GLYCOL SUBSTITUTE FOR HIGH POWER RF WATERLOADS

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Abstract

In waterloads for high power rf applications, rf power is dissipated directly into the coolant. Waterloads in frequency range <1 GHz are ordinarily designed for using an ethylene-glycol water mixture as coolant. Normally a mixture of about 30% glycol and 70% deionised water is used to increase the rf absorption in the VHF-UHF range. Due to the increased ecological awareness, the use of glycol is nowadays considered to be problematic. Therefore a glycol-substitute was searched for and found. The found sodium-molybdate based substitute is actually an additive for corrosion protection in water systems. Sodium-molybdate is ecologically harmless; for instance, it is also used as fertilizer in agriculture. A homoeopathic dose of <0.1% mixed into deionised water gives better rf characteristics than 30% glycol. The rf coolant features of this substitute were investigated and tested at our test facility for one year. In summer shut-down 2004 the glycol coolant of all 14 rf systems at DORIS-3, PETRA-2 and HERAe was substituted. The results of the investigations and tests are presented.

INTRODUCTION

The 500-MHz and 1-GHz rf systems at DESY utilize about 100 glycol-waterloads with dissipated powers ranging from 100 kW to 600 kW. These waterloads are designed as coaxial lines with a glycol-water mixture used as lossy dielectric and coolant. Most of them are 100-kW types and are in service as balance-loads at the magic-tees and hybrid couplers of the waveguide power distribution systems. The types of higher power capability are in service as circulator loads and dummy loads for klystron tests. Due to the increased ecological awareness, the use of glycol is nowadays considered to be problematic. In EU it is forbidden to discharge glycol into the sewage water system. In case of cooling system leakages one has to make sure that no glycol is lost. Since it is nearly impossible to avoid any glycol loss in large rf systems with approx. 100 waterloads and several hundred meters of piping system, a glycol-substitute was searched for. An additional motivation for searching a glycol-substitute was the necessary and time-consuming cleaning procedure in the case of a glycol-water flooded waveguide system as a result of a broken load window.

EXPERIMENTS ON A GLYCOL-SUBSTITUTE

For first general surveys our primarily used load type shown in Fig. 1 and Fig. 2 was chosen.

Figure 1: 100-kW, 500-MHz coaxial load for 30% glycol-water coolant. The load type was designed and build at DESY. Due to the usage of glycol the attenuation constant has been increased from about 17dB/m to 26dB/m @ 30°C coolant temperature. Thus it was feasible to make the design relative compact.
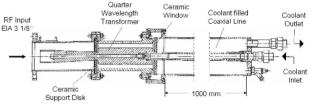

Figure 2: Cross-sectional view of the load shown in Fig. 1. The right half of the drawing represents the actual load with the coolant connections. Left to the ceramic window the transformer for matching the low coolant impedance to the 50Ω impedance of the 3 1/8´´ line is shown.

The return loss was measured first with the common used glycol-water mixture at different frequencies and coolant temperatures. Adjacent deionised water, salt water and tap water were measured to find out whether the dielectric loss effect of glycol could be replaced by the conductive loss effect of dissolved minerals. It turns out that simple tap water is a quite effective rf absorber because of its conductivity of approximately 300 µS/cm due to dissolved minerals. Unfortunately the potential for scale deposition makes it inapplicable for waterloads. Salt water (0.2 g NaCl per litre deionised water) gives a similar conductivity and rf absorbing property. But due to its corrosive potential it is also inapplicable for waterloads [1], [2]. In search of a substance having sufficient conductivity but no corrosive and scale deposition potential a perfect substitute was found. The found substance is an additive developed even especially to combat scale deposition and corrosion in closed hot-water cooling circuits. It is sold under the label CORRSHIELD™ MD4151 [3]. It is an aqueous alkaline solution with <25% sodium-molybdate Na_2MoO_4 and 0.5-2% sodium-hydroxide NaOH. Sodium-molybdate is ecologically harmless; for instance, it is also used as fertilizer in agriculture. At our waterloads a homoeopathic dose of 0.4% CORRSHIELD™ MD4151 mixed into deionised water leads to significant better load matching than a 30% glycol mixture (see measurements presented in Fig. 3 and Fig.4).
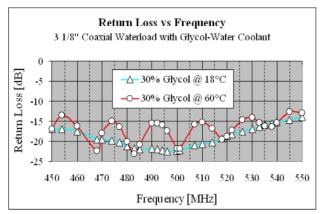
Figure 3: Measured return loss of the 100-kW load with glycol-water coolant. Due to the decrease of the attenuation constant at higher temperatures a standing wave built up inside the load. At frequencies where an integer number of half wavelengths fit into the load, the return loss has a minimum.
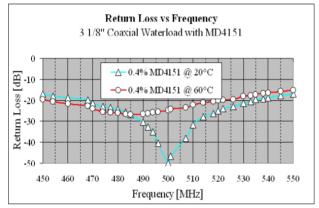

