PRACTICAL TEST OF THE LINAC4 RF POWER SYSTEM

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Abstract

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 power distribution scheme features a folded magic tee feeding the power from one 2.8 MW klystron to two LEP circulators. We present first results from the Linac4 test place, validating the approach and the used components as well as reporting on the klystron re-tuning activities.

INTRODUCTION

Linac4 is a linear accelerator for negative hydrogen ions 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. The normal-conducting accelerating structures are housed in a 100 m long tunnel which will be connected to the existing chain of accelerators and can be extended into a new high-energy linac if required by the CERN programs [1]. The high pulsed RF power for the Linac4 accelerating structures will be generated by thirteen upgraded 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 output power of the 2.8 MW klystrons is split allowing to either feed one DTL tank, or to feed two PIMS modules in parallel.

The re-use of existing LEP equipment, space limitations in the installation and tight phase and amplitude constraints pose a number of challenges for the integration of the RF power system [2], e.g., klystron instabilities and the control of the power splitting.

TEST-PLACE

The Linac4 test-place is equipped with a power distribution system similar to the machine installation allowing gaining experience with power splitting, testing and adjusting klystrons, and checking components delivered from industry under high power. The layout is shown in Figure 1. The magic tee in the centre can be replaced by a waveguide bend, then connecting only to one of the two branches or directly to a dry ferrite waveguide load. The two circulators are both connected to a motorized moveable waveguide short. Forward and reflected RF signals are measured by means of waveguide directional couplers at 5 different locations and fed to power meters in the control room. The power meter signals are analysed and stored in a LabVIEW application. The circulators feature a field correction coil in order to adjust the reflection. Building on experience from LEP operation, the LEP klystrons are kept in a lead garage for radiation protection reasons.

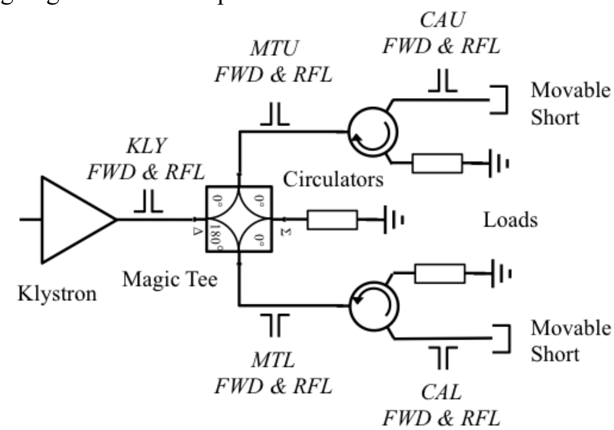

Figure 1: Test-place configuration.

The calibration of the klystron RF output power has been crosschecked with thermal measurements, giving an accuracy of 15-20%. Different waveguide directional couplers were mounted in series and adjusted to the calibrated reference signal.

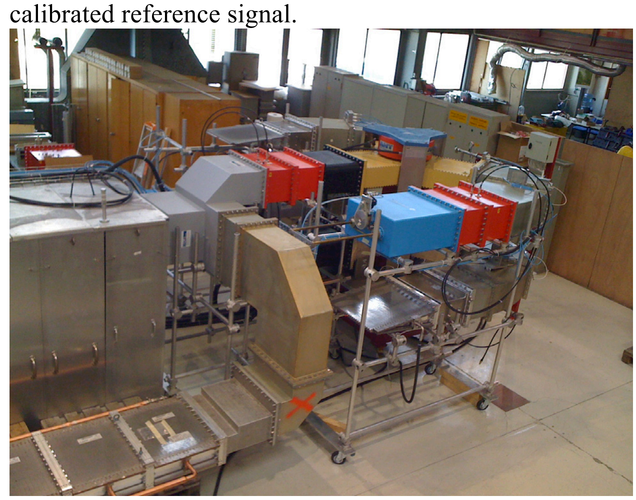

Figure 2: Linac4 test-place featuring power splitting by means of a folded magic tee (grey), two LEP circulators, two movable shorts (blue) and directional couplers for power measurements (red). The third port of the magic tee is equipped with an LHC load (bottom left).

LEP KLYSTRON UPGRADE

The Linac4 specifications require pulsed operation (1.4 ms pulse length, 2 Hz repetition rate) with a peak power per cavity of about 1 MW, depending on the RF cavity type (CCDTL, DTL, PIMS). Taking into account the margin for the low level RF (LLRF) and the losses in

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the power distribution system, each klystron shall provide a peak power of 1.3 MW or more.

