ISBN: 978-3-95450-236-3 ISSN: 2673-5350 doi:10.18429/JACoW-IBIC2023-TUP037

CHARGE MEASUREMENT WITH RESONATORS AT ARES

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Abstract

The ARES facility (Accelerator Research Experiment at SINBAD) is an accelerator to produce low charge ultrashort electron bunches within a range of currently 0.5 pC to 200 pC. Especially for eFLASH experiments at ARES an absolute, non-destructive charge measurement is required. To measure an absolute charge of individual bunches different types of monitors are installed. A destructive Faraday Cup is used as reference charge measurement device. To measure the charge non-destructively 2 Toroids, 1 Turbo-ICT and 2 cavity monitors are installed. The latter system consists of the cavity, front-end electronics with logarithmic detectors and µTCA ADCs. The laboratory calibration of the cavity system is performed by using an arbitrary waveform generator which generate the same waveform like the cavity with beam. This results in a non-linear look-up table used to calculate the ADC amplitude in charge values independent of beam-based calibration. The measured charges from the cavity monitors agree very well within few percent in comparison with the Faraday Cup results.

MOTIVATION

The beam charge determination is one of the most important properties to be measured in all accelerators. For this several monitor systems are developed and installed at every accelerator, but the absolute value of charge is always in discussion. At the Accelerator Research Experiment at SINBAD (ARES) [1–6] we installed different types of charge monitor systems: 2 Toroids, 1 Turbo-ICT and 2 cavity monitors. The charge value results are compared with a Faraday cup who serves as a reference system with good agreement to the other monitors; the expected charge loss of the Faraday Cup due to lost particles is simulated and smaller than 0.6 ‰ [7]. The cavity monitor system consists of a resonator where the first monopole mode at 1.3 GHz carries with the amplitude the charge information. This monitor system is firstly developed to detect the dark current from accelerators with the same accelerator frequency where the single dark current bunches generate superimposed fields within the resonator [8]; for this reason the system is called Dark current Monitor (DaMon). It was found that this resonating system is able to measure very low values of bunch charges. Therefore, the DaMon system is installed at several accelerators at DESY [9–12] to measure the bunch charge from several fC up to few nC. The calibration of the amplitude to the charge from a resonator to get the absolute charge is the issue of this contribution.

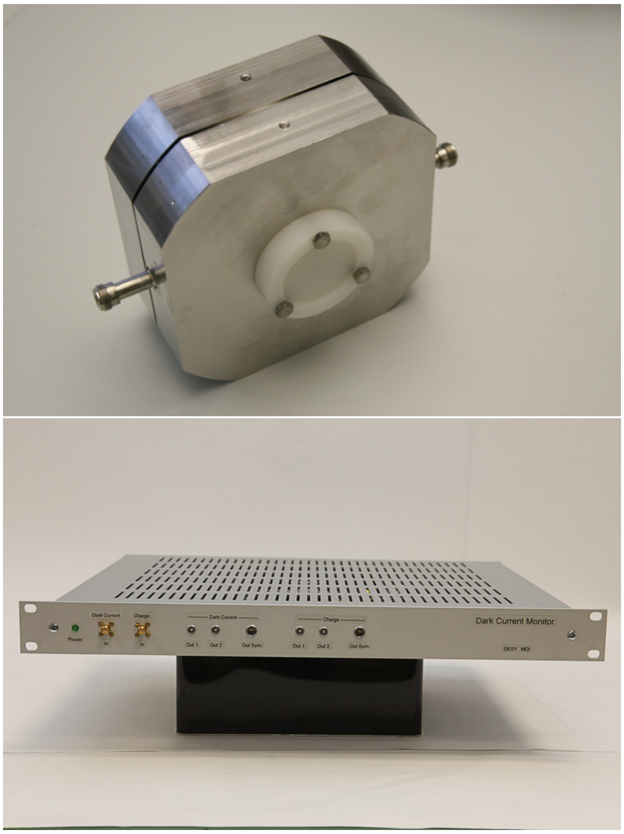

Figure 1: Picture of the resonator and the electronics box with front panel.

