A SCANNING MAGNET FOR A MICROTRON BEAM

S.Axinescu, R.Minea, I.Panaitescu*
Institute of Atomic Physics,
Institute of Physics and Technology of Radiation Devices,
Electron Accelerator Laboratory

Abstract

The parameters of a scanning magnet for use the 17-orbit microtron from the Institute of Atomic Physics, Bucharest are presented. The maximum magnetic induction is B_{max}=0.15T with a polar piece surface of 120×120 mm^2.

To simplify the supply circuits, the coil is fed with a sinusoidal waveform frequency 50 Hz, much less than the repetition frequency of the electron pulses from the microtron, 400 Hz.

Computations proved that in this case the non-uniformities of the current distribution in the sample to be irradiated are up to 30%, which is unacceptable. Using a third-armonic component 150 Hz, with an amplitude of 6% from the amplitude of the fundamental (50) Hz, the non - uniformities of the current distribution are of less than 10%.

The use of the scanning magnet allows to a beam cross-section of 5×40 cm^2at the output window with a beam average of 0.5 kW at a 10 MeV electron energy.1.

1 INTRODUCTION

The microtron has some advantages in applications like radiation processing. It is simpler than the linear accelerator [1], the extraction of the electron beam is easy and the energy spread is typically ± 50 KeV at 10MeV in the case of the microtron from the Institute of Atomic Physics, Bucharest [2].

For such purposes, a beam - line consisting of extraction system, focusing quadrupoles, deflecting magnet and scanning magnet was developed [3]. The last one is essential for applications in radiation processing when surfaces as large as possible have to be irradiated and the uniformity of the absorbed dose in the processed material is a must.

2 BASIC THEORY

The linearity of the magnetic induction B(t) in the scanning magnet is obviously needed and , hence, the linearity of the current feeding its coils. For a series circuit consisting of a resistance R and an inductance L, the equation to be solved is:

$u(t) = R \cdot i(t) + L \cdot \frac{\partial i}{\partial t}$ (1) where
$i(t) = 2 \cdot I_m \cdot f \cdot t$ (2) for $t \in \left[-\frac{1}{2 \cdot f}; \frac{1}{2 \cdot f}\right]$.

* Romanian Academy

I_m is the maximum value of the current and f is the repetition frequency.

Followingly, the voltage $u(t)$ on the exciting coils is:

$u(t) = 2 \cdot I_m \cdot R \cdot f \cdot t + 2 \cdot L \cdot I_m \cdot f$ (3) for $t \in \left[-\frac{1}{2 \cdot f}; \frac{1}{2 \cdot f}\right]$
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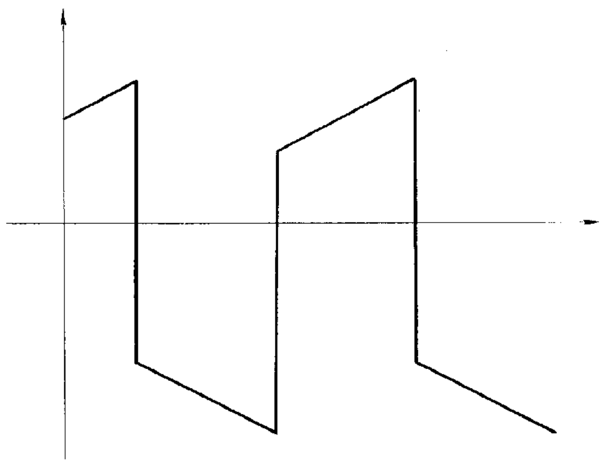

Figure 1: Ideal voltage waveform for a linear scanning magnet

This waveform is represented in fig.1 and is a rather complicated. In our case (gap length 6 cm , B=0.15 T, electron energy 10 MeV) the power needed in the exciting coils is about 200 W [3] and the amplifier is not so easy to build.

A first solution of this problem is to reduce the gap of the scanning magnet by introducing it inside the beam line, in vacuum. This of course causes the severe diminishing of the power in the coils but makes complications in choosing the materials of the whole scanning magnet which will work under 10^{-6} torr pressure conditions.

A second solution was chosen in our case. We decided to feed the coils with a sinusoidal waveform, frequency, 50 Hz , available from the mains.The advantages are clear, but it is necessary to perform detailed computations to check the uniformity , of the beam current distribution in the irradiated sample . Otherwise, the absorbed dose will be non-homogeneous.