The first part of the pulse is used for the high voltage modulator and the LLRF to close their control loops; during the beam passage, the klystron power in the cavity will jump to compensate for the beam loading. This mode of operation requires a very good stability of the RF output signal over the range 0.7 – 1.0 of maximum saturation power (Figure 3). The LEP klystrons, however, were originally designed for CW operation and tuned for high efficiency (> 65%). As a consequence the tubes are known to be prone to spurious instabilities caused by back-streaming electrons [3]. The presence of these electrons travelling backwards in the drift tube can lead to an oscillation mechanism. In the case of instabilities the pulse envelope shows indentations and/or the spectrum features side lobes (Figure 4).

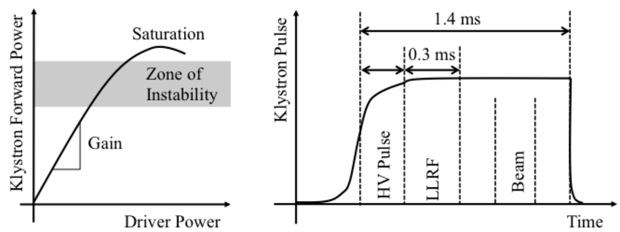

Figure 3: Klystron saturation curve & pulse envelope.

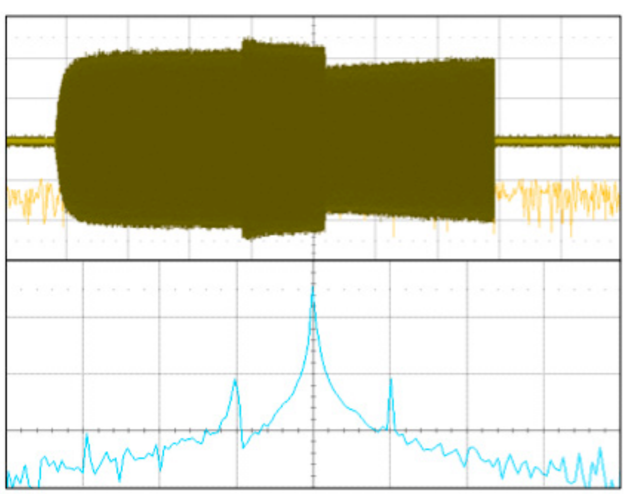

Figure 4: Top: Pulse with instability (100 µs per div). Bottom: Spectrum with side lobes (center 352.2 MHz, span 22.8 MHz and 14.4 dB per div).

This oscillation mechanism is a klystron design characteristics. Although there is no magic recipe to suppress it on an existing klystron (e.g., replacing the collector of the LEP klystron by a larger diameter collector is indeed not an option), a number of parameters susceptible to influence the output power stability have been investigated: the gain, the efficiency, the focus current, the cathode voltage, the input drive power and the reflected power in modulus and phase (Figure 5). Notice that the reflected power can be varied by means of the circulator current and the short position.

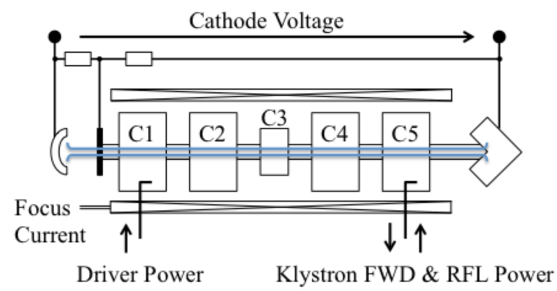

Figure 5: Klystron model.

For the following studies the klystron was connected only to the lower branch of the setup shown in Figure 1. The parametric study consists of a change of the short position (steps of 5 cm), minimizing the reflection seen by the klystron by means of the circulator current, and searching for the highest stable power level by slowly increasing the drive power. In this setup the SWR seen by the klystron varies between 1.01 and 1.16 with the highest values at 0 and 60 cm which is approximately 0.5 wavelengths apart. The circulator current is varied between -1 and -4 A.

Re-tuning the Bunching Cavities

In order to reduce the impact of the returning electrons, the second bunching cavity, C2, was re-tuned to reduce the gain between that cavity and the output cavity. Although modification of the overall klystron gain was observed, as expected, RF output power oscillations could not be reduced nor suppressed.

Influence of the klystron efficiency on the instabilities was also addressed by re-tuning the third cavity C3 to higher frequencies. Reducing the efficiency down to about 50 % unfortunately did not help in reducing the oscillations.

