RF PHASING FOR ELI-GBS LINEAR ACCELERATOR *

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Abstract

The RF linac for the ELI - Gamma Beam Source (ELI-GBS) is being installed in Bucharest-Magurele (Romania). Traveling wave (TW) accelerating structures and SLED cavities are powered by klystrons via waveguide network that includes directional couplers for power monitoring and feedback. Before RF conditioning can begin, the linac must be properly tuned in terms of the RF phase and cavity frequencies. The waveguide system was reviewed with respect to its electrical length to ensure correct RF phase tuning. This work was carried out after installation but prior to connecting the waveguides to the accelerating structures. Fine RF-phase adjustments will be achieved through mechanical deformation of the waveguides. Since each klystron feeds four structures, the waveguides must be tuned so that the RF phase at the entrance of each structure matches its longitudinal position in the accelerator. Considering that only 5-degree deviation in phase can be compensated by mechanical deformation of waveguides, larger discrepancies must be corrected physically by bending existing waveguide components to correct position or even reposition accelerator segments. Therefore precise analysis of the waveguide network was performed using a vector network analyzer. This paper reports the results of phase measurements performed on the assembled waveguide system. In addition, directional couplers were individually tested with VNA to verify their performance before integrating them into the system.

INTRODUCTION

The ELI-GBS is based on the RF linac operating in the S-band (2856 MHz). The linac consists of five accelerating modules, each contains one Canon klystron (50 MW peak) that feeds the four traveling wave structures with RF power. The TW structures are connected to the SLED system to enlarge the peak power [1], [2]. The layout of one linac module is presented in Fig. 1.

The beam energy gain per one module is expected to be approx. 160 MeV. The GBS-linac is designed for a top energy of 800 MeV to easily achieve approx. 750 MeV as required by the specification [2]. For optimal Linac operation the accelerating field and electron bunch at the input of each cavity must be synchronized in such a way that the electron bunch travels on the crest (or a predefined phase) of the oscillating RF field. To fulfill that requirement, the distance between the input couplers of two consecutive accelerating structures must be an integer of wavelength λ plus the phase shift resulting from the geometry of the waveguide system. Therefore, the geometrical distance between the four accelerating structures in the linac module has to be adjusted in a way that the phase progress in the waveguides connected to each structure has the same phase difference from the RF source to the input coupler plus or minus a correction that comes from the geometrical distance between two consecutive structures, i.e. has to meet a formula: $n \times \lambda \pm \delta$. In a perfect matched and undeformed waveguide system, the phase progress depends only on a geometry of the system's elements, and can be calculated considering the fact that the wavelength of the oscillating RF field confined in the waveguide differs from the wavelength in vacuum. Due to mechanical tolerances the progress of the effective phase can differ from the pre-calculated (designed) one, nevertheless that difference can be measured.

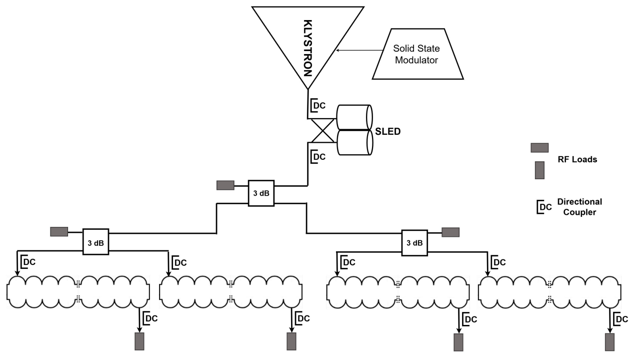

Figure 1: Linac module.

The evaluation and adjustment of the input phases of each cavity have to be done before performing the RF conditioning. For RF measurements, the vector network analyzer was used. The evaluation of the system's geometry was done following the measurements with use of a precise laser tracker.

Measurement setup

The measurement setup is presented in Fig. 2. The RF measurements with use of VNA and phase stable cables were performed to confirm the electrical phase length from the input port i.e., before the 3 dB coupler (φ_0) through the waveguide system that connect each TW structures with the RF source. Just one output port (φ_1, φ_2, φ_3, or φ_4) was used

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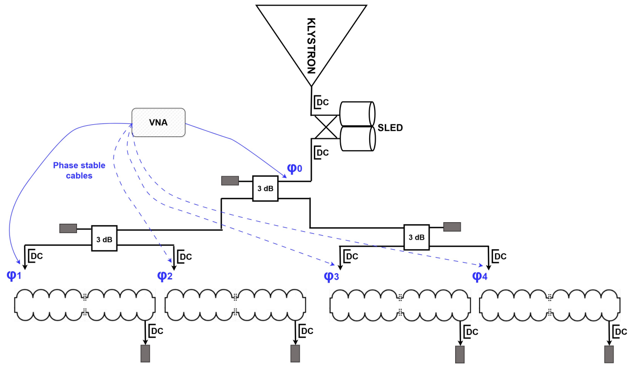

Figure 2: RF measurement setup.

at a time for the measurement, and other three ports were terminated with an RF terminator.

