ELECTRON ACTIVITY INTERLOCK FOR XFEL INPUT COUPLERS

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Abstract

One of dangers for TESLA-based linacs is uncontrolled discharge in vacuum parts of the input power couplers - discharge in residual gasses, field emission and multipacting. These may be destructive if the RF power is not reduced or switched off at the right time. The recent TTF3 input couplers have three electron pickups to detect the electron activity. But these vacuum feed-throughs and the electronic front-end are complicated and expensive. The goal of this work is to replace them by simpler and cheaper solution - by use of the inner conductor of the coupler as electron pickup.

INTRODUCTION

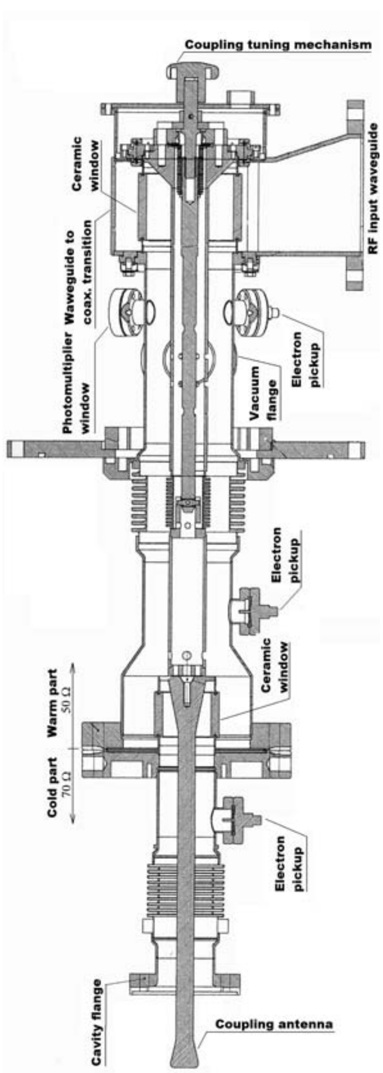

Fig. 1: TTF3 input power coupler

The TTF3 input power coupler (Fig.1), which after some modifications will be used for the XFEL, has its inner conductor RF shorted but DC insulated from the basis of the waveguide-to-coaxial transition. This makes possible to connect a positive bias (3.5 kV) to the inner conductor in order to suppress multipacting. However, for the FLASH operation it was never necessary.

If a discharge in vacuum part happens, one electrode emits electrons and gets positive charge. In this way induced voltage (or current through an external circuit), after removal of RF component and high voltage bias (if applied), can be used for electron activity measurement and interlock purpose.

RF NOTCH FILTER

The first filter stage is the capacitive grounding of the inner conductor. However, at full processing power (1 MW) and full reflection the residual RF voltage is still approximately 20 V (calculated by CST Microwave Studio), which is too much. For this reason the second stage, a 1.3 GHz 12-th order strip-line notch filter was designed and built. Its attenuation at 1.3 GHz is about 90 dB. The filter is designed to hold 3.5 kV bias if this will be applied.

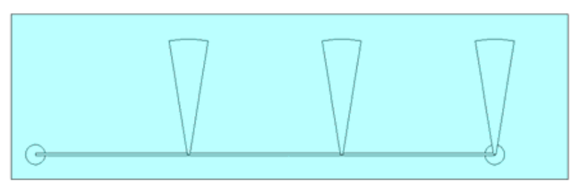

Fig. 2: Layout of the notch filter; input left, output right

Fig. 3: Filter PCB and package

FIRST EXPERIMENTAL SETUP

The processing of coupler (cleaning and outgasing of the inner surface) by controlled discharge is a perfect possibility to experiment with electron activity. The measurement of induced voltage across the input coupler is shown in *Fig. 4*. If the input coupler is loaded by low resistance, the level of discharge will be indicated by means of current (*Fig. 5*.). The adjustable bias source (-400 V … 0 … +400 V) was used to observe a bias effect to the discharge. The following measurements were performed at the beginning of conditioning process; the pulse duration was 20 μs and the input power approximately 200 kW. In the following text and charts positive voltages mean the + pole on the inner conductor and positive direction of currents means currents flowing from the inner conductor.

