# DIGITAL BEAM ATTENUATOR

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CLIENT: DR. CHARLES MISTRETTA
ADVISOR: DR. CHRIS BRACE

## ABSTRACT

Our client, Dr. Charles Mistretta, is researching the use of dynamically attenuated X-Ray beams during computed tomography (CT) scans. Dynamic attenuation has been shown to increase signal to noise ratio uniformity and decrease X-Ray scatter[3]. This improves image quality and reduces the necessary imaging dose[3]. Our client has developed a prototype to test digital beam attenuation (DBA) and asked us to design a system to automate the prototype motion. Our final design uses a linear stepper motor to actuate one wedge. We found the wedge travels with a constant acceleration and moves with 10173 µsteps/mm. As the motor is currently too wide to actuate multiple wedges, future designs will require a smaller stepper motor.

## INTRODUCTION

**Client: Dr. Charles Mistretta, UW-Madison**

- Departments: Medical Physics, Radiology, Biomedical Engineering
- Research: MRI and X-Ray Computed Tomography (CT)
- Project proposal: Mechanize a device used to test DBA

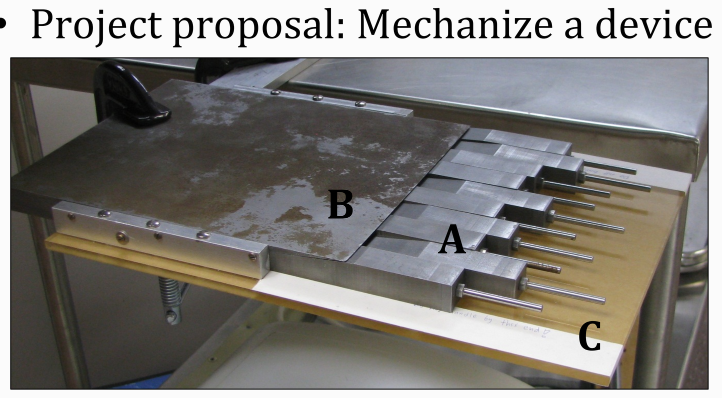



**Figure 1: DBA Prototype**
The prototype consists of ten hand-movable steel wedges (A) and a steel solid wedge (B). The prototype is mounted to a sheet of Plexiglas (C).
Photo Credit: Tim Szczykutowicz

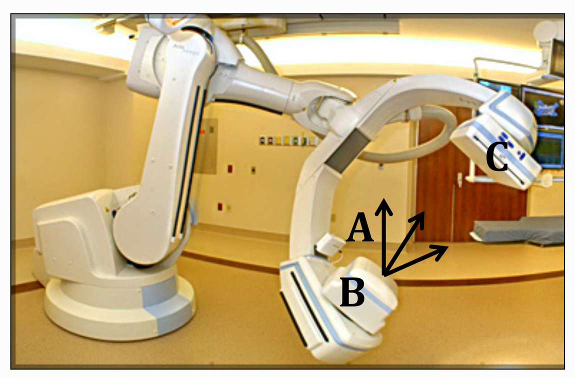



**Figure 2: C-Arm CT Scanner**
This scanner emits a fan-shaped array of X-Ray beams (A) from the source (B) and collects the X-Rays at the detector (C). It has a range of motion of 220 degrees. Photo Credit: Katherine Lake

(A)
(B)

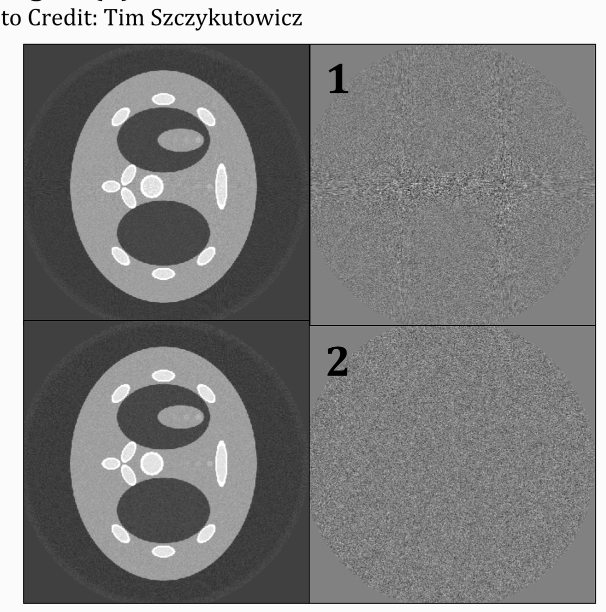



**Figure 3: CT Phantom Scans (A),(1) Without DBA and (B) ,(2) With DBA**
The DBA simulation uses 1240 leaves and the dose was 22% lower than the non-DBA simulation dose. (1) and (2) show reconstruction noise; (2) shows the preferred uniform noise of DBA images.
Photo Credit: Tim Szczykutowicz

