PROGRESS REPORT ON THE 500 MeV ISOCHRONOUS CYCLOTRON MESON FACTORY OF ETH ZÜRICH

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(Presented by H. A. Willax)

1. AIM OF THE PROJECT

The accelerator shall equip a new research center operated on a national scale. Main rearch shall be in the fields of elementary particle physics, nuclear structure physics as well as technical and especially medical and biological applications. It will enable to expand the physics covered by synchrocyclotrons with beam qualities (intensity, duty cycle, emittance) improved by a factor of at least 100.

Beams: The energy has been chosen at approx. 500 MeV where a radial resonance should provide good chances of practically full extraction. This quantitative extraction is a vital condition to the use of high beam currents (over a few 10 μA) as otherwise the machine would get rapidly unserviceable due to induced radioactivity. 500 MeV is well suited to produce very high fluxes of slow mesons and maximum stopped meson densities.

For the production of secondary beams external targets shall be mainly used. The shielding of the target, beam disposal and the purification of the secondary beams raise difficult problems enhanced by the extremely high activation. For the experiments, emphasis will most of the time be on beams of higher purity, emittance, energy resolution and also polarisation rather than high total fluxes. Table I gives fluxes expected after rather conservative calculations.

If highest extraction rates are not attained or simply to allow parallel or parasite experiments, internal targets may also be used in the field free sectors. Due to the strong focussing action of the field and the high gain per turn a large number (approx. 50) of multiple traversals through a 1 MeV thick target could be achieved. This « stacked » beam should yeld very high quality beams. The main accelerator hall is unshielded and slightly sunk into ground. The accelerator itself is shielded by movable blocks and connects to the external target assembly. The preliminary studies of the beam layout led to an arrangement as indicated in Fig. 1. Only purified secondary beams shall leave this main shielding .A special effort is made to allow a great number of experiments to remain set up and to operate 2-3 experiments simultaneously, or at least as parasite experiments.

2. RESEARCH

In the physics of elementary particles the most important fields will, as much as it can be foreseen years ahead, be: nucleon - nucleon interaction program with emphasis on polarized beams and especially the neutron interactions. Then precision experiments on pion - nucleon interaction, double pion production, rare pion decays. For muons precise work on intrinsic properties, capture etc. In nuclear structure physics very interesting approaches open: Mesic atoms whose radiation can possibly be analyzed by crystal spectrometers with unprecedented resolution yield charge and magnetic moment distribution inside the nucleus. Muon-nucleus scattering complements corresponding electron experiments. A vast new field are nuclear reactions with pions, like double charge exchange. Finally high resolution inelastic proton events at high energy should give novel information on the dynamical structure of the nuclei.

Applications in solid state physics and chemistry will be radiation damage but especially Mu—meson chemistry allowing very interesting experiments on binding forces. Of very special interest are biological and medical applications. Beside needed work on biological effects of different particles at all energies, protons can be used for controlled deposition of radiation doses at greater depth for radiation surgery. A very exciting possibility would be the use of negative pions for tumor irradiation. Due to the « stars » formed when they are stopped and absorbed by nuclei, their dose curve with depth is superior by an order of magnitude to radiations like gamma rays or electrons now used.

3. ORGANIZATION

The research facility shall be built at Villigen, in the immediate vicinity of the Würenlingen Reactor Institute. Collaboration with the latter in technical and radioactivity matters is considered important. The center shall provide advanced research facilities in nuclear physics to ETH and all Swiss universities. The teaching aspect shall remain efficient however, and some sacrifice on beam intensity seems justified to allow a flexible operation.

The time scale foresees a 5 to 6 years construction time from the final allocation of funds. The budget request is now submitted to the parliament which will render its decision during winter 1965/66. The building layout and site studies give rise to the hope that the construction program can be carried through quickly after the machine concept has been frozen. At present it is hard to predict this point, but we hope to reach it sometime next year.

