Diagnosis of dynamitron accelerator faults through the observation of narrow nuclear resonances

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DIAGNOSIS OF DYNAMITRON ACCELERATOR FAULTS THROUGH THE OBSERVATION OF NARROW NUCLEAR RESONANCES

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Résumé. — Des résonances nucléaires étroites servant initialement à calibrer l'énergie du Dynamitron 3 MV de Birmingham se sont montrées adéquates pour découvrir et identifier des conditions de défauts de l'accélérateur. La stabilité en énergie à court terme (quelques minutes) est habituellement de quelques dizaines d'eV. Cependant, les variations de plusieurs kV apparaissent plusieurs jours avant le défaut du redresseur thermo-ionique. L'ondulation de l'énergie du faisceau, ainsi qu'elle apparaît dans la largeur à mi-hauteur d'une résonance étroite (p,γ), a aussi été analysée pour indiquer la fréquence correspondant à la partie principale de cette ondulation. On peut ainsi très souvent identifier et corriger les défauts. Les défauts typiques produisent actuellement une augmentation de l'ondulation aux fréquences d'oscillateur de 50 Hz ou 128 kHz.

Abstract. — Narrow nuclear resonances, initially used to calibrate the energy of the Birmingham Radiation Centre 3MV Dynamitron, have proved useful in discovering and identifying accelerator fault conditions. Short-term energy stability (over e few minutes) of a few tens of eV is common. However, variations of many kV occur for several days before the failure of a thermionic rectifier. The beam energy ripple, as reflected in the full width at half maximum of narrow (p,γ) resonances, has also been analysed to indicate the frequency causing the bulk of the ripple, thus often leading to the identification and correction of faults. Typical faults usually produce increased ripple at either the 50 Hz or 128 kHz oscillator frequency.

1. **Introduction.** — The 3 MV Dynamitron accelerator [1] in the Birmingham Radiation Centre provides radiations of varying type and intensity for research groups from the University of Birmingham and the University of Aston in Birmingham. The main research interests are in neutron physics relating to nuclear technology [2] and in the analysis of surfaces by the detection of characteristic radiations emitted during proton bombardment [3]. The accelerator can also deliver up to 30 kW of electrons. The Radiation Centre is operated by a small academic and technical staff whose main function is to provide a service to various Departments from both Universities. An essential part of this service is to provide accurate measurements of the energy calibration, ripple and stability [4] and this is done using a range of well known nuclear resonance reactions and thresholds [5]. It was quickly realized, however, as a result of the series of regular checks, that variations in measured parameters could give important indications of faulty operation and even warning of imminent breakdown.

The DC high voltage in our Dynamitron is generated by parallel feeding of radio frequency power into a set of 64 series connected rectifier modules. The r.f. is provided by a 150 kW, 128 kHz oscillator which is powered from three-phase 50 Hz mains. The current through a 10^{10} ohm resistor string provides a measure of the total high voltage generated and stabilization is achieved by adjusting the oscillator power to keep the potential developed across a standard resistor at the end of the 10^{10} ohm chain equal to that of a stable preset value. This potential is also monitored by a digital voltmeter (DVM) and absolute calibration is achieved by measuring the DVM values at which a series of accurately known nuclear resonances and thresholds occur.

2. **Experimental details.** — An initial set of measurements established a calibration curve for the DVM readings in terms of kV on the accelerator. Subsequent checks on the apparent DVM setting at the Li (p, n) threshod, for example, when converted to keV using the calibration, gave an indication of the day-to-day accuracy of the calibration. The results of a series of measurements spanning almost a year are shown in figure 1. The standard deviation of all the measurements is $\pm$ 0.26 % and is indicated by dotted lines. On several occasions, thermionic rectifiers in the main high voltage stack failed and measurements immediately prior to this showed a wide variation in calibration within the span of a single day. Excluding

these values, the calibration for normal operation is accurate to about ± 0.15 %. The observed energy instability became a reliable indication of impending rectifier failure and allowed the experimental schedule to be adjusted to cause the least interference.