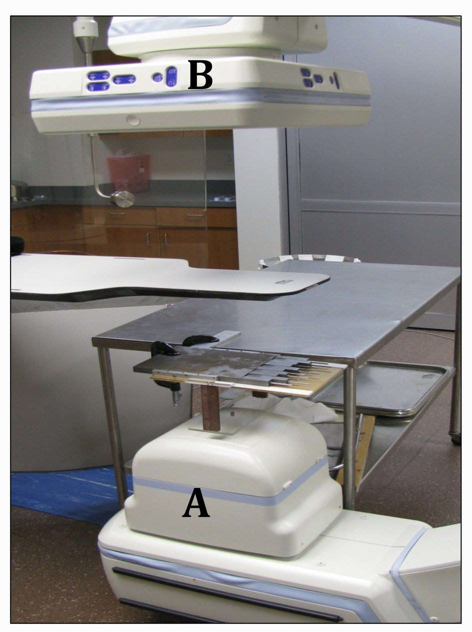



**Figure 4: Mounted DBA Prototype**
The prototype is mounted between the X-Ray source (A) and detector (B) to attenuate the X-Ray beams.
Photo Credit: Tim Szczykutowicz

## DESIGN CRITERIA

- Scalable actuation method
- Each wedge:
  - Move independently of other wedges
  - Attain pre-programmed positions dependent on time
  - Maximum 1mm movement increments
  - Stroke length > 4cm
  - Minimum speed: 15 mm/s
  - Flush with base plate and neighboring wedges
- Post-scan report of individual wedge position and corresponding time

## TESTING

### SCALABILITY ANALYSIS

(A) (B)

**Figure 5: Micro Linear Motor (A) and Micro Stepper Motor (B)**
Both are available commercially from Micromo. The linear motor produces linear motion and the stepper motor can be used with a lead screw to generate linear motion.
Photo Credit: [4], [5]

| Findings | |
|---|---|
| Wedge Width | 17.5 mm |
| Current Motor Width | 56.4 mm |
| Linear Motor Width[2] | 12.5 mm |
| Stepper Motor Diameter [1],[2] | 6-12 mm |

### POSITION

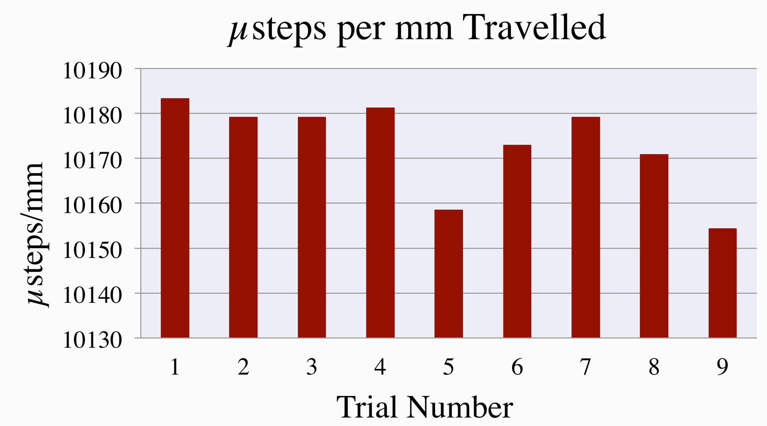



**Figure 10: Motor Positional Precision**
The motor can be precisely positioned using the integrated controller and lead screw. Nine trials using 500,000 µsteps/trial were completed.

| Experimental Data | |
|---|---|
| Average measured µsteps per mm | 10173[2] |
| Actual µsteps per mm | 10078 |
| Standard Deviation | 9.72 µsteps |
| Average Percent Error | .9356 % |
| Average Movement Increment | .026 mm/step |

### VELOCITY

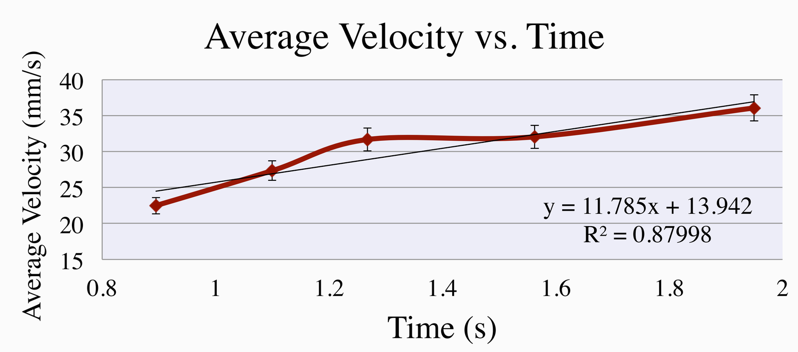



**Figure 6: Velocity Testing Results**
The time required to travel a known distance was measured and n = 10 trials were used to calculate the average velocity at each distance. The motor achieved an average velocity of 36 mm/s at d = 70mm and the estimated acceleration, using a the slope of a linear trendline, is 11.78 mm/s$^2$.

