# RF SOURCES FOR RECENT LINEAR ACCELERATOR PROJECTS

**Jean-Charles Terrien, Georges Faillon and Philippe Guidée**
**Thomson Tubes Electroniques**
**2, rue Latécoère - BP 23**
**78141 Vélizy-Villacoublay - FRANCE**

### Abstract

We present the state of the art of high power klystrons at Thomson Tubes Electroniques, along with the main technological limitations for peak power and pulsewidth. Then we describe the work that is under way to upgrade the performances, and some of the alternative RF sources that have been developed.

### Introduction

Recent changes in accelerator technology and growth of new applications are causing a significant evolution of characteristics specified for high power klystrons. Besides the classical requirements for high peak power, short pulse klystrons for linear accelerators on the one hand, for CW RF sources on the other, Thomson developed a complete range of long pulse klystrons able to provide a large amount of peak and average power. These tubes generally use the technology already applied to existing klystrons, but the requested performances are now close to the technological limits.

The improvements studied and now implemented should cover the requirements for the most recent projects of linear accelerators; they also offer a breakthrough for the future needs of very high peak power RF sources for linear collider projects.

### State of the art of high power klystrons at TTE

For practical reasons, high power klystrons can be divided in three families according to pulse length:

1) Short pulse klystrons (less than 10 μs). Two subdomains may be considered:

- existing conventional linacs, which require peak powers up to 45 MW for 4 to 5 μs (Table 1)
- future linear colliders, which would require peak powers in the range of 100 to 200 MW for about 1 μs.

It is noticeable that the SLAC 5045 klystron has performances intermediate between these two areas.

**TABLE 1**
**Selection of short pulse high power klystrons**

| P/N | Frequency (MHz) | Peak Power (MW) | Pulsewidth (μs) |
|---|---|---|---|
| TV 2022D | 1300 | 30 | 7 |
| TH 2128C | 2856 | 45 | 4.5 |
| TH 2100B | 2998 | 40 | 4.5 |
| TH 2132 | 2998 | 45 | 4.5 |

2) Long pulse klystrons for proton accelerators, FELs, superconducting linacs or industrial linacs. Typically the range of peak power spreads from 2 to 20 MW and the pulsewidth from 20 μs to 2 ms (Table 2).

**TABLE 2**
**Selection of long pulse high power klystrons**

| P/N | Frequency (MHz) | RF Power Peak (MW) | RF Power Average (kW) | RF Pulsewidth |
|---|---|---|---|---|
| TH 2140* | 428 | 4 | 5 | 100 μs |
| TH 2134 | 432 | 2 | 100 | 1 ms |
| TH 2118 | 433 | 6 | 200 | 220 μs |
| TH 2138 | 850 | 1.25 | 75 | 2 ms |
| TH 2143* | 1284 | 20 | 25 | 100 μs |
| TH 2104A | 1296 | 5 | 150 | 600 μs |
| TH 2115 | 1300 | 2.5 | 150 | 1 ms |
| TH 2104U | 1300 | 10 | 250 | 250 μs |
| TH 2130 | 2998 | 20 | 20 | 20 μs |

* under completion

3) CW klystrons such as the TH 2089B, recently delivered at CERN for the LEP-200 project, which supplies 1.38 MW CW (for a rated 1.3 MW CW) at 352 MHz. It is a sound basis for the development of higher power tubes, which would fit with future high energy linear accelerators.

### Technological limitations

The main limitation for high peak powers and pulse duration in klystron is electrical breakdown, which can occur at different locations in the tube.

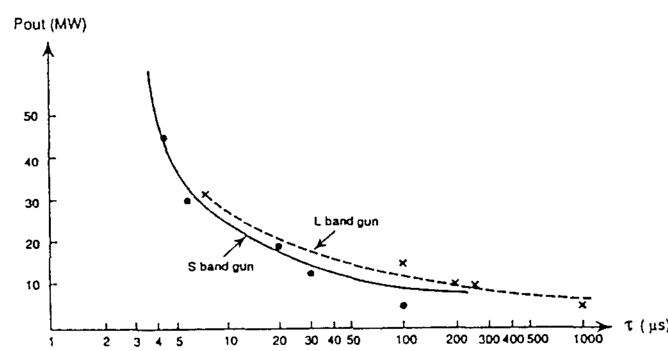


Fig. 1 Klystron gun breakdown limitations

- in the gun : arcing can appear along the insulators or between the electrodes. Behavior of the gun is strongly related to peak power (thus to the high voltage between the electrodes) and to pulse duration (Fig. 1)
- in the RF circuit : arcing can occur across the gap of the output cavity for very high peak powers or when a high VSWR of the load induces high electric fields in the cavity, and along the RF window ceramic, strongly depending on the quality of the brazing.

