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LONG TERM INVESTIGATION OF THE DEGRADATION OF COAXIAL CABLES

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Abstract

Coaxial cables are important components for the control and diagnostics of any accelerator facility. Their electrical and mechanical properties have major impact on the quality of the acquired analogue signals and in turn on the performance of the whole machine.

Cables installed in immediate vicinity to the beam line are exposed to ionizing radiation that is mainly generated by beam-loss. In this environment cables change their electrical properties which directly affects the signal on the receiver side and in turn the measured beam parameters. For the transport of broadband signals in the multi-GHz range cables using PTFE ("Teflon") as dielectric medium are used most frequently. Optimized products offer low insertion loss, small phase drift and large spectral bandwidth at a moderate price level. At the same time PTFE commonly known to be prone to radiation induced degradation. This statement holds for a qualitative discussion but real measurement data are rarely published. At the ELBE accelerator at Helmholtz-Zentrum Dresden-Rossendorf (HZDR) 40 GHz-bunch arrival time monitors (BAMs) are used to measure the arrival time of the electron bunches with high accuracy [1]. In order to improve the sensitivity of the setup it has been considered to replace the SiO2 cables connecting the beam line pickup and the electro-optical modulator (EOM) by low-loss and low-drift PTFE-based cables. Since these cables are exposed to the activated environment a long-term test has been performed to characterize the degradation of the sample cables under real conditions. A maximum accumulated dose of 93.85 kGy has been applied to the test samples.

MEASUREMENT SETUP

Preliminary Dose Mapping Setup

For the irradiation of cable samples a place had to be found which allowed to accumulate a dose corresponding to multiple years of normal operation within a much shorter time frame. At the same time the distribution of the gamma radiation should be as homogeneous as possible to avoid effects triggered by a local maximum. Since no dedicated beam time could be spend on this investigations it has been decided to mount two cable samples on an aluminum plate that was place behind the beam dump of ELBE's undulator U100. The dump is used routinely during user operation in the free electron laser (FEL) cave. The beam energy and therefore the emitted spectrum of Bremsstrahlung-photons is defined by the user's demand for the FEL operation. The characteristic spectrum of Bremsstrahlung is a broadband distribution were the maximum energy is defined by the electrons incident energy. Before the final setup was installed, a coarse field map using five alanine dosimeter [2] has been created. One sensor was put directly on the interpolated beam axis and four with a defined distance from the center. The sensor distribution can be seen in Figure 1 and the aquired data in Table 1.

Figure 1: Dose mapping setup.

Table 1: Preliminary Dose Mapping Behind U100 Beam Dump

Position	Name	Accumulated Dose
Top-Left	B1C2	780 Gy
Top-Right	B2C2	850 Gy
Bottom-Left	B3C2	2520 Gy
Bottom-right	B4C2	3330 Gy
Center	A4C1	19 260 Gy

Final Measurement Setup

For the final setup two types of cable have been installed concentrically around the imaginary beam axis on the base plate. In the following sections the two cable types are always referred as cable under test 1 (CUT1), and cable under test 2 (CUT2). Both samples were connected to a patch panel that was accessible by RF measurement equipment using 5 m patch cables made of the same cable type like CUT2. Before the installation of the base plate at the back of the beam dump, ten alanine dosimeters have been attached to the cable spools in order to give a good spatial resolution of

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the applied dose. The alanine dosimeter have to be removed to acquire the integrated dose over the whole time frame. For a punctual online measurement a Multidos radiation probe [3] has been installed next to the setup. The acquired measurement data from that probe has been used to scale the intermediate measurements with the accumulated dose. As a complementary information a temperature probe has been placed on the cable spools to make sure that the cable were not heated up beyond room temperature. Figure 2 shows the final installation of the two samples and the applied diagnostics.

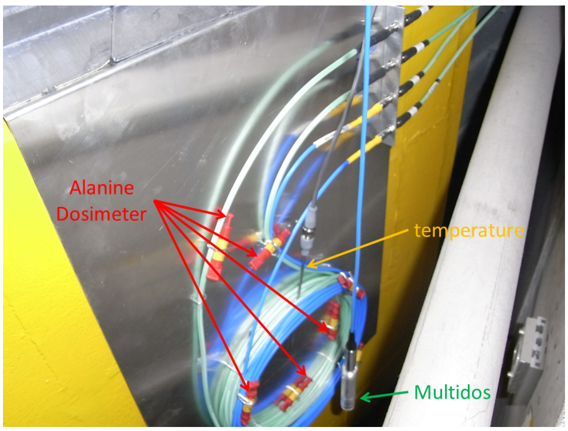

Figure 2: Final long term measurement setup.

The cable samples have been irradiated in the course of five subsequent ELBE user runs from October 2015 till December 2016. Since ELBE is a multi-beamline facility which can usually serve only one end station at a time, the dose has not been applied in a continuous manner but in many different user beam times.

