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ISOCHRONOUS CYCLOTRON FOR THERMONUCLEAR REACTORS DRIVING

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1 INTRODUCTION

Various concepts of nuclear reactor accelerator driving for the energy production and the incineration of the long lived radioactive isotopes that are obtained as a result of the nuclear reactors activity were developed during more than 40 years [1]. In order to meet modern requirement of having a beam of accelerated protons or deuterons inside a wide range of the beam intensity from several milliampers to some hundred miliampers and having the energy around 1 GeV and more, the cyclotron with separated sector magnets or the linear accelerator should be used.

The inclusion of an accelerator into the accelerator-reactor industrial complex puts special requirements to its characteristics, such as reliability, operation time, cost of manufacturing, different operation modes.

We are also discussing the range of parameters of accelerated beams and nuclear technologies exploring these beams.

2 MAIN REQUIREMENTS TO ACCELERATED BEAM

The energy and intensity of the beams of accelerated particles, which are required for various types of nuclear technologies, have been discussed in many papers. At the present stage of the accelerator technology it is assumed that in order to have a current of the accelerated protons up to 100 mA and more, only linear accelerator should be used. However, during continuous work of a linear accelerator there is an intrinsic problem of longitudinal losses, which does not permit to obtain required values of the average current [2].

As it has been discussed in many papers, the maximum value of the achievable current in a cyclotron is limited by 10 mA owing to losses of particles arising during an extraction. The similar conclusion was confirmed by the participants of the accelerators' seminar, that had taken place on the second ADTT conference (Kalmar, 1996) [3]. The similar current parameters of cyclotrons in the accelerator driven nuclear reactor projects were discussed on the last conferences [4].

At present the highest current is accelerated on the sector proton cyclotron PSI, Switzerland, with the energy Ep=590 MeV, Ip= 1.8 mA. The increase of the current up to 5mA [5] is planned.

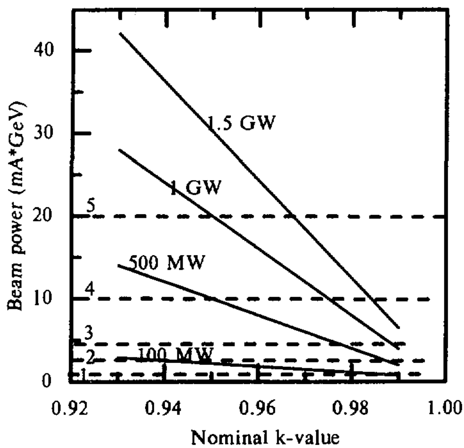

Figure 1: Required power of proton beam versus reactor multiplying coefficient. Dashed line means: 1- PSI - 1.8 mA, 0.59 GeV, 2- PSI - 5.0 mA, 3 - DC- 2.5 mA, 1 GeV/nucl., 4- DC - 5.0 mA, 5 - DC -10.0 mA.

According to calculation [6], the required current of the proton beam is to be $I_{req} \approx 18/T$ (mA), where T (GeV) -the energy of a beam, but the value of the current can vary within the limits of $0.6 I_{req} < I < 1.3\ I_{req}$ depending on a change of the reactor operation mode. In Fig.1 the dependence of the required power of the proton beam as a function of multiplying coefficient of reactor, taken from [6], is presented at the various values of the reactor power. Here the dashed line is used to show the position of the working beam of PSI cyclotron (1.8 mA, 0.59 GeV) as well as for the expected beam value (5mA). The parameters of the DC cyclotron, which is being developed in LNP JINR [7] is also given. It is clear, that the DC complex is quite good for the industrial devise up to 1GW. This result was obtained for solid (Th or U-Pu) fuel of the reactor. In paper [8] it was shown, that the energy amplifier (EA) having power 1.75 GW and working on the fast neutrons also requires a proton beam with energy 1 GeV and the current up to 10 mA.

The power of the accelerated proton beam P_b required for reactor driving is defined by the known formula [2,9,10] :

$$P_b = Wp \times Cn/(E_f \times N_f), \qquad (1)$$

where: W_p - thermal reactor power , C_n - energy loss of the beam for one primary neutron, $N_f = 1/\nu(1-k_{eff})$ - number of divisions, induced by one neutron in reactor, $\nu=2.2$ and E_f = 200 MeV - output of neutrons and energy at one division, k_{eff} -multiplying coefficient of the reactor. Note that, if k_{eff} =0.98, this device is considered as a storehouse of radioactive materials.

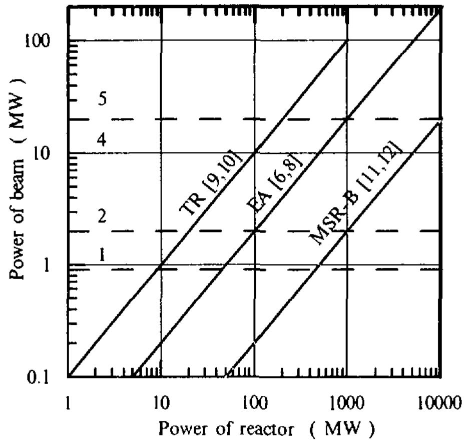

Figure 2: Required power of proton beam versus reactor power at k_{eff}=0.95. Dashed lines mean the same as in Fig.1.

