RADIO FREQUENCY CONTROL SYSTEM FOR THE DUVFEL

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Abstract

A new RF control system was designed and implemented to support short pulse High Gain Harmonic Generation (HGHG) experiments, which require sub-picosecond synchronization between the laser and the accelerating RF fields[1]. This control system consists of a 81MHz crystal oscillator to drive both the Ti::Sapphire laser and a 2856 MHz synthesizer, direct vector modulators that control the amplitude and phase of the klystron drive and vector de-modulators for amplitude and phase measurement. RF and electron beam based measurement results of the RF to laser jitter are presented as well as experimental results of synthesizing the RF directly from the 81.6 MHz pump laser pulse train.

INTRODUCTION

The DUVFEL linac is composed of four travelling-wave 2856 MHz accelerator tanks injected by a 1.6 cell photo-cathode gun, a magnetic chicane for bunch compression, and a 10 m undulator. The accelerator tanks are driven by three Thompson 2128 klystrons capable of 40 MW each. The first klystron output is split with 10 MW going to the gun and 30 MW divided between accelerating tanks one and two. Tank one is the reference tank with no high power phase or amplitude control. The gun and tank two have high power phase shifters and attenuators for control. The remaining two klystrons drive tanks three and four directly. A magnetic chicane between tanks two and three is used for electron bunch compression. At the end of tank four there is an analysing spectrometer magnet and a YaG screen beam position monitor (BPM) for measuring electron beam energy. The HGHG FEL operates by seeding the electron bunch by overlaying a laser pulse on the compressed electron bunch. The laser pulse induces energy modulations in the bunch which are converted into spatial modulation in a undulator. This spatial modulation produces coherent lasing in the final undulator. As the electron and seed laser pulses reach sub-picosecond lengths, timing jitter becomes a limiting factor in HGHG FEL performance.