4. ACCELERATOR DEVELOPMENT

As a proton accelerator to produce a beam of the required energy, intensity and quality for the Meson Factory Project, the ETH group proposed in 1962 a two stage proton accelerator (1) based on the working principle of Sector Focusing Cyclotrons (2). It consists of a AVF-Cyclotron of conventional design, the « Injector », accelerating protons to a reasonable technical limit (in our case 68 MeV) and a high energy stage for further acceleration to 500 MeV. In this second stage, which we call « Isochronous Ring Accelerator », 8 separated C-magnets with specially shaped contours provide the isochronous guide field and beam focussing mainly by the edge effect. Four r.f.-cavities with a high quality factor, operating on the H_{101} - mode at constant frequency, shoud allow a high energy gain per revolution at low r. f. - power consumption.

The main advantages we see in this arrangement are:

1) The production of a "CW" beam in a rather economical fashion.
2) Strongly improved conditions for an efficient beam extraction, due to a rather low average guide field, a sharp field drop off, a high energy gain per turn and defined starting conditions.
3) The possibility for the use of internal meson targets taking advantage of the forward production in a low field region and multiple proton traversals.
4) Access to the beam plane in free sections (for beam collimators probes, beam controls

TABLE I

Beam characteristics of ETH 500 MeV Ring-Accelerator

1)	External Proton Beam of Injector	(68 ± 0,25) MeV, pulse length 1...5 nsec, pulse separation 20 nsec
2)	External Proton Beam	(510 ± ½) MeV Maximum rf duty cycle = 25% Minimum pulse length 0,5 nsec, pulse separation 20 nsec
3)	Secondary Beams:	

Beam	Energy (MeV)	Intensity (sec^{-1})	Area	Remarks	Intensity of protons (μA)	Target
π^+	150 ± 3	$1{,}5 \cdot 10^7$	0,8 cm^2	—	10 intern	C_{12} 0,4 g/cm^2
π^-	150 ± 3	10^6	0,8 cm^2	—	10 intern	C_{12} 0,4 g/cm^2
π^+	150 ± 3	$2{,}2 \cdot 10^8$	0,8 cm^2	—	75 extern	C_{12} 9 g/cm^2
π^-	150 ± 3	$1{,}6 \cdot 10^7$	0,8 cm^2	—	75 extern	C_{12} 9 g/cm^2
μ^+	150 ± 12	$2 \cdot 10^7$	100 cm^2	2% π^+	75 extern	C_{12} 9 g/cm^2
μ^-	150 ± 12	$7 \cdot 10^5$	100 cm^2	2% π^-	75 extern	C_{12} 9 g/cm^2
Pol. p	490 ± 2,5	$2 \cdot 10^{10}$	1 cm^2	50% polarization scatt. angle 7°	75 extern	C_{12} 5 g/cm^2
Pol. n	490 ± 6	$8 \cdot 10^6$	20 cm^2	30% polarization scatt. angle 7° 10 m distance	75 extern	D_2 4 g/cm^2
γ from π^0	Max. at 150	10^7	10 cm^2	10 m distance	75 extern	C_{12} 9 g/cm^2
$\pi^{+\prime} \to \mu^+ + \nu_\mu$	30	$2 \cdot 10^8$	pro cm^2	10 m distance	75 extern	C_{12} 9 g/cm^2

