ACOUSTIC MEASUREMENTS OF RF BREAKDOWN IN HIGH GRADIENT RF STRUCTURES

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Abstract

We are developing techniques for processing the high gradient (75MV/m) X-band accelerating structures for the NLC. Accelerometers attached to the structures detect surprisingly large acoustic signals believed to be due to RF heating. On a pulse that causes breakdown, these signals increase substantially, producing up to 50 G accelerations at >20KHz. The timing and amplitude of these acoustic signals can provide information on the location and mechanism of the breakdowns.

1 MONITORING RF BREAKDOWNS

RF signals and radiation detectors have traditionally been used for processing the X-band structures for the NLC.

1.1 RF Signals for processing

The RF power reflected from and transmitted through an accelerator structure can be used to study breakdowns. The timing of the RF signals can provide information on the location of the breakdown, however on some pulses there appears to be RF power "missing" from both the reflected and transmitted pulses. An independent measurement of the amount and location of the power deposited in the structure is desirable.

1.2 Radiation signals for processing

RF breakdowns produce X-rays that can be detected and localized with a series of photomultiplier tubes. Unfortunately dark current from the structure can result in a high-energy beam (>1 MeV) and production of hard X-rays that confuse the measurements.

1.3 Acoustic Signals

The acoustic signals produced in the structure both during normal operation and with breakdowns were surprisingly strong. 50G accelerations were measured during breakdown events. The existence of an additional breakdown signal with good signal to noise encouraged the development of acoustic diagnostics.

2 ACOUSTIC SIGNALS FROM RF POWER

Accelerometers were mounted to each end of the 1.8 Meter long X-band accelerator structure. PMTs are used to measure the X-ray radiation generated by breakdowns. A fiber cable placed along the fiber fluoresces when excited by X-rays. Signals from this cable are used to trigger data acquisition for a breakdown event.

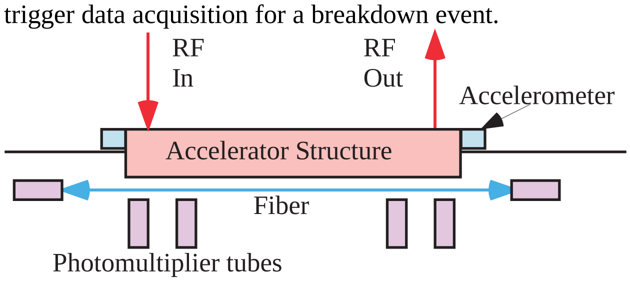

Figure 1: Accelerometer and PMT set up.

When pulsed RF was applied to the structure, acoustic signals consistent with a delta function impulse to the structure were recorded. A comparison of the measured acoustic energy, and the RF energy for power pulses without breakdown showed a linear relationship.

The acoustic sensors used had a bandwidth of approximately 50KHz. The resulting signal showed strong ringing, presumably due to structure resonance, and accelerometer resonance. The actual acoustic signal is believed to have a higher bandwidth than the sensors.

The source of the acoustic signal (in the absence of breakdown) could be due to two processes: Electrodynamic (photon) pressure, or RF absorption leading to a temperature rise, which produces an expansion wave. Of these, the second is believed to be more significant.

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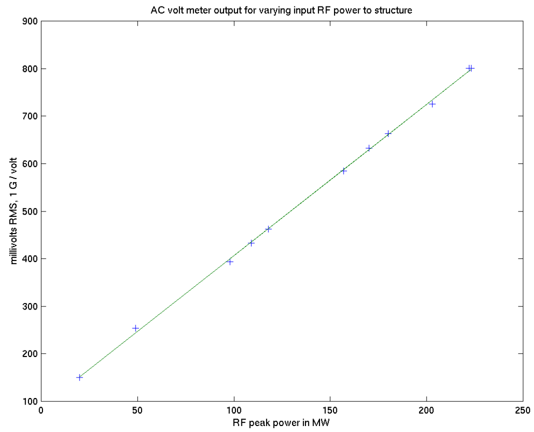

Figure 2: Acoustic intensity vs. RF peak power.

For pulses where there was breakdown, the acoustic signal amplitude was several times higher. This provided the possibility of locating the RF breakdown within the structure from the timing of the acoustic signals.

