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A TREATMENT BEAM CONTROL SYSTEM FOR IRRADIATION GATED BY RESPIRATION OF A PATIENT

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Abstract

A beam control system for irradiation treatment gated by respiration of a patient has been developed at HIMAC to minimize an unwanted irradiation to normal tissues around tumor. The system employs rf-knockout extraction with gate function. Preliminary experimental results, which were carried out with moving phantom and simulating signal of respiration, are encouraging.

1. INTRODUCTION

Clinical trial has been successfully progressing since June 1994, after commissioning of a heavy ion accelerator complex, HIMAC, dedicated to medical applications [1].

A high irradiation accuracy is required in heavy ion therapy because of the high dose localization. In treating a tumor moving along with respiration of a patient, in particular, damage to normal tissues around tumor is inevitable without beam control that gates irradiation according to respiration. A beam delivery scheme, which can respond to irregular respiration, should be applied in order to minimize the unwanted irradiation to normal tissues around tumor. At HIMAC, therefore, such a system has been developed [2,3].

The design considerations and the preliminary experimental results are reported in the paper.

2. BEAM CONTROL SYSTEM

A beam control system for the irradiation gated by respiration requires essential design considerations as follows. (1) Beam extraction method should respond quickly to a trigger signal according to irregular respiration. (2) Operation pattern of synchrotron should give maximum irradiation dose rate. (3) An aborting system of residual beam should be provided in order to avoid undesired activation by unused beam.

2.1 Extraction method

Concerning the irradiation gated by respiration, it is important to start and stop beam extraction promptly according to the beam "on/off" signal. One of the suitable extraction methods for this purpose is beam extraction using a transverse rf field resonated with a horizontal betatron tune, while a separatrix is kept constant, which is called "rf-knockout extraction". The transverse rf electric field is applied with frequency and amplitude modulation. The frequency modulation increases an extraction efficiency because it broadens a frequency band width corresponding to a horizontal tune spread at a resonant extraction. The amplitude modulation is applied to control a spill envelope of an extracted beam. Advantages in the present method are 1) prompt response to start and stop of the beam extraction because of using an rf electric field with a faster response compared with magnetic elements, and 2) a small emittance in the horizontal direction due to a constant separatrix. The results from experiments showed that the response is within 1ms and the horizontal emittance of beam extracted by the present method was reduced by about 70% compared with that by the ordinary extraction method. The extraction efficiency in the present method was more than about 85% which was comparable with that in the ordinary method. The details were reported in Ref. [2].

2.2 Operation pattern of synchrotron

To optimize an operation pattern of synchrotron, it is assumed that a respiration pattern is independent of an operation pattern of synchrotron, and an irradiation for treatment is continued infinitely. Under the condition, an irradiation dose rate is maximized at an extraction duty factor of 50%, because a beam can be extracted as long as the extraction period is coincident with an irradiation period permitted by the respiration pattern. If the extracted beam intensity can be infinitely increased, on the other hand, the dose rate is increased as increasing the duty factor. At HIMAC, therefore, the dose rate is maximized at the duty factor of 50% in the 0.3Hz operation of synchrotron. The effective dose rate in this operation can be kept at the operational value if the extracted beam intensity is increased by 70%, which will be easily realized.

All of the accelerated beam should be extracted as soon as the extraction signal is generated, to reduce effective irradiation period. On the other hand, an irradiation period more than 10 times longer than that of wobbling magnets is required to obtain a uniform dose in the lateral distribution. The amplitude of a transverse rf field is determined so that all of the accelerated beam is extracted during about 400ms in order to satisfy the above requirements.

2.3 Beam aborting system

In the irradiation gated by respiration, the residual beam has to be aborted around synchrotron, because the accelerated beam should not be extracted from synchrotron as long as a "beam off" signal is generated. Decelerating the residual beam to an injection energy as a beam aborting system is proposed to avoid unwanted activation around synchrotron. As a result of the preliminary test, the deceleration efficiency was about 80%. Details will be presented elsewhere[4].

Summarizing the above considerations, an operation patten of the beam control system for the irradiation gated by respiration is schematically shown in Fig. 1.

