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AVAILABILITY STUDIES COMPARING DRIVE BEAM AND KLYSTRON OPTIONS FOR THE COMPACT LINEAR COLLIDER

O. Rey Orozco, S. Doebert, M. Jonker, CERN, Geneva, Switzerland.

Abstract

The initial proposal for the Compact Linear Collider (CLIC) is based on a two beam-scheme to accelerate the main colliding beams. For low collision energies, the main beam could also be accelerated by powering the accelerating structures with klystrons instead of the two-beam scheme. This paper studies the feasibility of this new alternative in terms of machine availability. An implemented bottom-up availability model considers the components failure modes to estimate the overall availability of the system. The model is defined within a Common Input Format scheme and the AvailSim3 software package is used for availability simulations. This paper gives an overview of the systems affecting the beam powering availability and makes recommendations for availability improvements.

INTRODUCTION

CLIC, the study for a future linear accelerator project to collide electrons and positrons up to 3 TeV centre of mass collision energy, will provide unique opportunities for the exploration of the Standard Model and physics beyond the standard model [1].

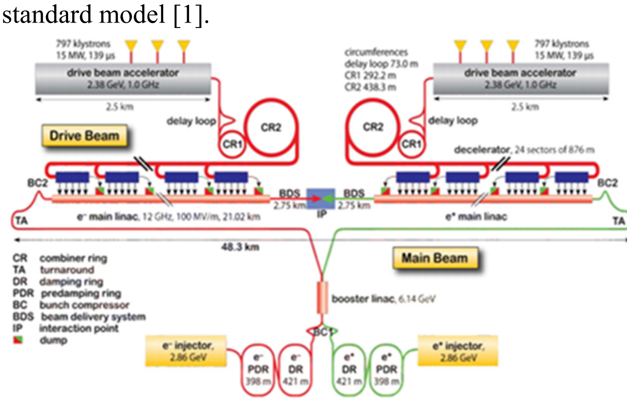

Figure 1. CLIC Layout at 3 TeV.

The layout of the CLIC accelerator complex is presented in Fig. 1. Particles are accelerated in two linear accelerators facing each other, such that the beams collide in the central physics detector.

CLIC is designed to be built-in stages of increasing energy: starting at 380 GeV, 1.5 TeV, with a final energy of 3 TeV. In order to reach the energy of 3 TeV in a realistic and cost efficient scenario, an accelerating gradient of at least 100 MV/m is needed, 20 time higher than the LHC. To this end, the novel two beam scheme has been proposed: a second beam, the Drive Beam, is decelerated in special Power Extraction and Transfer Structures (PETS) and the generated RF power is transferred to the Main Beam accelerating structures. However, for low collision energies, the RF power could be also produced by klystrons [2].

Several studies are on-going to demonstrate the feasibility of this klystron based design over a two-beam based approach. In this paper we study the viability of the two alternatives for RF powering generation in terms of machine availability.

It is important that the Klystron based design also includes the acceleration of the Main Beam, while the Drive Beam based design does not. In particular, the two beam modules, where the Drive Beam is decelerated and the Main Beam accelerated, are not included in the analysis of the Drive Beam based design. For this reason, the Two Beam modules should be included in the Drive Beam based powering system availability model to be able to compare the systems in terms of availability.

Availability is given as the fraction of the up time over the total time scheduled for operation.

RF POWERING SYSTEM DESIGNS

Drive Beam Based Design

The Drive Beam powering is based on an acceleration system with travelling wave structures, powered by klystrons [1]. A simplified layout of a full accelerating unit is shown in Fig. 2. The baseline design has 500 acceleration units per linac with 10% hot-standby RF powering system and Linac module units implemented for allowing failure tolerant operation. Klystrons and Modulators in this case are located on the surface with no access restrictions, failing units can be replaced without scheduling downtime.

