UNIVERSITY OF WISCONSIN–MADISON: DEPARTMENT OF BIOMEDICAL ENGINEERING

# Digital Braille Watch

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## Fall 2011

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# Abstract

Worldwide, the Braille system provides 284 million blind individuals with a way to read and write[1], yet no device exists that allows the visually impaired to read the time in Braille. In order to tell time, the blind currently rely on either talking or tactile watches. However, talking watches are disruptive, while tactile watches are difficult to read and fragile. In order to improve on currently marketed products, a Braille watch prototype that allows blind individuals to read the time in standard Braille was created. The prototype was developed using the Viper si2 SLA rapid prototyping machine and utilizes four disks which each rotate beneath a set of four pins. The surface of each disk is divided into three rings: outer, middle, and inner, each of which contains raised and lowered surfaces cut into the face of the disk. As the disks rotate via a gear mechanism interconnecting the four disks, the pins are raised and lowered to display the desired numbers. All six individuals who tested the final prototype could easily read the time and expressed necessity for such a product in the current market. The design still needs to be manufactured using a more reliable and precise method, increasing the durability and reducing friction between moving parts in the final prototype. A driving mechanism must also be incorporated in order to produce a fully functional watch. Additional future work includes completing the patent process with the Wisconsin Alumni Research Foundation as well as searching for a company to aide in the development, mass production and marketing of the Braille watch.

# Background

## *Problem Statement*

In order to determine the time, the blind currently depend on talking or tactile watches. However, talking watches are disruptive, while tactile watches are difficult to read and fragile. Developing a watch that displays the time using the standard Braille number system would allow blind individuals to discretely, accurately and independently check the time. This device should be fabricated using durable and precise parts, have a self-contained power supply, use standard Braille spacing, and be the size of a standard wrist-watch.

## *Braille Basics*

The Braille language is the universally accepted form of written communication for the visually impaired. It utilizes a system of dots arrayed in a three row by two column grid. Raised dots are then located in any of the six positions, displaying different letters, numbers and symbols based on the configuration. As is shown in Figure 1, the numbers 0-9 only use the top four positions of the three by two grid.

In order for this method of communication to be accurate and precise, universal specifications have been developed. Each dot must have a base diameter of 1.44 millimeters (0.057 in.) while being 0.48 millimeters (0.019 in.) in height. Within each individual grid, the dots must be at least 2.34 millimeters (0.092 in.) apart, measured center-to-center, and each individual character should be a minimum of 6.22 millimeters (0.245 in.) away from the neighboring character. [2]

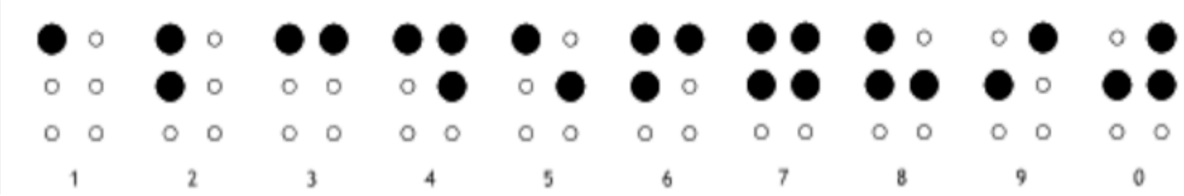


**Figure 1: Braille numerals 0-9**
*Image courtesy of PharmaBraille:* http://www.pharmabraille.co.uk/braille-alphabet.html

The distance between two Braille pins must be at least 2.34 millimeters apart, since this is the minimal distance required to distinguish between two points with the fingertip. This minimal distance is determined by mechanoreceptors located on the skin, which are activated by the slightest deformation of the skin due to contact. In order to discriminate between two points, there must be a deactivated receptor located between two activated receptors. Without the presence of a deactivated receptor, the brain would perceive the contact of the two points as one stimulus.

These receptors are distributed all over the body; however, they exist in higher concentrations in some areas. The distribution of these touch receptors is represented by a homunculus diagram, which shows that these receptors are present in high concentration in the fingertips, making the fingers more sensitive to touch. It was important to consider these sensory limitations and to consider spacing guidelines when designing the watch. [3]

## *Current Methods*

There are two types of watch products currently on the market for the blind: talking watches and tactile watches. Talking watches function by verbally relaying the time to the user whenever the user presses a button (Figure 2). This method is effective in communicating the time; however, it can be disruptive and draws attention to the user. Tactile watches, on the other hand, are silent (Figure 3). They function much like

**Figure 2: Talking watches verbally communicate the time**
*Image courtesy of Independent Living Aids, LLC:*
http://www.independentliving.co

**Figure 3: Visually impaired touch the hands of the tactile analog watch to tell the time**
*Image courtesy of Auguste Reyond:*
http://watchluxus.com/braille-watches-by-auguste-reyond

traditional analog watches, except the user must touch the face of the watch to feel where the hands are located. There are raised markings on the watch that indicate the positions of the numbers; however, there is no standard format for these markings, which vary from product to product. For this reason, these watches can be difficult to read and come with a learning curve when first used. Also, the hands of these watches are exposed to the user and, therefore, can be easily broken, damaged or bumped to display the incorrect time.

