10 MEV CYCLOTRON AND RF LINAC AS INSTALLATION FOR NEUTRON THERAPY

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The proposal of neutron therapy installation is considered. It includes 10 MeV proton cyclotron as first stage and 433 MHz RF linac with accelerating gradient near 8 MeV/m as final stage of accelerator. Linac using H(TE) mode RF field has permanent magnets in few drift tubes. Output proton beam energy is 70 MeV. Mathematical simulation brings out is possible easy enough to obtain required current and synchronize cyclotron and linac bunches. Realization of this proposal is the most beneficial in laboratories where 10...15 MeV proton cyclotrons is already working.

1 Request to Parameters of Accelerated Beam

Now the neutron therapy has received a rather wide circulation, in this area known experience is saved, requests to an optimum flow of neutrons and, hence, to accelerated deutron and proton beams, making therapy neutron flows are determined. By results of, available for today's day, at least, for 20% of patients, requiring in radiotherapies malignant tumours, neutron beam more preferable then proton ones.[1]. From a point of view intencity and the dephtes of radiation doze neutron flows with energy not below 20 MeV are desirable and intencity of a doze to ensure much easier then depth of penetration, wich determined by average energy of neutrons. From 17 centres in the world, wich apply neutrons for therapy purposes only 5 have installations wich can generate beam of fast neutrons with energy more then 20 MeV and, hence, with optimum for therapy of parameters. Comparative researches of proton and deutron reactions for production of neutrons on lithium and beryllium targets [2] have shown, that using of proton beams more preferable, since available for a today's day in laboratories proton beams have larger energy then deutron ones about in two times and with their help it can be received better neutron energetical spectra. The beams of neutrons with energy are higher 20 MeV it is possible to receive, for example, on lithium target of complete absorption with help 40-45 MeV falling proton beam and on beryllium target by a way of bombardment of 60-66 MeV protons. Though researches of varions targets with purpose of reception of therapy neutron flows of primary proton beams proceeds, it is clear, that proton beam with energy 65-70 MeV and current 50-100 mA could ensure a neutron flow for therapy with optimum parameters. Such beam in many accelerator centres it would be possible to receive, using as first stage of installation cyclotron with output proton energy 10-16 MeV and proton postaccelerating up to 70 MeV by probably more economical method. The linear accelerator of proton's from 10 up to 70 MeV with use of H-type resonators on frequency 433 MHz is here offered. Such accelerator is the most compact installation among all probable.

2 Formation of a beam on an Input of Postaccelerator

There are much cyclotrons in the world to work out proton beams with energy 10 MeV (or are a little bit higher), wich are used for radioisotope production. These isotopes are used for various needs, in particularly for the medical purposes. Such accelerator usually has frequancy of accelerating field in diapason 20-80 MHz and lets rather easily to have on an output proton beam with current up to 100 microamperes. (In case of acceleration of ions H- is greater). For example, cyclotron RIC-10, that has created by the Efremov Institute for isotope production, has on an output accelerated protons with energy 10 MeV and current 50 mcA. Emittance of a beam in phase planes, appropriate to vertical and radial fluctuations do not exceed of 50 .mm.mrad. The frequency of cyclotron resonators 40-43 MHz must be synchronized with frequency of the linear rf postaccelerator 433±5 MHz, that can be achieved by change of frequencies of their generators and resonators in allowable limits, that are determined by characteristics of devices. Practically it is always feasible, since in any case the workers radio frequencies of linear accelerator and cyclotron will differ on the order. In connection that linear accelerator works in pulsing mode, as should work and cyclotron. The transfer of cyclotron in a pulsing mode does not cause difficulties and can be carried out by timer, wich will ensure required duration of a pulse, pulse repetition and steepness of pulse edge (not more then 100 nanoseconds). One more problem is reduction of phase extent of a pulse of a current on an postaccelerator entrance. Linear rf accelerator with the worker frequency near 430 MHz is capable to accelerate without loss bunches of particles with emittances in a cross planes 35 .mm.mrad and phase extent 60 . It means that at relation of frequencies of cyclotron and linac 1:10 phase extent of bunches of current on an cyclotron output in relation to phase extent of its rf period must be not more then 12 grades. The reduction of cyclotron banch phase extent up to required size may be reached on first revolutions with the help of puller. It is possible, certainly, at the expense of loss of proton beam intensity.

The further reduction of bunch phase extent on an entrance of linac is carried out with the help rf resonator-buncher on frequency of the linac. Buncher mode type of electromagnetic field is E010. As result of these operations current intensity on linac entrance will be in 6 times lower then current intensity on cyclotron RIC 10 output (or the same type cyclotron), however surviving current will all the same more then enough for neutron therapy purposes. Layout of installation as whole is shown on fig 1.

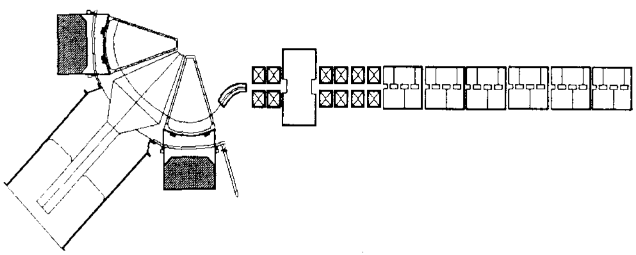

Figure 1: Layout of installatoin for neutron therapy

3 Linear RF Postaccelerator

The linear accelerator on a basis of H-resonators on frequency 433 MHz with rf field alternate phase focusing was offered for acceleration of H+ ions from 2 up to 12 MeV [4]. At acceleration from 10 up to 70 MeV the synchronous phase can be fixed (for example 30 grades) but it is required additional focusing for reception of radial stability of ion movement. Such focusing can be carried out lenses, located in drift tubes, as in the Alvarez type cavities. The view of proposed resonator is represented on fig.2.

