Alternative Design #2 Report
Adjustable Back Angle Controller (ABAC)

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Table of Contents

1. Alternative Design No.2
   1.1. Introduction        2
   1.2. Subunits
      1.2.1. Control Lever       4
      1.2.2. Lever         4-5
      1.2.3. Resistance Spring       5-7
      1.2.4. Electric Circuit       7-12
         1.2.4.1. Overview       7
         1.2.4.2. Potentiometer       8-10
         1.2.4.3. Inverting Amplifiers       10-11
         1.2.4.4. Difference Amplifiers       11-12
         1.2.4.5. Filter       12
      1.2.5. Electric Motor       12-13
      1.2.6. Actuator        13-14
      1.2.7. Support Frame       16-17
   1.3. Realistic Constraints       20-22
   1.4. Safety Issues        22-24
   1.5. Impact of Engineering Solutions     24-26
   1.6. Life-Long Learning       26-28
   1.7. References         29-30

Figures and Tables

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 1</td>
<td>Flow Chart of Device Operation</td>
<td>3</td>
</tr>
<tr>
<td>Figure 2</td>
<td>Basic Design of Handle</td>
<td>5</td>
</tr>
<tr>
<td>Figure 3</td>
<td>Calculation of Input Force on Springs</td>
<td>6</td>
</tr>
<tr>
<td>Figure 4</td>
<td>Free Body Diagram of Control Lever</td>
<td>7</td>
</tr>
<tr>
<td>Figure 5</td>
<td>Circuit Schematic</td>
<td>8</td>
</tr>
<tr>
<td>Figure 6</td>
<td>Typical Rotary Potentiometer</td>
<td>9</td>
</tr>
<tr>
<td>Figure 7</td>
<td>Internal Workings of Rotary Potentiometer</td>
<td>9</td>
</tr>
<tr>
<td>Figure 8</td>
<td>Operational Amplifier (Op Amp)</td>
<td>10</td>
</tr>
<tr>
<td>Figure 9</td>
<td>Inverting Amplifier Circuit</td>
<td>11</td>
</tr>
<tr>
<td>Figure 10</td>
<td>Difference Amplifier Circuit</td>
<td>12</td>
</tr>
<tr>
<td>Figure 11</td>
<td>Circuit for a Series Wound DC Motor</td>
<td>13</td>
</tr>
<tr>
<td>Figure 12</td>
<td>Worm Gear/ Lead Screw Drive System</td>
<td>14</td>
</tr>
<tr>
<td>Figure 13</td>
<td>Free Body Diagram of Lifting System</td>
<td>14</td>
</tr>
<tr>
<td>Figure 14</td>
<td>Linear Actuator Mounting Bracket</td>
<td>16</td>
</tr>
<tr>
<td>Figure 15</td>
<td>Properties of Aluminum-Beryllium 80/20</td>
<td>16</td>
</tr>
<tr>
<td>Figure 16</td>
<td>Overall Schematic at 0° Angle</td>
<td>18</td>
</tr>
<tr>
<td>Figure 17</td>
<td>Overall Back and Side Schematic at 70° Angle</td>
<td>19</td>
</tr>
<tr>
<td>Table 1</td>
<td>Proposed Budget</td>
<td>26</td>
</tr>
</tbody>
</table>
1. Alternative Design Project No.2

1.1. Introduction

Nursing is among one of the highest risk occupations for the development of back pain and injuries. Currently 17% of nurses experience chronic back pain due to working in a hospital setting. 36% of these back injuries in nurses can be contributed to patient handling. In addition to the back pain, women are also twice as likely to contract musculoskeletal disorders from the following work tasks: repeatedly lifting greater than 7 lbs, lifting patients more than 10 times per hour, making beds normally or often, and pushing beds or trolleys more than 10 minutes per day [1]. These daily tasks cannot be avoided; however, by the implementation of an automatic adjustable bed, nurses will incur less stress on their back during the adjustment of the patient.

Patients that suffer from back pain, obesity, and other debilitating diseases, require an inclined bed back to relieve pain or provide easy access to the bed. Current technology includes an adjustable bed back with a remote control that is accessible for both the patient and the caretaker. However, this does not accommodate users of all disabilities. For example, a patient with limited sight may find it difficult to find the remote or press the correct buttons to operate the bed. Some of the current beds that may operate at higher speeds are rough or jerky when stopped in position. This erratic movement also occurs in beds that have more than one speed.

The Adjustable Back Angle Controller will improve upon the current methods of adjusting a bed. This device will be controlled with a force sensitive handle located on the most accessible side of the bed. The basic concept of adjusting the back angle will take the input force on the handle and adjust the speed proportional to the force applied to the handle, i.e., more force on the handle outputs a faster speed to raise or lower the back angle. This concept works by adjusting the voltage supplied to a linear actuator with a potentiometer in the joint of the handle. This design will accommodate those with limited mobility and control; as well as prevent injuries to caretakers that attempt to sit the patients upright. The variable speed motor will control the actuator from zero to a safe maximum speed. This will allow for a smoother operation while still offering speedy adjustments when necessary. Overall this device will be user-friendly, smoother in operation, and less time consuming, making the operation less stressful. This operation is summarized in Figure 1.
Figure 1: Flow Chart of Device Operation
This report contains details of each subunit of the device, the testing the subunits, how safety is being addressed in the design, the impact of the design, and how this project has educated the designers. It differs from the previous report in that the new design no longer contains hydraulic parts because they are not acceptable for a hospital setting. Also, an electric circuit has been designed to control the linear actuator’s movement. Finally, the orientation of the actuator to the frame of the bed has also been adjusted.

