# DEVELOPMENT AND CALIBRATION OF A MULTI-LEAF FARADAY CUP FOR THE DETERMINATION OF THE BEAM ENERGY OF A 50 MeV ELECTRON LINAC IN REAL-TIME

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*Abstract*

The Physikalisch-Technische Bundesanstalt (PTB), Germany's national primary standard laboratory, operates a research electron LINAC with variable energy (0.5 – 50 MeV). A 128-channel Multi-Leaf Faraday Cup (MLFC) has been developed to measure the energy and the pulse charge in real time during the preparation or optimization of an electron beam of specific desired energy. The thickness of the entire leaf stack of the MLFC is sufficient to stop a 50 MeV electron beam. A dedicated electronic device has been developed for sequential readout of the charge collected by the leaves after each beam pulse. The range of the electrons and thus the distribution of the charge on the leaves depends on the energy. The MLFC was calibrated by recording charge distributions from monoenergetic electron beams of known energy. The MLFC is mounted at the end of the accelerator structure and replaces the beam dump. Energy, pulse charge and beam power from the MLFC measurement are displayed in real-time so that the influence of any manipulation of parameter setting on energy and beam power during beam preparation can be evaluated immediately.

## INTRODUCTION

The preparation of an electron beam of specific desired energy and beam power at a LINAC is an optimization problem with many parameters. All parameters which influence the HF power (as e.g. via the high voltage at the modulator) as well as the number of charged particles in a bunch to be accelerated (as e.g. via the gun emission) also change the energy of the beam. It is therefore very helpful to be able to measure the energy in real-time during the adjustment of a setting.

The range of charged particles and thus the initial distribution of the charge in a solid depends on their energy. By means of a MLFC it is possible to measure nearly instantaneously the amount of deposit charge as function of the range [1-3]. The corresponding energy can be determined from this charge distribution. MLFCs are already used in proton beam facilities for energy and range modulation measurements [4-7]. For proton beams are even two different types of MLFCs commercially available [8-9].

In this work we present a MLFC designed for electron beams up to 50 MeV with a dedicated self-developed readout device based on inexpensive electronic circuits for fast sequential readout of the 128 MLFC channels.

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## DESIGN AND OPERATING PRINCIPLE

The MLFC detector consists mainly of 128 galvanically insulated Al plates in a stack perpendicular to the beam. The Al plates act as capacitors and store the charge portion deposit by the beam pulse in each plate until their sequential readout. From the distribution of the charge on the plates or in the 128 corresponding readout channels, respectively, the beam energy is determined.

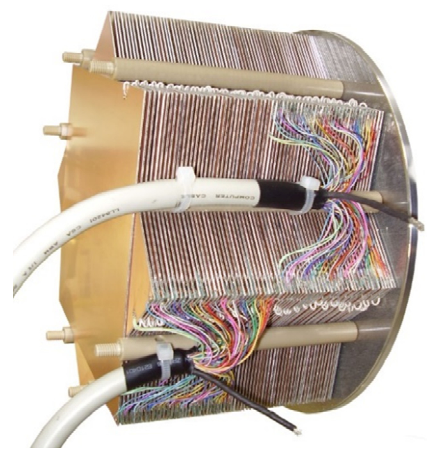

Figure 1: MLFC detector consisting of 128 leaves.

Figure 1 shows the MLFC detector without its housing. The dimensions and the total thickness of the leaf stack was chosen in such a way that it is large enough to absorb all primary electrons with the highest planned energy (50 MeV) and without scattered electrons leaving the detector laterally; On the other hand, the leaves are thin enough so that the charge distribution from an electron beam with the lowest planned energy (5 MeV) is still well resolved by the first 15 MLFC channels.

Each of the 128 MLFC leaves (15x15 cm) consists of a 0.625 mm Al plate, which acts as the actual beam absorber, a thin insulating layer (125 μm glass fibre) and a thin metal layer (35 μm Cu) on earth potential for shielding of the electric field from the charge stored at the Al plate. A further thin insulating layer (75 μm polyamide) works as galvanic insulation against the subsequent leaf. The insulation resistance of the Al plates is > 2 GΩ, so that the collected charge is stored virtually loss-free until its readout. Thanks to this feature, it is not necessary to read out all 128 plates parallel at the same time. Instead, signal acquisition can be done using a single charge integrator with a multiplexer. This simplifies the design, because otherwise 128 separate integrators would be necessary which have to be individually calibrated.

