# UNIFORM IRRADIATION SYSTEMS USING A ROTATABLE STAGE FOR TEST FACILITIES OF PEFP

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*Abstract*

A new irradiation facility has been developed using not only electric magnets but also a rotatable stage.

Generally, the scanning method using magnets has been widely used in most of facilities. However, in this study another new methods have been developed : Two scanning method using a rotatable stage have been proved to make uniform irradiation-as large as 20 cm in diameter with more than 90% uniformity. The mechanical wobbler system makes the same effect as the wobbler system. And the beam is swept along the spiral path with a fixed and variable angular frequency during the scanning in the spiral scanning system.

## INTRODUCTION

Irradiation methods are developed to irradiate uniformly over a large target. Those are a double-scattering beam delivery system[1], a wobbler system[2], a spiral beam scanning system[3, 4] and a raster beam scanning system[5].

Most of irradiation facilities have been adopted the wobbler scanning method or raster scanning method which utilizes two dipole magnets in series that are positioned and powered in such a way as to create a rotating magnetic field or rectangular areas by a zig-zag mode of the beam sweeping. It has been developed the spiral scanning method, which using magnets just like the wobbler system and the raster scanning system, in theory. But this method has not been proved experimentally.

A large area uniform irradiation can be realized without loss of particle energy and beam current in the wobbler scanning method, the raster scanning method and the spiral scanning method because of no interaction with the beam.

In this paper, we have developed the spiral scanning system, which utilizes not electromagnets but a rotatable target stage. Additionally, a mechanical wobbler system is composed of rotation and rectilinear motion of the stage that makes circular beam trajectory on the target. The method of measuring dose distribution is also considered in this study.

## SYSTEM DESIGN

### Beamline Instrumentation

The beamline layout, shown in Figure 1, has been outlined and is described in more detail below. The facility consists of a degrader system, a scatterer system, and a rotatable stage. An exit window is coated with the phosphor material(P42) so that the inflow and shape of the beam can be monitored. In addition, the degrader and scatterer system are placed after the exit window. The degrader and scatterer are a set of pure aluminum sheets and gold sheets of various thicknesses. The beam spot size and energy of the beam can be controlled by placing, in the beam, the appropriate subset of aluminum and gold sheets.

After the exit window, a target stage can move to 2.5m on linear motion block, so the beam energy and shape can control by air thickness, too.

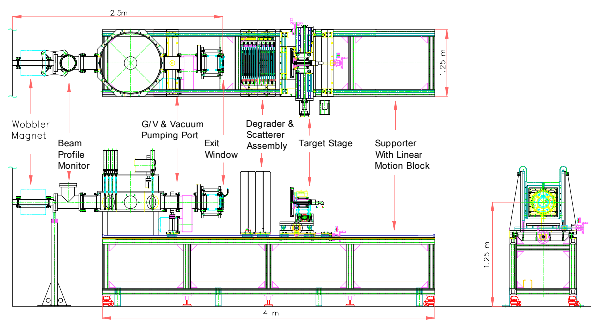


Figure 1: 50MeV beamline which is attached to the MC-50 cyclotron at KIRAM.

### Target Stage

To make circular and spiral trajectory of the beam without magnets, a rotatable stage is designed. Rectilinear and rotatable motion is performed by two servo motors and a ball screw. The maximum velocity is 1000rpm for the rotation and 50mm/s for rectilinear motion. The control and DAS system are built up with the Lab Window.

The target stage is used as a beam dump with 18mm pure aluminum for the 50MeV proton beam which is extracted from the MC-50 cyclotron at Korea Institute of Radiological & Medical Sciences. The cooling system is also adopted to protect organism samples.

### Measurement of the Uniformity

Film dosimeters widely used for radiation processing with electron beams and $\gamma$-rays are suitable for measurement of dose distribution because of their high spatial resolution and simplicity in the measurement.

Fluence distributions of the scanned beam were evaluated by GafChromic$^{TM}$ MD-55 film for the proton beam[6].


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## THE SPIRAL SCANNING SYSTEM

In order to produce a large uniform irradiation field by delivering a continuous beam or a shortly pulsed beam, the spiral beam scanning method can be applied. In this method, the beam is swept at a fixed angular frequency during scanning. The larger radius gets, the higher sweeping speed gets. The radial spacing of the trajectory has to get small to keep the particle density constant for producing the uniform irradiation field[4]. This method is convenient and simple for control.

