BREAKDOWN LOCALIZATION STUDIES ON THE SWISSFEL C-BAND TEST STRUCTURES

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Abstract

The SwissFEL main LINAC will consist of 104 C-band structures with a nominal accelerating gradient of 28MV/m. First power tests were performed on short constant impedance test-structures composed of eleven double-rounded cups. In order to localize breakdowns, two or three acoustic emission sensors were installed on the test-structures. In order to localize breakdowns we have analysed, in addition to acoustic measurements, the delay and phase of the RF power signals. Parasitic, acoustic noise emitted from the loads of the structure complicated the data interpretation and necessitated appropriate processing of the acoustic signals. The Goals of the experiments were to identify design and manufacturing errors of the structures. The results indicate that breakdowns occur mostly at the input power coupler, as also confirmed by vacuum-events at the same location. The experiments show that the LINAC test-structures fulfil the requirements in breakdown probability. Moreover developing a detection system based on acoustic emission sensors for breakdown localization for our C-band structure seems reasonable given the results obtained.

PREPARATION OF EXPERIMENT

During a breakdown (BD) waves in a frequency range of 50 kHz to 1000 kHz are emitted from the BD location. [2] Thus by using acoustic emission sensors mounted on structures, it should be possible to locate the BD with a precision of one cell (17mm). To test this idea, first a test setup on a dummy structure was built. In this setup the source noise can be controlled so that it is possible to trigger the recording and test the software that analyses the data. The setup consists of:

- Two Kistler 8152B Acoustic emission (AE) sensors that are used for detecting the acoustic waves in the test-structure. The bandwidth of these sensors is 50 kHz - 400 kHz.
- Two Kistler AE Piezotron couplers that are used for amplifying the sensor signal. These can be used to filter the signal or to calculate the RMS values of the measured signal.
- Hammer with a trigger - used as a source of sound waves (simulating a BD). It has a trigger that is used as a signal for starting the recording. The working principle of the hammer is to drop the ball on the surface of the dummy structure to create vibrations along it.
- Dummy structure.
- NI PXI data acquisition device. This can acquire an analogue signal with a maximum sampling rate of 1Ms/s (records data each microsecond). It can be used with up to 12 sensors simultaneously.
- An acoustic gel used to couple the sensor to the dummy structure, making it possible to detect the signal.

The setup is shown in figure 1.

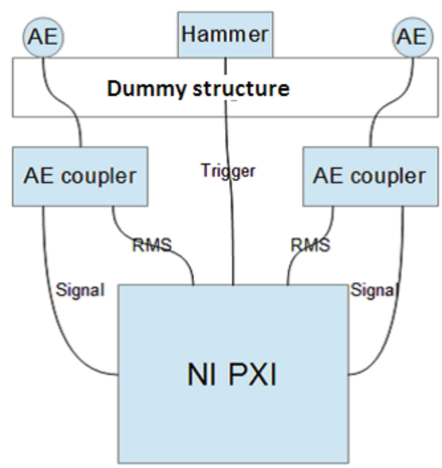

Figure 1: A schematic of the system used for measurements

The results obtained from testing with the dummy structure showed that it is possible to locate the source of the noise and that this system could be moved to a working test structure for further experiments with real BDs.

EXPERIMENTAL SETUP

The experiments on the real test structure see table 1 were made after the initial tests of the system and the commissioning of the data processing programmes. Other factors now should have been taken into account to do testing on a test-structure on the high power rf teststand, such as:

- Background noise of impulses during the high-power pulse operation of the test-structure;

- The limited space for placing sensors. The test structure consists of only 11 cells, some of which cannot be used for mounting sensors due to the way the structure was mounted;
- The heat of the structure which is kept at 40°C can deteriorate the coupling and weaken the recorded signal;

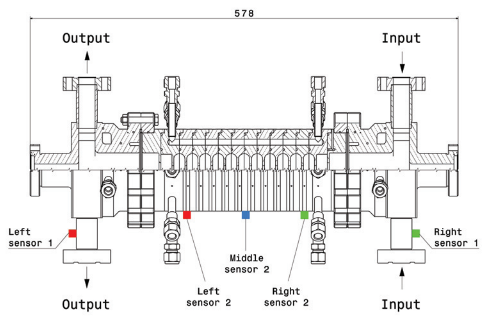

Figure 2: Sensor placement on working system. Sensor 1 shows the sensor position in the first tests and sensor 2 the position in the second tests [1].

Table 1: Main Parameters Used for the Analysis of RF BD Location.

RF Frequency	5.712 GHz
Number of regular cells	11
Phase advance per cell	2 pi/3
Group velocity	3.1%c
Length of cell	17mm

The experimental measurements were done at first using only two sensors placed on the input and output waveguides of the structure, as the limited space did not allow them to be placed onto the structure directly and there was no place for additional sensors. See figure 2.

The setup with two sensors on the waveguides was not precise enough; the ultrasonic waves coming from the BD location had to propagate through additional parts of the structure, including a steel flange and the input coupler. This made the calculations more complicated and decreased the precision of locating BDs. The sensors were therefore moved to the first and last cell of the structure and a third sensor was added in the middle of the structure. To make it possible to mount the sensors on the surface of the structure additional copper pieces were manufactured. This created an extra coupling surface between the copper piece and the structure, which was covered with acoustic gel to transfer the ultrasonic waves. Using this setup with three sensors a couple of hundred of BDs were recorded and later analysed.

RESULTS

The recorded BDs were analysed and the data post-processed. To locate the BD it is necessary to find the difference between the arrival time of the BD noise in the different sensors. To do this the signals were first filtered and then the correlation was calculated. The recorded signal looks like white noise with an amplitude peak corresponding to a BD event. See figure 3.

