RESONATOR FOR CHARGE MEASUREMENT AT REGAE

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Abstract

A resonator is developed for the diagnostics of dark current and charge measurements at the European XFEL, FLASH and PITZ. The first induced monopole mode TM_{01} at 1.3 GHz from charged bunches is used to detect the dark current and charge with high resolution at these accelerators. At REGAE this resonator with electronics is installed to detect the bunch charge because charges below pC are used and this device can resolve it non-destructively. The same electronics as for the dark current and charge measurement is used and the best resolution is measured to be 2.3 fC for 200 fC.

INTRODUCTION

The measurement of the beam properties during operation of an accelerator is an essential tool to control the machine. Some of these devices measure the properties destructively, but a setup with a non-destructive measurement is preferred because the running beam can be used afterwards for the experiment. To be non-destructively the fields generated by the charged beam produces signals at the non-smooth formed tube. One of the first beam property to be measured in an accelerator is the beam charge. Here a resonator is used where the beam induces electromagnetic fields at certain modes. The TM_{01} mode is detected by using antennas inside of the resonator guided to electronics. The amplitude is proportional to the charge of the beam. This device is designed to be installed at the European XFEL [1]. It is not only intended to measure the beam charge, the second task is to detect the dark current produced by field emission in the accelerator [2]. This is done by superimposing the induced fields of the weakly charged dark current bunches with their high repetition rate generated by the 1.3 GHz accelerator to a measurable level. The functionality is tested at the accelerators FLASH and PITZ [1], here the notation of a Dark current Monitor (DaMon) is defined.

At the Relativistic Electron Gun for Atomic Exploration (REGAE) the bunch charges are expected to be small compared to the accelerators mentioned above. But the DaMon has shown in the experiments that the beam charge resolution is good enough to resolved the low charges at REGAE [3]. Therefore this system of monitor including the electronics is installed at REGAE. In the following the system is described and the measurement results are shown.

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SETUP

The device consists of a resonator made from stainless steel with the frequency of the first monopole mode at 1.3 GHz and a bandwidth of 6.4 MHz. Two antennas are used for coupling-out the signals, see Fig. 1 and 2. The

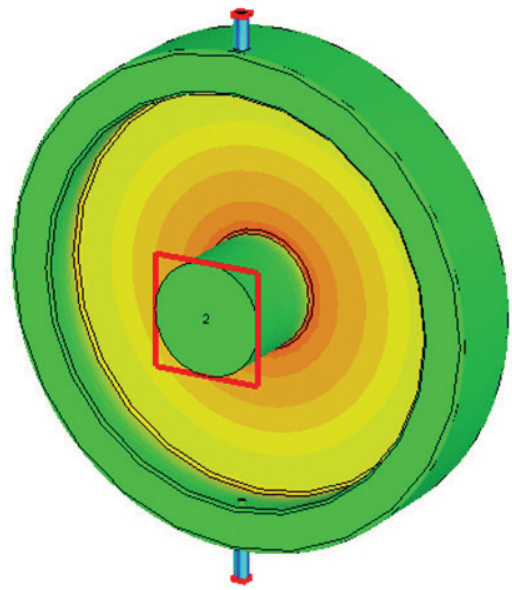

Figure 1: Simulated electric field strength with CST [4] of the first monopole mode TM_{01}.

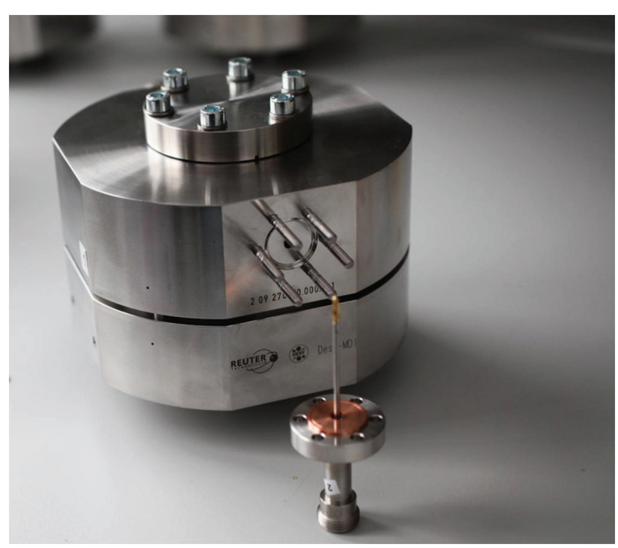

Figure 2: Photo of the DaMon with feedthrough; later is mounted with flange and seal on the DaMon body.

