Dynamic Beam Attenuator

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Abstract

In the US alone, 70 million Computed Tomography (CT) scans are performed each year, but it is estimated that 1 in 50 scans may lead to cancer[1]. In order to improve CT safety, our client, Dr. Charles Mistretta, is researching the use of dynamically attenuated X-Ray beams during scans. Dynamic beam attenuation (DBA) has been shown to increase signal to noise ratio uniformity and decrease X-Ray scatter, which improves image quality[2] and reduces unnecessary dosage passing through the patient[3]. We designed and actuated a set of parallel wedges that selectively attenuate X-Ray beams when placed in the X-Ray path. The device was found to be precise to 180 microns and 0.12±0.079% difference in attenuation reproducibility when tested with a CT scanner.

Introduction

Client: Dr. Charles Mistretta, UW-Madison

- Departments: Medical Physics, Radiology, and Biomedical Engineering
- Research: Magnetic Resonance Imaging and X-Ray CT
- Project proposal: Mechanize a device used to test DBA

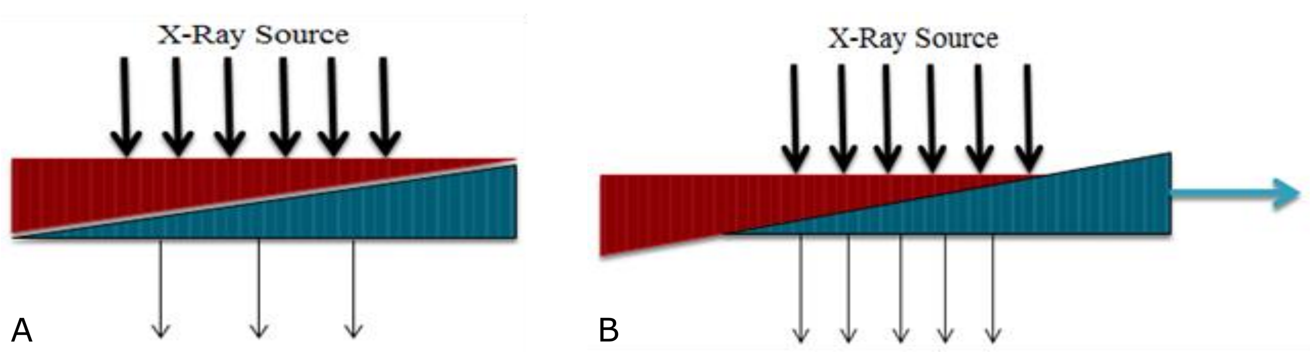

Figure 1: Wedge-Based Beam Attenuation
(A): The wedges are placed in the X-Ray field. Maximally overlapping wedges correspond to maximum attenuation – minimal X-Rays pass through the wedges and reach the patient.
(B): As one wedge moves out of the X-Ray field, the material thickness is reduced and more X-Rays pass through the wedges

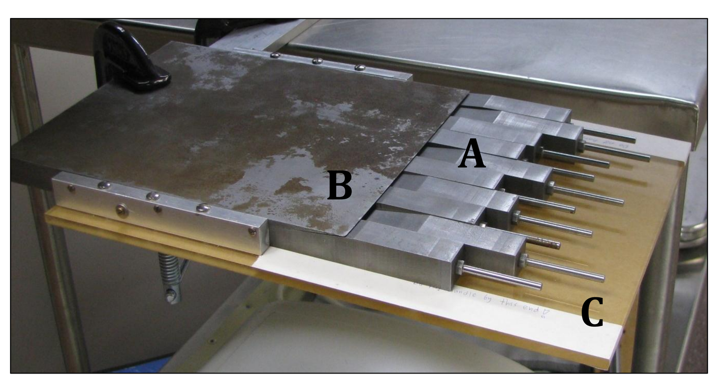

Figure 2: Original DBA Prototype
The prototype consists of ten hand-movable steel wedges (A) and a steel solid wedge (B). The prototype is mounted to a sheet of Plexiglas (C).

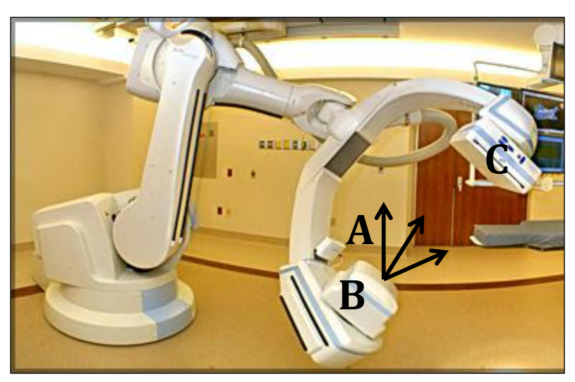

Figure 3: C-Arm CT Scanner
This scanner emits a fan-shaped array of X-Ray beams (A) from the source (B) and collects the X-Rays at the detector (C). It has a range of motion of 220 degrees.

