THE OUTLOOK OF MPC-10 CYCLOTRON USE FOR THE SOLUTION OF APPLIED PROBLEMS.

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ABSTRACT.

The compact isochronous MPC-10 cyclotron is now under construction at RRC KI. It has been especially designed to operate as part of positron-emission tomography centre. The main cyclotron parameters are given, the opportunity to use it for solving some applied problems not related with PET is considered in the report.

INTRODUCTION.

At present the RRC KI is being mounted the MPC-10 cyclotron, designed for negative hydrogen ions acceleration. The tests and adjustment of its various systems are being carried out. This cyclotron was espesially designed as a part of positron-emission tomography centre. Thus the main cyclotron parameters were determined by the requirements for production of ultrashort-lived radionuclides C-11, N-13, O-15 and F-18, in the amounts measured in Curies (Table 1).

Table 1. The main parameters of MPC-10 cyclotron.

Accelerated particles	H-
Extracted particles	H+
Beam energy (max)	10 MeV
Beam current (max)	50 mkA
Operating frequency	23 MHz
Harmonic mode	1
Pole diameter	80 cm
Magnetic field	1.5 T
Extraction radius	31 cm
Method of extraction	charge exchange
Extraction efficiency	100%
Number of extracted beams	2
H^- ion source	PIG, internal

However, it seems to be expedient to consider some other applications for the accelerator of this type, installed at the scientific physical centre and operating at PET only part time, thus increasing the accelerator efficiency factor.

The study of wear and corrosion resistances for the metallic detailes of various machines by the thin-layer activation method is one of the promising field of MPC-10 cyclotron application. The essense of this method, as known, is as follows. The detail region under its wear resistance study is irradiated by the beam of accelerated particles penetrating into the detail surface layer and react with the metal nuclei, producing various γ-radioactive isotopes. Thus for the ironmongery under irradiation by protons with the energy higher than 6 MeV the most preferable reaction is $^{56}Fe(p,n)^{56}Co$ with production of ^{56}Co radioactive isotope, which has a half-life period of 77.3 days, convenient for studying the wear resistance and a lot of intensive lines of short-wave γ-radiation. Then the operation of the mechanism in on-line regime is investigated at the test bench or directly during the exploitation process. Either the decrease in operating detail activity due to the attrition of the surface layer, or the increase in the activity of lubricant, where the wear products accumulate is registered with, as a rule, NaI gamma-detectors.

The main advantages of the thin layer activation method are:

1) an opportunity to investigate the wear process dynamics without disassembling the machine;
2) an opportunity to determine the wear resistance of surface having complicated geometry;
3) high sensitivity;
4) economic efficiency: in the wear studies by the thin-layer activation method, one can save up to 80% of expenses and up to 90% of time in comparison with other methods of wear studies [1].

The MPC-10 cyclotron is designed for acceleration one type of particles, therefore, irradiation mode of metal, which the surface layer is activized by protons, is proposed. First of all, it is an iron which remaines to be the main material the machine detail manufacture.

The activated layer thickness, which determines the possibility of wear studying by thin layer activation method, depends on the proton energy and on the angle of beam incidence upon the detail surface. Moreover, with the increase of the proton energy the Co isotope yield rises that allows one to reduce the detail irradiation time and hence to reduce the expenses on activation. However, at the energies exceeding 12 MeV reactions with productions of other isotopes has begun, which considerably reduces the method efficiency or even excluded the possibility of its application. Thus, the best proton beam energy for activating steel and iron is about 12 MeV. The activated layer thickness can be varied in a wide range (30-300mkm) due to the choice of beam incidence angle upon the detail surface. Changing the activation depth may also be effected by varying the proton energy from 9 to 12 MeV.

Such proton beam energies will make it possible to activate the details made of copper, titanium, chromium and others with the maximal activation depth of 250-300 mkm, that turns out to be quite sufficient for the majority of problems in the wear study in mechanical engineering.

The maximal intensity of the beam which activates the experimental detail, as a rule, is determined by the conditions of cooling the irradiated detail region. The local heating in the irradiated area should not result in an essential change in the mechanical properties in this region. The typical beam intensity values for activation are not more than 1 mkA.

Thus, the MPC-10 cyclotron completely satisfies the requirements for proton beam intensity from the point of view of its usage for the activation of the thin layer, but the maximal beam energy, taking into consideration energy losses at the output foil window turns out to be insufficient.

The second promising implementation the MPC-10 cyclotron can find in the neutron radiography method : for the non-destructive control of various products and materials in the atomic power production, in propulsion and rocket technologies, in the fields related with the creation of new materials and compositions.