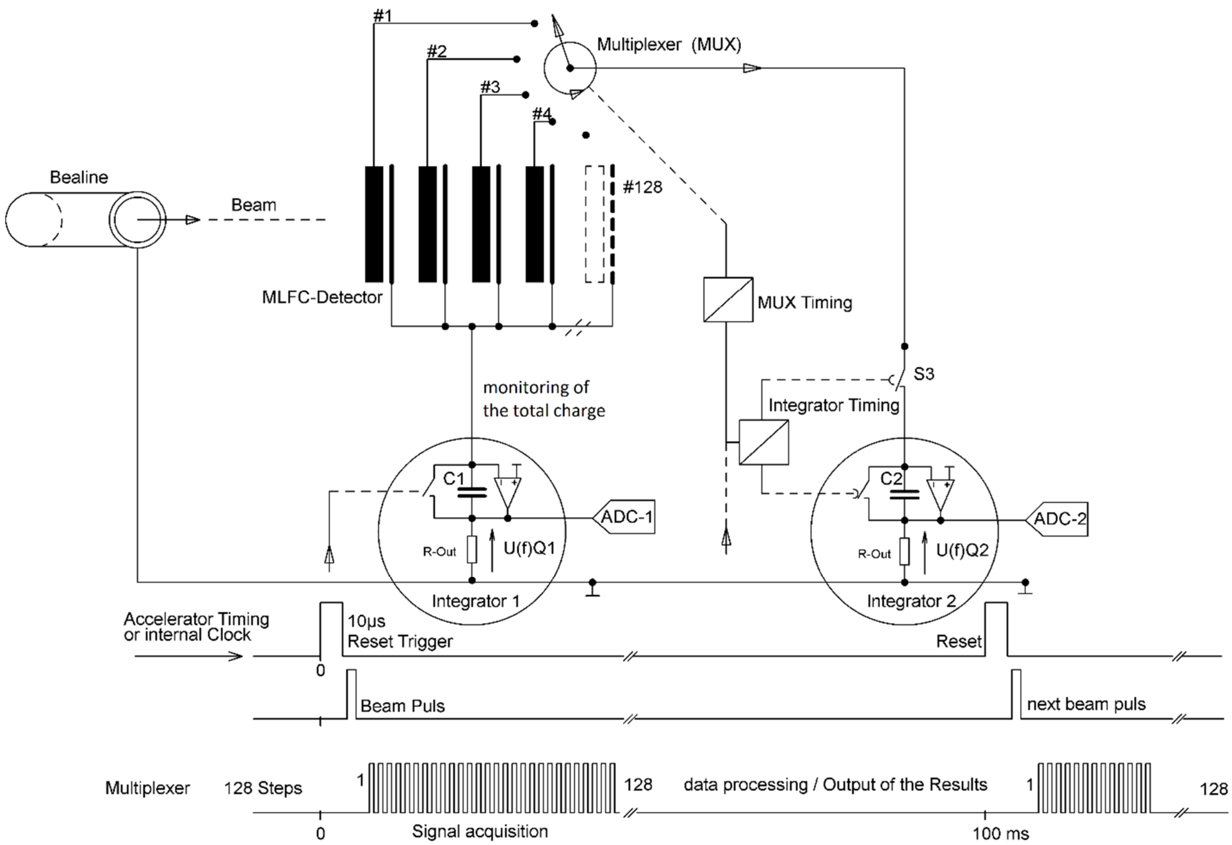


Figure 2: Schematic diagram for read out of the MLFC.

Figure 2 shows a schematic diagram for the readout of the MLFC detector. The 128 galvanically insulated Al plates are individually connected to one of the 128 inputs of a multiplexer and thus isolated from the rest of the electronics during the irradiation. The sequential readout of the charge on the 128 plates is done by the charge integrator "Integrator 2". The readout starts immediately after each beam pulse or after the total charge collected by the MLFC has exceeded a selectable threshold value. The total charge is monitored by charge integrator "Integrator 1" in the following way:

The charge collected on an Al plate creates an image charge of equal magnitude but opposite polarity on the thin Cu layers on earth potential next to the charged Al plate. The formation of this image charge induces a current during the charge balancing recorded by Integrator 1. All Cu layers are permanently electrically connected to each other and to the input of Integrator 1. In this way the total charge collected in all Al plates is constantly monitored without disturbing the characteristic charge distribution stored on the Al plates. Integrator 1 works bidirectionally, i.e. acts as charge sink during formation of the image charge at the irradiation and as charge source during the readout of the Al plates and the resulting vanishing oft the image charge.

The Cu layers are much thinner than the Al plates. Therefore, the portion of the beam charge collected by the Cu layers, which contributes to the charge recorded by Integrator 1, is negligible.

When sequentially reading out the Al plates, the Cu layers at earth potential shield the Al plate, that is being read out, from the electric field of the adjacent Al plate that is still charged. So, the grounded Cu layers between the Al plates avoid effects of influenced image charge from one Al plate to another and enables the sequential read out.