1.2. Subunits

1.2.1 Control Lever

The control lever will consist of three main parts; a lever, a potentiometer, and two resistance springs. The lever will be approximately one foot long, and will be in the shape of a flattened “S”. Figure 2 shows the preliminary shape which has been designed to keep the majority of the control lever below the surface of the bed, out of the way of both the patient and the care-giver, while still allowing easy access to the patient within the bed. The lever will be used to operate the potentiometer. The potentiometer will control the voltage supplied to the electric motor. When the lever is moved one way, the potentiometer will be varied so as to supply either a positive or negative voltage to the motor. If the lever is moved in the other direction, the motor will be driven in the opposite direction. The electric motor will rotate one way or another depending on the sign of the voltage. With a greater amount of deflection on the lever, the potentiometer will increase the voltage to the motor, which in turn increases the speed of the motor. The resistance springs serve a two fold function. First of all, they will return the lever to its zero position, which will maintain zero voltage sent to the motor, causing the motor not to move, and to lock with the use of an electromagnetic brake. Second, the springs will provide the proper resistance so that a specific force will be required to displace the lever a specified amount. Therefore, the greater force applied to the lever, the greater voltage sent to the motor and a greater output speed to the bed back.

1.2.2 Lever

The lever will be the object moved by the user to operate the Adjustable Back Angle Controller. Its shape will be ergonomic, so as to make operation of the device as simple and comfortable as possible. One innovation is the “S” shape which has been incorporated in Figure 2.
This shape is designed to keep the majority of the control lever out of the way, but allow both the patient and caretaker to comfortably work the device. This should also help reduce the occurrences of the handle being bumped, since only a fraction of it will be above the protection of the bed mattress. Another feature is a safety lock, which will be built into the handle. In the occurrence of the lever being accidentally bumped, this safety switch will prevent the bed from operating. The safety switch (similar in appearance to a hand brake on a bicycle) will be a simple open loop switch. When the safety switch is on, the loop will be open. Since the input is conveyed to the motor via an electric circuit, any break in this will prevent the motor from being driven. The safety switch will be placed on the under side of the lever so that accidental activation does not occur in the event of force being applied from the top of the handle, such as the patient rolling over on the lever, or a visitor sitting on it. The safety switch will only require as little as one pound of force to unlock, so that all users will be able to operate it easily.

1.2.3 Resistance Spring

The resistance springs are used in the control lever to bring the lever back to zero when the action is done, and to correlate an input force with an output displacement into the valves. To zero the lever, two springs with identical spring
constants (k) will be attached between the lever, and opposite sides of the retaining box. The springs are to be sized such that both springs are stretched an equal amount when the lever is in the zero position. By stretching both springs even in at zero, makes both springs act equally on the lever at all times. Both springs must also be stretched even when the lever is at its maximal displacement to both sides. This is required so that the shorter spring does not begin to compress and push back against the lever, making calibrations less precise.

To design the proper control lever, the characteristics of the resistor circuit system must be known. Once the relationship between the resistance-lever displacement and the voltage output by the circuit is known, the input to output force can be calibrated. With a known hand displacement (Δx), and a known spring constant (k), force required to displace the spring-lever is equal to the spring constant times the displacement (F=kΔx) as shown in Figure 3. For example, if the maximum displacement of the springs is four inches and knowing that the maximum force applied is 20 lbs, it can be calculated that the spring constant needed is five.

\[ F = k \Delta x \]

(F=kΔx; where \( x_2-x_1=\Delta x \))

**Figure 3: Calculation of Input Force on springs**

The force required to push at the end of the handle (P), can then be found by drawing a basic free body diagram of the lever with springs as shown in Figure 4, and describing the moment about point A. By solving for P, the force to displace the lever some amount (x) is directly proportional to the force applied. To test the spring for the proper spring constant, the spring will be attached to an immobile surface. We will then measure its un-stretched length. A series of objects of known weight will then be hung from the spring, and the final stretched length of the spring will be measured. To solve for the spring constant (k), \( F = k \Delta x \) can be rearranged to, \( k = \frac{F}{\Delta x} \) where \( \Delta x \) is the change in length measured, and F is the weight of the object hung from it. After several repetitions, it will be possible to determine whether the spring truly does exert with a constant force to stretch ratio, or if the spring is defective, as well as validating the spring constant.
Where:

Fs1 = k(L1)
Fs2 = k(L2)
P = input force
ΣM_A = 0 = P*L + Fs2*l - Fs1*l
P = l*(Fs1 - Fs2) / L
P = l*k*(L1 - L2) / L

