

KLYLAC PROTOTYPING FOR BOREHOLE LOGGING*

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Abstract

Linac-based system for borehole logging exploits KlyLac approach combining klystron and linac sharing the same electron beam, vacuum volume, and RF network enabling self-oscillation due to a positive feedback. The KlyLac prototype design delivers ~ 1 MeV electrons in a linac section using part of the beam injected from a sheet beam klystron (SBK). The linac part is based on a very robust, high group velocity, cm-wave, and a standing wave accelerating structure of a “cross-pin” type supplied by a sampler. The SBK part features a permanent magnet solenoid focusing, relatively low voltage, and high aspect ratio beam. The main SBK characteristics (perveance, power, and efficiency) are expected to be similar to that for a magnetron.

INTRODUCTION

Borehole logging tools utilize high-activity ^{137}Cs or ^{60}Co radionuclide sources for densitometry and lithology among other applications. These sources are always “on” imposing significant concerns to radiation safety during handling and transport, potential environmental pollution in case of loss downhole, and security/terrorism activity. The borehole depth of geophysical interest typically exceeds 3000 ft. The X-ray detectors generally operate at ambient temperatures ranging from below 0°C (up-hole calibration) to 175°C or even higher. Though a borehole size can be as large as 5” or even 10”, for a prospective logging tool diameter is limited by a ~ 3.5 ”.

In this paper we rely on the KlyLac concept for the tool reported earlier [1]. Unlike the KlyNac bi-resonant concept [2] employing external master oscillator and strongly coupled cavities (klystron output, gain, and few linac cells) we use here self-oscillation of a high gain klystron loaded directly by a multi-cell standing wave (SW) linac supplied by an RF sampler and a positive feedback loop. Thus no external oscillator is used as the self-oscillation process starts from noise. That scheme enables to avoid usage of temperature-limited devices such as circulators or solid-state electronics (e.g., RF synthesizers), whereas number of cells is limited only by linac structure robustness in the harsh environment and coupling coefficient between cells.

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STABLE SELF-OSCILLATION

Frequency change by 130°C causes ~ 28 MHz frequency detuning in a copper structure, which is 0.3% in X-band. Besides, substantial temperature gradients may occur along the structure while the tool is moving. Along with mechanical vibrations it means the linac resonant frequency may deviate by a substantial fraction of klystron bandwidth from the klystron central frequency. The feedback can provide the required flexibility in frequency self-adjustment provided a stable self-oscillation at power level sufficient for acceleration within a wide enough bandwidth is enabled by the feedback loop parameters. In CW mode stable operation was successfully addressed in that positive feedback scheme for an industrial high power linac operating without circulator [3].

To explore the stability conditions in a pulse mode we applied the cavity excitation model [4] with taking into account phase conditions. The calculation results given in Fig. 1 for 66 dB gain klystron indicate that a stable feedback performance is achievable at very low reflected power and practically feasible group delays.

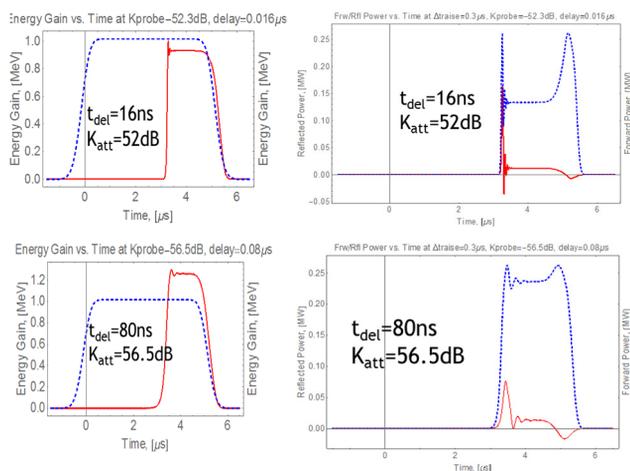


Figure 1: LEFT: Waveforms for accelerating voltage with feedback loop (red, solid) and klystron HV envelope normalized to max energy gain (dashed blue). RIGHT: Forward (dashed blue) and reflected (red solid) power waveforms. Top: Group delay 16 ns, loop phase advance 90° , attenuation 52 dB (including sampler). Bottom: Group delay 80 ns, loop phase advance 150° , attenuation 56.5 dB (including sampler).

