THE PROPOSAL OF THE ACCELERATOR COMPLEX OF THE MOSCOW KAON FACTORY

V. V. Balandin, A. G. Chursin, G. A. Dubinsky, S. K. Esin, N. I. Golubeva, A. I. Iliev, L. V. Kravchuk, V. A. Matveev, V. V. Paramonov, A. S. Pashenkov, Yu. V. Senichev, E. N. Shaposhnikova and S. P. Volin
Institute for Nuclear Research of the Academy of Sciences of the USSR, Moscow
V. P. Belov, V. A. Glukhikh, N. D. Malitskiy, Yu. P. Severgin, M. N. Tarovik and I. A. Shukeilo
Scientific-Research Institute for Electro-Physical Equipment, Leningrad
G. I. Batskikh, Yu. D. Ivanov, Yu. S. Ivanov, V. A. Konovalov, R. A. Meshcherov, B. P. Murin and Yu. F. Semunkin
Moscow Radio-Technical Institute, Moscow

I. 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. The Kaon Factory [1] is the next step after Meson Factory. In the Proposal of the Moscow Kaon Factory (MKF) the linear accelerator of the Meson Factory is to be used as the injector for the Booster [2]. Figure 1 shows the time-energy structure of the accelerator complex. Every second a $100 \mu s$ long macropulse of $600 MeV$ H^- ions from the linac with $3.1 \cdot 10^{13}$ 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 $9.3 \cdot 10^{13}$ 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 $125\ \mu A$ with slows extraction with the average current from linac being $500\ \mu A$. 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" [3].

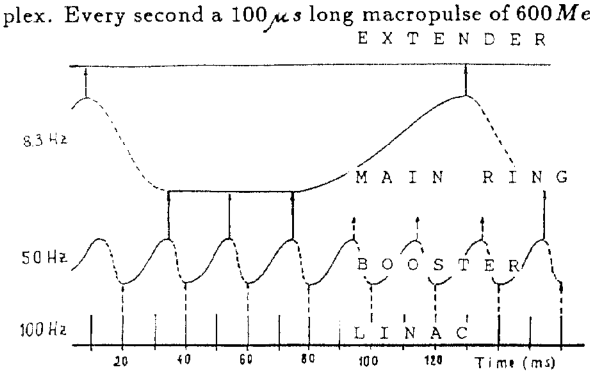

Figure 1: Time-energy structure

II. INJECTION FROM THE LINAC

At injection into the Booster, the bunches follow with $198.2\ MHz$. The length of the bunch from the linac is about 3° at $33.03\ MHz$ and the momentum spread is 0.6%. Since the rf frequency of the Booster is $33.03\ MHz$, three out of six bunches are rejected, which is done before injection into the linac. The debuncher is used to transport bunches from linac to the Booster with simultaneous bunch rotation in the longitudinal phase space. A single bunch injected into the Booster has ±11° phase size and ±0.1% momentum spread. We have chosen the injection scheme to get the desired particle distribution in the longitudinal phase space [4]. The initial difference between synchronous momenta of the linac and of the Booster is $\Delta p/p = -0.055\%$. Painting is provided by shifting the bunch phase during the injection: $\phi_0 = \pi/16(1 - \cos(t/T_{inj}))$. Due to the small duration ($140 \mu s$), injection is carried out without flat bottom magnetic field during the accelerating cycle that leads to the additional particle painting. This scheme provides ±0.33% momentum spread, 0.8 fill factor, phase size of ±106° and longitudinal emittance of 0.09 eVs. Numerical simulation of the longitudinal beam injection including coulomb interaction has been provided by program $LongBeD$ [5].

III. RF VOLTAGE PROGRAM

To obtain 0.9 eVs longitudinal emittance, rf voltage at injection in the Booster should be 780 kV. The voltage at extraction 660 kV is determined by the condition of microwave stability and longitudinal matching of the Booster and Main Ring. Magnet waveform for the Booster is complicated and consists of three parts - harmonic, linear and harmonic [6]. The ratio of rising time to falling time equals to 1.5. This law was chosen in order to minimize the number of rf cavities which is determined by maximum gap voltage 80 kV and rf power supply 220 kW. In this case the number of rf cavities equals to 21. In the Main Ring a maximum power supply per cavity is supposed to be 450 kW. The magnetic waveform with two harmonics allows to approximate the linear law and to have 42 rf stations. Assuming broadband impedance of the Main Ring and Extender to be $8\,\Omega$ the rf voltage at the end of the acceleration in the Main Ring and in bunched beam mode of Extender has to be at least $1200\,kV$ to avoid microwave instability. Rf voltage program (see Fig. 2) keeps the ratio of bunch height to bucket height in both rings no more than 0.8.