Figure 4: Free Body Diagram of Lever

1.2.4 Electric Circuit

1.2.4.1 Overview

The electric circuit, in Figure 5, serves to translate the mechanical action on the control handle into action of the linear actuator. Movement of the handle changes the relative voltages on either side of a potentiometer. The voltages are passed through separate inverting amplifiers, and are then compared by a differential amplifier. This final voltage is then applied to the motor on the linear actuator. The circuit will be designed and simulated in PSPICE. After the parts come in the circuit will be constructed on a protoboard and tested using a digital multimeter. Finally, the parts will be soldered into a circuit board designed for this purpose and once again tested with a multimeter before being integrated with the rest of the device.
1.2.4.2 Potentiometer

The potentiometer is directly attached to the handle. A potentiometer is a variable resistor that acts as an electro-mechanical transducer. This means that it converts mechanical stimuli into electric effects. The potentiometer will convert the displacement and direction of the handle into a variation of resistance within a circuit. A potentiometer has three terminals that can be connected to the rest of the electrical circuit. The resistance between the two end terminals is constant and is set at manufacturing. However, the resistance between the middle terminal and either terminal adjacent to it changes as the shaft is rotated. A typical potentiometer is pictured in Figure 6.
Inside the potentiometer is a long resistor with its ends attached to either end terminal. The middle terminal is connected to a wiper that moves along the resistor. The resistance between the end terminal and the middle terminal varies according to how far the wiper is along the resistor. This is shown in Figure 7.
the terminal as possible, the voltage at that terminal will be equal to the middle terminal. The opposite is also true. For this device the default position will be the center, where equal voltages will be output to both end terminals. When movement of the handle rotates the shaft and thus changes the position of the wiper, a voltage difference will appear at the two end terminals. When the lever is pushed downward, the potentiometer will be within the lower half of its range. The circuit will then output a negative voltage value, which will cause the motor to be driven in a direction which would lower the bed back angle. When the lever is raised, the potentiometer will be in the upper half of its range, causing the value sent to the motor to be positive, driving the motor in the direction corresponding to raising the bed back. These voltages will be amplified to control the actuator. In either case, greater displacement of the lever will produce a greater absolute value voltage output to the motor. This in turn will drive the motor at a faster rate.

### 1.2.4.3 Inverting Amplifiers

The voltage from each terminal is then sent to separate inverting amplifiers, of which operational amplifiers (op amps) are the central part. Op amps (such as the one shown in Fig. 8) are composed of resistors and transistors, all contained in a single IC chip.

![Op Amp](image)

Figure 8: Op Amp [4]

The resistors around the op amp will be configured with a resistor between the input voltage and the negative input ($R_1$) and with another between the output and the negative input ($R_f$). The positive input will be connected to ground. To simplify calculations, the op amps are assumed to be ideal. This means that there is no input currents, and the input voltages are equal. In this scenario, the output voltage is $V_{out} = -\left(\frac{R_f}{R_1}\right)V_{in}$ (see reference in Figure 9) [5]. By varying $R_f$ and $R_1$, the output voltage can be amplified up to the op amp’s control voltage. The inverting amps’ main purpose in this circuit is to amplify the
voltage from the potentiometer terminals to a level that can be used by the motor.

**Figure 9: Inverting Amplifier Circuit [5]**

1.2.4.4 **Difference Amplifier**

The two voltages from the inverting amplifiers are then both put into a single difference amplifier in Figure 10. The difference amplifier also uses an op amp, but the supporting circuit is different. In addition to the resistors configured like those in the inverting amplifier, there is a resistor between the 2nd input voltage and the positive input (R_2) and another between the ground and the positive input (R_g). In this case all of the resistors will have the same value, which creates an expression for the output voltage \( V_{out} = V_2 - V_1 \) [5]. The inverting amp from the potentiometer terminal associated with raising the bed back up will be \( V_1 \) and connected to the negative input on the difference op amp. Since the inverting amplifier had made it negative, having a greater \( V_1 \) will cause the difference amplifier to output a positive voltage. This will cause the motor to drive the linear actuator up. When \( V_2 \) is higher (i.e., the bed back will be moved down), then the output voltage will be negative and the motor will retract the actuator.
1.2.4.5 Filter

Between the difference amplifier and the motor will be a large resistor. This is to compensate for the fact that it will be difficult for the springs to center the potentiometer exactly. This will cause there to be a slight difference in voltage between the terminals, so there will be a small output voltage from the circuit. This resistor serves to prevent these small voltages from influencing the motor by effectively removing them.

