Linear Accelerators Principles, History, and Applications

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Linac Prehistory

- In 1911 Rutherford announced the discovery of the atomic nucleus by scattering of α-particle beams from gold foils.
- A few years later in 1927 Rutherford, in his presidential address to the Royal Society, made a strong request for higher energy nuclear probes.

Rutherford's statement in address to the Royal Society (1927)

" It has long been my ambition to have available for study a copious supply of atoms and electrons which have an individual energy far transcending that of the α and β particles from radioactive bodies. I am hopeful that I may yet have my wish fulfilled."

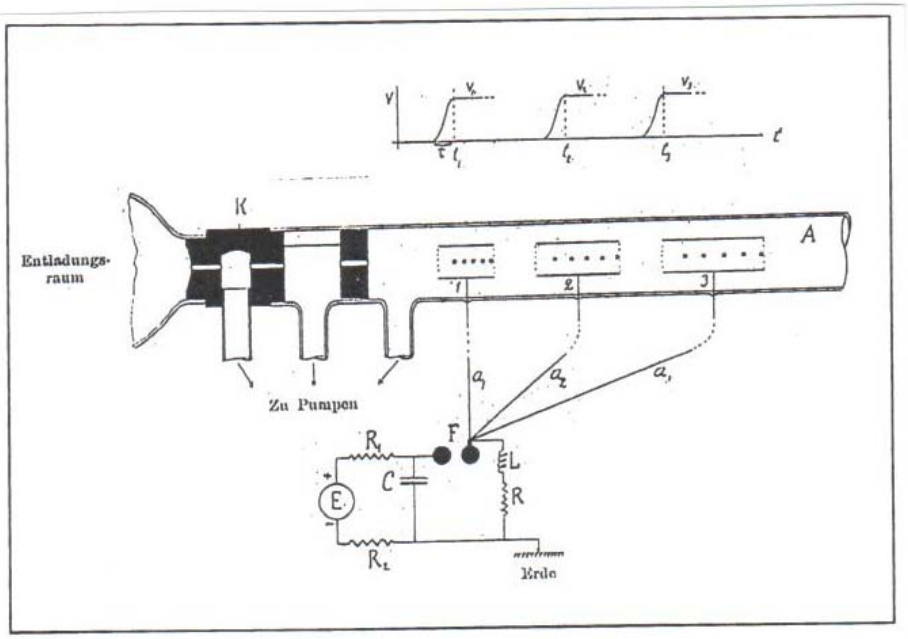
Rutherford's statement became a challenge to invent higher energy particle accelerators

- A race for higher energy particle accelerators involved an early competition between electrostatic machines, but electric breakdown was a fundamental limitation to high voltages.

- Meanwhile, it had already been realized by a few that another solution that avoided very high voltages was to use time-dependent accelerating fields.

Gustav Ising (1924) published an accelerator concept with voltage waves propagating from a spark discharge to an array of drift tubes.

- Voltage pulses arriving sequentially at the drift tubes produce accelerating fields in the sequence of gaps.

