An Automated System for the Measurement of Alanine / EPR Dosimeters

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NPL has for several years offered mailed reference dosimetry services based on alanine/EPR dosimeters, both at industrial and therapy dose levels. Compared to other methods of reference dosimetry, operator involvement in alanine/EPR has been found to be relatively high, and contributes significantly to the overall economics of the process. Commercially available sample changers are not suitable for high accuracy applications, and it has proved necessary to develop a dedicated automation system to handle NPL alanine dosimeter pellets. In this paper we describe an automatic sample changer for placing and retrieving alanine pellets into and out of the cavity of a standard research grade EPR spectrometer. Up to 32 pellets can be held in each removable sample tray. The sample changer software has been interfaced into the spectrometer control software to enable complete automation of the measurement process, including the optimization of spectrometer settings and rotation of the sample within the cavity.

Introduction

The advantages of the alanine/EPR system (Regulla and Deffner, 1982), such as near water equivalence, minimal energy dependence and non-destructive read-out, make the system particularly attractive as a reference dosimeter for both industrial processing and radiotherapy applications, and its use is steadily increasing. The mailed reference dosimetry service originally offered by NPL covered the dose range 70 Gy to 70 kGy, wide enough for most industrial applications such as the sterilization of medical devices and the treatment of foodstuffs. More recently, the service has been extended to the lower doses applicable to radiotherapy, and doses down to 5 Gy can now be measured with a precision of approximately 1% (1σ).

NPL alanine dosimeters comprise four cylindrical pellets in polyacetal holders. The pellets are individually pressed from a mixture of 90% (by weight) alanine and 10% paraffin wax (Arber and Sharpe, 1993). The pellets are nominally 2 mm high and 5 mm diameter, and are selected to lie within a mass range of 4 mg, centred in the region 52-58 mg. The four pellets in a dosimeter are measured individually and the measured EPR signal normalised for mass. A Bruker ESP 300 X-band spectrometer with a 9 inch magnet and standard "st4102" cavity is used for the EPR measurements. Readout at doses above 20 Gy is made by measuring the peak-to-peak height of the central feature of the radiation induced alanine radical spectrum. Below 20 Gy, spectrometer noise and baseline distortion increases significantly, and a spectrum fitting procedure, incorporating the entire spectrum, is used to improve accuracy.

In this paper we present a description of a handling system that has been developed to enable automatic transfer of alanine pellets between a storage rack and the pellet holder in the EPR cavity. Aspects of the pellet holder have been described previously (Sharpe et al., 1996), but are again described here, as they form an integral part of the complete automation system.

System overview

A block diagram showing the main modules involved in the automation system is shown in Fig. 1. The EPR spectrometer computer provides overall control of the system, with a separate automation computer being used to control the modules involved in the pellet positioning and loading. Communication between the two computers is via a standard serial data link. Pellet mass data from a balance is also sent to the automation computer. Once the alanine pellets have been weighed and loaded into the sample tray, the entire measurement procedure is automatic, including the adjustment of spectrometer gain settings to optimise the signal-to-noise ratio.

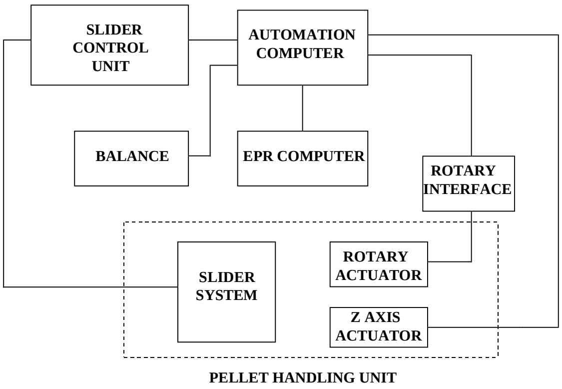

Fig. 1. Block diagram showing main components of EPR automation system.

The operation of an EPR spectrometer necessarily involves the use of an intense magnetic field. Particular care had to be taken in designing the automation system to ensure that none of the attached devices affected, or was affected by, the magnetic field. In practice this meant that unavoidably magnetic components, such as electric motors, had to be located outside the region of the magnet pole pieces. Pure fused quartz tubes were used for the pellet holder in the EPR cavity.

The achievable precision of dose measurement is critically dependent on the reproducibility of pellet positioning within the EPR cavity. In order to ensure reproducible positioning, a holder has been designed consisting of two concentric quartz tubes, as shown in Fig 2. The alanine pellet rests on top of

