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THE LINAC4 POWER COUPLER

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Abstract

Linac4 is employing three types of accelerating structures after the RFQ: a Drift Tube Linac (DTL), a Cell-Coupled DTL (CCDTL), and a Pi-Mode Structure (PIMS) to accelerate the beam up to 160 MeV at 352.2MHz. The structures are designed for a peak power of approximately 1 MW per power coupler, which is transported via rectangular waveguides from the klystron gallery to the RF cavities. The coupler itself consists of two parts: a ceramic window, which separates the cavity vacuum from the air in the waveguides, and a Tuner-adjustablewaveguide Coupler (TaCo), which couples the RF power through an iris to the cavity. In the frame of the Linac4 R&D both devices have been significantly improvedwith respect to their commonly used design. On the coupler side, the waveguide short circuit with its matched length has been replaced by a fixedlength _/4 short circuit. The RF matching is done by a simple piston tuner, which allows a quick matching to different cavity quality factors. In the window part, which usually consists of a ceramic disc and 2 pieces of waveguides with matching elements, the waveguide sections could be completely suppressed, so that the window became very compact, lightweight, and much simpler to manufacture. In this paper we present electromagnetic simulations, and tests on first prototypes, which were constructed at CERN.

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Abstract

Linac4 is employing three types of accelerating structures after the RFQ: a Drift Tube Linac (DTL), a Cell-Coupled DTL (CCDTL), and a Pi-Mode Structure (PIMS) to accelerate the beam up to 160 MeV at 352.2 MHz. The structures are designed for a peak power of approximately 1 MW per power coupler, which is transported via rectangular waveguides from the klystron gallery to the RF cavities. The coupler itself consists of two parts: a ceramic window, which separates the cavity vacuum from the air in the waveguides, and a Tuner-adjustable waveguide Coupler (TaCo), which couples the RF power through an iris to the cavity. In the frame of the Linac4 R&D both devices have been significantly improved with respect to their commonly used design. On the coupler side, the waveguide short circuit with its matched length has been replaced by a fixed-length $\lambda/4$ short circuit. The RF matching is done by a simple piston tuner, which allows a quick matching to different cavity quality factors. In the window part, which usually consists of a ceramic disc and 2 pieces of waveguides with matching elements, the waveguide sections could be completely suppressed, so that the window became very compact, lightweight, and much simpler to manufacture. In this paper we present electromagnetic simulations, and tests on first prototypes, which were constructed at CERN.

INTRODUCTION

$\lambda/4$ waveguide couplers, made of a tangential waveguide coupled to the cavity via an iris and closed with a short circuit at $\lambda/4$ from the coupling iris, are commonly used in electron linac standing-wave cavities at frequencies (> 1 GHz). The cavity is usually overcoupled via the iris, and the coupling is then matched to the required value by adjusting the short-circuit position thereby reducing the voltage on the iris. This coupler type has the advantage of separating the coupling section from the RF window, allowing to use a standard waveguide window, and of presenting lower surface fields than a standard coaxial coupler. For this reason this technique has been adopted for all the Linac4 cavities. However, the drawbacks are: i) at the relatively low Linac4 frequency (352 MHz) the couplers are bulky, and ii) that the length of the copper plated waveguide short has to be adapted for each cavity separately. Such a design was used for the first high-power tests of the PIMS cavity [1] and due to the long and expensive matching process, the simpler TaCo design was developed.

In the second part of the paper we describe the design features of a waveguide window, which is optimised for the use at 352.2 MHz. Commercial windows are usually built either with a large bandwidth or in a way that allows a simple re-matching (to different frequencies) of the waveguide to window transition via waveguide stubs or tuning blocks. The tuning mechanisms need a certain length of waveguide on either side of the actual window, which can be omitted if the window to waveguide transition is already matched for the frequency of the RF system. The result is a very compact and cost effective design, which was developed for the Linac4 cavities at CERN.

DESIGN OF THE LINAC4 TACO

Instead of using a $\lambda/4$ coupler made of 2 pieces TaCo uses a piston tuner close to the cavity iris to adjust the coupling to the cavity. (Details and comparison to other coupler types in [2]). Major advantages are the fixed location of the short circuiting plates (c.f. Fig. 1) for all couplers, which saves 2 waveguides flanges, a HELICOFLEX® gasket and the time required for measuring and machining the appropriate short for each cavity individually. The cavity-to-waveguide coupling can be adjusted by cutting a fixed tuner to the necessary length, or – with a movable tuner installed – the coupling can even be varied during operation.

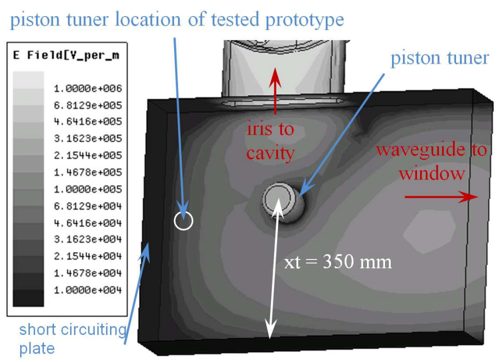

Figure 1: Linac4 TaCo: the max. el. surface field strength for 1 MW of input power. By adjusting the penetration of the piston tuner, the coupling to the cavity can be matched.