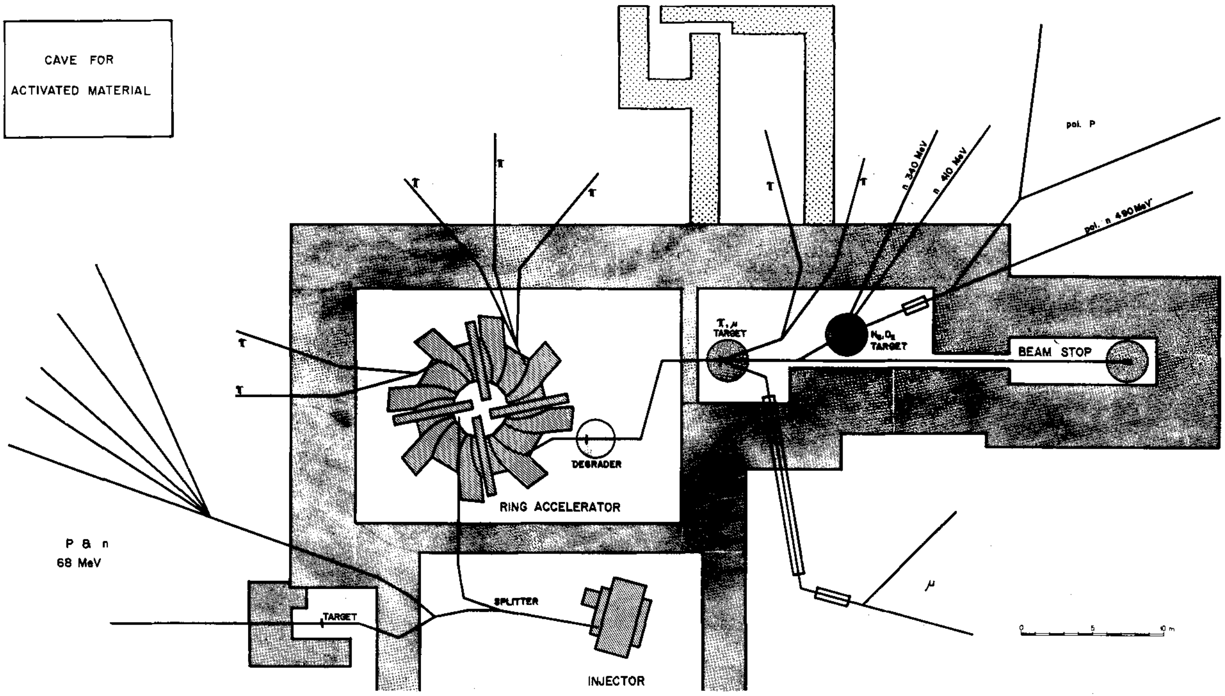

Fig. 1 - ETH Accelerator Project: example of a beam layout for primary and various secondary beams. Main experimental hall is 50×90 meters.

etc.) and simplification of the mechanical construction and servicing of the activated machine by using standard elements. Flexibility.

It is planned to have the injector cyclotron built by an engineering company experienced in the design and construction of AVF-cyclotrons. Two technically and financially reasonable offers have been submitted. The development, design and construction of the high energy stage shall be carried out under responsability of ETH in cooperation with Swiss industry and other accelerator laboratories.

Since summer 1963 we have tried to start the development work for the Isochronous Ring Accelerator using a "reference design" with the main parameters given in Fig. 2. An isometric view of this preliminary design is given in Fig. 3.

The main efforts went into:

Beam dynamics

Development of the sector magnets

Development of the r.f.-cavities and the power amplifier

Mechanical design and electronic engineering

Layout of the main beam trains and experimental area

Bulding layout.

The beam dynamical studies are based on the theories for AVF-cyclotrons by Gordon and Welton (3), Hagedoorn and Verster (4). A computer code by Vogt Nilson, Skarek and Joho (5) was modified for the use on the CDC 1604 A computer at ETH. This code computes equilibrium orbits, deviations from isochronism, Q_r, Q_z, eigenellipses, adiabatic damping, and in a further step general orbits with acceleration, injection, extraction and resonances. As input any theoretical or measured field matrix which is Fourier-analyzed and reconstructed to a "smooth" field map can be used.

For initial computations and the conceptual design of a 1:5 scale development model of the magnets a semi empirical field map including data from a 1:12 scale model was used. Together with the magnet group of the Engineering Company Oerlikon (MFO) the 1:5 scale model was designed under the aspect of compromising between beam dynamical requirements and practicality of fabrication of the pole plates. This model, consisting of two sector magnets, gave opportunity to study basic engineering problems such as methods of machining, coil assembly and positioning, flux distribution in the return path, dimensioning of the yoke, shimming etc., as well as information on the field superposition between sectors. An automatic measuring device enables us to obtain a fine mesh matrix for computations of the beam dynamics. The information derived from these studies is being used for determination of the final pole shapes, the main parame-