Figure 4: Measured return loss of the 100-kW load with 0.4% CORRSHIELD™ MD4151 coolant. The return loss at 500 MHz and 20°C coolant temperature is approximately 3 dB better compared to 30% glycol. At 60°C the difference is about 25 dB.

After this encouraging result the 1200 litre glycol-water coolant content of our test facility was exchanged for a 0.4% MD4151-water mixture. It was observed that also the other installed waterload types show better matching with this new coolant. The return loss improved between 3…6 dB, depending on load type and coolant temperature. The new coolant was tested for one year at our test facility to ensure that no negative long-term effects appear. In August 2004 the glycol-water coolant of all 14 rf systems at DORIS-3, PETRA-2 and HERA-e was replaced by a 0.4% MD4151-water mixture.

INVESTIGATIONS ON SODIUM MOLYBDATE

As already mentioned CORRSHIELD™ MD4151 is an aqueous alkaline solution with sodium-molybdate (Na_2MoO_4) as essential ingredient. It was assumed that the 25% fraction of Na_2MoO_4 is responsible for the high

attenuation constant. To confirm this assumption pure Na_2MoO_4–water solutions were investigated. For measuring the rf absorbing properties at different concentrations, temperatures and frequencies a coaxial measuring line was built (Fig. 5). For TEM-waves the attenuation constant due to dielectric losses is independent on the dimensions of the rf line. The chosen dimensions are: inner conductor diameter d=3mm, outer conductor diameter D=35mm, length l=206mm. With this dimensioning the inner conductor has sufficient mechanical stiffness, the diameter of the outer conductor is small enough to allow measurements up to approximately 1 GHz and the length is adequate to allow measurements up to below 100 MHz.

Figure 5: Coaxial measuring line for coolants.

Even though the impedance of the measuring line was chosen as high as possible (147 Ω @ ε_r=1) the impedance with the coolants to be investigated is quite low. The impedance range reaches from 15.5 Ω @ ε_r=90 to 19 Ω @ ε_r=60. To achieve an adequate transmission despite of the mismatch with respect to the 50 Ω impedance of the measuring setup the measurements were carried out at half-wavelength resonances.

Measuring Principle

The wave attenuation along a lossy line is

$$\frac{V_{out}}{V_{in}} = \exp^{-\alpha d}$$

However, the power ratio was measured.

$$\frac{V_{in}}{V_{out}} = \sqrt{\frac{P_{fwd} - P_{rfl}}{P_{out}}} = \sqrt{\frac{P_{in}}{P_{out}}}$$

The attenuation constant then can be calculated by

$$\alpha = \frac{1}{l} \cdot \ln\left(\sqrt{\frac{P_{in}}{P_{out}}}\right) \qquad (1)$$

α: attenuation constant [Np/length] (1 Np = 8.686 dB),
l: line length,
P_{fwd}: incident (forward) power,
P_{rfl}: power reflected at the line input,
P_{out}: output power at the end of the line,
V_{in}: wave amplitude at line input,
V_{out}: wave amplitude at line output,

