WAKE-FIELD INSTABILITY OF THE KEK 2.5-GEV LINAC

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Abstract

The wake-field instability was investigated using two types of intense beams at the KEK 2.5-GeV linac; a beam with a peak current of 10 A, a pulse width of 2 ns and an energy of 500 MeV, and that with 1 A, 17 ns and 2.5 GeV. The experimental results indicated a complex behavior due to the transverse wake-field instability, when the beam was given a transverse offset at the entrance of the accelerating cavity.

Introduction

A fine investigation of the wake-field instability caused by an intense beam is one of the most indispensable items for the research and development of future accelerator designs: the Japan linear collider[1] (JLC) and the injector linac of the proposed B-factory project[2] at KEK. In both designs, emittance growth during acceleration must be prevented in order to obtain a large luminosity at the collision point (JLC) and to attain a large positron yield at the target (B-factory).

Although fundamental aspects concerning the wake-field instability have been studied both theoretically[3] and experimentally,[4] their application to real accelerator design seems insufficient from various points of view. The multibunch instability due to a transverse wake field is well explained by, for instance, a Wilson's two-particle model,[5] and was intensively investigated in our experiments[6] at the primary electron section of the KEK positron generator linac[7] (a peak current of 10 A, a pulse width of 2 ns and a final energy of 250 MeV). For future large-scaled, high-intensity accelerators, however, wake-field effects will be more complex, since the length of the accelerator becomes very long and, accordingly, many factors which can cause the instability may appear. In this connection, we performed two experiments in order to clarify the distance dependence of the instability as a simple extension of our former experiments and to study the long-acceleration characteristics of the intense beam; one was achieved by extending the acceleration region of the KEK positron generator linac (10 A, 2 ns and 250 MeV) from 250 MeV to 500 MeV; the other was performed by using the 2.5-GeV linac with a peak current of 1 A, a pulse width of 17 ns and a final energy of 2.5 GeV. Although the results seem to be still too complicated to say anything decisive, some possible interpretations are discussed.

500-MeV experiment

In order to perform a 500-MeV experiment with an intense beam, we extended the acceleration region of primary electrons at the KEK positron generator linac to the end of the positron generator (500 MeV) by removing the positron production target, which is located at an energy of 250 MeV.

This 500-MeV accelerator comprises a high-intensity electron gun with a peak current of 10 A and a pulse width of 4.2 ns, a pulse compression section employing a subharmonic buncher with a modulation frequency of 119 MHz, a bunching section operating at 2856 MHz, and a 52 m-long regular accelerating section with a quasi-constant gradient of about 10 MeV/m at the same frequency. Through this regular section, a high-intensity, multi-bunched electron beam with a peak current of about 10 A and a pulse width of 2 ns, corresponding to about 6 bunches, is accelerated; the average energy reaches about 500 MeV at the end of the positron generator linac. Focusing quadrupoles are tuned so as to produce a betatron wavelength of about 30 m. A schematic layout is shown in Fig. 1.

The transverse wake characteristics were investigated at two energy-analyzing stations,[8] one in front of the target and the other at the end of the positron generator. By changing the initial offset of the beam at the entrance of the accelerating cavity, the transverse motions of each bunch at both stations were measured and compared. Fig. 2 shows the typical transverse bunch behaviors observed with the profile monitors at both stations. Thanks to the bunch-to-bunch energy difference due to a longitudinal wake field, the transverse positions of each bunch can be seen separately. The dependence of the transverse shift of the average position of all bunches on the initial offset is plotted in Fig. 3 for both cases.

