AN IRRADIATION PRODUCTION UNIT FOR POLYMER RESEARCH

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Abstract

Electron irradiation is a well known method in polymer research for studying polymer structure changes. Using an existing 6 MeV linear accelerator a general irradiation facility has been built which is especially suited for this purpose. The monitored dose is variable between 5 and 300 kGy and may be evenly distributed over the sample, with a typical size of 10x10x0.5 cm^3. The linac macro pulse frequency is in the range of 1 to 50 Hz and the maximum irradiation duration is in the order of minutes. Regarding sample conditions: the temperature can be controlled between 20 and 300 $^{\circ}C$ in an environment of pure nitrogen. The control system has been modernised using a PLC controller together with a visualisation program (Intouch®). Distributing the dose over the sample is realised either by sweeping the beam in the vertical direction using a bending magnet and moving the sample in the horizontal direction, or with the help of a permanent quadrupole magnet, inserted in the beam guiding system.

1 INTRODUCTION

A general irradiation facility has been realised in the cyclotron building of the Department of Physics of the Eindhoven University of Technology which is especially suited for the irradiation of polymer targets and can therefore be a tool in the research of polymer materials. It is based on a medical accelerator which has been used before to treat cancer patients.

This electron accelerator has been thoroughly modified and modernised [1] in order to make it suitable for the irradiation set-up. By using this machine as a basis the total cost of the project is rather small in comparison with the cost of a complete commercial set-up.

2 DESCRIPTION OF THE IRRADIATION FACILITY

The set-up, see Fig. 1, delivers a pulsed electron beam with a pulse duration of 3.6 μs with a pulse repetition frequency of ≤50 Hz. The average current is between 10 μA and 70 μA, depending on the current through the glow cathode. The corresponding electron energies are 6 MeV and 4 MeV respectively.

To achieve a more homogeneous depth dose distribution the average current is fixed at 10 μA.

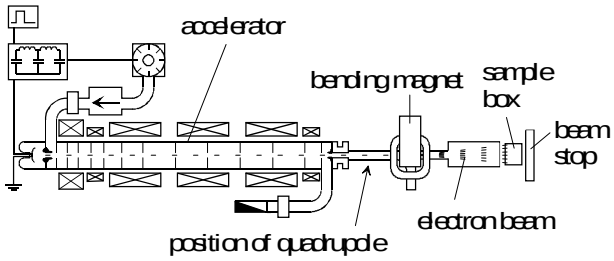

Fig. 1. *The accelerator and the added beam guiding system.*

With this facility it is possible to irradiate polymer samples with a size of max. 10x10x0.5 cm^3 with a varying dose between 5 and 300 kGy. The irradiation time is in the order of minutes. The dose must be delivered homogeneously over the sample with intensity variations within 10% and is being monitored with the same accuracy.

3 DOSE DISTRIBUTION

The dose distribution can be divided into two parts: the depth dose distribution and the surface dose distribution.

The homogeneity with respect to the depth dose distribution can be obtained in two ways: first by taking a thin sample, maximum 2.2 mm for a 6 MeV beam. Second, by using the almost linear increase in the beginning of the curve of the energy deposition with depth [2], see Fig. 2. This linear part can be used beneficially by giving the sample half the dose with the beam entering from the front, turning the sample around and giving it the remaining half with the beam entering from the back. In this way the dose increases linear with depth and both the linear increases add up to a total depth dose distribution within 10%. With this procedure the sample can have a maximum thickness of 15 mm.

Also the surface dose distribution needs to be homogeneous within 10%. Increasing the beam diameter and using the homogeneous top 10% results for a Gaussian distribution in discarding 90% of the beam current. Therefore sample irradiation usually takes place by using a scanning beam along vertical lines until the required dose is reached and moving the sample in the horizontal direction.

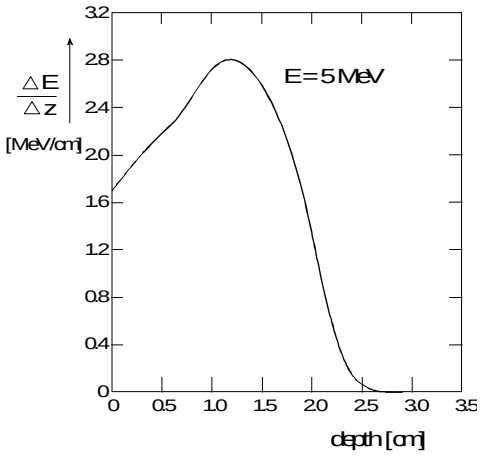

Figure 2 Calculated distribution of energy deposition of 5 MeV electrons versus depth in water. Figure based on [2].

The number of steps in both directions has a minimum of ten in order to obtain the required homogeneity. The beam deflection in the vertical direction is performed by using a fast bending magnet. The number of steps in the vertical direction is fixed because it is essential that the vertical deflection is synchronous with the pulse repetition frequency.

These steps are staircase type in order to minimise the effect of the inductive properties of the magnet and the number of steps is fixed at 16. In the horizontal direction the number of steps can be adjusted with a minimal step size of 0.5 mm.

