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DESIGN AND COMMISSIONING OF S-BAND RF STATION FOR AREAL TEST FACILITY

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Abstract

The RF station has been designed and constructed for AREAL Linac [1]. The constructional features and commissioning results of RF system are presented in the current article. The whole RF system is designed to work at 3 GHz frequency. The linac includes an electron gun for 0.5-8 ps electron bunch production with 1-10 Hz repetition rate. For linac RF control system a Libera LLRF [2] stabilization system is used. An important feature of the presented system is a high level synchronization of amplitude-phase characteristics, which provides the required accuracy for particle acceleration and bunch formation.

RF SYSTEM OVERVIEW

The AREAL RF system is supposed to consist of 3 RF stations: two of them are required for 1m long accelerating sections operation and one- for RF Gun. As a result there are 3 systems required to enable normal operation. The construction and pre-commissioning of RF gun and one klyston station has been finished recently (called Phase 1).

The basic approach to the new facility is the photocathode S-band RF electron gun followed by two 1m long S-band travelling wave accelerating sections. For calculations of RF gun cavity performance CST Microwave Studio is used.

The power consumption for the gun assumes 1MW RF power reserve. Thus if 6MW RF power is fed into the gun cavity the required accelerating voltage can be achieved.

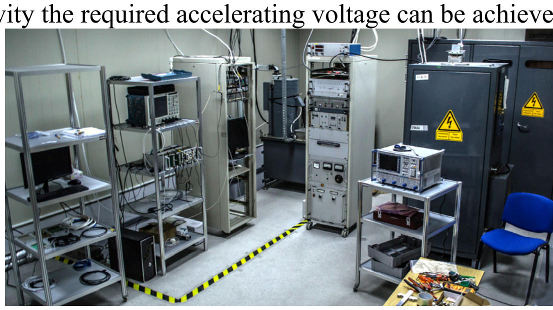

Figure 1: The layout of RF station.

Phase 2 will include the construction of second klystron station and the S-band travelling wave accelerating section. For electron bunch acceleration to nominal 20 MeV energy two 1m long 3 GHz travelling wave accelerating sections will be used. Electron bunch will get energy gain of 4 MeV in the Electron Gun and about 8 MeV in each of the accelerating sections resulting in the final energy of 20 MeV. In Figure 1 the current layout of the AREAL RF station can be seen.

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Table 1: Main Parameters of Gun RF System

Parameter	Single / Multi bunch
RF pulse length	3.8μs
RF peak power	7 MW
Repetition rate	1-10 Hz
Phase stabilization	< 0.5°
Amplitude stability	< 0.1 %

RF System Major Components and Equipment

RF system major components and equipments consist of the following:

- Master oscillator, LLRF and Timing
- Gun Cavity and accelerating sections
- Amplifiers and Klystrons

The following diagram illustrates the signal flow between MO, Laser, delay generator and other RF components.

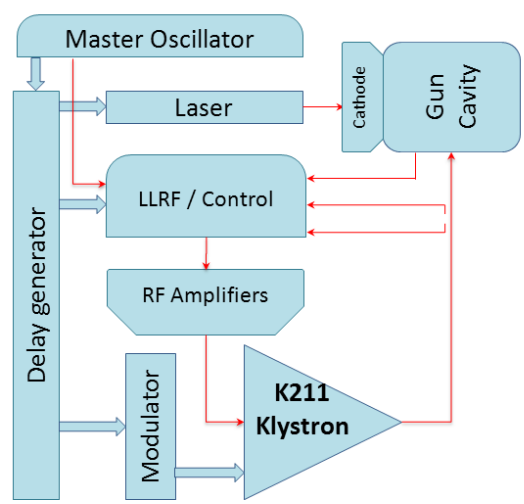

Figure 2: The diagram of signal flow between main components.