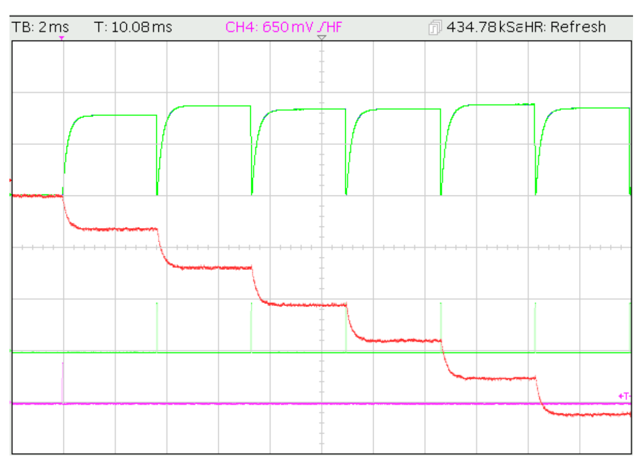


Figure 3: Oscillogram of signal from Integrator 1 (red) and Integrator 2 (upper green) during readout of the MLFC.

## SIGNAL ACQUISITION

### *Pulse Resolved Mode*

The readout device requires < 100 ms to scan all 128 channels and the software < 10 ms to analyse the measured charge distribution. This allows a pulse resolved measurement for up to 10 beam pulses per second. Three different measuring ranges of the charge integrator enable measuring of pulse charges from about 1 nC to about 10 µC. After each beam pulse, the total pulse charge stored in the Al plates is determined from the image charge at the Cu layers recorded by Integrator 1. If the selected measuring range of Integrator 2 is adequate for the stored charge, then the multiplexer starts to pass the individual detector channels to Integrator 2 for readout. The image charge measured by means of Integrator 1 decreases proportional to the discharge of the Al plates during the readout. Figure 3 shows the oscillogram of the signals from Integrator 1 (red) and Integrator 2 (upper green) during successional readout of 6 Al plates of the MLFC. The image charge decreases one step each time a further Al plate is read. Finally, the detector is discharged before the subsequent beam pulse.

### *Integrating Mode*

An integrating mode can be used if the pulse charge is below the detection limit (< 1 nC/pulse) or for low current CW beams. During the irradiation the entire charge deposited in the detector is continuously monitored by Integrator 1 without distorting the energy-specific charge distribution at the Al plates. The readout by means of Integrator 2 starts after reaching a freely adjustable threshold for the charge recorded by Integrator 1 or after a predefined time span. Thereafter, the detector is discharged for a few milliseconds and, if desired, the next measurement is started automatically.

The readout is done between the beam pulses. In case of a low current CW beam the irradiation during the readout hardly influences the charge distribution if the irradiation time is long with respect to the readout time (< 100 ms).

The electronics are designed to protect itself and the detector from overcharging even when switched off.

## CALIBRATION

The MLFC was calibrated with monoenergetic electron beams at the exit of a 180-degree magnetic spectrometer [10] at the 5 – 50 MeV beam line of PTB's research LINAC. Charge distributions are recorded as a function of the known beam energies. Figure 4 shows the maximum normalised charge distributions from the MLFC for different energies. The area integral of the normalised distributions increases linearly with the energy as shown in Fig. 5.

The MLFC was then installed at the end of the accelerator structure as shown in Fig 6. Using the calibration function (Fig. 5) the beam energy is determined from the measured charge distributions and displayed in real-time together with measured pulse charge and resulting beam power. Figure 7 shows the GUI for the control of the MLFC readout device and for the display of the results in real-time.

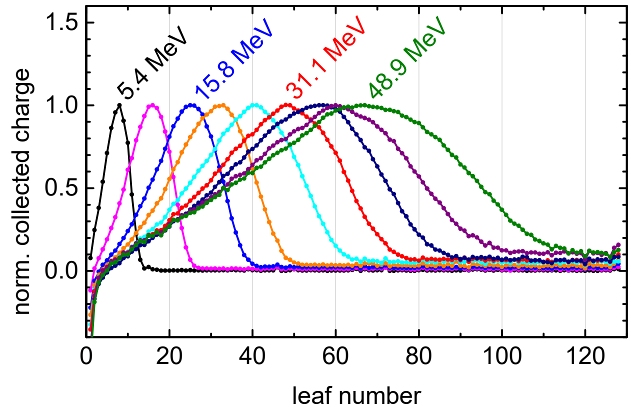


Figure 4: Electron distributions for different beam energies as recorded by the MLFC.

