

# RF POWER GENERATING SYSTEM FOR LINEAR ION ACCELERATOR

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## Abstract

An RF power generating system based on solid-state amplifiers has been developed for the linear accelerator of heavy ions. The report contains information on the characteristics and composition of the system, presents LLRF structure for RFQ and DTL section.

## INTRODUCTION

The scheme of the accelerating channel is shown in Fig. 1. Ion acceleration occurs in a chain of linear accelerating sections consisting of an RFQ and two DTL structures: DTL1 and DTL2. The beam matching between sections is carried out by the beam transport channels: low-energy LEBT between the source (IS) and RFQ, medium-energy channel MEBT1 between RFQ and DTL1, medium-energy channel MEBT2 between the accelerating structures DTL1 and DTL2. After acceleration, the beam is directed to the charge exchange target by the high-energy beam transport channel HEBT.



Figure 1: Scheme of the accelerating channel.

The RF power generating system is designed to excite powerful electromagnetic fields in the resonators of the linear accelerator that are stable in frequency, amplitude and phase. It conducts RF power over the feeders and provides pulse-by-pulse regulation of the amplitude and phase of the RF field.

Solid-state amplifiers (SSA), developed at JSC "NIITFA" [1], are used as powerful sources of RF power. Solid-state amplifiers are increasingly using recently as base elements of RF power generating systems for charged particle accelerators. This became possible due to existence of high-frequency transistors capable of operating at frequencies up to 10 GHz with a maximum output power of up to 1800 W [2].

Using the combined methods of addition and division of RF power RF engineers are able to create solid-state amplifiers with an output power of up to 500 kW for operation in pulsed and continuous modes [3]. All resonators of the linac are fed by separate independent high-frequency drivers, including power amplifiers, circulators, directional couplers, feeder inputs. The requirements for high-frequency power generators for linear accelerators are described in detail in [4]. The main technical characteristics

of the RF power generating system of the linear accelerator are presented in Table 1.

Table 1: Main technical characteristics

Name	Value
HF pulse duration, $\mu$ s	300
Maximum pulse repetition frequency, Hz	1
HF amplifiers are powered from an alternating current network 3x380 V, 50 Hz.	160
Power consumption from the network, kW	
<i>RFQ</i>	
Working frequency, MHz	40,625
RF losses (pulse / average), kW	535/0,178
Number of Amplifiers	4
<i>Matching channel MEBT1</i>	
Operating frequency, MHz (MEBT1)	81,25
Number of resonators	2
RF losses (pulse / average), kW	60/0,02
<i>DTL1</i>	
Number of $\lambda / 4$ -resonators	12
Operating frequency of DTL1 resonators, MHz	81,25
Total power of RF losses (pulse / average) in $\lambda / 4$ -resonators, kW	908/0,302
The number of amplifiers for excitation of $\lambda / 4$ -resonators	12
<i>DTL2</i>	
Operating frequency, MHz	162,5
Number of IH resonators	28
Total power of RF losses (pulse / average) in IH resonators, kW	4291/1,43
The number of amplifiers for excitation of IH resonators	28
<i>Matching channel MEBT2</i>	
Operating frequency, MHz	162,5
Number of resonators	1
RF losses (pulse / average)	60/0,02

The main purpose of the master oscillator as a part of the low-level RF system is to generate sinusoidal signal with frequencies of 40.625 MHz, 81.25 MHz, 162.5 MHz and an amplitude up to 1V. It maintains the specified phase difference between high-frequency exciting signals in resonators with accuracy of about  $1^\circ$  and change the phase differ-

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ence when changing the type of accelerated ions. The amplitude is under control as well. In addition, the LLRF adjusts the resonant frequency of the resonators to keep matching conditions in feeding cables. Mechanical plungers moved by stepper motors are used as tuners to adjust the resonant frequency of the resonators.

### RFQ

The RFQ excitation circuit is shown in Fig. 2. RF power generating system of the accelerating structure with spatially uniform quadrupole focusing consists of four identical amplifiers.