1.2.5 Electric Motor

The electric motor used to drive the bed back up and down will be a variable speed series wound DC motor. In this motor, the stator and rotor are connected in series across the voltage source (see Figure 11), producing equal operating current in both. By using a simple circuit (see Figure 5) to control the applied voltage, the DC voltage and speed of the motor can be controlled. As it was explained previously, the greater the voltage, the faster the motor runs causing the actuator rise or lower faster, and visa versa with less voltage. Depending on the polarity of the voltage, this will determine which way the rotor or armature rotates. Positive voltage will cause the rotor to rotate such that it drives the actuator up and raise the bed. Negative voltage will rotate the rotor in the opposite direction and cause the actuator to retract and lower the bed. The major drawback of this motor type is that if a "no load" condition occurs ("zero torque speed"), the motor could accelerate beyond its mechanical design limit and fail [6]. However, this will never happen in this device because there will always be some load on the system due to the weight of the bed back. In choosing a motor, it will have the appropriate rotations per minute (RPM) and be able to handle the voltage outputted by the circuit. This can be tested by
supplying a range of DC power to the motor and measuring the RPMs by hooking up a tachometer to verify its speed. For proper operation, the torque and horsepower need to be calculated and can be determined with Equation 1.

\[
\text{Power}(hp) = \frac{\text{torque}(\text{ft} \times \text{lb}) \times \text{angular speed}(\text{rpm})}{5252}
\]

Eq 1 [8]

1.2.6 Actuator

The actuator converts the rotational motion of the electric motor into linear motion to drive the bed back, up and down. This is typically done through the use of a lead screw or worm gear drive. As shown in Figure 12 below, the motor drives the lead screw in a circular motion. Due to the threading on the lead screw, and the load nut, this circular motion is transformed into linear motion as the load inches up the threading with each full rotation of the lead screw. The roles of the load nut and the lead screw can be reversed should the operation require it. In such a case, the motor would rotate a fixed threaded nut, in which the lead screw would sit. The load would then be placed at one end of the lead screw. As the nut is rotated by the motor, the lead screw will be forced through it, in one direction or the other, via the threading on each. This in turn would then drive the load upwards.
The rate of linear motion performed by an actuator such as this is a function of the revolution speed of the motor, in revolutions per min (rpm), and the pitch of the thread, in inches per revolution (in/rev), as shown in Eq 2.

\[ V = \text{threadpitch} \times \text{angularrspeed} \]  

Eq 2

With each turn of the nut, the lead screw will travel a distance equal to the pitch value of the thread. Therefore, the faster the motor spins, the faster the load is moved.

In this design, an actuator will be used to move a cart forward and backward along the length of the bed. A solid rod will then be attached between the cart and the bed back via a pin at the bed (upper pivot joint) and then cart (lower pivot joint), as shown in figures 13 & 14. This pin will allow the rod to pivot at both ends as the cart traverses a track. As the cart travels toward the foot of the bed, the horizontal distance between the lower pivot joint and the upper pivot joint will be come shorter. Since the rod remains a constant length, this means that the vertical distance between the two joints must increase.

To calculate the required materials for the actuator, the following free body diagram and equations are used.
Figure 13: Free Body Diagram of Lifting System

Where:

\[ F = \text{Weight of Patient} \times 0.45 \]

\[ h_2 = \text{Raise in bed at } \theta \text{ degree incline} \ (D \times \sin(\theta)) \]

\[ h_1 = \text{Length of Fully Retracted Actuator} \]

\[ \theta = \text{degree incline in bed back} \]

\[ D = \text{Distance of connection point from bed joint} \]

\[ F_A = \text{Force applied by actuator} \]

\[ \gamma = \text{degree tilt of actuator at } \theta \text{ degree incline in bed back} \ (\tan^{-1}\left(\frac{L}{h_1 + h_2}\right)) \]

\[ F_{\perp} = \text{Component of patient’s weight perpendicular to actuator} \]

\[ F_{\parallel} = \text{Component of patient’s weight parallel to actuator} \]

\[ L = \text{horizontal displacement of connection point} \ (D \times \cos(\theta)) \]

\[ I = \text{Area Moment of Inertia of Actuator Shaft} \ (\frac{\pi}{64} d^4) \]

\[ d = \text{Diameter of Actuator Shaft} \]

\[ c = \text{radius of Actuator Shaft} \]

\[ A = \text{Cross-sectional Area of Actuator Shaft} \]

\[ T = \text{Torque Output by Motor} \]

Bending Moment on Actuator (in*lbs):

\[ M = \frac{F_{\parallel}}{A} \]

\[ = \frac{F \times \cos(\gamma)}{A} \]  \hspace{1cm} \text{Eq. 3} \]

Stress due to Bending (psi):

\[ \sigma_{\text{bending}} = \frac{M \times c}{I} \]

\[ = \frac{F \times L \times \frac{d}{2}}{\frac{\pi \times d^4}{64}} \]

\[ = \frac{10.19 \times F \times D \cos(\theta)}{d^3} \]  \hspace{1cm} \text{Eq. 4}
Direct Shear Stress (psi):

$$\tau = \frac{F_{\perp}}{A} = \frac{F \cdot \sin(\gamma)}{A}$$

Eq. 5

Shear Due to Torsion (psi):

$$\tau_{\text{torque}} = \frac{T \cdot c}{J} = \frac{T \cdot \frac{d}{2}}{2 \cdot I} = \frac{T \cdot \frac{d}{2}}{2 \cdot \pi \cdot d^4} = \frac{5.09 \cdot T}{d^3}$$

Eq. 6

Assuming that the force from the patient’s weight is focused at about 1/3 of the length of the bed back, 35 inches in length, from the joint we assume that F is concentrated at D=15 inches. Therefore, the actuator will also be placed at this point so that the majority of the weight is directly supported. The bed is also projected to lift from 0 degrees to 70 degrees of incline. Therefore, the actuator will be under the greatest tensile and shear stresses while at its maximum amount of incline. To determine the proper material and diameter for the actuator shaft, we assume the maximum load of 180 pounds is applied at the connection. Knowing the force applied at the joints, the proper mounting brackets must be used to compensate for movement of the actuator as its angled. The clevis bracket (Fig. 14) will be pinned to both ends of the actuator to provide a sturdy attachment and allow for pivoting as the bed back angle changes.

