NUMERICAL STUDY OF COUPLING SLOT EFFECTS ON BEAM DYNAMICS IN INDUSTRIAL ACCELERATOR PROTOTYPE*

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Abstract

At Budker INP, the work is in progress on development of high-efficiency, high-power electron accelerator prototype. The accelerator has a modular structure and consists of a chain of accelerating cavities connected by on-axis coupling cavities with coupling slots in the common walls (the coupling constant is about 0.08). Main parameters of the accelerator are: operating frequency of 176 MHz, electron energy of up to 5 MeV, average beam power of 300 kW. The paper presents results of 3D electromagnetic field numerical simulations for ILU-12 accelerating structure with recovery of quadrupole filed disturbance because of large coupling holes. The results show that accelerating cell geometry chosen eliminates coupling slot influence on the beam dynamics.

INTRODUCTION

It is known that electromagnetic fields of non axial-symmetrical coupling slots in cavity walls may cause the elliptical beam shape at the accelerator output. The effect takes place because of action of two quadrupole lenses, formed by the slots. This effect was firstly observed at the linear accelerator of a positron source of VEPP-4 facility and described in the work [1] published in 1984. At that time, a numerical simulation of electromagnetic fields in cavities disturbed by coupling slots was not possible because of absence of appropriate algorithm for 3D electrodynamic task solving. Effect of the coupling slots on beam dynamics was numerically studied in early 90th with 3D RF code MAFIA [2]–[3].

That accumulated experience was used in development of the accelerating structure of the high-power industrial accelerator prototype, which is under creation at BINP[4]. The accelerator is based on the on-axis coupled standing wave structure. To compensate the coupling slot effects, the slots are aligned through accelerating cells and rotated through coupling cells (T-slot arrangement). Such slot arrangement leads to compensation of quadrupole lens actions and provides the absence of the through-cell coupling.

However, in all accelerating structures with half-cell termination the action of quadrupole lens is not compensated in the last and, that is of some importance, the first accelerating cell, in which that lens acts on the non-relativistic injected electron beam. Especially this effect must be concerned for the structures with internal injection (as for the accelerator prototype) due to the low energy of injected beam in that injection scheme. Also, one of sufficient task at accelerator prototype development is lossless transportation of high-power electron beam through the accelerator.

The simulations were made with CST Microwave Studio v5.0 3D RF code. Assuming that special shape of the accelerating cells in the prototype accelerating structure (they are close to coaxial cavities) should substantially weaken the effect, it was decided to test the simulation methods on the VEPP-4 accelerating structure, which electrodynamics parameters are somewhat close to that of the accelerator prototype (see Table 1), but accelerating cell geometry does not weaken the coupling slot effect. Also, for that structure there are accurate analytical estimations [1] and experimental results proved that for that structure the effect may be compensated by T-slot arrangement.

Table 1: Parameters of two accelerating structures

	VEPP-4 structure	Acc. prototype
Frequency	430 MHz	176 MHz
Number of cells	38	18
Aperture	50 mm	70 mm
Accel. rate	120 kV/cm	113 kV/cm
Coupling coeff.	10 %	7.8 %
Accel. gap	204 mm	110 mm

The paper presents simulation results for both accelerating structures and their comparative analyses.

SIMULATION MODELS

The simulations were done for 3-cell accelerating structures (accelerating cell and two coupling half-cells) with both posssible coupling slot arrangements. The number of mesh cells in CST Microwave Studio models is about 2500000, dual Athlon-2800+ PC was used.

Figure 1 presents the model for VEPP-4 accelerating structure (with H-slot arrangement).

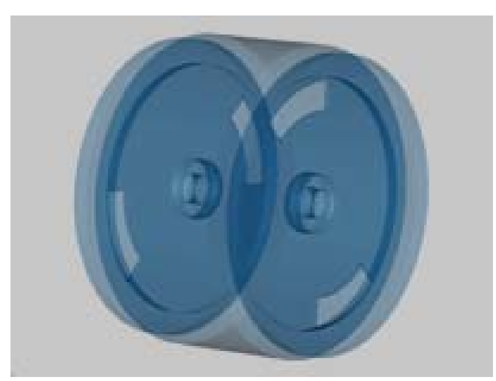

Figure 1: 3-cell simulation model (H-slot arrangement, VEPP-4 structure).