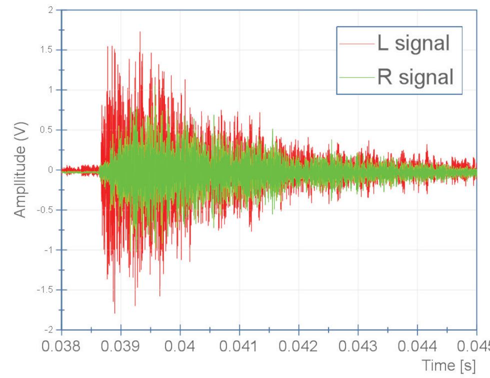

Figure 3: Recorded signal of a BD. Green - acoustic signal of right sensor, Red - acoustic signal on left sensor. The time difference between two signals is detected.

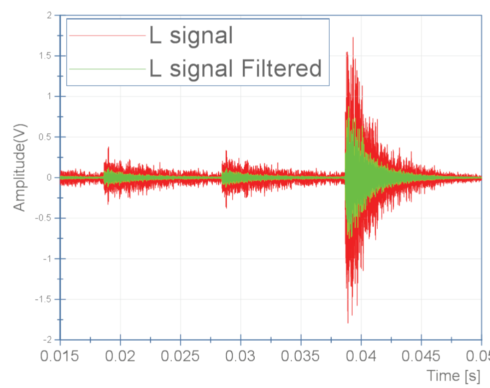

Figure 4: Difference between original and filtered signal. The last peak shows a BD event.

To see the spectral properties of signal and find the best way to filter the signal an Fast Fourier Transform (FFT) was made on the recording. This showed that the BD peak lies between 50 kHz and 100 kHz making it possible to filter out the background noise. In figure 4 it can be seen that the background noise is reduced significantly after filtering (green) in comparison to the original signal (red) while the important information of the BD start is not lost. The filtered signal was then correlated with recordings from other sensors to get the time difference between the signals and later calculate the location of the BD.

Different methods of filtering the signal were tested and the best result was achieved by using a High-pass (150 kHz) FIR Bessel filter with Hamming window. The frequency was chosen based on the FFT analysis made earlier. With this method 136 out of 365 measurements were considered precise. Other filtering methods discarded more measurements. The number of BDs recorded in each cell

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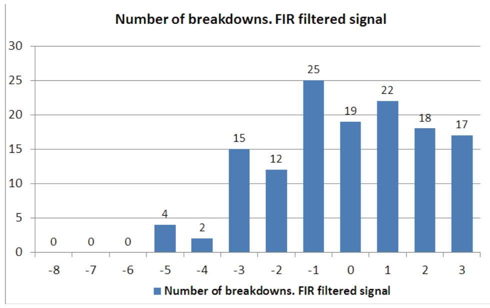

Figure 5: Number of BDs in each cell using FIR filtered signal. Cell number 0 is the cell on which the sensor was placed negative number means that the BD happened toward the input coupler.

are shown in figure 5. The negative cell number means that the BD has happened on the input coupler side of the structure.

RF DATA

We also attempted to measure the BD position by analysing the RF signals in a similar method to the one outlined, for example, in [3]. Two factors contribute to the timing of the BD signals, the time the BD occurred within the pulse and the distance it occurred along the structure, therefore two measurements of the signals need to be made to calculate the BD location. The main parameters used for the analysis are shown in Table 1. When a BD occurs within a structure the transmitted signal drops off and a large reflection of the RF power often occurs. In an attempt to increase the resolution of the method, the phase of this reflected signal relative to the forward signal is also measured.

The measurements were made on a test structure of the type described in [1]. Figure 6 shows the level of difficulty we had in accurately locating the BDs within the structure. This may be due to BDs which occurred in the wave guides, which are several meters long. We also expect a reasonably large error as the standard deviation in the falling edge of the transmitted signal was 40 ns. This corresponds to a distance within the structure of 37 cm, much longer than the structure itself. A similar deviation in the rise time of the reflected signal was also observed. When making the above calculations, it was attempted to mitigate this effect by using the times at which the reflected field was at 10 %, and the transmitted field at 90 % , of their maximums, rather than the midpoint of these edges.

Despite the lack of precision obtained by the method, it is possible to identify a cluster in figure 6 , which may suggest many of the BDs happen in the same location. To compensate for phase drift, the phase of the reflected signal prior to a BD was subtracted from the reflected phase measured during a BD. As this corrected phase is zero for the cluster seen in figure 1, it may suggest that these BDs occur at the same point in the structure which is reflecting the signal prior to BD.

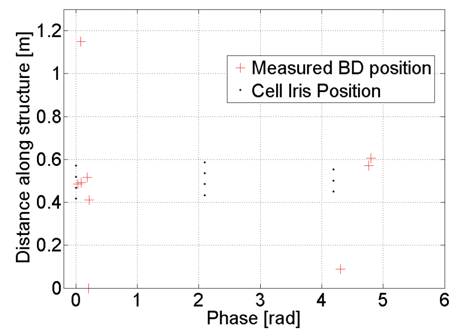

Figure 6: Scatter plot of calculated BD position along structure and phase of the reflected BD signal. The theoretical cell iris position is also shown.

CONCLUSIONS

We have commissioned the AE breakdown localization system and were partially successful in correlating the results with breakdown localization using the RF signals. BD localization precision with AE will be improved by using an array of sensors. The 2m long SwissFEL prototype structure, available from May 2013, will allow such set-up. The use of acoustic sensors which would not need a coupling material with the surface could ameliorate the measurement precision further.

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