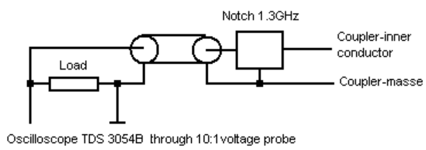

Fig. 4: Schematic of voltage measurement

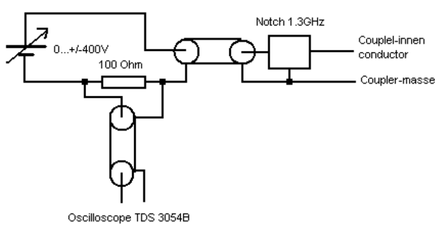

Fig. 5: Schematic of current measurement

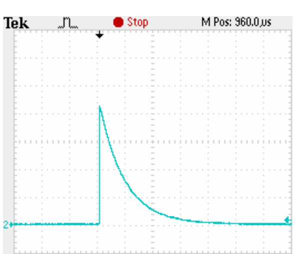

Fig. 6: Voltage on 10 kΩ load (50V / div)

Fig. 7: Current at zero bias (20mA / div)

Fig. 8. Current at +170V bias (100mA / div)

Fig. 9. Current at +200V bias (20mA / div)

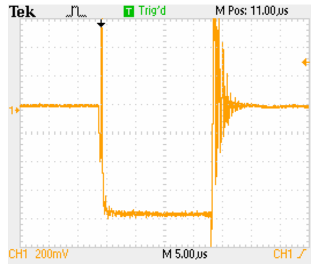

Fig. 10. Current at +205V bias (20 mA / div)

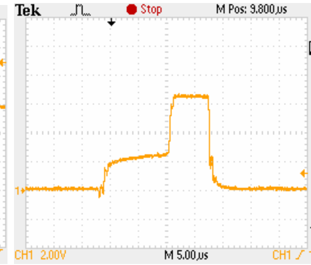

Fig. 11. Current at - 150V bias (200 mA / div)

Fig. 6 shows the voltage induced across the coupler and its decay (several nF total capacity) after switching the RF pulse off. The peak value of this voltage was +200 V. The positive sign of induced voltage indicates that the electrons are emitted from the inner conductor. Due to the very long decay time in comparison to the pulse duration it is better to measure current through low resistance load than the voltage. *Fig. 7 – Fig. 11* illustrate behavior of the current depending on applied DC bias. Please note, that at biases below +200 V (equilibrium of induced and bias voltage) the current is sourced by the coupler and flows against the bias power supply. As shown in *Fig. 8*, certain positive bias supports the discharge (but a positive bias in order of kilovolts efficiently suppresses multipacting). A certain negative bias also supports the discharge (*Fig. 11*).

LOGARITHMIC COMPRESSOR

Fig. 12: Prototype of the logarithmic compressor

The range of the RF discharge induced current is from zero up to hundreds mA, in extreme cases up to several A. In order to work out signals in range of several magnitude orders without problem with noise a logarithmic compressor was designed and a prototype was build. This device simply replaces original diagnostic and interlock card used on the horizontal test cryostat (Chechia). The next application should be on the coupler test stand and in the module test hall (to test whole cryomodule at once). The readout in DOOCS shows the waveforms in logarithmic (direct) or in linear (after software de-logarithmization) scale.

The logarithmic compressor is based on the AD 8310 logarithmic amplifier [1]. The amplifier has symmetrical input, frequency range 0 – 440 MHz, dynamic range up to 95 dB and an automatic offset correction. The last feature had to be set out of operation (it works only with harmonic signals) and the input offset had to be corrected manually. In order to protect the AD 8310 against high level of common mode interference (the cables between input couplers and control room are several tens meter long) the AD 215 isolation amplifier [2] fully isolates the coupler, cable and the AD 8310 from the rest of the electronics. The logarithmic intercept of the card is set to 10 μA of input current and logarithmic gain is adjusted to 1 V per 10 dB (2 V per decade). That means 100 μA gives 2 V output, 1 mA – 4 V , …, 1A – 10V.

