ELECTRON BEAM PULSE PROCESSING TOWARD THE INTENSITY MODIFIED RADIATION THERAPY (IMRT)

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Abstract

Radiation therapy attracts attention as a one of cancer therapies nowadays. Toward next generation of the intensity modulated radiation therapy (IMRT), the processing of electron beam is studied using a Laser photo cathode RF gun linear accelerator (LINAC). Accelerated electron beam pulse will be converted to X-ray pulse by a metal target bremsstrahlung method or by a laser inverse Compton scattering method**.** Recently, the radiation therapy of cancer is developing to un-uniform irradiation as IMRT. A photo cathode RF gun is able to generate a low emittance electron beam pulse using a laser light. We thought that a photo cathode RF gun can generate intensity and shape modulated electron beam by processing of incident laser light. Because of a low emittance, a processed electron beam pulse was able to accelerate keeping shape. Electron beam processing by photo masks in incident optical system and generated beams are reported here. Images on photo masks were transported to a photo cathode surface by optical relay imaging. Beams were monitored by Desmarquest ($Cr:Al_2O_3$) luminescence. Spatially separation of a spot to a spot is about 0.3mm. Modulated electron beam had fine spatially resolution enough to use radiation therapy.

INTRODUCTION

At present, the 1st of the death cause in Japan is cancer. The radiation therapy is developing remarkably as one of the cancer therapies in recent years. In America, the radiation therapy exceeds 63% of the cancer therapies. The radiation therapy of cancer in Japan was about 16% (150,000 persons) of the cancer therapy in 2003. The person who has a radiation therapy is expected 450,000 in 2015. Various radiations are used for the cancer therapy, γ-ray from ^{60}Co, X-ray converted from electron beam generated by accelerator, heavy ion and proton beam generated by accelerator. As for the radiation cancer therapy, when the dose is irradiated on the cancer tissue, the normal tissue and the scarfskin are irradiated, become a problem. When the side effect is strong, the quality of life of the patient decreases.

The radiation cancer therapies developed into the direction which reduces the dose to the normal tissue while concentrating the dose to the cancer tissue. A lot of ^{60}Co γ-ray sources are arranged for the gamma knife. The cancer tissue is arranged in the overlapping high dose area of those gamma rays. The dose can concentrate to the cancer tissue and the dose to the normal tissue can reduce.

The heavy ion beam cancer therapy is remarkable especially. When using a heavy ion beam, while reducing the dose which is irradiated to the scarfskin and the normal tissue, the dose can concentrate to the cancer inside the human body efficiently. On the other hand, the heavy ion accelerator is so big and expensive, thus it is only about 20 in all over the world. The all patients who need a radiation therapy can not be provided by the heavy ion beam therapy.

Intensity Modulated Radiation Therapy (IMRT)

The latest X-ray cancer therapy by LINAC is developing into the un-uniform X-ray irradiation such as the intensity modulated radiation therapy (IMRT). Present IMRT is explained here. The electron beam which was accelerated by a small LINAC is irradiated to the metal target and is converted into the uniform X ray. The shape and intensity of the generated X-ray are modulated by the multi leaf collimator. By turning the electron beam accelerator, it irradiates from multi direction and it reduces the dose to the scarfskin and the normal tissue. It becomes a safe irradiation method to the normal tissue. The X-ray irradiation equipment which used the electron beam LINAC becomes popular since it is small and cheap comparatively.

We are studying further development of the IMRT which used the photo-cathode electron accelerator. The laser photo-cathode LINAC generates the electron beam pulse by the photoelectric effect on the copper surface by UV laser light. The very high quality (=low emittance) electron beam compared with the conventional thermal electron gun can be generated and accelerated.

We thought the new idea toward the IMRT that the shape and the intensity distribution of the electron beam

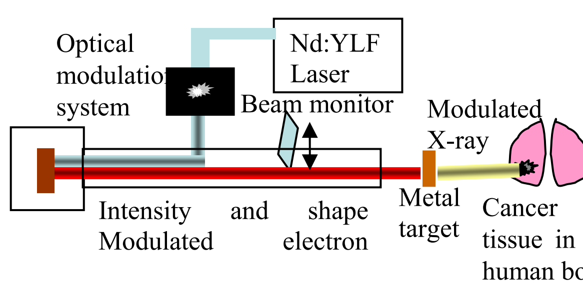

Fig.1 Concept figure of the Intensity modulated radiation therapy by the photo-cathode electron accelerator

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pulse can be controlled by processing the incident light pulse for the electron beam generation (fig.1)[1]. The processed electron beams are converted into the X-ray. And the IMRT of the next generation are developed in Osaka Univ. The electron beam processing for the IMRT by photo-masks in incident optical system and generated beams are reported here.