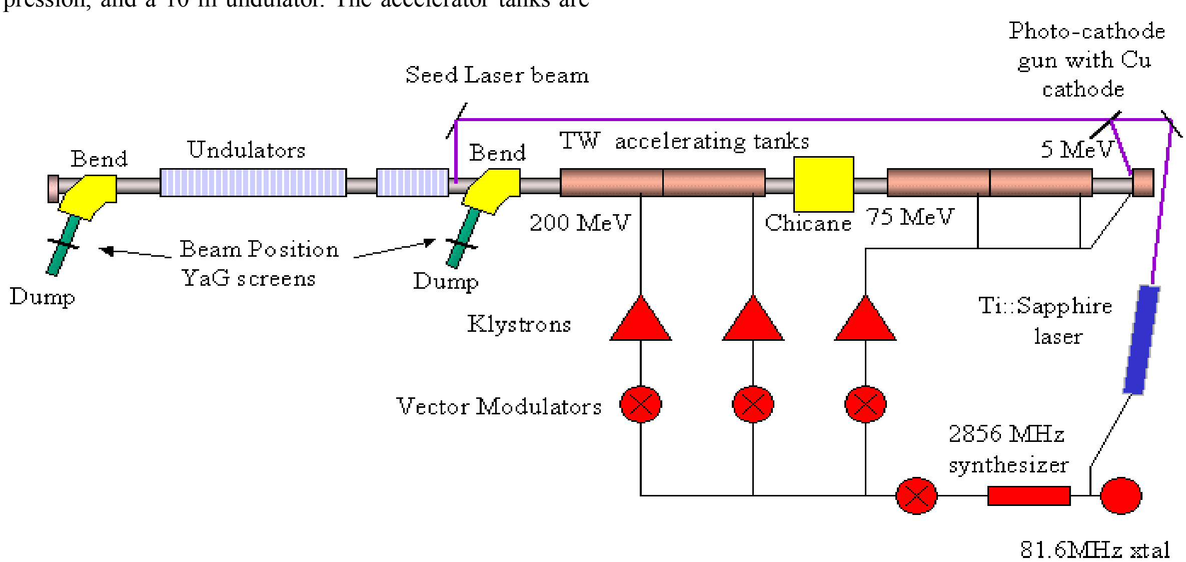

Figure 1. DUVFEL Facility Layout

RF SYSTEM DESCRIPTION

The layout of the DUV-FEL is shown in Figure 1. A 81.6 MHz crystal oscillator drives both the Ti::Sapphire pump laser and a 2856 MHz coaxial dielectric resonator synthesizer for the RF system. The synthesizer output is split to drive the 3 klystrons and provide the LO for phase measurements. A new Quadrature Vector Modulator developed at the DUV-FEL provides the amplitude and phase control. It utilizes a new communications chip by RF Micro-devices Inc., the RF2480 Direct Quadrature modulator. This device is specified to operate with an LO between 800 and 2500 MHz, and baseband I/Q channels from DC to 250 MHz. The 250 MHz modulation bandwidth will allow feedforward during the 2-microsecond rf pulse for pulse shaping, if required in the future. As-built the modulators have approximately a 5% amplitude ripple and 4-degree phase accuracy. In order to improve this each modulator is calibrated by recording the I and Q set

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points required to step the phase in 10-degree steps and maintain uniform amplitude. A polynomial fit to the calibration data is stored in the EPICS control system to drive the I and Q channels. After calibration the phase and amplitude variations are brought to 1 degree and 1 % as the phase is varied from 0 to 360 degrees. At very small amplitudes, ~1% of full power, the phase error approaches 10 degrees. In principle this could be corrected by calibrating over several amplitude ranges but this has been enough of a problem in normal operations to warrant the effort. The modulators have been installed and operating for over a year without any failures. They have proven to be extremely stable against thermal drift and noise since the entire modulator is on a single piece of GaAs.

A vector de-modulator has been prototyped using the Analog Devices AD8347 integrated circuit. Like the RF2480 this IC was designed for use in wireless communications systems with an RF bandwidth 800 to 2700 MHz. The baseband output bandwidth of 65 MHz easily accommodates the 2-microsecond pulse width of the klystrons. For testing an Agilent 8357 Network Analyzer (NA) provided the LO input to both the modulator and the demodulator. The modulator output signal was split to provide the transmission (S21) return signal to the NA and RF input to the demodulator. A LabView program was written to command the I/Q modulator in one-degree steps and provided an external trigger to the NA for each step. Figure 2 shows the input phase vs. the reconstructed output phase of the AD8347.

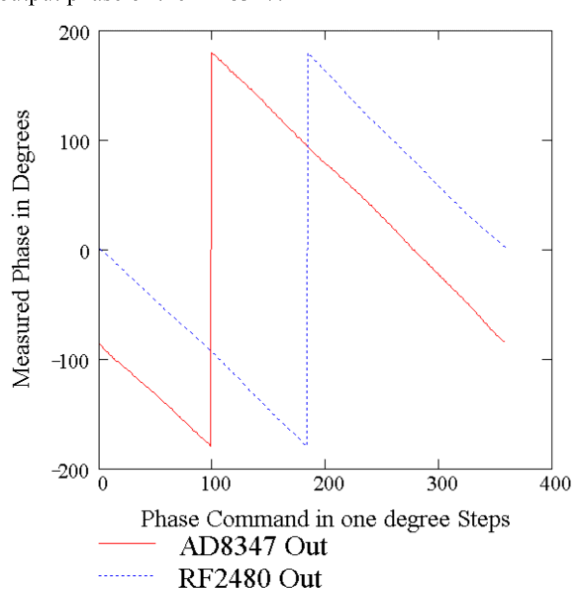

Figure 2. Phase Output of Vector Modulator as measured by Network Analyser and AD8347 de-Modulator

PHASE NOISE CHARACTERIZATION

The timing jitter between the electron beam and seed laser is critical for ultra-short pulse and cascaded HGHG FEL operation. The stability of the rf to laser system, and the shot to shot stability of the electron beam was characterized. Based upon the results of this system characterization an improvement in the rf to laser jitter was implemented.