3. EXPERIMENTAL RESULTS

An irradiation gated by respiration was preliminarily experimented by using a phantom moving along with a simulating signal of respiration [3]. In the experiment, synchrotron is operated by a cycle of 0.3Hz with a duty factor of 45%. Carbon beams with the energy of 290 and 400MeV/n are extracted from synchrotron by the rf–knockout method, and delivered through an irradiation system to an isocenter at a treatment room. Concerning the experimental setup in the treatment room, a phantom placed at the isocenter is moved with a stroke of 25mm and, is driven by a 0.33Hz sinusoidal signal that pretends respiration. The simulating signal is generated by a sensitive strain gauge set on the phantom. A collimator with an aperture of 40mm square is placed in front of the phantom in order to define an irradiation field, and is 450mm distant from the phantom.

Figure 2 shows a typical result of a beam extraction gated by the simulating signal. As can be seen in the figure, the beam was successfully extracted in only the permitting irradiation period. A penumbra size was also obtained by measuring a density of an exposed X–ray film attached with the phantom moving along with the simulating signal. Three cases, i.e, a fixed phantom, a gated irradiation to moving phantom, and an ungated irradiation to moving phantom were investigated as shown in Fig. 3. The penumbra size P_{80-20} in three case were obtained as 2.4, 6.1 and 19.4mm, respectively, where P_{80-20} is defined at the distance of the lateral dose falloff from 80% to 20%.

The P_{80-20} in the fixed phantom is naturally less than that in the gated irradiation, because the phantom in the latter case moves somewhat during the irradiation due to applying a sinusoidal wave as the simulating signal. However, the P_{80-20} in the gated irradiation is considerably reduced to 6.1mm from 19.4mm in the ungated irradiation.

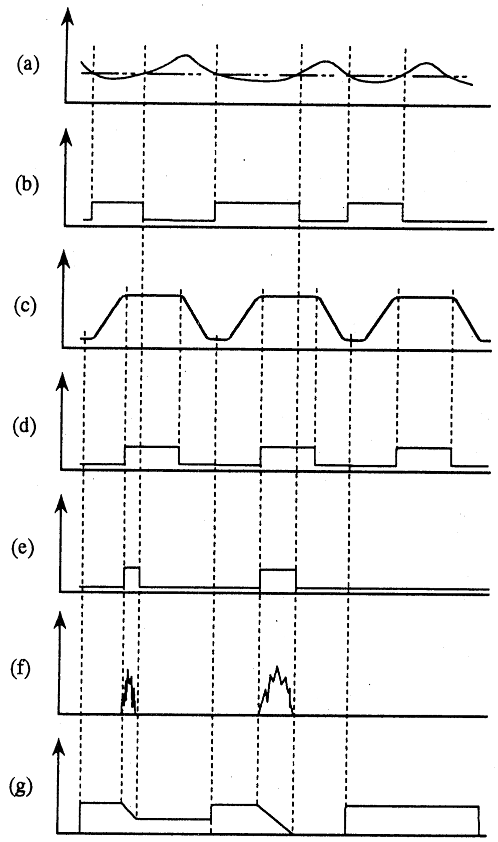

Fig. 1 Schematic operation pattern of the system for irradiation gated by respiration. (a) Respiration signal, (b) Permitting irradiation signal, (c) Operation pattern of synchrotron, (d) Flat–top signal, (e) Extraction signal, (f) Beam spill, (g) Circulating beam intensity.

4. CONCLUSION

The beam control system for irradiation treatment gated by respiration is developed. The beam control system's ingredients are; rf–knockout extraction that can respond to a respiration signal quickly, a 0.3Hz, 50% duty operation of synchrotron that maximizes dose rate, and a beam deceleration as a beam aborting system.

As preliminary results of experiment, an extraction gated by a simulating signal of respiration was successfully achieved. The penumbra size was also measured by using a phantom moved along with the simulating signal, and was considerably reduced to 6.1m from 19.4mm in the ungated irradiation. The system will play an important role in clinical study such as treatment for a lung or liver cancer moved along with respiration of a patient.

