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THE ACCELERATOR COMPLEX OF THE MOSCOW KAON FACTORY

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Introduction.

The tuning of the linear accelerator of the present Moscow Meson Factory is about to be completed. We are going to get first 600 MeV protons this year.

In accordance with the resolution on High Energy Physics of the USSR Government we have been designing the Project of Moscow Kaon Factory (MKF) since the middle of 1987. Now we collaborate with four institutes which contribute to the development of the Kaon Factory Project and we finished the Proposal of the MKF.

In the Proposal of the MKF the linear accelerator of the Meson Factory is to be used as the injector for the Booster being the first step of the MKF accelerator complex [1]. After charge exchange injection the H+ beam is accelerated in the Booster from 0.6 GeV to 7.5 GeV and in the Main Ring from 7.5 GeV to 45 GeV. At the end of acceleration the 45 GeV beam is transferred from the Main Ring to the Extender and then extracted slowly with 100% duty cycle.

The program of physics research to be carried out at the 45 GeV high - intensity proton beam was discussed at "The 5 All Union Seminar" [2].

The Time - Energy Structure of the accelerators complex.

Figure 1 shows the time - energy structure of the accelerator complex. Every second a 100 ms long macropulse of 600 MeV H^- ions from the linac with $3.1*10^{13}$ particles is injected into the 50 Hz rapid - cycling Booster and are accelerated to 7.5 GeV. Then three out of six pulses are transferred to the Main Ring. An other three pulses of the beam are used in the experimental area of the Booster. The Main Ring is filled during the 40 ms flat bottom magnetic field. The Main Ring accelerates $9.3*10^{13}$ protons per pulse from 7.5 GeV to 45 GeV during 50 ms. The reset of the field in the Main Ring takes 30 ms, thus one cycle is 120 ms long, for a repetition rate of 8.3 Hz. The Extender is need for slow extraction with 100% duty cycle.

This accelerators complex can produce an average current of 125 mA with slows extraction with the average current from linac being 500 mA. Figure 2 shows the proposed layout of the MKF and experimental areas, together with the meson facility.

Injection from the Linac.

At injection into the Booster, the bunches follow with 198.2 MHz (the frequency of accelerating field of the last part of the linac is 991 MHz). Every bucket of the Booster is filled by three bunches from the linac. Since the rf frequency of the Booster is 33.03 MHz, three out of six bunches must be rejected which is done before injection into the linac, just after the buncher. Figure 3 shows the result of longitudinal painting with three bunches. The length of the bunch from the linac is about $\pm 1^{o}$ at 33.03 MHz and the momentum spread is ±0.6%. To improve painting it is needed to reduce the momentum spread to ±0.1% - ±0.12% with simultaneous increasing of the bunch length to $\pm 7^{o}$ - $\pm 12^{o}$ by bunch rotation. The volume of the beam in six dimensional phase space is increased by a factor 10^3 at injection. Since H^- ions are injected into the Booster by stripping them to protons as they pass through a thin foil, Liouville's theorem on phase space conservation may be circumvented and the beam is required which is injected over many tens of turns. The need to increase emittance arises from the Laslett tune shift that must not be more than 0.2. The size of the longitudinal emittance is determined by the threshold for microwave stability and a value of loading during accelerating cycle as well as by a condition of longitudinal matching between machines. To satisfy all these conditions we have chosen ±0.35% momentum spread and the ratio of bunch height to bucket height to be 0.8.

Requirements for the Lattice Design.

The MKF lattices were chosen on the basis of the following requirements:

1. For slow extraction from the Extender a dispersionless long straight section of 150 m length is needed.
2. Straight sections with zero dispersion are necessary for rf cavities for Booster and Main Ring as well as for the insertion of Siberian snakes.
3. The Main Ring and the Extender should have the same shape to be placed in a single tunnel.
4. Crossing of transition was to be avoided in both rings.
5. For increasing the threshold of microwave instability without additional longitudinal painting especially near the end of the accelerating cycle small real γ_t in Main Ring and high real γ_t in Booster are needed.
6. Suppressing of depolarizing resonances in both rings.
7. Realization of large dynamic aperture for decreasing of

losses.

All requirements are met with racetrack lattices with superperiodicity 2 and having dispersion suppressors at the ends of the arcs in all rings.

Booster Lattice

The racetrack lattice with only modulation of quadrupole strength is not convenient for Booster [3]. Because there is not enough room for collimation, diagnostic devices etc. The choice of latti ce begins with the choice of transition energy that depends on many factors. The minimum adopted value of γ_t is equal to 18. For increasing γ_t the lattice has either a high betatron tune [4] or a modulated β-function [5] or a modulated bending radius ρ or both β and ρ modulated [6]. We considered all lattices that can be divided in two types:

- the "resonant" lattices (number of superperiods of the curved section S is approximately equal to the betatron tune, $S \approx \nu_x$) and
- the "nonresonant" lattices, where S far from ν_x.

In "nonresonant" lattice for the booster there is only one family of the focusing quadrupoles and the dynamic aperture is sufficiently large. However, this lattice is unsatisfactory for lack of flexibility (an increase in γ_t requires an increase of the ring length) and there are not enough place in the arcs.

The original "resonant" lattice is the racetrack lattice with modulation of only the β-function. It consists of two arcs and two matching straight sections. The arcs together have 8 superperiods (S = 8), each superperiod includes 4*FODO cells. But this lattice is unsatisfactory because of its small dynamic aperture when chromaticity is corrected.