Each linac module is fed by the klystron source whose output phase can be adjusted via the LLRF system [3]. To define the accelerator RF phase, the distance between the TW structures L1, L2 and L3 (Fig. 3) were measured with use of the laser tracker. There was a discrepancy of 0.1 mm up to 52 mm in L1, L2 and L3 measured between the input couplers of the TW structures and between the output ports $l1$, $l2$, and $l3$ of the waveguide system. Those differences were corrected by centering the distances and then gently physical bent of the waveguide components. The vacuum tests revealed good tightness and no leakage.

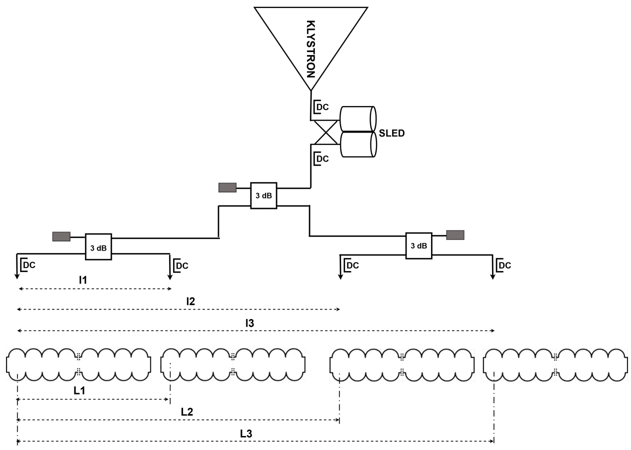

Figure 3: Geometry measurements.

RESULTS

The VNA measurements gave the phase progress between the input and output ports ($\varphi_0 \rightarrow \varphi_1$, $\varphi_0 \rightarrow \varphi_2$, $\varphi_0 \rightarrow \varphi_3$, and $\varphi_0 \rightarrow \varphi_4$) i.e., determined how the RF phase detected at the waveguide output ports depends on the RF phase from the source (adjustable by the LLRF system). The result for all five linac modules is presented in Fig. 4.

The electron beam that outputs the booster cavity achieves near the light speed. Therefore, it is more precise to determine the phase progress between the inputs to the first and other TW structures in the linac module. That means to measure the relative phase φ_1 and to calculate the phases φ_2, φ_3, and φ_4 that result from geometrical measurements of L1, L2 and L3. The measured lengths L1, L2 and L3 are presented in Fig. 5.

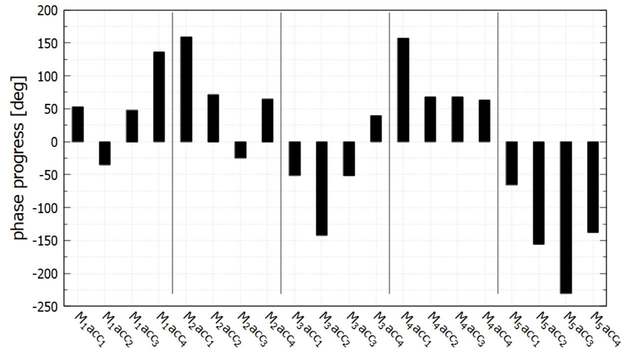

Figure 4: Phase progress between in- and out-ports.

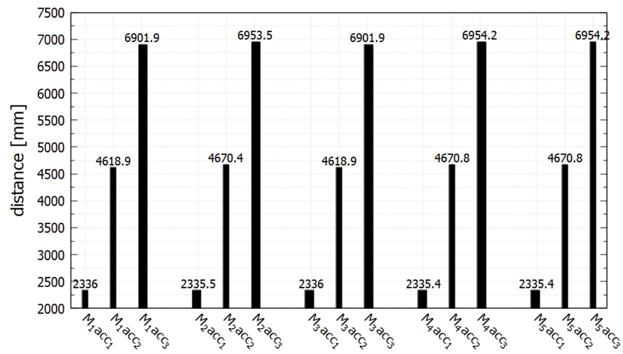

Figure 5: L1, L2, and L3 measured with laser tracker.