**Ugrading of klystron performances**

Moving the limitation of performance due to possible electrical breakdown in the tube has spinoffs on the design of all types of klystrons, from short pulse to CW operation. The subassemblies concerned by the improvement of the tube behavior are the electron gun (electrodes, cathode) and the RF output structure (output cavity, RF window).

*Improvement of the gun voltage standoff*

The first two parameters that can enhance gun performances are the optimization of the geometry of the electrodes and the lowering of their temperature. In the recently designed gun of the TH 2143 klystron (Table 2) for SSC, the calculated maximum electric field inside the gun is 8.8 kV/mm at 230 kV and the temperature of the focusing electrode has been brought down to around 300°C, whereas the cathode operates at 1000°C.

Improving cathode technology is another means to upgrade gun performances. Depleted cathodes minimize barium evaporation; osmium coating of the cathode or the use of different cathode materials such as scandate decrease the temperature necessary to extract the electrons. All these factors that improve the voltage standoff of the gun are implemented or under study at Thomson.

An extensive study of electrical breakdown in electron guns will also be done in the coming years, including the influence of electrode materials, surface and temperature, thermal and chemical treatments and cathode type and activation.

*Improvement of the RF output circuit*

Once the electron beam is obtained, the extraction of RF power may be limited by electrical breakdown appearing in the output structure of the klystron, either in the cavity or along the ceramic window.

There are several methods to improve single gap output cavity structures:

- with the constraint of keeping a high R/Q, design longer gaps and rounder noses, so as to reduce the electrical fields across the gap

- coat the noses with titane and reduce the electron interception, that triggers multipactor and arcing

- reduce the perturbations caused by reflected electrons due to a high VSWR of the load or to a incorrect optimization of the size of the collector

- keep a good symmetry of the output cavity : in Thomson S-band klystrons, drift-tube internal diameter is around 2 cm instead of 3, allowing for better coupling, higher efficiency and a smaller influence of the output iris as far as symmetry of the cavity is concerned.

Multigap output structures are another solution to reduce electric fields; Thomson keeps in touch with labs that work on such structures around the world and is ready to start with that technology if it becomes necessary.

When high peak or average power is under consideration, the RF output window becomes a critical part of the tube. Classical pill-box windows were developed for L and S-band klystrons, that can handle powers as high as 45 MW for 4.5 µs.
The choice of the material, the quality of the brazing and the coating of the window determine its performances and a continuous effort is done to improve this technology. For UHF klystrons, evanescent mode windows were designed; their diameter is smaller than the cross-section of the waveguide, which is mandatory when the dimensions of the waveguides become as big as 457 x 228.4 mm. Such a window is under development and has been designed to handle 2 MW CW.

**Performances expected from first stage of improvement**

Performances of existing klystrons are typically spread over the lower curve of Figure 2, which shows the peak RF power vs pulse length. The improvements implemented on the coming generation of high power long pulse klystrons aim to raise these performances up to the upper curve of the same figure. This change will address the requirements issued for the new generation of proton injector linacs and free electron lasers. The TH 2143 klystron is now under completion to enter in operation on the coupled cavity linear injector of the SSC in a few months. A similar breakthrough will occur in S-band with klystrons like the TH 2144 or TH 2151 able to provide from 20 to 40 MW of peak power in pulses in excess of 10 µs.

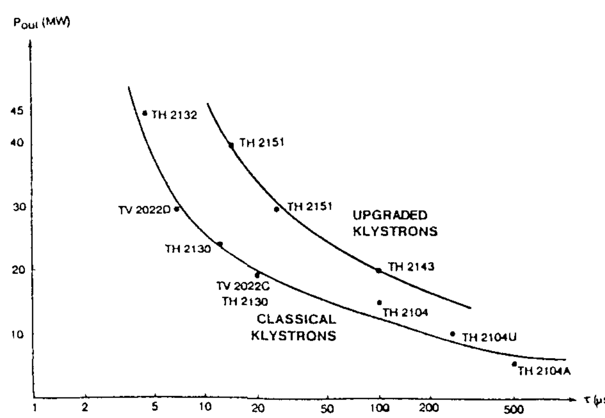


Fig. 2 Peak power vs pulse length diagram

**Solutions implemented to push back the technology limits**

- The double resonator pulse compressor (CIDR)

A way to get very high peak output power is the use of pulse compressors. These devices are passive structures that store energy for a few microseconds and release it for typically 0.5 to 1 μs. Thomson developped the CIDR [1] and last year 210 MW peak and 155 MW averaged over 0.8 ns were obtained at 3 GHz (Fig. 3).

