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 struc tures 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 analyser. 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 four travelling wave structures with RF power. The TW structures are connected to the SLED system to enlarge peak power. The layout of one linac module is presented in Fig. 1. The ELI-GBS linac design [1] is different from the previous design of the VEGA system from 2020, nevertheless in its initial configuration the accelerating modules are based on the same setup [2].

The beam energy gain per one module is expected to be approx. 160 MeV. The ELI-GBS linac is designed for a top energy of 800 MeV to easily achieve approx. 750 MeV as required by the specification. For optimal operation the accelerating field and electron bunch at the input of each TW structure 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 fulfil that requirement, the distance between the input couplers of two consecutive 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.

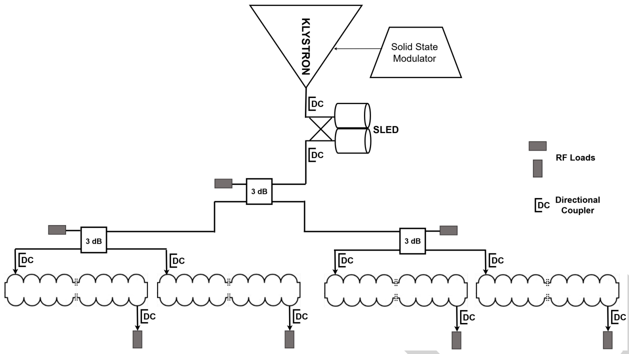

Figure 1: Linac accelerating module.

The evaluation and adjustment of the input phases of each TW structure have to be done before performing the RF conditioning. For RF measurements, the vector network analyser 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 at a time for the measurement, and other three ports were

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terminated with an RF terminator. The photograph of the system under test is shown in Fig. 3

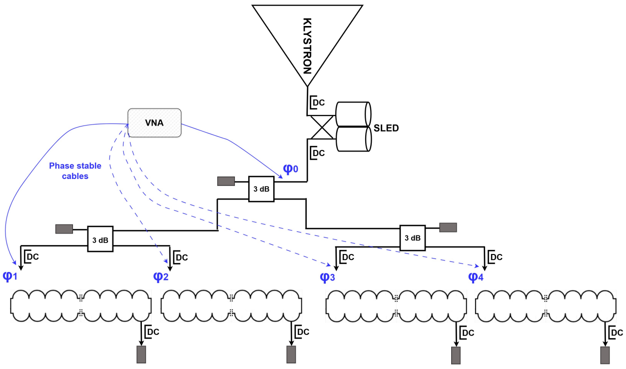

Figure 2: RF measurement setup.

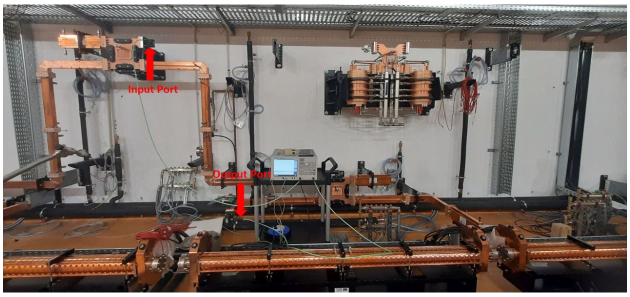

Figure 3: Photograph of linac module under RF test.

Each linac module is fed by the klystron source whose output phase can be adjusted via LLRF system [3]. To define the accelerator RF phase, the distance between the TW structures L1, L2 and L3 (Fig. 4) 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 input couplers of TW structures and between the output ports l1, l2, and l3 of the waveguide system. Those differences were corrected by centring the distances and then gently physical bent of the waveguide components. The vacuum tests revealed good tightness and no leakage.

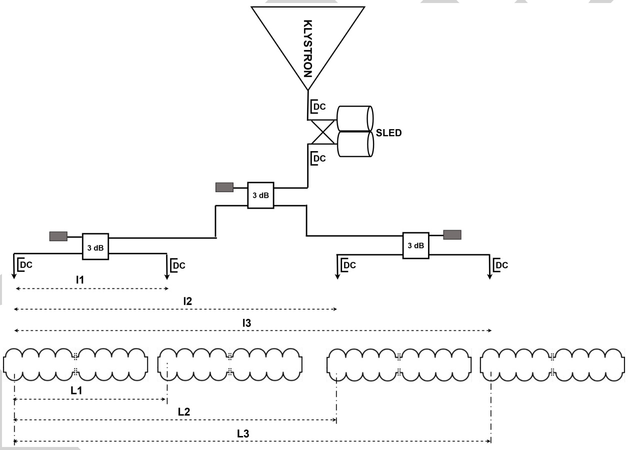

Figure 4: Measurements of geometry.

RESULTS

The VNA measurements gave the phase progress between the waveguides' 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 results for all accelerating modules are presented in Fig. 5.

