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Gas flow and related beam losses in the ITER neutral beam injector

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Abstract

The gas flow in the ITER neutral beam injectors has been studied using a 3D Monte Carlo code to define a number of key parameters affecting the design and operation of the injector. This paper presents the results of calculations of the gas density in the two accelerator concepts presently considered as options for the ITER injectors, and the resultant stripping losses of the negative ions during their acceleration to 1 MeV. The sensitivity of the model to various parameters has been studied, including the gas temperature in the ion source and the subsequent accommodation by collisions with the accelerator structure, and the degree of dissociation of the D_2 or H_2 in the ion source, and subsequent recombination during collisions with the accelerator structure. Additionally the sensitivity of the losses to details of the beam source design and operating parameters are examined for both accelerator concepts.

Keywords: ITER; Neutral beam; Gas flow; Injector

1. Introduction

The design of the neutral beam injectors (NBI's) for the International Thermonuclear Experimental Reactor (ITER) was carried out between 1995 and 2001 by the combined efforts of the interested ITER Home Teams (Europe, Japan and Russia) and the ITER Joint Central Team [1]. The injector is designed to provide ≈17 MW of power, in the form of 1 MeV deuterium atoms, to the tokamak plasma during 1000 s, or even longer pulses (up to 3600 s). The design at all stages was affected, to a large extent, by considerations related to the gas flows in the injector. Gas flow considerations have dominated the overall design of the injector because of the necessity to keep the injector compact, in particular to limit the length of the injector, hence that of the proposed gas neutraliser. The latter consideration has led to the subdivision of the gas neutraliser into four vertical channels, with consequent restrictions on the beam geometry and optics. However, the most significant "physics" consid-

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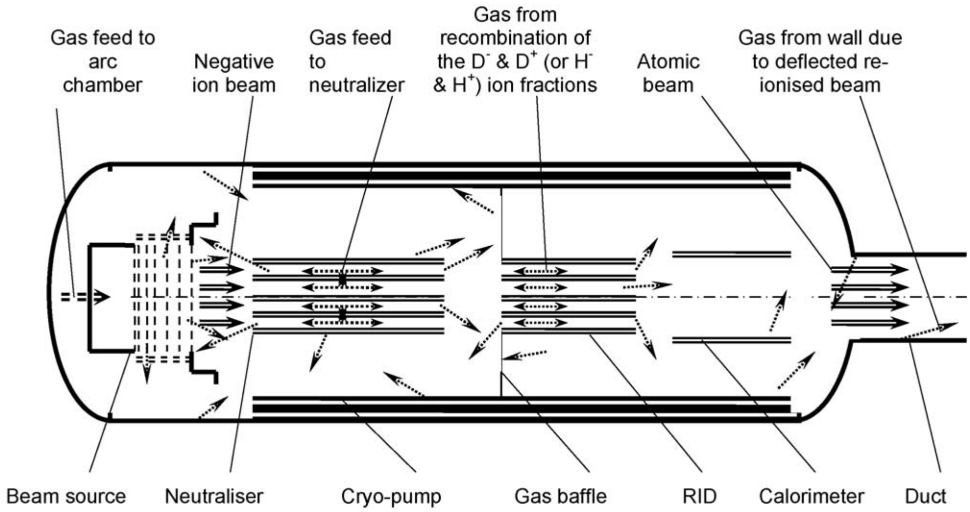

Fig. 1. The gas flow in the ITER NBI (shown with the MAMuG accelerator). The gas flow created by direct beam interception is not indicated. The dashed narrows indicate the possible gas flow directions.

eration is the loss of negative ions during acceleration by stripping on the gas escaping from the ion source. This paper presents the results of detailed calculations using a specially adapted 3D Monte Carlo code which can take into account heating and/or dissociation of the gas in the ion source. A general description of the latest design of the ITER injectors can be found in [1–5].

A simplified schematic of the gas flow in the injector is shown in Fig. 1. Gas (D_2 or H_2) is fed to the ion source for generation of the negative ions (D^- or H^-) and to the neutraliser to provide the gas target needed to the convert the accelerated negative ions to fast atoms. Gas other than that converted to beam particles is pumped by cryopumps lining the walls of the injector and only a small part of the total gas feed to the injector flows to the tokamak.

The gas feed to the neutraliser is defined by the geometry of the neutraliser and the target thickness required to obtain the optimum (i.e. maximum) neutralisation of the accelerated 1 MeV D^- ion beam, which is calculated (from cross section data) to be $1.4 \times 10^{20}\,\mathrm{m}^{-2}$. The maximum fraction of neutrals is ≈60%; the rest consists of ≈20% negative and ≈20% positive ions. Ions leaving the neutraliser are deflected and then intercepted in the residual ion dump (RID) and recombine to produce a molecular gas flow inside the RID.

2. Beam source and calculation model

The beam source (BS) consists of the ion source (arc chamber and extractor), where negative ions are generated and extracted, and the accelerator, where the energy of the negative ions is increased to 1 MeV. The extraction and acceleration system has to form the beam in a way so as to provide the required beam emittance. There are two candidates for the accelerator: The MAMuG accelerator (the Multi Aperture Multi Grid accelerator) [6], which is being developing by JAERI, Japan, and the SINGAP accelerator (the SINGle APerture or SINgle GAP accelerator) [7], which is under development in the DRFC, CEA, France. Fig. 2 shows the reference (Kamaboko [8] type) negative ion source with both variants of the accelerator. The choice between the accelerator concepts has not yet been made and therefore the analysis presented below has been carried out for both options.

The 3D Monte Carlo code used for the calculations reported here is based on the code first developed for calculations of the gas density distribution in the ITER beam line. The code has been enhanced and used to obtain detailed results for both candidate accelerators for ITER. The BS geometry was taken from the ITER NBI final (2001) drawings, including the complicated shape of the apertures in the extractor(s). The depen-