2.5-GeV experiment

The 2.5-GeV linac[9] is a dedicated machine for supplying a positron beam with a peak current of 4 mA and a pulse width of 40 ns to the Photon Factory, and a positron/electron beam with 15/100 mA and 2 ns to the Tristan ring. It was not designed for the acceleration of an intense beam, such as the primary electron of the positron generator linac. In order to study the wake-field instability due to a long acceleration of the intense beam with more than 10 nC, we increased the emission peak current of the electron gun from 300 mA with a pulse width of 2 ns to about 2-3 A with 17 ns by changing the grid pulser. The rest of the system was not changed for this experiment; the beam was split into about 50 bunches in a bunching section operating at 2856 MHz and a beam of about 1 A was accelerated in the regular section of about 450 m in length at the same frequency. The betatron wavelength was about 40 m at the first 100-m accelerating section and about 80 m at the others.

The wake-field instability was investigated by observing the waveform distortion of the beam current at the end of the linac and the transverse blow-up of the beam profile at the

2.5-GeV energy-analyzing station,[8] when the beam was given a transverse initial offset at the entrance of the first accelerating cavity. Typical waveforms of the accelerated beam with/without the initial offset are given in Fig. 4, indicating that the waveform was distorted from the tail (low energy side) when the instability took place. This corresponds to the transverse blow-up observed at the profile monitor of the energy-analyzing station (Fig. 5). In Fig. 5, a comparison of the two cases with/without an initial offset clearly shows that the transverse instability causes an oscillating blow-up of the trailing bunches (low energy side).

Discussions and Conclusions

500 MeV Experiment

Although a detailed analysis of the fundamental aspects of the wake-field instability has been carried out using the 250-MeV beam,[6] the distance dependence of the effect was not clarified experimentally. The present experiment clearly showed us this distance dependence. A rough estimation by a numerical integration of the equations of motion for each bunch could explain the difference in the slope of the two lines in Fig. 3.

As a result, almost all of the fundamental characteristics of the transverse wake field were experimentally elucidated and the validity of the multi-particle version of Wilson's two-particle model was also verified.

2.5 GeV Experiment

According to a theoretical prediction based on the multi-particle version of Wilson's two-particle model, the initial offset error must be less than 30-40 % of the final transverse shift. If one only leads the beam to the end of the linac without paying attention to the degradation of the beam quality, this error is not severe. However, the beam quality should be maintained during acceleration in order to obtain a high positron production rate for the B-factory or a large luminosity at the collision point for JLC. In these cases, the initial offset error becomes very severe.

In the present experiment, we could accelerate the intense beam with more than 10 nC and observe qualitatively that the instability effects were very sensitive to the initial offset error. The emittance was measured in order to check the beam quality quantitatively; the results are being analyzed and preliminary analysis shows an enormous increase in the beam emittance.

Unfortunately, the present experimental results are still insufficient to obtain limitations decisively concerning the following items: initial offset, cavity and Q-magnet misalignment errors. Detailed investigations will be carried out in the near future.

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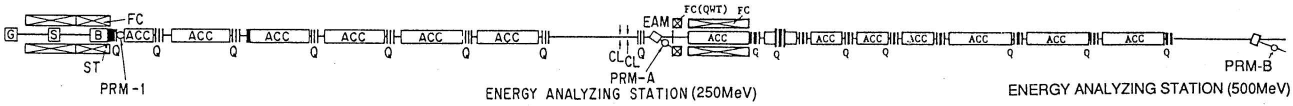
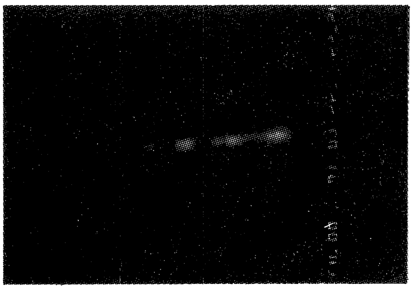
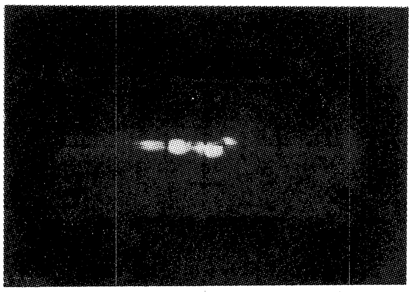


Fig. 1. Layout of the KEK positron generator linac. G is an electron gun; S, SHB; B, a prebuncher and a buncher; ACC, accelerating cavities; FC, focusing solenoids; Q, quadrupole magnets; ST, steering coils; EAM, an energy-analyzing magnet; PRM, profile monitors; CL; collimators; SL, a slit; WCM, a wall current monitor; BM, a bunch monitor; and T, a positron production target.