In addition to the currently available products, there is a concept watch that has recently been created called the Haptica Braille Watch (Figure 4). This design features a set of 16 rotating disks that circulate Braille dots in and out of the display to create the desired Braille numerals. Each disk contains a single Braille dot that is moved simultaneously with the other disks to display the time in Braille. This concept was created by David Chavez in 2008. Chavez is not an engineer and has not created a prototype for his design. [4]

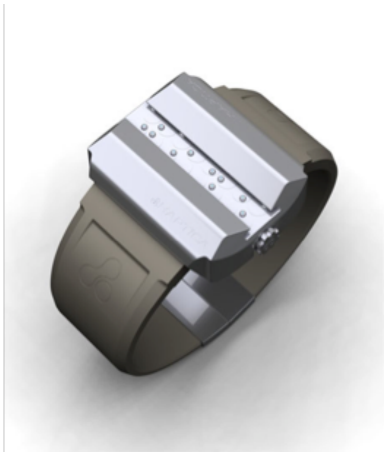


**Figure 4: Haptica Braille Watch design by David Chavez**

*Image courtesy of Tuvie Design of the Future:*
http://www.tuvie.com/haptica-braille-watch-concept/

## *Past Designs*

This is the sixth semester that a BME design team has worked on this project. The first two teams (Spring and Fall of 2008) developed a vibrating dots design, which features four vibrating motors that vibrate in sequence in order to communicate the time (Figure 5).

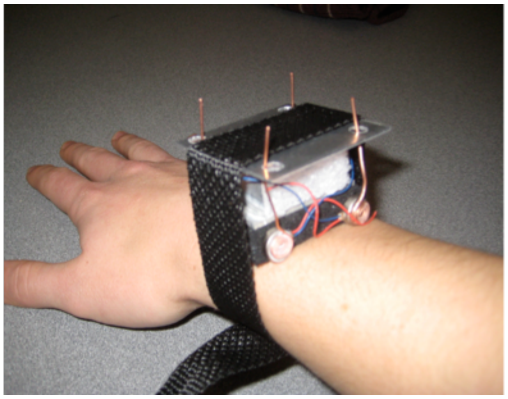


**Figure 5: Vibrating dots prototype created by Fall 2008 Team**
*Image courtesy of Fall 2008 Design Team*

When a user presses a button, four motors vibrate to signify one Braille numeral, and, after a short pause, vibrate again to denote the second numeral. This process is repeated until all four numerals have been relayed to the user.

A working prototype of the design was completed; however, it had some major drawbacks. First, the vibrations of the prototype had an over-stimulating effect due to the increased sensitivity that blind individuals have in their hands. This increased sense of touch is due to the fact that the blind constantly use their fingers to detect subtle tactile differences, including those encountered while reading Braille. Also, due to the large size of the prototype, the entire hand was required read the device. This ends up creating a sensation much different than using a single fingertip to read Braille. In addition, the design had high power consumption.

The third team (Spring 2010) designed the prototype shown in Figure 6. The design uses eight rotating disks to form the required Braille numerals. Each disk has four raised dots, which can be configured to form the top or bottom half of each Braille character (Figure 7)[5]. This design met the client's requirements and was the first existing Braille time-keeping device. However, many downfalls exist with this design. The prototype seen in Figure 6 is too large (155.70 x 117.35 x 57.15 mm) to fit on the wrist of a user, thus, the size must be cut down significantly. Also, this device uses eight moving parts, leading to high power consumption. With this design, there was not much opportunity to significantly cut size and power use. Finally, due to the mechanical nature of this design, the numbers were often difficult to read; the Braille display relied heavily on the accuracy of the servo motors used to rotate the disks.

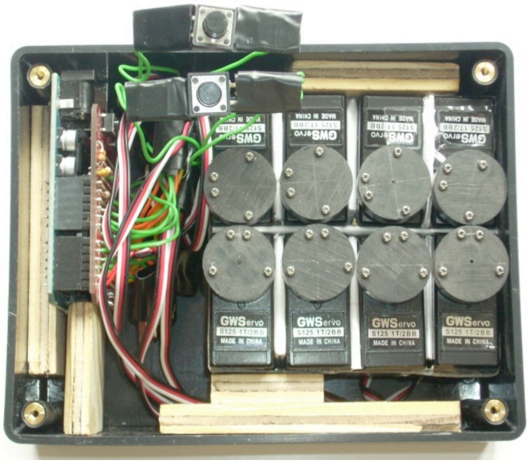


**Figure 6: Internal view of rotating disk prototype from Fall 2010 Team**

*Image courtesy of Spring 2010 Braille Watch Team*

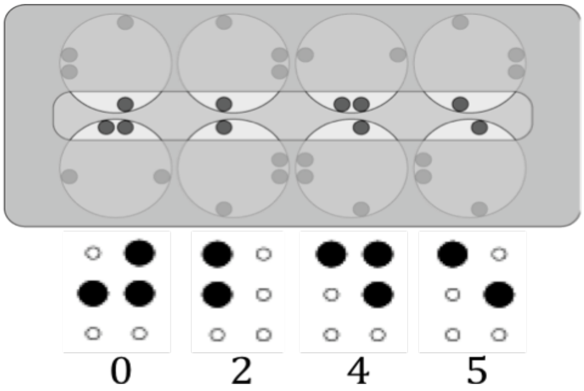


**Figure 7: By rotating 90º, 180º or 270º, the disks can combine to display the correct time**

The following design team (Fall 2010) developed a mechanism that utilized disk and pins to display time in Braille (Figure 8). The basis of this design was the four disks located beneath the watch surface, one for each Braille numeral. Above each disk, four pins were positioned to rest on the disk's surface. The portion of the disk against which the pins rest has both raised and recessed sections (Figure 9). If a pin is on the raised surface, it will be pushed slightly above the watch plane, and if not, the top of the pin will remain flush with the surface of the watch (Figure 10). When the disk rotates to different positions different combinations of pins are raised. In this way, all numbers, 0-9, can be displayed.

