

TOWARD EMITTANCE MEASUREMENTS AT 11.7 GHz SHORT-PULSE HIGH-GRADIENT RF GUN*

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Abstract

A short pulse high gradient RF gun (see Fig. 1) has been recently tested at Argonne Wakefield Accelerator (AWA) facility. The carried-out test showed that the 1,5-cell gun was able to inject 3 MeV, up to 100 pC bunches at room temperature being fed by 9 ns up to 300 MW 11.7 GHz pulses. The cathode field was as high as about 400 MV/m. So high field is aimed to mitigate repelling Coulomb forces substantially. In accordance with simulations the emittance could be as low as less than 0.2 mcm. To obtain so low emittance in the experiment, the gun is assumed to be equipped with a downstream linac to be fed from the same power extractor as the gun itself. Here we report design of the RF power distribution system splitting RF power among the gun and the linac, results of low-power tests, and emittance measurement plans for upcoming new experiment at AWA.

A CONCEPT FOR HIGH GRADIENT X-BAND GUN

High brightness beams appealing for XFELs and UEM essentially consist of a large number of electrons in a small phase space volume, i.e. a high peak current [1-2]. When such beams are generated from the cathode, there is a strong space charge force, which elongates the bunch and reduces its brightness. An optimal solution is to raise the accelerating voltage in the gun to mitigate repelling Coulomb forces. However, the maximum gradient is limited by the effects of RF breakdown.

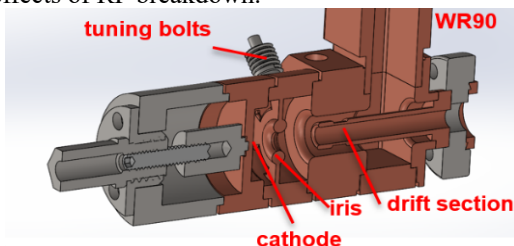


Figure 1: Engineering design of 11.7 GHz UHGPI.

We propose to utilize an ultra-high gradient and a short-pulse technology at room temperature. The probability of RF breakdown and pulse heating temperature are reduced as the RF pulse length decreases [3-4]. We present a development of an electron ultra-high gradient photoinjector

(UHGPI) operating with short RF pulse (9 ns scale) that is produced by a drive beam at AWA.

The proposed 11.7 GHz gun is a 1,5 cell overcoupled resonator with the perforated iris in-between cells in order to sustain strong coupling factor [5-6]. The Q-factor is slightly below 200 to accommodate 9 ns RF pulse. The gun was fabricated two years ago. During tests the gun generated ~3 MeV electron bunches accelerated at about 400 MV/m cathode field. The gun had ~10⁻⁶ breakdown rate and showed a very low average dark current.

RF GUN BEAMLINE

Next experiment will include emittance measurements. For this purpose, the beamline was designed (Fig. 2). It included drive beam line with PETS connected to the gun, solenoid, and diagnostic line based on a pepper pot. In accordance with simulations the emittance could be as small as ~0.2 mm×mrad. In order to obtain so small emittance, an additional linac with ~100 MV/m gradient behind the gun will be used.

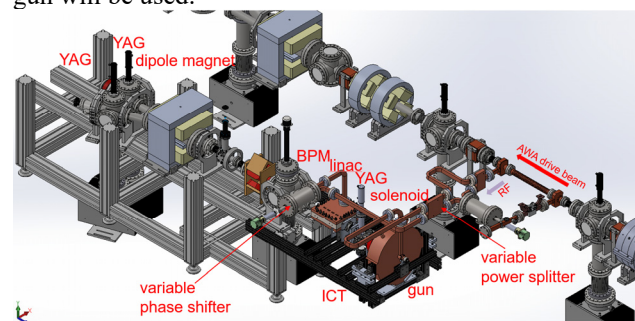


Figure 2: Beamline design for experiment #3.

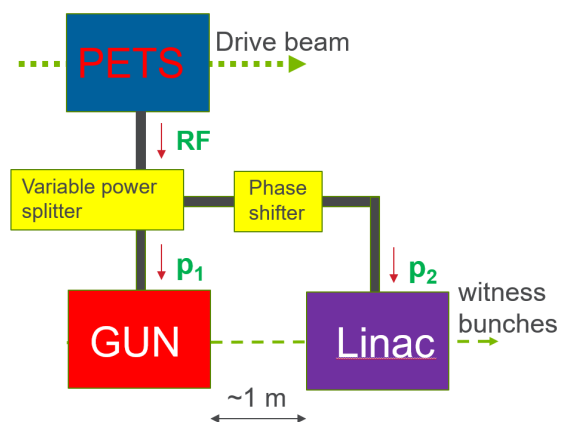


Figure 3: Scheme of gun and linac feeding.

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In order to feed this linac and the gun itself from one available PETS, we proposed using of a scheme containing a so-called variable power splitter, a variable phase shifter, and set of integration waveguides (Fig. 3). The mentioned variable power splitter will allow to deliver a proper amount of RF power to the gun and to guide the rest power to the linac. The phase shifter must provide the necessary phase for RF radiation in the linac to keep continuous acceleration of bunches in the linac as well as in the gun.