The RF matching of the external Q-value Q_{ext} is necessary for most standing-wave cavities since the construction process influences the final Q-value Q_0 of the cavity. To achieve a certain coupling β_d, $Q_{ext,d} = Q_0/\beta_d$ needs to compensate the unpredictable variation of Q_0 (typically about 5%). For this reason, standing-wave cavities are normally over-coupled by design ($Q_{ext,design} < Q_{ext,d}$). The coupler is then used to adjust Q_{ext} to $Q_{ext,d}$ by increasing $Q_{ext,design}$. If the piston tuner is positioned close to the cavity iris, TaCo cannot only increase but also decrease

Q_{ext} to reach $Q_{ext,design}$. Thus an adjustment in both directions becomes possible. Figure 2 shows the normalised coupling factor $\beta_n = \beta/\beta_0$ versus the tuner penetration for two different tuner locations.

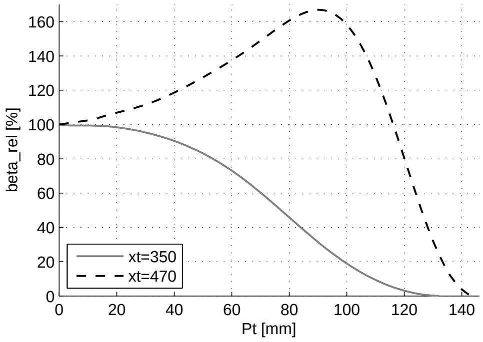

Figure 2: Coupling factor – norm. to the coupling w/o piston tuner – versus tuner penetration Pt for the nom. position ($xt = 350$) and one closer to the cavity ($xt = 470$).

For most Linac4 cavities (CCDTL and PIMS), the tuner will be positioned close to the centre of the waveguide (at $xt = 350$ mm, see Fig. 1), allowing a decrease of the coupling. However, for the five DTL couplers, the iris to the cavity is very short. Here, a coupler with a tuner distance of $xt \geq 470$ mm will be tested. Calculations predict a potential increase of the coupling factor by more than 60% which would allow the iris to be elongated by 25 mm to the same length used for the other couplers, which would ease the installation and connection of the DTL couplers.

PROTOTYPE TACO

The TaCo concept has been successfully tested at low- and high-power conditions. For these tests, a spare waveguide short circuit was equipped with a movable piston tuner (Fig. 3). This short circuit was then connected to a standard T-type coupler, used for the PIMS high-power tests [1]. Since this was not the nominal position of the tuner (see Fig. 1) it allowed to validate the peak field performance and potential for sparking or multipactor activities. Diameter, position and penetration of the piston tuner used for this test were such that the peak fields exceeded the ones of the nominal design by more than a factor of 4.

Figure 3: Prototype TaCo used for high-power tests

The low-power measurements agree very well with the simulations (compare [2]). For a first high-power test, the prototype TaCo was installed together with the first Linac4 PIMS cavity. The cavity could easily be matched to a reflection of less than -30 dB (VSWR=1.065). During the test with up to 1.1 MW in pulsed operation (0.8 ms pulse length, 2 Hz repetition rate) over 72 hours, the cavity-to-waveguide coupling remained constant and no sparking or multipactor activities were observed. This was confirmed by visual inspection of the short circuit after the tests.

WINDOW DESIGN

One of the critical items of a power coupler is the ceramic window and the coupler robustness mainly depends on its design. Because we have a long experience at CERN with single window couplers [3], we have decided to design the Linac4 window with a single ceramic.

To reduce cost, the number of components has been minimized. The design has been done such that the use of additional waveguide lines to match the ceramic is unnecessary. To do so, the matching of the window has been obtained by adjusting the diameter and thickness of the planar disk ceramic, which is inserted between two cylindrical to rectangular WR2300 half height waveguide flanges.

A fine matching of the window is obtained by optimizing the radius of the cylindrical steps on either side of the ceramic (see FM in Fig. 6). Several combinations of diameter and thickness values were found, which allow matching within the required specifications. Brazing constraints have imposed limits on the ceramic window size. Simulations with the chosen 400 mm diameter and 25 mm thickness ceramic window design can be seen in Fig. 4. This shows S_{11} curves corresponding to several matching step sizes, each varying by 2 mm. The calculated overall bandwidth is greater than 16 MHz with a S_{11} value better than -32 dB (i.e. better than 1.05 VSWR).

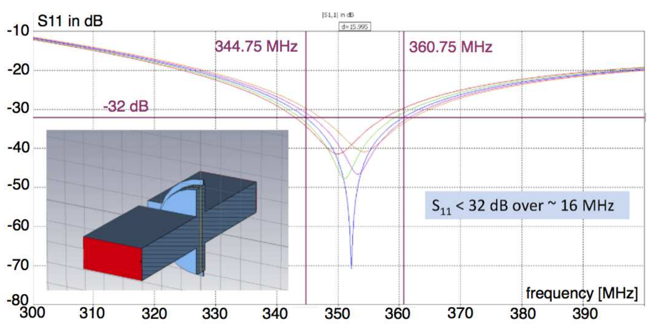

Figure 4: Microwave Studio simulation of the window showing input reflection loss vs freq.

