DUAL BEAM OPERATION ON THE HARWELL VARIABLE ENERGY CYCLOTRON

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Abstract

Dual beams of alpha particles and protons, and nickel and neon ions, have been developed for use in radiation damage studies of fusion reactor materials. Two different approaches have been used, one of which provides rapidly alternating beams by cyclic switching of the isochronous frequencies and the other a 'mixed beam' in which the two species of ions undergo simultaneous acceleration in the cyclotron. To increase the attraction of the first method, switching time between beams needs to be as short as possible, which for the VEC is of the order of a second for a frequency change as large as 0.7%. Mixed beams are more readily produced when the constituent ions have closely matched charge/mass ratios (say within 0.1%), and as an example, a mixed beam of 51 MeV $^{60}Ni^{6+}$ and 17 MeV $^{20}Ne^{2+}$ ions has been developed. A mixed beam of alpha particles and molecular hydrogen ions (for which the charge/mass ratios differ by the abnormally large amount of 0.7%) has also been developed despite difficulties from the gross detuning which is necessary in this case. Target currents for the mixed beam mode are generally lower than for the alternating beam mode, and are typically of the order 1 - 2 μA.

Introduction

There has been extensive use over the past 10-15 years of particle accelerators for studying the radiation damage produced in materials subject to high levels of radiation as in nuclear power reactors[1]. By a suitable choice of charged particle irradiations, a good simulation of the radiation damage in a reactor can be accomplished. In addition to the need to simulate the neutron damage, it is also necessary to simulate the production of helium that takes place during the neutron irradiations as a result of transmutation reactions. Although ideally the injection of helium (by alpha particle irradiation) should proceed simultaneously with the heavy particle irradiation, this has not been generally the case in the damage studies carried out to date on fast reactor materials. However in the study of neutron damage in fusion reactor materials which is now receiving increased attention, it is highly desirable to use dual beam irradiations and in this paper a description is given of how such irradiations can be achieved using only one accelerator.

The concept of dual beams from a single accelerator is made possible by the fact that it is a characteristic of cyclotrons that different species of ions can be accelerated at a given setting provided the various charge/mass ratios are the same or differ by only a small amount (say typically, < 0.1%). When applied to radiation damage work it is highly desirable that such beams have comparable penetrations in the target material. It is however a feature of dual beams that they have the same energy per nucleon with the result that in general the respective penetrations will not differ by more than about 30%, and by a suitable choice of ions and energies, a much closer match (better than 10%) can be achieved. The two sets of dual beams which have been developed to date easily satisfy this latter requirement.

Alternative Modes of Dual Beam Operation

The development of dual beams has been carried out by two different methods, one of which provides time discrete but rapidly alternating beams, and the other a 'mixed' beam in which the two types of ions have undergone simultaneous acceleration in the cyclotron. A description of the two modes of operation now follows.

(i) Alternating Beam Mode

In this mode the cyclotron tuning (frequency) is made to alternate as rapidly as possible from the isochronous frequency of one beam to that of the other. Although the frequency itself can be changed very rapidly, it is the response time of the fine tuning system of the cyclotron which dictates the frequency of alternation of the beams. In the case of the VEC fine tuning is provided by a movable plate at the side of the dee which acts as a capacity trimmer. Normal movement of the trimmer is made by a stepping motor, but there is provision for a much faster actuation by a hydraulic ram. The latter enables the trimmer to move a sufficient distance (roughly 25 mm) in just under a second to accommodate a frequency change of 0.64%, which is that required in the case of the alpha particle/molecular hydrogen ion combination. A block schematic of the system used for the alternating beam mode is given in Fig.1.

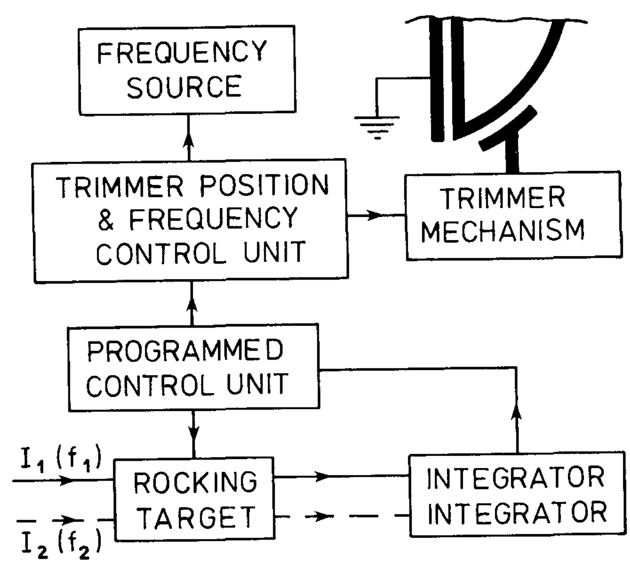

FIG.1. ALTERNATING BEAM MODE (BLOCK SCHEMATIC)

A typical output from the cyclotron would consist of a series of alternate pulses (roughly 3-5 sec. long) of $^{4}He^{2+}$ and H_2^{+} ions of the appropriate intensity. Procedures for setting up are straight forward as far as beam optimisation is concerned, as both beam components have the same magnetic rigidity and therefore the same behaviour down the beam line. Setting the timing sequence and movement of the fast trimmer does however need careful attention. The intensities of the two beams can be adjusted by ion source gas flow controls, and are monitored by two gated integrators, one registering alpha particles and the other molecular hydrogen ions.