The Master Oscillator (MO) is a key element of the RF system for generation of an accurate RF signal with the RMS phase jitter of 6.47 fsec[3]. The AREAL MO has several outputs: main 3 GHz with corresponding sub harmonics which serve as reference for all system parts. Some other synchronous frequencies such as local oscillator and sampling frequencies for DAC's are generated in Libera LLRF system, which also derive from MO 3 GHz signal.

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In the beginning of machine operation the MO and LLRF modules were placed in RF room under the temperature of 22-32 °C. Under mentioned conditions the drop of output power from MO and LLRF was observed. After final wiring the modules were moved to their stipulated place in Laser room with more stable temperature of 22 ± 0.1 °C. As a result the mentioned power fluctuations disappeared.

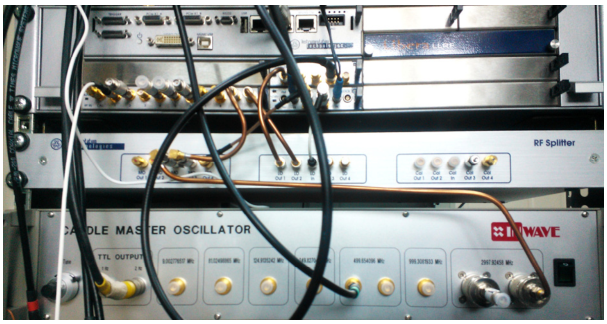

Figure 3: The layout of MO and LLRF in Laser room.

The Cavity voltage probe as well as the forwarded and reflected power from output of each 3 cascades of amplifiers (2W solid state low noise amplifier by Inwave, TH 2436 10KW klystron and K211 7MW klystron) are sampled and can be used in fedforward algorithm of LIBERA LLRF. Pulse to pulse RF phase correction was applied via adaptive feedforward of LLRF control system. The overall electron bunch energy stability was observed < 5 % during last month of machine operation.

The Timing system resulted now in simple delays via delay generator DG645 from Stanford Research Systems which in our chosen case has max 5 ps rms jitter.

Figure 4: The RF amplifiers: 2W (left top), 10 KW TH 2436 (left bottom) and 7 MW K211 klystrons (right).

MEASUREMENTS AND RESULTS

The final assembly and commissioning of sub-systems were finished in December 2013. As a result we have got the first beam through RF gun and experimental diagnostic beamline. After the final commissioning of accelerator components several machine studies were planned during May 2014. The goal was to accomplish the measurements of the main parameters of electron beam and the laser system, along with the observation of the performance of different systems during long run. We were operating the whole month with 24/7 operation regime in single bunch mode with 1-10Hz bunch frequency.

Thermal stabilization and cooling systems were providing the stable resonant conditions for electron gun as well as heat removal with stable operation for klystron and solenoid magnet. Gun resonance frequency dependence on body temperature has been measured during several weeks. During those measurements and also later on the operating thermal stabilization system has shown high stability and the observed temperature fluctuations were within ± 0.1° C, which corresponds to gun resonant frequency deviation of less than ± 8 kHz. During the stable operation the self-education system can reach up to ± 0.05° C.

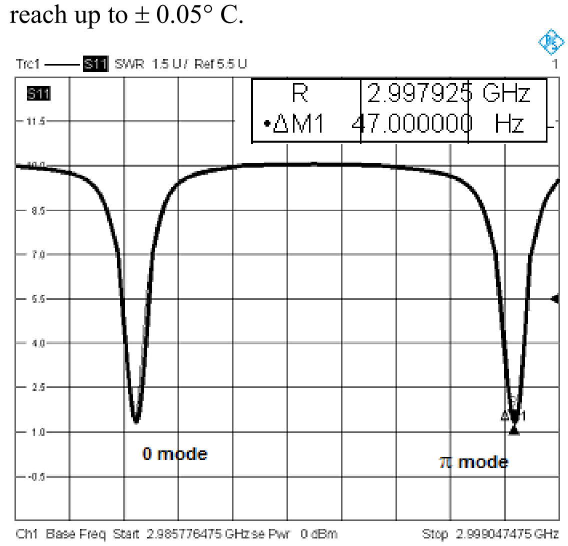

Figure 5: Resonant mode at 2.9979825 MHz adjusted by gun temperature.