The attenuation constant was measured at different Na_2MoO_4-concentrations, different temperatures and frequencies. The frequency range was given by

$$f_{min} = \frac{c_0}{2\sqrt{\varepsilon_r \cdot l}} \; , \qquad f_{max} \approx \frac{c_0}{\sqrt{\varepsilon_r \cdot (D-d)}}$$

f_{min}: 1st half-wavelength resonance (75…95 MHz),
f_{max}: 1st higher mode (E_{01} at 990…1200 MHz)

By counting the number of half-wavelength resonances over the frequency sweep, the dielectric constant ε_r can be calculated:

$$\varepsilon_r = \left(n \cdot \frac{c_0}{2 \cdot l \cdot f_{res}} \right)^2 \qquad (2)$$

f_{res}: frequency of the half-wavelength resonance
n: number of half-wavelengths along the line

With the attenuation constant α from Eq. 1 and the dielectric constant ε_r from Eq. 2 the loss factor $d = \tan(\delta)$ of the coolants can be calculated.

$$d = \tan(\delta) \cong \alpha \frac{c_0}{\pi \cdot f \cdot \sqrt{\varepsilon_r}} \qquad (3)$$

Failure $< 1 \; ^0/_{00}$ for $\tan(\delta) < 0.1$

Results

Some results are represented in the diagrams below. Fig. 6 shows the attenuation constant α of different coolants versus frequency. It strikes directly that the attenuation constant of the coolants is spread over a wide range at low frequencies on the one hand and is approximately independent from the used additive at about 1 GHz on the other. At 500 MHz the attenuation constant of a 0.01% Na_2MoO_4 solution is 10dB/m higher than of deionised water and comparable to a 30% glycol solution. The attenuation constant of a 0.1% Na_2MoO_4 solution is even 45dB/m higher.
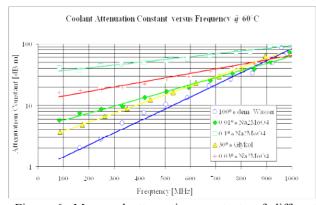

Figure 6: Measured attenuation constants of different coolants versus frequency at a coolant temperature of 60°C.

Beside the attenuation constant itself its temperature dependency is an important coolant feature. In case of decreasing with temperature the matching of the load suffers. In case of increasing with temperature the power absorption concentrates further and further to the input port of the load. This could result in local boiling of the coolant. In Fig. 7 the attenuation constant of different coolants versus temperature is represented. For a 0.01% Na_2MoO_4 solution the attenuation constant decreases with temperature, but the temperature dependence is less compared to the glycol solution. For a 0.1% Na_2MoO_4 solution the attenuation constant increases with temperature. The optimal dosage found for 500 MHz is 0.03%.
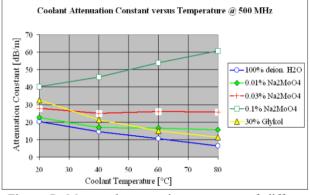

Figure 7: Measured attenuation constants of different coolants versus temperature at 500 MHz.

SUMMARY

The glycol-water coolant of all 500-MHz and 1-GHz rf systems at DORIS-3, PETRA-2 and HERA-e was successful substituted by deionised water with 0.4% CORRSHIELD™ MD4151 as additive for increasing the rf attenuation constant. The hazard of future glycol pollution of waveguide systems and sewage water is banished thereby. As a welcome side-effect the return loss of the waterloads increased by 3 to 6 dB. From further investigations resulted that the essential component of CORRSHIELD™ MD4151, responsible for the rf attenuation property, is the 25% percent fraction of Na_2MoO_4. Investigations on different Na_2MoO_4 concentrations showed furthermore that the optimal dosage for minimum $d\alpha/dT$ is 0.03% (equivalent to 0.12% CORRSHIELD MD4151).

REFERENCES

[1] H. Frischholz, "The LEP RF Power Plant", Chamonix-Meeting, CERN, Switzerland, 1997.
[2] H. Frischholz, private communication.
[3] CORRSHIELD™ is distributed amongst others by BetzDearborn, Germany and GE-Betz, Houston, Texas.