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INVESTIGATION OF TRANSVERSE WAKEFIELD AND BEAM BREAK UP EFFECT IN IRRADIATION LINACS

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Abstract

Study of beam break up effect in linacs has been done in recent years. The beam-induced high order dipolar modes, especially the TM11-like mode were investigated for the linacs both in travelling wave and backward travelling wave. Measurements of beam-break up in a travelling wave linac were carried out and results are discussed. Moreover, a theoretical model was developed for the irradiation linacs to study the detailed interaction between the transverse wakefield and the electron beam.

INTRODUCTION

The beam break up (BBU), also known as beam blow up or pulse shortening, is one of the collective beam instabilities in electron linear accelerators. The effect limits the capacity of achieving the high current for electron linacs. The phenomenon was first observed in a 25 MeV electron linear accelerator in 1957 in the Atomic Energy Research Establishment, Harwell, Britain. The current of the accelerator could not reach the rated value (1 A) because the output of the current would be shortened once the current was above 500mA. In the word, there is a current threshold in the linear accelerator [1]. The typical picture of the beam break up is shown in Fig. 1.

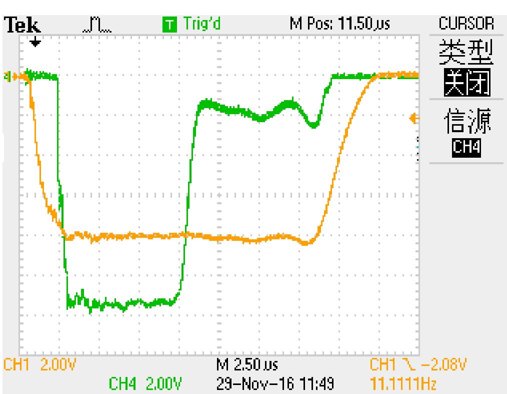

Figure 1: Oscillograms of the beam break up with the input (orange) and output (green).

The phenomenon of beam break up was also found in the irradiation linacs, both in travelling-wave (TW) and backward travelling-wave (BTW), in the accelerator laboratory in Tsinghua University and Nuctech Inc. Many experiments had indicated that the beam current would be limited by this beam instability. Many work has been done to study the effect [2]. Preliminary experiments had been carried out in backward travelling-wave linac. The mechanism of BBU had been investigated and the dispersion curve for single cavity had been calculated in CST. Also, a preliminary model had been established to describe the process.

This paper will present the progress in the study of beam break up. The high-order modes and the transverse wakefield were studied in both the travelling wave and backward travelling-wave linear accelerator. The experiments were carried out for the travelling wave accelerator. Moreover, the model has been modified and some key factors would be studied.

THE MODES AND FILED

Travelling Wave

As described in [2], the beam break up is caused by the beam-induced high order dipolar mode in the accelerator. The transverse wake field, generated by the interaction of the beam and the cavities will kick the following electrons in the same pulse. So firstly, we should figure out which modes play the important role in the beam break up and how the field distribute.

The models of single cavity and cavity chain for travelling wave linear accelerator have been built in CST to calculate the eigen modes and the wake field, see Fig. 2.

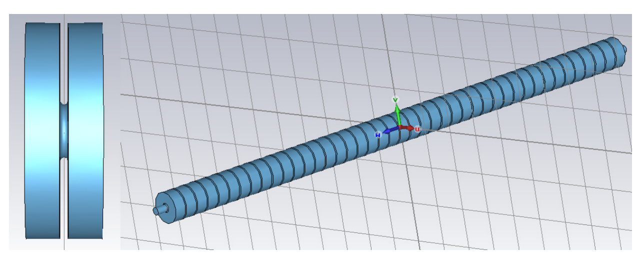

Figure 2: The model of single cavity (left) and the cavity chain (right) for TW accelerator.

The dispersion curve has been obtained for the structure. The most important high order mode is TM11 with 4.338 GHz. The group velocity is 0.001c and the phase is 182.2 degree. On the other hand, the wake field for the cavity chain has been calculated and the wake impedance is shown in Fig. 3. Three modes play an important role in the wake field and the wake field can be expressed by these three modes.

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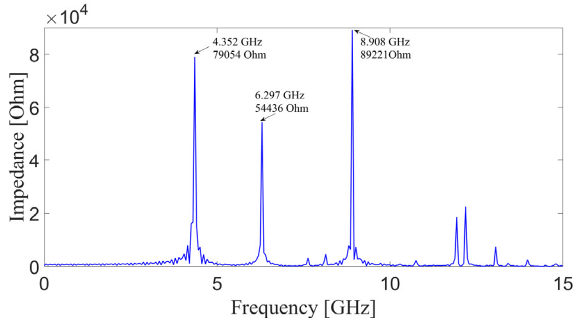

Figure 3: Wake impedance of the cavity chain for TW structure.