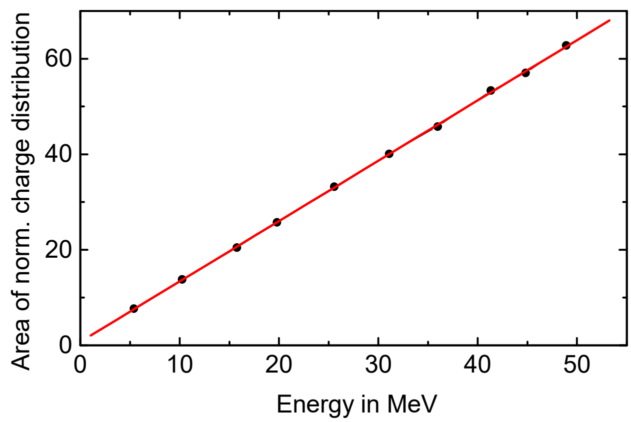


Figure 5: Calibration curve. Red line linear fit to data.

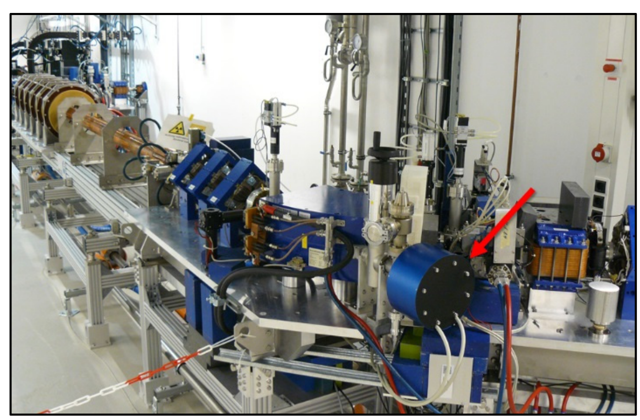

Figure 6: MLFC in its housing mounted at the end of the accelerator structure (red arrow) as replacement of a beam dump.

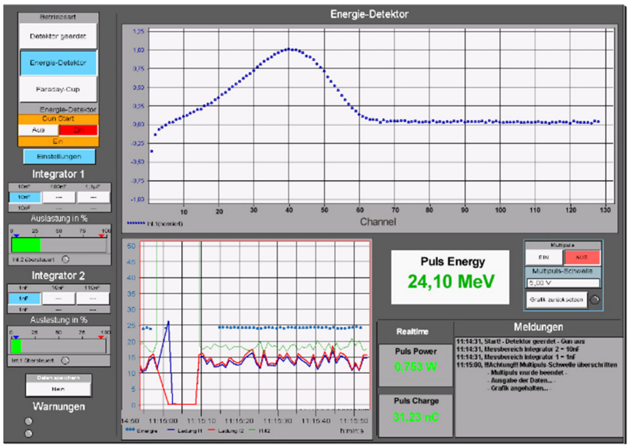


Figure 7: GUI for MLFC control and display results.

## CONCLUSION

The developed MLFC allows the pulse-resolved measurement of beam energy and power of the electron beam from a 50 MeV LINAC with variable energy. Energy, pulse charge and beam power from the MLFC measurement are displayed in real-time so that the influence of manipulated variables on these output parameters can be immediately assessed during the beam preparation.

Table 1 summarises the specifications of the developed MLFC system and Fig. 8 shows a photo of the MLFC detector as well as the readout device with their housings.

The design of the detector and the electronics is largely flexible in each direction and can be customized for other beam energies or currents by changing plate thickness or integrator measuring ranges, respectively. A test of the MLFC system for application in clinical proton and carbon beams is in preparation.

Table 1: Specifications

| | |
|---|---|
| Number of channels | 128 |
| Leaf material | 0.625 mm Al,<br>125 µm glass fiber,<br>35 µm Cu,<br>75 µm polyamide |
| Charge integrators | 2 |
| Measuring ranges | 3 |
| Readout time | < 100 ms |
| Max. beam pulse rate | 10 Hz |
| Pulse charge range | ~1 nC to ~10 µC |
| Energy range | 5 to 50 MeV |
| Detector dimensions | Ø22 x 14 cm / 5 kg |
| Patent Pending | PCT/EP2019/065254 |

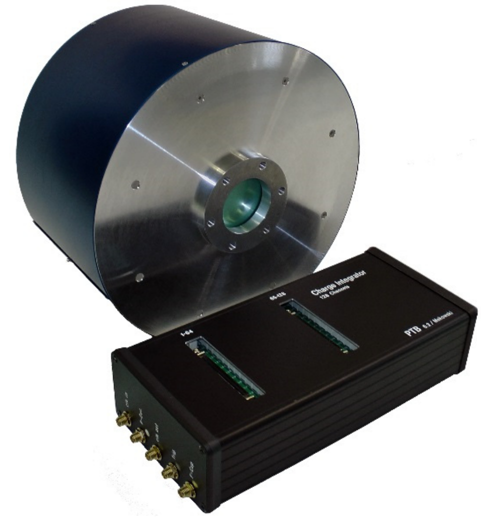

Figure 8: Photo of MLFC detector and readout device.

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