LOCALIZATION OF RF BREAKDOWN POINT IN A COAXIALLY LOADED LINAC CAVITY*

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Abstract

Here we report how the RF breakdown point (RFBP) can be localized in a coaxially loaded linac cavity with just the forward and the reflected power signal. The cavity uses 4 load cells instead of output coupler to absorb remanent power, so no transmitted power signal could be recorded. We propose two methods to analyze the measured signals and localize the RFBP. One method focuses on the time delay of the two signals while the other one focuses on the amplitude. Quantitative analysis showed the two methods were well consistent with each other and indicated the RFBP located at the end of the linac cavity.

INTRODUCTION

A compact terahertz free electron laser (THz-FEL) prototype has been built in Huazhong University of Science and Technology (HUST) [1]. In the prototype, a 0.85 m long linac is supposed to deliver electron beams with maximum energy of 14 MeV. A highlight of the prototype is that it uses coaxially loaded cells to absorb remanent power at the end of the linac. So there is no output coupler in the linac cavity, as shown in Fig. 1. With this scheme, the radial dimension of the solenoid can be largely reduced, which is consistent with the demand of compactness.
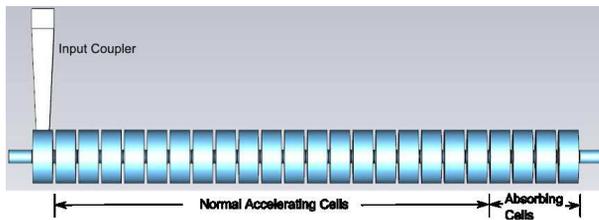

Figure 1: Sketch of the linac cavity. Phase shift per cell: $2\pi/3$; Resonant frequency: 2856MHz; Constant gradient.

The linac cavity consists of 1 input coupler cell, 19 normal accelerating cells and 4 load cells. The structure of the load cells are similar with those normal ones, except for the lossy materials. As shown in Fig. 2, the inner wall of the load cell is coated with lossy material, which is a kind of FeSiAl alloy. More detailed report of the lossy material can be found in [2,3]. The lossy material makes RF power attenuate quickly in the load cells. The power loss in each of the 4 load cells are equal and the total attenuation factor is designed to be -20 dB. According to the requirement of beam

energy, the accelerating gradient should reach 20 MV/m and the corresponding input power would be 16 MW, which indicates the pulse and average power loss in the load cells to be 11.1 MW and 2.2 kW. Fig. 3 shows the accelerating gradient and power loss (average value during a macro pulse) when the input RF power is 16 MW. It can be found that there is a sharp attenuation of electrical field and most RF power is dissipated in the last 4 cells.
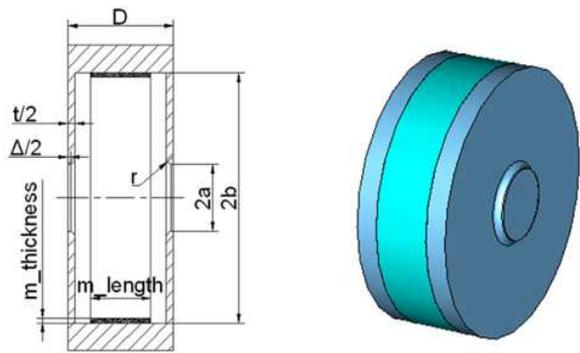

Figure 2: Load cells with lossy material coated on the inner wall.

RF conditioning is necessary to make the linac cavity suitable for normal operation. During the early conditioning process, RF breakdown occasionally occurred and the breakdown rate was about 1/100000. The emission current in a pulse could reach 1A. After a long time operation, no high emission current could be detected. We thought there was no RF breakdown or field emission any more. But the vacuum gauge still recorded abnormally high value sometimes. So we tried to measure the current and power signal in a smaller scale and found the field emissio still existed. At this time the emission current was around 0.1 A, much smaller than before. This strange phenomenon make us study the RF performance of the linac and localise the RFBP.

RF breakdown is an old issue and has been studied in many literatures [4–6]. As there is no output coupler in the linac cavity, conventional methods using signals from the forward and the transmitted power is no longer suitable to localise the RF breakdown point (RFBP) here. So we report in this paper how to determine the RFBP with just the forward and reflected power signal from the input coupler.