Design Criteria

- Each wedge must:
  - Move independently of other wedges
  - Attain pre-programmed positions dependent on desired metal thickness or attenuation value
  - Move at a maximum of 1 mm increments
  - Have a stroke length greater than 4 cm
  - Be flush with base plate and neighboring wedges
- Generate a post-scan report of individual wedge positions

Material Optimization

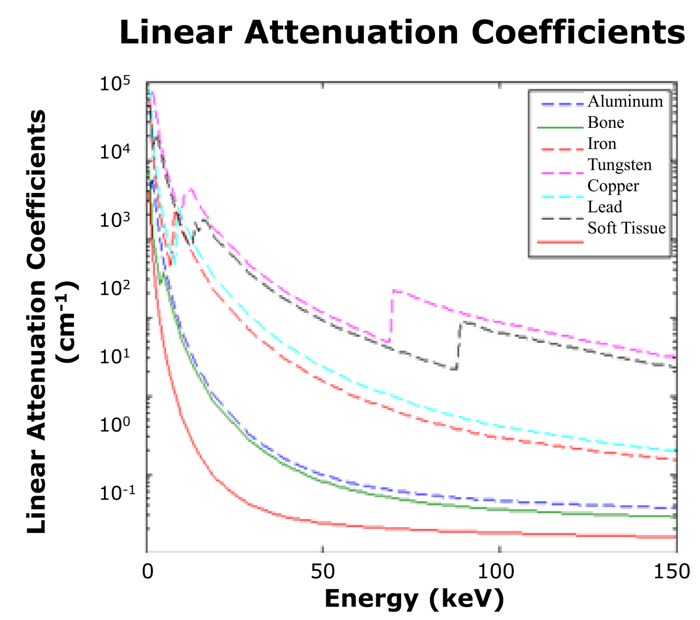

Figure 4: Material Attenuations
Linear attenuation coefficients as a function of energy for various materials using NIST material data[4].

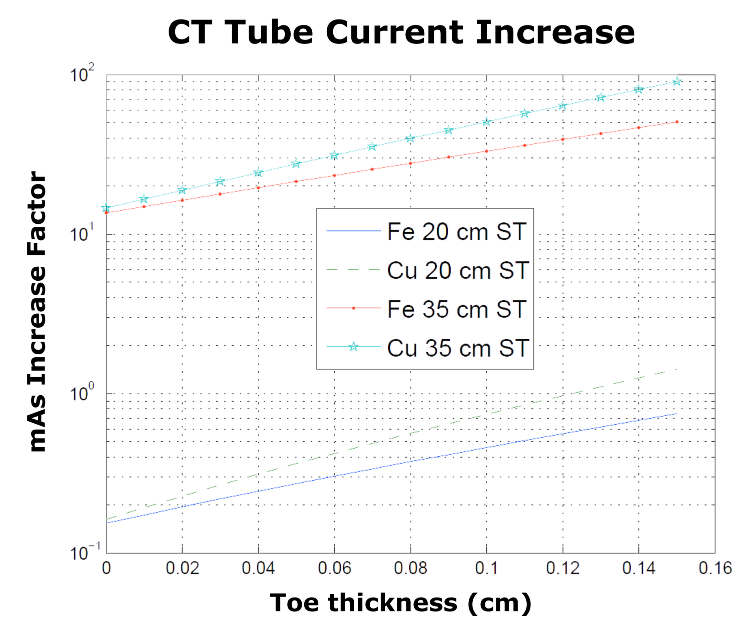

Figure 5: Required Current Increase
The necessary increase in mAs for copper and iron to compensate for the minimum amount of metal in the X-Ray path.

Table 1: Properties of wedge materials considered
Leaf thickness refers to the amount of material required to attenuate 36 cm of soft tissue and 1 cm of bone.

Material	Leaf Thickness (cm)	Cost per in³	Mass (g)
Tungsten	0.1205	$51.39	46.97
Lead	0.2456	$2.27	56.4
Copper	1.1401	$3.91	206.86
Iron	1.6342	$1.24	260.57
Aluminum	12.9709	$0.53	709.18

- Current CT scanners have a finite mAs increase, which eliminates tungsten and lead as metal choices
- After analysis, the original prototype with steel wedges was determined to be sufficient for proof of concept