Measurement Procedure

At the end of every user run, the scattering parameters (S-parameters) have been measured. While S21 and S12 are describing the transmission behavior of a device under test the parameters S11 and S22 are describing the reflection behavior of a sample. Since cables are passive devices, the two reflection and the two transmission coefficients are the same.

The measurements have been performed using a four port vector network analyzer (Rhode & Schwarz ZVA40) that has a bandwidth of 40 GHz.

In order to separate the behavior of the patch cables from the sample cables, the S-parameters have been measured before the carrier plate has been mounted on the back of the beam dump and measured again immediately after the end of the long term run when the plate has been unmounted. This turned out to be important because the used patch cables (CUT2-type) has a characteristic notch in the frequency spectrum that can not be observed in the spectrum of the CUT1.

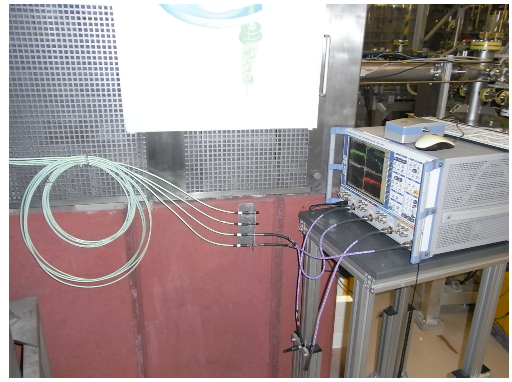
Figure 3: Scattering parameters measurement.

MEASUREMENT RESULTS

Long Term Dose Measurement

The long term dose measurement has been performed using the Multidos probe installed in immediate vicinity to the cable samples. Figure 4 shows the integrated dose for the measurement period. The markers in green indicate the individual measurements where the scattering parameters have been acquired and which accumulated dose has been applied to the samples to that point.

The Figures 5 and 6 are showing the results of the S21 measurements for CUT1 and CUT2 up to 40 GHz.

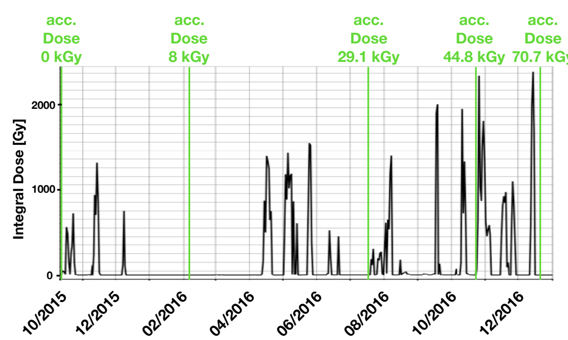

Figure 4: Accumulated dose acquired by a Multidos probe during long term measurement run.

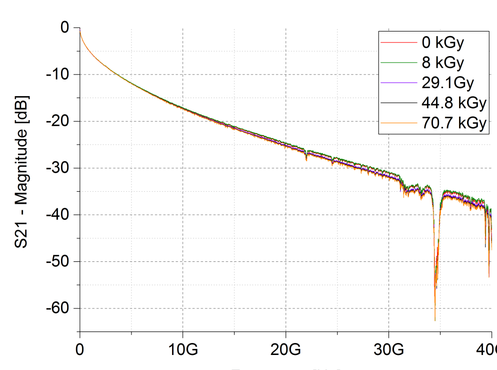

Figure 5: Degradation of 8 m CUT1 (measurements include two 5 m CUT2-type patch cables).

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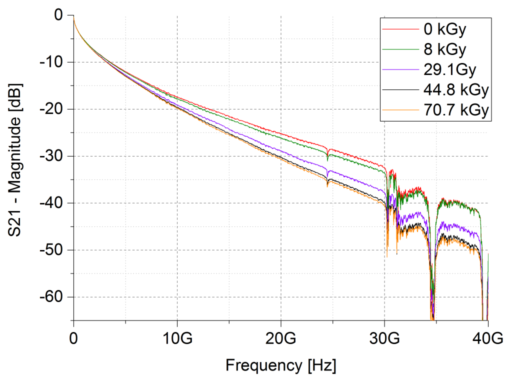

Figure 6: Degradation of 10 m CUT2 (measurements include two 5 m CUT2-type patch cables).

By comparing the degradation of both samples a major difference can be observed. While CUT1 showed a maximum change of the insertion loss of −0.8 dB at a reference point of 20 GHz, CUT2 changed by −5.38 dB. Considering the length difference of both samples the change of insertion loss differs by a factor of 4.3.

Final Dose Evaluation

The accurate determination of the applied dose has been done after unmounting of the carrier plate and read out of the alanine dosimeter. The acquired dose was dependent on the location of the probe on the plate. Figure 7 shows the distribution of the probes on the sample cables and Table 2 the accumulated dose of every individual probe.