RECORD OF RF BREAKDOWN

The power signal and the current signal are recorded with two oscillators. If field emission or RF breakdown occurs,
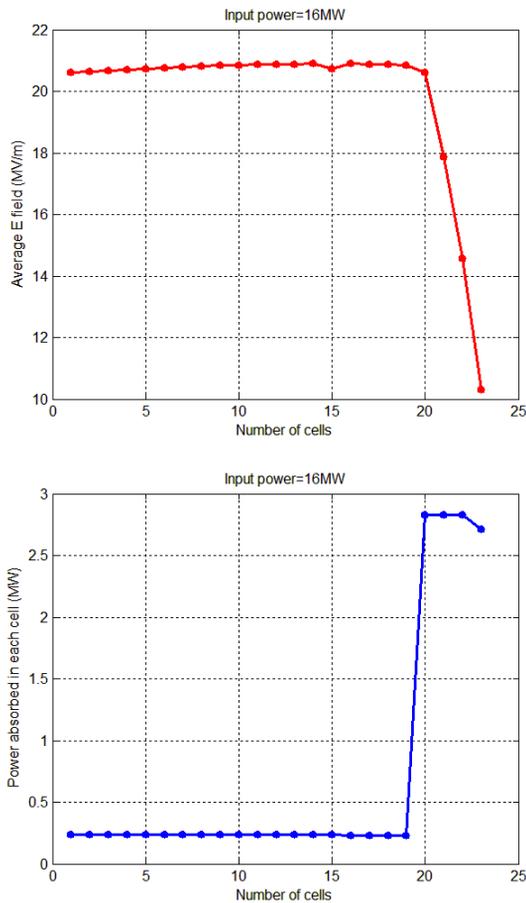
Figure 3: Accelerating gradient (Upper) and power loss (Lower) in each cell at P_{in}=16 MW.

it will induce abnormal waveform on the oscillators. A typical record of RF breakdown is shown in Fig. 5 and Fig. 6. When RF breakdown occurs, the burst of electrons will form a short plate at the occasion point and the RF power will reflect. In Fig. 5, the pink line indicates the backward power of the linac largely increases. It can also be found that the forward power of the linac slightly increases at the same time. It might be influenced by the backward power because there is no circulator in our waveguide system. Fig. 6 demonstrates the emission current of the same breakdown case. Emission current is only observed downstream the linac (FCT 2), which partially indicates the RFBP locates close to the end of the linac, otherwise FCT 1 would also detect emission current.

TIME DELAY BASED METHOD

Time delay based method to localize the RFBP has been introduced in Ref. [7]. As shown in Fig. 7, the pulse width of the forward and the backward power signal are W_1 and W_2 respectively and the time delay of the two signals are T. Then we have

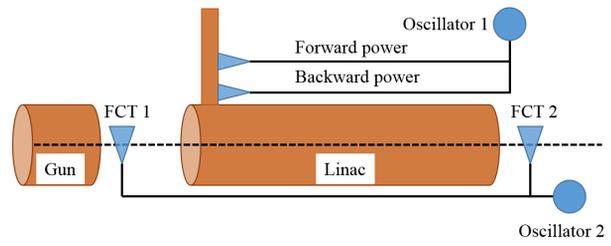$$T = (W_1 - W_2) + 2T_{RFBP}, \qquad (1)$$

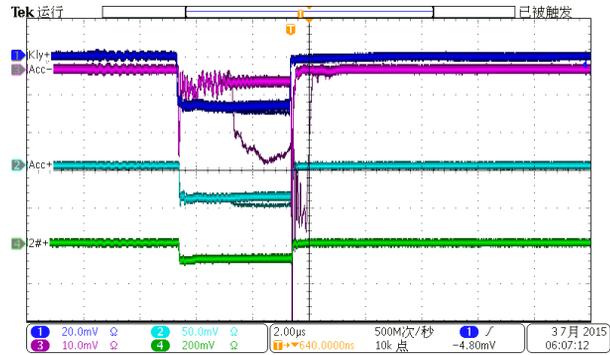Figure 4: Systematical setup of the RFBP detection experiment.