An alternative design investigated by us is the racetrack "missing magnet" lattice. Eight superperiods make up the two arcs. Each superperiod contains 4 regular FODO cells, but the two central halve-cells have no bending magnets ("missing magnets"). However, in this lattice it is impossible to achieve γ_t higher then 10. We therefore investigated the alternative lattice with both modulated β function and bending radius (fig.4). The arc's construction is identical to the previous lattice. To produce zero dispersion in both straight sections the arcs are tuned to $\nu_x = 6$. In the vertical plane the phase advance of the straight sections is chosen to be $2\cdot\pi$ for suppressing of spin-depolarization resonances and the tune of the arcs is 6.25. A high value of γ_t is obtained by the "missing magnets" and by the relatively small modulation of the β-function (2 families of QF). The numerical tracking gives a dynamic aperture of about 1300 π mm·mrad after correction of chromaticity for the on-momentum particle (fig.5). We believe that this lattice is optimal for the booster. Besides the above features there is enough place in the arcs for collimation of longitudinal losses [8] and diagnostic devices.

Extender and Synchrotron Lattice

The synchrotron lattice has been designed using a regular FODO focusing structure without superperiodicity [9]. The transition energy is determined by the horizontal tune ν_x ($\gamma_{tr} \sim \nu_x$) that equals $\nu_x = 7$. Every arc consists of 18 cells with $\pi/3$ advanced phase in the horizontal plane. The dispersion in the straight section is canceled by the "missing magnet" dispersion suppressors placed at the ends of arcs. The suppressor consists of two cells. One of them is empty and another one is the same as the arc cell. The tune for cell in both planes equals $\pi/3$ in order to have for arcs $\nu_{x,y} = 6$). The length of the straight sections is determined by the needed optics for the extender and equals 178 m. The total advanced phase is 7.25 for the horizontal plane and 8.25 for the vertical plane.

The Extender occupies the same tunnel as the Main Ring and has the same lattice in arcs. The Extender gives a continuous beam during the 120 ms cycle time via slow extraction. Dipoles have a maximum field of 1.8 T and quadrupoles of 1.1 T at the pole tip.

Slow Extraction

The Extender has two long straight sections LSS1 and LSS2. Slow extraction is performed in LSS1. LSS1 has two matching sections at its ends and extraction section EXS. Fig. 7 shows the lattice functions in LSS1 as well as the placement of the extraction elements (MPS1, MPS2 - the first and the second magnetic pre-septa, ES and MS are electrostatic and magnetic septa). The Extender is emptied by employing a third order resonance. Results of tracking studies are presented in fig.8.

The magnetic pre-septa are asymmetric quadrupoles. Both septa are identical. Each of them provides an angle of 0.5 mrad between circulated and extracted beams and has a length of 0.5 m.

The electrostatic wire septum is 5 m long with a field of ≃ 80 kV/cm. It deflects the beam by 0.85 mrad. The thickness of the wires will be 50 μm.

Magnetic septum deflects extracted beam into the derivation line. The thickness of the septum determined by the beam separation at the entrance of the magnet and is found to be 2 cm.

RF Cavities.

We consider now tunable cavities with perpendicular bias [9] as the working (first) variant. Calculations were made to chose cavities which are able to provide parameters needed with reasonable consumption of rf power and power of the bias circuit. With a maximum rf power density of less than 1 W/cm^3 in ferrites cavities for the Booster will produce an accelerating voltage 80 kV, the cavities for the Main Ring 140 kV. In comparison with the LANL-TRIUMF cavities, R/Q values and the volume of ferrite (relative) are lowered. For cooling of the ferrite rings we will use metal plates with radial slots. Development of technological processes to produce large (outer diameter 850 mm) yttrium ferrite rings is under way. An rf stand for full-scale cavity testing is under construction.

Also under consideration variant of the cavities proposal using a special varactor for capacitive tuning is . This leads to the possibility to remove expensive ferrites and the biasing circuit.

Beam Stability.

We perform the longitudinal painting during injection into the Booster with 3 bunches spacing by 60 degrees. The maximum bunching factor B_f obtained in numerical simulation equals 0.33. The bucket height is 20% larger than the bunch. We have longitudinal emittance of 0.09 eV-s.

The space charge term of longitudinal impedance divided by mode number changes during acceleration in the Booster from -i280 to -i10. To avoid microwave instability the upper bound on the inductive wall term in the booster with γ_t=18 becomes 10 Ω.

The Main Ring operates above the transition energy with γ_t=7. Condition of longitudinal microwave stability is satisfied if inductive wall term of broad-band impedance does not exceed 8 Ω.

The parasitic modes of the rf cavities are serious sources of longitudinal instability. Passive mode damping of the parasitics helps to control them by active damping. Coupled-bunch modes around the rf frequency (n=h 1, h 2) will be damped by feedback loops connected with the rf system.

Landau damping of longitudinal modes is present only at the beginning of the accelerating cycle. Later on it is lost because the coherent frequency shift becomes larger than the half spread in incoherent frequencies.

To provide transverse stability of low frequency coupled-bunch mode the special construction of vacuum ceramic chamber and broad-band feedback system are under development. In the Main Ring the natural chromaticity must be corrected to positive value.

Conclusion

We have outlined the Proposal of the Accelerators Complex Lattice of the Moscow Kaon Factory. It allows to have simultaneous beams of the following parameters:

1. $I_{av} = 250\ \mu A$, $W = 7.5$ GeV, $f = 50$ Hz, $t = 1.1$ ms

2. $I_{av} = 125\ \mu A$, $W = 45$ GeV, $f = 8.3$ Hz, $t = 3.3$ ms

3. $I_{av} = 125\ \mu A$, $W = 45$ GeV, continuously

Besides taking account of the possibilities of the linac and the 600 Mev - Accumulator - Stretcher one can consider that it will be the powerful Accelerators and Accumulators Complex for nuclear research in the field of high intensity physics and thin process.

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