(ii) Mixed Beam Mode

Development of mixed beams is in general confined to those in which the constituent ions have charge/mass ratios which differ by about 0.1% or less. For differences much greater than this the degree of detuning of the cyclotron frequency that is necessary in order to be able to accelerate both sets of ions, will result in unacceptably large phase excursions and consequent loss of ions.

A mixed beam of 51 MeV $^{60}Ni^{6+}$ and 17 MeV $^{20}Ne^{2+}$ ions, for which the difference in charge/mass ratio is .08%, has been successfully developed.

The ion source used on the VEC is of the PIG variety with the normal provision for gas injection. In the case of the Ni/Ne combination a graphite insert [2] in which nickel is embedded, is incorporated in the plasma chamber. As a result of heating by the plasma, nickel vapour is produced, diffuses into the plasma and becomes ionised. The intensities of the Ni and Ne components can be controlled by adjustment of the arc power and neon flow rate respectively.

A mixed beam of 4 MeV $^{4}He^{2+}$ and 2 MeV H_2^{+} ions has also been developed despite the very large detuning which is necessary in this case. To keep the phase loss within bounds, it has been necessary to reduce the number of turns over which acceleration takes place (by increasing the dee voltage) to such an extent that the injections radius is larger than the outermost position at which the ion source can be placed. The resultant problems have been partially overcome by a combination of harmonic correction and the use of a large gap between the ion source and puller electrode which reduces the initial energy gain and hence the effective injection radius.

Intensity Measurement. In the case of a mixed beam, the total current can be measured in the usual manner using an isolated target. To determine the relative proportions of the two components in the mixed beam use is made of a nuclear scattering plus particle identification technique. By insertion of a thin gold foil (thickness ca 140µg/cm^2) into the beam, scattered particles are detected in a solid state detector (see Fig.2), the output from which is fed into a programmable multi-channel analyser (Intertechnique IN90). Following acquisition over a short period (normally 5 sec.), the data is processed and the resultant ratio of the intensities of the two beam components displayed on the VDU. By continuously re-cycling the data acquisition and processing, a constantly updated value of the intensity ratio is available . The required ratio, which is pre-determined by the user, is obtained by making suitable adjustments to the cyclotron frequency and ion source conditions. When a stable condition has been reached, counting is stopped, the scattering foil retracted and target irradiation started. Periodic checks of the intensity ratio are made during the course of the irradiation.

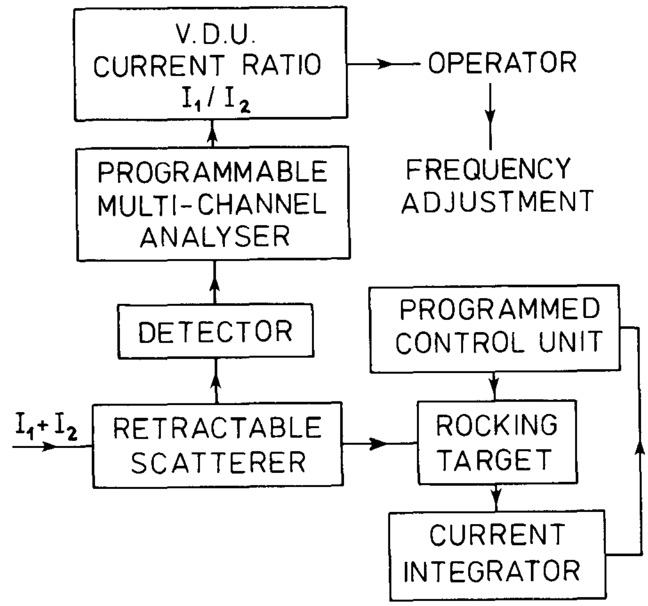

FIG. 2. MIXED BEAM MODE (BLOCK SCHEMATIC)

In both modes of operation the beam is scanned and the target is rocked in the beam direction during irradiation, the object being to produce in the target material a volume region of uniform damage. For the $^{4}He^{2+}/H_2^{+}$ combination, typical target currents are 10µA and 2µA for the alternating and mixed beam modes respectively. In the case of the Ni/Ne mixed beam the current is ca 2µA.

Conclusions

Although ideally dual beams would be produced by using two separate accelerators, it has been shown here that beam combinations of the type useful for radiation damage work, can be successfully produced in a cyclotron. The development will be extended to other ions, including for example those of molybdenum which is a material of particular interest in fusion systems.

Acknowledgements

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References

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