**Figure 8: Disk and pins prototype developed by Fall 2010 Braille Watch Team**

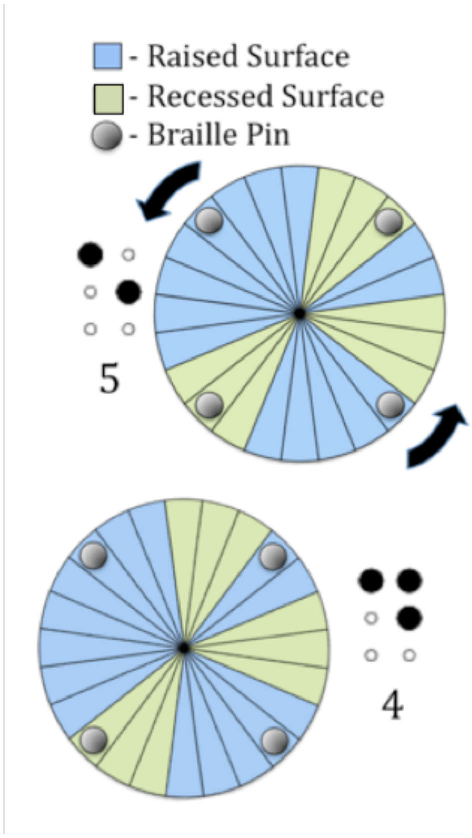


**Figure 9: The raised and recessed surfaces on the disk cause different numbers to be displayed**

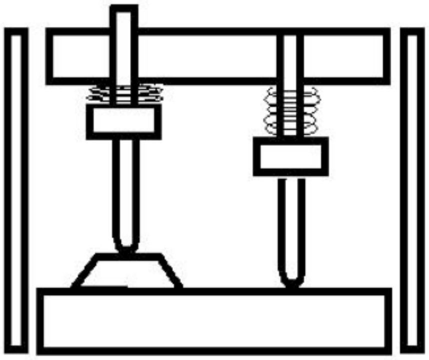


**Figure 10: The raised surface on the disk pushes the Braille pin to the surface of the watch**

A benefit to this design over the previous one is that that only four moving parts are needed. This lowers the energy required to power the watch. Also, smaller servos were used since only 165° of rotation was needed to rotate the disks opposed to the 270° previously needed. This design also removed the ambiguity of the Braille number display. The pins remained in place, causing the Braille dots to remain aligned. However, upon completion of a prototype, several shortfalls of this design were apparent. The design still consumed too much energy, as a USB cord was needed to power the watch. In addition, the distance between Braille characters and dots within the Braille characters was much larger than standard spacing. These two concerns made it difficult to alter this design in its current form. A design that could further lower power consumption and achieve standard Braille spacing was needed.

## *Gear and Pins Mechanism*

First developed in the Spring of 2011, the Gear and Pins design utilized the raised and lowered surfaces introduced with the design in Figures 9 and 10. There were once again four disks, one for each Braille digit needed to display the time, which had raised and lowered portions (Figure 11). Four pins set with standard Braille spacing rested on a section of the disk aligned over three separated tracks, with the two diagonal pins functioning off of the same track (Figure 12). As the disk rotated, the combination of raised and recessed sections beneath the pins changed, subsequently altering the number displayed at the watch surface.

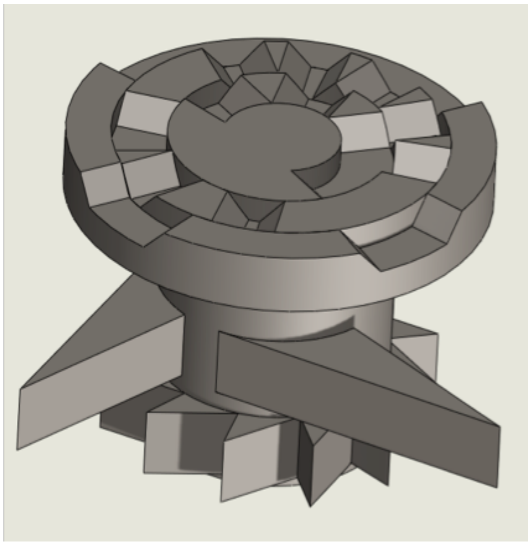


**Figure 11: Disks with different combinations of raised and lowered surfaces can display different numbers numbers**

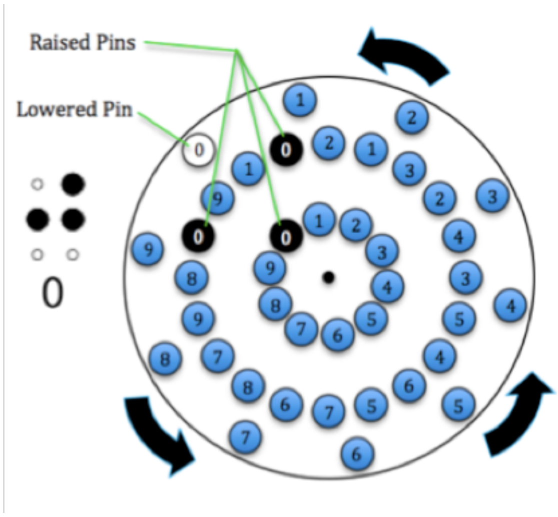


**Figure 12: Number layout of a Gear and Pins disk, which can display the numbers 0-9 as it completes its rotation**

Another important aspect of this design is the gear system that existed between the disks. This system allowed for the complete rotation of one disk to be translated into a partial rotation of a neighboring disk. This can be seen in Figure 13; a full rotation of the one tooth gear led to a partial rotation of the multi-tooth gear. This gear mechanism