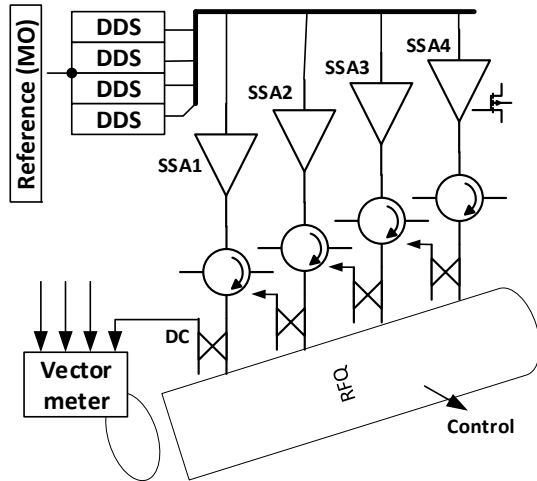


Figure 2: RFQ excitation circuit: MO- master oscillator, DDS- digital direct synthesizer, DC- directional coupler.

The calculated value of pulsed RF power consumption in the structure is 560 kW, including heating losses and beam loading [5]. Four SSAs with an output power of 190 kW provide stable excitation of nominal power of the HF field in the structure.

The phase synchronization of the high-frequency signals excited in the accelerating structure is provided by the master oscillator. Feedback signals from the structure and from reflectometers are fed to the master oscillator unit, which is designated in the diagram as a vector signal meter.

The coupling of the loops to the structure is arranged under atmospheric condition by a fine rotation of the feeder port around their axis from 0 to 360°.

When working together on the total load, the amplifying stages can influence each other, therefore high requirements are imposed on the identity of their phase and amplitude characteristics. For protection purpose circulators are installed at the outputs of the amplifiers.

### DTL1

Quarter-wave accelerating resonators are sections of coaxial waveguides bounded by a conducting flange at one side, and by drift tubes at another one.

Each of the twelve resonators DTL1 is excited through the high-frequency feeder by correspondent amplifier. The

phase and amplitude at the amplifier's input are provided by the master oscillator. Other elements around the DTL resonators are similar to the RFQ. Figure 3 shows the distribution of RF power losses in resonators depending on their order.

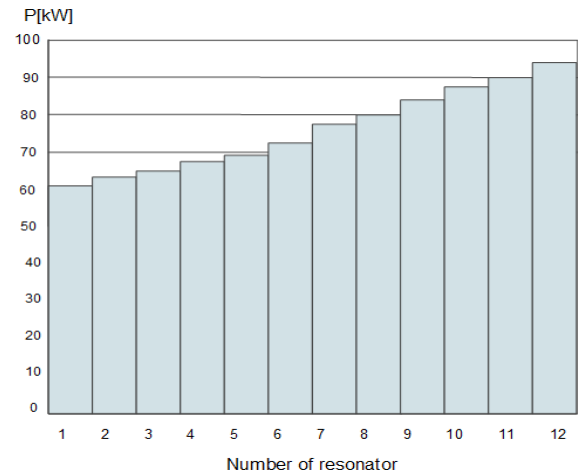


Figure 3: RF power losses depending on resonator position.

The output power of the SSA should not only compensate the losses in the resonators but also translate power to the accelerating the beam. The nominal output power of the amplifier should be 75% of its maximal capability. This requirement is typical for all types of SSAs used in the RF power generating system. The excitation scheme of two-gap  $\lambda/4$  resonators is shown in Fig. 4.

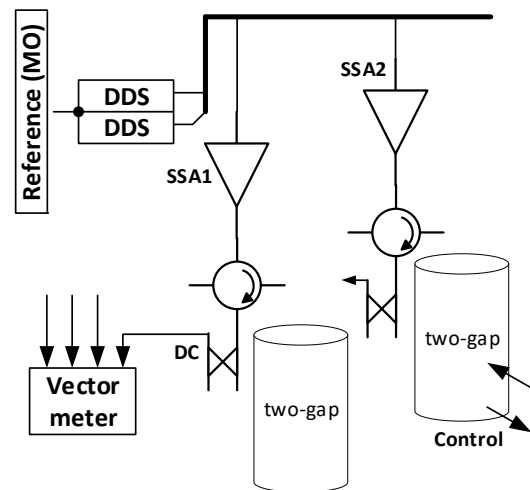


Figure 4: DTL1 resonator excitation circuit.

Mechanical plungers moved by stepper motors are used as tuners that adjust the resonant frequency of the resonators. To measure the frequency detuning of the resonators, high-frequency feedback signals are used: one RF signal from the control loop of the resonator and two RF signals from a reflectometer.