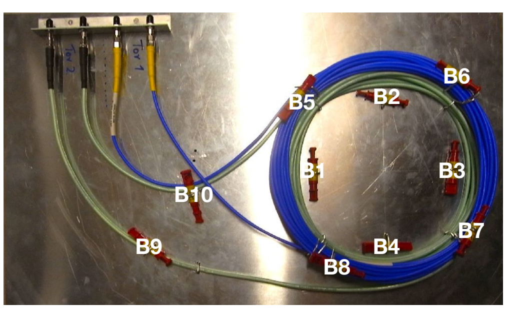

Figure 7: Distribution of Alanine Dosimeter.

Table 2: Final Dose Mapping Behind U100 Beam Dump

Name	Accumulated Dose
B1	64.28 kGy
B2	51.36 kGy
B3	93.85 kGy
B4	83.66 kGy
B5	30.38 kGy
B6	29.52 kGy
B7	57.85 kGy
B8	43.81 kGy
B9	9.40 kGy
B10	13.80 kGy

The measurements in Figures 5 and 6 are dominated by the patch cables that could not be avoided for the in-situ characterization. For a final evaluation the S-parameters have been measured without patch cables and compared to the reference measurement before the samples have been installed in the test setup. A third set of data has been acquired after carefully unwinding the cables.

Figures 8 and 9 are affirming the results of the in-situ measurements. The two samples showed a much different sensitivity to ionizing radiation.

From the cable dimension, metallisation and used dielectric it is possible to calculate the cable performance. Using Equation (1) the frequency dependent insertion loss IL(f) can be calculated from the resitive loss factor K1 and the dielectric loss factor K2 [4].

$$IL(f) = K1 \cdot \sqrt{f} + K2 \cdot f \qquad (1)$$

A Python code was used fit the parameters K1 and K2 from the measured data. The results are presented in Table 3 by applying the non-linear least squares curve_fit method. With that it can be shown that the main source of degradation was the increasing dielectric loss (K2) while the resistive loss (K1) barely changed. The high energy photons changed the structure of the dielectric materials and in turn the electrical properties. This is supported by the drop in performance after unwinding the cables. CUT2 showed a much higher sensitivity to mechanical stress than the CUT1.

Table 3: Extracted Loss Factors

	K1	K2
CUT1 before test	0.313	0.0053
CUT1 after test	0.319	0.0099
CUT1 unwound	0.319	0.0099
CUT2 before test	0.249	0.0066
CUT2 after test	0.250	0.0308
CUT2 unwound	0.250	0.0340

Figure 8 is documenting the excellent spectral performance of the CUT1-type cable and indicates that the notches visible in Figure 5 are solely introduced by the applied patch cables.

CONCLUSION

The measurement setup behind the U100 beam dump at ELBE proofed to be a convenient and robust installation that enables the investigations of radiation induced damage to accelerator parts.

The two cables under test showed a significantly different behavior even though both are made of similar components. The measured differences are subject to further investigations. As a result of the performed calculations it could be shown that the resistive losses are less sensitive to ionizing radiation while the dielectric losses are increasing.

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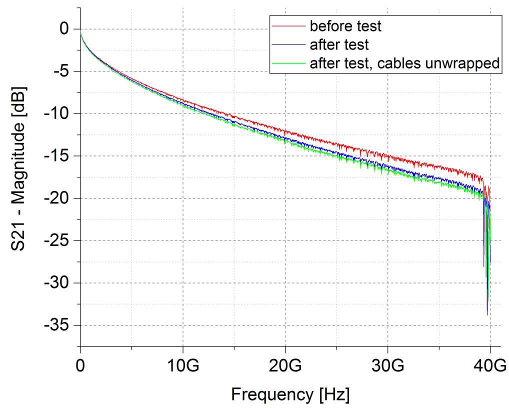

Figure 8: S21 measurements of CUT1 before and after the test mounted on the aluminum plate and unwound after the procedure.

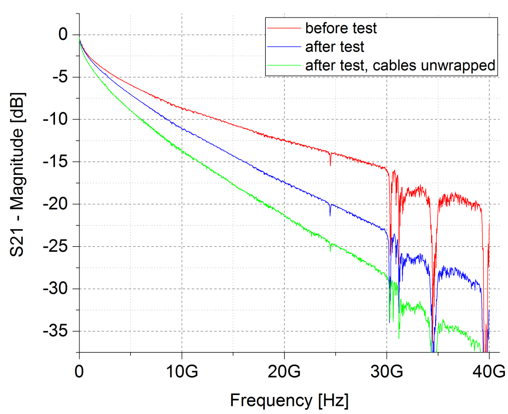

Figure 9: S21 measurements of CUT2 before and after the test mounted on the aluminum plate and unwound after the procedure.

The performed long term study has led to the conclusion that PTFE-based cables can be used in a radiative environment like an linear accelerator with high average current and moderate beam loss. But the cables need to be evaluated before being applied to the machine.

For ELBE the CUT1-type cable is going to be used to transport the broadband pickup signals for the bunch arrival time monitor to the electro-optical modulator.

ACKNOWLEDGEMENTS

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