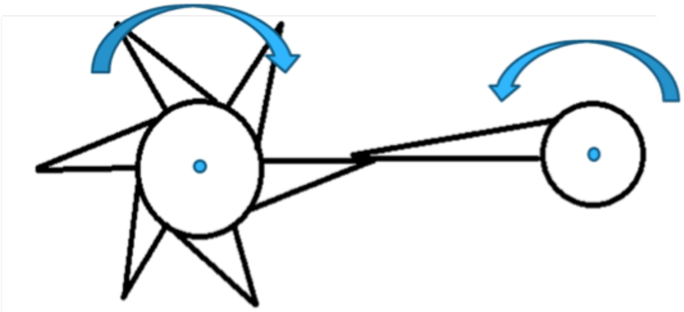


**Figure 13: The full rotation of the gear on the right leads to a 60° partial rotation of the gear on the left, creating a gear system similar to that of the odometer**

allowed the disks to move in an incremental motion, as opposed to a constant rotation. Additionally, by attaching a motor to a single driving gear, the entire design could be controlled via one constant rotating motion.

While a driving mechanism was never integrated, this design would require significant less power than other previous designs since only a single motor is needed. This is beneficial since the watch must have a small and self-contained power source. Overall, the design was significantly smaller than past designs and standard Braille spacing could be achieved by overlapping the disks (as was done for the Fall 2011 design – see 'Final Design' section). Not only did this make the design more portable, the prototype (Figure 14) was easier to read. However, due to the small size of the design and its features, extremely accurate and precise methods of fabrication were needed.

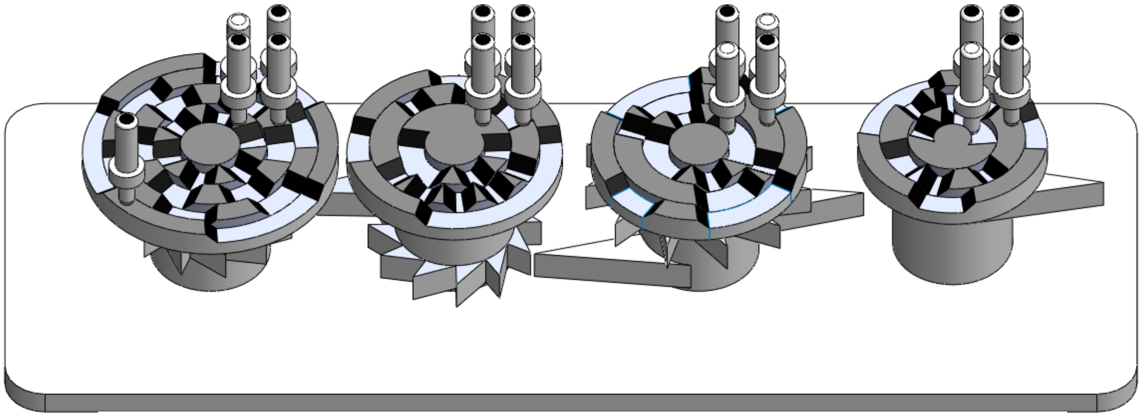


**Figure 14: Spring 2011 design without casing displaying the time 07:54PM**

# Design Considerations

## *Design Specifications*

The clients for this project are Holly and her blind son, Colton Albrecht. Together, they developed the idea of a Digital Braille Watch. In order to meet the needs of all potential users of the product, a list of design criteria was created. The design must be able to accurately display the current time in Braille and operate without any noise or vibrations. The watch must not be dangerous to the user, so moving parts and electronic components must be contained properly. The final design should be as close to wristwatch size as possible and should utilize standard Braille spacing. For more information on the product design specifications, see Appendix A.

## *Funding*

Since caring for a blind child can be financially taxing, it is difficult for our client to provide funding for this project. As a result, we turned to outside sources to try to offset the financial burden on our client. Based on advice from our advisor, John Puccinelli, we will be consulting with the University of Wisconsin-Madison Department of Biomedical Engineering to fund this project.

# Final Design

The final design for the Fall 2011 Braille watch team was a modification of the Gear and Pins design shown in Figure 16. Although standard braille spacing within each character had already been achieved in the Spring 2011 design, the distance between each numeral still needed to be standardized. In order to achieve standard spacing between the numerals and further reduce the size of the watch, the disks were rearragned and overlapped (Figure 15). The overlapping was made possible by layering the disks at different heights and by placing the pins over different sections of each disk. Figure 16 demonstrates how the pins were placed over the top right region of Disk 2 and Disk 4 and over the bottom right region of Disk 1 and Disk 3.

This design is the first that completely follows standard Braille spacing guidelines and is approximately the size of a wristwatch. Additionally, this is the first design to utilize the drive gear, which will be the gear directly controlled by a motor once the rotating mechanism is decided and incorporated. The drive gear communicates with Disk 1, which interacts with Disk 2, which then rotates Disk 3, which, ultimately, controls Disk 4 (Figure 17). This relationship simplifies the design, as 1 RPM of the drive gear will control the entire watch.