(a)



(b)

Fig. 2. Typical transverse behaviors of the bunches photographed at the profile monitor of two energy analyzing stations: (a) at the 250-MeV station and (b) at the 500-MeV station . In these figures, the vertical direction corresponds to a transverse displacement, while the horizontal direction corresponds to the beam energy (The left-side is high-energy side). The initial transverse offset was set at 2.5 mm.

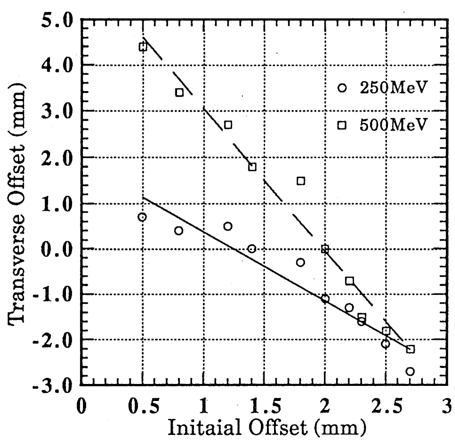
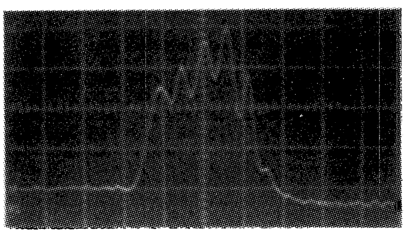
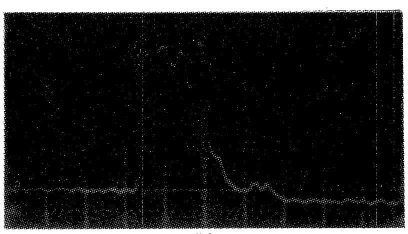


Fig. 3. Dependence of the transverse shift of the average position of all bunches on the initial offset for the 250-MeV case and the 500-MeV case. The difference of the slopes of the two fitted lines are interpreted as being the distance dependence of the transverse wake-field effect.

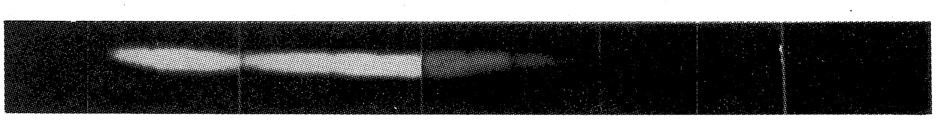


(a)

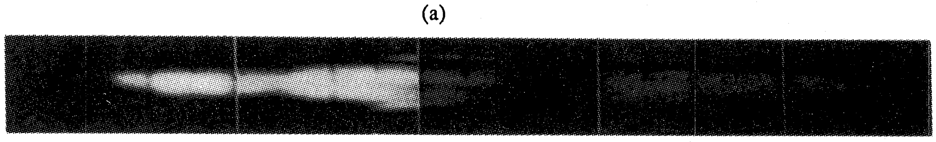


(b)

Fig. 4. Typical waveforms of the accelerated beam with (b) /without (a) the initial offset.



(a)



(b)

Fig. 5. Typical transverse behaviors of the beam photographed at the profile monitor of the 2.5-GeV energy analyzing station with (b) /without (a) the initial offset. It shows that the transverse instability causes the oscillating blow-up of the trailing bunches (low energy side) in the case (b).