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HIGH-CHARGE TRANSMISSION DIAGNOSTICS FOR BEAM-DRIVEN RF STRUCTURES

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Abstract

The Argonne Wakefield Accelerator group (AWA) has been using high charge bunch-trains (>450 nC) for structure wakefield RF power generation and high power testing (100s of MW) for many years. These experiments involve fast beam-tuning for high charge transmission through small aperture wakefield structures over a large range of charge levels. The success of these experiments depends on real-time, non-destructive, fast charge measurements with devices that are robust in the high-charge and high-powered RF environment. AWA uses Bergoz Integrating Current Transformers (ICT) which are ideal for these critical charge measurements. The devices used, the method developed and their application are detailed.

INTRODUCTION

The Argonne Wakefield Accelerator (AWA) facility is dedicated to novel and advanced accelerator research, with particular attention to Structure Wakefield Accelerators (SWFA) for future colliders [1]. One of the unique challenges of the experimental program is the difficult task of tuning the beamline in order to ensure that the 65 MeV high-charge, short pulse electron bunch-trains are transmitted through SWFA devices with transmission approaching 100%. An example is wakefield generated Two-beam Acceleration (TBA) [2]. The charge is high (often hundreds of nC per pulse), and the structures have small apertures. The potential wakefield power generated per nC transmitted increases with the length of the structure. The power potential also increases as the beam aperture is made smaller for a given charge [3]. Therefore the transmission difficulty increases with the potential for power generation. To ensure the best results, it is necessary to be able to effectively monitor the charge at the input and output of the structure. In fact, it is essential to the success of these experiments. The scheme that has been developed to do this is described herein, which will be referred to as the ICT monitor scheme diagnostic.

THE EXPERIMENTAL SETUP

AWA conducts many different types of SWFA experiments, however there is one category, the high-power RF test, that will serve to illustrate the beauty and simplicity of the ICT monitor scheme diagnostic for tuning the beam for good transmission and stable high-power extraction. The goal of this type of experiment is to use the AWA drive beam to drive a Power Extraction and Transfer Structure (PETS) with a high-charge bunch train, a recent example is described in Ref. [4]. A metallic PETS which is currently in service will produce more than 400 MW RF power in each approximately 10 ns pulse at 11.7 GHz (X-band) from an 8-bunch train. Extracted power is transmitted through evacuated WR90 waveguides to the device under test (DUT), some type of Structure Wakefield Accelerator (SWFA) or related RF device. These may be metallic, dielectric, metamaterials or a hybrid such as the dielectric disk acclerator (DDA). Experiments are executed in order to study different structure design performance under high RF power and the associated high-gradients occurring within the structure, pushing them to the breakdown limits. The structures vary widely in frequency with AWA covering the range from 11.7 GHz to more than 100 GHz. Since there is an inverse relationship of structure frequency to the beam aperture, the higher frequency structure with aperture of less than 1 mm will see maximum charge transmission limited to 4 bunch trains totaling 20 nC compared to the 8 bunch, 500 nC transmitted through the 17 mm aperture of an X-band metallic structure. But monitoring and assuring good transmission is essential in all cases. The AWA drivebeam photo-injector [5]

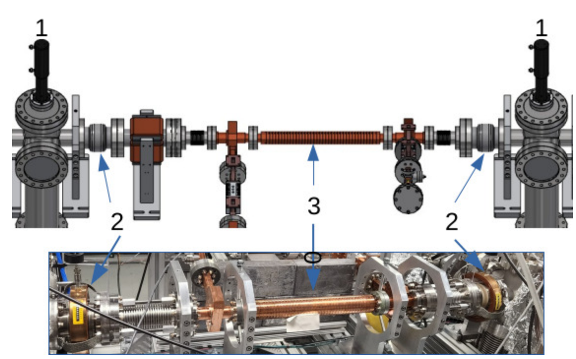

Figure 1: Experiment layout: Top: PETS vacuum installation drawing, Bottom: an installation photo illustrating the X-band PETS at AWA with some important diagnostics. Total distance from YAG to YAG is 144.5 cm. 1) YAG station 2) top: ceramic break for ICT 2) bottom: ICT as installed over ceramic break 3) PETS