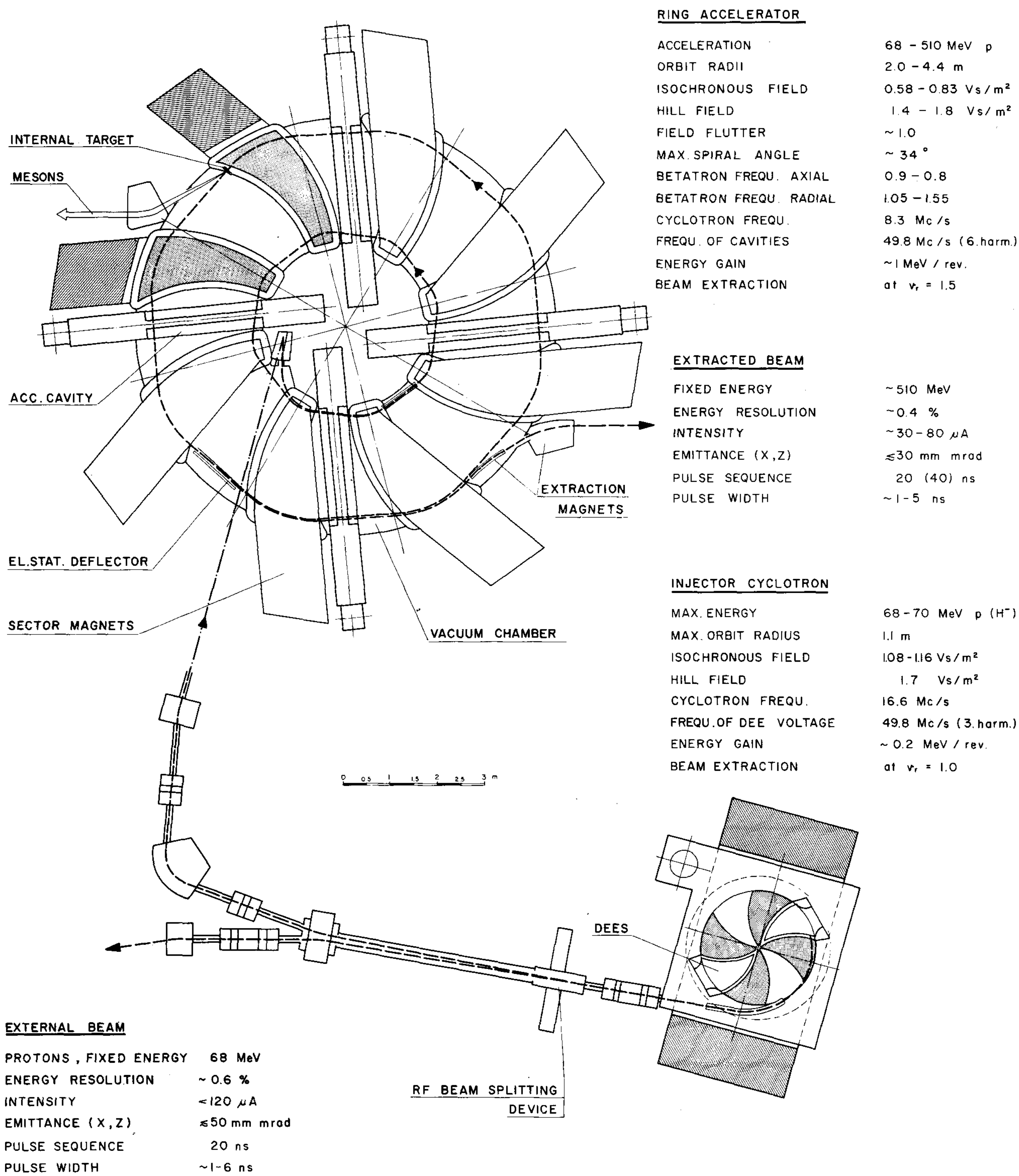

Fig. 2 - Reference design and main parameters of the Two Stage Isochronous Accelerator for 500 MeV protons.