The neutron radiography technique is based on the dependence of the substance-neutron interaction cross-sections on neutron energy and on the characteristics of a substance. The main peculiarity is the clearly pronounced leap-character of the general behaviour of the effective cross-sections of thermal neutrons interaction with nuclei unlike in the interactions of gamma and X-ray radiation with matter. The total cross-sections of some isotopes reach very high values and it often turns out that the neighbouring nuclei have a many-times smaller cross-section. As a result, one can control the content of a number of elements in the products of complicated chemical structure by a degree of neutron flux attenuation. The essence of the neutron radiography technique is as follows : an object under study is examined with the penetrating collimated beam of thermal neutrons and, at the same time, the neutron flux distribution beyond the object is registered by the detector. The nuclear reactors are mainly used for NR as a powerful sources of thermal neutrons. They can provide high fluxes of thermal neutrons : $n*10^6$ neutrons/cm^2s beyond the collimator. Accelerators (cyclotrons) can also be used for production of neutrons for NR. In this case the most preferable reaction is $Be^9(p,n)B^9$. As a result of this reaction, the neutron yield is maximal, and since the neutrons of a lower energy are produced, the process or their further thermalization is more effective.

The advantages of using the cyclotron as compared to the reactor are evident :

- neutron generation stops with switching off the cyclotron beam, i.e. the neutron source is controlled;
- the system is compact and easely to operate;
- there is considerable gain in electric power.

In particular, the NR studies with baby-cyclotrons, as neutron sources, have already been done in Japan for a long time [2].

If one turns to the MPC-10 cyclotron with the increase of the maximal energy of the extracted proton beam up to 12 MeV the neutron flux from the point source (Be-target) will be equal about $2*10^{11}$neutron/mkA*s [2]. With the increase of the beam current up to 200 mkA, the thermal neutron flux density after the collimator can be equal about 10^6 neutrons/cm s, i.e. is approaching in its value the similar value for the reactors.

From the above-said one can conclude that it is necessary to increase the maximal energy of the extracted beam up to 12 MeV in the wear studies and in the NR-technique, as well as to increase the beam current up to 200 mkA (for NR) for an effective the MPC-10 cycloton using.

ION ENERGY INCREASING.

The increasing of the maximal energy of H- ions, accelerated at the MPC-10 cyclotron, from 10 to 12 MeV requires increasing the magnetic rigidity from 0.456 to 0.5 T*m that is expected to be attain both due to the average magnetic field raising and due to extraction radius raising. The magnetic field will be increased up to $\sim$ 1.55 T; its further increase turns out to be unexpedient because of the abrupt growth of the required magnet main coil ampertums (due to the saturation of the magnetic circuit iron) that reduces the accelerator efficiency. Moreover, an essential increase of the magnetic field will lead to the necessity of the magnetic structure geometry considerable changing due to the changing of the radial field shape and the decrease of the flutter, determining the vertical focussing of ions.

The isochronous magnetic field profile is being formed up to the radius of about 30 cm. Thus the acceleration of H^- ions at the last revolutions takes place in the region of magnetic field edge, in radii from 30 to 33cm, where the stripping foil to obtain the energy of 12 MeV must be located. Despite the phase shift of about 30°, which the particles will get, they will not leave the accelerating phase.

The extraction of H^- ions with the energy of 12 MeV is expected to be performed into the same channels as the 10 MeV particles. This will be attained due to suitable selection of the stripping foil position by the azimuth. Besides, moving the stripping foil by the radius and azimuth one can vary the energy of extracted protons from 9 to 12 MeV.

The increase of the accelerating structure resonance frequency up to 23.7 MHz, corresponding to the magnetic field will be attained due to some structural peculiarities of the resonance system.

The MPC-10 resonance system design provides the possibility of tuning its frequency from 23 to 25 MHz by changing the dees different in area; the possibility of fine tuning the resonator frequency by changing the gap between the dee and the cover is also provided. Finally, the capacitive trimmers - remotely driven - will allow one to adjust and to stabilize the resonator frequency under operating conditions. All this excludes the necessity in the insertion of a complicated system of movable short-circuited plates.

In order to increase the resonance system operation stability, the artificial capacitive link between the resonance lines is provided. The connection is supplies with an additional capacity between the rods of resonance lines.

The MPC-10 resonance system has been numerically simulated and studied with a full scale mock-up at the frequencies of 23 and 25 MHz. The measurements have demonstrated full agreement between the calculation and simulation. The resonator quality factor has been measured, $Q \sim 2250$.

The industrial broadcasting transmitter PKM-20 providing up to 25 kW in the operating frequency range is expected to be used for the resonator excitation. In accordance with the calculations and measurements, this power is a priori sufficient for providing the cyclotron operating conditions.

ION SOURCE.