1.2.7 Support Frame

After understanding all the loads that this device needs to withstand, a strong support frame for the actuator can be determined. The most practical metal to use in this situation is Aluminum-Beryllium (Al-Be) 80/20. This is a light weight, durable, easy to assemble, and cheaper way to structure this verse welding steel parts together. Below in Figure 15 is a picture of Al-Be 80/20 and chart of its mechanical properties. The design of this structure is seen in the overview of the frame in Figure 16 and 17. This material will be ordered in the
proper sizes and put together in the machine shop. Once the frame is finished, it will undergo a series of loading tests to test the strength of the structure. If failure is to occur, reinforcement will be added where necessary.

<table>
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<th>Property</th>
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<tr>
<td>Melting Point (°F)</td>
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<td>19 to 28</td>
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<tr>
<td>Color</td>
<td>Gray</td>
</tr>
</tbody>
</table>

**Figure 15: Properties of Aluminum-Beryllium 80/20 [11][12]**

The overall schematic of the design (as illustrated in the Microsoft VISIO drawings in Figures 16 and 17) demonstrates the pivoting of the actuator to allow for movement as the bed is operated and sustains a low profile when retracted. Also, the handle is positioned out of the way and designed for easy access. All parts are secured with bolts to the frame of the bed or the Aluminum. To demonstrate the final workings of this automatic back angle controller, it will be fastened to a mock bed platform. It can be made out of scrap Al-Be 80/20 or welded with steel and have a metal platform attached to mimic the mattress. This will allow the device to be tested under the weight of humans lying on the platform.
1.3. Realistic Constraints

Naturally, when designing a new device, there will be some constraints. The only ethical concern is that this device must be designed with the patients and users safety in mind. Safety precautions are addressed in detail in the international standards and in the section below. For this design all materials used must be durable so that they can lift and hold up to 180lbs, be readily available, environmentally safe and be able to be sterilized. With the implementation of the brush series wound DC motor, there are concerns about the longevity of the brushing mechanism. However, this is not a major issue because it still has a considerable life span, especially for this low impact situation. With any load bearing device, the wear and tear on the screws and fixtures will also be a concern with the devices sustainability. Finally, the availability of the parts used in manufacturing the device was considered and it will be economically feasible for mass production.

According to internationally recognized quality and safety standards, there are some constraints to consider when designing. The International Standards Organization (ISO) [13] and the International Electrotechnical Commission (IEC) develops rules to follow in order to reassure that the product is reliable and will meet expectations in terms of performance, safety, durability and other criteria. The following standards were taken from the IEC website because they closely match the building requirements of the adjustable bed design [14]:

- **IEC 60073** Basic and safety principles for man-machine interface, marking and identification - Coding principles for indicators and actuators. Establishes general rules for assigning particular meanings to certain visual, acoustic and tactile indications. Has the status of a basic safety publication in accordance with IEC Guide 104.
- **IEC 60364-4-41** Low-voltage electrical installations - Part 4-41: Protection for safety - Protection against electric shock. Specifies essential requirements regarding protection against electric shock, including basic protection (protection against direct contact) and fault protection (protection against indirect contact) of persons and livestock. It deals also with the application and co-ordination of these requirements in relation to external influences. Requirements are also given for the application of additional protection in certain cases.
- **IEC 60447** Basic and safety principles for man-machine interface, marking and identification - Actuating principles. Establishes general actuating principles for manually operated actuators forming part of the man-machine interface associated with electrical equipment, in order to increase the safety through the safe operation of the equipment and facilitate the proper and timely operation of the actuators.
• IEC 60529 Degrees of protection provided by enclosures (IP Code). Applies to the classification of degrees of protection provided by enclosures for electrical equipment with a rated voltage not exceeding 72.5 kV.

• IEC 60534-6-1 Industrial-process control valves - Part 6: Mounting details for attachment of positioners to control valves - Section 1: Positioner mounting on linear actuators. Intended to permit a variety of positioning devices, which respond to a linear motion, to be mounted on the actuator of a control valve, either directly or by employing an intermediate mounting bracket. Applicable where interchangeability between actuators and positioners is desired.

• IEC 60601-1 Medical Electrical Equipment: General Requirements for Safety. Applies to the safety of medical electrical systems, as defined as follows: combination of items of equipment, at least one of which must be medical electrical equipment and inter-connected by functional connection or use of a multiple portable socket-outlet. Describes the safety requirements necessary to provide protection for the patient, the operator and surroundings. Cancels and replaces the first edition published in 1992 and its amendment 1 (1995) and constitutes a technical revision.

