CHARGED PARTICLE BEAM ACHROMATIC SCANNING SYSTEM

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ABSTRACT

Principle of construction of achromatic systems with a beam bend angle, varied in time. Magnet-optical system of an industrial tomograph is given as an example. The system ensures achromatic deflection of an accelerated particle beam in scanning on a long target.

INTRODUCTION

Bringing of charged particle accelerators into medicine and many branches of industry forms a necessity to develop new schemes of external magnetic devices, meeting requirements to their characteristics. In particular, it is important in many problems, that transverse dimension of a beam during beam scanning along extended objects should not change. In the famous scanning devices, consisting of a beam transverse focusing system and a pulse deflecting magnet, beam dimension in scanning does change. Mainly, it is due to available pulse spread of particles in a beam and drift of their average energy.

Principle of construction of scanning systems with achromatic properties is under consideration in the paper.

PRINCIPAL STATEMENTS

Any electromagnetic device, deflecting charged particle beams, produces different-force effect on particles, which differ in a pulse. Further movement in a drift space of axial particles with a different pulse in relation to an average particle is characterized by a distance:

$$\Delta X = \mathcal{D}(S)\frac{\Delta P}{P_0} \quad (1)$$

where $\mathcal{D}(S)$ is dispersion, $\Delta P/P_0$ is a relative pulse spread of particles.

Beam transverse dimension in the bend plane will increase by ΔX correspondently.

If one takes a restangular magnet as a deflecting element, then linear and angular dispersion at its output will change:

$$\mathcal{D}_2(t) = \rho(t)(1-\cos\varphi(t))$$
$$\mathcal{D}_2'(t) = tg\,\varphi(t) \quad (2)$$

where $\rho(t)$ and $\varphi(t)$ are radius and bending angle of an axial particle with P_0 pulse.

Let us formulate a question as follows. What is it necessary to do in order to obtain absence of separation at the output of this magnet, that is $\mathcal{D}_2(t)=\mathcal{D}_2'(t)=0$? It is necessary to produce separation of particles at magnet input by means of previous optics so, that linear and angular dispersion should change in accordance with the low:

$$\mathcal{D}_1(t) = \rho(t)(1-\cos\varphi(t))$$
$$\mathcal{D}_1'(t) = -tg\,\varphi(t) \quad (3)$$

Is it possible to do it and with what expenses? Dispersion control by means of quadrupole lenses is possible, provided by presence of dispersoin in places, where they are placed.This means, that optics, preceding pulsed magnet, is to contain bending magnets, producing dispersion. Since at $\varphi=0$ dispersion is to be $\mathcal{D}_1(t)=0$, and $\mathcal{D}_1'(t)=0$, pulsed magnet is to be preceded by an achromatic magnetic system. Furthermore, in order to fulfil the condition (3), it is sufficient to have two controlled quadrupole lenses. But pulsed quadrupole lenses will distort monoenergetic beam. As a result, a transverse dimension of a beam will chahge, but it will take place due to other reason. This effect may be illiminated by introduction of two additional pulsed quadrupole lehses, which are installed in places, where linear dispersion is absent. Law of gradient change in pulsed lenses is to satisfy solution of four equations, two of which are transcendental ones.

Thus, in general consideration the problem turns out to be a rather difficult one. Authors of the paper [1] have found solutions, which allow to make considerable simplifications. Let us formulate main statements of these solutions:

Let us assume, that optical system has two identical quadrupole lenses, fild gradient of which differs in a sign only and matrix of transition between them has a identity transformation in both planes. Then, perturbations, introduced on a transverse movement of the monoenergetical beam by the first lens on a way of beam movement, will be fully compensated by the second lens.

Thus, dispersion may be controlled, not distorting a monoenergetical beam. But this requires construction of a bending system with special properties. Example of such systems have been considered in the paper [2].

Under such condition it is necessary to have two pairs of pulsed quadrupole lenses $Q_{1,2}$ and $Q_{3,4}$ for dispersion control. Law of gradient change in them must satisfy solution of the system of equations:

$$\Delta\mathcal{D}_1(Q_{1,2})+\Delta\mathcal{D}_1(Q_{3,4})=\rho(t)(1-\cos\varphi(t))$$
$$\Delta\mathcal{D}_1'(Q_{1,2})+\Delta\mathcal{D}_1'(Q_{3,4})=-tg\,\varphi \qquad (4)$$

where $\Delta\mathcal{D}_1$ and $\Delta\mathcal{D}_1'$ are changes of linear and angular dispersion at input of the pulsed magnet, which are caused by the influence of pairs of the pulsed lenses Q_{12} and $Q_{3,4}$.

