KLYLAC PROTOTYPING FOR BOREHOLE LOGGING

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DoE SBIR Phase II 1st year project
Linac-based source to eliminate proliferation hazard and radiological dispersion ("dirty bomb")

The design should be capable of:
- Scalability to replace Cs137 source (>~2.5 MeV energy)
- Borehole target: \(\varnothing 3.5\"
- High operating temperature: up to ~140-150°C
- Vibrations: ~(1-2)G
- External magnetic fields (n×100 Gauss)

Cs137:
~30 years
half lifetime
Borehole Tool Schematics

self-oscillating KLYNAC with feedback

On-ground station

KlyLac concept
C. Nygard, Patent number 2,922,921, 1960
S.O. Schriber, Canadian Patent 1040309, 1978
B. Yu. Bogdanovich PAC’97

KlyNac (LANL)
Smirnov
B. Carlsten, K.E. Nichols
NIMA877 (2018)
The main goal of the Phase II project is to demonstrate operation of a ~1 MeV KlyLac prototype capable to produce 5 µA beam current and beam average power >5 W (corresponding to a few Ci activity).

* E-beam energy: ~1 MeV
* Pulse current: >2mA
* Pulse power: >5 kW
Sheet Beam Klystron (SBK) section

Robust bi-periodic linac structure

Thermionic Pulsed Diode E-Gun

Positive feedback loop self-oscillating RF system starting from noise.

That system enables fast self-adjustment of the frequency provided it is stable.
Self-oscillation performance

\[
\frac{dU}{dt} + (1 + \beta_c) \frac{\omega}{2Q_o} U = \frac{\omega}{Q_o} \sqrt{\beta_c R P_{f r w r d}(t, U)}
\]

NIMA 868 (2017)

Normalized HV Envelope and accelerating voltage

Energy Gain vs. Time at Kprobe = 52.3 dB, delay = 0.016 μs
Energy Gain vs. Time at Kprobe = 56.5 dB, delay = 0.08 μs
Energy Gain vs. Time at Kprobe = 51 dB, delay = 0.045 μs

\( t_{\text{del}} = 16 \text{ns} \), \( K_{\text{att}} = 52 \text{dB} \)

\( t_{\text{del}} = 80 \text{ns} \), \( K_{\text{att}} = 56.5 \text{dB} \)

\( t_{\text{del}} = 45 \text{ns} \), \( K_{\text{att}} = 51 \text{dB} \)

Forward and reflected power, MW

\( t_{\text{del}} = 16 \text{ns} \), \( K_{\text{att}} = 52 \text{dB} \)

\( t_{\text{del}} = 80 \text{ns} \), \( K_{\text{att}} = 56.5 \text{dB} \)

\( t_{\text{del}} = 45 \text{ns} \), \( K_{\text{att}} = 51 \text{dB} \)

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Technical Risk Mitigation

Stabilization of self-oscillation (group delay reduction)
- Flatten the klystron Gain(f) by detuning the cavities;
- Introduce equalizer into the feedback loop (multi-pole filtering).

Other technical solutions for KlyLac Phase II
- Extremely robust linac (high group velocity, $R_{sh}$ independent on $t$).
- Adapt the design to M0.5 ScandiNova modulator 24 kV 23-28 A.
- Increase aspect ratio of the SBK cavities to increase field flatness and coupling coefficient (gain, efficiency).
- 3-section PM “solenoid” for the linac section.
**Challenge:** how to provide
1. uniform interaction at
2. right frequency,
3. sufficient beam coupling \( (M>0.45) \)
4. i/o RF coupling required \( (Qe\sim200-350) \).
5. Tunability

New beam aperture: 3.7 mm × 50 mm
(instead of 4.79 mm × 30 mm)

**Input cavity**
Custom ceramic PCB coupler
SBK Cavities Performance

Input cavity

F = 9.366(9.378) GHz
Qo = 2860(2784)
Qe = 345(360)
RdQ = 14.7(14.07)
M = 0.51
\[ \sigma_{\text{rms}}(M^2R) = 6(4)\% \]

Output cavity

F = 9.361 GHz
Qe = 315, Qo = 3235
RdQ = 11.9
M = 0.5
\[ \sigma_{\text{rms}}(M^2R) = 6.5\% \]

Penultimate cavity

F = 9.377 GHz
Qo = 3380
RdQ = 12
M = 0.49
\[ \sigma_{\text{rms}}(M^2R) = 6.7\% \]

Idle cavities

F = 9.366(9.378) GHz
Qo = 2860(2784)
Qe = 345(360)
RdQ = 14.7(14.07)
M = 0.51
\[ \sigma_{\text{rms}}(M^2R) = 6(4)\% \]
Enhanced efficiency at reduced voltage 38→24 kV due to re-designed cavities and lower perveance per beamlet.
Accelerating section: Design Challenges

- Extreme robustness:
- No tuners for structure cells
- E(z) and Rsh(z) should not depend on: \(T^\circ\), \(\nabla z T^\circ\), and vibrations
- Minimum possible transverse dimension
- Large frequency separation > thermal detuning

Rsh=41 M\(\Omega\)/m
Kc=0.36 (\(\beta gr=0.36\))

Transverse (tube ID) size: 0.54\(\lambda\)
Frequency separation: 80 MHz

Detuning caused by temperature is up 27 MHz
Linac beam dynamics

Field profile along the linac

Beam rms size and emittance

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Phase II linac tube with holes EDM-ed for pins

Phase I Cross-pin 6-cell mockup

No tuning is required!

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Summary

- Stable feedback operation is proved to be feasible
- Low voltage flat beam beamstick is designed
- SBK gun is under fabrication
- PPM SBK is designed
- Extremely robust linac structure is designed, fabrication is in progress.

Next steps

* Test the SBK gun under fabrication.
* Assemble beamstick and test it.
* Fabricate SBK structure, assemble and test it.
* Fabricate transition region, attach it to the SBK and the linac.
* Perform KlyLac tests.
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