The acoustic wave speed in the structure was measured by tapping the structure at various locations with a hammer, and then measuring the difference in arrival time between the acoustic signals. A wave velocity of 1900M / second was measured, fairly similar to the sheer wave speed in copper of 2300M / second, and clearly not the result of pressures waves which have a speed of 4700M / second. [1]

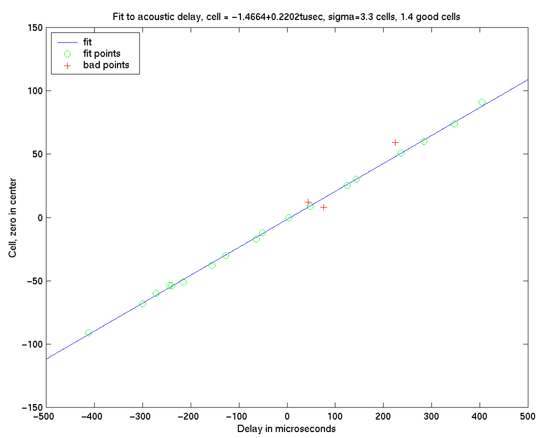

Figure 3: Acoustic wave speed in structure

Note that the RF pulse length 200 nanoseconds is much shorter than any of the acoustic time scales involved. Due to the complex mechanical shape of the accelerating structure, the resulting acoustic signal is quite complex, and it has so far been difficult to extract timing information.

3 ACOUSTIC SIGNALS FROM BREAKDOWNS

3.1 Signals from a series of pulses

The signal from one of the accelerometers was recorded on a long record length (50,000 point) oscilloscope set for peak hold. The resulting record shows approximately 30 sequential RF pulses at 60Hz. A much larger than normal acoustic signal can be observed on pulse 16. On this pulse a large reflected RF power was also recorded. The RF was disabled for 10 pulses after the breakdown. When the RF was turned back on, there was an immediate and apparently larger breakdown.

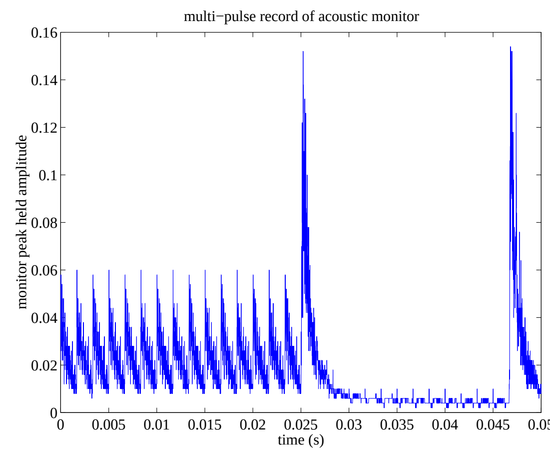

Figure 4: Acoustic signals from a series of RF pulses.

3.2 Acoustic timing information

The acoustic signals from a number of breakdown events have been recorded. Although no algorithmic method has been developed to measure the timing information, there appear to be timing differences between different breakdowns. As the RF signals are instantaneous on this timescale, this is believed to be due to changes in the locations of the breakdowns.