With 16 steps taken in the vertical direction and 10 steps in the horizontal direction one complete scan takes 3.2 s and with a 10 μA beam current this delivers 640 Gy of dose in a water phantom of 10x10x2.5 cm^3. A minimum dose of 5 kGy then takes 8 scans which take 25.6 seconds plus the time it takes to transport the sample in the horizontal direction which is about 5 minutes. A maximum dose of 300 kGy is delivered in 469 scans which takes 25 minutes plus transportation time so any treatment should take less than about half an hour.

Special applications require the entire sample to be irradiated at the same time, e.g. for applications in the research of polymer growth in a watery solution [3]. For these cases the pulse repetition frequency can be lowered to 1, 2, 5, 10 and 25 Hz and the beam position is fixed. Furthermore the beam diameter can be increased using a removable quadrupole magnet with a focal length of 8.65 cm for 6 MeV electrons [4]. This results in a increasing beam diameter and at the end of the beam guiding system the increase in the vertical direction is a factor of nine and in the horizontal direction a factor of seven.

The quadrupole which is used in the set-up has been provided by Goudsmit Magnetic Systems. It is constructed of permanent magnetic material so that it does not require an additional power supply. The construction consists of two parts which enable the magnet to be easily added to and removed from the beam guiding system. Positioning pins ensure the correct construction procedure.

Finally the doses monitoring needs to be done with an accuracy of at least 10%. The doses used here are rather high. For these doses radiation detectors are commercially available and there are two manufacturers, viz. GAF Chemicals Corp. and Far West Technology Inc [5]. The detection method involves a special dye (hexahydroxyethyl pararosaniline nitrile) which changes colour when exposed to radiation. In the equipment from Far West which has been used in the set-up, the dye is applied to a nylon carrier which is available in the form of sheets of one square centimetre. In practice the dose is monitored by irradiating the film together with the sample if the temperature conditions allow it, otherwise the film and sample are given a separate but identical treatment. Depending on how the material is handled an accuracy of about 5% can be obtained.

4 SAMPLE CONDITIONS

The linac operates under vacuum while the sample is irradiated in an environment of pure nitrogen under atmospheric pressure. Therefore the beam has to be coupled out through an aluminium window with a thickness of 100 μm. The beam is scattered by the foil with a mean angle of 8.2°. After this foil the electrons travel through 2.5 cm of open air before they enter a box containing the sample.

At the front of the box the mean radius of the beam has increased from the initial millimetre to about 3.6 mm. Ten cm downstream, at the end of the box, the mean beam radius is 18.0 mm.

The irradiated sample is placed inside the box and the exact location depends on the kind of experiment which is performed. The box is intended to control the environment of the sample: it enables a irradiation treatment in pure nitrogen and the temperature inside the box can be increased to a maximum of +300 °C using two heating elements mounted in the side walls of the box, together with one thermocouple in each side wall for temperature monitoring.

Both the heating elements and the thermocouples are mounted in such a way that they can not be irradiated by the electron beam directly. This box is constructed of aluminium as this material produces the least radiation if it is struck by high energy electrons. The box has walls of 35 mm thick for good heat transfer on the left and right. The front and back foils of the box, where the beam passes through, are necessary to contain the nitrogen within the box and should disturb the beam as

little as possible. This is why a thickness in the order of 10 μm of aluminium has been chosen.

5 THE CONTROL SYSTEM

In order to safely control the set-up attention has been paid to active and passive safety measures. One of the active measures is that the set-up is operated using a programmable logic controller which interacts with the operator via a pc using the visualisation program Intouch®; this also allows for the machine to be operated easily.

Each user is given a security level and this operator can only turn the machine on and off. If a malfunction occurs this is indicated and the machine will not start up. Operators with higher security levels are able to intervene. The third and final level allows for the machine to be operated manually: every single step in the start up procedure must be instructed individually. This level is especially useful in testing individual components and it requires a detailed understanding of the set-up. Another active safety measure is the radiation detector near the machine which shuts the machine down in case of an irregularity.

There are also passive safety measures: the radiation is shielded off to the outside world by placing the set-up inside a concrete vault with 50 cm thick walls and using a combination of concrete and lead inside the vault. Furthermore, the components of the machine which are at high tension are shielded with grounded metallic plates and the production of ozone has been minimised by minimising the distance of the electrons through open air.

6 CONCLUSIONS

A multi purpose irradiation facility has been realised suited for the irradiation of e.g. polymer targets. The irradiation facility is based on a originally medical linear accelerator. By using this machine as a basis the total cost of the project is a rather low in comparison with the cost of a commercial set-up. The electron accelerator has been modified and the control system modernised using a PLC controller together with a visualisation program which leads to easily operating the whole equipment. With the hierarchy levels in the control safety is ensured.

The electron beam with a pulse width of 3.6 μs has an adjustable pulse repetition frequency of $\leq$ 50 Hz.

The polymer samples temperature can be controlled between 20 and 300 °C in an environment of pure nitrogen. The monitored dose is variable between 5 and 300 kGy and is evenly distributed over the samples.

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