Final Design

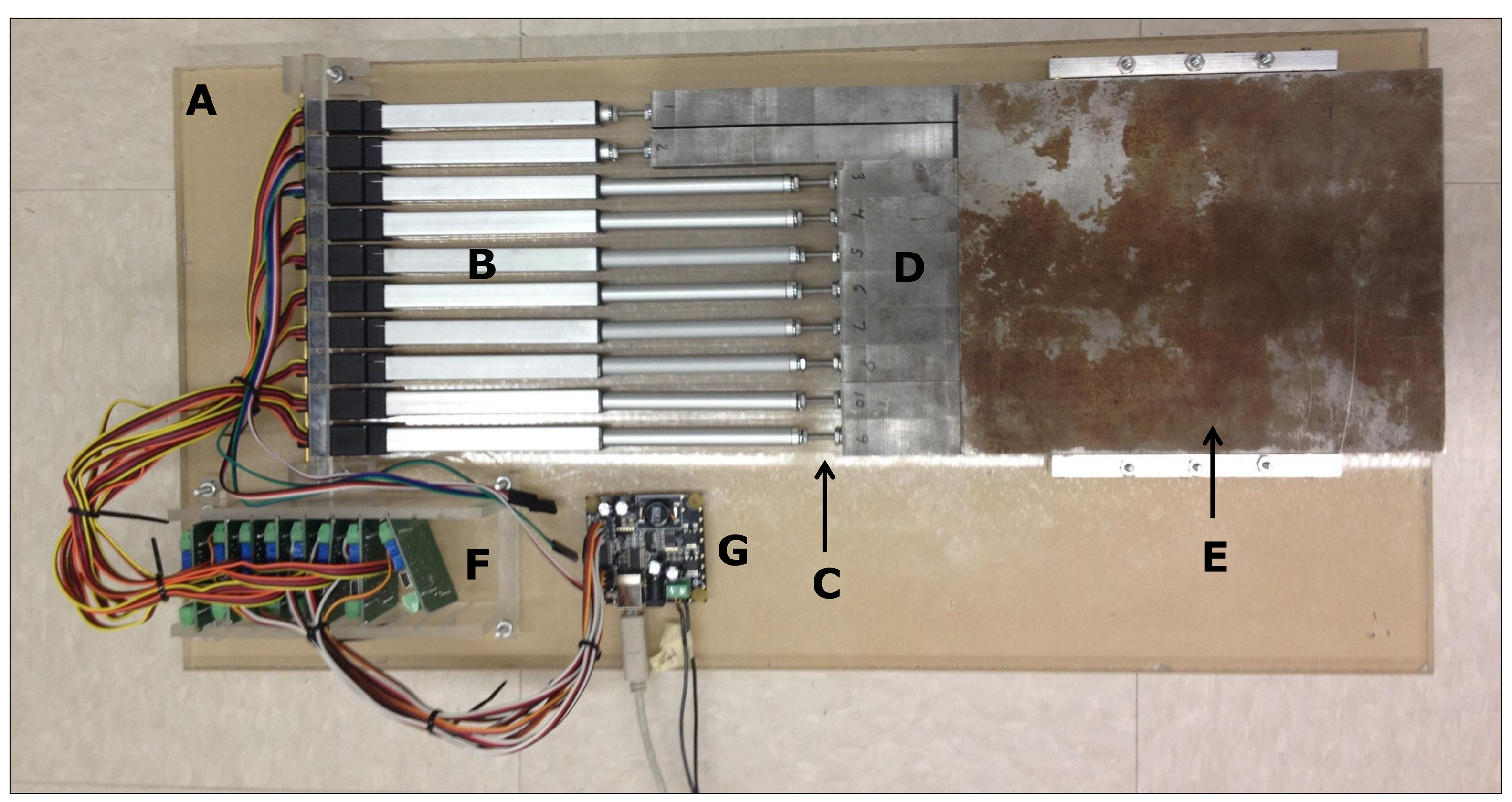

Figure 6: Final Device

(A): 30.5 x 61 cm acrylic base
(B): Firgelli L12-I and L12-P 12 V Linear Servomotors with 100 mm stroke length and 50:1 gear ratio
(C): Motor to wedge coupler
(D): Ten 15 x 17.5 x 220 mm steel wedges
(E): Fixed 175 x 220 mm steel wedge
(F): Eight linear actuator controller boards
(G): PhidgetAdvancedServo 8-motor controller