Acoustic monitor signals - structure ends

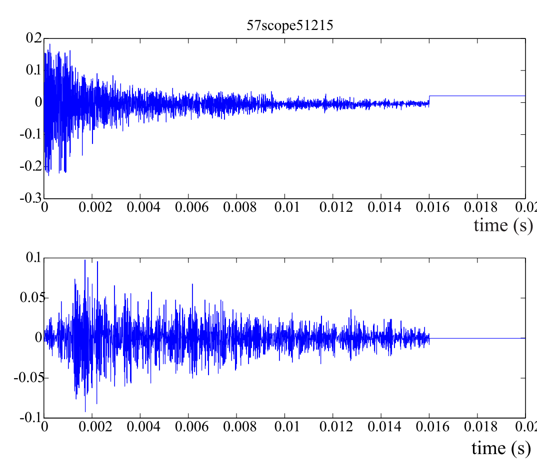

Figure 5: Sensor #1 data starts early

Reflected and load forward RF

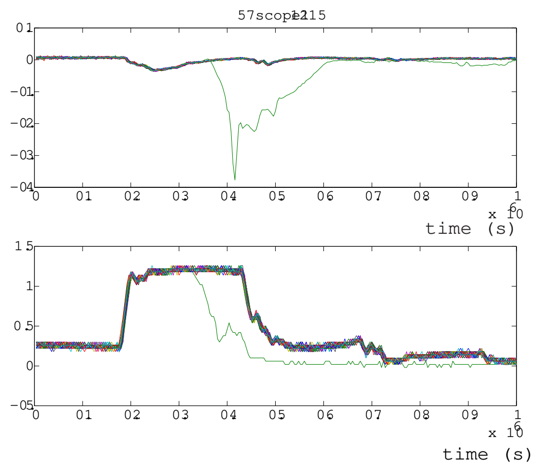

Figure 6: RF reflected and transmitted signals for same pulse as fig. 5

Note that in the acoustic signals, channel one (front of the accelerator) starts early. In the RF signals the reflected signal starts at approximately the same time as a power dip is seen in the transmitted signal, implying a breakdown near the front of the structure.

Acoustic monitor signals - structure ends

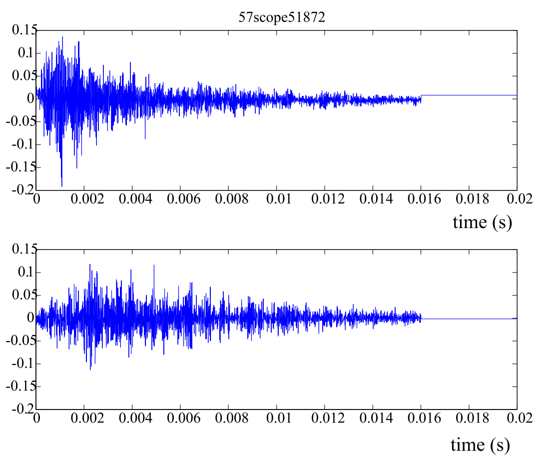

Figure 7: Sensor #1 signal delayed relative to figure 5.

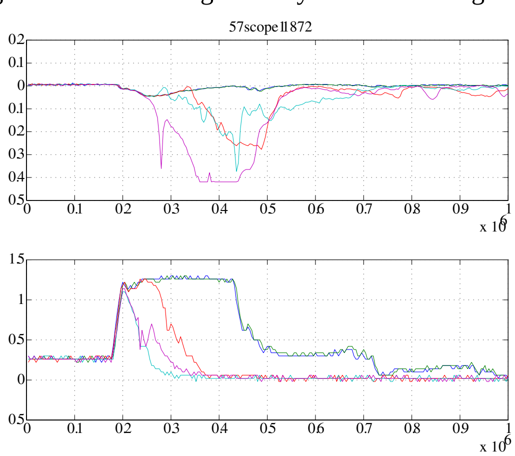

Figure 8: RF signals for the same pulse as fig 7.

Note that in the acoustic signal, channel one is delayed (relative to the pulse in figure 5). The RF signals show a difference in time between the reflected signals, and the dip in the transmitted signals, implying a breakdown occurring at some distance from the front of the structure.

3.3 Breakdown precursor signals

For some breakdowns, both acoustic and RF signals will increase on pulses before the primary breakdown pulse. It maybe possible to improve processing by combining RF and acoustic data to predict large breakdowns and then interrupt the RF to prevent damage.

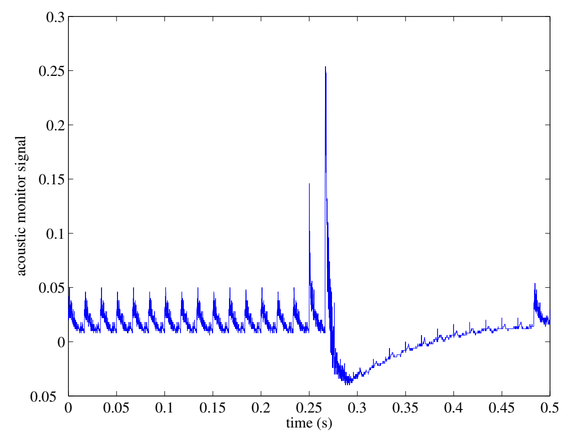

Figure 9: Acoustic breakdown “precursor” signal.

4 SUMMARY

Acoustic signals provide an additional source of information about breakdowns in RF structures. The timing of the signals appears to contain information on the location of the breakdown. Use of these signals for RF processing of the NLC X-band structures is beginning

REFERENCES

[1] David R. Lide editor “CRC Handbook of Chemistry and Physics 78th Edition”, CRC Press New York 199