RF POWER GENERATION IN LINAC4

O. Brunner, N. Schwerg, E. Ciapala, CERN, Geneva, Switzerland

Abstract

Linac4 is a linear accelerator for negative Hydrogen ions (H^-) which will replace the old Linac2 as injector for the CERN accelerators. Its higher energy of 160 MeV will increase the beam intensity in the downstream machines. Linac4 is about 100 m long, normal-conducting, and will be housed in a tunnel around 12 m below ground. The Linac4 tunnel will be connected to the existing chain of accelerators and can be extended to the new injector chain.

The high RF power for the Linac4 accelerating structures will be generated by thirteen 1.3 MW-klystrons , previously used for the CERN LEP accelerator, and six new klystrons of 2.8 MW all operating at a frequency of 352.2 MHz. The integration of the RF power system into the building is presented and the technical specifications as well as the performance of the various high-power elements are discussed. The modifications required for the use of the LEP klystrons are emphasized. The power distribution system including the power splitting requirements are also described.

INTRODUCTION

CERN has recently built the Large Hadron Collider (LHC), a superconducting circular particle accelerator designed for colliding two beams of protons at an energy of 7 TeV. The LHC is housed in a tunnel of 27 km circumference, about 100 m underground. In order to improve LHC performance, CERN has launched a long-term program for the progressive replacement or upgrade of the old chain of accelerators presently used as injectors for the LHC. The Linac4 project is the first element of this program [1].

Linac4 is a linear accelerator for negative Hydrogen ions (H^-) which will replace the old Linac2 as linear injector for the CERN accelerators. Its higher energy of 160 MeV will give increased beam intensity in the downstream machines. Linac4 is about 100 m long, normal-conducting, and will be housed in a tunnel about 12 m below ground on the CERN Meyrin site. A surface building will house the Linac4 equipment. The Linac4 tunnel will be connected to the existing chain of accelerators and can be extended to the new injector chain [2].

The Linac4 accelerating system consists of a Radio-Frequency-Quadrupole (RFQ), a chopper line, Drift-Tube-Linacs (DTL), Cell-Coupled-Drift-Tube-Linacs (CCDTL) and Pi-Mode-Structures (PIMS), all operating at a frequency of 352.2 MHz [3]. The Linac4 scheme with transition energies and approximate length is shown in Fig. 1. Table 1 summarizes salient parameters of the RF system.

Table 1: Salient Parameters of the Linac4 RF System.

Parameter	Value	Unit
Operating frequency	352.2	MHz
Peak power	2 x 1.3 / 2.8	MW
Repetition rate	2	Hz
Pulse length	1.6	ms
Average power	10	kW
Waveguide	WR2300	–

The high-power RF system is subjected to the following constrains: optimum re-use of the existing equipment of the Large Positron Electron Collider (LEP), space limitation between the cavity windows at high beam energies and stringent phase and amplitude requirements for the (H^-)-beam. The phase has to be controlled with an accuracy of $\pm 0.5^o$ and the amplitude by $\pm 5\%$ statically and $\pm 0.5\%$ dynamically [4].

POWER DISTRIBUTION

In phase 1 of the Linac4 operation most of the accelerating structures will be powered by LEP klystrons, nevertheless, for the DTLs and the last 4 PIMS modules, new 2.8 MW klystrons have to be used. In the first case, the maximum power per RF window of about 1 MW requires feeding the structure through two windows with the inherent strong constrains on the RF phase. In the latter case, the distance between two adjacent PIMS does not leave enough space for the installation of two klystrons.

We distinguish 3 different powering schemes: 1) single klystron powering a single structure, 2) pairs of LEP klystrons powering one structure each, and 3) a new 2.8 MW klystron powering two structures (or one DTL through two apertures). Over the course of operation, scheme 2) will be replaced by scheme 3), compare Fig. 1.

While the layouts 1) and 2) consist of the usual amplifier, isolator (circulator and RF-load) and waveguide system, the design of layout 3) is more challenging. As shown in Fig. 2, the RF power is split directly at the amplifier's output by means of a custom made magic-tee and then fed to two circulators. The sum port of the magic-tee is matched with a high power RF-load. The two circulators connect to the accelerating structures and to an RF-load, each.