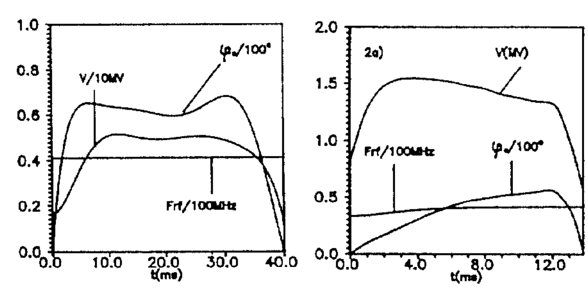

Figure 2: RF voltage program

IV. LATTICES

From the general consideration of lattice designs for low energy synchrotrons [7,8,9], a lattice with both modulation of the β-function and ρ is most suitable for Booster ring. The Booster has a racetrack shape with two 180° arc and two

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dispersion-free straight sections. The arcs have 8 superperiods. Each superperiod contains 4 *FODO* cells, two central halve-cells have not dipoles ('missing magnets'). The horizontal tune of arc equals to 3, that gives zero dispersion in long straight sections. The phase advance of the straight sections in the vertical plane is chosen to be $2 \times 2\pi$ for suppressing of spin-depolarization resonances and the vertical tune of arc is $6.25 / 2$ A high γ_t is obtained by the 'missing magnets' scheme and by using relatively small perturbations in the arc's quadrupoles. The Booster lattice functions are shown in Fig. 3.

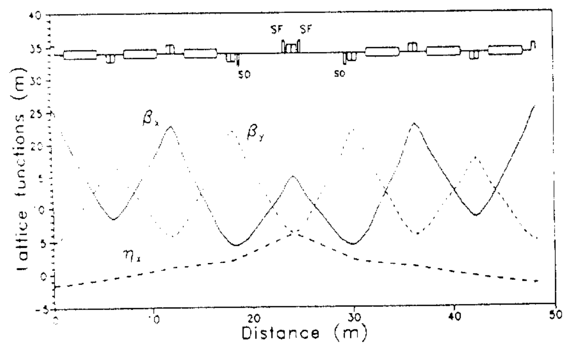

Figure 3: The Booster lattice functions

The Main Ring racetrack lattice has been designed using a regular *FODO* focusing structure with superperiodicity 2. The transition energy is determined by the horizontal tune and is below injection energy, $\gamma_t = 6.6$. The 180° arcs contain 18 cells with $\pi/3$ advanced phase for each cell in both planes. The dispersion in the straight sections is canceled by the 'missing magnet' dispersion suppressors placed at the arc ends. The rf cavities, the injection and extraction systems are placed in the straight sections of the length 178 m. The natural chromaticity is corrected by installing the sextupole magnets near to each quadrupole magnet in the arcs to positive value. The Extender occupies the same tunnel as the Main Ring and has the same lattice in arcs. Dipoles have a maximum field of 1.7 T and quadrupoles of 1 T at the pole tip. The Extender gives an almost continuous beam during the 120 ms cycle time with the extraction losses on low level — less than 0.1% via the combination of the resonant extraction mechanism and septa [10]. The extraction system itself includes two magnetic pre-septa, the electrostatic septum and the Lambertson magnetic septum and was designed in the one of the two long straight sections. Both magnetic pre-septa are identical. Each of them provides an angle of 0.5$mrad$ between the circulated and the extracted beams and has a length of 0.5 m. That allows to decrease the particle losses at the electrostatic septum in 40 times. 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 mm. The Lambertson magnetic septum deflects the 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 2.5 cm. The scheme of the beam separating along the extraction section is shown in the Fig. 4. Deeper hatching in the figure corresponds to more dense beam ($MPS1$, $MPS2$ — the first and the second magnetic pre-septa, ES and MS are the electrostatic and the magnetic septa)..

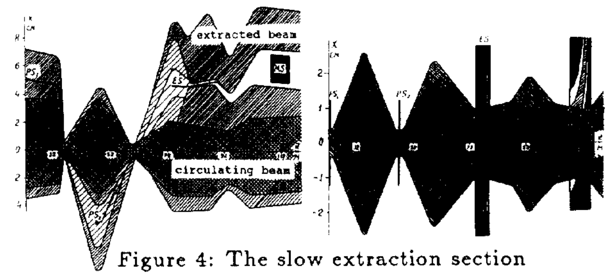

Figure 4: The slow extraction section

V. BEAM STABILITY

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 $\gamma_t = 18$ becomes 10 Ω. The Main Ring operates above the transition energy with $\gamma_t = 6.6$. Condition on longitudinal microwave stability is satisfied if inductive wall term of broadband impedance does not exceed 8 Ω. In both rings the worst situation for microwave instability occurs at the end of acceleration cycle. The high impedance parasitic modes of the rf cavities are serious sources of the longitudinal instability. Passive mode damping of the parasitics helps to control them by active damping. An upper limit for the parasitic shunt impedance increase with a frequency and for lowest modes has value of 4 $k\Omega$ for the Booster and 11 $k\Omega$ for the Main Ring. In the case when parasitic modes from different cavities overlap, this limit gives 0.25 $k\Omega$ per cavity. 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.