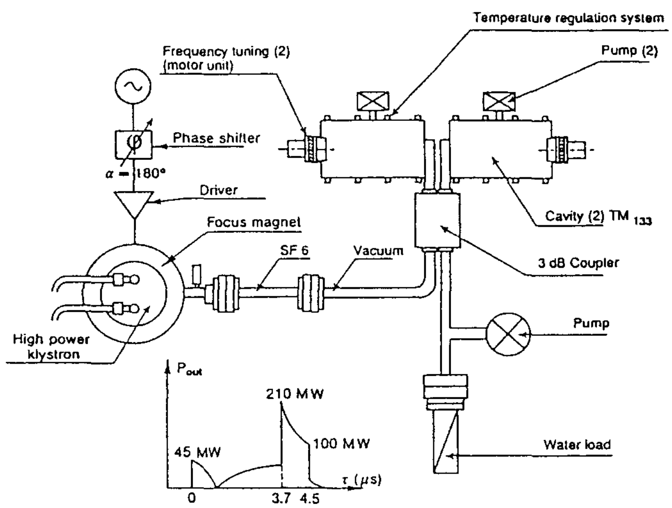


Fig. 3  CIDR layout and measured performances

- The Multi Beam Klystron (MBK)

The MBK is a klystron-like tube where several parallel beams share a common RF interaction structure (Fig. 4). This arrangement gives a high current, low voltage device, giving a significant size and weight reduction while maintaining high efficiency and gain and solving the arcing problem. 64 kW CW were demonstrated with a four beam device at 18kV [2].

Up to L-band, the MBK can use fundamental mode cavities; for higher frequencies the output structure should use higher modes and oversized cavities should be designed.

- Other RF sources are under study at Thomson and other laboratories. In the high current area the relativistic gate effect klystron (perveance of the order of 30 to 40 μperv.) is an exemple of such a device, which are still on the experimental stage [3].

## Conclusion

Present high power klystron technology has reached its maturity and fills almost all existing requirements for linear accelerators. More demanding requests are now expressed, which call for three operating domains:

- very high peak power in short pulses for projects of linear colliders under study

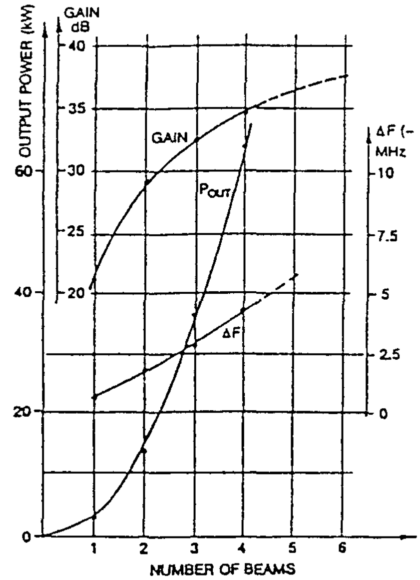


Fig 4  MBK experimental performances

- high peak and average power in long pulses for modern proton injector linacs, free electron lasers and radioactive transmutation facilities

- high CW power for storage rings and high current linacs.

The R&D program carried out aims to bring realistic solutions for RF sources necessary for the emerging generation of particle accelerators.

## References

[1] "Progress report on 3π/4 backward TW accelerating module for the Elettra 1.5 GeV electron injector", P. Girault et al, EPAC 92, Berlin march 1992.

[2] "Advantages of Multiple Beam Klystrons (MBK)", C. Béarzatto, M. Brès, G. Faillon, ITG 92, Garmisch Partenkirchen, may 4-5, 1992.

[3] "Gate effect klystrons", N. Gerbelot, M. Brès, G. Faillon, ITG 92, Garmisch Partenkirchen, may 4-5, 1992.