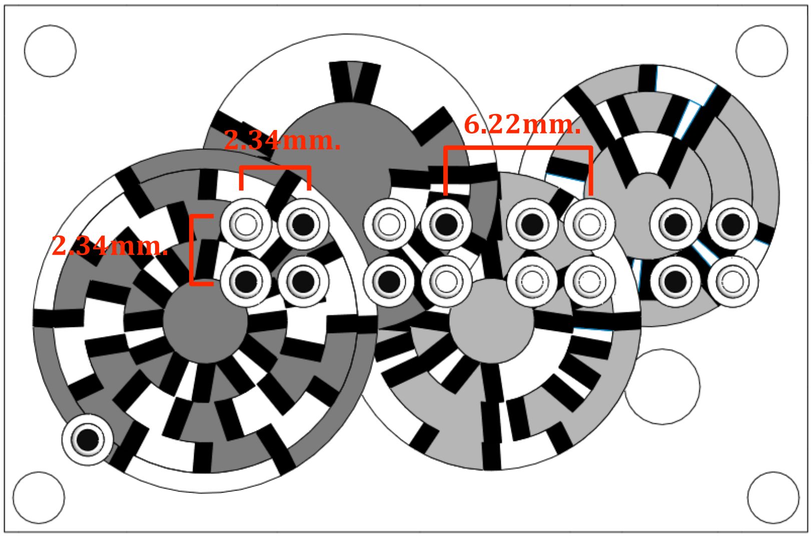


**Figure 15: Standard Braille Spacing between the Braille characters was achieved by rearranging and overlapping the disks**

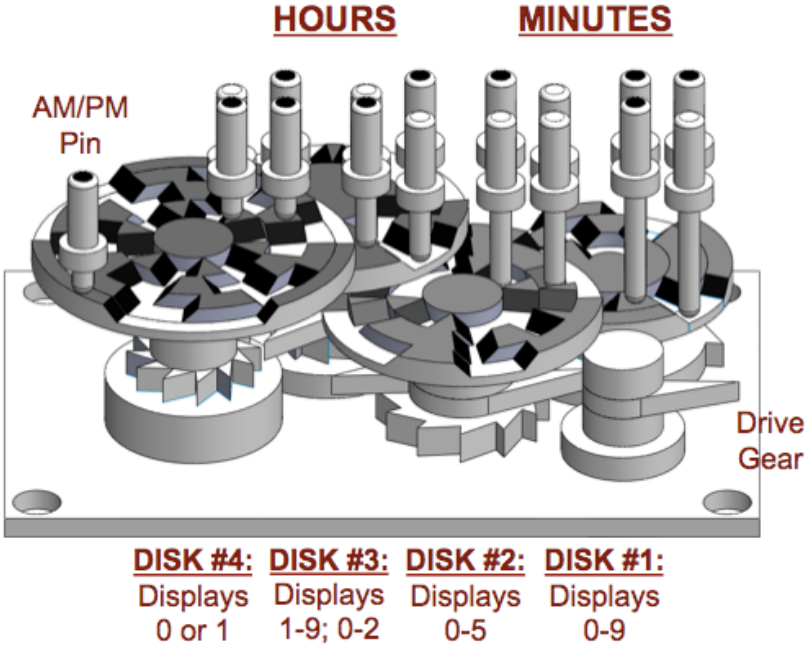


**Figure 16: Pins rest over top right region of Disk #2 and #4 and over the bottom right region of Disk #1 and #3**

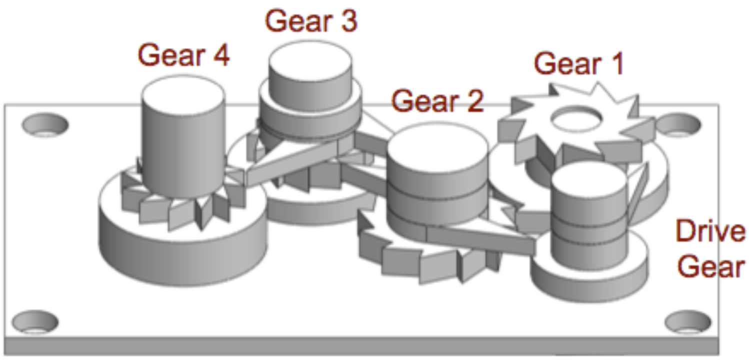


**Figure 17: 1 RPM of the drive gear will control the entire watch**

### *Disks*

The watch had to be manufactured with extreme precision in order to accurately fabricate the small parts. While more reliable and precise fabrication methods were considered (see 'Design Fabrication'), this semester the Viper si2 SLA printer (~0.051 mm. precision) available at Wisconsin Institutes of Discovery was used to fabricate the entire prototype. As can be seen in Figure 16, Disk 1 and 2 are used to display the minutes, while Disk 3 and 4 are used to display the hours. Accordingly, each disk surface is unique since each disk must display a different set of numbers: Disk 1 displays numbers 0-9, Disk 2 displays numbers 0-5, Disk 3 displays numbers 1-9 and 0-2, and Disk 4 displays numbers 0-1. Since the watch displays 12-hour time as opposed to 24-hour time, Disk 4 contains a fourth track of raised and lowered surfaces in order to include an AM/PM pin. A raised pin signifies PM, whereas a lowered pin signifies AM (Figure 16).

