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A SLOW RF-LASER FEEDBACK FOR PHIL PHOTOINJECTOR

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Abstract

PHIL [1] is a low energy (E<5 MeV) and high current (1nC/bunch) electron beam accelerator at LAL. It uses a laser beam to extract electron bunch from a copper cathode at a repetition frequency of 5Hz.

The stability of the beam charge at PHIL is a key issue for the successful operation of the physic experiences that use the machine. It is also one of the most important specifications of a laser driven high current RF gun.

Two Integrated Current Transformers (ICT) and back-end electronics are used to monitor the stability of the beam charge at PHIL, with an accuracy of about 1pC [2].

At PHIL, the electron beam charge is quite stable, but we often note a slow charge drift on long duration experiences.

Several types of jitter can impact the stability of the beam charge. The fluctuations of the RF power or the RF to laser relative phase drift could have significant influence on the machine stability, due to temperature variations and electronic components overheating.

To correct the phase drift, we describe, in this work, a method based on slow analog-digital feedback loop between the RF wave in the gun (3GHz) and the synchronization signal of the laser (75MHz).

It allows maintaining the jitter between the laser pulse and the RF wave stable at a very low value (1° of 3GHz). As a result, the electron beam charge will be maintained at a stable level, to meet the requirements of users.

ACCELERATOR DESCRIPTION

Photoinjector

PHIL is a test facility at the Laboratoire de l'accélérateur linéaire (LAL), Orsay. The main goal of the accelerator is testing photoinjection as part of research and development of advanced RF gun.

The principal beam line of the machine is devoted to beam characterization (bunch length, transverse emittance) and standard instrumentation testing. A second beam line is used to analyze the energy distribution using a dipole (figure1).

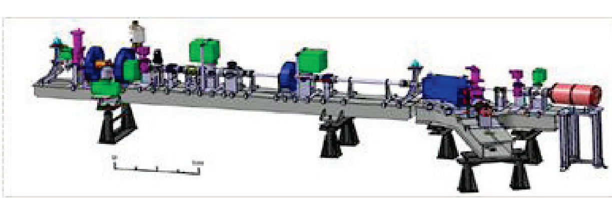

Figure 1: Drawing of PHIL beamlines. Blue boxes are magnetic elements; orange is the RF gun, green boxes stand for vacuum pumps.

Table 1: Specifications of PHIL [3]

Energy, Mev	Energy spread %	Charge , single pulse, nC	Frequency, GHz	Repetition rate, Hz	Pulse duration, ps	Emittance πmmmrad
5	< 1	0.01-2	3	5	5-10	< 5

In addition to research and development activities, PHIL is open to physics experiences that need low energy and well-defined electron beams for detector calibration.

RF Chain

The primary goal of the RF chain at PHIL is to generate and amplify the 3GHz signal destined to electron beam acceleration. It has also the role of synchronizing the laser oscillator and diagnostic facilities (figure 2).

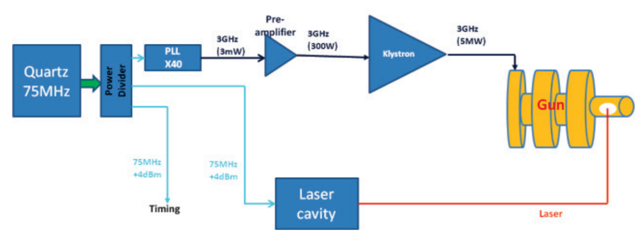

Figure 2: Drawing of PHIL RF chain and synchronization system.

It consists essentially of a quartz oscillator generating a reference signal at 75MHz turned into 3GHz via a PLL. A pre-amplifier and a klystron amplify the RF signal to reach 5MW in the gun.

The reference signal is also used to lock the laser oscillator and to generate 5Hz pulse frames for synchronizing diagnostic systems.

PHASE DRIFT AT PHIL

In photoinjector based accelerator, an accurate synchronization between the RF wave and the laser beam is highly required. This allows having an uniform electron beam with a stable charge value [4].

The RF gun of PHIL is a 2,5 cells [5].It is designed to get a maximum axial electromagnetic field at the cathode level (z=0) (figure 3) when it is hit by the laser pulse. The electromagnetic field can be adjusted using a phase shifter in low level RF electronics, to change the characteristics of the beam (charge, energy, dark current).

