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Electron sources for medical linear accelerators. Accelerator physicist view.

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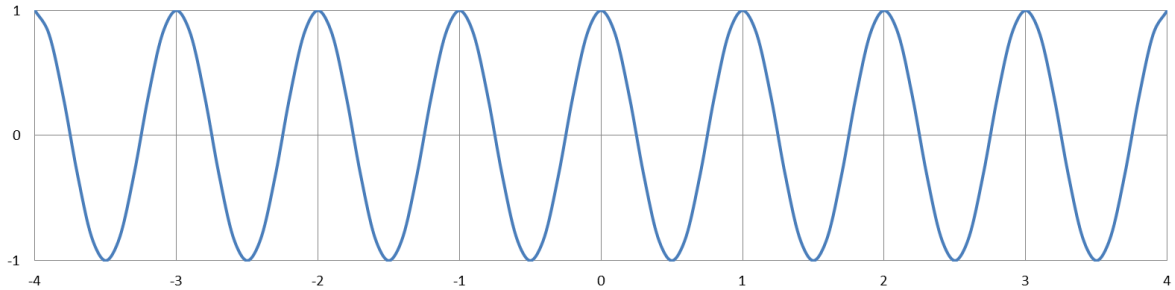
Outline

- Injector specification
- Thermionic emission and cathode materials
- Triode electron sources
- Injector of electron linac
- Conclusion

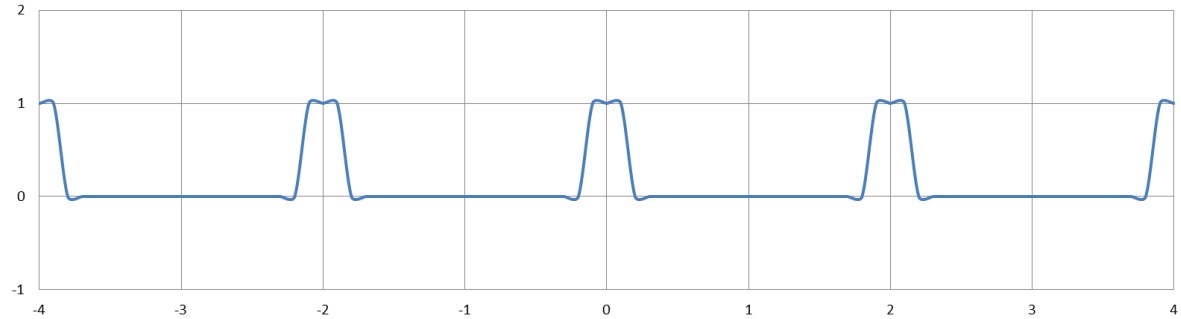
Electron source for medical electron accelerator

- Physical parameters
  - Average current – 10 μA
  - Electron energy - 6 MeV
  - Beam spot size (FWHM) – 1-3 mm
  - Beam loses – 0.01%
  - Beam time structure (train-pulsed)
- Coast
  - Manufacturing
  - Infrastructure
  - Operation
  - Maintenance
- Reliability

