LINAC RF CONTROL SYSTEM FOR CANDLE. DESIGN AND SIMULATION

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Abstract

The design and constructional features of the control system for 500 MHz and 3 GHz RF system of CANDLE linac are presented. The linac includes an electron gun that is modulated by 500 MHz generator to produce 1 ns electron bunches, 500 MHz and 3 GHz bunchers, pre-accelerating cavity and the main accelerating section at 3 GHz . An important feature of the presented control system is a high level synchronisation of amplitude-phase characteristics of the sub-systems that provide the required energy-space characteristics of the accelerated beam. This puts strict requirements on RF frequency, amplitude and phase stabilization. A digital feedback system has been adopted to provide flexibility in the control algorithms. The main feature is a 9 MHz sampling rate for the cavity signals and digital I/Q detection. The design was performed using the RF analyze tool, based on MATLAB SIMULINK, which allows the simulation and analyzes of the field regulation quality. The simulation results for CANDLE Linac RF system, based on the output parameters of electron beam are given.

LINAC RF CONTROL SYSTEM COMPONENTS.

For Linac RF control system a sampling rate 9 MHz is chosen. To measure the real and imaginary parts of the down converted cavity probe signal it is necessary to have 2,25 MHz Intermediate Frequency (IF). If the amplitude and phase of the local oscillator kept constant with respect to master oscillator, the down converted signal contains information of amplitude and phase of the input RF signal. By sampling this 2,25 MHz IF signal with 9 MHz rate one will obtain 4 samples per cycle, every two consecutive of those samples can be represented as a real and imaginary part of a corresponding field vector [2]. A vector modulator controls the incident RF wave coming from a master oscillator. Directional couplers and waveguide tuner are inserted in each waveguide path to measure forward and reflected power and to adjust the phase. Each cavity is equipped with high power input coupler and field probe antenna or loop. 500 MHz buncher cavity has a mechanical frequency tuner, which is driven by stepper motors. For 3 GHz buncher cavities low Q design is chosen to handle the phase control without feedback using only fast phase tuners. All field probes are split up into two or more parts. One of them will be used for feedback, others will be reserved for other possible measurements. This signal will be down converted and sampled with fast ADC, which transmits the sampled data to a Digital Signal Processor (DSP). Forward and reflected waves are also down converted and sampled for monitoring and feedback. The control system for whole linac requires 2 DSPs one for 500 MHz, the other for 3 GHz RF control. All the DSPs, DACs and ADCs will be located in four crates with VME-bus interface.

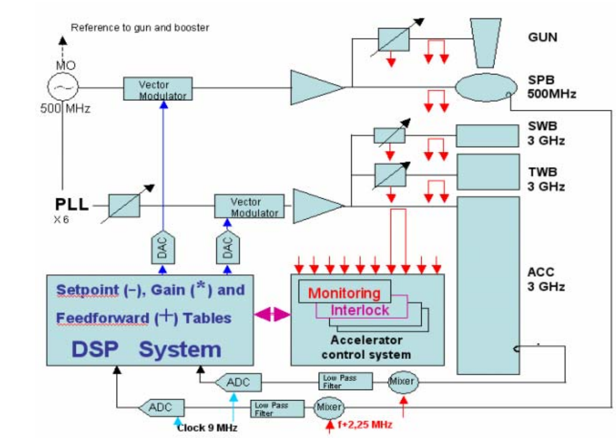

Fig. 1. Scheme of the RF control system for Linac.

TIMING

Sampling frequency (9 MHz clock) must be synchronized to the RF and local oscillator frequency. All the frequencies are derived and phase locked to a master oscillator. The reference frequency has been chosen 500 MHz. The timing system design and appropriate methods to distribute the signals are under development and will be presented in further reports.

HARDWARE

DSP: For sampling rate 9 MHz and large input output capability the DSP C6000 is chosen (floating point parallel digital signal processor TMS320C6701 made by Texas Instruments) with 64-bit address and data buses.

ADC and **DAC**: It is planed to use ADCs and DACs (DESY development), which have external timing inputs and internal memory and are suitable for communications with Texas Instruments DSP.

The ADC board consists of four independent ADC channels with 14-bit A/D converters operated at 9 MHz (max 10 MHz) sampling frequency.

The DAC board has two channels (16-bit D/A converters).