During conditioning of RF window and electron gun. some sparks in waveguides were observed. The problem was successfully solved by filling waveguides with nitrogen gas under 2,5 bar.

The stability of high voltage and RF control issues were studied in RF laboratory before the final assembly of the system at AREAL site. During preliminary measurements the high voltage stability and flatness of RF pulse was obtained < 1% for nominal modulator voltage of 200 kV.

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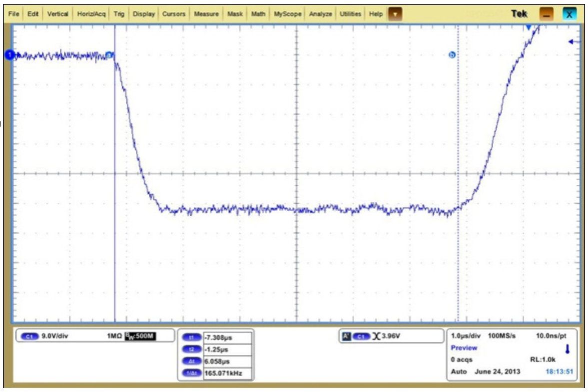

Figure 6. HV stability during RF pulse < 1 %.

After conditioning and final tests of RF system and electron gun more than 6.2 out of supplied 7 MW of RF power was injected to gun.

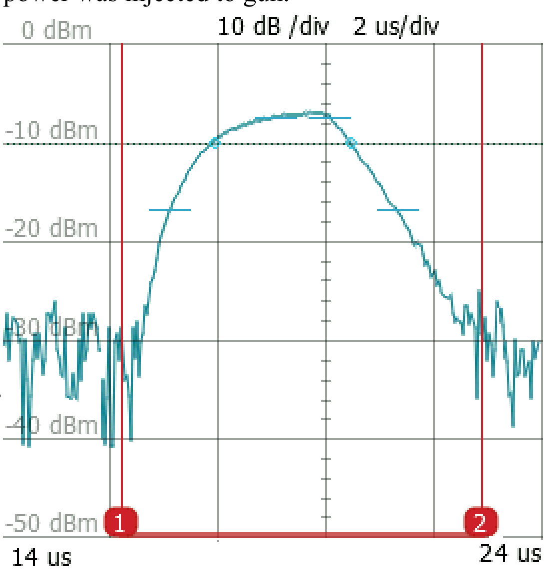

Figure 7. Measured forward power from K 211 klystron 6,2MW.

The operation in π-mode standing wave RF gun resonator according to injected power implies in peak accelerating gradient of about 90 MV/m and, as a result, electron bunch energy on spectrometer arm was measured and made about 3.7 MeV[3]. In order to upgrade AREAL to 20 MeV, two similar RF stations will be used to supply accelerating structures. The phase correction and regulation between stations with LLRF control system will be applied to keep the synchronization between systems.

INTERLOCK SYSTEM

For emergency reasons we have modified analogue interlock system via integrating existing RF interlock to the whole AREAL analogue interlock network.

The digital interlock system implemented for HV modulator. Now one can easily modify the interlock logic during operation. For the whole RF system it will be implemented during next months.

CONCLUSION

AREAL linear accelerator phase 1 construction was completed at the end of 2013. The majority of the tasks defined for RF group were performed according to the schedule.

The synchronization of the laser and RF was performed by locking laser synchronization block, which has additional trigger opportunities to decrease beam jitter.

The analog interlock system was implemented and tested.

The digital interlock system was implemented yet for HV modulator only. It is planned to implement it for the whole RF system within next months.

Performed measurements coincide well with the expected results. RF phase/amplitude regulation etc. was performed to provide uninterrupted and stable operation for experiments. The upgrade of the machine to 20 MeV with more experimental possibilities is currently in the evaluation process.

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[2] http://www.i-tech.si/accelerators-instrumentation/libera-llrf
[3] http://www.inwave.ch