PROPOSAL OF A PHOTOCATHODE IMPULSE-GUN AND FOLLOWED BY IMPULSE ACCELERATING STRUCTURES TO PRODUCE LOW EMITTANCE ELECTRON BEAM

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Abstract

The photocathode impulse-gun must be one of the best methods to produce low emittance electron beam for FEL. To raise the beam energy up to around 10MeV, RF cavity will be used. However, there is drift space between the photocathode impulse-gun and RF cavity. The beam emittace will get worse due to space charge effect in passing through the drift space. Thus the drift space should be as shorter as possible. Minimizing the space charge effect is essential for the early stage of beam acceleration at an electron beam source and a following pre-acceleration. Mechanically unavoidable drift space degrades the beam emittance drastically. We propose a combined structure of a photocathode impulse-gun followed by an impulse accelerator.

INTRODUCTION

There is a laser pulse driving photoinjector to produce electron beam with the structure of low emittance and short time width for FEL. This can make a very short single pulse beam by using laser. In addition, to suppress space charge effect, which makes the beam emittance grow, strong electric field of 1GV/m with time duration of a few ns is supplied to the photocathode plate. Thus, the electron beam produced by laser reaches at a relativistic speed momentarily. De Loos et al. have already proposed such a method [1]. Their set-up shows that a gap between cathode and anode is 2 mm and is powered by 2 MV, 1 ns pulse. The feature of the obtained beam by their method is of energy of 2 MeV and low emittance below 1 π mm mrad. We, here, name this method photocathode impulse-gun. Their results seem to be one of the best methods for FEL as an electron gun. They do not mention the high voltage generation device in the paper at all. To accelerate further the obtained low emittance beam, Kiewiet et al. [2] proposed that an RF cavity operated with S-band standing wave was installed just after the photocathode impulse-gun. However, the initial low emittance increases due to space charge effect in drift space before the electron beam enters into a following cavity. The detail about the emittance under the various conditions is discussed in reference [3]. To solve the serious problem of the space charge effect, we propose an idea, which can suppress the space charge effect and furthermore can accelerate the beam up to around 10MeV in a short distance of 10cm or less. We describe the method.

EMITTANCE GROWTH DUE TO SPACE CHARGE EFFECT IN DRIFT SPACE

We discuss two beams, which are accelerated to 2MeV by the photocathode impulse-gun. We assume that the radiuses of two beams are the same sizes of 0.25mm. One has the time width of 50fs and the charge of 200pC. The other is 1 ps and 4.0nC, respectively. The charge densities of two beams are equal. Only their time widths are different. The latter beam has just 20 times longer time width than that of the former one. The structures of two beams after 20mm-long drift space were analytically calculated and the results are shown in Fig.1 [4]. For the beam with a smaller charge, the transverse beam size grows a little. On the other hand, the size of the beam with larger charge increases by a factor of seven. It is clear that the space charge and a drift space degrade beam emittance. To suppress the space charge effect, drift space should be as shorter as possible. And the beam must be led to an RF cavity in a short distance. However, if a normal cavity or an accelerating structure is used, drift space becomes indispensable due to a mechanical structure such as flanges. To shorten drift space, DC accelerating structure operated by impulse high voltage (HV) generator should be installed instead of an RF cavity.

We calculated electric field map about the model proposed by De Loos et al. by using MAFIA. The result is shown in Fig.2, where the gap between two plates is 2mm and the radius of an anode is 2mm. The radius is not the same as De Loos et al. Because when we calculated the electric field, we noticed that the electric field near the edge of the anode bends greatly as shown in Fig.2. To obtain straight electric field on the axis, we set up wider radius. We also found that the electric field strength on the axis was rather small comparing with that in the place between two plates. This calculation says that the energy of produced electron beam does not attain 2MeV, even if electric field of 1MV/mm is supplied to the gap of 2mm. To solve such problems, we propose an idea, which is explained in the following chapter.