As shown on Fig. 5 and 6, the window is composed of just eight components (c.f. Fig. 5 and 6):

1. a planar disk ceramic of 400 mm diameter and 25 mm thickness,
2. a thin copper ring of 1.25 mm thickness,
3. a second copper ring,
4. a stainless steel ring (316 LN),
5. a stainless steel spacer (304),
6. a HELICOFLEX® gasket,
7. a vacuum side, waveguide to cylindrical, stainless steel flange (316 LN), and
8. an air side, waveguide to cylindrical, stainless steel flange (304).

The construction process is as follows. The ceramic (1) and the first thin copper ring (2) are brazed together, while the second copper ring (3) is brazed with the stainless steel ring (4). These two subassemblies are electron-beam (EB) welded along the two common copper edges, EB1 and EB2 in Fig. 6. These two EB weldings ensure mechanical rigidity and EB1 also ensures vacuum leak tightness. A cooling channel, CC in Fig. 5, has been made in between the two copper rings to cool down the ceramic in case of future higher power requirements.

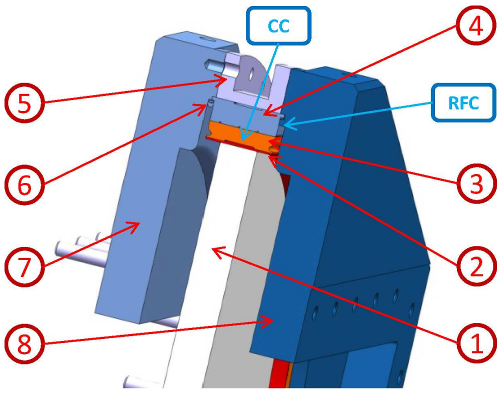

Figure 5: Window design

As shown in Fig. 6, this sub-assembly is inserted between the two stainless steel flanges (7) and (8). The spacer (5) is dimensioned to ensure the correct mechanical force is given to the HELICOFLEX® gasket (6). It also guaranties a correct centring of the ceramic and a well defined contact of the RF knife edge (RFC) on the air side flange.

The fully assembled window is very compact and adds less than 120 mm to the total waveguide length (Fig. 5).

PROTOTYPE WINDOW

To validate the design, a prototype window has been built (Fig. 7). The first sub-assembly with the challenging brazing of the thin copper ring and the large diameter ceramic has been tested and is vacuum leak tight.

Two aluminium waveguide flanges and one spacer have been machined to perform low power RF tests with the prototype window. The measured max. transmission is at 352.0 MHz instead of 352.2 MHz without any further tuning measures (c.f. Fig. 7), and thus the prototype frequency agrees well with the simulation.

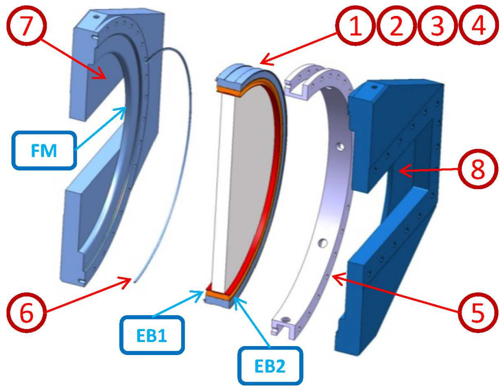

Figure 6: Window mounting

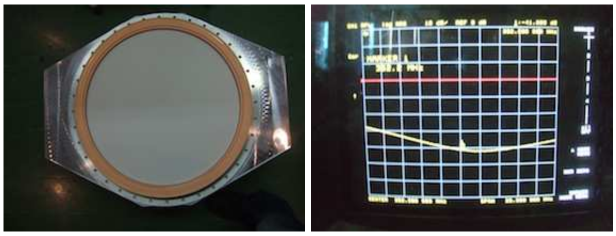

Figure 7: Prototype window and frequency measurements (marker at 352.2 MHz).

Several actions are planned in the near future to fully validate the complete design:

- Ti sputtering of the vacuum side of the ceramic (to avoid multipacting),
- copper plating of the stainless steel flange, vacuum side, to reduce losses in case of higher power requirement, and
- RF tests at full power, i.e. 1.4 MW pulsed 2 ms / 50 Hz.

SUMMARY

A tuner adjustable waveguide coupler (TaCo) and a compact RF window were developed and tested at CERN. Both devices form the Linac4 power coupler, which will be used at 25 cavity ports. Since the design is more cost effective than commercial solutions and more adapted to the Linac4 needs, CERN is now preparing the construction of the complete series.

REFERENCES

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[2] R. Wegner et al. Tuner-adjustable waveguide Coupler (TaCo). to be published

[3] E. Montesinos, SPL power coupler possible designs Part I: General considerations, talk at Review of SPL RF power couplers, CERN, 16-17 March 2010.