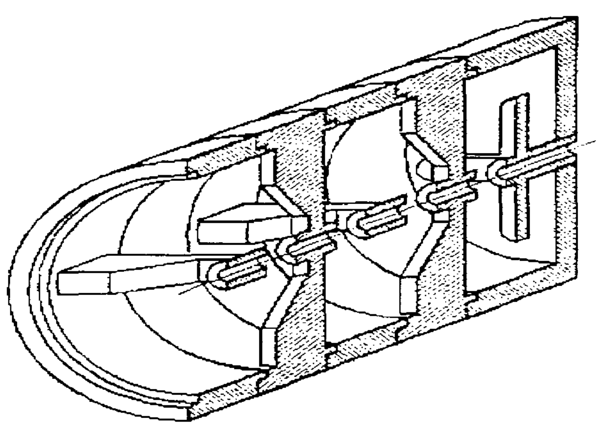

Figure 2: H-resonator with drift tubes and crossed holders. Drift tubes are fasten on holders, revolved for next drift tubes on a corner, close to 90 grades. In first and last half-cells of H-resonator, cross-shaped tuning elements may be placed. Another name this accelerator is IH type linac, namely linac using H(TE) mode rf field for acceleration. At an arrangement focusing quadrupole lenses in each second drift tube (the other holders can be turned attached to tuning of resonator) probably to supply simultaneous stability of longitudinal and radial movement. It is known, that IH type linac has much higher shunt impedance then Alvarez type in the velocity region of v/c=5-10%. In our case IH-resonator will have shunt impedance comparable to Alvarez structure impedance but essentially smaller dimensions. The modeling of dynamics of particles in sistem of H-resonators with additional focusing since energy 10 MeV has shown opportunity of reception 70 MeV proton beam by use 6 resonators with length about 1.5 metres each. Average gradient of acceleration in structure may be made 7.9 MeV/m. The initial data for numerical modeling were following.

Table 1: Initial data for numerical modeling.

Beam emittances in xx' and yy'planes	35 mm.mrad
Maximum field in accelerating gaps	180 kV/cm
Sinchronous phase in accelerating gaps	30 grades
Phase extent of bunches on linac entrance	60 grades
Radius of the accelerating channel	6,26 mm
Maximum relative energy spread of particles	$\pm$2%

Under these conditions and change of focusing lens gradient from 140 T/m to 70 T/m to end of linac, number of gaps about 100, it is possible to accelerate beam without loss at reduction of emittance a little bit smaller, then in 1/p times (p-average longitudinal momentum),and using of the half-aperture of the channel. We shall notice, that initial data taken at account can be executed at a contemporary technological level. Such effective utilization of H-resonators, certainly, appear possible due to actual absence of current load.

4 RF Feed System

3D modeling of rf field was produced with help code ISFEL 3D. It allowed to determine electrodinamical parameters of H-resonators. Main characteristics of linac resonators are given at table 2.

Table 2: Main characteristics of H-resonator.

Resonator diameter	140 mm
Drift tube outer diameter	18 mm
Quality factor	14500
Relation Emax/Emax axe	1.5
Condensed energy in resonator	1.8 J
Losses in walls	380 kW

Here are Emax-maximum field strength in resonator, Emax axe-maximum field strength in resonator on the axe of beam. RF feed system that now is under testing in the Efremov Institute use endotron type device as power amplifier. This device integrate circuit of amplification and output tuned circuit. In our case endotron "Kiwi" is used as final cascade amplifier and have following parameters. (see table 3)

Table 3: Parameters of final cascade amplifier.

Frequency	433 MHz
Pulse power	400...500 kW
Average power	8 kW
Pulse duration	120...150 mcsec
Frequency range	50 MHz
Gain factor	20 dB
Efficiency	50%

Three modulators for master oscillator, intermediate and final cascades of amplification are connected to a load through agreeing pulsing transformers. The feed of modulators is carried out from a three-phase network 50 Hz, 380 V. The rf system is supplied circuits of autotuning of frequency and stabilization of field amplitude, wich compensate slow and fast fluctuation of amplitude and frequency. The resonator and the rf feed system can be executed in a kind of the uniform module.

5 Conclusion

The offered installation for neutron therapy has a number advantages. In first, the construction of a complex on the basis of available already cyclotron and rather inexpensive linear accelerator will cost in 2-3 times cheaper then creation of a complex of neutron therapy from zero. Secondly, the compactness of installation as a whole makes possible its accomodation in available rooms of accelerator laboratories and the radiating safety can be supplied with amplification of local protection in target area. Thirdly, in a neutron therapy complex can enter acting cyclotron with preservation of beam channel, for example, producing of isotopes for PET.

References

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2. T. Nakamura et al. N and Gamma Production from Thick Targets. Atomic Data and Nucleon Data Tables, vol 32 N3 May 1955, page 471.