A METHOD OF NON-DISTURBING DIAGNOSTIC OF SCANNED ELECTRON BEAM

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1 INTRODUCTION

High energy electron irradiation of solids goes together with a local heating of the interactions area. In case of a pulsed beam the temperature jump upwards under the impact of an incident single pulse can be evaluated according to the formula

$$\Delta T = \frac{j \cdot \tau_i}{c_p}\left(\frac{dW}{dz}\right), \qquad (1)$$

where *j* is the beam current density, τ_i is the pulse width, c_p is the heat capacity of the material, *(dW/dz)* are the linear electron energy ionization losses (the *z*-axis coincides with the beam propagation direction). At beam parameter characteristics of a high-current linac $\Delta T \leq 10K^o$.

If the pulse width satisfies the condition

$$\tau_i < d / c_s , \qquad (2)$$

where *d* is the characteristic beam size on the interactions area, c_s is the speed of sound; one should note that in the material under irradiation an acoustic wave of thermoelastic nature is generated [1].

The purpose of the report is to demonstrate the possibility of using the above effect for non-disturbing monitoring of a high-power (≥10kW) scanned electron beam.

2 MODEL

In order to lower the beam perturbation by a primary transducer let us consider a thin rod (string) of the length *L* , as sensor of the latter. Let us denote as *U(x,t)* the absolute rod point displacement along the rod axis *X* during the time *t*. This value satisfies the equation [2]

$$\frac{\partial^2 U}{\partial t^2} = c_s^2 \frac{\partial^2 U}{\partial x^2} - k\frac{\partial q}{\partial x}, \qquad (3)$$

where

$$c_s = \sqrt{E/\rho}, \quad k = \frac{\alpha E}{\rho c_p}\left(\frac{dW}{dz}\right),$$

$$q(x,t) = \int_0^t j(x,\tau)d\tau ,$$

E is the Jung pulse modulus, ρ is the rod material density, α is the temperature expansion coefficient.

Solution of the equation (3) for a wave propagation in the positive direction of the *X*-axis gives the following:

$$U(x,t) = \frac{k}{2c_s}\int_0^t q(x - c_s(t-\tau),\tau)d\tau . \qquad (4)$$

If the rod made from a magnetostrictive material and goes through the inductance coil, placed in the magnetic field (magnetostrictive line [3]), then the acoustic pulse *U(x,t)* induces at the coil ends the following signal as a result of the reverse magnetostriction effect

$$V(t) = \Re\left(\frac{\partial U(x_1,t)}{\partial t} - \frac{\partial U(x_2,t)}{\partial t}\right), \qquad (5)$$

where $\Re = (4\pi/c)sn\gamma E$, *c* is the speed of light, *s* is the coil cross-section area, *n* is the number of turns per unit length, γ is the magnetostriction coefficient, x_1 and x_2 are the coordinates of the coil beginning and end respectively.

Analysis of the formula (5) indicates that it describes the oscillatory process with the time interval between start-off and the first zero being $t_O = \tau_1 + d/c_s$, while the signal amplitude is determined by the particle on line density maximum. To put inductance coils at both ends allows to exercise control over the transducer acoustic length during its exploitation. The presence of coil-rod coupling across the magnetic field allows, as well, to monitor the beam current pulse signal which is induced throughout the rod as a consequence of the secondary electron emission prior to the acoustic signal generation. The in-between time interval t_d allows to determine the coordinates of the on-line scanned beam in the real-time regime.

3 EQUIPMENT

For production acoustic line a **FeCo50%** magnetostrictive tape with the dimensions $0.3x0.05x750mm^3$ was used. The tape was strung over a hard frame using the acoustic dampers to bring down the amplitude of signals reflected from the line ends. Each line end goes axi-simmetrically through the inductance coil which is under the permanent magnet field. Fig.1

shows a schematic of the setup for recording and processing of the transducer signals.