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field distribution is cylinder symmetric with an almost independent field amplitude at the beam tube with 40.5 mm diameter. The voltage of a monopole mode after a beam passage is given by

$$U = U_0 \sin(\omega t) e^{-\frac{t}{\tau}}, \tag{1}$$

with $\omega = 2\pi f$, the measured resonance frequency $f = 1300.1 \pm 0.1$ MHz, the decay time $\tau = Q_L/(\pi f)$ and $Q_L = 203 \pm 5$ the measured resonator loaded quality factor. The amplitude is given by

$$U_0 = qS, \tag{2}$$

with the sensitivity $S = \pi f \sqrt{\frac{Z}{Q_{ext}}\left(\frac{R}{Q}\right)}$, where q is the beam charge, $Z = 50\,\Omega$ is the line impedance, $Q_{ext} = 245 \pm 4$ is the measured resonator external quality factor and $(R/Q) = 82.9\,\Omega$ is the simulated normalized shunt impedance [4]. All values (except for (R/Q)) are determined by laboratory measurements and in agreement with the design values (the resonator is produced with high precision without tuners). Using equation (2) the beam charge can be calculated by measuring the voltage amplitude. The quality factor of the resonator is designed such that the signal is negligible after 1 μs.

The monitor is installed at REGAE after the accelerator, see Fig. 3. One antenna is connected with the charge input of the electronics, with a 10 dB attenuator in front of it to

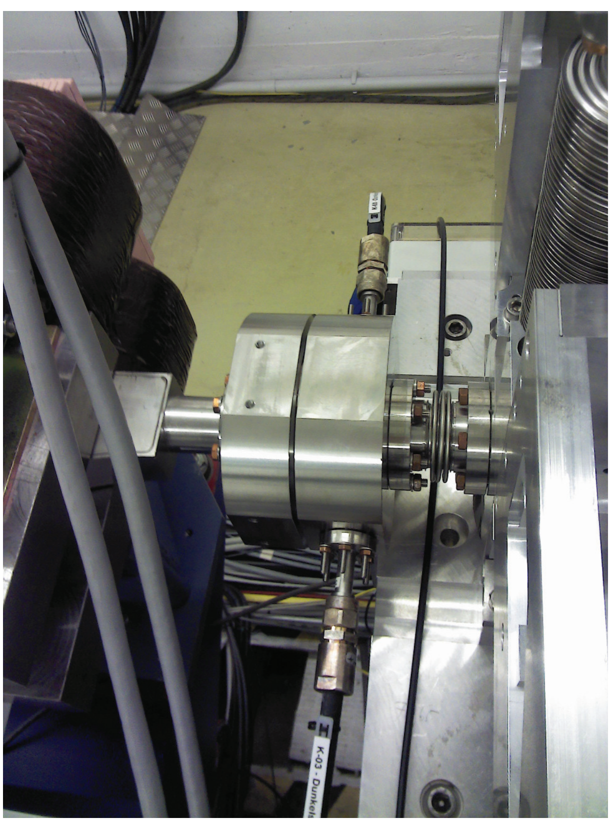

Figure 3: Photo of the DaMon installed at REGAE.

work in a higher charge range compared to the dark current input. Later is reserved to work at low charges. Therefore both channel at REGAE are intended to measure the charge of the beam. Each signal of the two antennas is processed by electronics which consists of circulator, band-pass filter, limiter, down conversion to an intermediate frequency, logarithmic detector and offset and gain control, see Fig. 4. Due to the logarithmic detector the signal processing range

Figure 4: Photo of the DaMon electronics. From left: power control LED, dark current input, beam charge input, 3 dark current outputs (2 times single ended and 1 differential), 3 beam charge outputs.

is 80 dB. The processed signals are connected with a digitizer: 16 bit and 200 MS/s for each channel to not restrict the resolution due to the ADC. The electronics is free running, only the ADC gets a beam trigger from the REGAE timing system.

