DEVELOPMENT OF THE NEW TYPE MLIC WITH PMMA PLATES AND GRAPHITE ELECTRODES

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Abstract

The MLIC (Multi-Layer Ionization Chamber) that has a lot of ionization chambers stacked in the depth direction is a useful detector for measuring the depth dose distribution (DDD). By using the MLIC, the measurement time and the amount of beam for dosimetry are drastically decreased. In HIMAC (Heavy-Ion Medical Accelerator in Chiba), the MLIC has been effectively used for QA (Quality Assurance) measurement of heavy-ion therapeutic beam since 2002. We are developing a new type MLIC that has electrodes made of graphite on the surface of the polymethyl-methacrylate (PMMA) plates for particle therapy. The purpose is to obtain the same results as the DDD measured in water. We will report on the progress of the development.

INTRODUCTION

In heavy ion therapy, the quality of the beam has to be checked every day. The DDD is an important indicator of the beam condition. However, the DDD measurement needs much time with the existing method that used the dosimeter moving step by step in the depth direction. The MLIC can measure the DDD at once. It has a lot of measurement points regularly arranged in the depth direction. Therefore, it does not need time for changing the depth position of the dosimeter. In addition, the amount of the beam used for the measurement of the DDD could be reduced.

In HIMAC, the MLIC has been used since 2002. It has contributed to the increase of the number of treatment by shortening the measuring time of the DDD. More specifically, the measuring time was reduced to about 3 minutes from about 20 minutes. It does not include the time to set up and to put away the detector.

From the experience in using the MLIC, it has been recognized as useful means for quality assurance of the heavy-ion therapeutic beam in HIMAC. On the other hand, it was found necessary to improve the accuracy of the dosimetry with the MLIC. In external beam therapy, the dose distribution in water is treated as a reference. Therefore, it is preferable that the output of the MLIC closes in the DDD in water. However, the MLIC used in HIMAC is not so because it has the electrode substrates made of glass epoxy plate (FR4) and copper foil. These electrode substrates also have been used for an energy absorber of the heavy-ion beam. The materials of them are composed of higher atomic number elements than water. The varieties of the fragmented particles generated by these materials are different from ones generated in water, under irradiation of the heavy-ion beam. In such effect, it is expected that the measurement result of the existing MLIC is different from that of the DDD in water.

We are developing the new type MLIC (See Figure 1) that can output the equivalent data of the DDD in water. This MLIC has the electrode substrates made of PMMA and graphite. The constituent atoms of these materials are only hydrogen, carbon, and oxygen. Therefore, the effect of the fragmented particles generated inside the new type MLIC will be close to the water phantom. However, we have not yet reached that make a specific assessment for the results of the new type MLIC, for now. In this paper, the progress of its development is described.

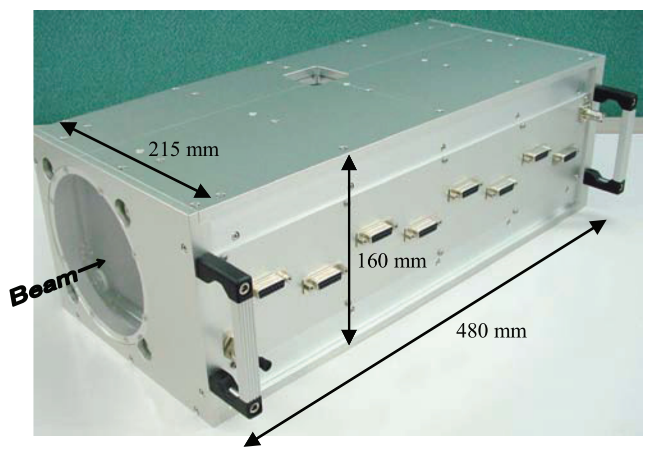

Figure 1: The picture of the new type MLIC.

