

DYNAMIC OPTICAL MODULATION OF THE ELECTRON BEAM FOR THE HIGH PERFORMANCE INTENSITY MODULATED RADIATION THERAPY

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Abstract

The radiation therapy of cancer is developing to un-uniform irradiation as the Intensity Modulated Radiation Therapy (IMRT), for reduce dose to normal tissue and concentrate dose to cancer tissue. 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 modulated electron beam by optical modulation at the incident optics dynamically. Because of a low emittance, the modulated electron beam pulse was able to accelerate keeping shape. Human body is always moving, for example breathe, thus the cancer is also always moved. For radiation therapy, electron beam must be synchronized to breathing. Toward the high performance (high speed modulation and high special resolution, etc) IMRT, dynamic optical modulation of the electron beam pulse were studied using a Photo cathode RF gun. Images on photo masks were transported to a photo cathode surface by optical relay imaging. Dynamic optical control of electron beam was carried out by remote mirror. Modulated electron beam had fine spatially resolution enough to use radiation therapy. Spatially separation of a spot to a spot is about 0.3mm. Moving electron beam images like an electron beam movie was measured. That thing was impossible by former methods. Modulated and moving electron beam was reported here.

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. 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.

As for the radiation cancer therapy, when the radiation beam is irradiated on the cancer tissue, also the normal tissue and the scarfskin are irradiated, these become problems. When the side effect is strong, the quality of life of patients decreases. The radiation therapy of cancer is developing for reduce the dose to normal tissue and concentrate the dose to cancer tissue.

Various radiations are used for the cancer therapy, γ -ray from ^{60}Co , X-ray converted from electron beam

generated by small LINACs, heavy ion and proton beam generated by large accelerators.

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 a 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. All patients who need radiation therapy cannot be provided by the heavy ion beam therapy.

The latest X-ray cancer therapy used un-uniform X-ray irradiation such as IMRT. Present IMRT is explained here. Electron beam which was accelerated by a small LINAC is irradiated to the metal target and that is converted into uniform X-ray. The shape and intensity of X-ray are modulated by multi leaf collimator. Multi leaf collimator is made by many small metal pieces and moving mechanically. And those metal pieces stop and reduce intensity of X-ray. By turning and rotating the accelerator, it can irradiate from multi direction and it reduces dose to scarfskin and normal tissue. It becomes a safe irradiation method to the normal tissue. The X-ray therapy equipment which used the electron beam LINAC can become popular since it is small and cheap comparatively.

A photo cathode RF gun was able to generate a low emittance electron beam pulse using a laser light pulse. We thought that the photo cathode RF gun can generate intensity modulated electron beam by optical modulation at the incident optics dynamically. Because of a low emittance, the modulated electron beam pulse was able to accelerate keeping shape. Human body is always moving, for example breathe, thus the cancer is also always moved.

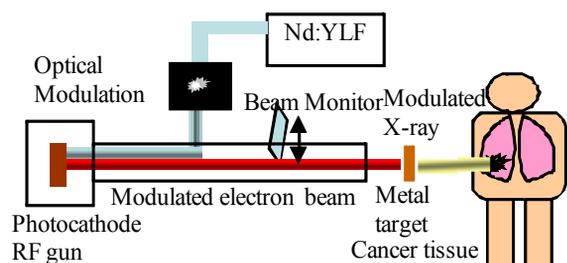


Figure 1: Concept of high performance IMRT, dynamic optical modulation of electron beam by a Photo cathode RF gun

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For radiation therapy, electron beam must be synchronized to breathing and other moving of a body. Toward the high performance (high speed modulation and high special resolution, etc) IMRT, dynamic optical modulation of the electron beam pulse were studied using a Photo cathode RF gun LINAC. Modulated and moving electron beam was reported here. Accelerated electron pulses will be converted to X-ray pulses by a metal target bremsstrahlung method or by a laser inverse Compton scattering method. This problem will be reported elsewhere.

EXPERIMENTAL

Electron beam pulses were generated by a laser photo-cathode RF gun S-band LINAC at ISIR in Osaka University. 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 cathode surface. Photo-masks were used for the shaping of an incident laser light as the preliminary optical processing. Images on the photo-mask were transported to the cathode surface. As a second stage study of light modulation of electron beam, the electron beam was moved dynamically by a remote mirror in incident optics system.

Electron was generated by the photo- electric effect on copper surface. Maximum acceleration electric field which was operated by 2856MHz RF reached 100 MV/m at the cathode surface. Electron beam which generated at cathode surface was accelerated immediately to about 5MeV in the 1.6 cell RF cavity. Therefore, the expanse of the electron beam by the coulomb repulsion force among electrons was reduced. Coaxial solenoid was arranged to compensate the emittance growth of electron beam at the downstream of the electron gun. This solenoid was very important for imaging of electron beam.

Electron beam was monitored by CCD camera images of luminescence of the scintillator (Demarquest AF995R). When electron beam accelerated up to 32MeV by an accelerating 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 already reported in ref [1].

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 shown in Fig.2 upper side. Various photo masks were used, such as two holes, triangle, cross type, multi holes, etc. In Fig.2 lower side, 8 spots electron beam and cross shape electron beam was observed at exit of the electron gun. Since original laser intensity distribution was the Gaussian

distribution, it thinks that the centre of the shaped electron beam became strong. Total size of processed electron beam was about 3.2mm. Spatially separation of a spot to a spot at the exit of the gun is about 0.3mm. One spot size was about 1mm. Shaped electron beam had fine spatially resolution enough to use radiation therapy.