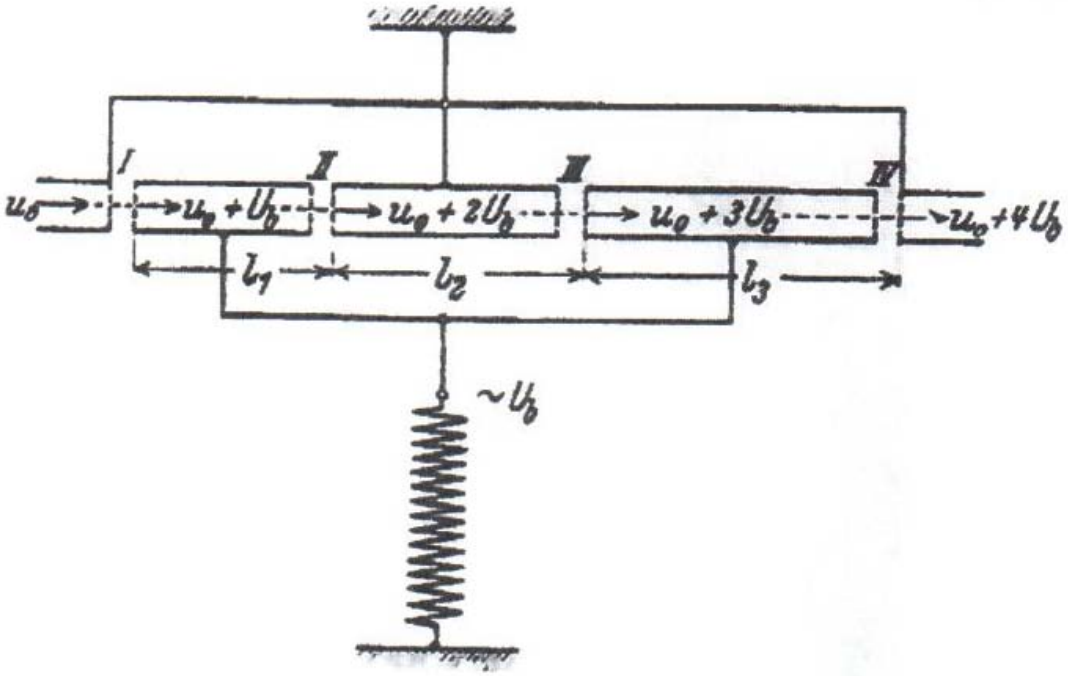


- **But Ising was unable to demonstrate the concept.**

In 1927 **Rolf Wideroe**, Norwegian graduate student at Aachen University discovered Ising's 1924 publication in the university library.

- Wideroe simplified Ising's concept by replacing the spark gap with an ac oscillator.

- **For his PhD thesis Wideroe built and demonstrated a simple linac, which had one drift tube between two accelerating gaps.**



The accelerator concept with the oscillator was demonstrated by Rolf Wideroe (1928)

- Wideroe applied a 25-KV, 1 MHz AC voltage to the drift tube between two grounded electrodes. The beam experienced an accelerating voltage in both gaps.
- He accelerated Na and K beams to 50 keV kinetic energy equal to twice the applied voltage.
- This is not possible using electrostatic voltages.

From ***"The Infancy of Particle Accelerators, Life and Work of Rolf Wideroe"***

ed. Pedro Waloschek

"My little machine was a primitive precursor of this type of accelerator which today is called a 'linac' for short. However, I must now emphasize one important detail**. The drift tube was the first accelerating system which had earthed potential on both sides**, i.e. at both the particles' entry and exit, and was still able to accelerate the particles exactly as if a strong electric field was present."– **Rolf Wideroe**

Ising and Wideroe established principle of resonance acceleration

- **Particles can gain arbitrarily high kinetic energy from successive traversals through the same accelerating fields with moderate voltages.**
- Particles acquire a small energy increment with each traversal.
- No basic limit to maximum kinetic energy.
- Method can be applied to linear accelerators (linac) or to circular accelerators (cyclotron or synchrotron).

But with low (1-MHz) frequencies available at that time, linacs for faster protons and electrons had impractically large gap-to-gap spacings.

- The gap-to-gap spacing is **v/2f** so high-velocity particles require high oscillator frequency to obtain satisfactory energy gain per gap.

- At least a few hundred MHz were wanted, but RF frequencies available then were no more than 10 MHz.

- **Higher frequency microwave sources were unavailable until after WWII, a benefit of radar developments for the war.**

The first proton and electron linacs were built after WWII

1946-1950s

Interest in linacs grew after WWII.

- Development of pulsed RF power sources at hundreds of MHz and with megawatts of power **removed the technical barrier** for electron and proton linacs.

- **Invention of synchrotrons** was important for linacs since synchrotrons need linac injectors.

- Linacs have an advantage of better beam quality, an output beam focus with **smaller size and better energy resolution.**

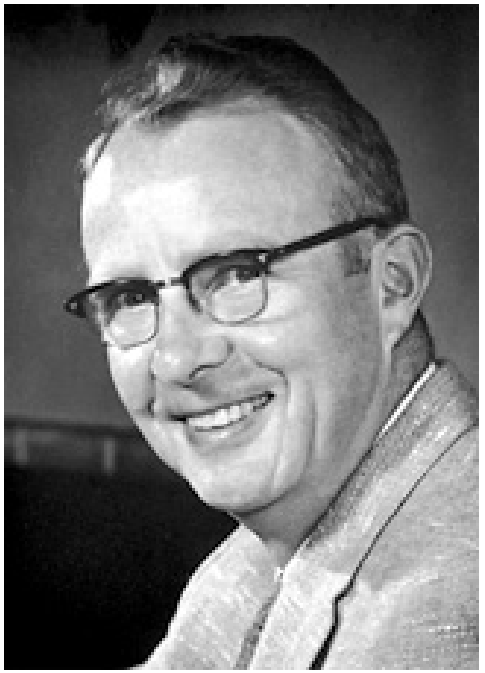
First proton linac in 1947

- Luis Alvarez at Berkeley designed a proton drift-tube linac 12-m long, 1-m diameter,

  4 MeV to 32 MeV, initially using surplus 200-MHz vacuum tubes.

- Alvarez introduced a **copper resonant cavity** for better efficiency, loaded with an array of **drift tubes,** and excited in a **TM_{010} power efficient mode.**

- Later, transverse focusing with **quadrupoles in drift tubes** were implemented.



Shows drift tubes supported by conducting stems, and E and B fields in drift tube linac