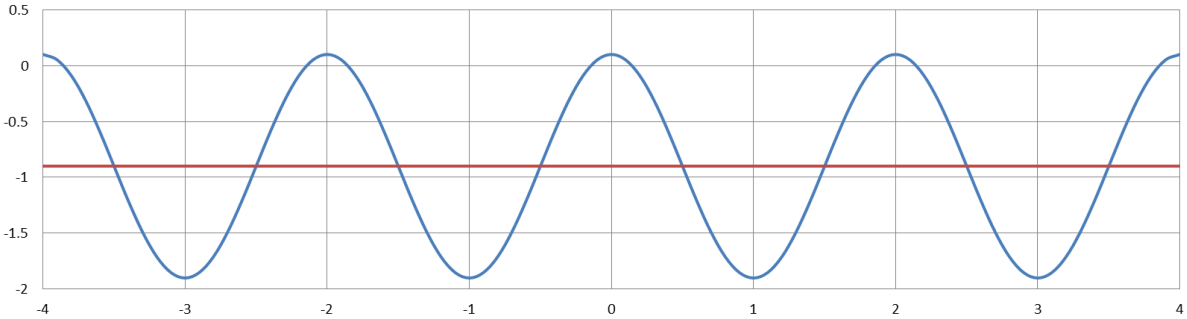
Beam specification I



RF field



Required beam structure

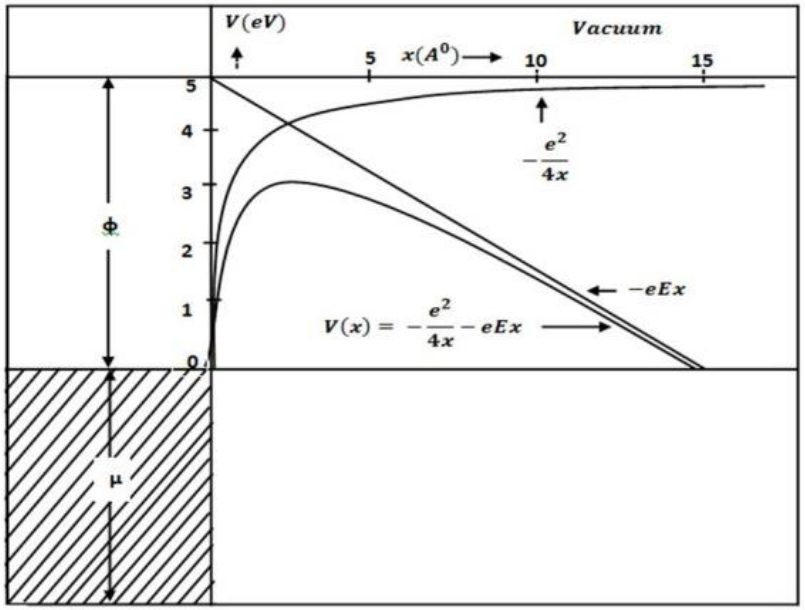


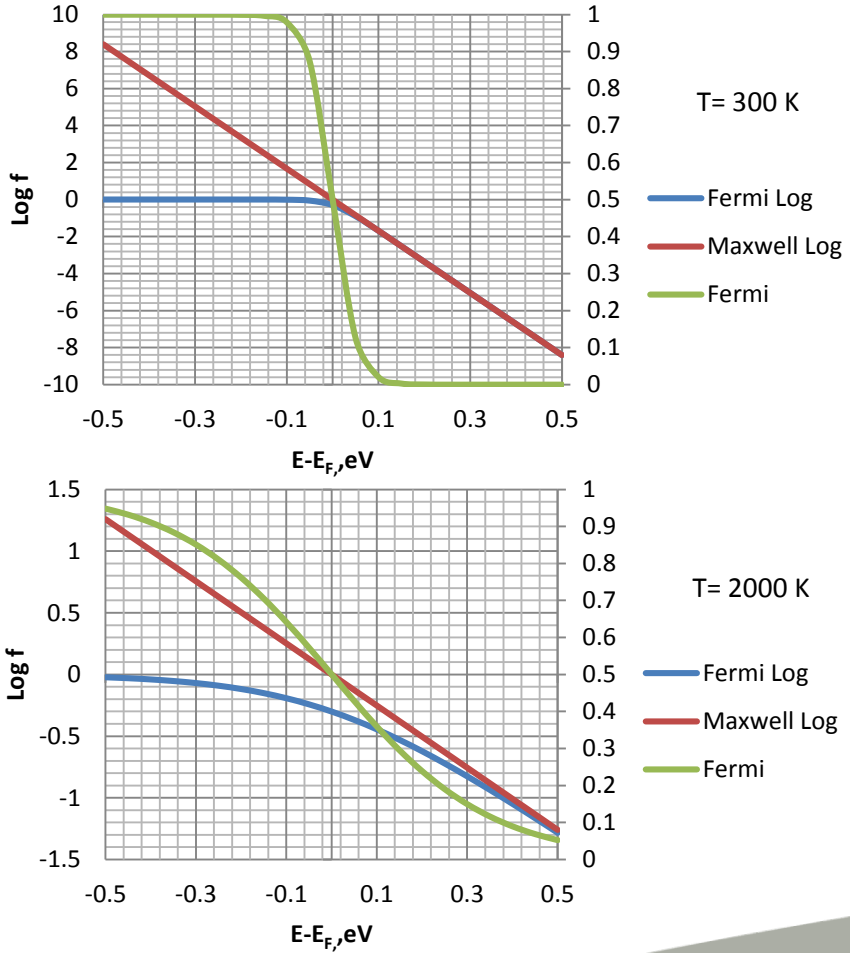
Grid voltage

Beam specification II

- The accelerator is going to be used for X-ray generation
  - Maximum power density which can withstand cooled W target is 1 kW/mm^2
  - At a beam diameter of 1 mm it gives maximum beam power at 6 MeV beam electron energy 800 W
  - That limits average beam current by 133 μA
- At 10 μA average current at a beam pulse length 5 μs in S-band linac and a repetition rate of 300 Hz we have 6.7 mA average pulse current
- At a 60° pulse length from the cathode we have cathode peak current 40 mA

Electrons in metal





- Fermi-Dirac distribution

$$f_F \sim \frac{1}{1 + e^{\frac{E - E_F}{kT}}}$$

- Maxwell-Boltzmann distribution

$$f_M \sim e^{-\frac{E}{kT}}$$

- At high energy, $E - E_F \gg kT$

$$f_F = f_M$$

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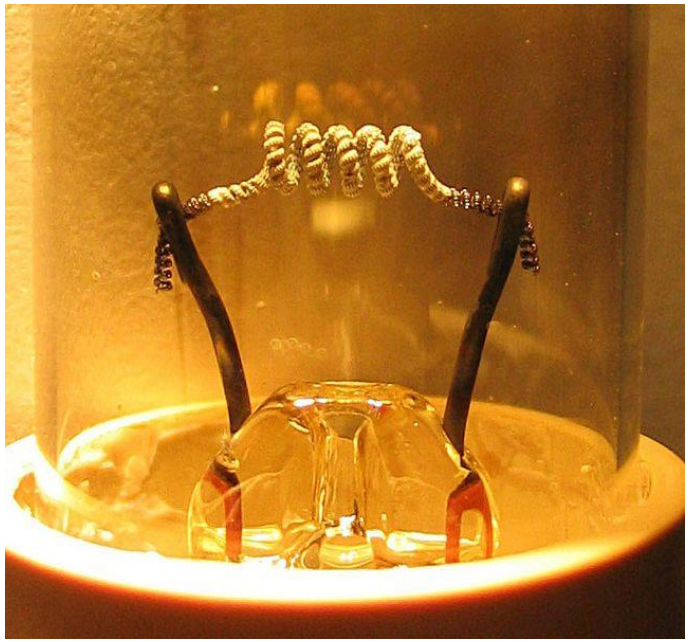
How to extract electrons from the metal?

- To heat the metal cathode to increase amount of high energy electrons in the distribution
  - Practically limited by 2500 °K
- To apply high electric filed in order to reduce effective work function
  - Practically limited by the value 10 MV/m
- To cover metal with a coating which reduce the work function
  - Wide field for investigation
  - There are many different coatings which allow to reduce cathode work function and its operational temperature
  - Operational stability?

Thermionic cathodes



Experimentally investigated in 1901by Richardson: $\mathrm{J} = A_G T^2 e^{-\frac{\varphi}{kT}}$,

Where $A_G = \lambda_r A_0$, and $A_0 = \frac{4\pi m k^2 e}{h^3} = 1.20173\, A/mm^2/K^2$

$\lambda_r \simeq 0.5$ is defined by material properties

Thermionic cathode materials

Material	Operational Temperature, °K	Work function, eV	Specific emission [A/cm^2]
Tungsten	2500	4.5	0.5
Thoriated tungsten	2000	2.6	5
Dispenser cathodes	1200-1500	2.0	3-15
LaB_6	1700	2.7	20
CeB_6	1800	2.65	20

At a cathode peak current of 100 mA and at a specific emission of 10 A/cm^2 we need a cathode with diameter of 1.1 mm