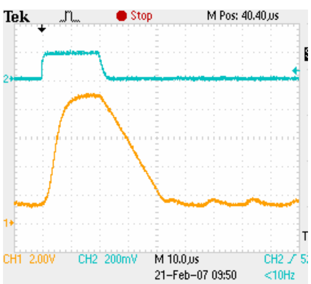

Fig. 13. Coupler processing pulse 20 μs, power 50 kW

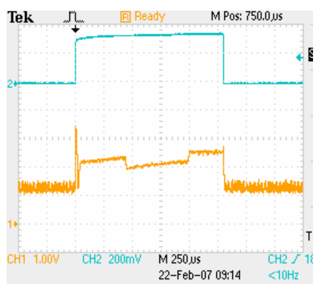

Fig.14. Coupler processing pulse 1.3 ms, power 200 kW

The orange traces in *Fig. 13* and *Fig. 14* are the examples of electron current waveforms during processing. The blue traces are envelopes of RF pulses. The reference of the orange traces correspond to 10 μA, one vertical division represents one decade (20 dB).

EXPERIENCE WITH NEW MEASUREMENT SYSTEM

The newly built measurement system is applied during coupler and cavity processing in the vertical test cryostat at DESY (Chechia). The signals are compared to signals from three original electron pickups and to other interlock sources. Here are some examples:

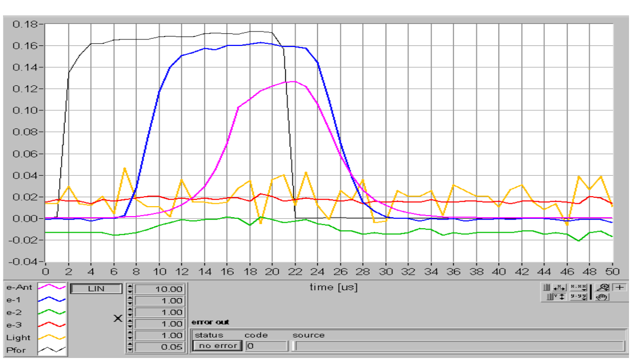

Fig. 15: Coupler processing (cavity out of resonance), pickup 1: 0.8 mA (blue), inner conductor: 12 mA (purple, linear scale)

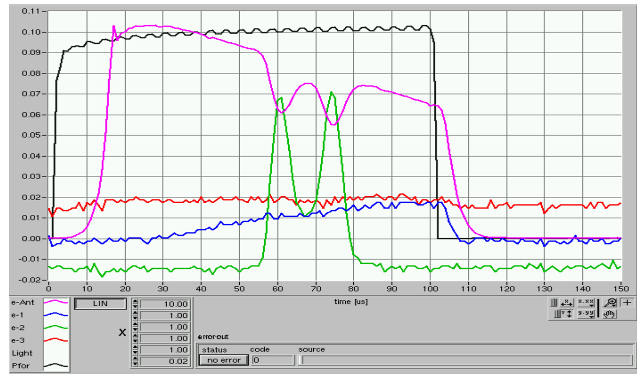

Fig. 16: Coupler processing (cavity out of resonance), pickup 1: 0.1 mA (blue), pickup2: 0.37 mA (green), inner conductor: 10 mA (purple, linear scale)