Let us reduce condition (3) to a center of pulsed magnet. Then at angles of beam deviation $\varphi<30^\circ$ necessary values of linear and angular dispersion will have a view:

$$\mathcal{D}_0(t)\simeq 0 \quad ; \quad \mathcal{D}_0'(t)\simeq-\varphi(t) \qquad (5)$$

If one places a pulsed lens in a confocal point with respect to a centre of a pulse magnet, it will not disturb linear dispersion $\mathcal{D}_0$ in the magnet centre, but will not ensure angular dispersion $\mathcal{D}_0'$ control.

Thus, taking account of the statement (1), it is enough to have a pair of quadrupole lenses. But in this case requirements are alredy imposed not only for the bending system, but to all the magnet-optical scheme wholly.

Realization of these statements in a concrete device is shown below (fig. 1).

SYSTEM OF INDUSTRYAL TOMOGRAPH BEAM SCANNING

Let's consider magnet-optical system of industrial tomograph as an example of achromatic systems of beam scanning. Lay-out diagram of electromagnetic elements of a tomograph is shown in fig.1.

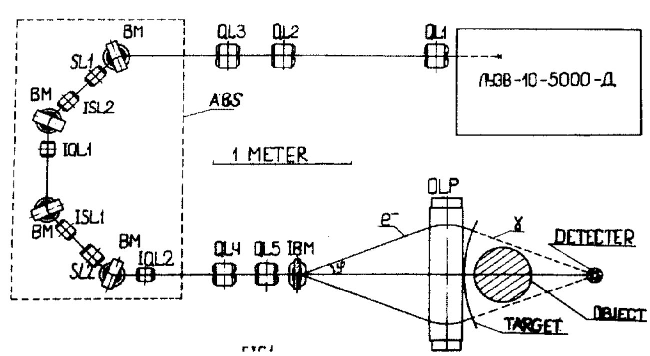

FIG.1.

Magnet-optical system includes the following constant elements: quadrupole lenses QL, forming a beam, wide-aperture lens QLP and four bending magnets BM, forming an achromatic bending system ABS. Chamber angles of BM magnet faces and distanse between them have been selected so that half an ABS system has a minus identity matrix and the whole system has an identity matrix of transformation in both planes. Also, magnet-optical system of the tomograph has pulsed elements: controlling quadrupole lenses IQL1,2 and scanning magnet IBM. Transition matrix between IQL1 and IQL2 lenses is minus identity in both planes due ABS system properties, and IQL2 lens is situated in a point, confocal for a centre of IBM pulsed magnet. IQL1 and IQL2 pulsed lenses differ in a sign of a field gradient only and are switched on in synchronism with IBM pulsed magnet. They are supplied from a same source of current. Beam deviation control is implemented by a syngle source.

In order to compensate chromatic and spherical aberrations, constant SL and pulsed ISL sextupole lenses, switched on in sychronism with the pulsed IBM magnet and pulsed quadrupole IQL lenses, are introduced into the bending ABS system.

Fig.2 shows beam envelopes and a trend of dispersion function in the magnet-optical system of the tomograph for beam deviation by pulsed IBM magnet through the angles $\varphi_1 = 20^\circ$, $\varphi_2 = 0^\circ$, $\varphi_3 = -20^\circ$. As it is seen from fig.2, in this case a disturbance of the monoenergetical beam is absent at the output of the bending ABS system and dispersion is absent at the output of the pulsed IBM magnet.

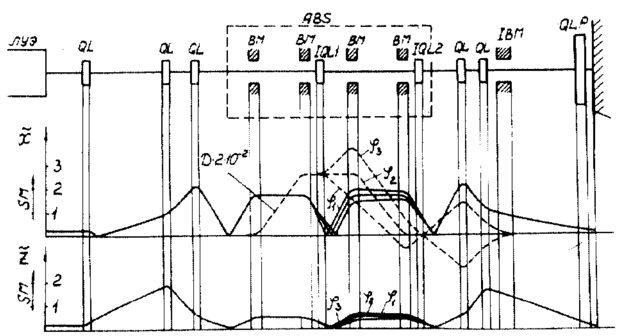

FIG.2.

Main parameters of electromagnetic equipment of the scanning system are given in the paper [3].

CONCLUSION

Theoretical and calculational studies prove possibility of construction of non-complicated achromatic systems with a variable angle of beam bend. Application of such systems in large-sized product tomography will allow considerable reduction of exposure time.

REFERENCES

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