The phase progress $\varphi_1 \rightarrow \varphi_2$, $\varphi_1 \rightarrow \varphi_3$, and $\varphi_1 \rightarrow \varphi_4$ was calculated for each linac module (Table 1), considering that the wavelength $\lambda \approx 104.97$ mm, 1 degree ≈ 0.29 mm, and 1 mm ≈ 3.43 deg. Also $22 \times \lambda = 2309.23$ mm. The calculations determine how the RF phase detected at each TW structure with a fixed length and in the linac with a fixed length of intersections depends on the adjustable output phase of the source.

Table 1: Calculated RF phases at waveguide outputs

Modul nr		[mm]	[deg]
M1, M3	$\varphi_1 \rightarrow \varphi_2$	27	92
	$\varphi_1 \rightarrow \varphi_3$	0.4	1.5
	$\varphi_1 \rightarrow \varphi_4$	-26	-88
M2	$\varphi_1 \rightarrow \varphi_2$	26	90
	$\varphi_1 \rightarrow \varphi_3$	52	178
	$\varphi_1 \rightarrow \varphi_4$	26	89
M4, M5	$\varphi_1 \rightarrow \varphi_2$	26	90
	$\varphi_1 \rightarrow \varphi_3$	52	180
	$\varphi_1 \rightarrow \varphi_4$	27	91

Subtraction of the measured RF phases at the consecutive waveguide outputs (see Fig. 1) results in the measured values of the phase progress i.e., $\varphi_1 \rightarrow \varphi_2$, $\varphi_1 \rightarrow \varphi_3$, and $\varphi_1 \rightarrow \varphi_4$, which can be confronted with calculated values from Table 1.

Table 2: Measured RF phases at waveguide outputs

Modul nr		**[deg]**
M1	$\varphi_1 \rightarrow \varphi_2$	88
	$\varphi_1 \rightarrow \varphi_3$	5
	$\varphi_1 \rightarrow \varphi_4$	-83
M2	$\varphi_1 \rightarrow \varphi_2$	88
	$\varphi_1 \rightarrow \varphi_3$	184
	$\varphi_1 \rightarrow \varphi_4$	94
M3	$\varphi_1 \rightarrow \varphi_2$	91
	$\varphi_1 \rightarrow \varphi_3$	1
	$\varphi_1 \rightarrow \varphi_4$	-91
M4	$\varphi_1 \rightarrow \varphi_2$	90
	$\varphi_1 \rightarrow \varphi_3$	182
	$\varphi_1 \rightarrow \varphi_4$	94
M5	$\varphi_1 \rightarrow \varphi_2$	91
	$\varphi_1 \rightarrow \varphi_3$	165
	$\varphi_1 \rightarrow \varphi_4$	73

The accelerator phase "seen" by the electron bunch for each TW structure can be calculated as difference between measured (Table 2) and calculated (Table 1) RF phases at the input to each TW structure. The result is presented in Fig. 6.

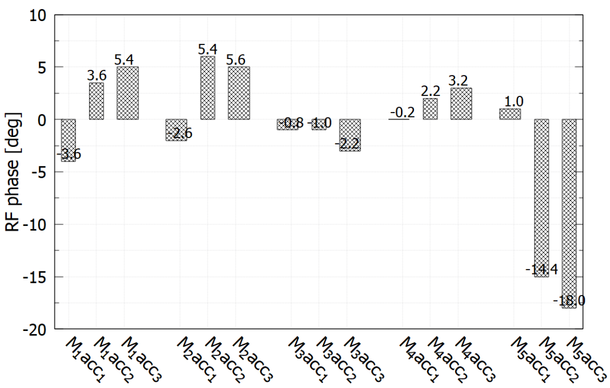

Figure 6: Accelerator RF phase.

For the practical reasons, the directional couplers that connect the waveguides with the TW structures were tested separately on a test bench. The S-parameters were measured and the phase progress verified. It was confirmed that the electrical length of each coupler differs from each other for approx. $\pm 1 deg$.

CONCLUSION

The measurements with the use of VNA were performed on all five linac modules to check how the phase of the RF signals progresses through the waveguide system. The measurements were confronted with the calculations that were preceded by the accurate measurements of the physical lengths of the accelerating structures and the linac intersections. The goal was to know how the RF phase at the input of each TW structures depends on the RF phase at the output of the klystron source. The results were carefully analyzed. It was decided that the linac modules M3 and M4 are tuned well enough and no deformation is needed. The modules M1 and M2 will be fine tuned by the physical deformation of the waveguide components and the little shortening of the distance between the TW structures. The significant RF phase shifts at the last module are planned to remain uncorrected as the resulting negative accelerator phase at that position can help to limit the bunch length growth due to chromatic effects from the magnets in the transport line towards the interaction chamber. The lower energy gain and the higher energy spread is expected to be marginal.

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