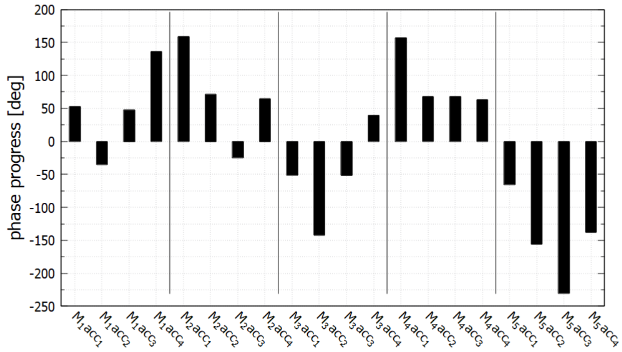

Figure 5: Phase progress between in- and out-ports of waveguide system.

The electron beam that outputs the RF electron source (described in [1]) 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. 6.

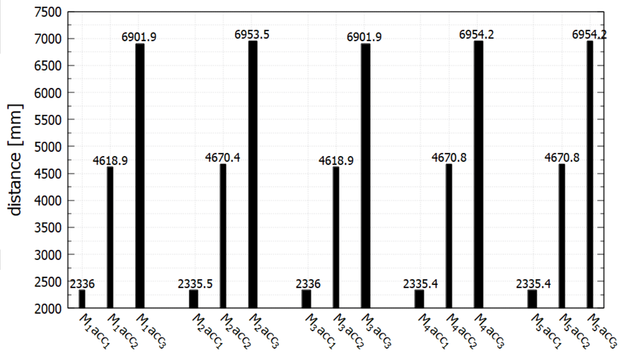

Figure 6: L1, L2, and L3 measured with laser tracker.

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

Subtraction of the measured RF phases at the consecutive waveguide outputs results in the measured values of the phase progress i.e., $\varphi_1 \rightarrow \varphi_2$, $\varphi_1 \rightarrow \varphi_3$, and $\varphi_1 \rightarrow \varphi_4$ (see Table 2), which can be confronted with the calculated values from Table 1.

Table 1: Calculated RF Phases at Waveguide Outputs

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

Table 2: Measured RF Phases at Waveguide Outputs

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

The accelerator phase “seen” by the electron bunch for each TW structure can be calculated as difference between measured and calculated RF phases at the input to each TW structure. The result is presented in Fig. 7.

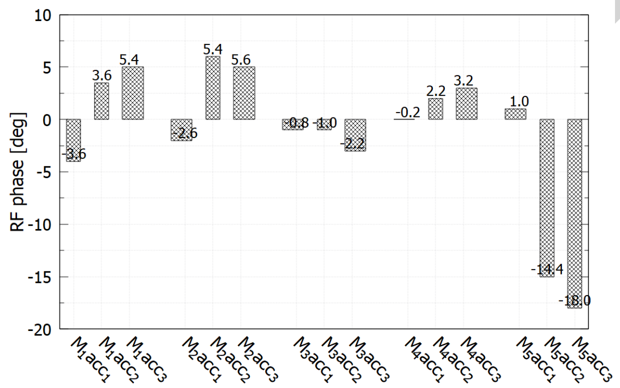

Figure 7: Accelerator RF phase.

For 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. $\pm 1 deg$. The photograph of the measurement setup is presented in Fig. 8.

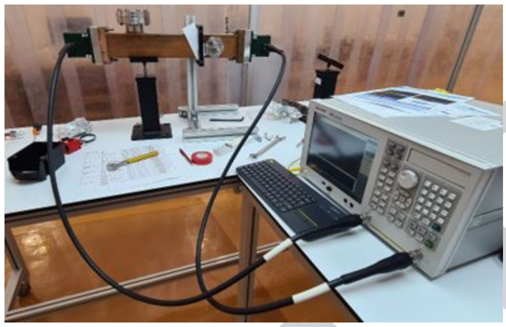

Figure 8: Setup for measurement of S-parameters of directional couplers.

CONCLUSION

The precise analysis of the ELI-GBS linac accelerating modules was performed with use of VNA to check how the phase of RF signals progresses through the waveguide system. The RF measurements were confronted with the calculations that were preceded by the accurate measurements of the physical lengths of the TW structures and the linac intersections. The purpose was to know how the RF phase at the input of each TW structure depends on the RF phase at the output of the klystron source. The results were carefully analysed. The conclusions were made that no any mechanical deformation of linac modules M3 and M4 is necessary. The modules M1 and M2 will be fine tuned by physical deformation of the waveguide components and little shortening the distance between the TW structures. The significant RF phase shifts at the last module are going to be not corrected, as the resulting negative accelerator phase at the end of linac can help to limit the bunch length growth due to chromatic effects resulting from the magnets in the transport line. The lower energy gain and higher energy spread is expected to be marginal.

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