

Status of the Exploration of an Alternative CLIC First Energy Stage Based on Klystrons

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Abstract

The Compact Linear Collider is based on a two-beam scheme to accelerate the main, colliding beams. This scheme allows very high centre-of-mass energies to be reached. At low collision energies the main beams could be accelerated by powering the X-band accelerating structures with klystrons instead of the two-beam scheme. We explore this option and indicate the parameters such a machine might have and present the outline of a design.

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The Compact Linear Collider is based on a two-beam scheme to accelerate the main, colliding beams. This scheme allows very high centre-of-mass energies to be reached. At low collision energies the main beams could be accelerated by powering the X-band accelerating structures with klystrons instead of the two-beam scheme. We explore this option and indicate the parameters such a machine might have and present the outline of a design.

INTRODUCTION

The beam is accelerated in the CLIC [1, 2] main linac by normal-conducting X-band accelerating structures. The necessary RF power to feed these structures is extracted from a drive beam, which runs in parallel to the main beam, by Power Extraction and Transfer Structures (PETS). However the RF power could also be produced by klystrons. In the past, this has indeed been proposed in the JLC-X and NLC [4] designs, which also used normal-conducting X-band accelerating structures fed by klystrons. Two clear advantages of a klystron-based design over a two-beam based design at low energy are that the technical development of full RF unit prototypes is nearly done and that they can be tested more easily. The production of the high-current drive beam for two-beam power generation is relatively costly but is the better option for a high-energy facility.

In this paper we first present the choice of accelerating structure design for the klystron-driven alternative and then discuss the detailed hardware layout.

STRUCTURE CHOICE

The CLIC design has been optimised for cost at the full collision energy of 3TeV [3]. This optimisation systematically considered constraints from the detectors, the beam dynamics and the performance of the main linac accelerating structures. It led to the choice of the main linac acceleration frequency and gradient as well as other accelerating structure parameters like the aperture and length.

We performed a similar study for the klystron-based design [5] using a simplified layout and cost model and only a limited number of accelerating structures that had been good candidates for the 500GeV design of CLIC. The cost model assumed the cost of an RF unit composed of two klystrons, their modulator and a pulse compressor to be equal to the cost of 4.6m of main linac.

Based on this study one can draw the following conclusions



Figure 1: XL5 klystron.

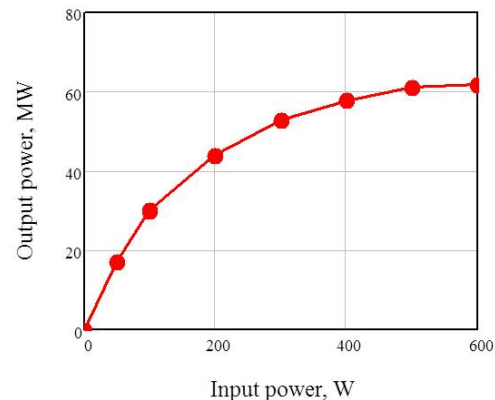


Figure 2: The amplification curve of the XL5 klystron measured at 411 kV at CERN.

- A number of different structures lead to comparable costs for a klystron-based CLIC linac. The luminosity is comparable to that of the drive-beam based design. The pulse length in all cases is the same as for the drive-beam design.
- A design based on CLIC_G, the current structure design for 3 TeV, would be on the lower end of the cost band. It would achieve the same luminosity as the drive-beam based first energy stage of CLIC in the staging scenario B, which uses the 3 TeV structure also for the first energy stage.
- At least half of the cost of the main linac is in the RF powering systems, which replace the drive beam.

Table 1: Parameters of the single accelerator unit.