VI. POLARIZED BEAM

The acceleration of polarized proton beam is intented up to the top energy [11]. During the acceleration in the Booster 14 imperfection and 13 intrinsic resonances will be encountered. The high-periodicity arcs of the Booster allow to reduce the number of intrinsic resonances by tuning the straight sections to an integer $\times 2\pi$ phase advance in the vertical plane making them "invisible" for spin. A partial snake with the stationary superconducting longitudinal magnetic field is proposed for the Booster. The spiraling motion and additional focusing of the solenoids are corrected by the special quadrupole system. The linear spin resonances are eliminated for the magnetic field integral 12.5 $T\,m$ in one straight section if the fractional part of the betatron tunes is less 0.2. Due to the low periodicity and large acceleration range the Main Ring has a high number of depolarizing resonances: 72 intrinsic and 71 imperfection. The Siberian Snakes adoption is planed to avoid the passage though all spin resonances. The length of the straight sections provides the space long enough for Siberian Snake.

VII. RF CAVITIES

Two types of tunable *RF* cavities, with inductive tuner using ferrites with perpendicular bias and capacitive one using magnetron as a varactor, are now under consideration. Ferrite tunable cavities were optimized [12] to provide parameters needed with reasonable consumption of RF power and power of the bias circuit, to have lowered R/Q (in comparison with the $LANL - TRIUMF$ cavities) values and relatively small amount of ferrite. RF parameters of the $USSR$ produced yttrium ferrites with saturation less then $800\,G$ were tested at low level RF signal. Ferrites with magnetic quality greater then 10^4 were chosen. Development of the process to provide large (outer diameter $850\,mm$) rings is under way now and first (technological) ring for Booster RF cavity is ready. RF cavity for the Main Ring is designed to test both ferrite and varactor tuners and is now under manufacturing. The varactor for Main Ring cavity is now under autonomous testing (Fig. 5). The RF cavity with varactor tuner (shorter

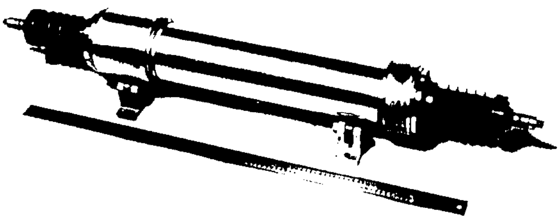

Figure 5: The varactor

and much more simpler in design then ferrite tunable one) for Booster is under development. An RF stands for full—scale testing are under construction.

VIII. VACUUM CHAMBER

The Booster and Main Ring magnets will have ceramic vacuum chamber (CVC) of high-density, high-purity alumina with very thin continuous conducting coating and overlaied metal strips with it to provide low eddy current heating, longitudinal impedance and low secondary emission yields simultaneously. The using of alumina ceramic provides an excellent vacuum and radiation properties for desired vacuum and radiation levels. The first stage of our investigations in the field of CVC was successfully completed in March, 1991. We have a ceramic segments with length $250\,mm$, accuracy of outside sizes $30\,\mu m$ and $4\,mm$ wall thickness. The design of the two types of the joints has been made - glazed joints with 450 or $1100C^\circ$ (strength about 0.6 of ceramic strength) and diffusive-pressure joints with strength 0.95 of ceramic strength. Extensive mechanical and vacuum tests have proven its a very good reliability for $KAON$ vacuum system. The investigations of the manufacturing silver/ceramic paste, Cu and Mo conducting RF-strips on the inside ceramic pipe surface has been made. The other materials for RF-shield (*Al, Stainless Steel, Ni, Ti*) will be considered. One of the main problem are the charging and the dynamic of the secondary electron emission in the ceramic vacuum pipe. This had led to interest in the properties of the ceramic surface. The apparatus for these investigations are using low intensity current and single-pulse methods. Maximum secondary emission yield (SEY) for our alumina was about 7.0 at the primary energies of the electrons $450 - 750\,eV$. With such SEY in accordance with our experimental results for all ceramic materials the $e - p$ instability may be possible. For *ISIS* vacuum pipe design (Rutherford Laboratory, England) the RF-wire is the secondary emission shield. With the perspective using of the RF-shield on the ceramic surface - the minimum effective CVC wall thickness in magnet gap to achieve the desired field strengths we propose to cover all inside surface by very thin ($0.2\mu m$) conducting layer to damp the SEY up to $1.0 - 1.3$ (for Cu layer with thick 0.2 micron maximum SEY is 1.3). In this case such thin layer give us the additional eddy-current losses, but from our estimate this losses will be small part of the integral losses in the CVC. The next step of our investigation - the production of the curved ceramic segments with length $500\,mm$ and the same accuracy. We have a first good results in this direction. The range of materials for injection-extraction magnets and experimental area with a very high radiation levels and with possibility of direct interaction of the beam with ceramic surface should include a nitrid ceramics- view point supported by our preliminary experimental results. This ceramic is also competitive from a technology and cost points of view.

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