DESIGN OF THE NEW TYPE MLIC

The MLIC has a lot of ionization chambers stacked in the depth direction. The ion chambers of the new type MLIC are parallel plate type. Each electrode substrates are placed orthogonal to the beam traveling direction. The momentum of the beam particles are lost by passing through the electrode substrates. In essence, progresses to the back side of the MLIC, the beam particles slow down. The amount of charge collected by each stacked ionization chambers has varies depending on the depth position. Therefore, we will get the DDD as the Bragg peak. The measuring range of the new type MLIC is about 280 mmWEL (Water Equivalent Length) that corresponds to 400 MeV/u carbon beam.

Figure 2 shows the structure of the new type MLIC. And, Table 1 is the specification of it made for Gunma University Heavy Ion Medical Center.

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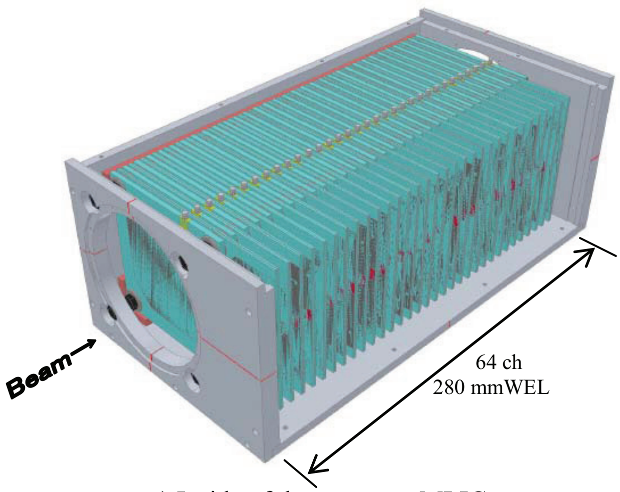
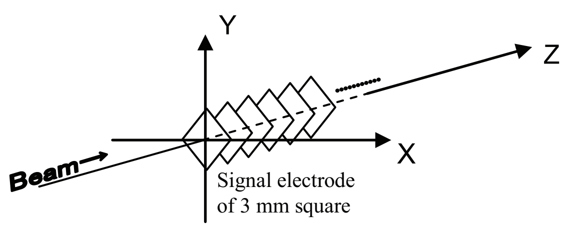


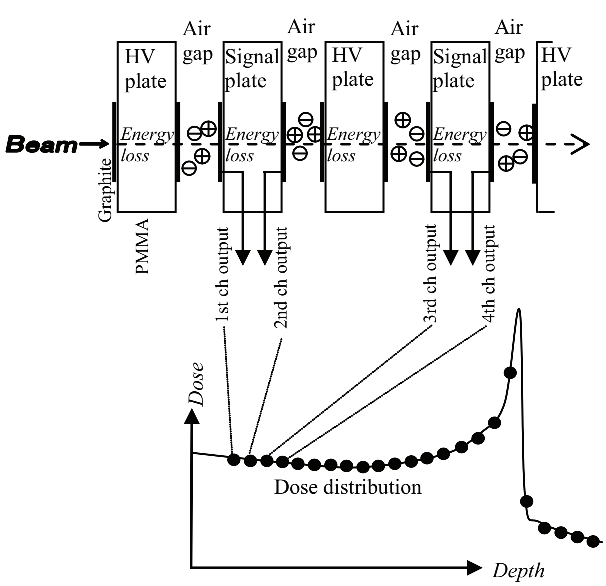
a) Inside of the new type MLIC

The stacked ionization chambers are parallel plate type. Each electrode substrates are placed orthogonal to the beam traveling direction.



b) The array of the signal electrodes

The signal electrodes were placed regularly the beam traveling direction at the center of the irradiating area.



c) Arrangement of the electrode substrates

The HV (high voltage) plates and the signal plates are stacked alternately. This figure shows the overview of the DDD measurement.

Figure 2: The structure of the new type MLIC.