is the source of high-charge bunch-trains. The photoinjector

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UV laser produces 0.3 ps, 262 nm light pulses. The available UV energy per pulse is 5 mJ before the splitter. The tuning procedure begins with setup of the bunch-train produced from each single UV pulse which splits it into 8 pulses with 769 ps spacing. This is accomplished by using the specially designed laser multi-splitter and its adjustable delay lines. Once the laser has been set, the operator must scan the electron beam phase and use the data to carefully set the intra-bunch timing. The phase scan is done by varying the RF phase and watching for the onset of photoemission by monitoring the ICT signal immediately after the gun. In addition to the ICTs, available diagnostics include beam-position monitor (BPM), spectrometer, scanning slits for emittance measurement, and Yttrium aluminum garnet activated by cerium scintillation screens (YAG:Ce) for viewing the transverse profile, moments and position of the beam along the beamline. The next steps are to tune the beam through the linac, making careful observations at the YAG:Ce screens.

TRANSMITTING THE BUNCH-TRAIN

The bunch train must be transported, then focused and transmitted through the wakefield structure. As previously stated, the wakefield structure is installed between two diagnostic stations which include YAG:Ce screens for observing the transverse beam position and size, and ICTs for measuring the charge per pulse, see the drawing in Fig. 1. In order to receive a signal from the beam, a gap in the conducting vacuum chamber wall in the form of a brazed ceramic ring must be in place near the ICT. In addition, the wall currents must be conducted around the ICT and across the gap (see Fig. 1) bottom. Wall current is conducted via the braided flat cables over the ICTs, visible to the left and right. During high-power testing runs, the power is gradually raised by incrementally increasing the charge. For each charge increase, input and output RF signals are recorded and carefully monitored for any signs of trouble such as arcing, breakdown, or multi-pacting by using a high-speed, high-sampling rate oscilloscope connected to a calibrated bi-directional coupler.

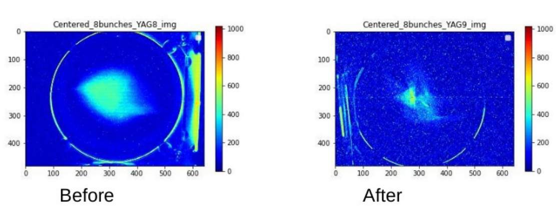

Figure 2: Beam images before and after the wakefield structure. 8 bunch train. Average transmission 100%.

The YAG:Ce images are necessary for tuning the beam with good transmission through the large aperture beampipe of the linac section and bringing it to the DUT. The YAG images before and after the structure are helpful for setting the quadrupoles and beginning to tune the beam through the structure. As an example, see the pair of images from before and after the PETS depicted in Fig. 2. Before the structure the 8 bunch train appears as a single blob of light. After exiting the structure the individual bunches are diverging and separated, but it is impossible from the images alone to know the level of charge transmission. This is when the ICT Monitor scheme comes into play.

ICTS

The two types of ICTs used at AWA are pictured in Fig. 3.

Figure 3: AWA uses two types of ICTs. In-flange (left) and In-air (right). The ceramic break is integrated into the in-flange model.

The ICTs used before the PETS are Bergoz Instrumentation 20-turn in-air ICTs with a sensitivity of 1.25 Vs/C. The ICT is a passive current transformer specially designed for pulse charge measurements. Its output signal is a pulse of well defined shape, independent of beam position. The integral of this pulse, which yields the charge, is also independent of input pulse length. The ICT works equally well when used to measure single pulses or 8 bunch-train charges. Sensitivity of the used ICTs yields a peak value of about 40mV per nC and a pulse width of about 70ns. As a result, the ICT pulses can be easily integrated, for example, using an oscilloscope. [6]. The specifications of the oscilloscopes used for this particular application at AWA are 1 GHz bandwidth, with 2 to 10 GS/s sampling rate. As recommended by Bergoz, in order to eliminate parasitic signals, two types of common-mode chokes have been installed on both ends of the ICT output cable. Previouly, apparently due to the parasitic signal generated when high-charge is passing through small apertures, without the common mode chokes, the transmission would sometimes be computed as a couple percent above 100%.