The phase and amplitude in the two paths (labeled A and B in Fig. 2) depends on the symmetry of the magic-tee, the working point of the circulators and the lengths of the waveguide system. The waveguide system is designed such to reduce static differences to a minimum. The residual error and dynamic effects, e.g. thermal drift, can be compen-

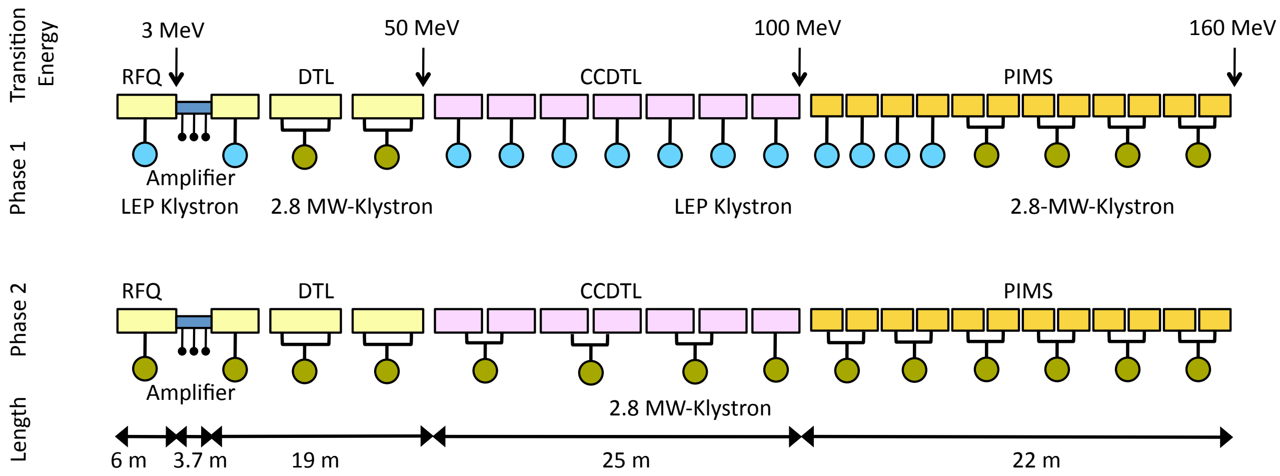

Figure 1: Linac4 accelerating structures and RF power system with approximate length and transition energies: Phase 1 with thirteen 1.3 MW klystrons (reused from LEP) and six new 2.8 MW klystrons. Over the years of operation pairs of LEP klystrons will be replaced by new 2.8 MW klystrons. In phase 2 the machine runs only with new klystrons.

sated by a phase-shifter in one of the two branches. The overall RF signal is controlled by the LLRF system [5].

All powering schemes are analyzed based on measured or specified S-parameters of the different components allowing to predict phase and amplitude differences. The power splitting between the two cavities (A and B) as well as the amount of power disposed in the load (C) is studied by means of Mason's rule [6] implemented in [7]. This allows to investigate the phase and amplitude difference between the different branches depending on the circulator working point as well as production tolerances of the magic-tee. The proposed solution for the power splitting will be validated in spring next year at the dedicated Linac4 test stand.

COMPONENTS

The high RF power for the Linac4 accelerating structures will be generated by thirteen LEP klystrons of 1.3 MW and six new 2.8 MW klystrons (Phase 1), see Fig. 1. Over the years of operation, pairs of LEP klystrons will be replaced by 2.8 MW klystrons (finalized in Phase 2). Fourteen, 5 MVA (peak), 1.8 ms / 2 Hz modulators will power either one 2.8 MW or two 1.3 MW klystrons.

The associated circulators and the magic-tees will be equipped with ferrite RF loads. The slow controls and interlock electronics are an evolution of the system developed for the LHC [8].

LEP Klystrons

Seventeen 1.3 MW klystrons from three different manufacturers were recuperated from LEP. Two major modifications of these klystrons are necessary to cope with the operational mode of Linac4:

1. In order to optimize the HV cabling, and therefore to minimize the stored energy, the original HV tank of the klystron must be replaced. The new design integrates the klystron filament heating transformer, the mode anode voltage divider as well as measurement test points. Only one high voltage cable ($\approx$ 4 m) is necessary to connect the klystron to the modulator. The modulating anode voltage divider will be individually adjusted as a function of the klystrons perveance and performance. The final Linac4 modulator will be equipped with a specially developed system which will allow trimming of the klystron cathode current over a large range [9].