### *Gears*

Incorporated into the bottom of each disk is a series of gears. The gears are uniquely designed for each individual disk (Figure 16). This gear system allows for the drive gear's rotation alone to control all four disks. When the drive gear rotates 360° counterclockwise, it interacts with Gear 1, causing Disk 1 to spin a total of 36° clockwise. This rotation of Disk 1 causes it to transition from one number to the next (Figure 18). When Gear 1 completes a full rotation, the longer gear from Gear 1 interacts with the shorter gear of Gear 2 (Figure 17), causing Disk 2 to rotate 30° counterclockwise. This once again leads to a transition in numbers, as is seen in Figure 18. In this same manner, each gear communicates with its neighboring gear all the way to Gear 4. The calculations for the complete gear mechanism and other design components can be found in Appendix B.

### *Pins*

The pins (Figure 19) are designed with a circular platform in the middle, keeping them supported atop the middle compartment of the casing and preventing from them from falling into the compartment containing the disks. Since this circular platform is

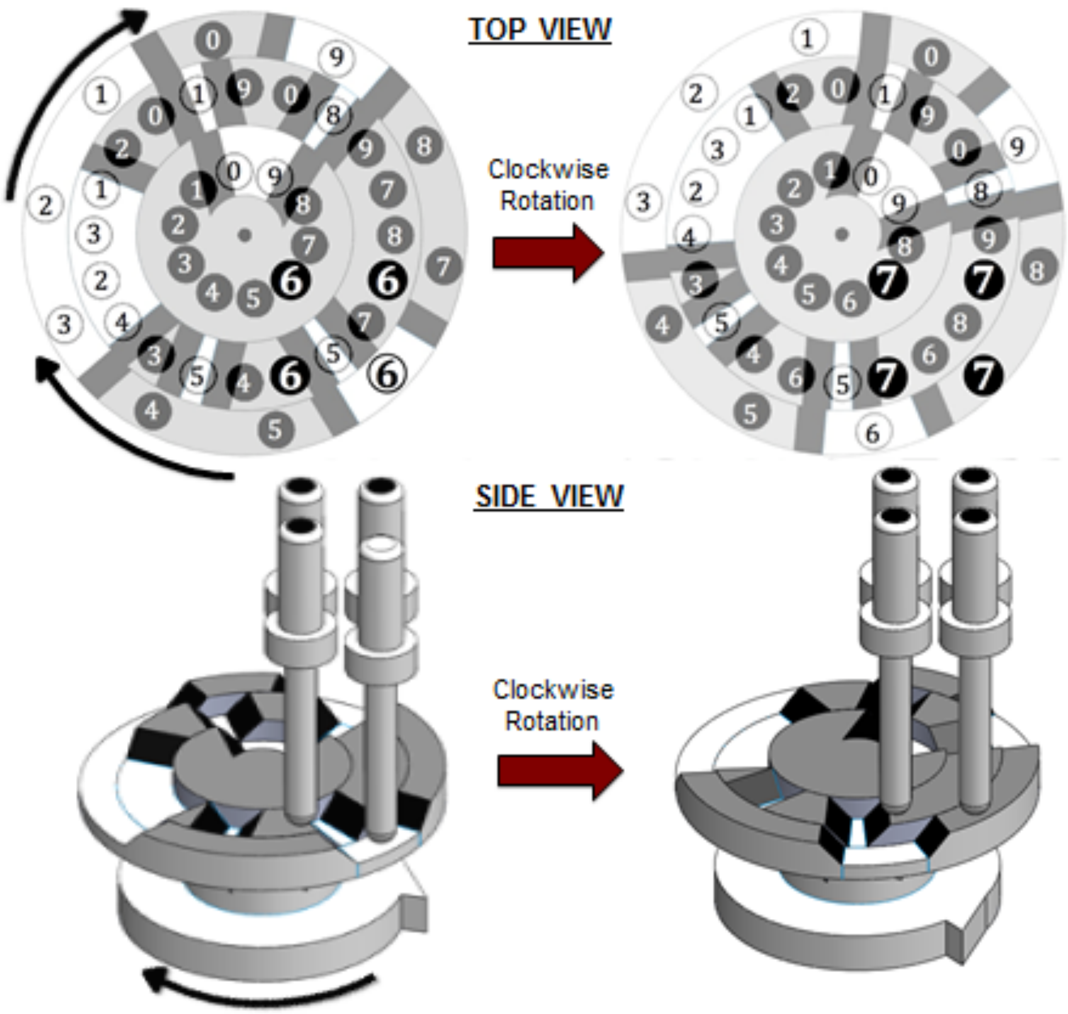


**Figure 18: As Disk 1 rotates clockwise, different combinations of pins are raised and lowered and the user will detect a different number**

