HIGH TRANSPARENT MATCHED WINDOW FOR STANDING WAVE LINEAR ACCELERATORS

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Abstract

This paper proposes a particular Dielectric Window (DW) for Standing Wave (SW) Linear Accelerators (LINAC's). This study investigates the in-frequency return loss behaviour of the LINAC, in order to improve matching and transmitting conditions while maintaining the optimum coupling between LINAC and High Power Microwave (HPMW) source. Device design considers the DW input interface as an Input Matching Network (IMN) at the LINAC Normal Mode (NM) working frequency. Thus, design formulas are provided and Computer Aided Design (CAD) techniques are proposed.

A prototype has been made and tested by performing cold S-parameter and Percentage Depth Dose (PDD) measurements of a LINAC with the proposed DW and with a traditional DW.

The proposed device offers more energy transport attitude over the traditional DW, as shown by a return loss increase of 167 % and an output electron energy increase of 5.5% while maintaining the same LINAC input power settings. This solution can offer a decrease of power line size, weight and cost. An after brazing global improvement of the accelerator figures of merit is also possible, as this study have demonstrated...

INTRODUCTION

Vacuum Tubes and LINAC employees Dielectric Windows (DW) to separate the Ultra High Vacuum (UHV) atmosphere to the normal atmosphere in the transport waveguide (which connects the device to the HPMW source), ensuring the microwave power transmission. These windows are made by a waveguide section, in which a solid dielectric medium is inserted.

The most common kind of window is the pill-box type. This window is a double Rectangular Waveguide (RWg) to Circular Waveguide (CWg) transition containing in the centre a dielectric cylindrical plate, typically made of typically alumina ceramic [1]. The internal profile of a Pill-box window is depicted in Fig. 1. Several technological solutions can be adopted, as for example SF6 filled for high-power transmission [1], long pill-box type windows, with a very long longitudinal size [2], or with oversized diameter in order to reduce the RF field strength on the ceramic surface for very high power transfer [3]. Due to complexity of the Electromagnetic field distribution, DW design is by then supported by Computer Aided Design (CAD) techniques [4].

This paper shows the design of a Dielectric Window, according to [5], for a Standing Wave LINAC to be employed in a medical mobile electron LINAC, dedicated to Intra Operative Radiation Therapy (IORT). The whole Medical Device is required to be as small and light as possible: therefore, oversized and long structures are preferably avoided.

After the manufacturing process, every LINAC may present a degradation of its electromagnetic characteristics, and often an increase of the reflection coefficient. By connecting to the LINAC input port a DW made with a high Insertion Loss (IL), these reflections reduces, but transmission efficiency decrease. Choosing a low IL one, the transmission increases but multipath reflections through the LINAC remains unchanged, respect to the same using a high IL medium.

At the end of the complete LINAC fabrication, the matching input characteristics of the system are been inevitably modified. The proposed strategy for improving LINAC Matching is the association of a low IL DW and a waveguide based Input Matching Network (IMN). The assembly of these two devices has been defined as High Transparent Matched Window (HTMW).

Since the IMN is placed in the low pressure section and it can be inserted by screws without vacuum loss and further Matching degradations, it can be sized basing on the effective measured input parameters of the finally brazed LINAC at its frequency of resonance.

A prototype is described with cold measurements of scattering parameters and hot measurements of the electron energy reached by a LINAC which employees this technology.

PILL BOX WINDOW DESIGN

The DW inserts a discontinuity in the power transmission line. Since the CWg is partially filled with alumina ceramic, this may be treated as equivalent to the CWg filled uniformly with a dielectric having effective relative permittivity ε_r' [4]. This assumption simplifies the problem providing initial values that must be optimized.

Since the power transport system is based on RWg, we can consider the wavelength of the fundamental mode in the rectangular waveguide as a known value λ_{gR}.

The CWg radius which ensures the local transparency of the line discontinuity inserted by the DW, can be found by applying the (1) [5]:

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$$r = \frac{\lambda_0 \ p'_{11}}{2\pi\sqrt{1 - \frac{\lambda_0^2}{\epsilon'_r \ \lambda_{gR}^2}}} \quad (1)$$

where λ_0 is the wavelength on free space, r is the radius of the CWg and p'_{11} is the first zero of the one order Bessel function derivative ($p'_{11} = 1.841$). The wavelengths λ_0 and λ_{gR} are calculated referring to the NM resonant frequency of the LINAC and, in particular, λ_{gR} refers to the dielectric constant which fills the RWg.