3 PERFORMED COMPUTATIONS AND RESULTS

Firstly a graphic solving of the problem was made. For circular poles, at different times, the position of the beam on the sample to be irradiated was graphically determined. Then, a detailed analytical computation was performed. The pole faces are squares with length a and the distance from the poles to the sample is b. The beam deviation becomes:

$$\Delta l\,(t) = \frac{E}{300 \cdot B \cdot \sin(2 \cdot \pi \cdot f \cdot t)} - \sqrt{\frac{E^2}{9 \cdot 10^4 \cdot B^2 \cdot \sin^2(2 \cdot \pi \cdot f \cdot t)} - a^2} + b \frac{a}{\sqrt{\frac{E^2}{9 \cdot 10^4 \cdot B^2 \cdot \sin^2(2 \cdot \pi \cdot f \cdot t)} - a^2}}$$

(4) where E is the electron energy in MeV, and B, the maximum value of the magnetic induction in Tesla (a and b in meters).

For E= 10 MeV, B=0.15 T, f=50 Hz, a=0.12m and b=0.5m computations proved that the current distribution on the sample to be irradiated has a non-uniformity of about 30%, which is clearly unacceptable.

By adding a third armonic component in the coils current with the amplitude of 6% from the fundamental one :($B(t) = B \cdot \sin(2 \cdot \pi \cdot f \cdot t) + 0.06 \cdot B \cdot \sin(3 \cdot 2 \cdot \pi \cdot f \cdot t)$ in (4)) ,the equation (4) gives non-uniformities in the sample to be irradiated of less than 10% [3], a more acceptable value.

In fig.2, the current distribution in the irradiated sample is represented, resulting from the performed computations, in both cases , with and without third-armonic component.

4 EXPERIMENTAL RESULTS

The scanning magnet parameters are:

Polar piece surface:120x120mm^2;

Coils:4,000 turns, copper $\Phi = 1$mm;

Gap:60mm;

Inductance L=14H(measured)

Magnetic induction B=0.133T(measured).

Feeding of the coils was performed using series resonance, with a capacitor of 0.66 μF. This gives obvious advantages, minimizing the power consumption. The measured values were:

Coils voltage: 6 kV;

Coils current: 1.2 A;

Impedance: 5kΩ;

Resonant capacity: 0.66μF;

Resonant circuit voltage: 250 V;

The measured maximum beam deviation from the central position was 20 cm on the material to be irradiated . Measurements were performed at 10 MeV electron energy , with 50 Hz coils current, without the third-armonic component It remains to perform dose measurements for check the validity of the computed current distribution on the sample in both cases, without and with third-armonic component in the scanning magnet coils.

5. CONCLUSIONS

The feeding of the scanning magnet coils with a sinusoidal excitation current seems to be an interesting idea. The 50 Hz frequency and the use of a series resonance circuit simplifies the design. Superimposing a third-armonic component in the coils current improves significantly the linearity of the beam deviation vs. time.This is equivalent to an homogeneous absorbed dose in the irradiated sample and from computations results that the non-uniformities are of less than 10% in this case.

5 REFERENCES

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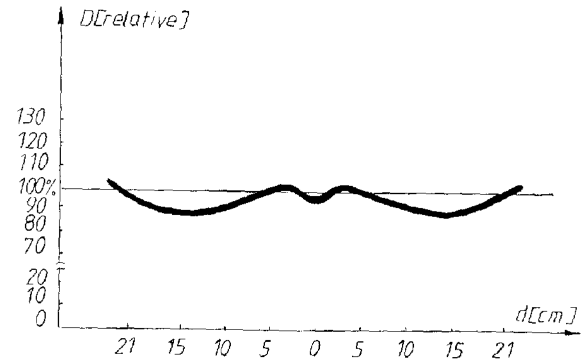
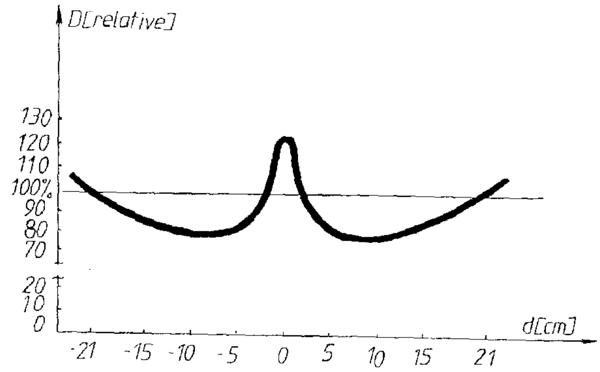


(a) scanning magnet coils fed with a 50Hz sinusoidal waveform



(b) scanning magnet coils fed with a 50 Hz sinusoidal waveform and with a third-armonic component (6% from the 50 Hz fundamental amplitude).

Figure 2: Current distribution