Table1: Specification of the new type MLIC

Size of the casing (without handles)	Width 215 mm Height 160 mm Depth 480 mm
Material of the casing	Aluminum alloy with anodized
Weight	about 18 kg
Aperture size	ϕ 128 mm
Material of the aperture window	PMMA
Thickness of the aperture window	2.32 mmWEL
Number of channels	64 ch
Measuring Range	about 280 mmWEL
Resolution of depth position	4.3-4.4 mmWEL
Thickness of PMMA plates	3.5 mm
Thickness of graphite electrodes	10-20 μ m
Air gap	3 mm
Size of the signal electrodes	3 mm square
Sensitive volume	27 mm^3
Operating high-voltage	+0.6 kV

The MLIC outputs weak current signals, therefore, the measuring system must be careful to noise. The MLIC, the high-voltage power supply, and the measuring module must have a common ground level that is grounded at a single point. Figure 3 shows an overview of the cabling. The guard electrodes enclosing the signal electrodes are grounded indirectly through the measuring module, and insulated from the casing of the MLIC in order to prevent creating the ground-loop.

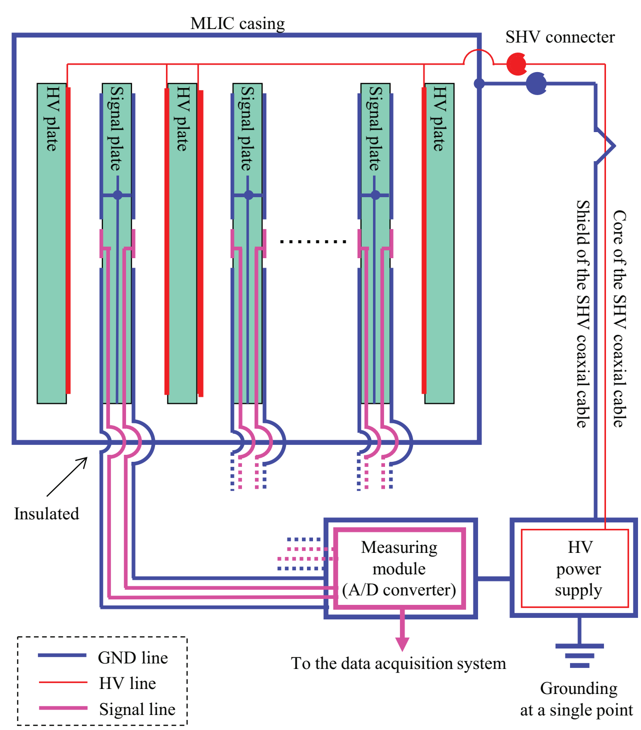


Figure 3: Overview of the cabling.

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On the normal operation, the applied high-voltage to the new type MLIC was determined to be +600 V from the measured data (see Figure 4). The voltage characteristic was flat above +200 V, so the applied voltage must be more higher. Other hand, considering the risk of discharge, the voltage value must not be too high.

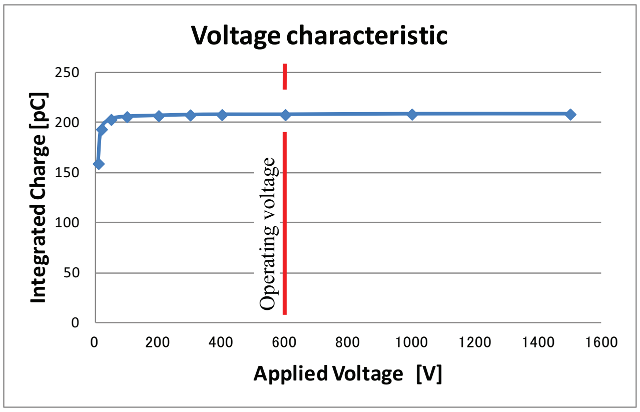

Figure 4: Voltage characteristic of the new type MLIC.

CALIBRATION OF THE MLIC

A calibration of the MLIC is needed in order to measure the DDD. The calibration of the MLIC has two purposes, the one is to correct the individual difference of each channel, and other one is to enable that the measurement results are treated as the DDD. The outputs of each channel of the MLIC mean only the amount of collected charge. The amount of the change is affected from such as the dark current, the beam divergence, and atmospheric. Each effect has to be corrected before the calibration. And then, the output data of the MLIC with these corrections can be compared with the reference of the DDD that was measured using the water phantom.