Assuming the gas permittivity very similar to the vacuum, the effective permittivity of the whole CWg section may be evaluated as the average value with respect to the volumes occupied by the disk and the vacuum or gas, as expressed by the (3), where L is the total length of the CWg section and ϵ_r^{disk} is the relative permittivity of the dielectric medium of the disk.

$$\epsilon'_r = 1 + \frac{t}{L}\left(\epsilon_r^{disk} - 1\right) \quad (3)$$

The length L must be defined to have maximum power transfer and, according to [4,5], it can be given by the (4), in which a and b are respectively the long and the short side of the RWg section.

$$L = \ \lambda_{gR} \frac{\sqrt{\epsilon'_r}}{2} \frac{b}{a} \quad (4)$$

Since the analytical design is a simplification of the real dimensioning problem, L as well as t must be optimized by an electromagnetic simulation. In fact, some modes under cut off in the vacuum might be over cut off in the dielectric disk. Since the waveguide may be pressurized [1], t must be enough wide to endure the stress on the disk surface [6]. By using a multiphysics software, the optimization can be extended with a Thermo-structural analysis, in order to compute the electromagnetic behavior modifications due to the thermo mechanical induced conditions, as described in [7]. The optimization has shown an optimum length of the circular sections L = 27 mm and optimal dielectric plate thickness t = 2.4 mm.

INPUT MATCHING NETWORK DESIGN

At the NM frequency of resonance, without the window, the LINAC Power Coupler (LPC) shows the External Reflection Coefficient ρ_{Ext}.

A pill-box DW is connected to the LPC and ρ_{Ext} is transformed to ρ_{in}' which can be measured and an opportune IMN can be designed. The IMN transforms ρ_{in}' in ρ_{in} by placing it to the centre of the Smith chart, providing the right matching condition between the LPC and the HPMW source and ensuring the optimum reflection coefficient ρ_{Opt} shown by the LPC to the LINAC (Fig. 1). The optimum reflection coefficient ρ_{Opt} makes unitary the coupling factor β of the LPC.

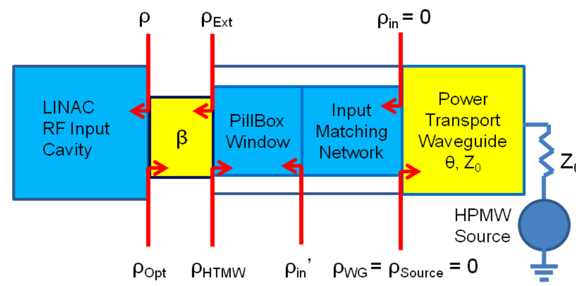

Figure 1: Devices disposition and reflections coefficients.

The IMN network can be realized through a RWg section loaded by an iris element earned in a flanged parker gasket. In order to obtain $\rho_{in} = 0$ we propose to design an iris according to theory described in [8].

Since the iris may lead evanescent modes, the implementation of an IMN circuit by employing waveguide elements is limited by a condition on the minimum distance between iris and DW. In order to avoid the effects of such evanescent modes, we assume that the iris must be placed at a minimum distance of $2\lambda_{gR}$ form the LPC. For technological reason, we have placed the iris at the LINAC input section, namely at a distance less than $2\lambda_{gR}$. Such proximity increases complexity of the structure because produces a coupling between the evanescent and propagating modes that makes very difficult to obtain a simple formula for the choice of the geometry of the window, like those discussed in [9]. Hence, more complex models based on equivalent circuits that take into account the presence of evanescent accessible modes [10,11] must be used. In order to match the LINAC analyzed in this study, the IMN has been implemented by a capacitive iris with large thickness realized in a Parker gasket with d=21.7 mm and t=3.3 mm.

FABRICATION AND MEASUREMENTS

The HTMW prototype has been designed for an R.F. standing wave side coupled LINAC of the IORT dedicated mobile accelerator NOVAC 11®, described in [12], working a 2.998 MHZ in π/2 NM.

Input characteristic of this LINAC has been measured in air atmosphere without DW and in UHV with the traditional DW. In both cases, with a negligible difference, it has shown a quality factor Q_0=12200, a Coupling Factor k=1.35 and a Return Loss (RL) of 16.5 dB, as shown in Fig. 2. By using the complete HTMW we have obtained a RL of 44.0 dB, as shown in Fig. 3, while maintaining a good value of Q_0=12140 and improving the coupling factor to k=0.99.

In order to asses quantitatively the improvement achieved, a direct measurement of the accelerated beam has been performed, both with the traditional DW and with the HTMW. Electron beam energy has been measured according to IAEA TRS 398 protocol [13]: Percentage Depth Dose (PDD) curves have been

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measured with both different LINAC configurations, using PTW MP3 XS water phantom with suitable detectors and PTW Mephisto mc[2] processing software [14]. These measurements have been performed on the NOVAC 11, with the same excitation conditions. The specific pulsed power output P_{RF} =2.5 MW is transmitted to the LINAC with a pulse duration τ=4μs and a frequency of pulse repetition f_{PRF}=5Hz Electrons to be accelerated are provided by a custom electron gun (e-Gun) with opportune cathode voltage V_{KAT}=11.5KV. According to [13], the e-beam average energy E_0 at the phantom surface is given by

$$E_0\,[\mathrm{MeV}] = 2.33[\mathrm{MeV}\cdot\mathrm{cm}^{-1}]\cdot R_{50}\,[\mathrm{cm}] \qquad (12)$$

being R_{50} the depth where the measured dose is half with respect to the maximum.