SIMULATION AND RESULTS

The simulation is used for assessment of the performance of the designed RF system of Linac. The main blocks and interconnection structure are similar to those shown in Figure 1. The RF sub-systems contain blocks with accompanying initialization files. Klystron block has measured non-linear characteristics in an input-output mapping table. Cavities are given by set of differential equations with own characteristic values of impedance R, resonance frequency ω_0 and quality Q:

$$\dot{v}_{\mathrm{Im}} = -\omega_{1/2} v_{\mathrm{Re}} - \Delta\omega v_{\mathrm{Im}} + \frac{R\omega_{RF}}{2Q} I_{\mathrm{Re}}$$

$$\dot{v}_{\mathrm{Re}} = \omega_{1/2} v_{\mathrm{Im}} + \Delta\omega v_{\mathrm{Re}} + \frac{R\omega_{RF}}{2Q} I_{\mathrm{Im}}$$

$$\Delta\omega = \omega_0 - \omega_{RF}$$

where I_{Im}, I_{Re} real and imaginary parts of current and ω_{RF} RF frequency.

Each subsystem has its own delay time, which consists of the beam pass time and time to reach the next subsystem. The "Quantizer" is used in "Control" block to simulate 9 MHz sampling as an ADC (continuous discrete converter).

The following perturbations should be controlled by this system and brought to condition:

- Current fluctuation, excitation of HOMs, wake fields,
- Timing signal accuracy, phase noise from oscillator,
- Cavity filling, power reflections, cavity resonance frequency changes.

The further goal is an on-line diagnostics during the prototyping phase, tuning and operation of the RF system.

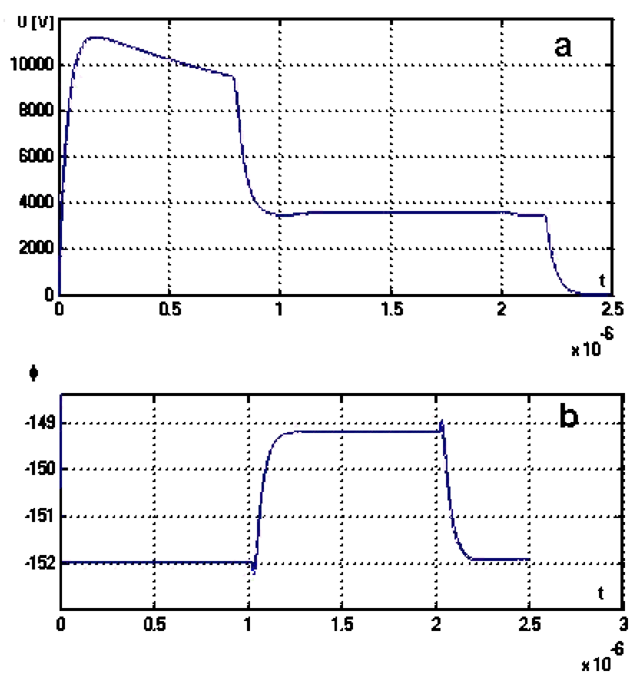

Fig. 2. Amplitude (a) and a phase (b) of the field excited in the Standing Wave Buncher

On Fig. 2. and 3 the amplitude and a phase of the field excited in SWB and TWB are shown. One can see that voltage and phase remain stable during passage of a beam (from 1 up to 2 μs). Deviations from setpoint are only 0.1 % of amplitudes and 1° for phase which, can be easily reduced to 0.1° by means of feedforward by pre-tuning a phase at passage of a beam.

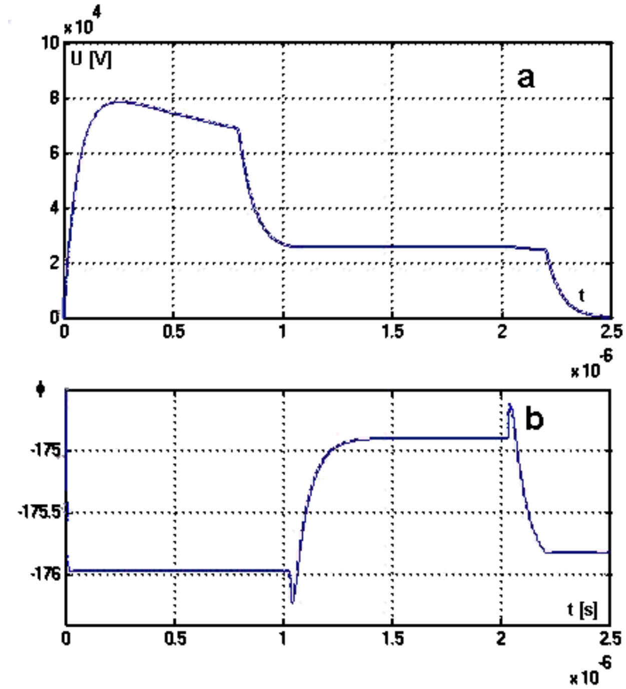

Fig. 3. Amplitude (a) and a phase (b) of the field excited in the Traveling Wave Buncher.