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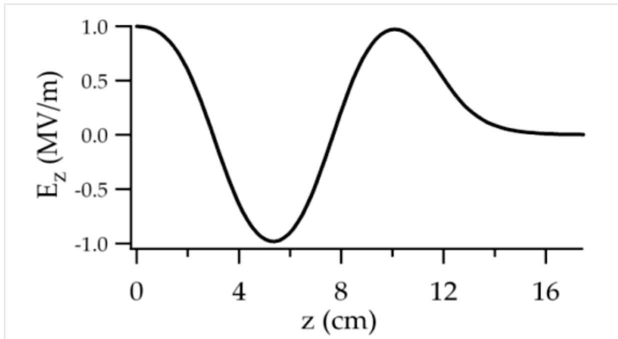

Figure 3: Normalized axial electric field of the RF photo-gun.

Several tests were performed to verify the good synchronization RF-Laser at PHIL and its stability during long time experiments. The figure 4 shows the bench used to achieve these measurements.

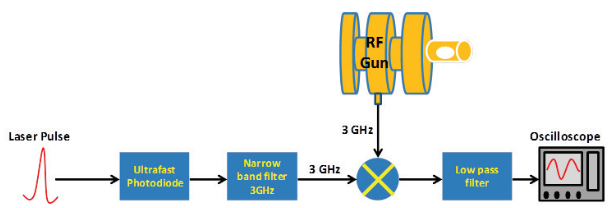

Figure 4: Bench measurement of the relative phase RF-Laser at PHIL.

In this case, the laser pulse is converted into electrical signal using ultrafast photodiode. A filter is then used to extract the 3GHz harmonic. The relative phase is proportional to the voltage level at the mixer output.

The result of this test applied on PHIL during 58 hours, are shown on figure 5:

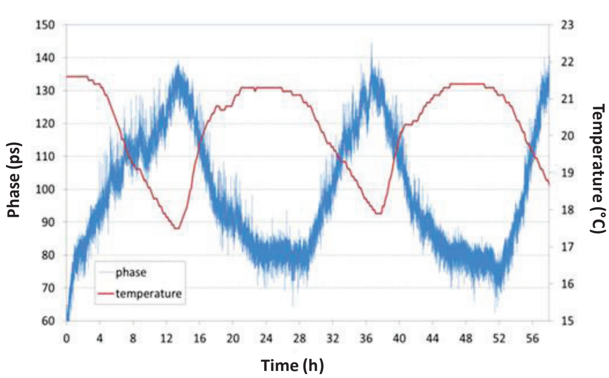

Figure 5: RF-Laser phase (blue) and temperature (brown) variations at PHIL.

In addition to phase, we measured temperature variation in order to establish its influence.

The graph shows slow and periodic variations of phase corresponding to day-night cycle temperature. The phase variation amplitude can reach 60ps over 10 hours operation. This corresponds to 65° of 3GHz signal in the gun. The phase variation interval induces a charge loss of about 25% when we are operating at maximum charge (Figure 6).

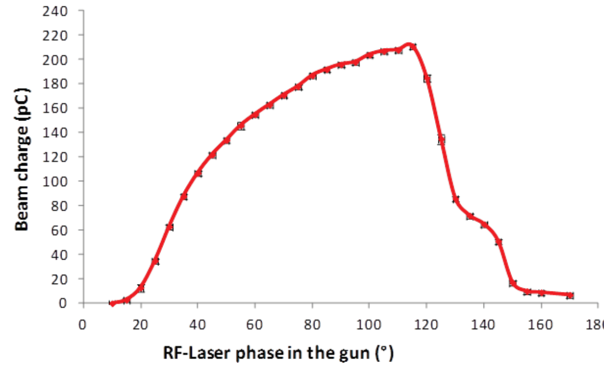

Figure 6: Beam charge Versus RF Phase.

The graph above shows the correspondence between phase and charge. We note the sensitivity of beam charge to phase variations. A phase drift can induce an increasing or decreasing of charge level, depending of the working zone.

The phase fluctuations are principally due to temperature variation, but also due to the overheating of some electronic components. As a direct consequence, we cannot get good charge stability for long duration experiences

FEEDBACK LOOP

As described above, PHIL suffers from a slow phase drift due to temperature variations. The phase drift value calculated from the graph (figure 5) is about 5ps per hour. It corresponds to 1ps of drift every 12 minutes. The principal goal of our feedback is to maintain the phase drift lower than 1ps. Therefore the loop is programmed to introduce phase corrections every 10 minutes (1.7mHz), or when the phase is higher than 1ps.

The solution initially considered is a feedback loop able to measure permanently the RF-Laser relative phase, and acts on a phase shifter for correction when needed. Initially the system presented in figure 4 was used to measure the phase. It shows a good accuracy on short duration, but it becomes less accurate when it is used for permanent measurements. Basically, the laser pulse position on the photodiode (PD) is not stable; it requires regular intervention for alignment. The variations of the laser energy or position on the PD are equivalent to phase variation, as they influence directly the voltage level at the mixer output. This imperfection degrades seriously the system accuracy.