Backward Travelling Wave

The models of two cavities and cavity chain for backward travelling wave linear accelerator have also been built in CST. Other than the TW structure with axis coupling mode, the BTW structure adopts the side coupling mode. The coupling holes between the cavities are not all the same but perpendicular to each other. So the model of two cavities with periodic boundary has been used for the eigen modes calculation, see Fig. 4 (left). And the models of two cavities and the whole cavity chain, see Fig. 4 (right), are both used for wake field calculation.

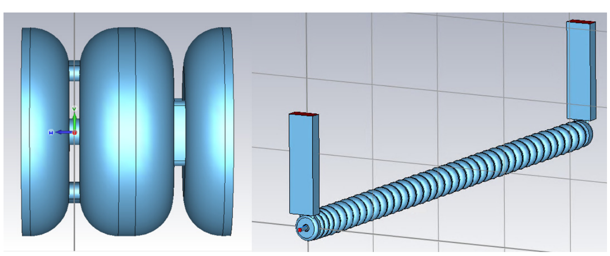

Figure 4: The model of two cavities (left) and the whole cavity chain (right) for BTW structure.

The eigen modes for two cavities is much more complicated than the single cavity. The frequencies of the high order modes have mixed up and should be distinguished. Finally the dispersion curves for the dominate mode and the typical high order modes are shown in Fig. 5. The TM11-like mode is in 4.974 GHz. The group velocity is close to zero and the phase is 242.9 degree. That means this mode may be trapped into the two cavities.

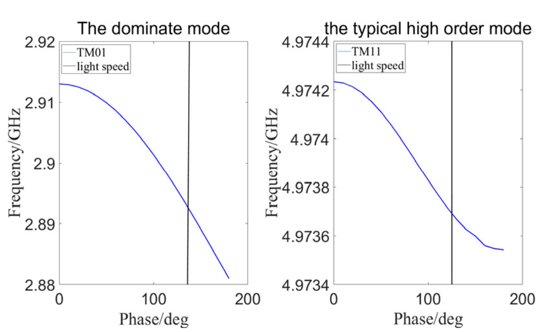

Figure 5: Dispersion curves for two modes.

The wake field for two cavities and the whole cavity chain have been calculated and compared, see Fig. 6. There are more degenerate modes and parasitic modes in the wake field. The typical mode for two cavities is the TM11-like mode in 4.966 GHz. But this mode is not so typical for the whole chain. The wake field of two cavities would be chosen for dynamic simulation.

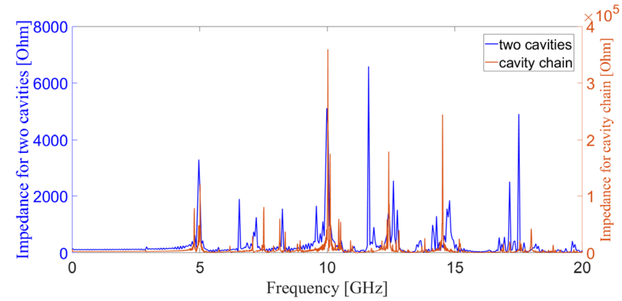

Figure 6: Wake impedance of the two cavities and the whole cavity chain for BTW structure.

EXPERIMENTS EXPLORATION

Experiments have been carried out in a 10MeV travelling wave linear accelerator system. The accelerator is used for irradiation. And the system is comprised of modulator, klystron, electron gun, travelling wave accelerator and water target. Besides, there are three focusing magnets along the accelerator to restrain the beam.

Firstly, we scanned the pulse widths and the beam current values and compared the output pulse waveform with the same current in magnets. The pulse width and the beam current restrict each other. There exists a threshold beam current if the pulse width remains unchanged. The relation of the pulse width and the beam current threshold is shown in Fig. 7.

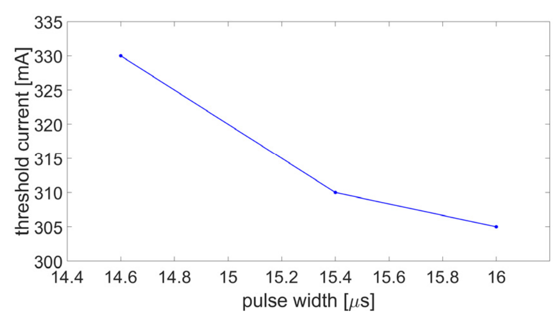

Figure 7: The relation of the pulse width and the threshold current.

