PRACTICAL REVIEW ON BEAM LINE COMMISSIONING PROCEDURES AND TECHNIQUES FOR SCIENTIFIC AND INDUSTRIAL ELECTRON ACCELERATORS

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Abstract

Accelerator science constantly requires improvement in electron beam quality for both scientific and industrial applications. Examples of parameters on existing systems that affect overall beam quality include vacuum stability, component level alignment, RF phase matching, electron injection parameters, etc. A proper beam-commissioning process allows the characterization of initial parameters that tune system setup appropriately to improve net beam quality and becomes a valuable source of data to guide system operation. We discuss methods and possible obstacles during the commissioning process of accelerator systems experienced at RadiaBeam.

INTRODUCTION

While most scientific and research facilities have their procedures and guidelines for the accelerator beam line commissioning process it is important to update and validate these steps in terms of contemporary technologies and up-to-date scientific knowledge. The varying designs of RF linear accelerators requires validated instrumentation to characterize and commission these linacs. To aid in their commercial and contract production of different linacs, RadiaBeam has designed and constructed a multipurpose test beamline (Fig. 1) for commissioning different electron linear accelerators manufactured at RadiaBeam [1-3].

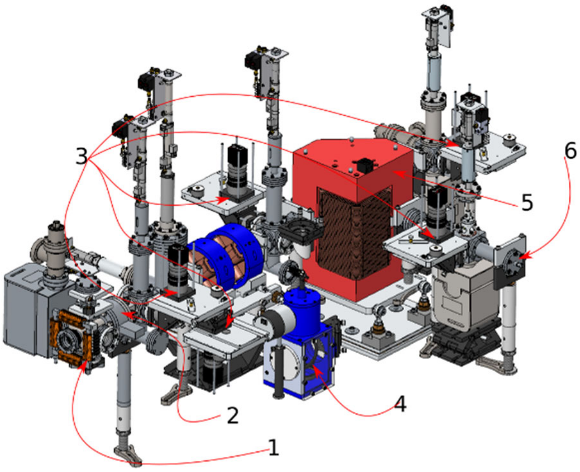

Figure 1: Test beam line for low energy (up to 10 MeV) accelerator commissioning. 1 – steering magnet, 2 – Turbo ICT, 3 – beam profile monitors, 4 – THz interferometer for bunch length [4], 5 – spectrometer dipole, 6 – Faraday cup.

This beamline is suited for six fundamental measurements important for any accelerator: beam charge, transverse position, shape, energy, bunch length, and emittance. Each parameter requires one or several different devices to be measured accurately and with a certain degree of reliability. Here we will discuss general procedures and techniques for commissioning test beamlines for scientific and industrial linear electron accelerators with modern measuring devices.

CHARGE MESURMENTS

Precise charge measurements are always a challenge in any case study. To accurately determine bunch charge three independent measuring systems are implemented: a Bergoz Turbo Integrating Current Transformer (ICT) [5], a traditional toroidal current transformer (CT) [6], and a commercial RadiaBeam impedance-matched Faraday cup [7]. The Faraday cup can be easily replaced to ensure full attenuation of higher energy electors. Four important positions were monitored by these devices: drift section entrance with Turbo ICT, spectrometer bend section end with faraday cup, straight beam line drift after spectrometer dipole with CT, and end of beamline with faraday cup.

The Bergoz Turbo ICT is a toroid-based current sensor which performs integration with a secondary coil and therefore measures bunch charge in addition to average current measurements with low noise and high accuracy. The ability to measure ultra-short bunch charges down to a few pico-Coulombs upon external or internal triggering allows characterization of photocathode driven electron sources, such as RadiaBeam's commercially available 1.6-cell photoinjector guns.

Regular current transformers do not give direct bunch charge measurement but provide the average current reading over an RF pulse. A traditional current toroid is used to characterize dark current emissions of a linac while also being capable of measuring macro pulse current of thermionically-driven linacs, such as RadiaBeam's medical, industrial radiography, and sterilization linacs. The Turbo ICT can also be used to measure current by integrating the current values over a time constant. In addition to inductive charge measurements, a 50-Ohm impedance-matched Faraday cup is used to measure charge. The impedance matching gives a faster response time and the ability to measure the charge of short pulses. However, the small collector size of ~15-mm diameter (chosen for impedance matching to the 35-mm beam tube) requires careful beam alignment both for beam capture and to limit errors associated with

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secondary electron production. Though it is challenging to maintain beam size along the 2-meter-long diagnostic beamline, a quadrupole doublet is used to place a waist near the Faraday cup.