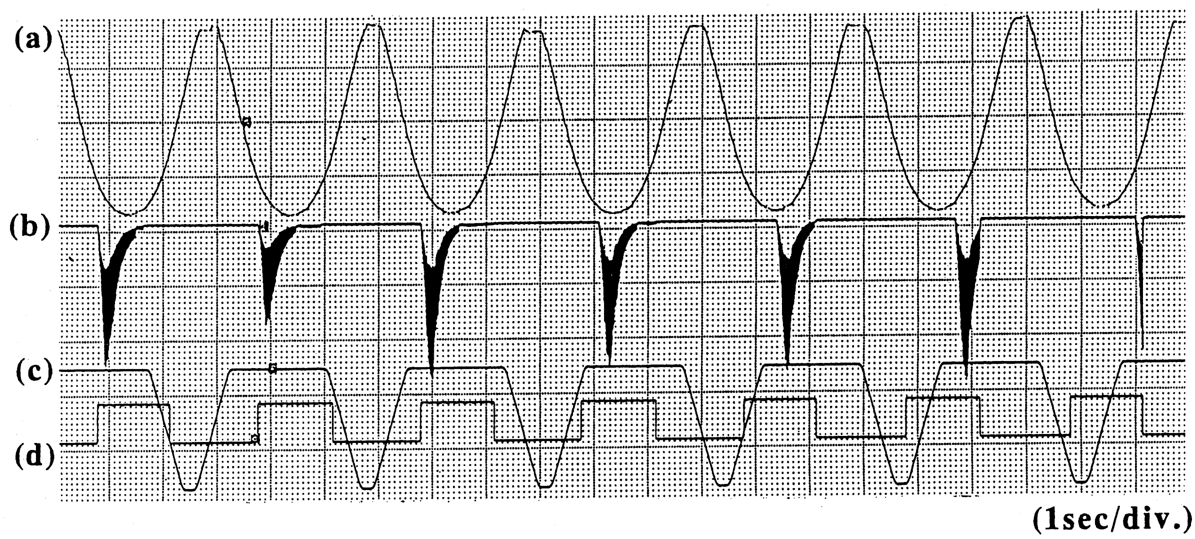

Fig. 2 Beam extraction gated with the simulating signal of respiration in 400MeV/n carbon beam.
(a) Simulating signal of respiration, (b) Beam spill, (c) Operation pattern of synchrotron, (d) Permitting irradiation signal.

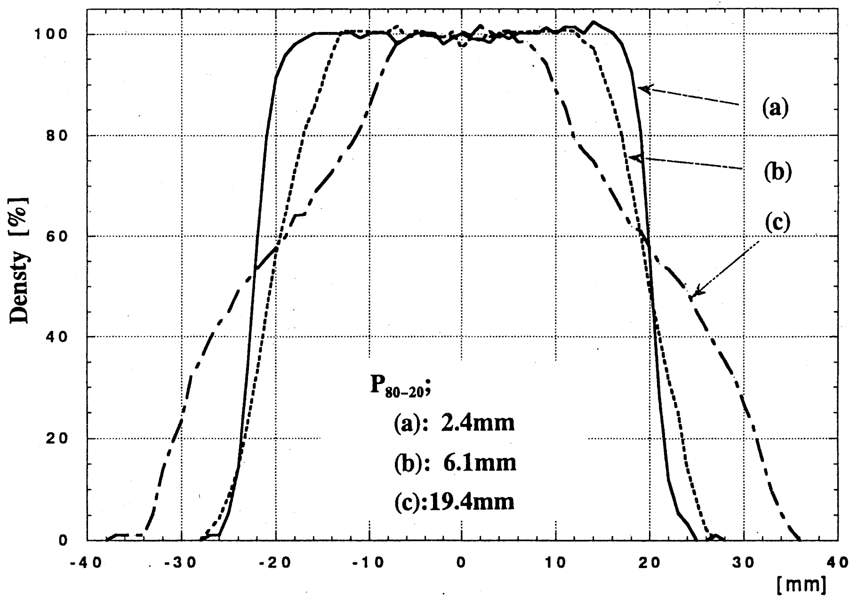

Fig. 3 The lateral dose distribution in 290MeV/n carbon beam. (a) fixed phantom, (b) gated irradiation to moving phantom, (c) ungated irradiation to moving phantom.

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