SETUP

The DaMon system consists of the resonator integrated into the beamline, a front-end electronics (see an example in Figure 1) and ADCs. One resonator has two identical outputs to ensure symmetry in the resonator, which are connected with low loss coaxial cables to the front-end electronics. Both inputs are processed differently in the electronics. The charge channel (Q) is in most applications attenuated to be able to provide higher charges with band pass filters, logarithmic detectors (for high dynamic range) and followed by gain and offset adjustments to adapt to the 16 bit ADC. The dark current channel (DC) has in addition a down converter in the logarithmic detector with free oscillating reference signal to provide higher sensitivity. This channel was foreseen to superimpose the dark current bunches with acceleration frequency 1.3 GHz but for other accelerators this channel is used for bunch charge measurement too. Therefore, the DC channel provides higher sensitivity and can be used for lower charge values compared to the Q channel.

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CALIBRATION PROCEDURE

The sensitivity of the resonator (or amplitude of the oscillating voltage as a function of the charge) is calculated with the resonance frequency f, the connection impedance Z, the external quality factor Q_{ext} and the shunt impedance $\left(\frac{R}{Q}\right)$ to be $S = \pi f\sqrt{\frac{Z}{Q_{ext}}\left(\frac{R}{Q}\right)}$ [13]. Here f and Q_{ext} are measured for each resonator; the shunt impedance is used from simulation results but should only negligible vary for each resonator. The charge can be calculated with the measured amplitude U to be $Q = U/S$. Up to the electronics the amplitude is reduced due to the attenuation of the cables, therefore each cable attenuation is measured at the resonance frequency 1.3 GHz. The electronics processes the signals differently at each channel, described in the setup chapter. To calibrate the electronics in the laboratory a signal at the resonance frequency with different amplitudes are generated and the output are monitored. For the dark current channel a continuous wave (CW) was applied which was sufficient for this kind of measurement. Since the DaMon system was developed for the dark current measurement the same CW signal was applied for the Q channel. But this CW signal enters different sections of the logarithmic detectors compared to a pulsed signal. Therefore, a pulsed signal should be more suitable for the calibration for the charge. Especially when the DC channel is used to measure the bunch charge since the down conversion is different in comparison of a damped signal. The pulsed signal (damped signal) is generated with an arbitrary waveform generator, see Figure 2. The generated signal corresponds in frequency and decay time with those expected from the resonator. The amplitude is varied to get a table of the electronics response function. In Figure 2 the output of the electronics is visible with an oscilloscope for one amplitude. The final calibration is realized with the installed electronics in the rack room with connected 16 bit ADC.

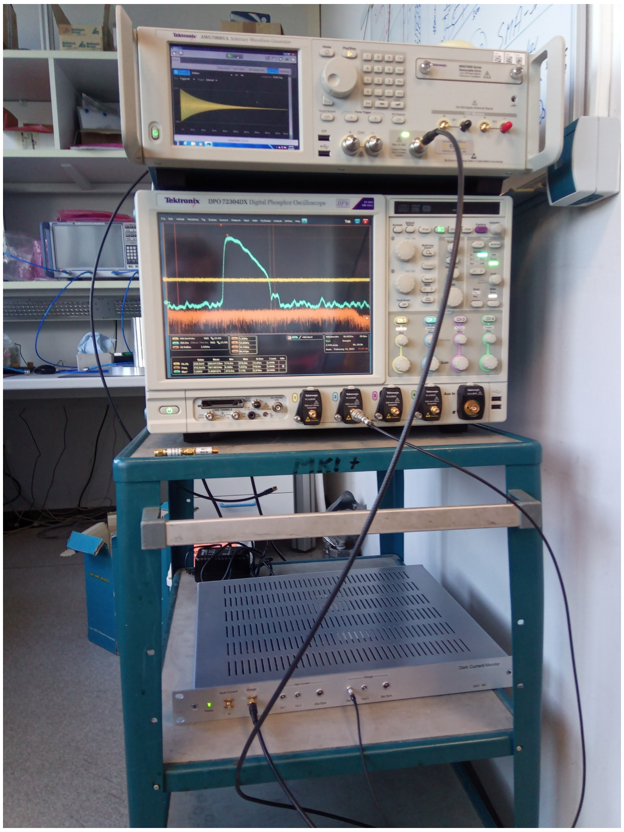

Figure 2: Calibration setup in the laboratory.