Examples of industrial electron sources

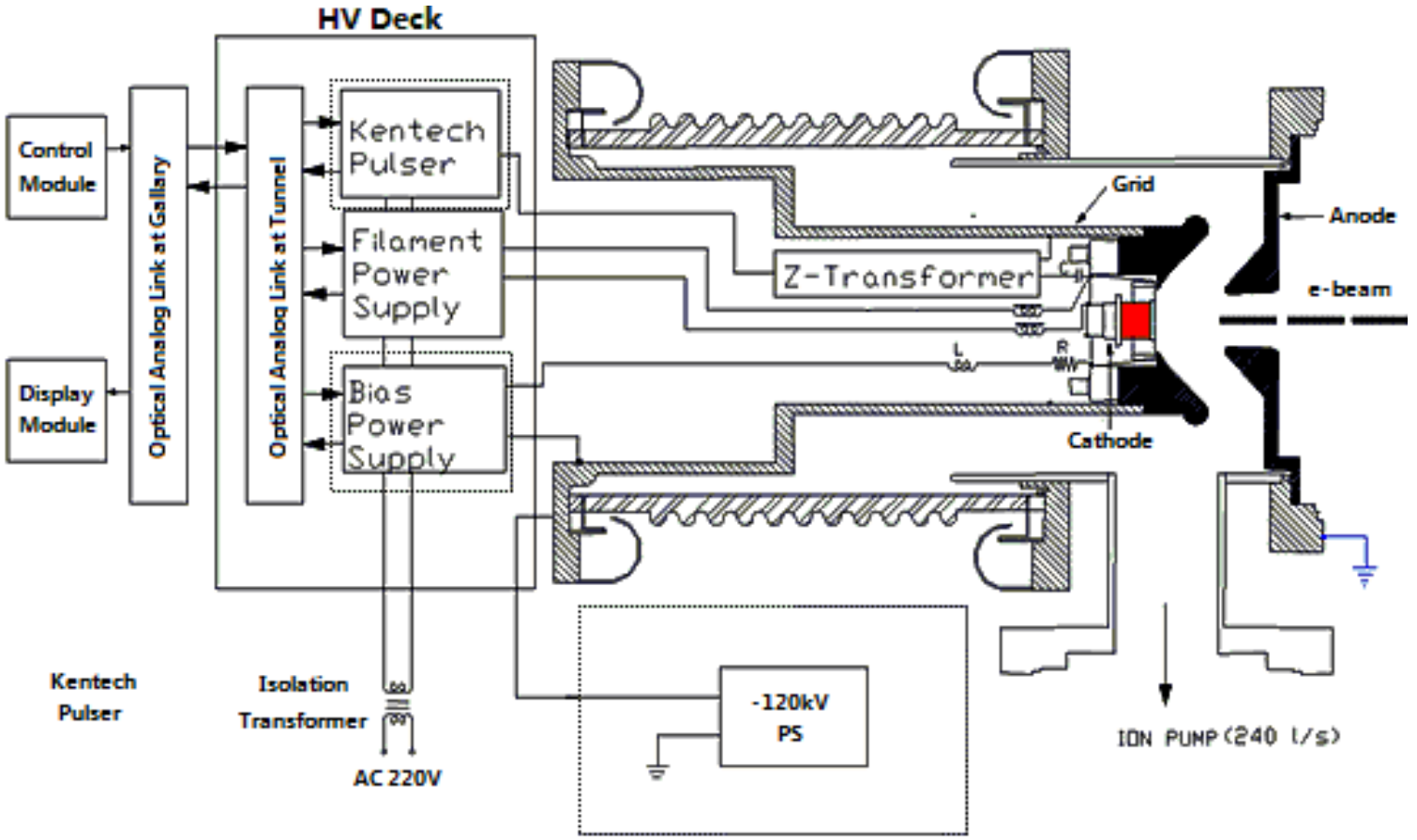
JRC NJK2110A2

Grid modulated electron source with 4 mm Ir coated dispenser cathode with specific emission of 10 A/cm^2

JRC NJK2211

Grid modulated source with 6.3 mm cathode

Typical triode electron source



Electron injector for NSC KIPT linac

Electron source infrastructure

- High voltage power supply, DC or pulsed DC are widely available from different manufacturers,
- Cathode service insulated from the ground
  - Cathode heater, AC – widely available
  - Grid modulator, RF – depends on specifications
  - Grid bias, DC/RF – depends on specification
- High potential transformer – widely available
- Local control – needs to be investigated but should not be a problem
- High voltage optical transmission – needs to be investigated

Conclusion

- Electron injector for linear RF accelerator should be built on the basis of a triode electron source
- The source should have module construction with easy on site replaceable modules
- Every module should be available from at least two manufacturer

Grid modulated 6mm LaB_6 emitter