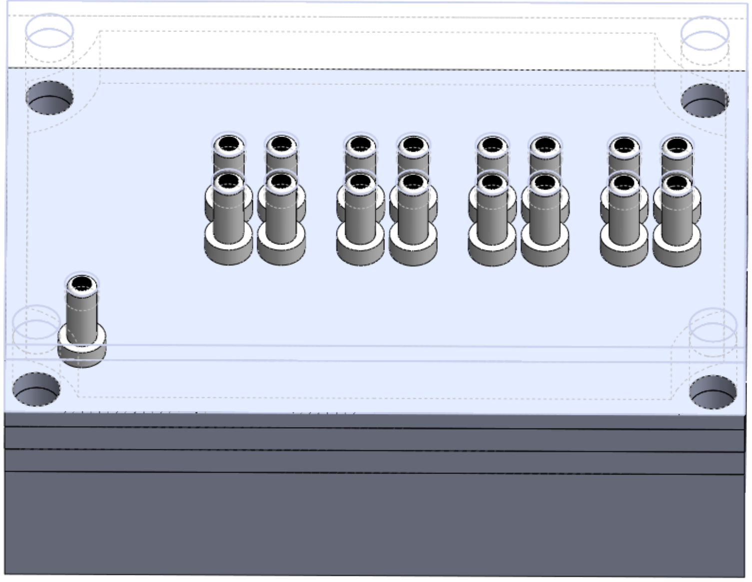


**Figure 19: The circular platform of the pins allows each pin to be mounted on the surface of the middle casing**

larger than the holes in the top and middle compartments of the casing, this platform keeps the pins stabilized and prevents them from falling out of the watch. The platform also provides support for the springs that push against the lower side of the top casing of the watch (Figure 10). The pins are designed with a rounded bottom in order to easily slide over the surface of the disk. The top is also rounded to provide a user-friendly interface. The design requires a total of 17 pins, 4 to display each number and 1 to display AM or PM. Figure 16 shows that the bottom portions of the pins have to be different lengths in order to interact with the surface of each disk.

## *Springs*

In order to hold the pins inside the casing, springs are mounted on the pins, keeping the pins from rising when in the recessed position (Figure 10). The springs that are used are 1.778 mm. in diameter and 3.048 mm. in length. These springs have a spring constant, *k*, of 5.357 g/mm, meaning, that when the maximum number of pins are raised (15 pins are raised at 07:17PM) a distance of 0.48 mm. (the height of standard Braille), the springs would exert 38.570 g. on the top of the casing. The internal forces of the design are discussed further in the 'Force Calculations' section.

### *Casing*

The casing of the watch, which houses the disks, gears, pins and springs, includes three separate parts that, when screwed together, form the final casing. The bottom portion contains four axels for the integrated gear and disk parts (Figure 11) to fit on, each 3.81 mm. in height. This prevents the gears and disks from experiencing translational motion, while allowing rotation with minimal friction. The middle portion of the casing covers the gears and disks and has four grids of two by two holes, as well as a hole for the AM/PM pin. As is shown in Figure 19, these are the holes through which the bottom portion of the pins fit. The top portion of the casing, which serves to contain the pins and the mounted springs, has a similar set of holes through which the user will ultimately be able to feel the raised and lowered top portion of the pins (Figure 20).

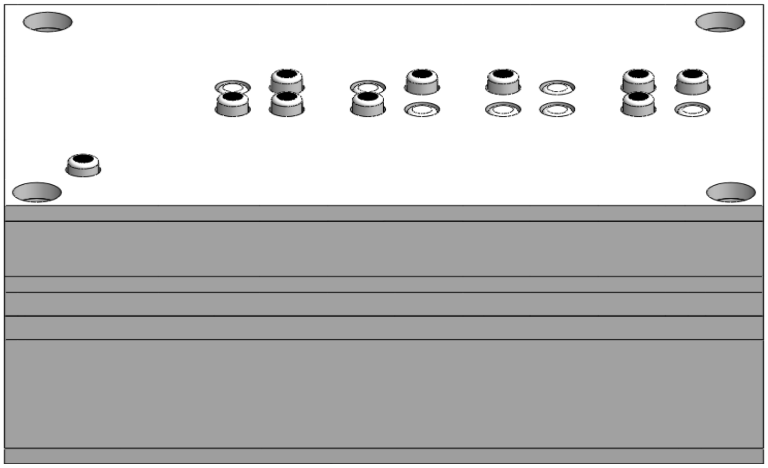


**Figure 20: Braille Watch assembly displaying 09:16 PM**

### *Assembly*

Aided by the casing design, the assembly of the prototype is straightforward. First, the integrated gear and disk parts are placed on the corresponding axel in the bottom part of the casing. For presentation purposes and in order to test the mechanism of the watch, the drive gear is designed so that it can be rotated manually by hand. In the future, this gear will ideally be attached to a motor, which would allow for a functioning Braille watch (see 'Future Work'). Once all the disks and the drive gear are in place, the middle portion of the casing is placed on top of the disks, enclosing the disks and gears between the bottom and middle portion of the casing. The pins are then appropriately placed in the holes located on top of the middle portion of the casing (Figure 19). As mentioned earlier, the bottoms of the pins are different lengths and are designed based on the disk the pins interact with; the distance between the disk surface and the top of the middle casing vary due to overlapping of the disks (Figure 16). Once the pins are positioned in the middle portion of the casing, springs are mounted on the circular platform portion of the each pin. To finalize the assembly, the top portion of the casing is appropriately placed over the pins and the three sections of the casing are screwed together. The final dimensions of the completed prototype are 35.636 x 23.393 x 17.805 mm, a 60% size reduction compared to the prototype from Spring 2011 shown in Figure 16.

One of the downfalls of this prototype is the roughness of the disk surfaces, a result of the 3D printing. Despite the fact that the Viper si2 printer offers a resolution of 0.051 mm, there are still noticeable "steps" on the transitional surfaces of the disks (the slanted surfaces between the raised and lowered portions). Due to these steps, the interaction between the base of the pins and the surface of the disks is not smooth enough to allow for easy rotation. In order to counteract this friction, white lithium grease was applied to the surfaces of each disk. This sufficiently lubricates the surfaces, making rotation of all four disks possible, but significant friction still exists. Additionally, the gears are fragile and can easily be chipped. In order to overcome these setbacks, a more reliable and accurate method of manufacturing is needed.