The resulting electronics responds is shown in Figure 3 for the Q and DC channel. The CW signal measurements agree to each other but for a pulsed signal a difference is visible for higher amplitudes. The number of measurement points for the old CW was increased to check that charge non-linearities are not caused due to interpolations from the electronics responds. For the overall calibration the pulsed signals are used to generate a look-up table for each channel including the information about each resonator sensitivity, cable attenuation and ADC conversion to voltage. Between each point in the table the values are interpolated to calculate from the measured ADC amplitude back to the charge.

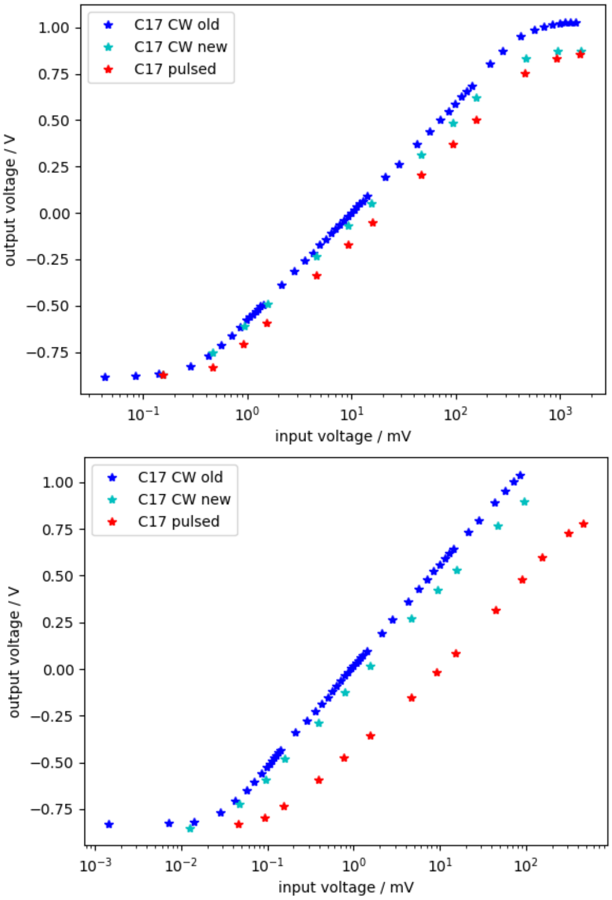

Figure 3: Response function for Q channel on top and for the DC channel below for electronics serial C17 installed at ARES. Each channel has three measurements: dark blue with CW signal in the laboratory, bright blue for CW signal and 16 bit ADC and red for pulsed signal.

BEAM CHARGE MEASUREMENT RESULTS

In Figure 4 the measurement of the first DaMon system at ARES for the Q channel and a charge range up to 210 pC is shown. The Q channel is attenuated with 20 dB before the signal enters the electronics to provide a charge range up to 1 nC. The values are compared with the Faraday Cup charges. The absolute values on top are fitted with a polynomial 1. order. The slope shows the factor between DaMon Q channel and Faraday Cup results: with CW calibration a disagreement of 6.7 % is shown, with the pulsed signal the disagreement is reduced to −3.4 %. The lower diagram shows the ratio between Q channel and Faraday Cup charges as a function of Faraday Cup charge. For charges above 100 pC the values are linear, therefore for accelerators operating above this value the DaMon Q channel shows the same as the Faraday Cup, below this charge the CW calibration shows non-linearities. This non-linearity is reduced to ±3 % with the pulsed signal calibration.

