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High-Efficiency Klystron Design for the CLIC Project

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Abstract: *The CLIC project requests new type of RF sources for the high power conditioning of the accelerating cavities. We are working on the development of a new kind of high-efficiency klystron to fulfill this need. This work is performed under the Eucard-2 European program and involves theoretical and experimental study of a brand new klystron concept.*

Keywords: mono-beam klystron; high-efficiency; CLIC; kladistron.

Introduction

Cern's CLIC (Compact LInear Collider) is an international project of a 3 TeV lepton collider. More than 70 institutes from at least 30 countries are working on this 50 km-long collider. Its purpose is to study Terascale physics, especially Higgs boson, electroweak symmetry and dark matter. To perform such high-energy collision engineers and scientists proposed a 'two-beam acceleration' scheme. Instead of klystrons the main beam is accelerated by the RF power produced by a drive beam.

The main beam will be generated in a 120000 cavities-accelerating structure. These cavities need to be conditioned on XBOX3 test bench at CLIC Test Facility (CTF3) with high-power microwaves. This bench currently works with a 6 MW Toshiba klystron.

In order to fasten these tests and save electrical power [1] we propose to design a high-efficiency 12 MW klystron (or kladistron) with the help of Thales Electron Devices (TED). Preliminary design of this 1.5 $\mu A/V^{1.5}$ perveance klystron showed that an efficiency of 70% could be reached.

Kladistron principle

A kladistron is a high-efficiency mono-beam klystron with a large number of cavities (at least twice as many as in a classical klystron). Instead of giving a "large" kick to the beam in a small number of cavities, its interaction line gives a "soft" kick in a large number of cavities [2].

Like a conventional klystron, the beam is generated by an electron gun and confined by a magnetic field. The RF signal is sent to the input cavity; electrons are smoothly bunched by several intermediate cavities. The electron beam is softly shaped with low energy dispersion - an "adiabatic" phenomenon, hence the name kladistron (kl-adi(abatic)-stron) - to amplify the RF signal and drive it to the output cavity. The intermediate cavities are weakly coupled to the beam and the quality factor is low to limit peak gain and risks of self-oscillations.

Development scheme

In order to check to kladistron principle we first proposed to work on the improvement of an existing high frequency klystron. The 4.9 GHz – 50 kWCW TH2166 klystron was chosen. This tube was designed in the early 2000's for the Mainz Microtron Project.

As shown in figure 1, this 1 $\mu A/V^{1.5}$ perveance 6-cavities klystron reaches an efficiency of 50%. We first checked that our simulation codes' results are consistent; we simulated the TH2166 klystron with the Thales code Klys2D and the time domain code MAGIC2D (Figure 1). Both predicted efficiency and input power at saturation are pretty close to Thales test results.