ICT MONITOR PROGRAM

The ICT monitoring software was developed natively at AWA and uses the NIVISA libraries to communicate with the scope. From the GUI (see Fig. 4) the scope with the desired ICT signals is selected and up to four scope traces downloaded and displayed on a virtual scope panel. Once the signals are active the user can directly monitor the charge graphically and numerically in one window choosing any or all four signals. The other panel allows the choice of any two ICTs along the beamline, integrates the signals and calculates the percent transmitted charge from point A to point B. This may be plotted shot-by-shot in the panel, serving to inform the operator when efforts at tuning through the structure

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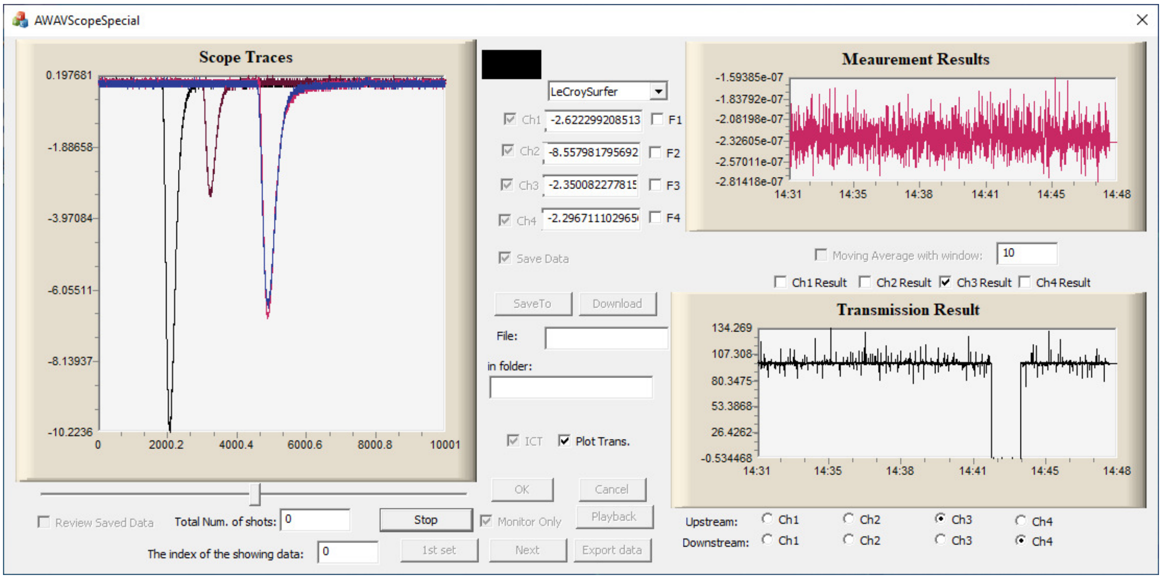

Figure 4: Screenshot of the ICT Monitor GUI during a recent experiment. Four ICT signals are being monitored along the beam line. The average transmitted charge is 245 nC, average transmission 100%.

are succeeding or making things worse. If desired, the ICT data can be saved synchronously along with the RF signals, BPM data and beam images from YAG screens. With the addition of this ICT monitoring scheme, the ICTs which have long been an essential diagnostic at AWA have improved the tuning process, making it much more systematic and straightforward. This has streamlined the use of the PETS for RF high-power tests.

CONCLUSION

The development and implementation of the ICT monitor scheme for transmission diagnostics has been instrumental to the success of many SWFA experiments at the AWA. Its success hinges on the proven dependability of the robust wide-dynamic range Bergoz ICT. The AWA SWFA program has been strengthened and become more efficient thanks to this improved approach to beam tuning through small-aperture structures. The next step is to automate the tuning process using the output of the ICT Monitor as feedback. The ICT Monitor Scheme may also be contemplated as an ideal entry point for further application of Artificial Intelligence and Machine Learning (AIML) at AWA in the near future.

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