Beam Jitter Measurements

The final electron beam energy is related to the field strength and timing jitter of the accelerating fields as

$$E_f(t) = \sum_i E_i(\cos(t + \Delta\phi_i))$$

where i denotes the ith rf system. The laser to RF jitter dominates the jitter between the seed laser and the electron bunch, in particular at the photo-cathode gun. Since we are measuring E_f which is a function of energy and phase there is a contribution of tanks 2 and 3 amplitude jitter that "hides" the actual measured value of ϕ_{rf}. In order to separate this effect from others we have performed the following measurements.

The jitter was measured using the first bending magnet as a spectrometer and measuring the beam position on a YaG screen, similar to zero-phasing bunch measurements[2]. For these experiments the nominal beam energy was 60.6 MeV. The gun phase was set to 30 degrees, tank 1 on crest, tank two 23 degrees off crest and tank three was phased so as to cancel the energy chirp of tank 2, near 90 degrees phase. The beam was centered on the YaG screen downstream of the first spectrometer magnet. The phase of the rf system with respect to the laser system can be adjusted with an I/Q modulator just after the rf synthesizer. This was used to introduce a +3 degrees and – 3 degrees phase shift to calibrate the beam position on the YaG screen in degrees of RF or time. Figure 3 shows the jitter in picoseconds of the nominal and +/- 3-degree calibration electron beams.

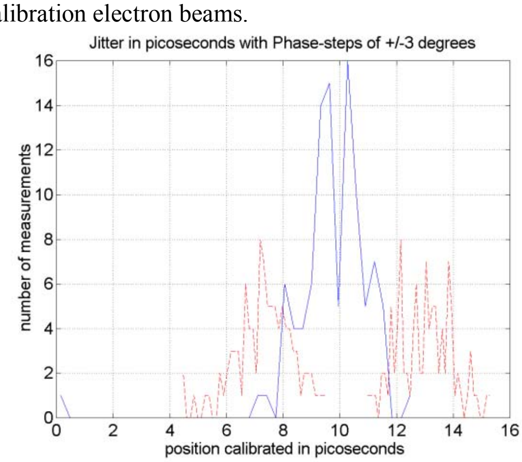

Figure 3. Beam jitter as measured by position on YAG screen after spectrometer magnet.

This measurement was repeated but with the variable being the klystron 2 voltage. A 10^{-3} relative klystron voltage shift on tank 3 is shown in Figure 4. The klystron 2 PFN voltage was measured with an oscilliscope and varied shot-to-shot by 10^{-4} rms. This voltage variation is not enough to explain all of the jitter in figures 3 and 4.

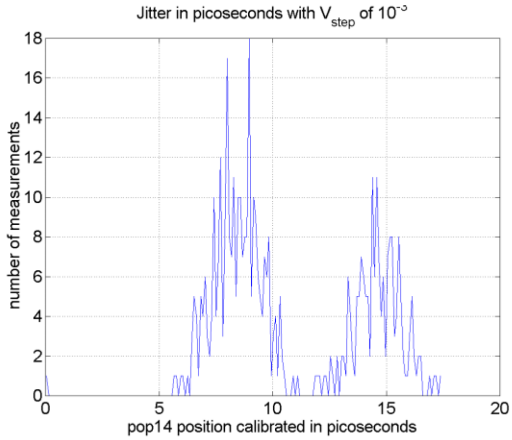

Figure 4. Beam position with 10^{-3} relative voltage step on tank 3 klystron. The standard deviation of the tank 3 klystron voltage was measured to be 1 x 10^{-4}.