MEASUREMENT

The properties of the resonator, the cable attenuation and the electronics responds function in a table are measured. These data values are taken to calculate the amplitude back to a charge for each channel. This results in a calibration table which is used to convert the measured voltage amplitude in a charge value; the nearest calibration points from the table are interpolated to the corresponding charge. The output of the measurement is shown in Fig. 5. The lower diagram shows the measured voltage as a function of time. The amplitude of each channel is different because of different attenuation of the channels. The first channel with 10 dB attenuation is defined for higher charges: between 2 and 50 pC. The second channel is defined for charges between 10 fC and 2 pC. Therefore the second channel is proposed for better resolution at lower charges; this can be seen too at the number of digits of the charge values for each channel below the diagram. In addition the charge of the last 8 bunches are visible in bar charts with a calculated average. A short history of the charge is shown on top of the diagram.

To measure the resolution of the system the charge values of both channels are subtracted to calculate the resid-

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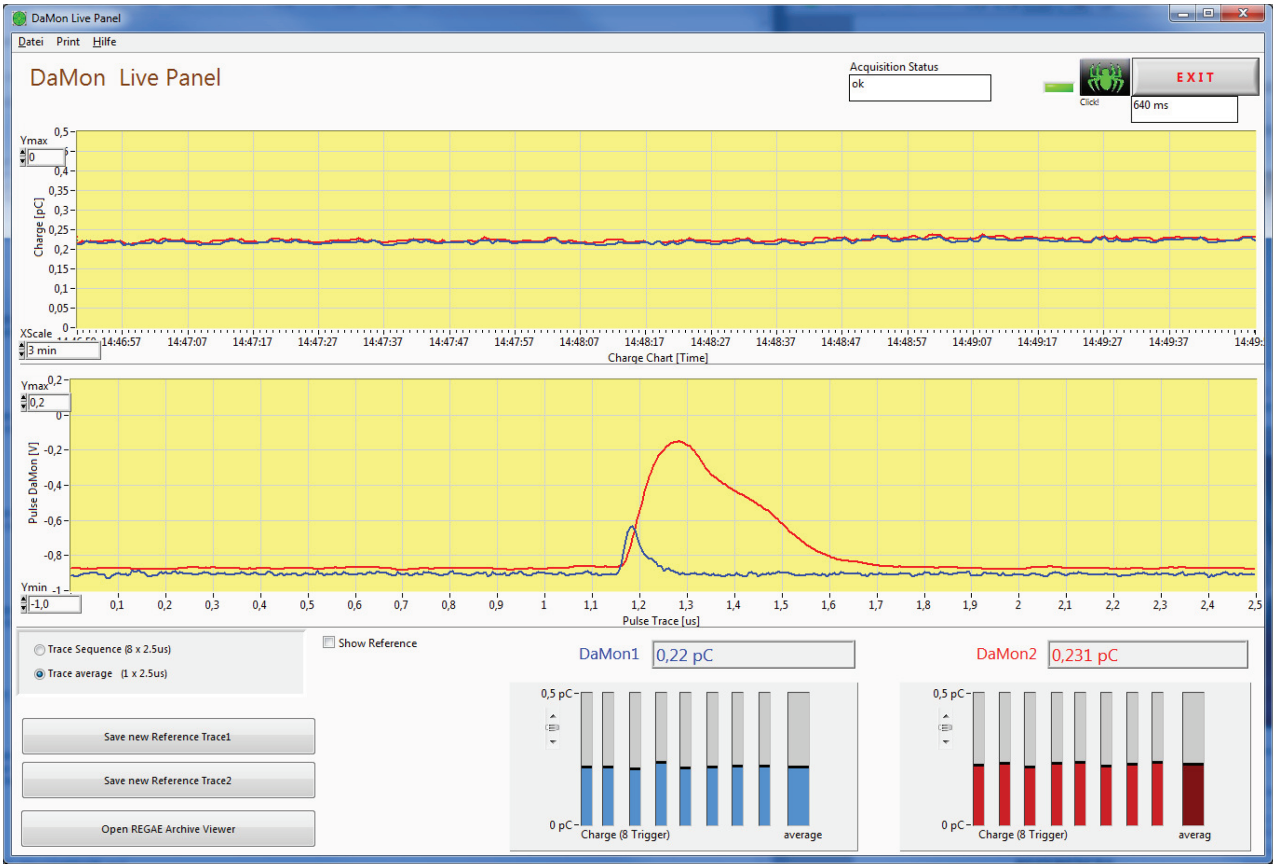

Figure 5: Graphical User Interface of the DaMon output. Top diagram: a history of the charge values for few minutes; lower diagram: recent voltage as a function of time of both channels with blue the first channel and red the second channel; below: recent calculated charges for last 8 bunches of both channels with the same color definition including an average.