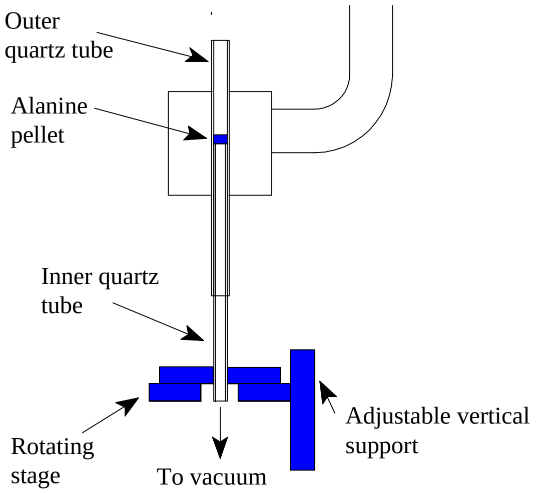

Fig. 2. Schematic diagram of holder for alanine pellet within EPR cavity

the inner tube at the centre of the cavity, and is held in place by a weak vacuum. The inner tube is connected to a rotating stage, which enables automatic rotation of the pellet by 90^o half way through the measurement sequence. The pellet can be withdrawn from the holder by application of a vacuum at the top of the outer tube. Accurate lateral positioning is ensured by precise machining of the outer tube to have an internal diameter of 5.2 ±0.1 mm, compared to a measured pellet diameter of 5.02 ±0.02 mm. In order to prevent pellets catching when being inserted, the top of the tube is flared at an angle of 22^o to the vertical, giving an opening diameter of 6.4 mm.

Coarse vertical adjustment is provided by a manually operated jack, with fine control achieved by the use of an encoder controlled actuator. The ability to automatically vary the vertical position of the pellet in the EPR cavity allows the height at which the maximum signal is obtained to be readily determined. This operation is carried out periodically as part of regular system performance checks, or if the inner quartz tube has been changed. Both the vertical (Z axis) and rotary actuators are commercial units, originally designed for accurate positioning of optical components. The actuators chosen have resolutions of 0.1 µm and 0.36 seconds of arc respectively, and are shown in schematic form in Fig 2.

A weak vacuum applied to the inner quartz tube helps the pellets to drop smoothly after being released at the top of the outer tube. The vacuum is increased to hold the pellet securely when the inner quartz tube is rotated.

Pellet loading system

The essential requirement for the pellet loading system is the ability to transfer individual pellets between a storage rack and the holder in the EPR cavity. It is also essential that the somewhat brittle pellets are transferred without significant loss of mass. It is particularly important in the context of a calibration laboratory handling customers' samples, that the system is fail-safe. The system needs to be able to detect malfunctions, such as incorrect pellet position or the loss of a pellet, and to take action to minimise the risk of damage.

An overall view of the pellet loading system is given in Fig. 3. For clarity, the system is shown disconnected from the EPR spectrometer; the quartz tube is normally inserted into the EPR cavity as shown in Fig. 2. The pellet loading system is securely clamped to the magnet frame of the EPR spectrometer using a manually operated XY table with locking facilities. The system is based on a motorised slide unit having 1000 encoder steps per

