproplex cleaning. Before cleaning, the surface was covered by black copper-oxide deposits. After cleaning, the clean copper and brazing surfaces are visible.

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THE AUTHORS

Robert Svoboda (Ph.D., Physics, University of Vienna, Austria, postdoctoral studies on reactor metallurgy in Saclay, France) has been with the chemical laboratory of Alstom Power, Baden, Switzerland since 1969 (formerly part of Brown Boveri & Cie), where he headed the Power Plant Chemistry Section, and starting in 1992 the Power Plant Chemistry Department in Mannheim, Germany. He has since returned to Switzerland as a technical advisor. His work is concentrated on water chemistry, corrosion and radiation technology.

Christoph Liehr (Dipl.-Ing., Chemical Engineering, University of Dortmund, Germany) has been with the chemical laboratory of Alstom Power, Germany since 1987 (formerly part of Brown Boveri & Cie, and ABB), where he is a specialist in power plant chemistry. His responsibilities include R&D projects, chemical power plant engineering, and chemical investigations in the home laboratory as well as in power plants. One of his specialties is generator cooling water chemistry. So far he has chemically cleaned more than 25 generators, produced by both his parent company and by other OEMs.

Hans-Günter Seipp (Dipl.-Ing. (FH), Chemical Technology) was with Alstom Power Support GmbH, Mannheim (formerly part of Brown Boveri & Cie) from 1965 until his retirement in 2003, where he first headed the Water Chemistry and Corrosion Group. He has actively contributed to several working groups under VGB, DIN, etc. for more than 38 years and has published more than 75 technical papers in power plant chemistry.

CONTACT

Robert Svoboda
ALSTOM (Schweiz) AG
Materials TGTM
P.O. Box
5401 Baden
Switzerland

E-mail: robert.svoboda@power.alstom.com

Hans-Günter Seipp
Augusta Anlage 23
68165 Mannheim
Germany

E-mail: hans-guenter.seipp@t-online.de

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