General	
structures per unit	8
Unit length [m]	2.0
Energy gain per unit [MeV]	183
Klystron	
Pulse length [ns]	1950
Peak power [MW]	59
Voltage [kV]	460
Current [A]	234
Efficiency [%]	55
Dual moded SLED II pulse compressor	
One delay line length [m]	17.7
Output pulse length [ns]	244
Output power [MW]	490
Power gain	4.64
CLIC_G accelerating structure	
Structure length [m]	0.23
Input RF power [MW]	61.3
Gradient (loaded) [MV/m]	100

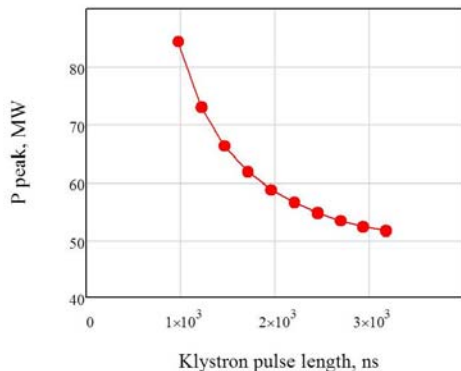


Figure 3: The single klystron peak RF power vs. klystron pulse length for the fixed output pulse length (244 ns) and peak RF power after SLED II pulse compressor (490 MW).

Based on these results we decided to use the CLIC_G structure for the first study of the klystron-based approach in order to identify potential issues and to estimate the cost in more detail. Using the outcome of the study a full optimisation of the structure choice and design can be performed.

RF-UNIT LAYOUT

The accelerator single unit layout is similar to the one originally proposed for NLC/GLC, where two klystrons powered by single modulator are followed by single SLED II pulse compressor and RF distribution network capable of delivering RF power to a few accelerating structures [6]. We have used a rather conservative upper limit on the peak RF power to be produced by a single klystron: 60 MW. The choice is based on the demonstrated performance of the 12 GHz XL5 klystron, see Fig. 1, that

Table 2: Linac parameters at 375 GeV.

Linac energy overhead	10%
Linac filling factor	≈ 0.75
Number of klystrons	4484
Number of structures	17936
Active length/single linac	2.242 km
Length/single linac:	3 km
bunches/pulse	312
particles/bunch	$3.72 \cdot 10^9$
repetition rate	50 Hz
Luminosity	$10^{34} \text{cm}^{-2} \text{s}^{-1}$

has been fabricated at SLAC and currently is in production in industry [7]. The measured output power is shown in Fig. 2. This limit is more relaxed than the 75 MW, which had been originally proposed for NLC. While this power has been demonstrated at SLAC and KEK [6], such tubes have never been commercialized. We scaled the existing SLED II pulse compressor parameters to match the CLIC_G accelerating structure pulse length and adopted the layout to feed 8 accelerating structure per unit; this corresponds to the length of one CLIC module in the drive-beam based scheme. Finally we selected a klystron pulse length of about $2 \mu\text{s}$, which allows to produce the required input power for the accelerating structures with the available peak power of the klystrons, see Fig. 3. In our calculations we also included 10% RF power losses in the rest of RF distribution system. The selected parameters of the single accelerator unit are summarised in Table 1.

Based on the experience in RF design gained worldwide during last decade, we reviewed the RF distribution system. The original one proposed for NCL/JLC [6] could not be directly applied due to the very compact (0.23 m) accelerating structures spacing. The solution utilizing TE01 line and special tap-off extractors, see Fig. 4, proposed in [8] fits best in our case. It will provide high peak RF power capability, low RF losses (0.4%) and high vacuum conductivity. The line length is $\approx 1.8\text{m}$. All tap-off extractors have practically the same design. Such a line can be easily adapted to any layout (number of accelerating structures). The complete accelerator unit layout is presented in Fig. 5.

The overall linac parameters are listed in table 2. The beam parameters are the same as in staging scenario B for CLIC. The already very large number of klystrons required at 375 GeV collision energy sets a practical limit to the klystron-based option.