### *Numerical Simulation*

A numerical calculation was carried out to decide conditions of the experiment and to study effects of operating parameters on the uniform irradiation.

Figure 2 shows cross sections of the two-dimensional particle distributions and this results indicate that minimum radius of the beam trajectory is the dominant parameter.

Because it is clear that for better uniformity of irradiation the number of revolutions of the beam which covers the target should be larger, because of increasing of total revolutions induces decreasing the minimum radius of the beam trajectory and the velocity of rectilinear motion at that position. We define the minimum radius as the value when the beam situate the first a quarter revolution in this study.

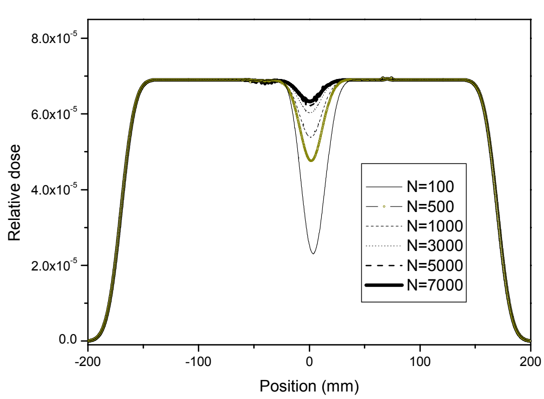


Figure 2: Number of revolutions vs. relative dose ($\sigma = 10mm, R = 170mm$).

Numerical calculations were carried out for illustrating the dose distribution depending on the Gaussian beam size($\sigma$) when the total revolutions($N = 1500$) and the maximum radius of scanning($R = 170mm$) is constant. It is interesting to note that a sharp beam induces more precise flat zone with the greater sinking depth. However, the broad beam makes a gentle ascent of the dose distribution.

These results indicate that increasing of the beam size induces the improvement of uniformity as shown in figure 3.

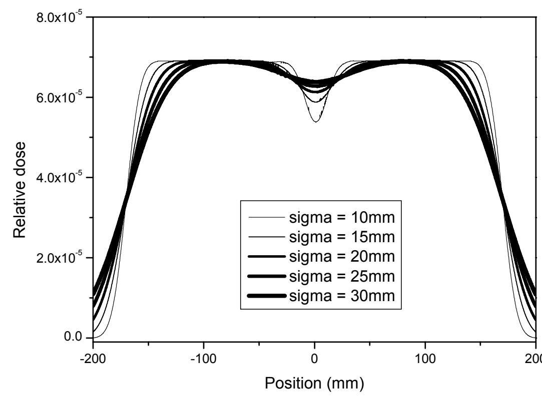


Figure 3: Dose distribution with various beam sizes.

### *Experiment of the Spiral Scanning Method*

As mentioned before, the minimum radius of the beam trajectory is the dominant parameter and the velocity of rectilinear motion is limited as $50mm/s$. So, we try to a different method to overcome the limitation of subsidence at rotational center and velocity of the rectilinear motion. In the experiment, the system parameters were set as $w = 1950rpm$, $R = 250mm$, and $N = 3250$ and the rotatable stage motion is started at $-5mm$ from the original position. In figure 4, the experimental result is compared with the numerical result.

It is observed that a large uniform dose distribution can be produced by this method which accomplished a flat zone of more 30cm diameter with over 90% uniformity.

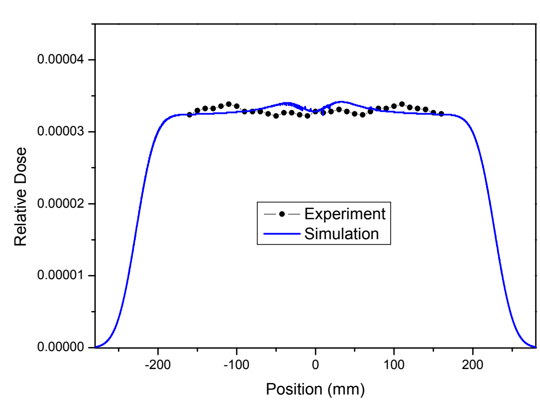


Figure 4: A fluence distribution measure by film dosimeter and calculation result of spiralscanning method

## MECHANICAL WOBBLER SYSTEM

Generally, the wobbler system utilizes two dipole magnets in series that are positioned and powered in such a way as to create a rotating dipole field. A uniform dose distribution is achieved by superposition several circular trajectories with different intensities. A higher dose is required in the outer beam trajectory than that required for the smaller inner trajectory.