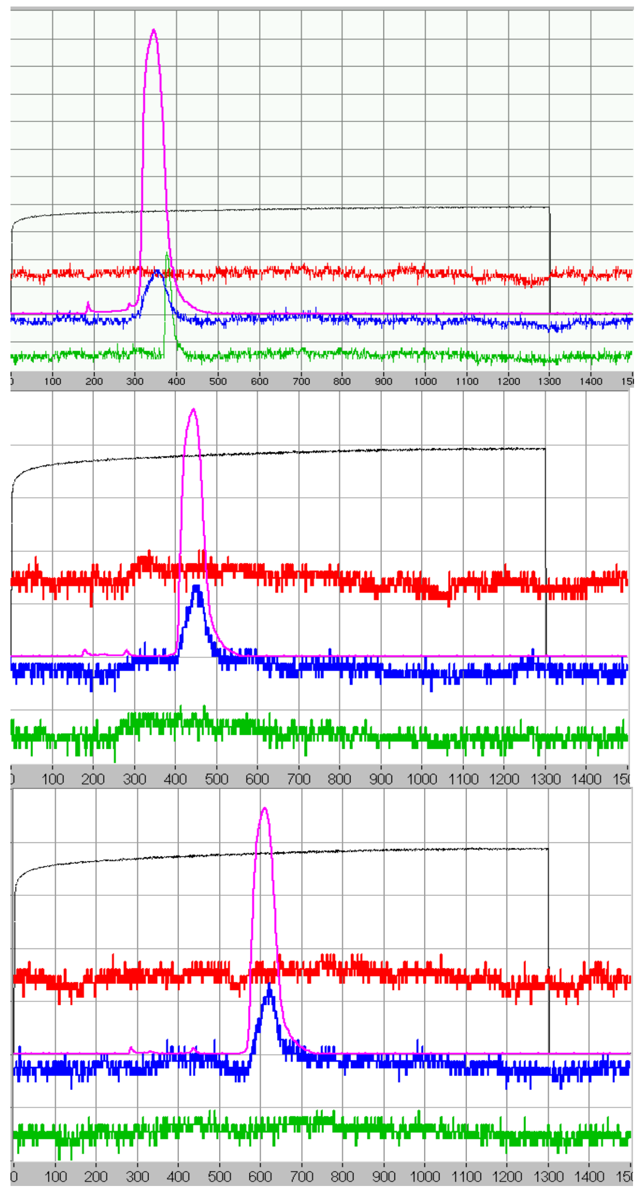

Fig. 17: Effect of processing - discharge ignites later and later

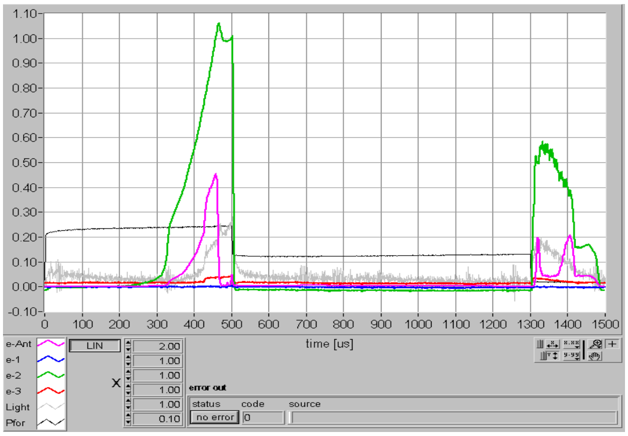

Fig. 18: Cavity processing (on resonance), e-2 interlock event. Pickup 2 current: 5.25 mA (green), inner conductor current: 225 mA (purple, linear scale)

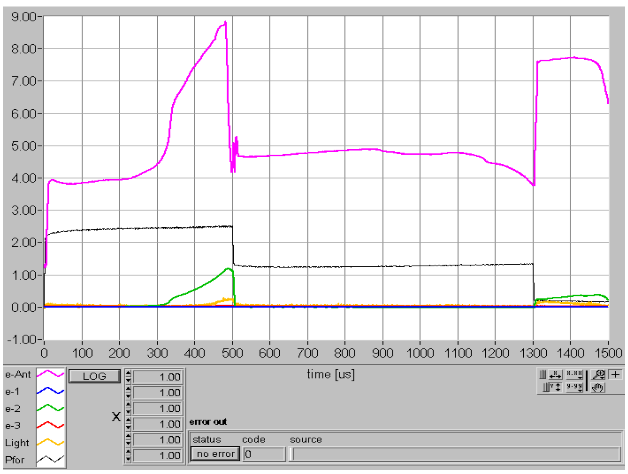

Fig. 19: Cavity processing (on resonance), e-2 interlock event. Pickup 2 current: 6 mA (green), inner conductor current: 250 mA (purple, logarithmic scale)