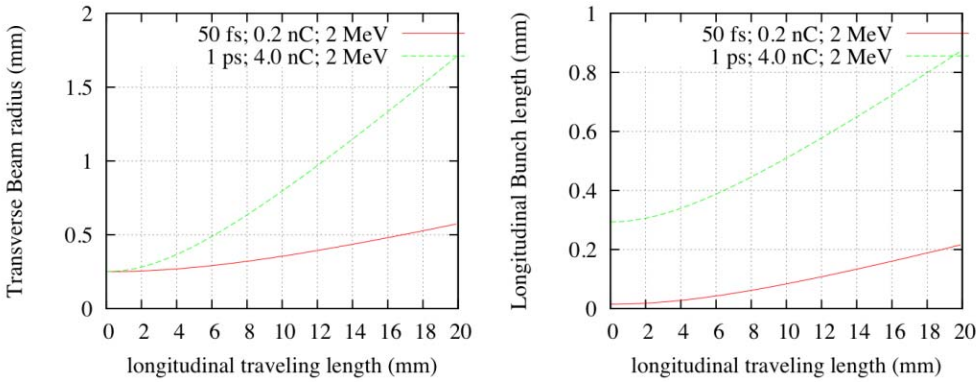

Figure1: Two beams with the energy of 2MeV and their radiuses are the same sizes of 0.25 mm. Broken line shows a beam with the time width of 1ps and the charge of 4.0nC. Solid line shows the other beam with 50fs and 0.2nC, respectively. They pass through drift space of 20mm long. Beam sizes get larger to transverse and longitudinal directions due to space charge effect.

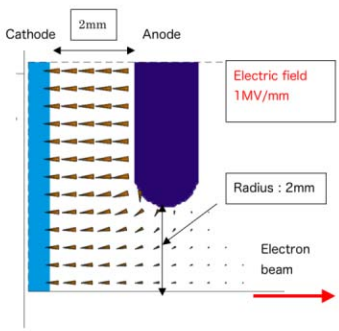

Figure 2: Electric field was calculated by the computer simulation code of MAFIA. The gap length is 2mm and the radius of the anode is 2mm. Supplied electric field is 1MV/mm. The electric field near the edge of anode plate greatly curves. Beam emittance is grown there.

IMPULSE HIGH VOLTAGE (HV) GENERATOR

High voltage generator with short time width has been widely used in particle physics for the tracking measurement of charged particle. Spark chamber with high voltage generator is popular as an example. And HV generator named Marx generator was developed and has been used widely. Chikovani and Roinishvili et al [5] developed an apparatus named streamer chamber, which is able to see the tracks of charged particles in three dimensions. The feature of the HV generator for a streamer chamber used in the experiment of UA5 at CERN were a10ns-time width, a high voltage of 2MV by 1Hz, and the experiment was ended without trouble. We may say that impulse HV generator has been technically established. To shorten the time width of high voltage at the level of 1 or 2ns, the combination of Chikovani's method and modern instrument of laser technology makes it possible. It seems that de Loos et al. [1] made a simulation by thinking of this kind of impulse HV generator. It must be noted that there is a paper that Brussaard et al. [6], made the impulse HV generator.

A METHOD TO RAISE THE BEAM ENERGY AND KEEP THE LOW EMITTANCE

To produce low emittance beam from electron gun, De Loos et al [1] performed the simulation by using the impulse HV generator and the photocathode impulse-gun. Basing on their result, we propose an idea to suppress the growth of emittance. In the figure 1, we showed that drift space after the photocathode impulse-gun degrades the emittance. Our idea can shorten the drift space and furthermore can raise the electron energy up to around 10MeV or so. The schematic mechanism is shown in Fig.3. In the figure, the photocathode impulse-gun is first installed and followed by short drift space. And a structure consisting of two plates and small gap is set up. We name the structure impulse accelerating structure. We supply a pulsed high voltage generated by impulse HV generator to the impulse accelerating structure. And we construct a series of the impulse accelerating structures as shown in Fig.3. If we assume the gap length of 2mm, total length becomes less than 5cm. In addition, if the impulse HV generator could supply stable high voltage of 1MV/mm, we could obtain high energy and low emittance electron beam in a short length. Even if the impulse HV generator can not supply the strong electric field of 1MV/mm, we can decrease the maximum electric field at lower level such as just half of 1MV/mm, of which field is good enough to raise the electron beam