• IEC 60601-1-2 Top Level standard for electromagnetic compatibility for electrical medical equipment.

• IEC 60601-1-6 Medical electrical equipment - Part 1-6: General requirements for safety - Collateral standard: Usability. This Collateral Standard describes a usability engineering process, and provides guidance on how to implement and execute the process to provide medical electrical equipment safety. It addresses normal use and use errors but excludes abnormal use.

• IEC 60601-2-38 Particular requirements for the safety of electrically operated Hospital beds. Specifies requirements for safety of electrically operated hospital beds. The object of this standard is to keep the safety hazards to patients, operators and the environment as low as possible, and to describe tests to verify that these requirements are attained.

• IEC 60601-2-46 Medical electrical equipment - Part 2-46: Particular requirements for the safety of operating tables. Specifies safety requirements for operating tables, whether or not having electrical parts, including transporters used for the transportation of the table top to or from the base or pedestal of an operating table with detachable table top.

• IEC 61800-1 Adjustable speed electrical power drive systems - Part 1: General requirements - Rating specifications for low voltage adjustable speed DC power drive systems. Applies to general purpose adjustable speed DC driven systems which include the power conversion, control equipment, and also a motor or motors. Excluded are traction and
electrical vehicle drives. Applies to power driven systems (PDS) connected to line voltages up to 1 kVAC, 50 Hz or 60 Hz.

- **IEC 62955-1** *Primary batteries - Summary of research and actions limiting risks to reversed installation of primary batteries.* Provides information relevant to the safe design of batteries and battery powered devices together with appropriate cautionary advice to consumers. This report is primarily intended to be used by battery manufacturers, equipment manufacturers, designers, standard writers, consumer organizations, and charger manufacturers. This report may also be of assistance to educational authorities, users, procurement personnel, and regulatory authorities.

### 1.4. Safety Issues

As with all engineering projects, the safety of the hospital bed’s user is paramount. This project is designed for widespread use, and if even one patient or caretaker is significantly injured, then it is a failure. The device will be employed in hospitals where children will be, as well as those with reduced coordination and muscle control, so the exposed parts will be rounded off to prevent significant lacerations and contusions from collision. Another basic safety feature is the absence of exposed joints that can cause pinching if someone’s hand is in the wrong place at the wrong time. Between January 1, 1985 and January 1, 2006, FDA received 691 incidents of patients caught, trapped, entangled, or strangled in hospital beds. The reports included 413 deaths, 120 nonfatal injuries, and 158 cases where staff needed to intervene to prevent injuries. Most patients were frail, elderly or confused [15]. Also, the Center for Disease Control and Prevention reports that in 1995, five out of every 100 admissions into a hospital in the United States resulted in a nosocomial infection [16]. These hospital-acquired infections resulted in 88,000 deaths in that year alone. In order to control the spread of bacteria and viruses between bed users, the exposed parts will all be made of easily-sterilized aluminum.

More advanced safety issues have also been taken into account. In the frenzied activity of the hospital, it is certain that someone will accidentally bump into the control handle, and the bed should not be adjusted under those circumstances. A safety lock system will be implemented in order to avoid this. On the underside of the end of the handle there will be a long lever similar to a bicycle brake lever which must be depressed in order for the system to act on any movement of the handle. This lever will be easily pressed so that those who cannot exert much pressure with their fingers, such as those with arthritis and Parkinson’s, will be able to operate it. The maximum speed that the bed can be raised and lowered is also important for the safety of the patient. If the bed back is adjusted too quickly, further injury or disorientation is possible depending on
the state of the patient. This maximum speed is regulated by the simple circuit design attached to the rheostat that measures the variable forces applied to the handle. The absolute maximum will be set at a safe level for those that are not in a fragile state, but can be easily set lower to protect those that are in critical condition.

The mechanical actuator lift must also be safe. Due to its position in a contained area underneath the bed, physical contact with the patient and others will be minimal. Even so, the electrical wiring will be insulated and fuses will be included for safety in the event of a power surge. The wires will be protected so that no electrical shock will occur per the IEC 60364-4-41 standard mentioned above. In the event of a power loss, a back-up battery will be implemented per the safety standards of IEC 62955-1. Otherwise, the variable speed motor will be powered by either a wall plug and be protected via IEC 61800-1. So, all precautions have been taken to ensure that the patient is protected from the electricity. Also, if power is lost, the bed will remain in its current position instead of suddenly falling to horizontal. This is an advantage to a mechanical actuator because it will not budge from its position unless a voltage is applied to the motor to give it power again.

Of course before any product is marketed, there are a series of validation steps that include vigorous testing procedures, specifications, and standards to be met in order for the product to be considered safe for public use. The IEC has set some recommended guidelines to be followed for the Technical Reports (TR) to ensure it is tested properly. Below are a few safety issues, in compliance with the standards mentioned above, to be considered during development—especially if this device is marketed.