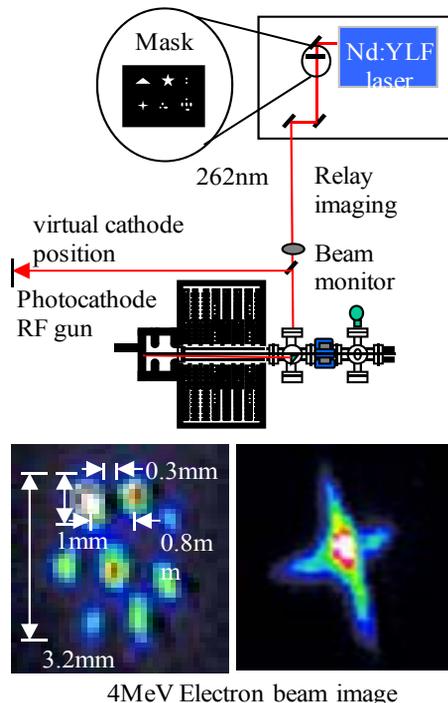


Figure 2: Shaped electron beam by photo masks in incident optics had fine spatial resolution.

In the next step, dynamic optical modulation of electron beam was carried out. For achievement of high speed, high spatial resolution and computer controlled optical modulation; we consider the integrated mirror devices as a DMD™ (digital micro mirror devices by Texas Instruments) and/or DM (deformable mirror). A DMD is integrated device of millions of micro mirrors. By a micro mirror switching ON/OFF, shaping and intensity modulation of light are carried out. Laser light have a Gaussian like spatial distribution, i.e. the centre of laser light is high intensity. For short pulse laser, intensity modulation is difficult by only one DMD. For this reason, laser light will be separated for DMD and DM. DMD is suitable for shaping and Deformable mirror is suitable for intensity modulation. Shaped and intensity modulated light were mixed and transported to a photocathode. The fact that affinity of the image diagnostic device is high is one big advantage of our method. Based on real time output image of CT (computed tomography) and PET (positron emission tomography) and MRI (magnetic resonance imaging) etc. and therapy plan on a computer, irradiation can be controlled easily. Human body is always moving, for example breathe, thus the cancer is

also always moved. For radiation therapy, electron beam must be synchronized to breathing. At present stage there are several problems in the use of DMD.

In order to show the fact that dynamic optical control of the electron beam is possible, basic experiment was carried out by simple experiment system. Laser light was divided to two passes, one made the light intensity small by filters, and another made the size small by a mask. A remote mirror was used in the optical pass of small size and high intensity (Fig.3). The high intensity small spot was moved around the low intensity large spot. Simple

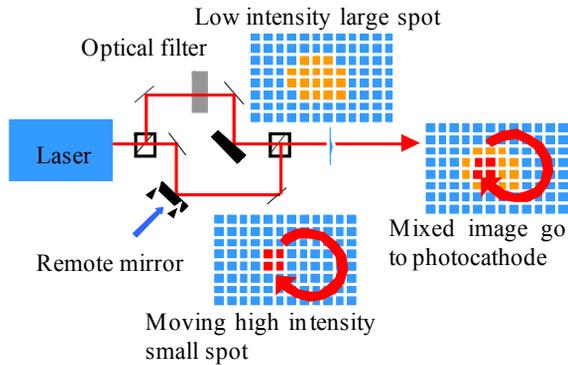


Figure 3: Basic experiment of dynamic optical modulation of electron beam.

electron beam movie was measured as a demonstration of dynamic optical modulation of electron beam. Former method cannot do this type electron beam modulation. Snap shots of electron beam movie are shown in Fig.4. As a second step of optical modulation of electron beam, the electron beam processing dynamically by a remote mirror in incident light optics system was succeeded.

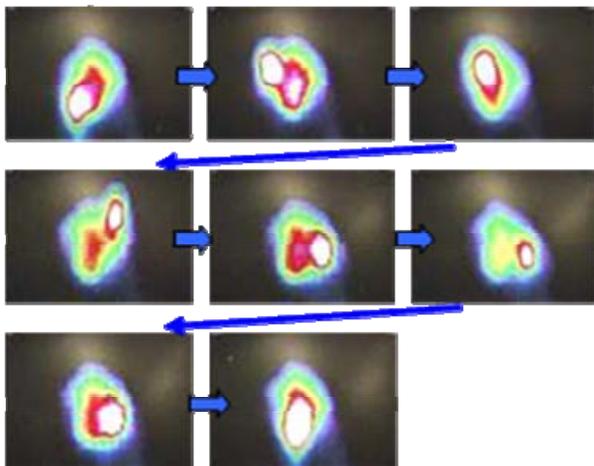


Figure 4: Pick up snap shot images from electron beam movie.

SUMMARY

Toward the high performance IMRT (high speed modulation and high special resolution, etc), we thought a new idea that shape and intensity distribution of electron beam can be controlled dynamically by processing incident light for a photocathode. Electron beam which modulated by photo-masks had fine spatially resolution enough to use radiation therapy. As a second stage study of light modulation of electron beam, the electron beam processing dynamically by photo-masks and by a remote mirror in incident light optics system were succeeded. The shape of electron beam will be controlled with a computer and optical devices at the real time automatically.

REFERENCES

[1] J. Yang, T. Kondoh, K. Kan, T. Kozawa, Y. Yoshida, S. Tagawa, Nuclear Instruments and Methods in Physics Research A 556(2006)52-56