2. The LEP klystrons were originally designed for CW operation and tuned for high efficiency ($> 65\%$). As a consequence the tubes are fairly unstable below saturation. This phenomenon is due to backscattered electrons and is a common feature of high efficiency klystrons.

   In opposition to the LEP machine, the Linac4 machine requires a very good stability of the RF output signal over the range of 0.7- 1.0 of maximum saturation power . In principle this should be achievable by properly retuning the klystron cavities. The associated impact on the klystrons performances, the efficiency loss in particular, will be crucial. Retuned klystrons are expected to achieve at least 1.1 MW at nominal D.C. power. Preliminary retuning tests carried on an EEV klystron are encouraging: 1.1 MW peak output power (104 kV, 22 A), group delay ≤ 250 ns at 1.5 dB below the saturated output power, stable under all operating conditions.

After modifications, each klystron will undergo a series of tests prior to installation in the Linac4 machine. These tests consist in measuring and verifying all klystron parameters

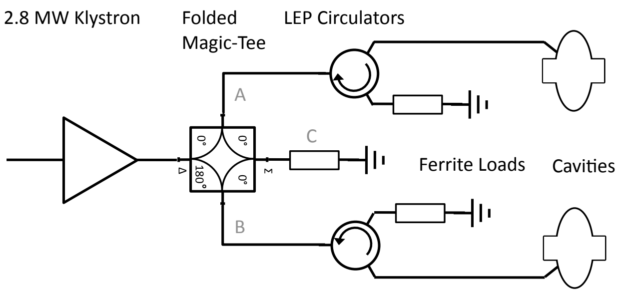

Figure 2: Powering scheme 3) consisting of one 2.8 MW klystron powering 2 structures (or one DTL through two apertures) via 2 LEP circulators. The reflected signal is deposited in three RF-loads.

and also in long reliability runs.

New 2.8 MW Klystrons

Six power stations must be equipped with more powerful RF amplifiers. For this purpose, six (+ two) new 352 MHz 2.8 MW klystrons have been ordered. As for the modified LEP klystrons, stability along the saturation curve and short ($\leq 250\,\mathrm{ns}$) group delay are amongst the main constraints imposed by the fast RF feedback requirements.

Waveguides

The waveguide components used for Linac4 are of the EIA standard type WR 2300 (non-pressurized). For the surface installation (klystron hall) full-height (two-to-one aspect ratio) and for the down link and the installation in the tunnel half-height waveguides are used (compare [10]).

Circulators

More than twenty 1.3 MW circulators could be recuperated from LEP and are being refurbished. Due to the limited space in the klystron hall it was decided to mount pairs of circulators onto one support structure (see Fig. 3). Each circulator is equipped with sensors for the permanent magnet and the cooling water temperature. These values serve as input for the temperature compensation unit implemented in a PLC: The thermal drift can be compensated for by adjusting the current of the compensation coil. In a later stage, the forward and reflected power shall be used to reduce the reflection on the input and output ports of the circulator.

Folded Magic-Tees

In addition to a good balance between the two output ports, the magic-tee is also subjected to specific mechanical constrains. The overall length has to be limited to 1.4 m and the centers of the two E-bent output ports has to match the distance of the two circulators, i.e. 0.8 m, see Fig. 3.

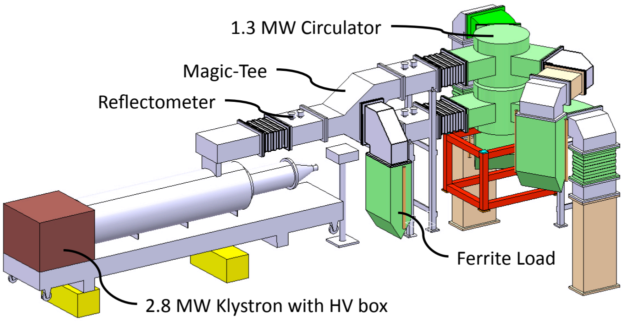

Figure 3: Artistic view of the powering scheme 3 (Courtesy of R. Ricol).

OUTLOOK

The high RF power generation and distribution scheme will be tested at CERN next year. The tests consist of the verification of the performance of the recuperated LEP equipment, e.g. klystrons and circulators, and will extend to test of the fully implemented power splitting scheme. Should the power splitting yield unsatisfying or unforeseen results, it will be possible to resort to 2.8 MW circulators and standard magic-tees.

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