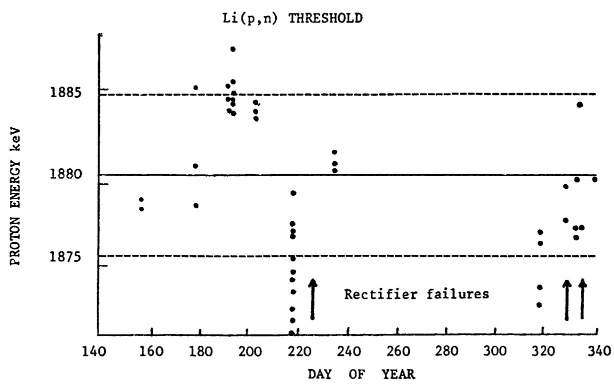

FIG. 1. — Measurements of the energy threshold of the Li (p, n) reaction over a period of approximately one year. Values are plotted relative to a fixed accelerator energy calibration. The arrows indicate dates on which thermionic rectifiers failed and the dotted lines represent plus or minus one standard deviation.

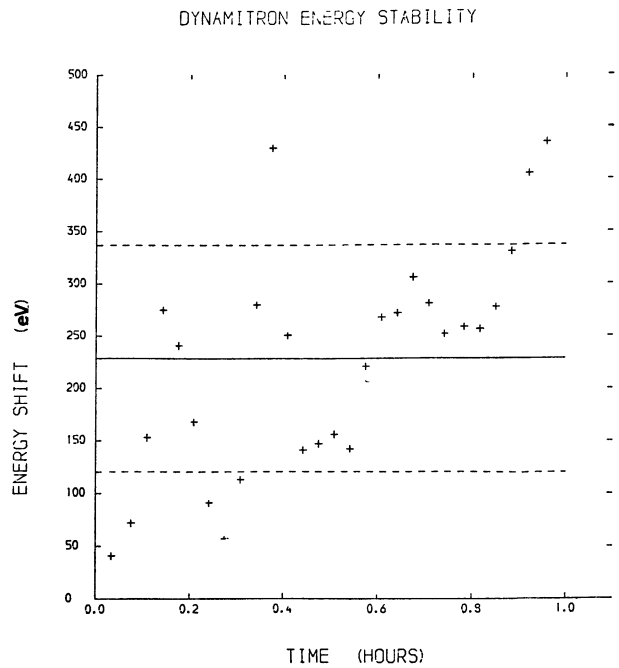

FIG. 2. — The energy shift, as a function of time, of the Dynamitron measured by observing the change in count rate on the very sharp leading edge of the 992 KeV ^{27}Al (p, γ) resonance.

A similar change in calibration has been observed when attempts are made to run the Dynamitron at or near its voltage condition point. This is thought to be due to corona discharges and to X-ray production due to electrons backstreaming up the beam tube causing ionisation of the SF_6 gas surrounding the high voltage resistor board, thus modifying its impedance slightly; the degree of modification depending on how hard the accelerator is conditioning. It is thought that the changes observed due to a failing rectifier probably also originate in the X-rays produced due to internal arcing. The rectifiers in the Radiation Centre Dynamitron were replaced with solid-state units at the end of 1975 and the calibration is now independent of the state of the rectifiers. These modules consist of many hundreds of small components and when one of these fails it never has more than a few hundred volts across it, thus removing the source of X-rays.

Under normal operating conditions the energy stability over a period of minutes has been measured to be of the order of ± 100 eV. These measurements, shown in figure 2, were made by observing the change in count rate of gamma rays from the Al (p, γ) reaction when the accelerator energy was set to correspond to a point half way up the very narrow resonance at 992 keV.