energy up to 5MeV by using the set-up as shown in Fig.3. Adjusting the gap length between cathode and anode in consideration of the beam length of longitudinal direction, the beam is transported to the following accelerating structure with low emittance kept.

It must be noted that Van der Geer et al. [7] have already made a similar proposal before we mentioned above.

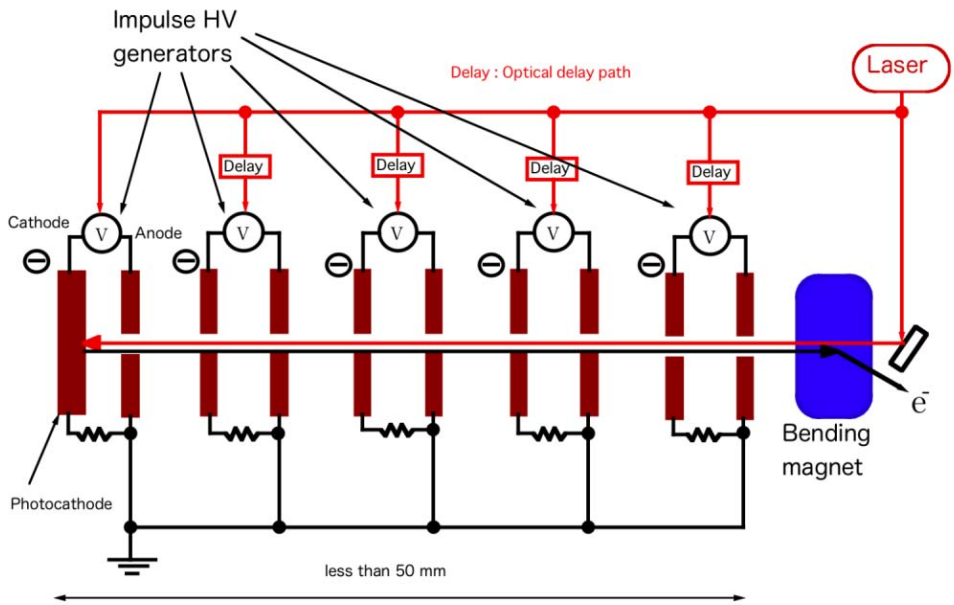

Figure 3: Schematic view. Electron beam is radiated from the cathode plate by laser. The gap between cathode and anode is around 2mm and supplied high electric field of 1MV/mm with an impulse HV generator in a short time of a few ns. The following accelerator structures are also supplied electric field by the impulse HV generators. Every impulse HV generator is fired simultaneously by laser timing system synchronized with a fundamental radio frequency with the timing accuracy of around 1ps. Total length from photocathode to the end of accelerating structures is less than 5cm.

SUMMARY

In order to obtain the electron beam that satisfies the demand of FEL, it is necessary to use impulse HV generator. We think that photocathode impulse-gun, which combines the HV generator with laser, is one of the best methods as the electron gun. To accelerate the beam with low emittance kept, the issue of drift space has to be solved. We think that only the impulse accelerating structures combined with the impulse HV generator can solve it. We think it is the best solution at present.

ACKNOWLEDGEMENT

The author wishes to thank A. Mizuno, T. Kobayashi, H. Tomizawa, Y. Ohashi, H.Ego and T. Asaka for their helps and encouragements.

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