To overcome accuracy problems, a new approach was adopted (figure 7). This approach takes into account that the laser contains initially an intern feedback that maintain it locked to the synchronization signal (75MHz), so the laser system could not be included in the feedback loop. It is simpler to act on laser synchronization signal than on the laser pulse.

Therefore, the optical path of the laser (red arrow on Figure 7), of about 15m in the air, is not taken into

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account to design the loop. A dedicated manipulation was performed over one day to measure the variation of the laser phase between the laser cavity and the gun. The observed variation is negligible compared to required precisions.

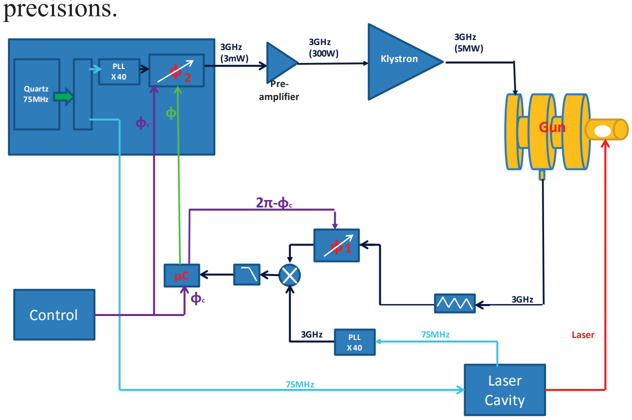

Figure 7: Schematic of feedback loop at PHIL.

The feedback loop is composed of two parts:

An analog part related to laser synchronization signal. Its main role is to convert 75MHz into 3GHz and compare it to 3 GHz coming from the gun. The phase information is transformed into DC voltage.

The second part is digital, composed of a microcontroller (NXP LPC 1768), programmed with C code. It digitizes the DC voltage, and acts on the phase shifter ($\phi 2$) when the phase variation is higher than 1ps. The microcontroller (µC) used in this experiment, has 12bits ADC with a maximum voltage of 3.3v (800µV resolution). This allows a high accuracy in the acquisition of DC voltage, and a fine control of the phase shifter.

To increase the efficiency of the feedback, the initial RF-laser phase must match the linear area of the transfer function of the mixer (figure 8).

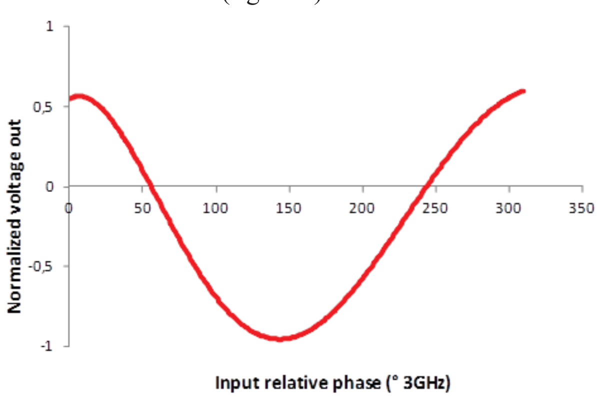

Figure 8: Transfer function of 3GHz mixer.

Adjusting the phase to the linear area of the mixer allows us to have a maximum voltage out when the phase moves slightly.

It also allows an easy programming of the µC, with only a linear function which includes a phase range of about 100°.

It is necessary to adjust the phase on the middle of the linear area of the mixer before starting the feedback, in order to avoid any dysfunction. In our case, the µC is driven by a Labview program that fixes the phase (using phase shifter Φ1) before each starting up.

In the other hand, the operation of PHIL requires to tune the phase when needed, in order to meet the requirements of users in terms of energy, charge or dark current. The effect of this voluntary change in phase could be cancelled by the feedback. To avoid this side effect, a second phase shifter (Φ1), driven by the µC, is placed between the gun and the mixer. Any voluntary phase changes coming from the machine control system, is detected by the µC and compensated using the phase shifter Φ1. This way, we can only correct the phase shifts related to the temperature.

CONCLUSION

In this work, a slow analog-digital feedback was developed. Its main role is to maintain the jitter between the laser pulse and the RF wave lower than 1ps. The jitter is essentially due to temperature and electronics components overheating. The analog part of our system controls the phase variations permanently, and allows introducing the needed corrections using a microcontroller.

The integration of our system will have a positive impact on physic experiences performed at PHIL. It meets the essential requirements of users: uniform electron beam and a stable charge.

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