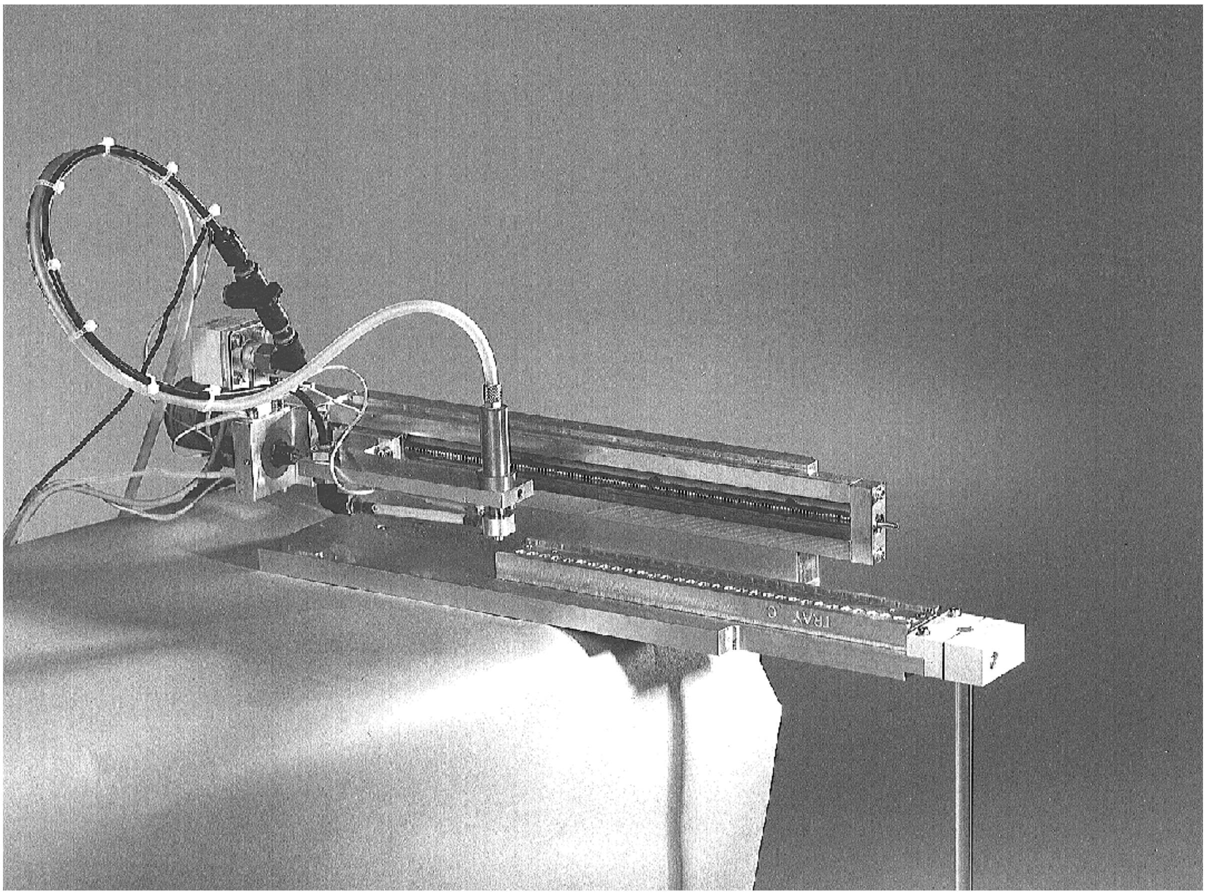

Fig. 3. Pellet loading system and quartz sample tube.

revolution with a lead screw pitch of 1 mm, and is capable of achieving a precision of better than 0.01 mm. The pellets are held in a horizontal tray with 32 holes; the tray is located with a high degree of reproducibility using aluminium dowels. The stepper driven slide is used to position a vertical actuator directly above the pellet to be moved. A vertical actuator and vacuum holder are used to raise and lower the pellets, see Fig. 4. The vertical actuator consists of a phosphor bronze cylinder and piston. Phosphor bronze was chosen both for its immunity to magnetic fields and for its wear resistance. The piston is raised or lowered by the application of vacuum or pressure, as appropriate. Information from a switch at the bottom of the cylinder is used to ascertain whether or not the piston is fully raised. The stepper motor can only be activated if the piston is fully up, thereby minimising the risk of the slider jamming.

An aluminium vacuum holder provides a secure means of carrying the pellets between the tray and EPR cavity. A weak vacuum is used to attach the pellet to the holder. Once the pellet is held the level of vacuum is increased to improve the grip. This phased increase in vacuum is necessary to prevent damage to the pellet when it makes initial contact with the holder. This is especially relevant on retrieval from the EPR cavity, where the relatively long path length means the pellet can achieve high speeds if too strong a vacuum is applied. A small positive pressure is applied to the holder to aid release of pellets. A pressure sensor in the line to the vacuum holder is used to determine whether or not a pellet is securely held.

The position of the slider is measured using a 1000 line encoder attached directly to the lead screw. The program controlling the automation system regularly interrogates the encoder to check that the required position has been reached. A reproducible zero reference (or ‘home’ position) for the encoder is essential for accurate positioning, and this is provided using a motor stop switch mounted on a sprung buffer. The zero reference is reset each time the unit is switched on. The encoder is also used by the motor control software to detect a stall condition and to cut power to the motor if unexpected resistance to movement is experienced.

System testing

The system has been fully tested to ensure that all

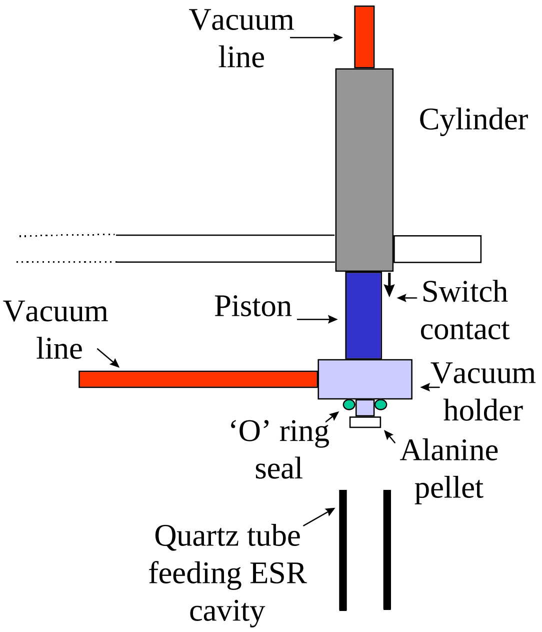

Fig. 4. Detail of pellet transport mechanism.

design requirements have been met. A number of possible failure modes were simulated, including piston sticking, motor stalling, pellet loss, air pressure loss and mains power interruption. In all cases, the system stopped in a "safe" condition to await manual intervention. Accuracy of pellet handling was tested by repeated measurements of the same pellet. Between each measurement, the pellet was returned to, and retrieved from, the sample tray. Each tray position was used in turn i.e. a total of 32 transfers and measurements. The pellet had been irradiated to a dose of 20 kGy. Two such tests were carried out, the repeatability of pellet measurement being ±0.1% (1σ) in both cases. This is not significantly different to results obtained by manual pellet placement, demonstrating that the automatic handling system does not damage the pellets.

Conclusion

An automatic handling system for pressed alanine pellets has been successfully developed. The system fits onto a standard research EPR magnet/cavity combination and interfaces to the spectrometer control computer via a serial data link. Each sample tray holds 32 alanine pellets (8 standard NPL dosimeters). Measurement repeatability is equivalent to that obtained with manual handling.

References

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