With a traditional DW, the output measurements have shown a R_{50} of 3.29 cm, corresponding to an average energy of about 7.7 MeV, as shown by the red curve reported in Fig. 4. By using the proposed HTMW on the same LINAC with the same RF power excitation, we have obtained a R_{50} of 3.47 mm, corresponding to energy of about 8.1 MeV, as shown by the blue curve reported in Fig. 4. The HTMW, inserted on the NOVAC 11® LINAC, is shown in Fig. 5.

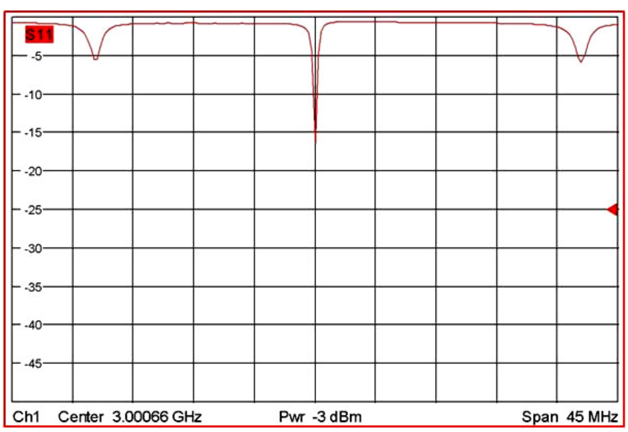

Figure 2: Measured reflection scattering parameter of the LINAC with the only traditional pill-box window.

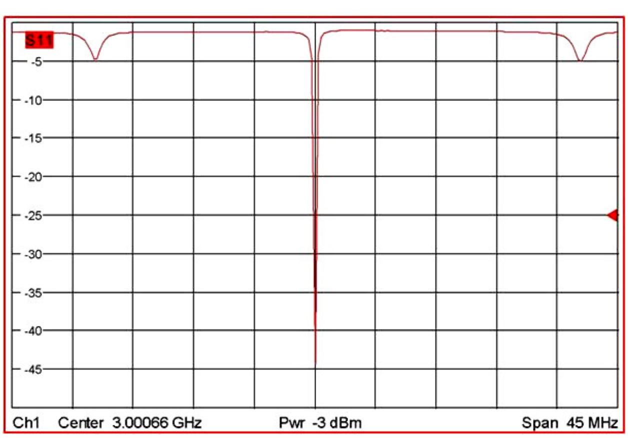

Figure 3: Measured reflection scattering parameter of the LINAC with the whole Tuned Window.

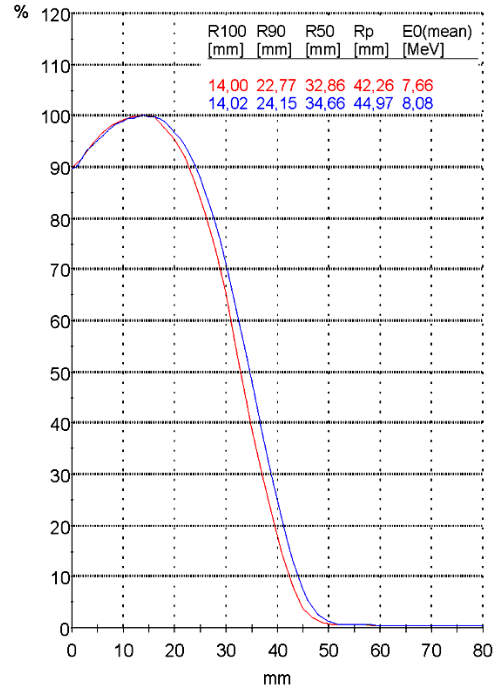

Figure 4: Percentage Depth Dose measurements: The elaboration results of Mephysto mc[2] are shown in the table above the curves and measured values are plotted in the underneath curves: The red curve and the first row of values refer to the LINAC with a traditional DW. The blue curve and the second row of values refer to the LINAC with the whole HTMW.

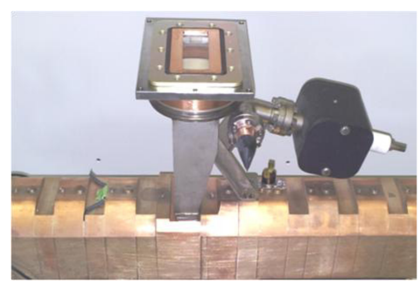

Figure 5: The HTMW on the NOVAC 11 LINAC.

CONCLUSIONS

A particular dielectric window (HTMW) which includes a waveguide iris-based matching network has been designed and built. An after brazing global improvement of the LINAC is possible by employing the HTMW.

Measurements of the reflection parameter at the LINAC input port, with the HTMW, have shown a Return Loss increase of 167%, over the LINAC with only a traditional DW. As documented by Percentage Depth Dose measurements, by using the proposed HTMW we have obtained an electron energy increase of 5.5% while maintaining the same LINAC input power settings.

This improvement allows to use lighter and cheaper insulators or circulators in the Radiofrequency power transmission chain, and a bit lower power sources. This solution can offer a decrease of power line size, weight and cost.

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