CONCLUSION

One potential design of a klystron-based first energy stage of CLIC has been presented. The design uses the same accelerating structure as the 3 TeV stage of CLIC and achieves the same luminosity and power consumption as an equivalent drive-beam based first stage. The costs of klystron and drive beam machines are also equivalent around 350 GeV, however the latter clearly has a lower

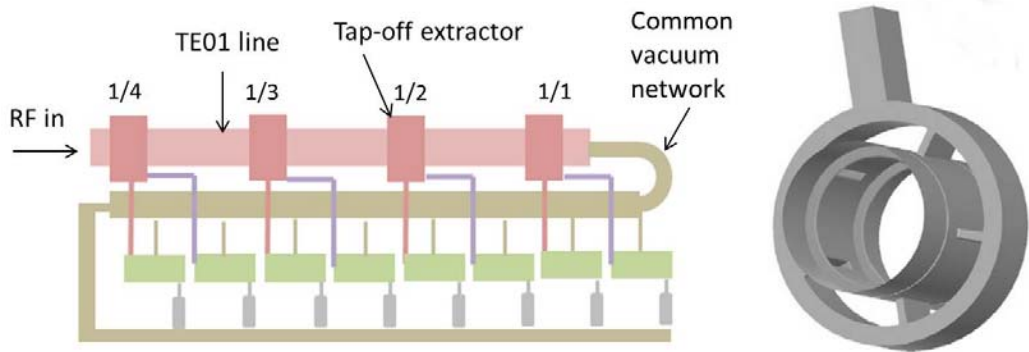


Figure 4: The concept of RF In-line distribution system (left) and general view of the special tap-off extractor (right).

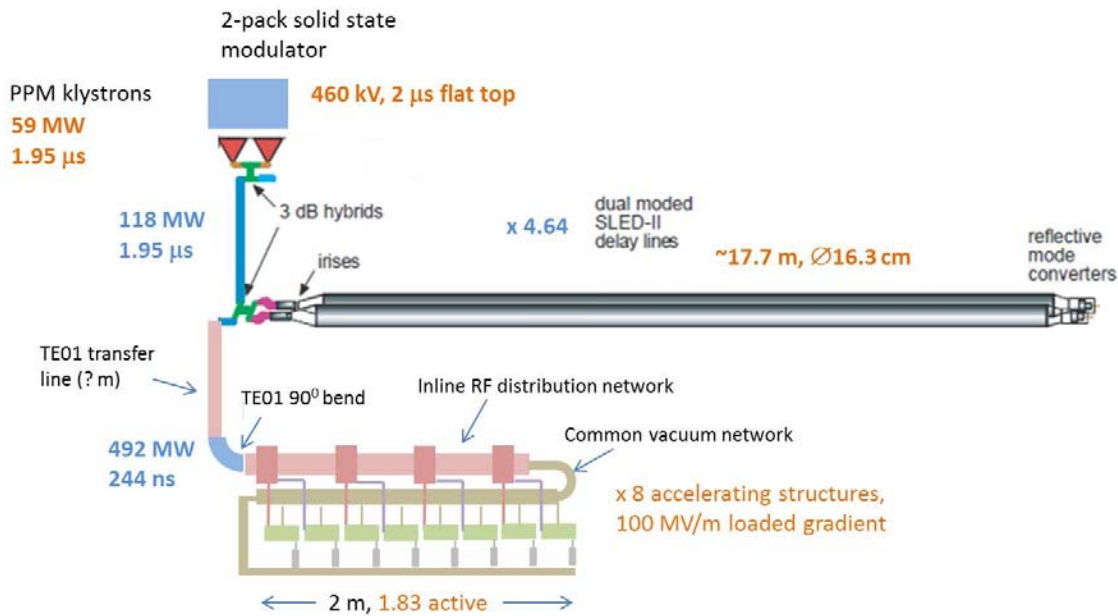


Figure 5: The single accelerator unit layout

cost per additional GeV. The equivalence at an initial energy stage leaves open the possibility of either pursuing a more technically mature first stage with the klystron based machine or a drive beam first stage which would result in a lower total project cost, if later stages are considered. A klystron-based first stage could be followed by a drive beam-based energy upgrade by increasing the linac length using the same accelerating structures but in the new part powered by klystrons. The beam parameters in the main beam generation complex and the main linac would remain the same except for the final energy.

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