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The same model for the accelerator prototype structure is shown in Fig. 2.

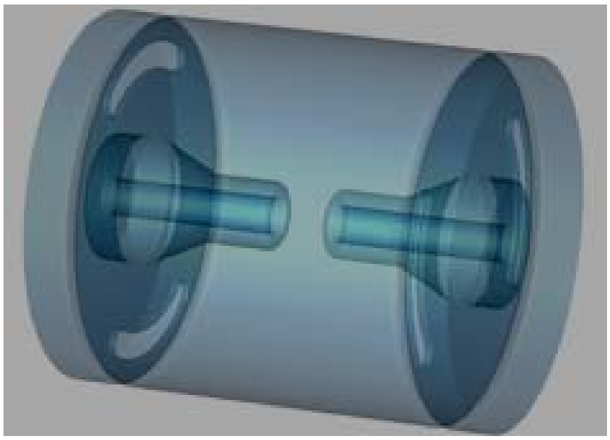


Figure 2: 3-cell simulation model (H-slot arrangement, accelerator prototype).

SIMULATION RESULTS

The amplitudes of the quadrupole disturbance fields are small-scale comparing to axial-symmetric radial and longitudinal (accelerating) fields. So, it is more convenient to study the azimuthal components of quadrupole fields, because of absence of azimuthal symmetric fields in accelerating structure. Quadrupole nature of disturbed field is illustrated in Fig.3, which shows the distribution of absolute value of azimuthal component of electric field around the axis at a constant radius at the accelerating cell center for VEPP-4 structure with H-slot arrangement.

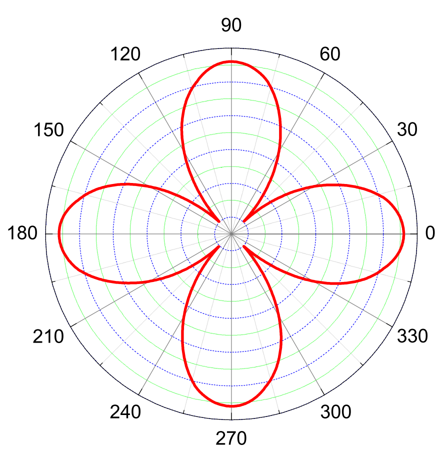
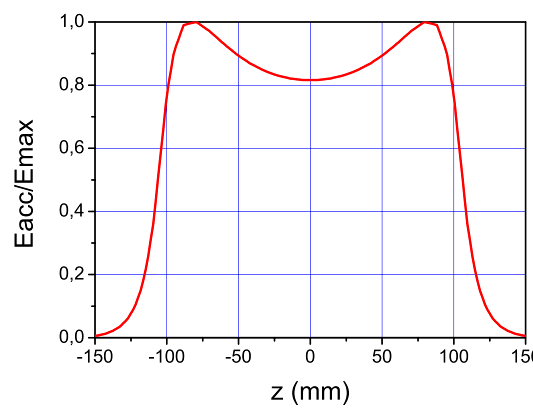


Figure 3: Distribution of absolute value of azimuthal electric field around the axis at constant radius at accelerating cell center (VEPP-4 structure, H-slot arrangement.)

One of our goals of VEPP-4 structure simulation was to compare the obtained results with analytical estimation made in [1] (estimation was made for H-slot arrangement).

The quadrupole field in paraxial approximation may be represented by a linear function of radius $r \cdot \left.\frac{\partial E_r}{\partial r}\right|_{r=0}$ and characterized by its gradient. Ratio of quadrupole gradient to the maximal accelerating field may be taken as a parameter that characterized an extent of the quadrupole field on the transverse beam dynamics. In [1] the maximal value of this parameter is evaluated as $10^{-3}\ cm^{-1}$.

