National Radiation Laboratory

The NRL kV-cassette – A penetrameter for the estimation of peak kilovoltage on diagnostic x-ray machines

J C Le Heron
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THE NRL kV-CASSETTE —

A PENETRAMETER FOR THE ESTIMATION OF PEAK KILOVOLTAGE ON DIAGNOSTIC X-RAY MACHINES

The kV-cassette is an adaptation of that described by Ardran and Crooks (1) which has become quite well-known. Its principle has been described thoroughly in the original publication and also in relation to other methods (2). A more detailed report of the NRL kV-cassette and its calibration is in preparation (3). Essentially, the kV-cassette relies upon the property of a heavily-filtered (homogeneous) x-ray beam that beam penetration depends strongly on kV-peak and only weakly on further filtration. In the kV-cassette two pairs of intensifying screens are used, one pair fast, the other slow. When exposed to the x-ray beam, which is filtered heavily through a copper reference filter, an x-ray film in the cassette produces corresponding high and low optical densities. A stepwedge in the path of that portion of the x-ray beam reaching the faster screen reduces locally the intensity of the beam, and one particular step (the matching step) produces an area of optical density equal to that for the slower screen (reference density). Since the penetration of the heavily-filtered x-ray beam depends essentially only on kV peak, the matching step of the wedge is an index of kV-peak.

The calibration of the cassette is therefore a plot of the thickness of matching wedge step (copper reference number) against kV-peak. For different x-ray generator waveforms different calibrations will apply, since in multiphase waveforms a higher proportion of photons is generated at higher kV and the resulting beam penetration is greater. The difference in calibration between various waveforms decreases with reference filter thickness and increases with kVp.

The optimum thickness of the reference filter, and consequently the wedge steps, varies with the kV. Hence different thicknesses of reference filters are used for the different energy ranges. For the main diagnostic x-ray range of 70-110 kVp, the NRL kV-cassette assembly comprises:

A. An epoxy resin-encased unit enclosing:

(i) a copper reference filter of thickness 4 mm;

(ii) an 8-step wedge with nominal steps 40, 52, 64, 76, 88, 100, 112, 124 thousandths of an inch consecutively (copper reference numbers);

(iii) a lead mask containing two rows of holes, eight under respective wedge steps and seven staggered and closeby, but not under the wedge. These latter are the reference density holes.

(For other kV ranges the reference filter thickness and wedge steps are tabulated with their calibration data. Relevant calibration data are appended to this report.)

B. A radiographic cassette containing two Du Pont Hi-Plus intensifying screens mounted front and rear; and one Du Pont Par Speed screen front-mounted together with another screen with its back outermost to complete the arrangement. The rear screens are mounted on lead to reduce the effect of back-scatter. The speed ratio of the two screen combinations is about 4.0.

Each NRL kV-cassette assembly has been given a code number. The code number appears on both cassette and wedge, and the calibration refers to the combination. Different wedges and cassettes are not necessarily interchangeable. The kV-cassette should be recalibrated not less frequently than annually, at NRL. Calibrations at NRL are performed on a 2-pulse diagnostic x-ray machine and a constant potential x-ray machine. These have been calibrated by an absolute K-edge method described by Williamson (4) and improved by Le Heron (3). There is also direct voltage-divider measurement of kV on the constant potential machine, as discussed by Chapman and Le Heron (5).

Procedure in Outline

The x-ray film cassette should be loaded with any blue-sensitive x-ray film and the wedge unit placed over it in the orientation determined by the construction of the cassette. The x-ray beam should be centred on the cassette and well-coned with the edges of the beam within the area of the wedge unit. An appropriate exposure is made and the x-ray film processed in the normal way in an automatic processing unit. The optical densities of the spots on the processed film should be measured with a transmission densitometer, and a plot made on 2 cycle x 2 cycle log/log graph or on 2 cycle semilog paper, of optical density versus copper reference number for those dots under the wedge. The reference dot optical density in the region of the matching step of the wedge is then taken to find from the graph the copper reference number to which it exactly corresponds (see figures 1 and 2). Using this reference number, the kVp is then read off the calibration graph for the appropriate x-ray generator waveform.

Details

The following points should be kept in mind during use of the kV-cassette.

1. The x-ray film used in calibration was Agfa Curix RP-2. Only slight inaccuracy is introduced by using other film except that because the intensifying screens are blue/ultra-violet emitting, green-sensitive x-ray film is inappropriate.

2. The usual focus-to-film distance should be about 1 m, but lesser distances, such as 50 cm, are appropriate in the 70 kVp region. However, to prevent

non-uniformity of irradiation, unduly short focus-to-film distances should be avoided and the stepwedge should always be aligned with its length perpendicular to the anode-cathode axis. Since the x-ray beam intensity varies considerably with angular displacement from the central axis (particularly along the anode-cathode axis) the angle subtended by the stepwedge at the focal spot should be as small as possible.