Charge Measurement Procedure

Charge measurement gives the operator a fair amount of information about electron source performance or RF phasing in case of ultrashort pulses. For the second case while varying RF phase one will observe charge growth in a certain region. For nominal operation parameters, one must choose one of two modes: most efficient acceleration (on-crest) or higher bunch stability (off-crest) in most cases. Choosing the RF phase depends on various parameters of particle source initial accelerating field, etc. To make the right decision for different applications additional data is needed. Transverse and longitudinal beam profiles as well as beam energy measurements are yet another important characteristic for accelerator operation able to provide this data. A combination of data from these sources will provide the optimal operation configuration of the accelerator.

TRANSVERSE BEAM-PROFILE MEASUREMENTS

The test beamline is configured with four transverse beam profile monitor stations equipped with YAG screens, neutral-density filters for light attenuation, bandpass filters for selectively viewing the YAG emission, and an optical lens system for different focusing parameters. Additionally, some stations are equipped with optical transition radiation foils. The current design uses modified compact RadiaBeam's Integrated Beam Imaging System [8] based on Allied Vision Mako 131B cameras (chosen for the ease of their GigE compliant interface, large and dense CMOS sensor, power-over-ethernet capability, and low-cost) coupled with a five-position motorized filter wheel (Fig. 2). This setup has a fixed focal length for each beam profile station which reduces overall cost, allows for repeatable measurements by removing operator adjustability, and can still provide high resolution of 1280x1024 pixels.

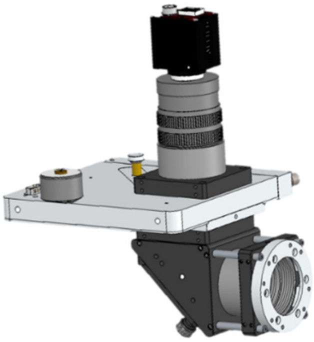

Figure 2: Transverse beam profile station optical system.

Four positions along the beamline were chosen to place profile monitor stations: diagnostic line entrance (also coplanar with emittance masks), at the spectrometer entrance, after spectrometer bend, and the final is placed after the spectrometer at a matched distance to the spectrometer YAG. The drift section profile monitor is also equipped with a glass mirror directed against beam propagation direction in order to observe electron source (thermionic element or photocathode) condition or to act as an OTR profile monitor for extremely dense beams.

Transverse Profile Measurements

Initial beam profile characterization takes place along with charge measurements. The first step is to measure dark current parameters. The shape usually looks uniform (Fig. 3(a)) and can be interpreted as a true beam if charge measurements are not considered. The charge is usually close to the noise level of the ICT.

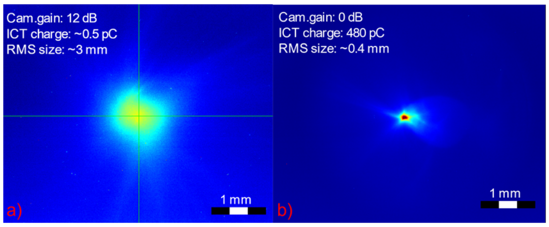

Figure 3: Dark current (a) and true beam (b) profiles on a YAG screen.

By capturing the image of the dark current and subtracting its data from camera readings one can receive a true beam profile after enabling the electron source regardless of its nature.

Figure 3(b) shows the true beam profile gained on the test beamline during characterization of a photocathode gun. The beam profile has additional rays coming from the main beam which are a sign of misalignment between the photocathode gun's solenoid, excitation laser, and the RF cavity.

RF AMPLITUDE AND PHASE SCAN

RF phase shifting also affected charge and energy readings (Fig. 4). According to this data, the operator must can find the optimal point of maximizing charge, beam energy or its transverse shape depending on accelerator application case.