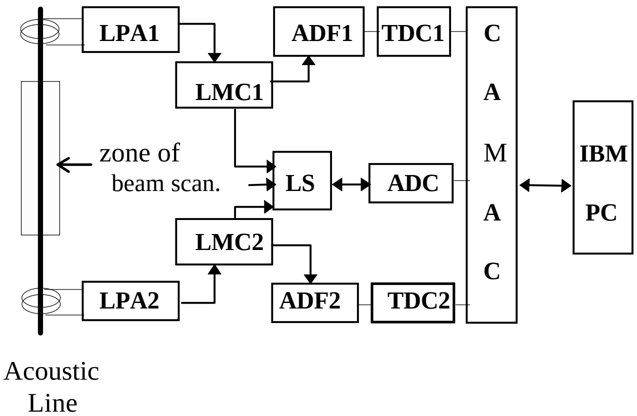

Fig.1. Block diagram of the analyzer channels

Initially, the coil signals come into the linear pre-amplifiers (LPA). The amplitude-temporal analysis of their output signals is computed via the amplitude-to-digital converter (ADC) of the custom design as well as by the time-to-digital converter (TDC) using IBM-type network care of a CAMAC-standart bus. In order to trim the LPA outgoing signals with the input digital converter characteristics a linear matching couples (LMC) and an amplifier-discriminator-former (ADF) where designed. The latter transforms the magnetostrictive line analog signals into the logic ones, the time intervals between which are digitized in the TDC. A multi-channel linear switch (LS) at the ADC input allows to exercise a program control over the incoming objects of amplitude analysis.

4 RESULTS

The experimental studies on pulsed electron beam-induced signal generation in the magnetoacoustic line were performed on LU-10 linac. The accelerator operated in the following regime:

- mid electron energy, MeV	11.5
- pulse width, μs	3.2
- rep. rate, Hz	300
- pulsed current amplitude, A	~1
- beam scanning frequency, Hz	3

During the studies the two above-mentioned signals at the magnetoacoustic line output were observed (Fig.2). A comparison between shapes of the first signal from each transducer and the signal fed into the accelerator chamber of the pulsed current transducer (Rogovski coil) ascertained their similarity. In the meantime, a second (acoustic) signal from the line transducer was observed with a changing temporal interval t_d versus the first outgoing beam signal, with the variation frequency t_d coinciding with that of the beam scanning. The maximum and minimum intervals t_d^{max} and t_d^{min} were measured, whence according to the formula

$$\Delta X = c_S (t_d^{max} - t_d^{min}) , \qquad (6)$$

the beam scanning area length ΔX was determined.

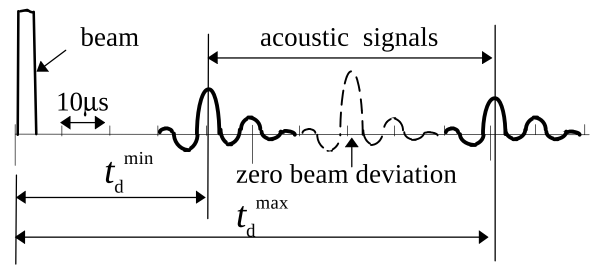

Fig.2. Typical magnetoacoustic line signals

One can determine the c_S value as

$$c_s = L / (t_{d,1} + t_{d,2}) , \qquad (7)$$

where $t_{d,1}$ and $t_{d,2}$ are time intervals for each transducer respectively.

During the simultaneous monitoring of the on-line signal and current in the scanning system magnetic coil one can determine the beam particle energy value, using the beam deviation amplitude $\Delta X/2$ and the corresponding magnetic induction in the magnet gap at the given scanning system geometry.

A simple mathematical treatment of the signals allows to additionally measure the beam width at any point on the line, take evaluations for energy spectrum width, for average beam power and, also, averaged over beam cross-section, its linear current density and absorbed dose rate, i.e. the basic parameters of radiation technology monitoring.

5 REFERENCES

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