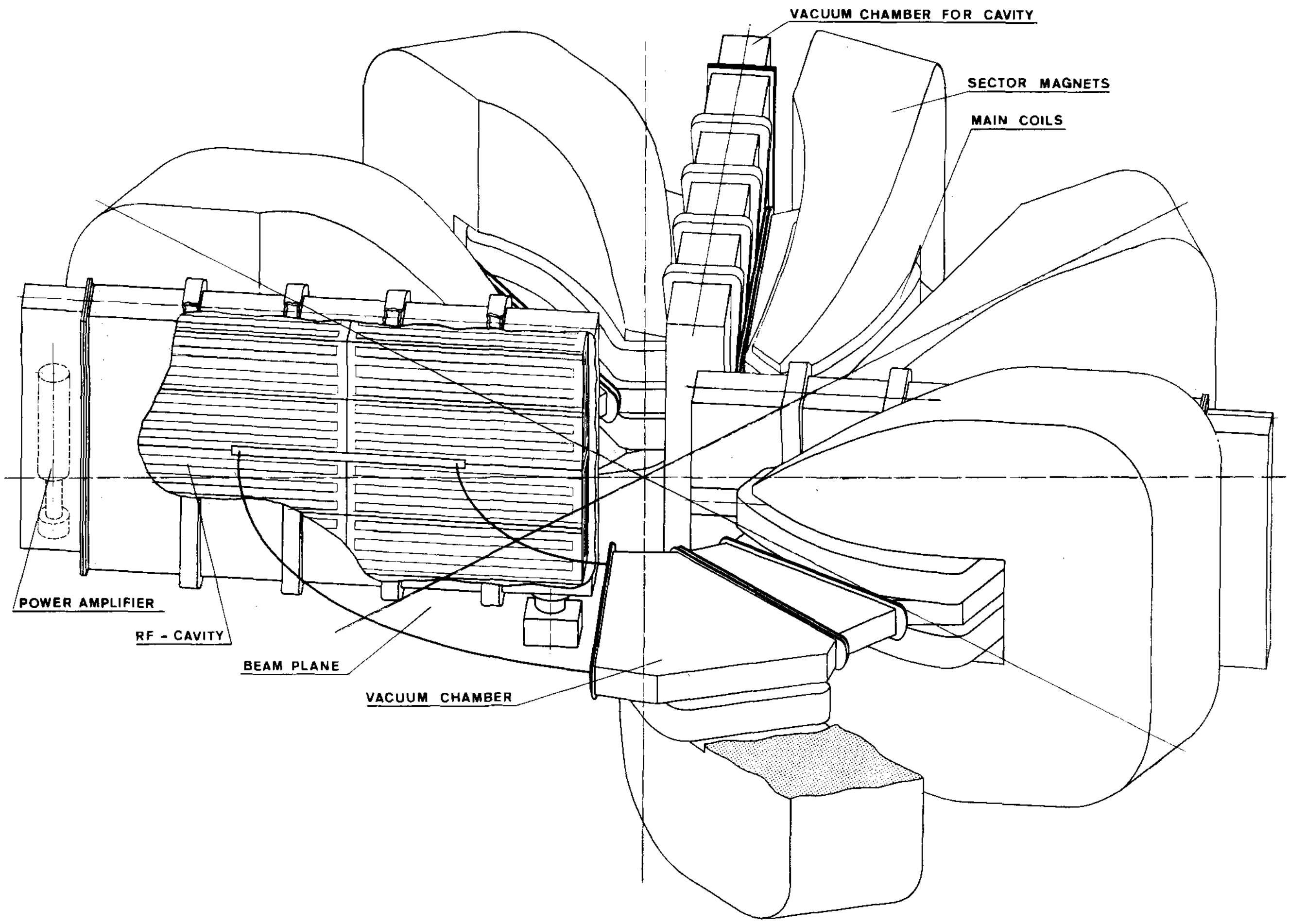

Fig. 3 - Isometric view of the Isochronous Ring Accelerator.

ters of the machine and for the design of a prototype of one full scale sector-magnet.

