COMPUTATIONAL CHARACTERISTICS OF A NEUTRON SOURCE BASED ON THE CERN COLLIDING-BEAMS ACCELERATOR

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The computational characteristics of a pulsed source of thermal neutrons, which can be implemented on the basis of the colliding-beams accelerator under construction at CERN, are presented. The calculations were performed at the All-Russia Research Institute of Experimental Physics (Sarov) using the GEANT-3 program developed at CERN and our own program S-95. The neutron source is assumed to be a cylindrical tungsten target with an internal neutron moderator made of zirconium hydride bombarded by protons from a colliding-beam accelerator. The maximum power of the source is estimated on the basis of the results of calculations of the dynamical stresses in tungsten. To decrease the negative impact of mechanical stresses, recommendations are formulated dividing the target efficiently into individual elements.

It is well known that the large hadron colliding-beam accelerator under construction at CERN (Switzerland) is intended mainly for performing experiments with heavy particles, including protons, accelerated up to 7 TeV. As an ancillary application of the proton beam from the storage ring, consideration is being given to the development of a high-power pulsed source of thermal neutrons. Calculations and conceptual designs have been used to develop a general scheme and to estimate the parameters of this source [1, 2]. The calculations were performed by a Monte Carlo method based on the SHIELD universal transport program and the FLUKA and CALOR hadron programs. In the works indicated, the computational results obtained for the dependence of the neutron yield of the accelerator target are presented and the arrangement of experiments on the direct measurement of the cross section for neutron–neutron scattering is examined [3].

The most important components of the accelerator ring under construction at CERN are two storage rings. Accelerator protons enter these two rings and accumulate there. Then they are extracted in the form of intense beams, including in directions towards one another. The storage rings are cleaned every 10 h. The total number of protons in the beam at the exit is $3 \times 10^{14}$. The beam enters a graphite suppressor and is finally quenched in the aluminum and iron components in the shielding. A tungsten target, which converts protons into neutrons, is to be placed in the beam path in the graphite. The duration of the proton beam from the storage ring is 80 µsec. As shown in the reports [1, 2], moderation of neutrons, generated in the target, in zirconium hydride can produce a source of thermal neutrons with flux density $1.5 \times 10^{19} \text{ sec}^{-1} \text{ cm}^{-2}$ and pulse duration (width at half-height) 120 µsec.

Calculations of the source indicated above were also performed at the All-Russia Research Institute of Experimental Physics using two Monte Carlo programs working together: GEANT-3 (CERN) and S-95 (All-Russia Research Institute of Experimental Physics) with neutron constants from the ENDF/BVI library [4]. The purpose of the first program is to calculate the high-energy neutron flux generated in the target by protons and the purpose of the second program is to calculate the process of moderation of these neutrons and the flux density of thermal neutrons in the moderator cavity. In the GEANT-3
program, the proton stopping is calculated mainly for collisions played out with the nuclei. These events generate a flux of new particles. Before the first collision and in the time intervals between collisions, weak stopping of neutrons occurs as a result of the ionization of atoms.

The limiting values of the parameters of the neutron source discussed above were estimated taking into account rigorously a dynamic thermal shock appearing in the target as a result of the sharp heating of the tungsten in the proton beam. For this, very accurate analytical solutions of the problem of dynamic thermoelasticity for a monolithic target and for the components of the target were used. Recommendations for the best partitioning of the target into independently secured fragments were formulated on the basis of an analysis of the results of thermomechanical calculations.

Characteristics of the Neutron Field Produced in a Target by One Proton from a Colliding-Beam Accelerator.

A tungsten target consisting of a hollow 60-cm high circular cylinder with outer diameter 40 cm was studied. The inner diameter of the tungsten target was taken to be 20 or 16 cm. It was also assumed that the proton beam from the accumulator is parallel to the axis of the target, has a uniform density over the transverse cross section, and covers the entire volume of the tungsten (and only the tungsten). A neutron moderator consisting of zirconium hydride (ZrH$_2$) was placed inside an axial cavity in the tungsten cylinder. A 10-cm in diameter axial cavity was created in the zirconium hydride: the cavity passed completely through or was short (10-cm high) at the center of the moderator (Fig. 1). The spectrum, fluence, and flux density of the moderator cavity per proton from the storage ring and calculated in the free-atoms approximation and taking account of the chemical bond between hydrogen and the zirconium atoms were tracked. In so doing, we thought that the neutrons from the source under study would be used effectively precisely in the cavity indicated.

The spectrum and the total neutron yield from a 20 cm in diameter and 60 cm high tungsten target bombarded with 1 TeV protons were calculated first to test the computer programs. The results were compared with the the computational results obtained with the SHIELD, FLUKA, and CALOR programs at the Institute for Nuclear Research. It was found that the results agreed with one another. After the comparison was made, the main calculations of the neutron and thermal characteristics of the targets presented in Fig. 1 were performed for 7 TeV protons. The computed number of neutrons produced by one proton in the target, the fluence of the flux of thermal ($E < 1$ eV) and fast ($E > 1$ eV) neutrons in the moderator cavity, likewise referred to one proton from the accumulator, and the duration of the thermal-neutron pulse at half-height are presented in Table 1.

The normalized histogram of the spectrum for the fluence of neutrons with energy $E < 1$ eV is presented in Table 2.

It is interesting that if the proton beam striking the target is instantaneous, then the duration of the neutron pulse with $E < 1$ eV is 90 µsec.

The type $b$ target in Fig. 1 differs from the type $a$ target by a thicker tungsten layer and a smaller zirconium hydride layer. Table 1 shows that when a type $a$ target is replaced by a type $b$ target the total number of neutrons produced by the protons increases slightly, the thermal-neutron pulse duration decreases, and the fast-neutron fluence almost doubles.

Calculations for a type $b$ target were performed in the free-hydrogen-atom approximation and in a more accurate approximation that takes account of the chemical bond between hydrogen and zirconium. The data in Table 1 show that the more accurate calculation taking into account the chemical bond between hydrogen and zirconium gives a higher fluence of thermal neutrons in the moderator cavity and a much shorter duration of the thermal-neutron pulse.