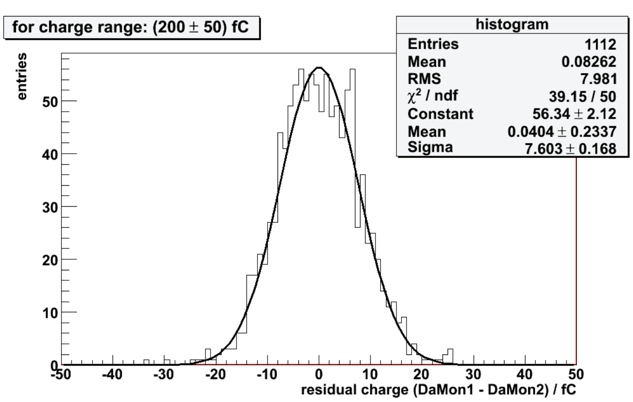

Figure 6: Residuals between charge measurement of both DaMon channels for a charge around 200 fC with a Gaussian fit.

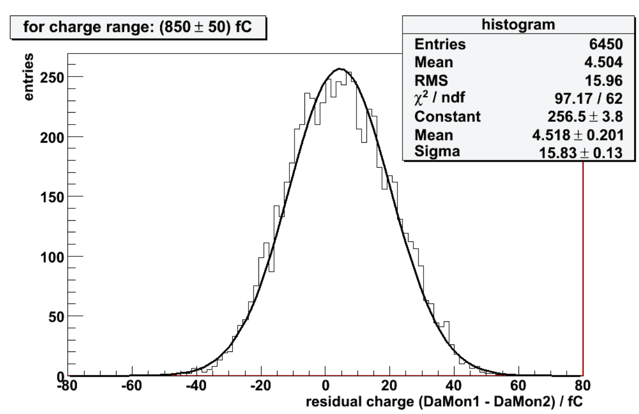

Figure 7: Residuals between charge measurement of both DaMon channels for a charge around 850 fC with a Gaussian fit.

uals, see Fig. 6, as an example at 200 fC and Fig. 7 for 850 fC. Both diagram show a Gaussian fit with the results. For higher charges the mean difference differs to zero due to a not perfect laboratory calibration. This is already improved by correcting the channel 2 values at the overlapping part of both channels but still a small difference is left. The standard deviation results in an overall resolution of both channels. Comparing both diagrams one can see that the resolution for lower charges is better. Assuming that channel 2 has a better resolution because of the 10 dB attenuation the resolution can be divided with this factor. In Fig. 8 the resolution is presented for different charges measured at the REGAE running period between March and August 2013. As one can see that the resolution for chan-

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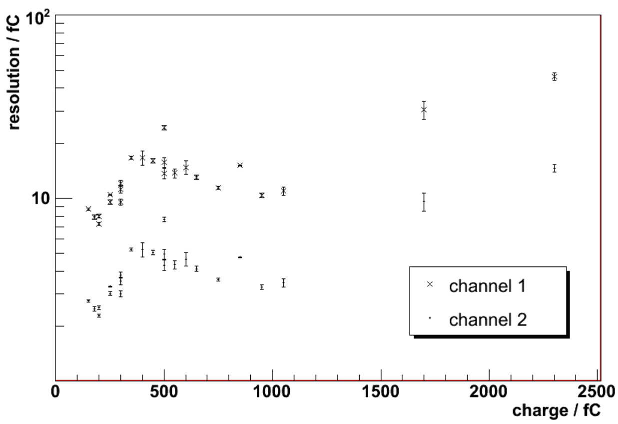

Figure 8: Resolution for each channel as a function of charge used at REGAE. The resolution is corrected by 10 dB difference between channel 1 and 2.

nel 2 is better due to this additional attenuation of channel 1, furthermore the resolution depends logarithmically on the charge due to the logarithmic detection. The best resolution is measured with channel 2 at 200 fC to be 2.3 fC.

SUMMARY

The DaMon is installed at the REGAE beamline with the same electronics which is used at PITZ and FLASH for the measurement of beam charge and dark current. This monitor is used to measure the charge with both channels at REGAE. The resolution of this non-destructive monitor resolve the requirement of the charge measurement at REGAE, the best resolution is measured to be 2.3 fC at 200 fC.

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