For development of the r.f.-cavity the dependance of main parameters such as frequency, modes, voltage distribution and the quality factor on the dimension of cavity and gap were tested on several 1:5 scale models. In order to investigate problems of voltage holding, r.f.-discharges in vacuum, multipactoring, the f.r.-power feed-in, stabilization of voltage and phase as well as mechanical engineering problems a full scale cavity in a large vacuum vessel has been built. The power amplifier for the system using an Eimac Tetrode 4CW 50,000 has been constructed and is in the state of improvement.

Mechanical engineering studies on the arrangement and assembly of the vacuum chamber, the support structure, and the layout of the cooling circuitry have been made. A main engineering problem is the connection of the toroidal vacuum chamber with the magnet poles.

On the electronic engineering sector further development of stabilized power supplies using SCR's is carried on. Studies of the whole power-control - and interlock-system of the accelerator have been started.

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DISCUSSION

SNOWDON: Is it possible that the beam quality of the extracted beam is such that the 500 MeV accelerator itself could be used to inject into a still higher energy accelerator.

WILLAX: We have not examined this question and it would be hard to answer offhand. The quality of the extracted beam depende largly on the beam transfer from the low energy cyclotron to the ring accelerator and on the properties of the magnetic field in the ring. We aim for a radial and axial emittance of 30 mm mrad of the extracted beam.

MESON FACTORIES IN USSR

(Presented by N. L. Zaplatin)

I. A METHOD FOR VARYING FREQUENCY OSCILLATIONS IN A RELATIVISTIC CYCLOTRON *

The problem of the highly effective extraction of accelerated particles from a relativistic cyclotron (RC) is among the basic ones since the successful use of the RC as a high energy machine and the fruitful maintainance of the accelerator are possible only, if, practically, a 100% of particles are extracted.

Tre spiral structure of the RC magnetic field causes the appearance of internal nonlinear resonances with radial oscillation frequency $Q_r = N/q$, where N is the number of spirals, q is the whole number (the resonance order). With $N = 8$ the nonlinear resonance of the 4-th order ($Q_r = 2$) corresponds to about 820 MeV. The design of the Mc^2 cyclotron of the Oak Ridge National Laboratory (USA) (1) envisages the use of the nonlinear resonance $Q_r = 8/4$ for constructing the extraction system with an efficiency of about 95% which has been obtained on an electron model of this accelerator.

According to the reconstruction design of the Dubna synchrocyclotron (2) the final energy is 700 MeV, $Q_r = 1.8$ and there is no possibility to directly employ the resonance method of extraction.

Here a method is proposed which allows to increase radial oscillation frequency at a given radius up to a required value, for instance, up to two. In this case, the axial oscillation frequency is not changed. Consequently, a strong dependence of radial oscillation frequency upon energy at a given r is eliminated and it becomes possible to employ the resonance method for extracting particles accelerated in the RC in a wide range of maximum energies.

1. Consider radial motion in the RC whose magnetic field structure in the median plane is

$$H_z(r,\varphi) = H(r)\,[1 + \varepsilon_1 \mathrm{Sin} \cdot (\frac{r}{\lambda} - Nl) + \varepsilon_2 \mathrm{Sin}\,(\frac{r}{2\lambda} - \frac{N}{2}\varphi + \delta)] \qquad [1]$$

where H(r) is the average magnetic field, ε_1 is the amplitude of the working harmonic, ε_2 is the amplitude of additionally introduced harmonic, δ is the phase of this harmonic with respect to the working one, $2\pi\lambda$ is the radial step of the fundamental structure of the magnetic field. Further, we shall assume that N is even and $\varepsilon_2 < \varepsilon_1$.

Equations describing particle motion in quasistationary approximation and the cylindrical system of coordinates are written as

$$r'' - \frac{2r'^2}{r} - r = -\frac{e}{pc}\left[1 + \frac{r'^2}{r^2} + \frac{z'^2}{r^2}\right]^{1/2} \cdot \left[(r^2 + r'^2)\,H_z - r'z'H_r - z'rH_\varphi\right] \qquad [2]$$

V. P. Dmitrievsky, V. V. Kolga and N. I. Polumordvinova: Laboratory of Nuclear Problems, Joint Istitute for Nuclear Research (USSR).