- **ISO/IEC GUIDE 46: Comparative testing of consumer products and related services - General principles.**
- **IEC/TR 62354** General testing procedures for medical electrical equipment. This Technical Report applies to medical electrical equipment as defined in IEC 60601-1. Its object is to provide guidance on general testing procedures according to IEC 60601-1.
- **IEC/TR 62296** Considerations of unaddressed safety aspects in the Second Edition of IEC 60601-1 and proposals for new requirements. This Technical Report is primarily intended to be used by: manufacturers of medical electrical equipment, test houses and others responsible for assessment of compliance with IEC 60601-1, and those developing subsequent editions of IEC 60601-1.
- **IEC 61310-3** Safety of machinery - Indication, marking and actuation - Part 3: Requirements for the location and operation of actuators. Specifies safety-related requirements for actuators, operated by
the hand or by other parts of the human body, at the man-machine interface. Gives general requirements for: - the standard direction of movement for actuators; - the arrangement of an actuator in relation to other actuators; - the correlation between an action and its final effects. Based on IEC 60447, but is also applicable to non-electrotechnical technologies. Covers single actuators as well as groups of actuators forming part of an assembly.

- **IEC/TR 61258** Guidelines for the development and use of medical electrical equipment educational materials. Outlines a generic process for developing materials for education and training of operators of medical electrical equipment. It may be used by standards organizations, manufacturers, regulatory agencies, hospital managers, physician and nurse educators, and others involved directly or indirectly in education and training of users/operators.

- **IEC 61123** Reliability testing - Compliance test plans for success ratio. Specifies procedures for applying and preparing compliance test plans for success ratio or failure ratio. The procedures are based on the assumption that each trial is statistically independent.

- **IEC 60605-2** Equipment reliability testing - Part 2: Design of test cycles. It applies to the design of operating and environmental test cycles.

### 1.5. Impact of Engineering Solutions

Our design project is a portable, easily-installed or removed, cost-effective, automatic lift mechanism. It has been designed with a “universal fit” in mind for basic hospital bed models, with or without side railing. The lift mechanism may be safely installed in convenient locations for operation by the patient as well as the caregiver. The lift mechanism is adaptable to meet changing needs of the patient. Our design meets internationally recognized quality and safety standards for medical equipment.

The automatic lift mechanism is inherently cost-effective for health care facilities since it can be purchased independent of the hospital bed. If the automatic lift feature is desired, purchase of new beds having the feature “built-in” will not be necessary as replacement of existing standard or basic hospital beds is not necessary. As necessary for patient care, the health care facility would have the option of either installing the lift mechanism on existing beds or purchasing new standard, less expensive beds and installing the lift mechanism.

The availability of our automatic lift mechanism for standard hospital beds in clinics or hospitals around the world can positively affect the health care setting in terms of allowing the patient more independence from the caregiver supervision. The societal common good would be served by narrowing the gap
between basic health care equipment in the U.S. versus that in third world countries.

Our design or product’s cost impact to health care facilities, exiting and new, is exemplified per the following. Our design has the estimated retail price of less than $313 (refer to budget Table 1). A standard bed (e.g., manual crank lift by A1 Adjustable Beds) is listed as $712 [17]. The price of a deluxe hospital bed model number SS3TPKGTM by A1 Adjustable Beds, with the automotive lift mechanism as well as other, possibly unnecessary features, is listed as $3200 [18]. Installing our automatic lift mechanism on new standard hospital beds vs. purchasing a deluxe hospital bed is estimated to be $2175 cost savings. Savings can be considerable for a small clinic; purchase of 15 new basic beds and the automatic lift mechanism, will yield an estimated savings of $32,621. If use of existing, standard beds is possible, purchase of only the lift mechanism is necessary to receive the same. The savings of course can be used to purchase other equipment or supplies, especially beneficial for non-profit organizations.

The Adjustable Back Angle Controller will make the lives of many around the world much easier. From nurses and aids to patients suffering from a wide range of afflictions, ranging from blindness to any number of diseases causing tremors and the lost of motor skills. In particular, our design is capable of assisting each of our clients and wide range of disabilities.

Every day, people develop back pain as a result of their occupation, injury or life style. Occupations such as nursing and home aids are of the most likely to develop some kind of back problem. This is mostly due to the constant repositioning of patients to prevent bed sores or for therapies. With patients suffering from back pain, an inclined back position provides some relief as well as helping to improve the patient’s condition. Persons with obesity can often have trouble breathing while laying fully reclined position, however raising their resting angle up will open the air ways allowing for easier breathing. It is also difficult for the elderly, obese or sufferer of other debilitating conditions to simply get out of bed while laying flat. This often means that a nurse of aid must assist the individual in sitting up, and stabilize them while getting off the bed. An adjustable bed, however, allows either the patient or the aid to life the patient’s back into an inclined position, relieving the aid of any strain on their back while bending over the bed, and assisting the individual to sit up. An adjustable bed is very useful in all of these cases, and often makes the caretaker’s job much less strenuous.

With the aid of our Adjustable Bed Angle Controller, these benefits can be enjoyed by individuals such the clients Matt and Akiko, who have vision problems. With our design, it will be much easier for the blind or visually
impaired. This is made possible because the lever will always be in the same position, while still remaining out of the way. In addition, instead of fumbling with button, our design allows the patient to operate the bed by pushing the lever down to lower the bed, and up to raise the bed. This intuitive design will allow all users to operate the bed without the learning curve required to learn where each button is located, and the functions they provide.