EXPERIMENTAL

Electron beam pulses were generated by a laser photo-cathode RF gun s-band LINAC at ISIR in Osaka University shown in Fig.2. This photo-cathode was made of Oxygen-Free Copper. Fourth harmonic generation (FHG: 262nm) of Nd: YLF laser (Timebandwidth) with 5ps pulse duration was injected into a photo-cathode perpendicular toward a copper surface.

Several kinds of photo-masks were used for the processing of an incident laser light as the preliminary optical processing method. Optical images on the photo-mask were transported to the cathode surface. Processed light was incident into the central axis of the RF cavity. Electron was generated by the photo- electric effect at copper surface. Maximum acceleration electric field at the cathode surface reaches 100 MV/m. Electron beam pulse generated at cathode surface was accelerated immediately to about 5MeV by the 1.6 cell cavity which operated by 2856MHz RF. Therefore, the expanse of the electron beam by the coulomb repulsion among electrons is reduced. Coaxial solenoid was arranged to compensate the emittance increase of the low energy electron beam at the down stream of the electron gun. By this feature of the photo cathode electron gun, the electron beam which kept the processed shape can be accelerated to the high energy. Furthermore, this electron beam pulse was accelerated to about 35MeV by 2m travelling wave accelerate tube.

Normalized transverse emittance was about 3mm-mrad at 1nC. Typical electron pulse duration was about 5ps at 1nC. The detail of the ISIR photo-cathode LINAC was reported else where [1]. Electron beams were monitored by CCD camera images of the Desmarquest ($Cr:Al_2O_3$) luminescence.

RESULTS AND DISCUSSIONS

The 4th harmonic generation of the Nd:YLF picosecond laser which was processed by the various photo masks were injected into the photo-cathode.

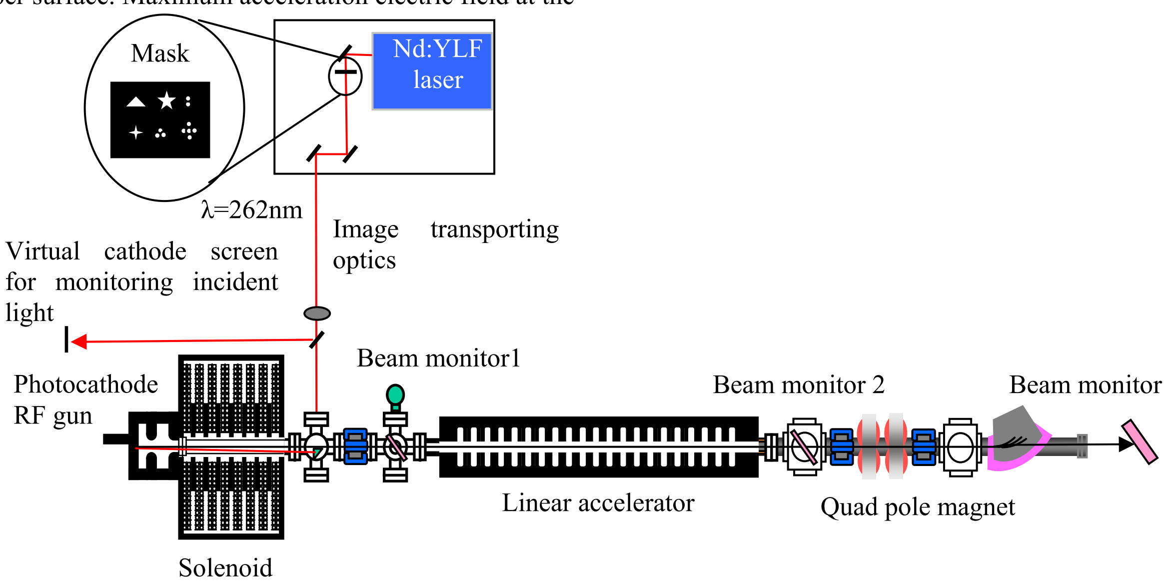
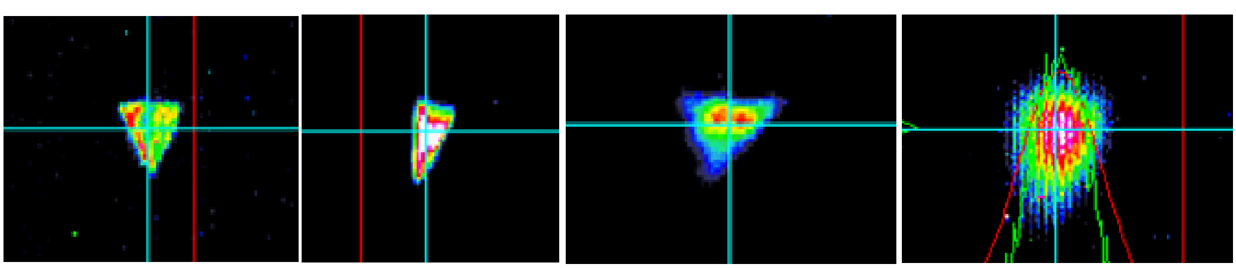