Correction of the dark current

The MLIC and the measuring module have dark current. In proportion to the time required for the measurement, the component of the dark current will be added to the integrated charges.

This correction requires the data of the dark current that was measured before the irradiation. At i-th channel of the MLIC, the obtained signal without irradiation ($C_{i,\mathrm{dark}}$) is the data of the integrated dark current. The required time for measurement of dark current is defined as t. The dark current of i-th channel ($I_{i,\mathrm{dark}}$) is given by Eq. (1).

$$I_{i,\mathrm{dark}} = \frac{C_{i,\mathrm{dark}}}{t} \quad (1)$$

The corrected value of dark current (X_i) is given by Eq. (2), Where T is the measuring time of the beam and x_i is the output of i-th channel at that time.

$$X_i = x_i - I_{i,\mathrm{dark}}\, T \quad (2)$$

The dark current correction should be done before other corrections that are described later.

Correction of the beam divergence

This correction means geometrical correction. Irradiation beam tends to diverge, therefore, the amount of the beam that is received at a signal electrode depends on the depth position of it.

The depth size of the MLIC is 480 mm, however the water equivalent range is 280 mm. It means that the actual position of the electrode substrate is different from the water equivalent position. The outputs obtained at actual positions have to be modified as measured at the water equivalent positions. As shown in Figure 5, the base point of beam divergence is called the virtual source position. The fluence decreases in inverse proportion to the square of the distance from the virtual source position. Then, the correction factor of i-th channel (D_i) is given by Eq. (3).

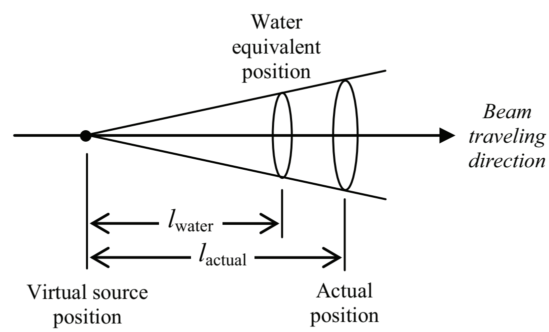

Figure 5: The beam divergence.

$$D_i = \frac{{l_{i,\mathrm{actual}}}^2}{{l_{i,\mathrm{water}}}^2} \quad (3)$$

The actual positions of each electrode substrates were measured relative to the MLIC casing at the time of manufacture. Further, by using the beam, the water equivalent positions of them were measured from the shifting amount of the Bragg peak.

Correction of the condition of atmospheric

This correction cancels the effects of atmospheric pressure and temperature. The correction factor (A) is given by Eq. (4). This factor is the same for all channels.

$$A = \frac{P_{\mathrm{ref}}}{P}\,\frac{K}{K_{\mathrm{ref}}} \quad (4)$$

P: actual value of atmospheric pressure [hPa]
P_{ref}: reference of atmospheric pressure [hPa]
K: actual value of temperature [Kelvin]
K_{ref}: reference of temperature [Kelvin]

The value ($X_{i,\mathrm{correct}}$) that is applied all corrections is given by Eq. (5).

$$X_{i,\mathrm{correct}} = A\, D_i\, X_i \quad (5)$$

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Figure 6 shows the corrected data of the MLIC. This data was measured by irradiating carbon beam of 380 MeV/u.

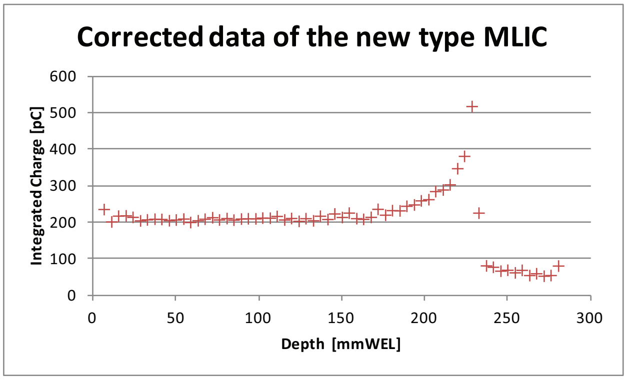

Figure 6: The corrected data of the new type MLIC.