Figure 5: Channel 1: forward power of the klystron; Channel 2: forward power of the linac; Channel 3: Backward power of the linac; Channel 4: non-important.
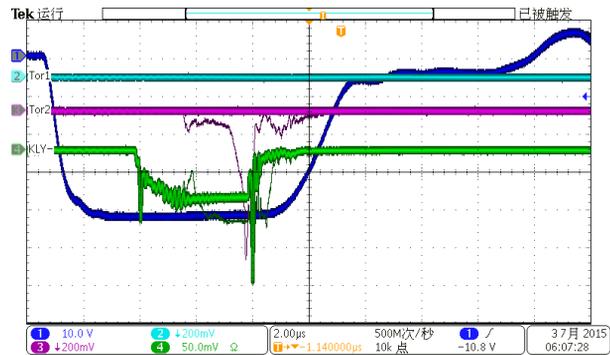

Figure 6: Channel 1: voltage record of the modulator; Channel 2: current record upstream the linac; Channel 3: current record downstream the linac; Channel 4: backward power of the klystron.

where T_{RFBP} is the filling time from the entrance of the linac to the RFBP.

Eq. (1) assumes that the time delay of the forward and the backward signal results from two portions. The first portion is related with the filling time, T_{RFBP}, from which the position of the RFBP can be localized. The second portion is related with the time delay between the power flow and the breakdown case, which means that breakdown occurs after the RF power reaches the RFBP. From the RFBP's point of view, one pulse can be divided into two parts. Before the breakdown occurs, RF power will propagate downstream normally, while after the case, RF power will be reflected.

The time delay, τ, will be equal to the width difference of the forward and the backward signal, i.e. $\tau = W_1 - W_2$. Then with measuring the time delay and pulse width of the forward and the backward power signal, the RFBP can be localized.
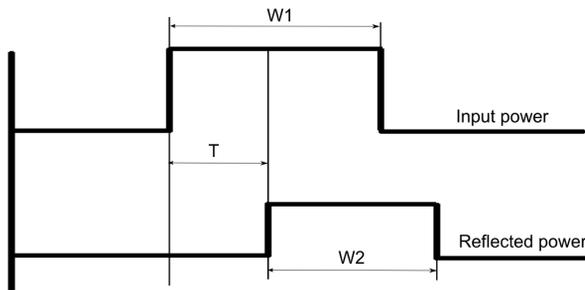

Figure 7: Illustration of the time delay based method.

Referring to Fig. 5, the pulse width of the forward and the backward signal are $W_1 = 4\mu s$ and $W_2 = 2.8\mu s$. The time delay of the two signals is $T = 1.8\mu s$. Then with Eq. (1), we can get $T_{RFBP} = 0.3\mu s$. As the filling time of the linac is 0.3 μs, it is concluded that the RFBP locates at the end of the linac.

To be noted, the filling time of one cell is around 15 ns, while the resolution of the oscillator is 800 ns. So the time delay based method can not give accurate position of RFBP on the level of cell.

AMPLITUDE BASED METHOD

Considering a breakdown case, RF power propagates from the entrance of the linac to the RFBP and then reflects back to the entrance. The detected backward signal is a portion of the forward one as the linac is a lossy instrument. The ratio of the two signals is

$$R = \frac{P_{re}}{P_{in}} = e^{-4D(\sum_{k=1}^{N}\alpha_k)}, \qquad (2)$$

where P_{re} and P_{in} are the backward and the forward power signal detected at the entrance; D and α are the length and the attenuation factor of one cell; N is the number of cells in a cavity.

Still referring to Fig. 5, the recorded forward and backward power of the linac are 7 MW and 0.47 MW respectively. With Eq. (2), we can get $21 < N < 22$. So it is concluded that the RFBP locates at the third load cell (cell number $k = 22$).

It should be noted that the amplitude based method assumed the RF power was totally reflected at the RFBP, other-wise the detected backward power signal would be smaller. If this is the case, the backward signal would be the sum of three parts, which is not observed in our case.

CONCLUSION

The time delay based method and the amplitude based method are applied to localise the RFBP in the HUST linac cavity. Both the two methods only use power signals detected at the input coupler, i.e. forward power and backward power. Limited by the time resolution of the oscillator, the time delay based method can not give accurate position of the RFBP, but it indicates the RFBP locates close to the end the cavity. The amplitude based method is more accurate and concludes that the RFBP localise in the third load cell. From this point of view, the two method coincide with each other very well.

It is worth to point out that the emission mechanism of the load cells is still unclear. More analysis and simulations on this topic will be performed in the future.

ACKNOWLEDGEMENTS

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