Design and Validation of a X-ray Meter for the Developing World

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Abstract

In developing world hospitals, economic constraints do not allow the purchase of commercial diagnostic x-ray meters to evaluate the quality of x-ray machines. To provide hospitals a means of testing x-ray tube quality, a low cost x-ray meter was designed and validated with simulated signals and an x-ray machine. This meter was designed for Engineering World Health (EWH) to be distributed to developing world hospitals as a low cost alternative. The meter consists of a x-ray detector, x-ray Tube Quality circuit and Exposure Time circuit. The Tube Quality circuit compares the x-ray spectrum at two different kilovolt peak (kVp) settings, and the exposure time measurement has a resolution of 20 ms.

X-ray Production

X-ray machines produce photons of energies within the spectrum corresponding to the machines kVp value (Fig. 1).

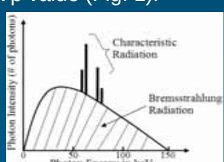

Fig. 1: *X-ray spectrum produced by an x-ray machine [3].*

When x-ray tubes fail, they are not able to produce the proper amount of high energy x-rays and therefore can not produce images with valid contrast.

X-ray Detector

The low cost detector utilized for the meter was designed previously [1]. Detector consists of a scintillation material coupled with a photoconductor and enclosed in a custom aluminum casing (Fig. 2).

When x-rays encounter detector, its voltage output changes proportionally to the area under the spectrum, which is related to the photon energies present.

- Detector has been validated and can distinguish varying kVps and x-ray energies [2].

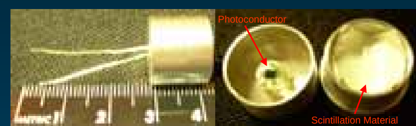

Fig. 2: X-ray detector components & casing.

Attenuation Concept

A filtering system is utilized to accomplish beam hardening. X-rays were attenuated by:

- Known amounts of 50, 60, and 70%
- Using aluminum plates

Only higher x-ray energies are used in the tube quality determination.

- Attenuation increases detector sensitivity to changes in tube quality (Fig. 3)

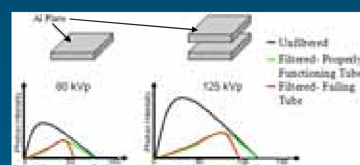

Fig. 3: Attenuation of x-ray spectrum with aluminum filter plates

- During failure, the tube cannot produce high energy photons needed to create an attenuated output signal equal to a functioning tube [4].
- Higher output voltage from the detector for a failing tube

Meter Circuit Design

- Meter consists of a tube quality circuit and an exposure time circuit (Fig.4).
- Circuits were validated using simulated signals

Tube Quality Circuit

- Compares output of detector to reference voltage at two kVp values.

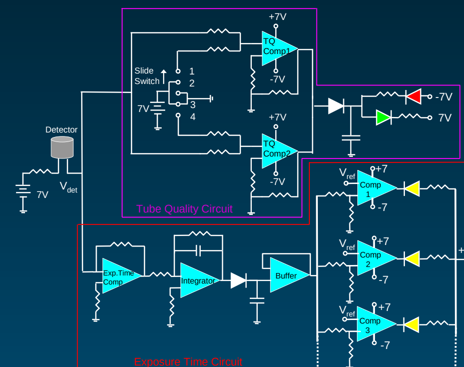

Fig. 4: Overall meter circuitry. Comparator cascade consists of 8 comparators (3 shown).

Exposure Time Circuit

- Converts detector output to constant signal, integrates to determine time, and displays output with LEDs; each illuminated yellow LED represents 20ms of exposure time.

Attenuation Testing

- Testing occurred on a Siemens Polyphos 50 x-ray machine at Baystate Medical Center
- Oscilloscope measured detector outputs

Fig. 5: Testing set up at Baystate Medical Center

Testing Completed

Detector output measured at 81 &125kVp with:

- Attenuation: 0, 50, 60 and 70% of signal
- Simulation of failing tube at 10, 20, & 30%

Results

- Significant difference between 50% and 70% at 81 and 125 kVp.
  - An ANOVA and Tukey analysis determined the significance at $p<0.05$

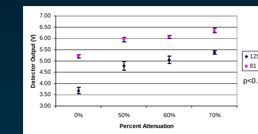

Fig. 6: Attenuation results at 0, 50, 60 and 70%.

Simulation of Failing Tube

- Attenuation at 10, 20 and 30% (Fig. A and B)

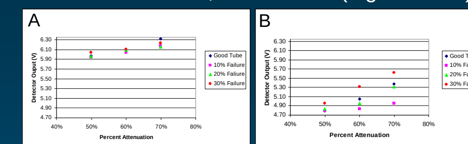

Fig. 7: Failing tube simulation at (A)81 & (B)125 kVp

- Detector output is inconsistent: higher attenuations should yield higher voltages
- May not be properly simulating failing tube

Future Work

- Design a new method for simulating a failing x-ray tube
- Set reference voltages for tube quality circuit

Conclusion

The initial attenuation testing resulted in significant differences in output between 50 and 70% attenuation, as well as between 60 and 70% at both 81 and 125 kVp. The results show the detector can detect a difference of 10% attenuation. The failing tube simulation results were not consistent with initial testing, therefore a new method to simulate a failing tube is needed. These results indicate that this novel design will be able to detect both tube quality and exposure time.

References

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