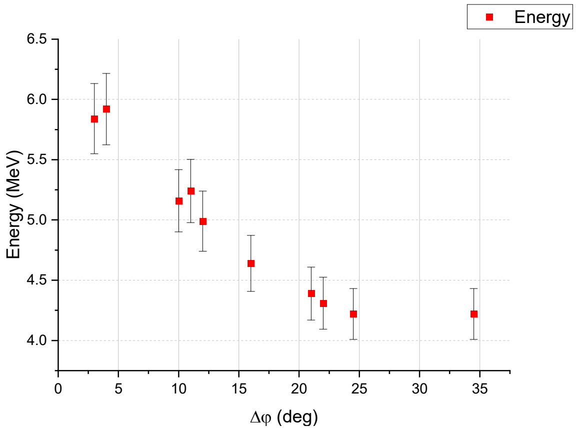

Figure 4: Beam energy vs. RF phase shift from arbitrary zero.

To determine optimal operation parameters RF phase and amplitude scans are performed during charge measurements. Beam profile is monitored through these experiments to verify optimal transverse shape. Figure 5 shows beam transverse shape evolution with RF phase variation.

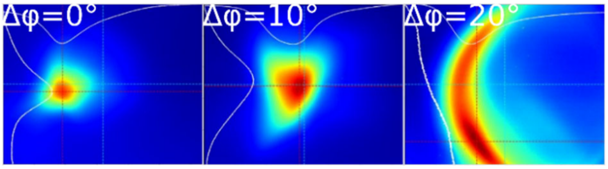

Figure 5: Transverse beam profile evolution with RF phase shift (phase delta is relative to arbitrary zero assigned to “nominal” operation).

BEAM ENERGY MEASUREMENTS

The current test beamline is configured with a 90-degree bend section dipole for beam energy measurements. This bend section is equipped with beam profile monitor YAG station and Faraday cup at the end of the path (Fig. 1). The operator can choose two ways to determine beam energy: buy adjusting current value on the dipole to maximize charge reading on the Faraday cup or buy centring beam profile on the YAG screen visually. While both options have near the same amount of error, the second approach provides additional information on energy spread of the beam. This is achieved by using last beam profile monitor at the end of the straight section and focusing electrons in horizontal direction creating a solid thin vertical line. This line will expand after enabling bending dipole according to electron energies (Fig. 6).

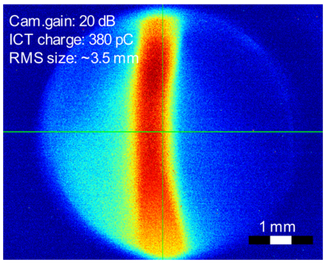

Figure 6: Beam profile on the spectrometer YAG after the 90-degree bend dipole.

EMITTANCE MEASUREMENTS

The test beamline has several options to perform emittance measurements: using set of two emittance masks (vertical and horizontal) and by using focusing duplet within a quadrupole scan technique.

Emittance vertical and horizontal masks are made with a single path line forming a periodic pattern of 100-µm slits arranged in steps of 300 µm. The third beam profile monitor is located 80 cm after emittance masks allowing to determine beam RMS geometric emittance via the equation:

$$\epsilon = \sqrt{< x^2 >< x'^2 > - < xx' >^2}\ .$$

Additional energy measurements will provide data for calculating normalized emittance.

Quadrupole scanning is a simple technique of measuring the beam size of the particle beam as a function of the magnetic field strength of a quadrupole magnet at certain distance from that magnet. Current setup allows to perform such measurements.

LONGITUDINAL BEAM PROFILE

Measuring bunch length is an important longitudinal beam parameter, this system takes advantage of RadiaBeam’s Bunch Length Interferometer System (BLIS) [4], based on compact Michelson THz interferometer design. This configuration allows to measure electron bunches of the picosecond scale length.

CONCLUSIONS

This work was aimed to generalize aspects of electron accelerator beam line commissioning process through a review of some of the current devices and methodologies we have recently been in the process of utilizing. Some practical results of beam parameters measurements are shown from recent activity in the commissioning of a unique photoinjector. Though most measurements are charge and energy related it is important to validate them with additional monitoring such as transverse beam profile. Experimental results shown in this work demonstrate wide abilities of universal test beamline and how it can aid in defining a path forward in commissioning an electron beamline.

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