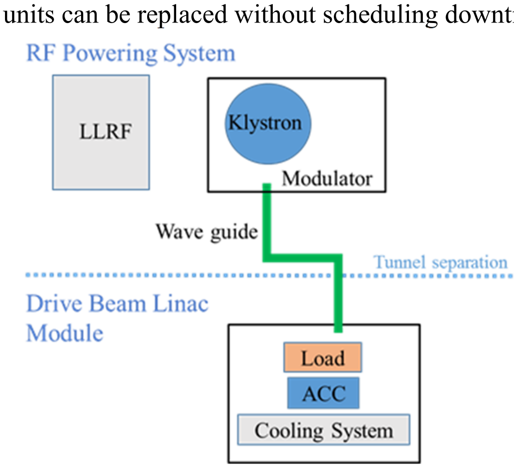

Figure 2. Simplified layout of the Drive Beam based powering design.

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Klystron Based Design

The klystron based accelerator unit layout is based on two klystrons powered by a single modulator and followed by an RF distribution network delivering power to 8 accelerating structures [2]. A simplified schema of the Klystron based powering unit is shown in Fig. 3. This alternative design has 1500 accelerating units per linac with 10% hot-standby RF powering system and RF module units implemented for allowing failure tolerant operation. Klystrons and Modulators in this case are located in the accelerator tunnel with no access during operation, failing units can be replaced on scheduled maintenance days only.

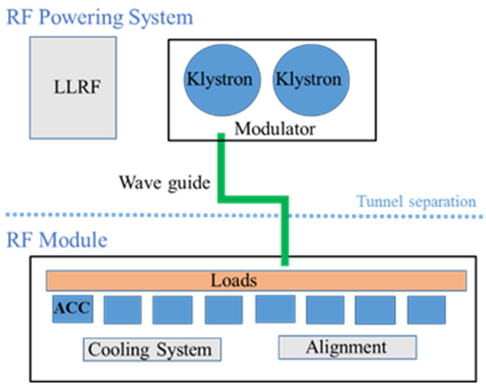

Figure 3. Simplified layout of the Klystron based powering design.

In both cases we assume that the hot-standby spares are installed and running, with a different timing so they don't affect the beam. When a failure occurs and a spare needs to be used, the trigger is switched to be in time with the beam. The hot-standby spares are strategically placed along the machine to ensure such a model.

AVAILABILITY MODELLING

Modelling Approach

The failure behaviour is modelled by the parallel and serial combinations of the components faults. To this end, each component or element in Fig. 2 and Fig. 3 is assigned a failure mode and a maintenance strategy. The main parameters used for availability predictions, are based on experts' estimates and operational experience. These are Mean Time to Fail (MTTF) and Mean Time to Repair (MTTR). The same failure modes are considered for the components in both designs, except for the Modulator in the klystron based design which has an additional failure mode.

Simulation Software Tool

AvailSim [3] availability simulation software has been adopted to study the failure behaviour of the Main Beam powering schemes. In this discrete event simulation program, events represent failure modes. Events affect system parameters that are used to represent the accelerator physical operational parameters. At the same time, events can trigger the activation of further events. This permits modelling system dependencies and corrective maintenance actions after a failure.

AvailSim was originally developed at SLAC in the framework of the ILC study [4] and the tool is now being extended in the framework of the ESS project in collaboration with CERN.

Table 1. Number of components in each design and parameters for simulation.

Component / failure	No. of components Drive Beam	No. of components Klystron	MTTF (h)	MTTR (h)
LLRF	500	1500	26300	3
Klystron	500	3000	50000	12
Modulator 1	500	1500	100000	1
Modulator 2 (*)			10000	1
Wave guides	500	1500	100000	3
Loads	500	24000	50000	3
Accelerating Structure	500	12000	8760	0.03
Alignment System (*)	0	1500	100000	3
Cooling System	500	1500	43800	6

(*)Failures present only in the Klystron based design.

Assumptions

The availability simulations are based on the following assumptions:

- The simulated operation time is one year.
- Components failure behaviour follow an exponential distribution.
- Failed components are repaired only when the system is down due to components failures.
- All repairs must be finished before restarting operation.
- Only the Accelerating Structures and Klystron based Modulator failures can be fixed remotely as they occur.
- The implemented 10% hot-standby spares are again available every time operation (re)starts

AVAILABILITY PREDICTIONS

Drive Beam Based Design

The baseline powering system can operate for around 1470 hours without seeing a system failure due to the implemented hot-standby spares. Overall, the Drive Beam based powering system is available 99% of the total operating time. Table 2 summarizes the system performance.