The integrated waveguides connected all components together. Because RF pulse is only 9 ns long, its included a delay waveguide section to power the linac and the gun so that in both components electrons would have seen the highest acceleration gradient.

Variable Phase Shifter

The phase shifter's design is based on a so-called "trombone" idea that implies sliding of one waveguide in another one (Fig. 4). The actuator in the Fig. 4 allows to change an effective WR90 waveguide length. This design was chosen to obtain a broad frequency band that is necessary to operate with the short RF pulse. In order to avoid an excess leakage of RF power in-between sliding surfaces, we implemented rejecting RF chokes. Special irises were inserted to avoid reflection. The reflection in simulation was so small that the field structure in the Fig. 5 looks like a non-reflection wave.

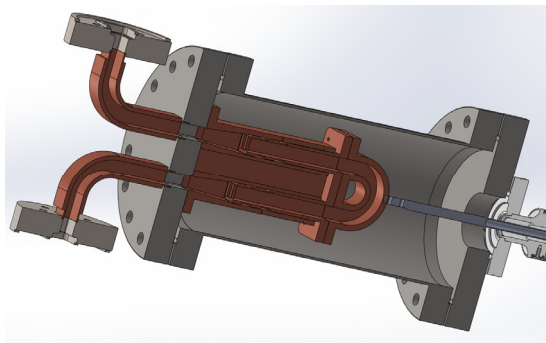


Figure 4: Variable phase shifter.

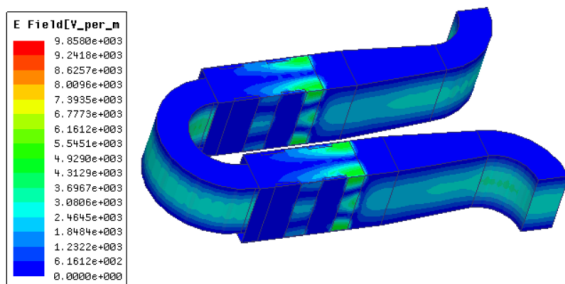


Figure 5: Field structure at phase shifter.

The phase shifter was tested at low-power level. The Fig. 6 shows how the inserted phase depends on current position of the actuator. One can see that 30 mm range of the position is enough to obtain more than 360° change of the phase. The reflected signal was at level -20 dB. The Fig. 7 demonstrates broad frequency band of the phase shifter.

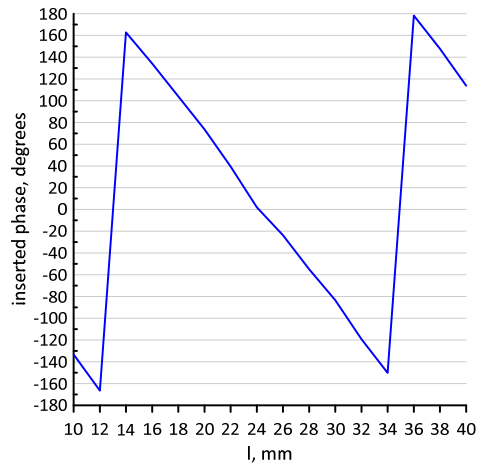


Figure 6: Inserted phase vs actuator position.

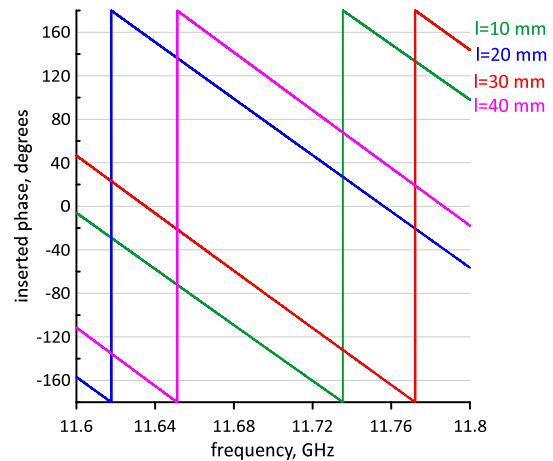


Figure 7: Inserted phase vs frequency for several positions of the actuator.

Variable Power Splitter

The power splitter design exploits an idea to split power in equal parts between two waveguides in one of which the phase shifter is installed and then to combine the phase shifted signals by means of a -3 dB hybrid. The power splitter in the Fig. 8 consists of a simple T-splitter, the previously described variable phase shifter, and the mentioned -3 dB hybrid.

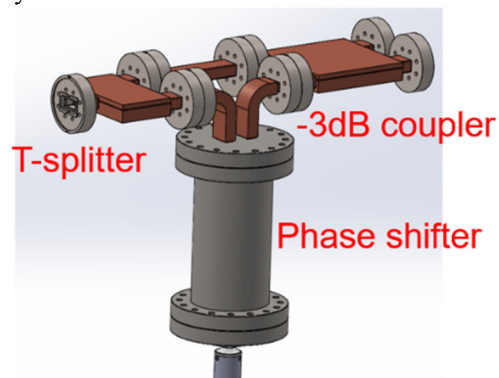


Figure 8: Variable power splitter.