Laser to RF Phase Jitter

The phase jitter between the laser and RF system was measured by monitoring a sample of the Ti::sapphire laser output with a fast (10 GHz bandwidth) diode detector. The 35th harmonic at 2856 MHz was filtered, amplified and compared against the 2856 MHz synthesizer output in a mixer. The error signal was low pass filtered at 300 kHz, and amplified. This signal was analysed with a Dynamic Signal Analyser (DSA). The I/Q modulator was used to calibrate the data by introducing a +/- 3-degree phase shift. The results are shown in Figure 5.

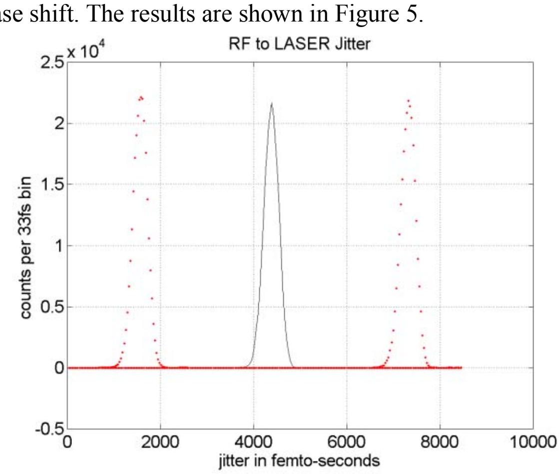

Figure 5. Laser to RF jitter in an 8 second histogram length with +/- 3-degree calibration traces.

In order to reduce the jitter between the laser output pulse and the 2856 MHz accelerating field methods of locking the rf to the laser oscillator pulse train were investigated. Since the rf is the 35th harmonic of the 81.6 MHz finding an IF frequency for a conventional loop[3] required division by an odd integer. Although possible, odd division is difficult to perform without adding additional noise. It was decided to use the laser oscillator to derive the rf frequency directly. The laser oscillator output pulse train at 81.6 MHz was detected with a photodiode with 10 GHz bandwidth, and 3 Amp/W sensitivity. The 35th harmonic was filtered out with a bandpass filter resulting in –30 dBm signal strength. This signal was amplified to 0 dBm and sent to the low level RF system, as described above. The RF to laser jitter measurement was repeated and is shown in Figure 6. Each trace represents a histogram of the phase detector output with a 3.8microsecond sample time and an 8 second histogram length. The right trace is a +2-degree calibration taken by stepping the I/Q modulator phase that is inside the measurement loop. The 2-degree step is nearly the minimum step size that produces sufficient accuracy for reliable calibration with our current set-up. The Digital to Analog Convertors (DAC'S) that drive the quadrature modulators are only 12 bit and produce quantization of the phase steps below 1 degree in some quadrants.

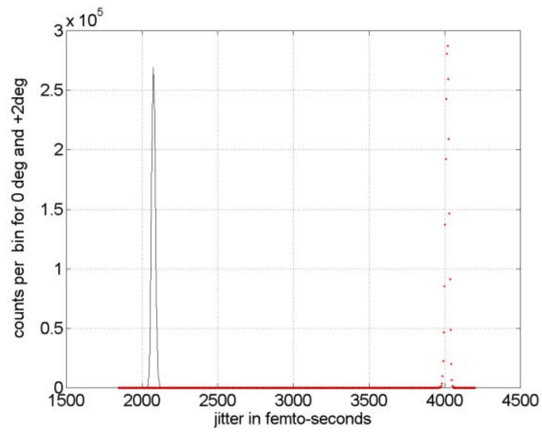

Figure 6. Laser to RF jitter in 8-second histogram length when RF is driven by laser output. A +2-degree calibration trace is on the right, second calibration trace omitted to improve scale for clarity.

CONCLUSIONS

Driven by the need for sub-picosecond jitter between a photo-cathode laser and the linac rf system a program of improvements to the rf system has been undertaken. Implementing a new vector modulator enabled accurate and repeatable phase and amplitude control. Measurements of the laser and rf have identified specific problem areas producing this jitter. Operation with a laser driven rf source has greatly reduced the front-end jitter of this system, from 400fs FWHM to <40fs FWHM

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