The oscillation mechanism nevertheless strongly depends on the impedance seen by the klystron (i.e.: short circuit position and circulator current). Under well-defined conditions the klystron remains stable over the complete saturation curve. This will have to be studied in more details to assess whether the stability domain copes with the Linac4 requirements

Increasing the DC Power

At a cathode voltage of 100 kV (20 A, nominal conditions) the zone of instability expands from 850 kW to saturation. It was observed that the instability threshold moves upwards with increasing klystron DC power: at 108 kV (23 A), the klystron remains stable up to 1 MW. Under these conditions the klystron peak RF power reached 1.48 MW at saturation. Although its efficiency is somewhat lower, its gain remains constant and its behaviour in the zone of instability does not seem to be affected by the higher power levels. Similar observations were made when operating the klystron straight on a ferrite load of maximum -28 dB reflection.

At higher DC power levels, the efficiency drops down very rapidly.

POWER SPLITTING

In the configuration shown in Figure 1 the power splitting between the two branches, MTU and MTL, is influenced by the behaviour of the two circulators and the positions of the motorized sliding short circuits at their output ports. For every short circuit position the input reflection of each of the two branches is minimized by adjusting the circulator current.

For the following typical measurements the lower movable short circuit is kept at the position of highest reflection (0 cm). The klystron is run at saturation level (1.42 MW) above the instability region. The upper short is moved over a distance of 50 cm.

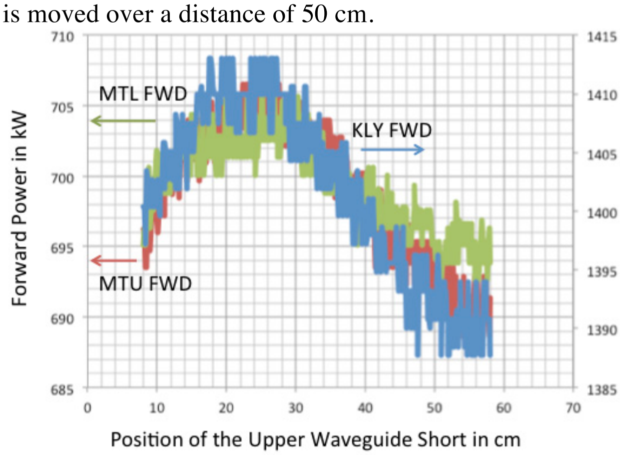

Figure 6: Forward power.

Figure 6 shows the 3 forward power signals measured during the sweep. The klystron forward power varies by less than 1% depending on the short position indicating good isolation of the power source and the cavity installation. The two branch forward signals are balanced within less than 1%.

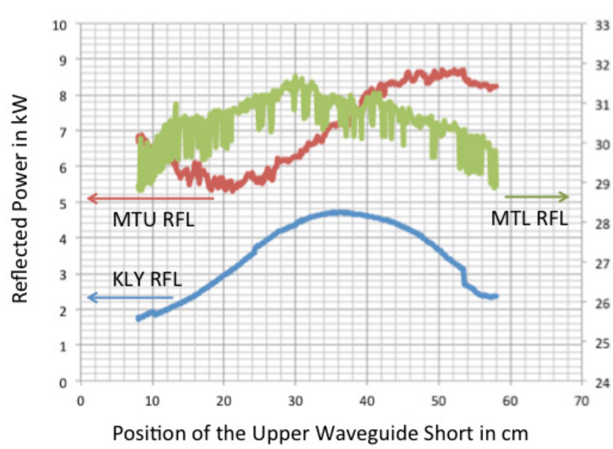

Figure 7: Reflected power.

Figure 7 shows the reflected or backwards traveling power. The reflection in the lower installation (MTL RFL) is an order of magnitude greater than the reflection to the klystron and from the other branch, which can be attributed to the good isolation by the magic tee.

CONCLUSIONS

The CW LEP klystrons were successfully operated in pulsed mode with a DC power 25% above the design value giving a peak power of 1.45 MW. Above 1 MW output power the system develops instabilities that could not be cured by re-tuning the bunching cavities. The relatively narrow domain over which the klystron remains stable along the saturation curve will have to be studied in order to assess whether a LEP klystron can be operated above 1 MW.

First tests of the high power RF distribution system for Linac4 accelerating structures have been performed. The power splitting scheme consisting of a folded magic tee and two LEP circulators could be validated. The isolation of the two branches is successful within the measurement accuracy. Fine adjustments will be made with phase-shifters during machine commissioning.

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