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The feedback group delay includes the klystron and the transmission line group delays of the loop. The system can be stabilized further by reduction the klystron group delay. One way to do it is decreasing of external Q-factors of the klystron cavities. Another way is equalizing, i.e. flattening of the klystron gain-frequency characteristic. The equalizing can be addressed in two ways: by detuning of the klystron cavities or using corresponding filters in the feedback loop.

THE KLYSTRON PART OF THE KLYLAC

Our previous KlyLac development [1] employed a multi-beam klystron (MBK), which suffers from fabrication complexity, lack of tuning flexibility, and relatively low efficiency. Therefore we designed a 6-cavity sheet beam klystron SBK having $3.7 \text{ mm} \times 50 \text{ mm}$ beam tunnel, and fed by a 23 A, 24 kV beam for the same frequency $\sim 9.4 \text{ GHz}$. The “beamstick” simulation is shown in Fig. 2.

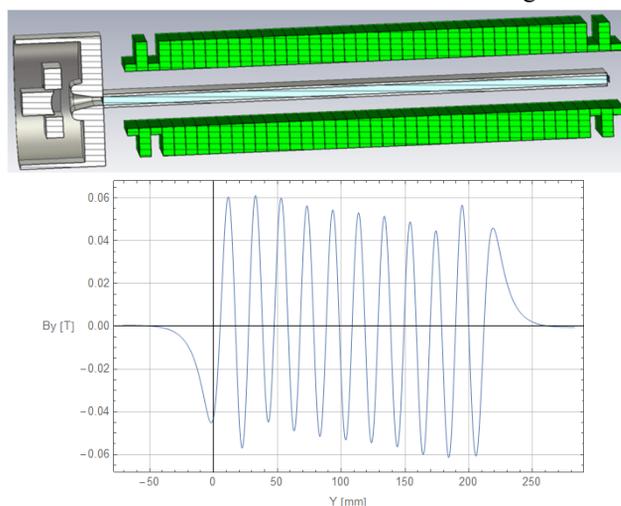


Figure 2: SBK gun and PPM focusing system designed for the KlyLac (top), magnetic field profile of the PPM system (middle) and the SBK “beamstick” simulation (bottom).

The flat-field cavities designed for SBK are shown in Fig. 3. They provide relatively high beam coupling coefficient $M \geq 0.49$, $R/Q \geq 11.9 \Omega$, and better than 6.7% relative rms deviation of the shunt impedance (with transit time factor) across the tunnel width. The external Q-factors for the input and output cavities are ~ 360 and 315 respectively. Note for input cavity we are using a coupler based on ceramic PCB (0.63 mm Alumina) rather than a standard feedthrough with SMA connector. That enables to make the coupling much more compact and capable of higher temperatures being more suitable to brazing.

AJDisk [5] simulations performed for the SBK cavities above indicate substantial efficiency $\sim 34\%$ and 66 dB gain at bandwidth from 13 MHz to 40 MHz dependently on cavity tuning (see the tuners in Fig. 4). The expected power according to the AJDisk simulations is 208 W for

23 A beam and 150 W for 18 A beam, which is enough to accelerate the beam to $>0.9 \text{ MeV}$ energy.

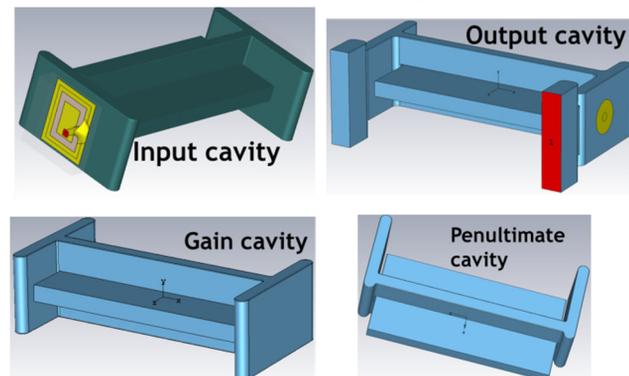


Figure 3: SBK cavities designed for the KlyLac.