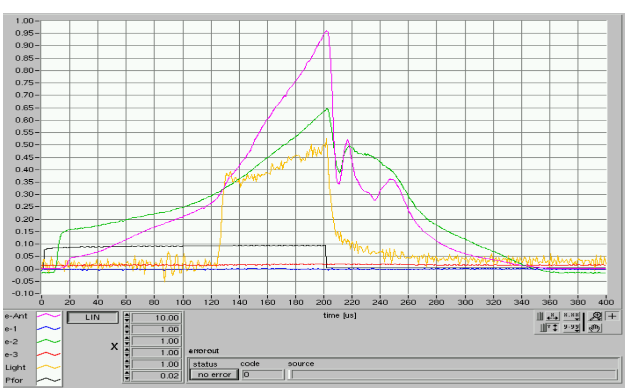

Fig. 20: Cavity processing (on resonance), light interlock event: pickup 2 current: 3.25 mA, inner conductor current: 95 mA (purple, linear scale)

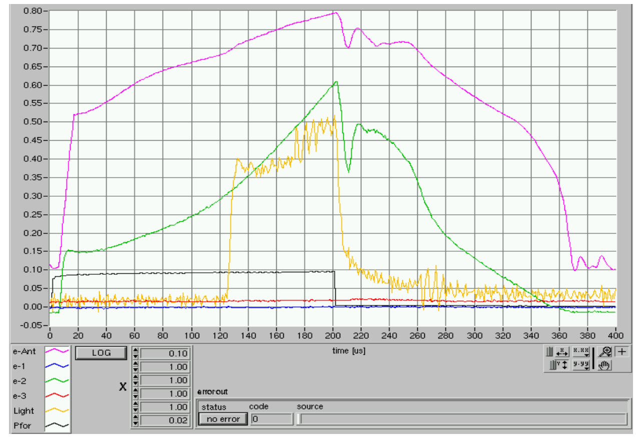

Fig. 21: Cavity processing (on resonance), light interlock event: pickup 2 current: 3.05 mA, inner conductor current: 100 mA (purple, logarithmic scale)

Fig. 15 - Fig. 17 are examples of coupler processing with detuned cavity. As the processed couplers were not new (already processed in the past) the electron activity is not strong and no interlock was triggered. The *Fig. 16* shows an integration effect of the inner conductor over the coupler length - the discharge currents from areas around pickup 1 and 3 are positive, but from pickup 2 area is negative. *Fig. 17* illustrates the processing effect - the discharge needs more and more time to be ignited.

The next figures were taken during cavity processing. As the cavity is on the resonance, the quick phase variation of reflected wave moves standing wave extremes along the coupler resulting in more complicated waveforms of discharge currents. *Fig. 18* and *Fig. 19* illustrate an electron interlock event (pickup current over 5 mA), *Fig. 20* and *Fig. 21* show an photomultiplier interlock event (light in vacuum part).

CONCLUSIONS

During all test we observed very good correlation between pickup and inner conductor signals and there was no event with strong pickup and weak inner conductor signals observed. The current from the inner conductor is very strong (apx. 200 mA corresponds to the pickup interlock threshold) and needs no special circuitry to be worked out. The logarithmic compressor is a very useful tool for experimental purposes, but for triggering of interlock (e.g. at 200 mA) at XFEL would not be necessary and very simple and cheap electronics could be used instead.

The research of electron activity electron is not finished yet, but the collected result make this solution promising. We need to collect more waveforms, especially with new (and "dirty") couplers. The final electronics and computing solution have to be found too.

ACKNOWLEDGMENTS

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REFERENCES

[1] Analog Devices: "Fast, Voltage-Out DC–440 MHz, 95 dB Logarithmic Amplifier AD8310", datasheet, 2005, http://www.analog.com/UploadedFiles/Data_Sheets/AD8310.pdf

[2] Analog Devices: "120 kHz Bandwidth, Low Distortion, Isolation Amplifier AD215", datasheet, 1996, http://www.analog.com/UploadedFiles/Data_Sheets/AD215.pdf