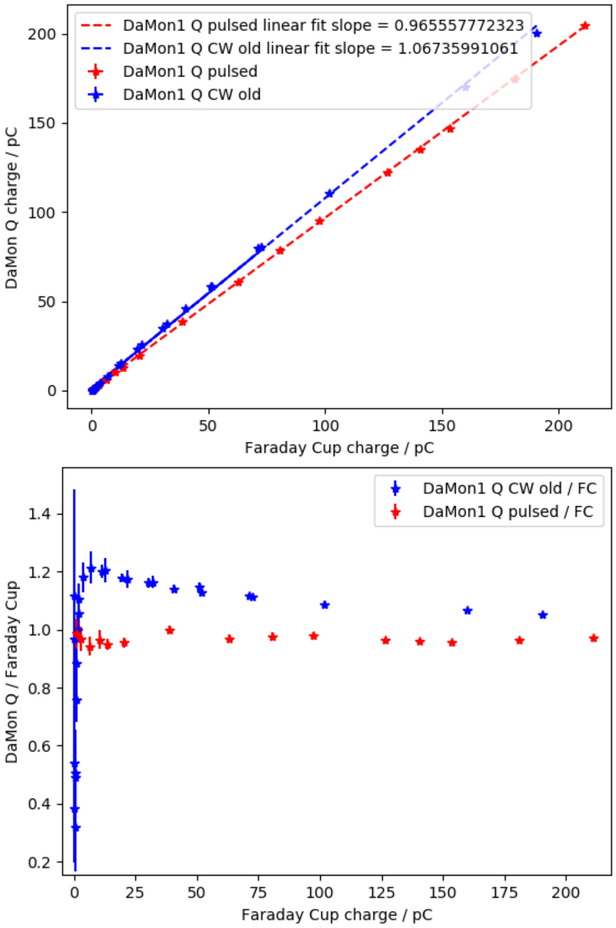

Figure 4: Top: measured charge of the resonator Q channel as a function of Faraday Cup charge; below the ratio of Q channel to Faraday Cup charge as a function of Faraday Cup charge. Error bars are standard deviation caused by beam charge variation.

Figure 5 shows the charge measurement results with the DC channel in comparison with the Faraday Cup; here the charge range is only up to 15 pC because for higher charges the electronics is in saturation. Therefore, this channel is intended for small charges. The absolute values are fitted too and show almost the same slope; the CW values were defined only up to 10 pC. In the lower diagram the ratios are shown and a strong non-linearity is visible for the CW calibration with an overestimation of the charge by a factor of almost 2. With the pulsed signal calibration the variation from a linearity is reduced to be only ±5 %. Still slightly higher charge is measured with the DC channel which could be corrected beam based.

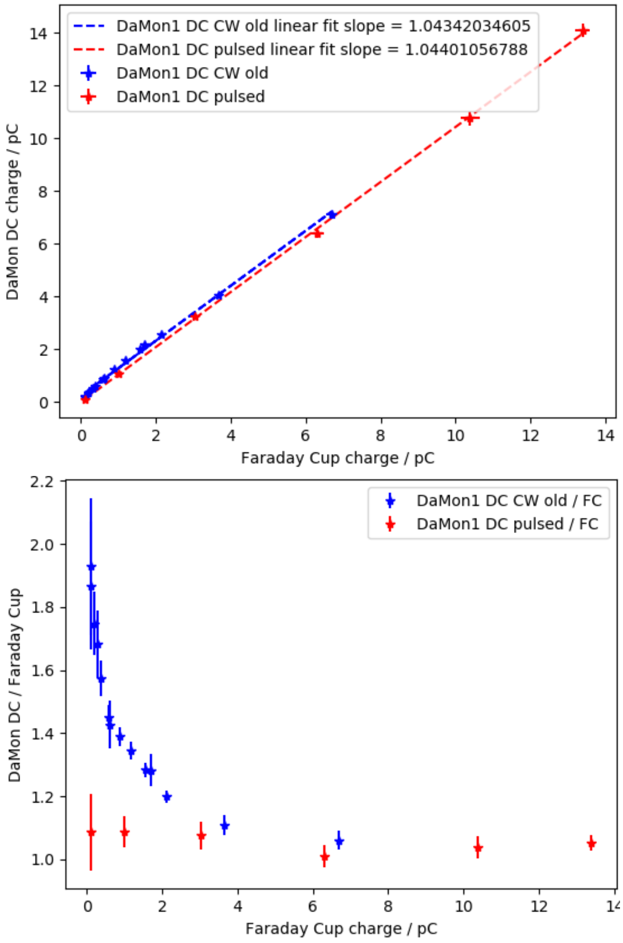

Figure 5: Top: measured charge of the resonator DC channel as a function of Faraday Cup charge; below the ratio of DC channel to Faraday Cup charge as a function of Faraday Cup charge. Error bars are standard deviation caused by beam charge variation.

SUMMARY AND OUTLOOK

Charge measurement with resonators must be calibrated carefully. A beam independent laboratory calibration was developed and the results were compared with a Faraday cup. A calibration with CW pulses show non-linearities for low charges. A laboratory calibration with the same signal as it is expected from the resonator improves the non-linearity and absolute charge values. The laboratory calibrations will be improved due to automatic variation of the amplitude of the signal generator and readout from the ADC. In addition, a new electronics board is in development as a rear transition module for μTCA crates with larger dynamic range due to two additional amplifiers for different amplitudes for each channel.

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