In a mechanical wobbler system which is proposed in this paper, the circular trajectory of the beam can be made by rotative and rectilinear motion of a stage. The dose intensity of trajectories was controlled by irradiation time, respectively.

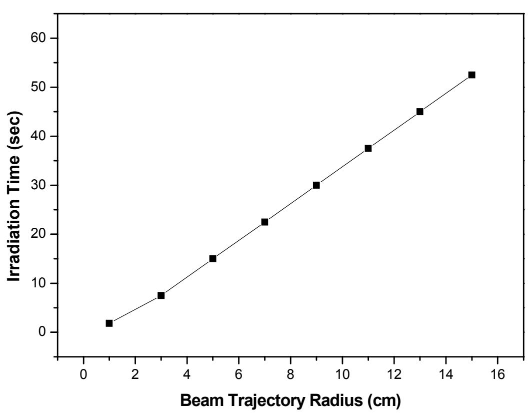


Figure 5: Experimental condition of irradiation time and moving distance.

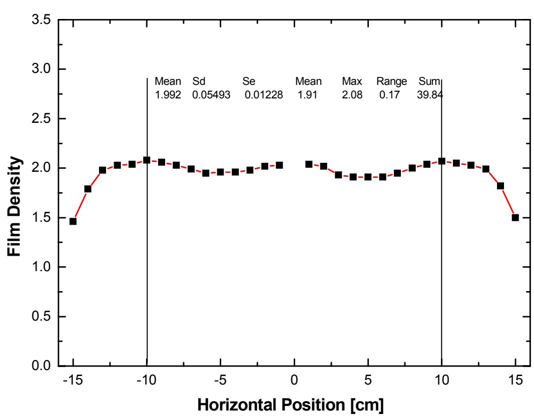


Figure 6: A fluence distribution measure by film dosimeter of mechanical wobbler method.

A large uniform field is obtained by superposition of circular beam trajectories. The gaps of radii are set as $\sigma$ of Gaussian distribution. In the experiment, the radius of the beam trajectory is increased as $2cm$ because of $\sigma$ is about $22mm$.

Figure 5 shows the relation between irradiation time and radii of the beam trajectories. It is observed from Figure 6 that a large field of uniform doses is produced with this method. The dose rate of a proton beam which is extracted from MC-50 cyclotron is $5Gy/s$.

It has been shown that a superposition of circular beam trajectories of approximately Gaussian-shaped beam spots can produce a flat field of 20cm diameter with a net mean dose of $50.7Gy/cycle$ and the uniformity of 90%.

## CONCLUSION

The spiral scanning method and the mechanical wobbler method were developed using a rotatable stage and were experimented with a 50MeV beamline which is established by the Proton Engineering Frontier Project. Numerical calculations for these methods were carried out and the results indicate that large fields of uniform doses can be obtained by a rotatable stage without magnets. It is inferred from the experimental results that up to $20cm$ diameter fields with 90% uniformity can be achieved by a spiral scanning method and a mechanical wobbler method only using a rotatable stage.

## ACKNOWLEDGEMENT

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## REFERENCES

[1] A.M. Koehler, R.J. Schneider and J.M. Sisterson, "Flattening of proton dose distributions for large-field radiotheraphy", Medical Physics, 4 (1977) 297.

[2] T.R. Renner, W.T. Chu, "Wobbler facility for biomedical experiments", Medical Physics, 14 (1987) 825.

[3] M. Fukuda, S. Okumura and K. Arakawa, "Simulation of spiral beam scanning for uniform irradiation on a large target", Nuclear Instruments and Methods in Physics Research A, 396 (1997) 45.

[4] Y.K. Batygin, V.V. Kusin and S.V. Plotnikov, "Circular Beam Scanning of Large Targets", Proc. $4^{th}$ European Particle Accelerator Conf. London, UK, 1994, pp. 2435-2437.

[5] Th. Haberer, W. Becher, D. Schardt and G. Kraft, "Magnetic scanning system for heavy ion therapy", Nuclear Instruments and Methods in Physics Research A, 330 (1993) 296-305.

[6] http://www.ispcorp.com

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