Many people suffer from conditions which affect their motor skills. Conditions such as severe arthritis as well as Parkinson’s disease greatly diminish an individual’s manual dexterity as well as their ability to grasp small object. The operation of a handle which requires limited grasping power, and no dexterity to move, as opposed to a wired remote control with numerous small buttons required to operate the bed, would be of great benefit to individuals such as our client Lakisha who suffers from Parkinson’s disease.

The Adjustable Back Angle Controller will be a very affordable alternative to the typical fully-electric adjustable bed. With an estimated retail price of $313, combined with its smooth operation, infinitely adjustable speed, and ergonomic and intuitive control, the functionality is well worth the price tag. The costs of production are kept down by the use of existing parts, but combined in a manner which allows for new and better operation of an existing product.

Table 1: Proposed Budget

<table>
<thead>
<tr>
<th>Parts Involved</th>
<th>Price Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum for Handle and Framing</td>
<td>$35</td>
</tr>
<tr>
<td>Rheostat and circuitry</td>
<td>$50</td>
</tr>
<tr>
<td>Tension Springs (2)</td>
<td>$10</td>
</tr>
<tr>
<td>Linear Actuator</td>
<td>$150</td>
</tr>
<tr>
<td>Stainless Steel Framing (80Al/20)</td>
<td>$100</td>
</tr>
<tr>
<td>Variable Speed Motor</td>
<td>$500</td>
</tr>
<tr>
<td>Misc. (Bolts, attachments, etc.)</td>
<td>Max. $50</td>
</tr>
</tbody>
</table>

| Total Estimated Retail Price                  | Max. $895   |
| Max. $313                                     |             |

1.6. Life-Long Learning

Work on this project has expanded the knowledge of the engineering students. Much research was required to understand the problems associated with this design. New material and techniques were acquired such as the concept of extended physiological proprioception (EPP). This concept implies that devices should react to the user’s input in an intuitive manner, creating the sensation that it is an extension of the user’s own body. EPP was integrated into the device
through the force-sensitive handle that changes the pressure within the closed hydraulic system.

In order to design a handle that is used to detect the force placed upon it, many different methods were considered. There are many ways to detect the forces placed on an object, but thus far there has not been a handle constructed for this purpose. While exploring the options for this part, the first idea used load cells to detect the force, since they were used in Biomechanics lab to measure the tension force on various objects. After looking into load cells by visiting various commercial and educational websites, it became apparent that most load cells are not designed to detect the small forces required by this project. Also, they are relatively expensive and would deplete the budget for the project. Another rejected idea involved strain gauges to detect force. The functional part of a strain gage is a resistor that changes value when it is stretched or compressed. A supporting circuit applies a constant DC voltage to the gage and also detects the voltage output from the sensor. The gage would be attached near the base of the handle to determine the force by detecting the extent that the metal is deformed. Research into strain gages showed that they could be calibrated to detect force in the desired range, but the conditions of the handle had to be held constant to a degree not acceptable in the public setting that the device will be used. For instance, strain gages must be kept at a constant temperature in order to make correct readings, and their resistance also changes with time, so the supporting electrical circuit would need to be adjusted regularly.

The optimum design for the handle uses springs in a way to translate the force placed on the handle into a displacement angle that directly influences the hydraulic circuit. This uses Hooke’s law, which is \( F = -kx \), where \( F \) is the force applied, \( k \) is the spring constant, and \( x \) is the distance stretched.

Another major system learned was the basics of hydraulics. Hydraulic circuits are similar to electric circuits. In fact, pressure can be analyzed exactly like voltage by Kirchoff’s voltage law. Pascal’s law is also very important to operation of the device. Pascal’s law states that \( P_2 - P_1 = \rho g (h_2 - h_1) \), where \( P \) refers to the pressure, \( \rho \) is the density of the liquid, \( g \) is the acceleration due to gravity, and \( h \) is the height of the liquid. This law is significant because it means that pressure is transmitted thru a closed circuit undiminished. This allows the circuit relying on the hydraulic pressure to operate with a relatively simple design. However, as the hydraulic design progressed, it became clear that the system would be too complex, bulky, messy, and generally not hospital-friendly.

The design currently being considered uses a variable speed DC motor to drive a linear actuator. The DC motor must be series wound so that a change in the voltage supplied to it would change the speed that the motor works, which in
turn changes the speed that the actuator adjusts the bed. The actuator itself works in a manner similar to a nut rotating on a bolt. The central portion of the actuator is threaded like a bolt and the portion that extends is attached around it. As the central portion rotates, the piston is extended or retracted based on the direction it is turning. Through this Life-long learning process, engineers constantly discover new and better ways to solve a problem. This will in the end result in the most efficient design.
1.7. References

[1]  

[2]  

[3]  

[4]  
21 Oct 2006 <http://www.ladyada.net/make/x0xb0x/fab/images/an6562.jpg>.

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