After normalizing of the RF feedback signals, the vector meter calculates their amplitudes and phases. The phase

difference between the reflectometer and the control loop is used as an indicator of frequency error.

## DTL2

DTL2 accelerator consists of resonators excited by H-mode loaded with drift tubes. The value of nominal RF losses depending on the resonator position is shown in Fig. 5.

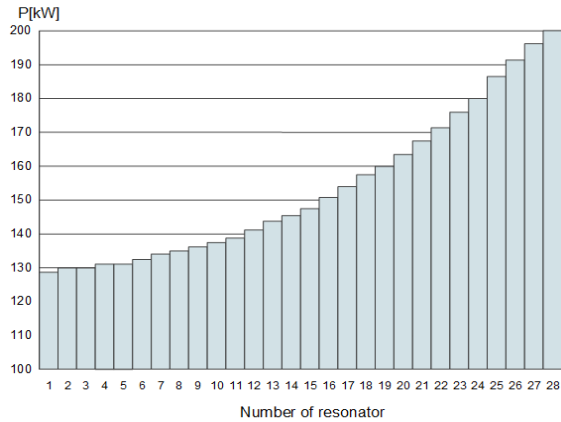


Figure 5: RF power losses depending on resonator position.

The total number of resonators is 28, excluding resonators of matching section MEBT2 and the downstream de-buncher. The maximum dissipating power in the resonator walls reaches 200 kW in pulse.

The diagram of the RF system for IH resonators with drift tubes is shown in Fig. 6. Twenty-eight SSAs provide accelerating resonators with the necessary power to create HF fields and accelerate the beam of charged particles. The resonant frequency of the resonators is tuned using mechanical plungers moved by stepper motors.

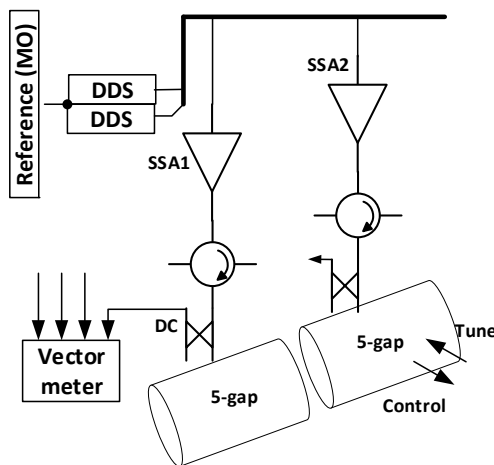


Figure 6: DTL2 resonator excitation scheme.

## RELIABILITY OF THE RF SYSTEM

The reliability of the HF power generating system of the linear accelerator can be estimated by a statistical method, which is valid for a large number of amplifying channels. The reliability of operation is determined by the relative

downtime  $T_d$ , which depends on the mean time of the channel between failures  $T_f$ , the average recovery time of the channel  $T_r$  and the number of channels  $n$  [4]

$$T_d = \left[ T_r \cdot \left( \frac{T_f}{n} + T_r \right)^{-1} \right] \cdot 100\% \quad (1)$$

The average time to failure of the amplifier channel depends on the complexity of the devices included in it. Assuming the number of channels  $n = 50$  and the recovery time  $T_r = 30$  min. at  $T_f = 1000$  hours, we get

$$T_d = \left[ 0,5 \cdot \left( \frac{1000}{50} + 0,5 \right)^{-1} \right] \cdot 100\% = 2,4\% \quad (2)$$

A significant part of the recovery time is spent on diagnosing the causes of failure. Modern computer-based diagnostic systems can significantly reduce this time. The design of RF power amplifiers for this accelerator provides for interchangeability of units. Thus, the reliability of the RF power supply system in the presence of redundant units and modules can reach 98%.

## CONCLUSIONS

Considering the achievements in production of high-power transistors made by LDMOS (Laterally Diffused Metal Oxide Semiconductors) technology and the current trend of replacing electric vacuum devices with grid control with solid-state elements, a project of an RF system was developed. Power supply of the LU-2 accelerator based on SSA as powerful sources of RF power. Despite the large number of channels and increased requirements for the parameters of amplifiers and the control system, the use of SSA will increase the reliability of the RF power supply system.

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