In dependence on the inserted phase, the power ratio at the -3 dB hybrid outputs could be changed in 0%-100%

range. The power splitter shown in the Fig. 8 was fabricated and tested at low-power level before to proceed to high-power tests. The Fig. 9 shows power ratio of the output signals as a function of actuator's position of the phase shifter. The power loss was as high as -0.5 dB. The reflected signal was at level -20 dB.

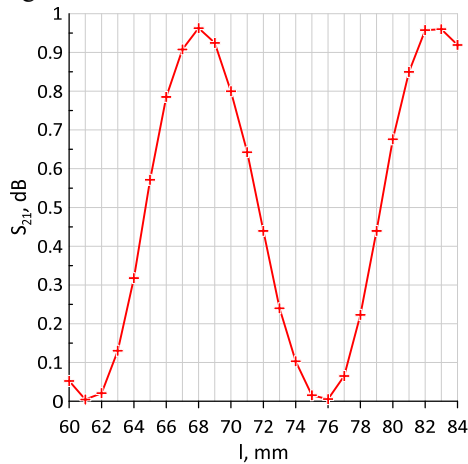


Figure 9: Transmission of power to one of two outputs.

HIGH-POWER TESTS

For high-power tests of the phase shifter and power splitter we used the scheme shown in the Fig. 10. The scheme allowed to measure forward, reflected and two output signals using three directional couplers. The components were tested being fed by RF radiation produced in PETS.

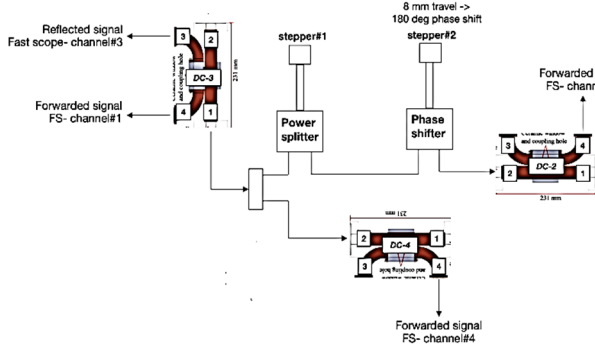


Figure 10: Scheme for high power tests of phase shifter and power splitter.

To characterize the phase shifter we recorded mutual phases of channels #1, #2, and #4. The Fig. 11 shows that result of the measurements and confirms that the inserted phase could be as large as more than 180°. The Fig. 11 was plotted for the drive bunch charge 330 nC that corresponds to more than 200 MW. We did not observe a noticeable breakdown at this power level.

The Fig. 12 shows ratios of #1, #2, and #4 signals when the actuator's position of the power splitter was varied. One can see that power ratio of the splitter's outputs could be varied in the desired full range. The RF power for power splitter test was as high as more than 300 MW. In this case the number of breakdown events was also low.

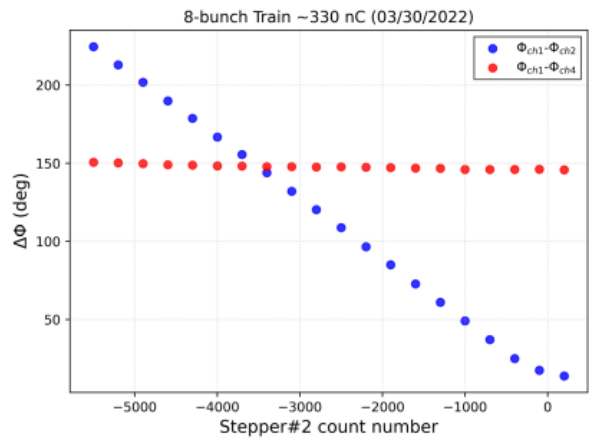


Figure 11: Mutual phases of measured signals vs actuator position.

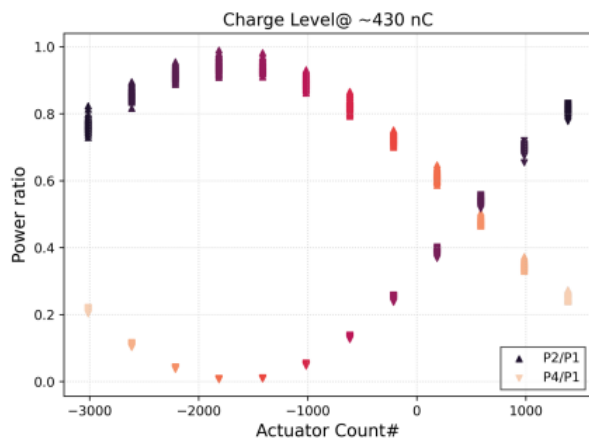


Figure 12: Power ratio of output signals vs actuator position.

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