Testing

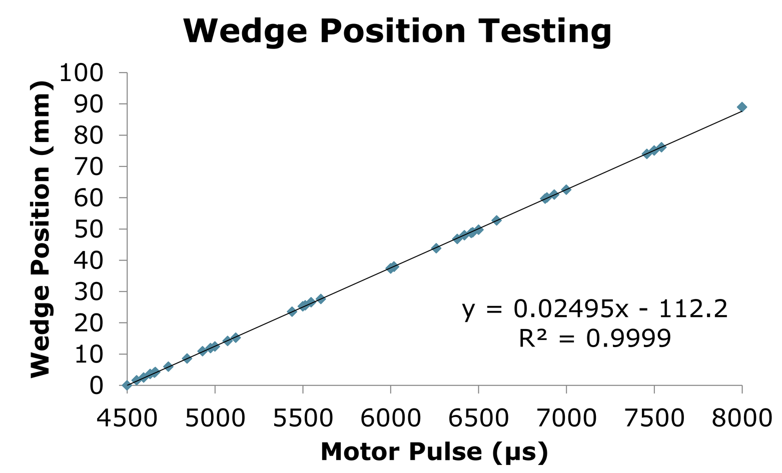

Figure 7: Wedge Positioning
Linear relationship between motor input and wedge position.

Repeatability using Calipers

- Inputted randomly generated pulses from driver program to motor controller
- Wedge position was measured with calipers
- Determined that a wedge can be reliably positioned within 180 microns

Repeatability using CT Scanned Images

- Wedges were imaged, moved, returned to the starting position, and re-imaged
- Repeated four times
- Images were subtracted to test for reproducibility
- Subtracted images showed 0.12±0.079% difference in attenuation from test to test
- Satisfies our clients' requirements

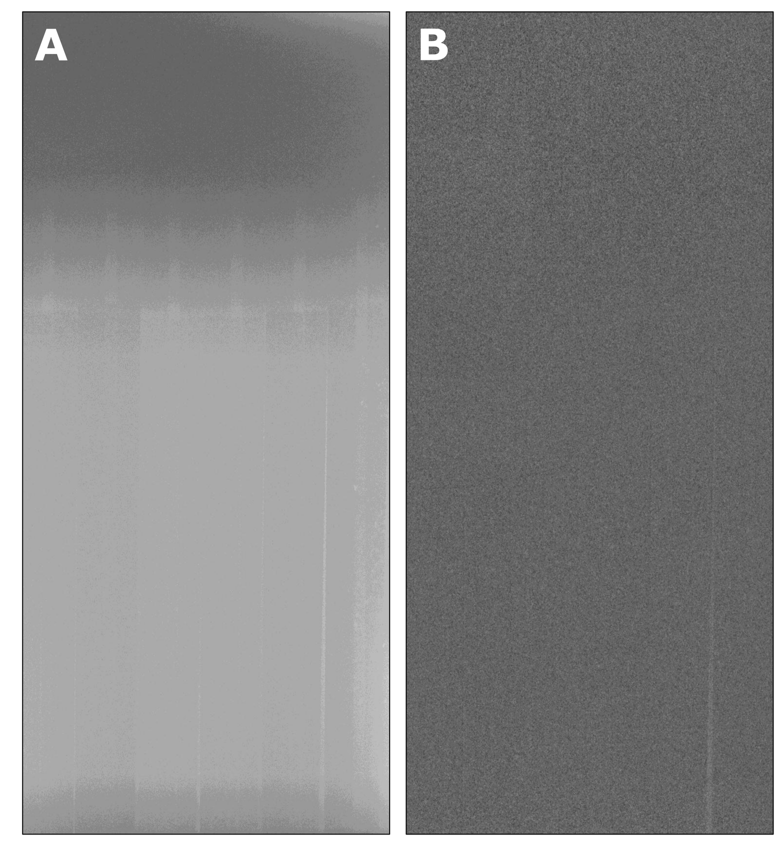

Figure 8: CT Images of Wedges
(A): Image of seven wedges
(B): Subtraction of two images before and after movement

Future Work

- Test device with phantoms using CT
- Quantify dose reduction, signal to noise improvement, and scatter reduction with DBA
- Present findings to Siemens
- Reduce device size
- Patent design
- Integrate into a future generation of CT scanners

Acknowledgements

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- Dr. Charles Mistretta
- Tim Szczykutowicz
- Dr. Thomas Yen
- Kevin Royalty
- Siemens USA

References

[1] Brenner, D.J. (*2010*). Slowing the Increase in the Population Dose Resulting from CT Scans. *Radiation Research*: December 2010, Vol. 174, No. 6b, pp. 809-815.
[2] Brenner, D. J., & Hall, E. J. (2007, November). Computed Tomography — An Increasing Source of Radiation Exposure. *The New England Journal of Medicine* , 357:2277-2284.
[3] Szczykutowicz, T. and Mistretta C. A. (2011). Practical considerations for intensity modulated CT. *Proceedings of SPIE Medical Imaging*, vol. 8313, no. 161.
[4] Hubbel, J.H., & Seltzer, S.M. (1996). Tables of X-Ray Mass Attenuation Coefficients and Mass Energy-Absorption Coefficients, NIST X-ray Attenuation Database.