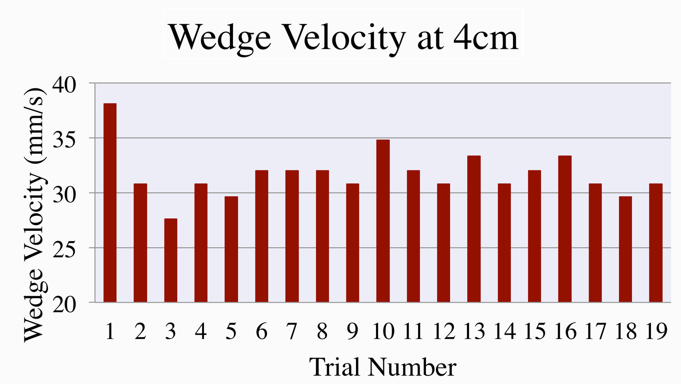



**Figure 7: Wedge Velocity at Stroke Length**
The average velocity at the stroke length of 4cm is 31.67 mm/s with a standard deviation of 2.15 mm/s.

### FORCE

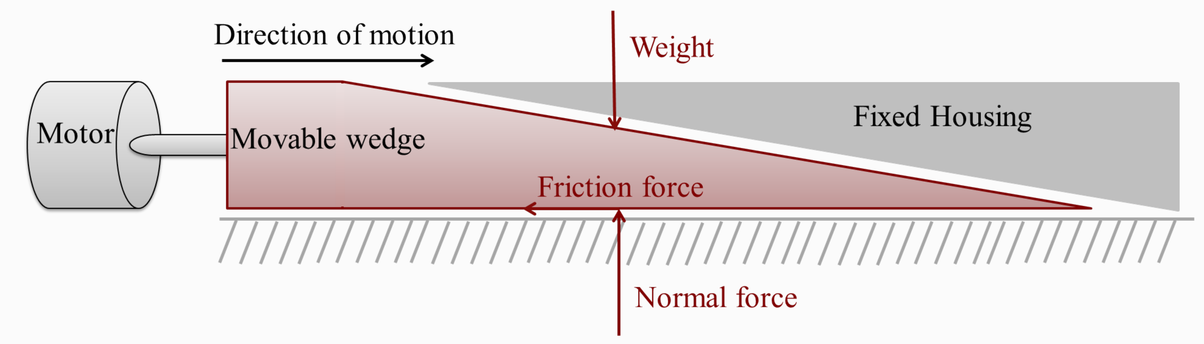
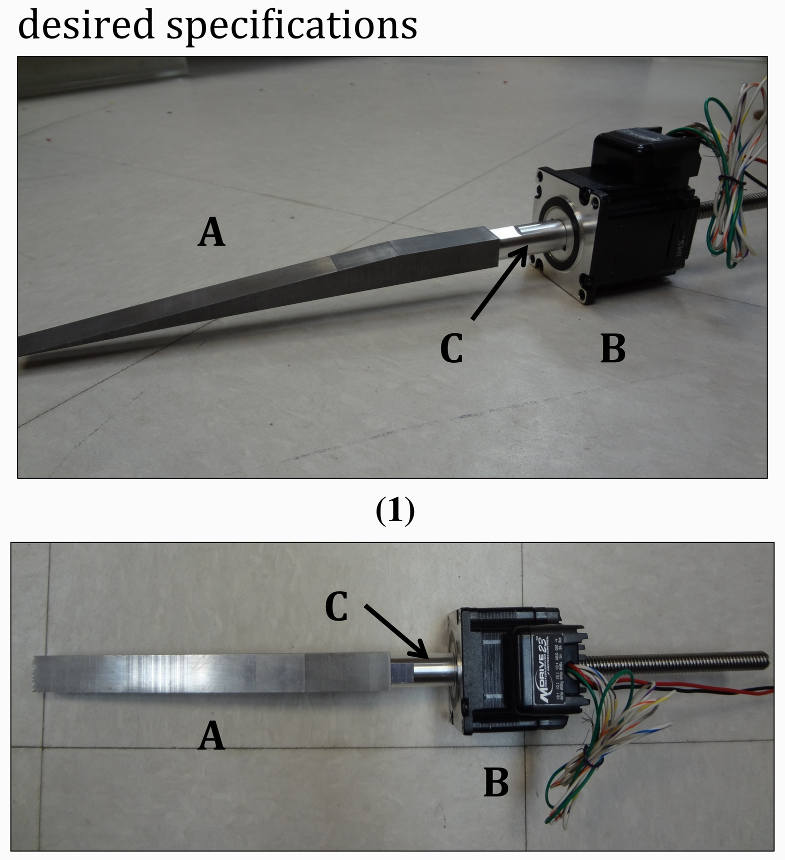