3. Exposure (mAs) should be such that the reference dots have an optical density in the range 0.6 to 1.5. This range corresponds, in general, to the most sensitive portion of a film's response to exposure. Very short exposure times should be avoided since considerable variations in the tube peak voltages can occur during the first few cycles of an exposure. Thus the exposure time should be sufficiently long (>0.2 sec) to reduce the effect of these initial variations. To avoid very short exposure times when higher kilovoltages are set, the focal distance may require to be increased.

   The thick copper filter used to obtain x-ray beam homogeneity necessitates relatively long exposures to obtain a radiographic image. These long exposure times reduce any effects due to irregularities that might occur from variations in the kV waveform during the initial few cycles of generation. At lower kilovoltages exposures are unfortunately quite heavy, and x-ray tube loading limits must be watched closely.

   Clearly, unless a machine is indeed in precise calibration it is not possible to specify appropriate mAs factors at each kV. An initial film is required as a trial exposure. As a guide, at 80 kV and at a focus-to-film distance of 1 m, 300 mAs can be used as a starting point.

4. Wherever feasible, the x-ray beam should be severely coned to the area of the wedge. This minimises scattered radiation reaching the film.

5. The x-ray film should be processed with the length of the stepwedge perpendicular to the processor rollers. This is to minimise any variations in the processing of stepwedge dots and their adjacent reference dots. Where small-sized film is used this may not always be possible, and processing perturbations should therefore be kept in mind as a possible source of error. If processor rollers are not clean or are worn, roller marks of varying density can invalidate optical density readings.

6. When optical densities are being read, it will be noted that despite all precautions during exposure, there are slight variations in the densities of reference spots. The actual value to use is that which best represents

the density in the region of the matching wedge step. It is for this reason, of course, that a row of reference spots is provided rather than a single central spot.

Calibration Curves

Each calibration curve is a linear least squares regression line of kVp on copper reference number. A linear fit was considered applicable for the narrow energy range involved, and this was borne out by the values of r^2 obtained. Confidence intervals for the prediction of an individual value of kVp for a given CRN, X_k, were determined using:

$$\hat{y} \pm t_{n-2,\frac{\alpha}{2}} s_{y/x} \sqrt{\left(1 + \frac{1}{n} + \frac{(X_k - \overline{X})^2}{\Sigma X^2 - (\Sigma X)^2/n}\right)} \; .$$

The 95% confidence interval is very closely approximated by ±2 kVp and this is shown on the graphs with the dashed lines.

Acknowledgements

Construction, including engineering design of the kV-cassette assembly, was performed by Mr D. Faulkner, Technical Officer, whose contribution is gratefully acknowledged.

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References

1. Ardran, G.M. and Crooks, H.E. Checking diagnostic x-ray beam quality. British J. of Radiology, 41, 193, 1967.

2. Hospital Physicists' Association (UK) The Physics of Radiodiagnosis. HPA Scientific Report Series - 6 (Second Ed. revised 1976) London; HPA, 1977.

3. Le Heron, J.C. Kilovoltage determinations on diagnostic x-ray tubes. NRL Report in preparation.

4. Williamson, B.D.P. X-ray machine kilovoltage calibrations by the use of K-fluorescence radiation. NRL Report 1974/6.

5. Chapman, R.H. and Le Heron, J.C. K-fluorescence radiation calibration of the primary standards kVp metering system. NRL Report 1979/13.

FIGURE 1: DIAGRAM OF A PROCESSED EXPOSED FILM (ACTUAL SIZE)

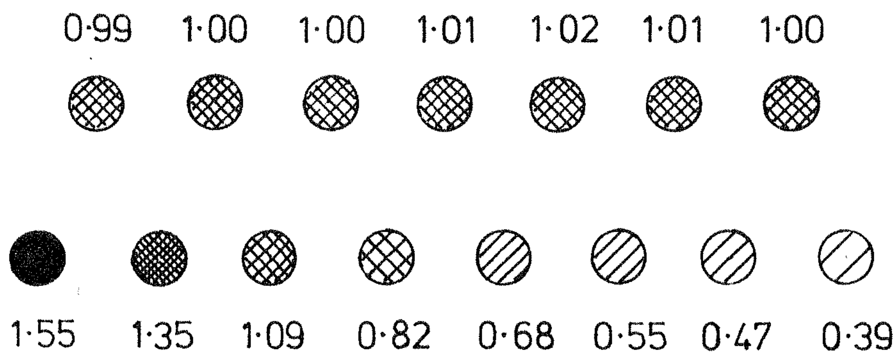

FIGURE 2: SAMPLE GRAPH TO SHOW WORKING PROCEDURE