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Table 2. Drive Beam based powering availability predictions.

Availability	Times down	Downtime /year	MTTF (h)	MTTR(h)
99%	6	4 days	1470	15

In one year of operation, we expect to observe around 14 failures of the system followed by an average of 15 hours of downtime.

Analysis of the components failures and downtime contributors, as shown in Fig. 4, indicate that LLRF, Klystrons and Cooling System dominate the Drive Beam based powering system failure.

From the 50 hot-standby spares available, the RF powering modules spares are depleted after an average of 1320 hours of operation, whereas at this time there are in average 21 Drive Beam Linac spares modules left.

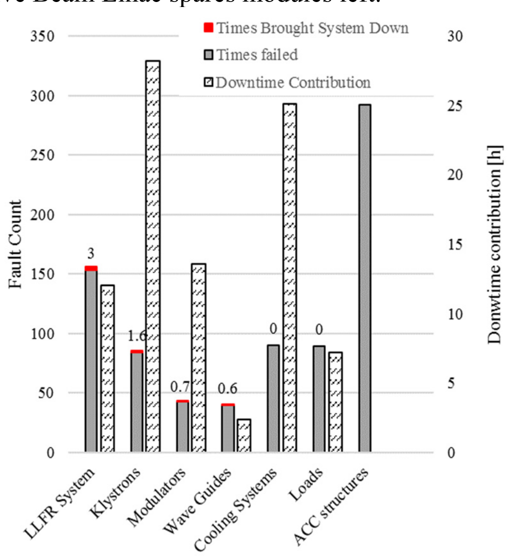

Figure 4. Components failure number and downtime contribution in one year of operation for the Drive Beam based powering.

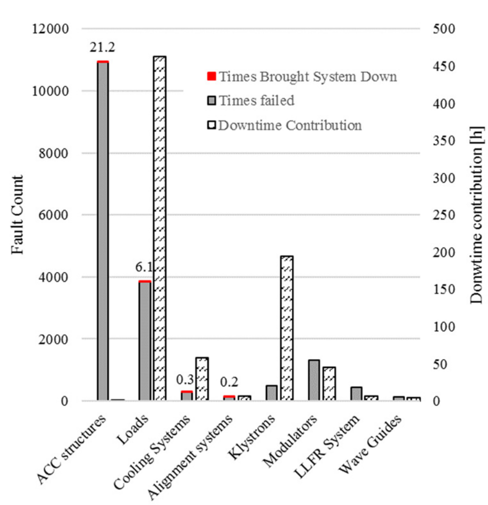

Figure 5. Components failure number and downtime contribution in one year of operation for the Klystron based powering.

Klystron Based Design

The alternative powering system can operate around 287 hours without seeing a system failure due to the implemented hot-standby spares. Overall, the Klystron based powering system is available the 91% of the total operating time. Table 3 summarizes the main figures of the system performance.

Analysis of component failure and downtime contributors, as shown in Fig. 5, indicate that Loads and Klystrons dominate the Klystron based powering system failure.

From the 150 hot-standby spares available, the RF modules spares are depleted after an average of 277 hours of operation, whereas at this time there are in average 107 RF powering spares modules left.

Table 3. Klystron Based Powering Availability Predictions

Availability	Times down	Downtime /year	MTTF (h)	MTTR(h)
91%	28	35.5	287	28

CONCLUSIONS

The main interest in carrying out availability predictions is to identify the components compromising more the system overall performance, eventually driving changes in components reliability requirements. Results may also be used to derive recommendations for spare management.

Regarding the baseline design, namely the Drive Beam design, the predictions show an overall optimum availability of 99%. In this case, the components with higher failure rates are governing the system availability.

Instead, for the klystron based design with an estimated availability of 91%, components, in higher number (loads and klystrons) are dominating the system availability. Relating this to the spares, one should consider increasing the number of RF modules spares while decreasing the number of RF powering modules.

For the results to be completely comparable, the Two Beam modules should be included in the Drive Beam based powering system availability model.

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