In [11,12,13] the molten-salt reactor burner (MSR-B) is suggested to be used for the incineration of long lived products of disintegration reactors the main feature of which from the point of view of an accelerator consists in the fact that $N_f = 1/(K_1 \times K_2)$, where $K_1 = 1-k_{eff1}$ and $K_2 = 1-k_{eff2}$ are multiplied coefficients of the separately taken cascades MSR-B. Under this condition we get for N_f (MSR-B) the value 20 -30 times greater than in the case of N_f (EA), that is, see (1), we get the decrease of the required power of the external neutron source.

In Fig.2 the dependences of the required power of the accelerated proton beam with the energy 1 GeV on the reactor power for resent types of reactors are shown at k_{eff} =0.95. As it is seen from (1) the power of a proton beam depends linearly on the power of the reactor W_P. It is evident from Fig.2 that when using a beam of the modern cyclotron (PSI-0.8MW) it is possible to start manufacturing experimental reactor of specified types with power up to 100 MW, and in the case of MSR-B it is further possible to construct a plant.

3 REQUIREMENTS TO ACCELERATOR

3.1. Losses during the acceleration

The question of beam losses during the acceleration and the extraction is highly important for beam currents up to 100 mA and more and requires fundamental computer research and experimental modelling. For beams ~1.0 mA the experimental data [5] show that the losses do not exceed 0.8 μA, and the activation of the accelerator units is insignificant. At present the question of losses at the beam power 1-5 MW is a technological problem, however it requires the high culture of the cyclotron operation and control, that is not a simple task, and demands for many years of real work.

3.2 The reliability of a plant

It is assumed, that the operation time of the accelerator-reactor industrial complex should be 50 years. Magnetic systems of cyclotron installations (PSI, TRIUMF, phazotron JINR) have shown high reliability during many years under the operation. A main source of failures are high-frequency systems. In the modern projects of cyclotron up to 12 resonators with powerful generators are used [4, 5]. For the reliable work of an accelerator the service breaks are required, emergency stops are also possible. This question is installation dependent.

In paper [9] it is indicated that in order to have the uniform distribution of external neutrons inside an active zone and the reduction of a beam power from one source it is possible to use several accelerators, to inject beams from different sides of the installation. It would also increase the reliability of the installation as a whole. In opposite, the project of Los Alamos [2] assumes to work with one linac for several targets but one may have doubts in reliability of such a scheme.

3.3 The opportunity of manufacturing and commissioning

The preparation of the technical project for the cyclotron complex can be started in a near future without significant fundamental research. As it was mentioned above, the cyclotron with the characteristics which are close to required ones is already working [5].

In JINR LNP [7,14] and in other scientific centers [4] the significant works referring to high current cyclotrons are fulfilled, which permit to begin the design of controlled subcritical reactor with an external beam at about 1 MW and higher.

Taking into account that cyclotrons permit updating the installation to increase the energy adding a new ring as well as the intensity of the accelerated protons, increasing of HF power, it is possible to use an earlier projects and developments to control more powerful nuclear reactors.

Increasing the number of cyclotrons and reactors in the complex we get the opportunity to move the beam from one its part to another, in order to do scheduled and repair jobs without stopping the whole complex.

4 CONCLUSION

Long-term dispute about preferred role of a linac or a cyclotron driven thermonuclear reactor is not very important. We assume that these accelerators supplement but do not exclude each other. We agree with the authors of [6,9] that it is necessary to start with the project of the low - power accelerator-reactor experimental complex. In the nearest years it should be cyclotron-reactor. This will give an opportunity for the development of high current accelerators and accelerator driven nuclear installations.

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Аленицкий Ю.Г. E9-98-204
Изохронные циклотроны
для управления термоядерными реакторами

Рассматриваются основные требования к ускорителю как к части производственного ядерно-энергетического комплекса. Предложен диапазон параметров пучка ускоренных протонов или дейтронов, для получения которых выгодно использовать изохронный циклотрон. Обсуждается возможность использования циклотрона для создания экспериментальных управляемых реакторов различных типов.

Работа выполнена в Лаборатории ядерных проблем ОИЯИ.

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Alenitsky Yu.G. E9-98-204
Isochronous Cyclotron
for Thermonuclear Reactors Driving

The main requirements to an accelerator as a part of an electronuclear power plant are considered. The range of the parameters of the accelerated proton and deuteron beams, for which the isochronous cyclotron is the most profitable, is proposed. An opportunity of using the cyclotron to drive the research reactors of various types is considered.

The investigation has been performed at the Laboratory of Nuclear Problems, JINR.

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