**Figure 11: Wedge Free Body Diagram**
A free body diagram was used to estimate the friction forces experienced by the wedge during motion. It assumes an additional normal force caused by the motor torque and negligible interactions with neighboring wedges. Using µs = 0.4 between the 275g steel wedge and the Plexiglas base, the calculated static friction force is F = 1.08N.

## FINAL DESIGN

**Accomplished:**

- Used Mdrive 23 plus linear actuator[1],[2]
- Utilized scalable actuation method
- Independently actuated one wedge to desired specifications




(2)

**Figure 8: Single Wedge with Motor Attachment (1): Side View (2): Top View**
The M-Drive 23 Plus linear actuator (B) is connected to the wedge(A) with an adapter (C) and can drive the wedge a 4cm stroke at a velocity of 31.67 mm/s.
Photo Credit: Katherine Lake

**Movement Characteristics**

- Initial Velocity 25 mm/s
  - Satisfies 15mm/s requirement
- Maximum stroke length 10 cm
  - Satisfies 4cm requirement
- Minimum movement increment 7.5E-5 mm
  - Satisfies maximum 1mm requirement

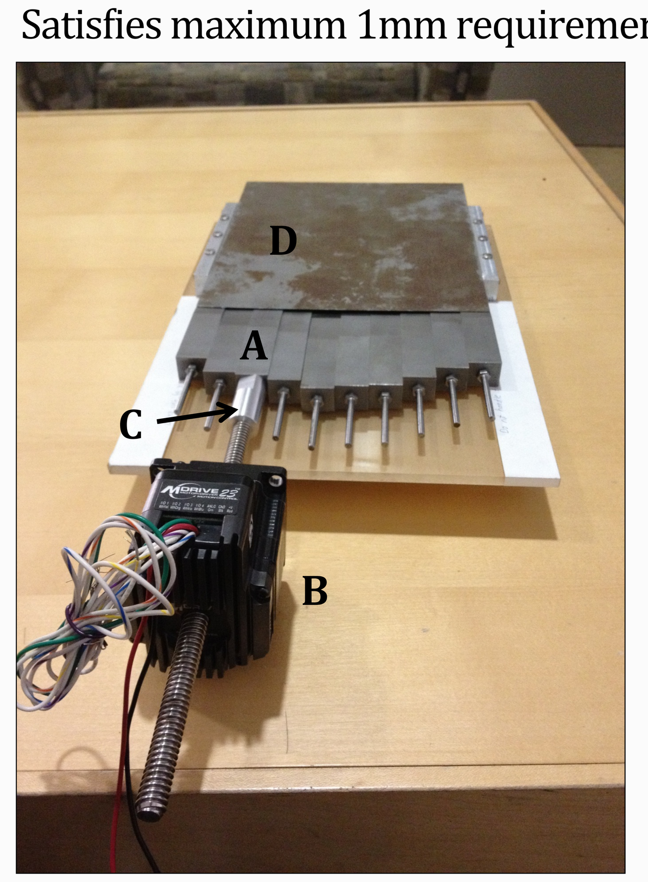
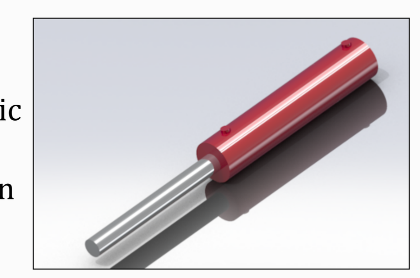



**Figure 9: Actuated Prototype**
The motor (B) drives the actuated wedge (A) inside the prototype housing (D) with a stroke length of up to 10 cm. The wedge is connected to the motor via a adaptor (C).
Photo Credit: Katherine Lake

## FUTURE WORK

**Figure 12: Hydraulic Cylinder**
In some cases, micro hydraulic cylinders are more suited for applications of precise motion control in small spaces.
Photo Credit: [6]



- Actuate all wedges
- Increase number of wedges
- Utilize smaller motors
- Sinusoidal wedge motion
- Investigate hydraulics

## ACKNOWLEDGEMENTS

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[1] Condit, Reston and Douglas W. Jones. "Stepping Motors Fundamentals." 26 January 2004. 7 December 2011 <http://ww1.microchip.com/downloads/en/AppNotes/00907a.pdf>.
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