On Fig.4 the amplitude and phase of a field excited in accelerating section are shown. One can see from figures 4 and 5 deviations of voltage from the established value only 0,5 % and remain stable during beam passage: falling of amplitude is only 0.03 %, and a phase - 0.4°.

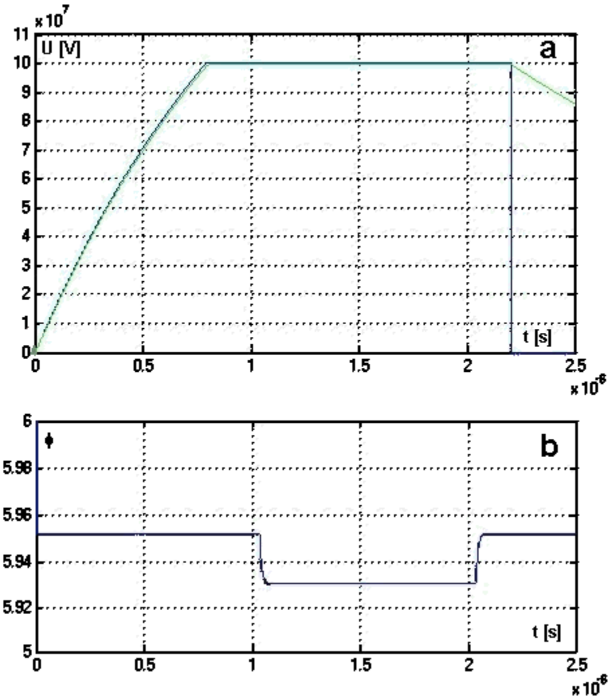

Fig. 4. Field Amplitude (a) and a phase (b) excited in accelerating section.

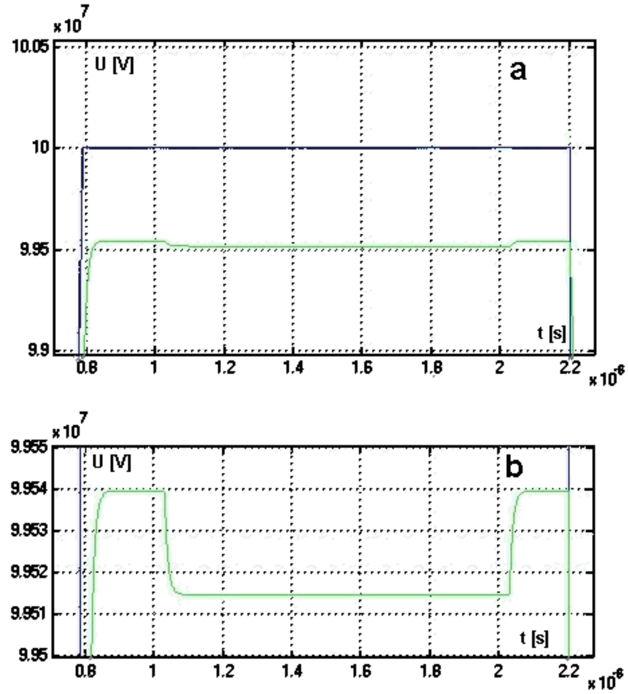

Fig. 5. Change of field amplitude during passage of a beam (magnified 70 (a) and 2000 (b) time)

CONCLUSION

The simulation results of RF control system have shown that the chosen configuration of the linear accelerator and RF control system will allow providing required parameters of an electron beam from the linear accelerator and satisfy the operational requirements [4].

The important property of the carried out research is stability of parameters of the electron beam, which is provided at independent accelerator operating mode on the basis of the data analysis and RF feedback. However the constructional design of the RF control system under development and needs to further detailed studies to optimize the performance of the system. The studies will include the component test stage, which will be done at the stage of prototyping program.

REFERENCES

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