An internal radial ion source has been chosen for the MPC-10 cyclotron . Initially, the ion source, PIG type, with self-heated cathodes, was manufactured and one was tested at the special test bench. At this ion source was obtained a beam H^-ions with energy 15 keV, at the current 1 mA, at the gas flow 9,5 cm^3/min (B = 0,6 T). Unfortunately, the disigned ion source had two main drawbacks: a) hard discharge ignition and frequent breakdowns along the insulator surfaces in the process of ignition; b) short life time of a cathode under operating conditions, moreover, for application of the MPC-10 in the method of neutron radiography, one should increase ion current, extracted from the source, without increasing (better reducing), the gas admission to the source. In connection with the above-said, we have started the investigation of an ion source with directly-heated cathode [3]. In order to increase the cathode and the reflector life-time they have been made of low-sputtered, electrically-condacting ceramics (initially, the the cathodes were made of tantalum) This allowed us to increase a few-times life-time of the ion source and provided the reliable operation of the insulator. Moreover, the H^--ion beam current was increased up to 1,3 mA, at gas flow Q = 8 cm^3/min, that was related with a finer discharge adjustment to the optimal operating mode. The insertion of molybdenum non-cooled convertor in the extraction slit zone allowed to increase the ion beam current up to 2 mA in constant arc regime (U_{arc}= 230V, I_{arc}= 3,5 A, B = 0,85 T), at the energy 14 keV and Q = 8 cm^3/min. The dependences of H^-- ion yield on the gas flow to the ion source and on the extraction voltage under operating conditions are given in Fig.1 and Fig.2. At present, some studies are done in order to find out the mechanism of the converter effect upon the ion yield from the source. It seems to be important to determine whether the H^--ions are mainly produced upon the converter surface or in the volume discharge zone, meanwhile the converter assists in their drift to the extraction slit. If the assumption that main roll in this process is played the volumetric ion production and the drift of charged particles are corroborated, this will allow us to increase ion current (up to 4-6 mA) or without reduction in the beam current, to reduce the gaseous loading on the cyclotron and to increase ion source life-time by the geometry optimization of the converter, and a discharge chamber with extraction slit.

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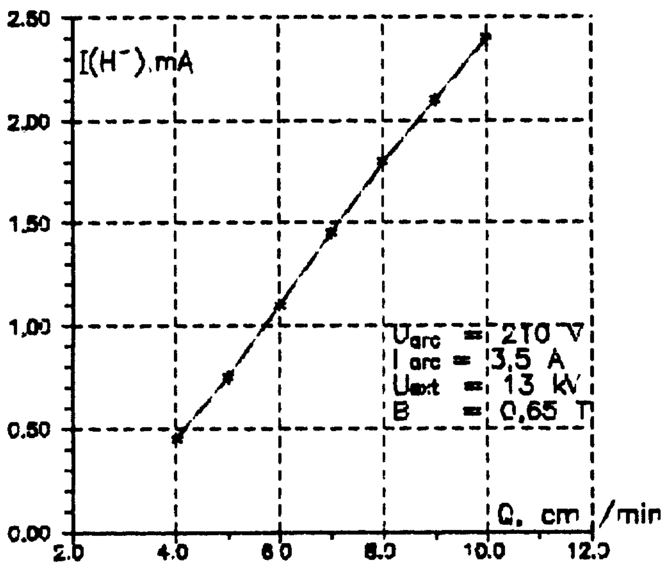

Fig 1 Dependence ion beam current on hydrogen flow

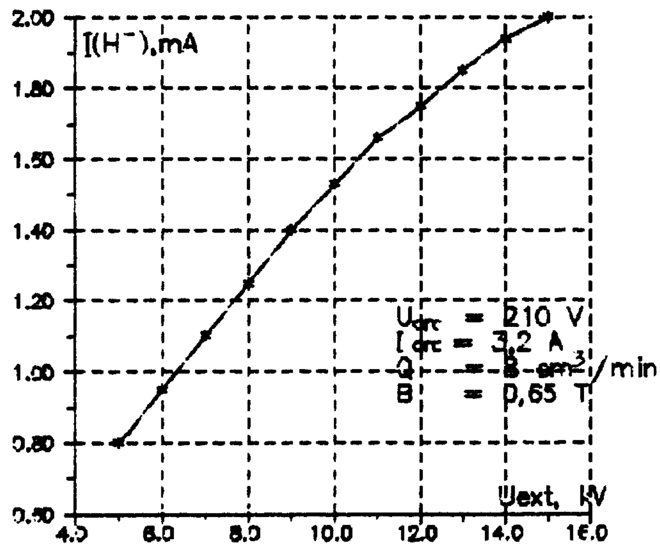

Fig.2 Dependence ion beam current on extraction voltage