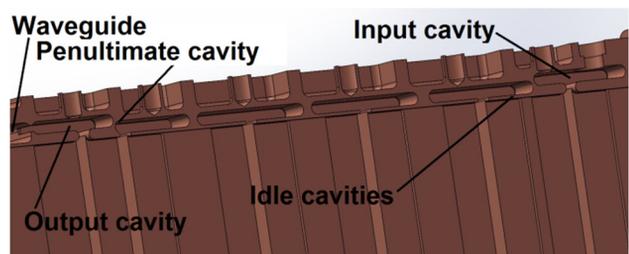


Figure 4: Fragment of SBK RF structure with tuners.

KLYLAC ENGINEERING

Careful analysis of the challenging requirements to the system resulted in the following design guidelines for the linac: a) Extreme robustness; b) Avoidance tuners for structure cells; c) Structure performance in terms of $E(z)$ and $R_{sh}(z)$ should not depend on temperature and its gradient as well as vibrations; d) Minimum possible transverse dimension; and e) Large frequency separation comparable to the frequency shift caused by temperature. Among many structure variants considered the cross-bar structure employed in Cornell synchrotron [6] is the most suitable for our X-band application [7] to provide operation in harsh environment at 150°C temperature and above.

Assembly of the KlyLac structure prototype has been CAD-designed in two variants: i) using standard flanges, existing sub-components, and also standard vacuum equipment (see Fig. 5); and ii) custom engineered flanges and components to fit 3.5” borehole including compact NEG pumps (see Fig. 6).

As it can be seen from Figs. 5 and 6 for fabrication of the KlyLac structure, we apply clam shell (split) approach (including linac, SBK and transition between them). Fabricated parts of the linac are shown in Fig. 7.

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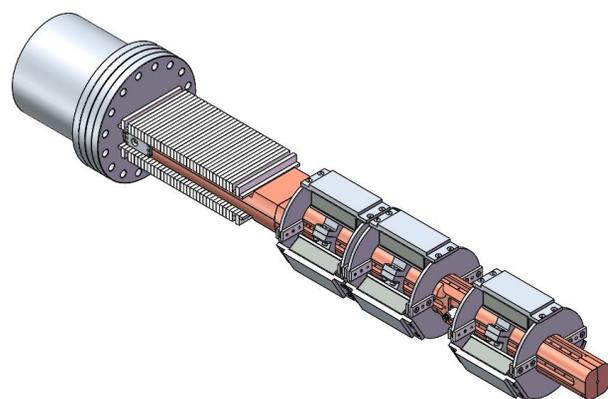


Figure 5: Assembly and exploded view rendered for the KlyLac prototype using standard flanges (DN100CF for the gun) and COTs components.

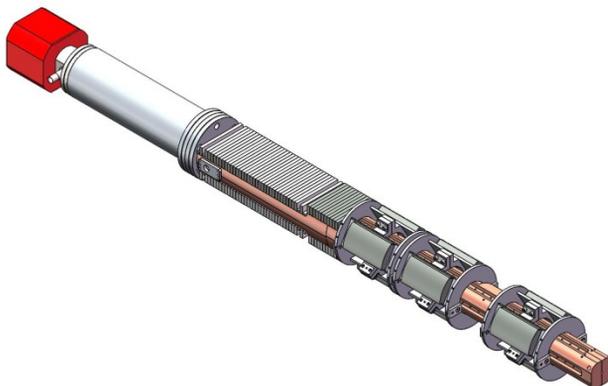


Figure 6: Assembly (top) and cut view (left) rendered for the KlyLac prototype that fits 3.5" diameter using DNF35CF and custom components including NEG pump (upstream the KlyLac structure). The external cylindrical

housing of the tool as well as the detectors, wires, and converter are not shown.

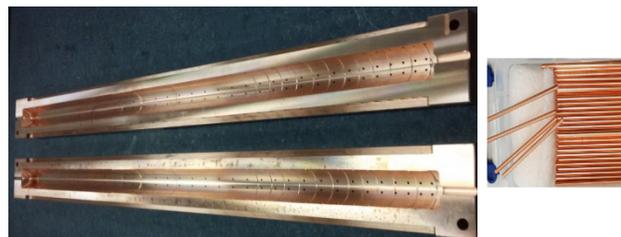


Figure 7: Linac parts fabricated: tubular housing with EDM-drilled holes (left) and pins (right).

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