Results of simulation for VEPP-4 structure for both coupling slot arrangements are shown in Fig.4. All electric fields are normalized to the maximal accelerating field and taken at half-aperture radius. The maximal value of $\frac{1}{E_{acc}} \cdot \left.\frac{\partial E_r}{dr}\right|_{r=0}$ may be obtained from normalized quadrupole field distribution and is $1.5 \cdot 10^{-3}\ cm^{-1}$, so 3D numerical simulation is in good agreement with analytical estimations.



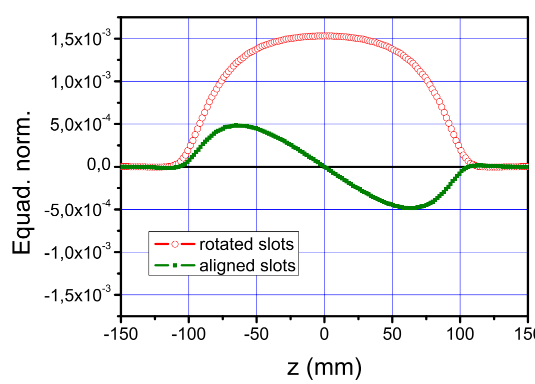


Figure 4: Results of VEPP-4 structure simulations. Longitudinal distributions of **a)** accelerating and **b)** quadrupole normalized fields at half-aperture radius are shown for both coupling slot arrangements.

The same results for the accelerator prototype structure are shown in Fig.5. The maximal value of $\frac{1}{E_{acc}} \cdot \left.\frac{\partial E_r}{dr}\right|_{r=0}$ is $2 \cdot 10^{-4}\ cm^{-1}$, that is about an order smaller than for VEPP-4 structure. So, it may be concluded that quadrupole effects on beam dynamics in regular part of accelerator prototype structure at T-slot arrangement will not be significant.

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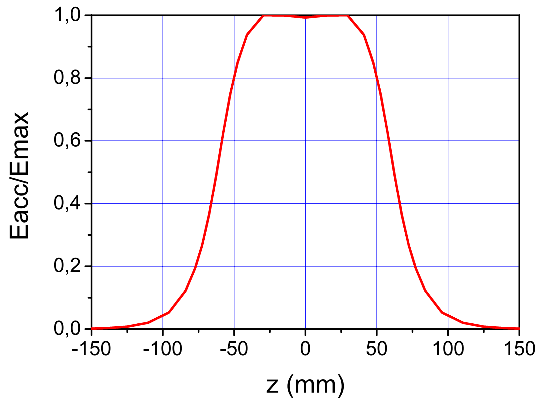
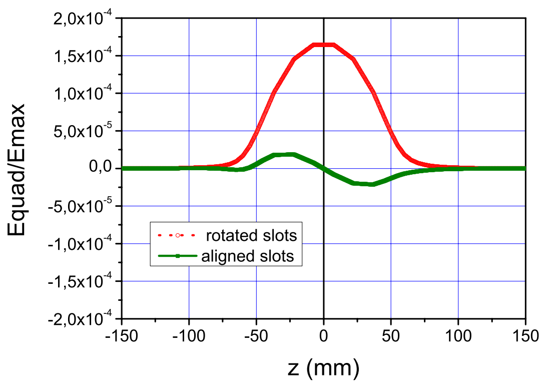


a)



b)

Figure 5: Results of accelerator prototype structure simulations. Longitudinal distributions of **a)** accelerating and **b)** quadrupole normalized fields at half-aperture radius are shown for both coupling slot arrangements.

Quadrupole lens strength in the first accelerating half-cell may be estimated as half of that of the summary lens in H-slot arrangement geometry. Using formulae for quadrupole lens focusing strength from [2] without paying regard to transit time factor, it may be derived that focal length of the quadrupole lens in the first accelerating half-cell of the accelerating prototype structure is by order larger than that of the VEPP-4 accelerating structure first half-cell.

CONCLUSION

Numerical study of RF field disturbance due to coupling slots has been carried out for two standing wave on-axis slot-coupled accelerating structures. 3D RF code CST Microwave Studio was used. Comparison of results obtained proved the practical smallness of coupling slot effect on beam dynamics in ILU-12 accelerating structure and so allowed us to simulate the beam dynamics in axial-symmetric RF fields [5].

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