The beam instability would be stronger as the beam current increased in the same pulse width. The beam pulse would be shorter and shorter as the beam current increased. On the other hand, the focusing magnets affect the BBU phenomenon a lot. When the beam break up occurred, we can adjust the current of the magnets to decrease the beam instability. This phenomenon is what we did not observed in the experiment for backward travelling-wave linear accelerator.

Experiments on backward travelling-wave linear accelerator had been presented in [2]. The focusing and oriented magnets are just located in the head of the accelerator and the effect is not so obvious.

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DYNAMIC SIMULATION

Travelling Wave

The preliminary modelling and simulation have been presented in [2]. Then the wake field for the travelling wave accelerator has been updated. Several modes have been considered into the components of the wake field. Also the beam size has been taken into consideration. It is worth noting that the wake field in our simulation codes is regarded as the standing wave in both TW and BTW codes. For TW accelerator, the group velocity is 0.001c. The transmission of the wake field may affect the interaction between the beam and the field.

The different initial beam current values have been scanned in the codes to simulate the motion of electron with different initial transverse offset. After the simulation, we can get the motion trail of electron along the accelerator. So the maximum transverse offset can be obtained according to the track. The relationship is shown in Fig. 8. The maximum transverse offset is nearly in exponential growth with the beam current. The beam aperture is about 10 mm for TW structure. For certain initial offset, there exists a beam current threshold. The threshold would be 200 mA when the initial offset is 0.5 mm.

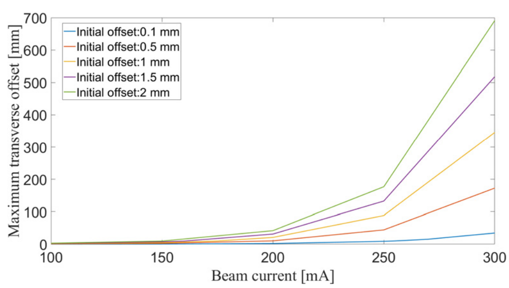

Figure 8: The maximum transverse offset of the track with different beam current and initial offset.

The wake field is composed of several modes. Some work has been done to explore which mode affects the most. The wake field component of the first three modes has been loaded into codes respectively. The initial transverse offset is set to 1 mm. The relationship of the maximum offset and the beam current is shown in Fig. 9. The first order mode, TM11, contributes the most to the interaction. It is more important than the sum of all other modes.

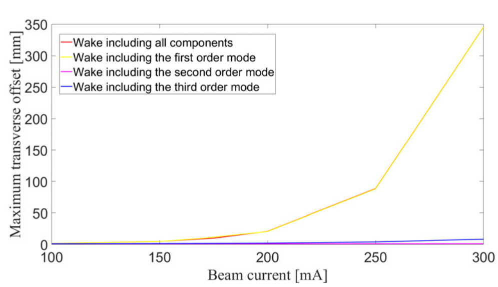

Figure 9: The maximum transverse offset of the track with different beam current and wake components.

Backward Travelling Wave

The codes for BTW structure is similar to the ones for BW structure. The typical wake field for BTW structure is almost motionless. The same work has been done in this codes. The relationship of the maximum offset and the beam current is shown in Fig. 10. The beam aperture is about 5 mm for BTW structure. The threshold would be 130 mA when the initial offset is 0.5 mm. For the wake components in BTW structure, the conclusion is the same. The TM11-like mode is the main mode in wake field.

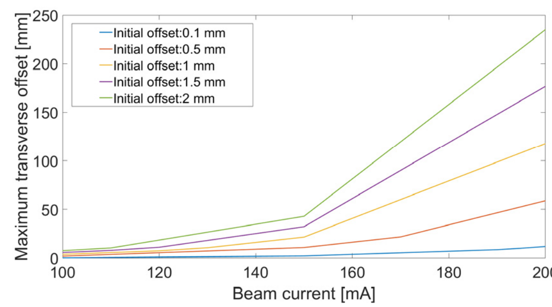

Figure 10: The maximum transverse offset of the track with different beam current and initial offset.

There are some divergences between the results from simulation and experiments. The threshold current is bigger in experiment. That means the focusing magnetic field should be considered into the codes.

CONCLUSION

Further study of beam break up in irradiation linacs has been done in Tsinghua University. The high order modes and the components of wake filed for both TW and BTW structure have been investigated. Experiments in TW accelerator system have been presented. The threshold current has been calculated by dynamic simulation. The first order mode, TM11-like mode, affect the most in the BBU. More work should be done in the future to optimize the dynamic simulation.

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