Calibration of the MLIC

The corrected data of the MLIC was compared with the DDD measured by using water phantom as reference value. In this case, both have to be obtained in the same beam irradiation conditions. In addition, at the time of comparing, the water equivalent positions of each channels of the MLIC have to be matched the depth position of the water phantom. The ratio between the two was used as calibration constant. The calibration constant of *i*-th channel (k_i) is given by Eq. (6).

$$k_i = \frac{W_{\mathrm{ref}}}{X_{i,\mathrm{correct}}} \quad (6)$$

W_{ref}: reference value measured by using water phantom

If the new data (element: y_i) is measured under arbitrary condition of irradiation, the DDD (element: $Y_{i,\mathrm{calib}}$) will be obtained by using Eq. (7).

$$Y_{i,\mathrm{calib}} = k_i\, Y_{i,\mathrm{correct}} = k_i\, A\, D_i\, (y_i - I_{i,\mathrm{dark}}\, T) \quad (7)$$

MEASUREMENT OF THE DDD

Using the new type MLIC calibrated by above method, we measured some DDD under different conditions of irradiation.

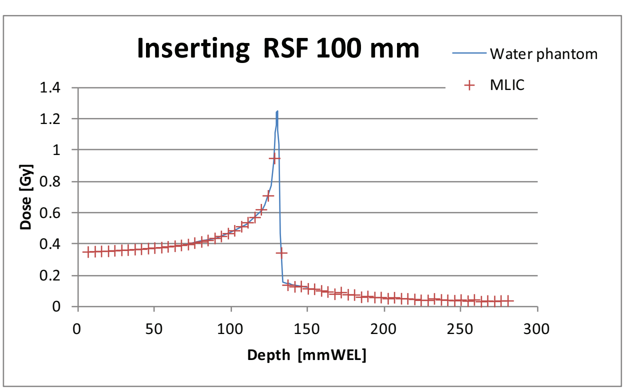

Figure 7: Inserting RSF of 100 mm (carbon 380 MeV/u).

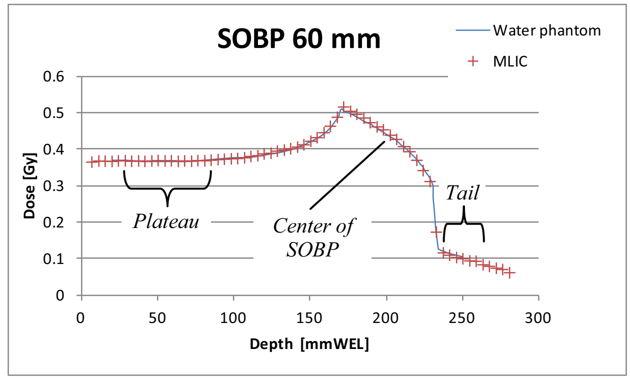

Figure 8: SOBP 60 mm (carbon 380 MeV/u).

Table2: Relative displacement of the MLIC data in Fig.8

Subject of comparison	Displacement
Plateau region (average)	+0.4 %
Center of SOBP (Depth: 201.5 mm)	+1.1 %
Tail part (average)	-4.7 %

The DDD of Figure 7 was measured by irradiating carbon beam of 380 MeV/u with 100 mm range-shifter (RSF). Figure 8 shows the result of spread-out Bragg Peak (SOBP) of 60 mm. In each figures, the measuring data of the water phantom layered on the MLIC data. Table 2 shows the relative displacement of the MLIC data from the water phantom data in Figure 8.

CONCLUSION

The new type MLIC showed a trend that meets our expectation. The displacement from the reference that was measured by using the water phantom was about a few percent as shown in Table 2, however, it is only evaluation in limited conditions of irradiation. To get confirmation of water equivalent, it has to been tested in many conditions.

In the case as to check the difference of the beam quality in the day-to-day, the new type MLIC is not required water equivalent. So it may be used in the current state.

ACKNOWLEDGMENT

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