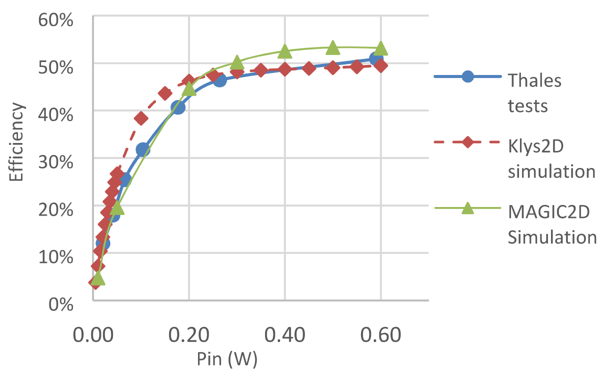

Figure 1. TH2166 efficiency as a function of the input power

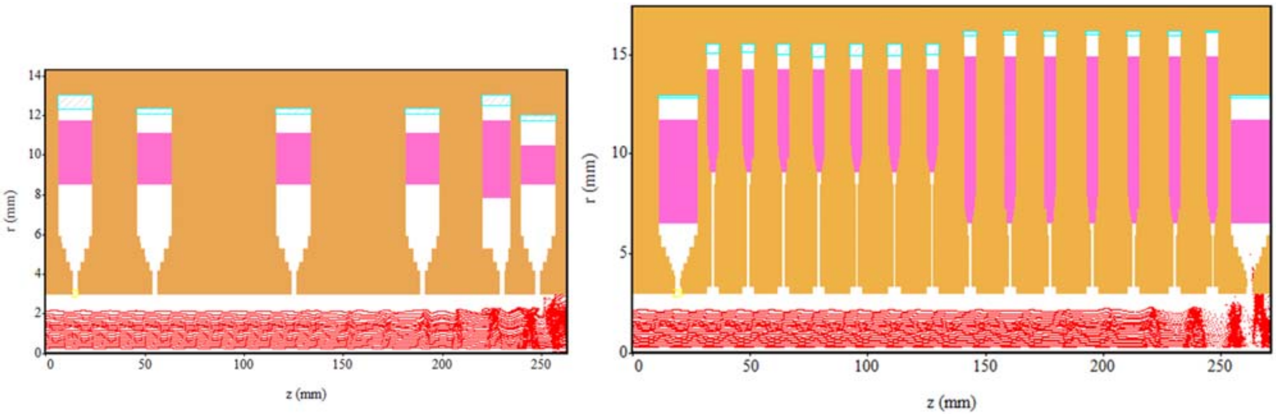

Figure 2. Electron beam in the TH2166 Klystron and in the TH2166 Kladistron - MAGIC2D simulation

In parallel, we ordered at TED a new set of electron gun, collector, solenoid, input and output cavities in order to build a higher efficiency version of the TH2166. Our main concern is then the design and production of a new 243mm-long interaction line involving 10 to 20 cavities. This TH2166 klystron improvement is called TH2166 Kladistron.

Simulations results

We used AJDisk (SLAC Code) [3] and Klys2D to decide the number of cavities and choose their electro-magnetic properties. These software are 1D and 2D simulation codes respectively. These programs simulate a steady-state klystron interaction line. The beam/cavity interaction can be characterized by a lumped circuit with parameters such as frequency f0, quality factor Q0 and R/Q. We chose these parameters to increase the efficiency, to avoid gain peaks and to keep the same interaction line length. We also simulated TH2166 electron gun with Optic2D (TED code) to be able to inject a realistic beam into Klys2D and MAGIC2D.

The detailed design of the cavity shapes was then performed using COMSOL. Two new kind of cavities was designed to fulfill this kladistron requirements (low R/Q and Q0). We chose to produce 14 intermediate cavities (7 of each kind) with drift spaces long enough to avoid cavities coupling. Indeed, we found out that the drift space between two adjacent cavities had to be greater than 9 mm.

MAGIC2D is an ATK PIC code; this finite-difference, time domain code is suitable for studying spurious oscillation phenomenon in klystrons. We modelled the axisymmetric geometry of the TH2166 Kladistron interaction line. The efficiency and stability was verified using first a laminar electrons beam with a homogeneous magnetic field. We then applied the measured TH2166 magnetic field values and injected the more realistic beam coming from the Optic2D code.

Our Kladistron simulation results (Tab.1 & Fig.2) are promising, with an increase of the efficiency of nearly 10 points and a better bunching process although the magnetic field seems too weak at the end of the line. However a lower kladistron efficiency was calculated with Klys2D compared to Magic2D.

Table 1. MAGIC2D results comparison of the standard TH2166 and the kladistron version

	Efficiency	Pin saturation	Gain
TH2166	50 %	0.2W	50 dB
TH2166 Kladistron	60 %	1W	48 dB

Conclusion

During the year 2015 we designed several klystron configurations. Our simulations showed that increasing the number of cavities leads to higher efficiency with good stability. Detailed engineering design and production of the intermediate cavities will start in spring 2016 and first tests are foreseen before the end of 2016.

Acknowledgements

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