Measurements of the beam energy ripple have been made by observing the yield curve from narrow Al (p, γ) resonances in which natural resonance width and target thickness are always less than 10 % of the measured width. Typical results taken over a period of several months are shown in figure 3 where it can be seen that the full width at half maximum of the curve increases roughly linearly with accelerator voltage. A value of approximately 1.5 keV is typical at 2 MV. On occasions, however, the measured ripple is found to increase very rapidly with accelerator voltage, as can be seen in the upper curve in figure 3,

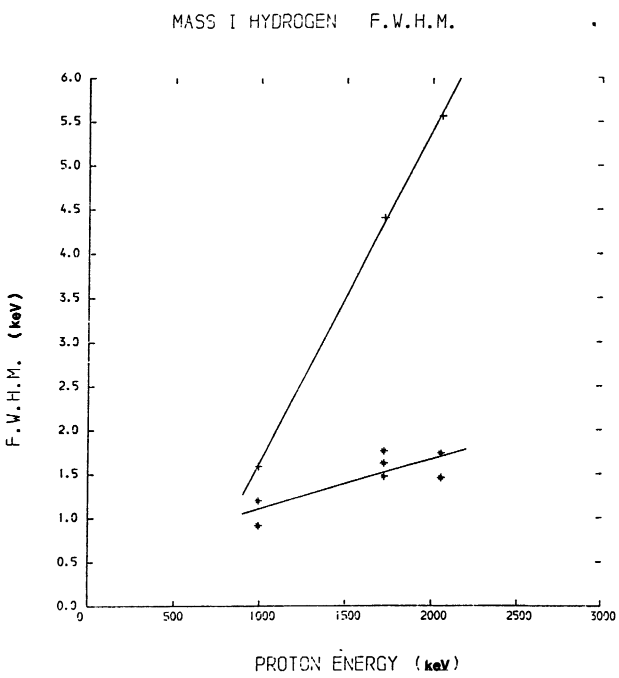

FIG. 3. — Measured full width at half maximum of various ^{27}Al (p, γ) resonances. The target thickness was not more than 100 eV at 1 MeV. The lower curve is a composite of many measurements over several months of normal operation. The higher curve was measured when rectifiers in the oscillator power supply were faulty.

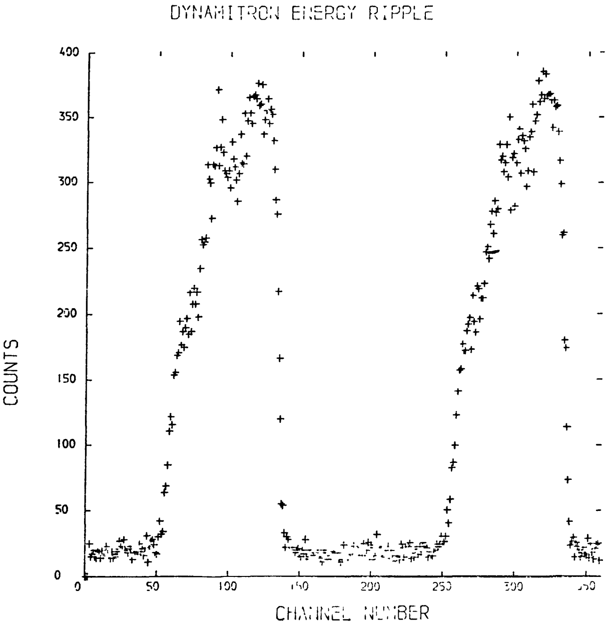

FIG. 4. — Yield from the 992 KeV ^{27}Al (p, γ) resonance measured in time correlation with 50 Hz mains frequency. The time axis calibration is 100 μs per channel and the figure covers nearly two full cycles. The strong time correlation is clear.

indicating a serious fault. The source of this increased ripple is usually associated with one of the characteristic frequencies of the accelerator. The particular frequency can be found in the following manner : When the accelerator energy is set just below a very sharp nuclear resonance, only the higher energy component of the cyclical ripple will reach the resonance energy. If, therefore, the yield is measured at times synchronised with one of the accelerator frequencies, the reaction yield will be strongly correlated only for that frequency mainly responsible for the beam ripple. Figure 4 shows a typical result for the gamma ray yield for the 992 keV Al (p, γ) resonance measured in time correlation with the 50 Hz mains frequency. A strong time correlation is obvious, indicating a fault associated with the mains frequency and this was found to be faulty rectifiers in one arm of the three-phase power supply to the oscillator.

3. **Conclusion.** — These results indicate the value of making regular measurements of accelerator performance, leading to increased operational efficiency by allowing early correction of faults.

References

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