Fig. 2 The laser photo cathode electron linear accelerator with the optical processing incident optical system (photo-masks and image transport optics) and the electron beam monitor (desmarquest plate and CCD camera)



(a)Laser Image on the Virtual cathode screen (b) The electron beam image at the exit of the electron gun (c) The electron beam image at the exit of the accelerator tube (d) The electron beam image in the air at the exit port

Fig.3 CCD camera images of the luminescence of the desmarquest plate.

Various photo masks were used, such as two holes, triangle, cross type, multi holes, etc. The electron beam shape was observed at exit of the electron gun (Fig.3(b)), behind the linear accelerator tube (Fig.3(c)) and in air near the exit port (Fig.3(d)) respectively. The image of the laser which was processed by the triangle photo-mask and the images (the intensity modulated) of the electron beam in each place of the accelerator was shown in figure 3. The image of the laser which was monitored in the position which is equivalent to the cathode was a sharp triangle(Fig.3(a)). The image on the triangle photo-mask was transported to the cathode. The electron beam image at the exit of the electron gun was most cleared (Fig.3(b)). It was observed by the beam monitor plate (desmarquest) that the electron beam was accelerated as keeping the shape approximately. The shape of the electron beam at the exit of the electron gun was good comparatively. The shape of the electron beam changed gradually a little. At the accelerator exit (Fig.3(d)), the spot diameter of the electron beam spread respectively. Then, the distance among the spots of the electron beam spread in the case of the two spots pattern. When trying to make the electron beam small by the quadrupole magnet, the shape can not be kept.

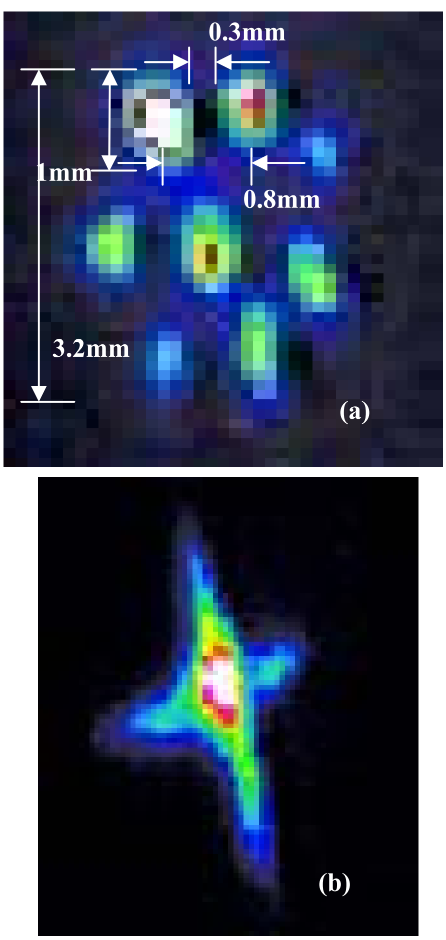


Fig.4 Spatially resolution of (a) the multi spots electron beam and (b) the cross shape electron beam

The other images of the processed electron beam are shown in Fig.4, (a) the 8 spots electron beam and (b) the cross shape electron beam. When the electron beam was accelerated, multi-spots was keeping a shape than the integrate type. Since original laser intensity distribution was the Gaussian distribution, it thinks that the center of the electron beam became strong, too. The shape of the electron beam will be easy to break by the space charge effect when the non-uniformity of the intensity distribution is big, like a cross shape electron beam. The multi-spots type electron beam was easy to keep a shape; because of the space charge effect may be small comparatively. Spatially separation of a spot to a spot at the exit of the gun is about 0.3mm. One spot size was about 1mm. Total spots size was about 3.2mm. Modulated electron beam had fine spatially resolution enough to use radiation therapy.

SUMMARY

Toward the intensity modulate radiation therapy of cancer; we thought the new idea that the shape and the intensity distribution of the electron beam pulse can be controlled by processing the incident light pulse for the electron beam generation. The electron beam processing for the IMRT by photo-masks in incident optical system as a preliminary study are reported here. It succeeded in the generation of the electron beam which modulated a shape and intensity by processing light by the incident optical system for the photo cathode RF electron gun linear accelerator. Modulated electron beam had fine spatially resolution enough to use radiation therapy. In the next step, the intensity and shape modulated electron beam irradiate to the metal target and convert into the X-ray by the bremsstrahlung method. The shape of the electron beam will be controlled with the computer at the real time automatically.

REFERENCES

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