## Design Fabrication

### *Photolithography*

In order to fabricate a more durable and precise prototype, several methods of fabrication were considered. Photolithography, the process of using UV light to transfer 2D geometric shapes from a photomask to a substrate containing a photoresist chemical (Figure 21), could be used to create a mold for the watch parts. This process is used for microfabrication and can provide precision of 10 µm laterally with ~1µm of edge roughness. The 2D geometric shapes are created using computer-aided design (CAD) and printed using a high-resolution image setting system on a transparent sheet. Depending on the desired shape, either a negative or a positive image can be designed and printed. The transparent sheet can be used as a mask for exposing UV light on a substrate containing a photoresist chemical. The exposure of UV light causes the chemical to crosslink. Baking of the photoresist is then required followed by removal of the residual photoresist by soaking the part in solution. The thickness of the 3D part can be adjusted by controlling the spinning of the photoresist onto the substrate[7].

A variety of materials could be used to fill the mold in order to produce the final parts. However, due to the complexity of the geometry associated with the disk surfaces, it would be difficult to produce a mold that would allow for prototype fabrication. Nevertheless, this method could be used to make the gears, which could then be fused to the disks. In order to manufacture the disks, a different fabrication method is required.

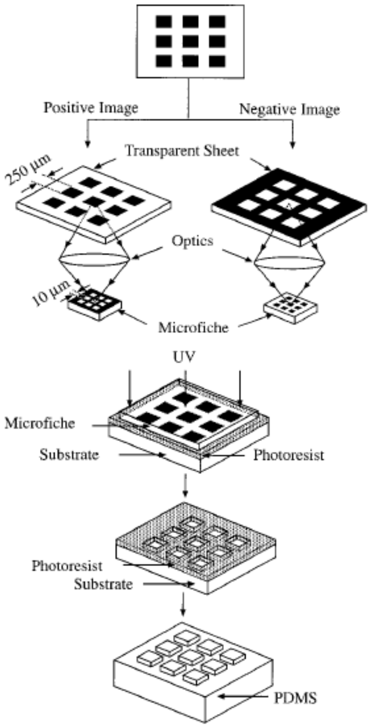


**Figure 21: Different 2D geometries on a photomask allow for the creation of the corresponding 3D geometries on a substrate containing a photoresist chemical**

*Image courtesy of Connexions:*
Deng et al. 1999

### *Computer Numerical Control (CNC) Milling*

CNC Milling is used to machine solid materials by controlling a milling cutter with computer software (Figure 22). Using a computer-aided design (CAD), a mill can be automated to cut the desired parts. The accuracy of the individual mill depends on the cutter being used. There are cutters available that can provide accuracy up to 10 μm; however, it would be difficult for any cutter to penetrate into the sharp corners on the surface of the disk[8].

In order to explore CNC milling as a potential fabrication method, numerous companies were contacted. Tosa Tool, a local rapid prototyping company, is currently helping the team determine how CNC milling could be used to fabricate the parts. If this approach is pursued, CNC milling would provide metal parts, allowing for a more reliable and durable final product. However, since each part must be custom-manufactured by a CNC specialist, CNC milling is expensive.

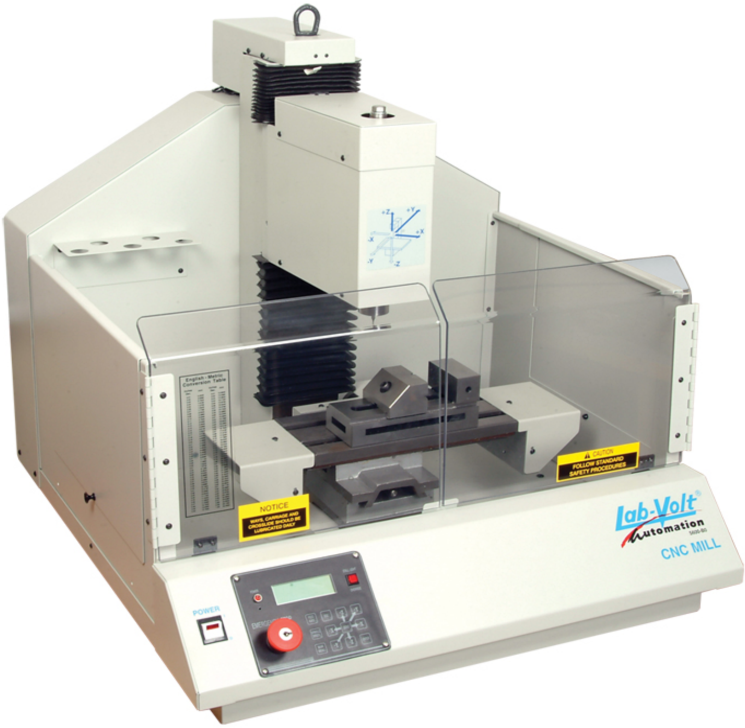


**Figure 22: CNC mills use computer-aided designs to control a cutter to produce metal parts**

*Image courtesy of Lab Volt:*
http://www.labvolt.com/uploads/products/full/5600-cnc-millnew.jpg

### *Injection Molding*

In order to perform injection molding, first, a negative mold of the part must be created. Using an injection molding machine, molten thermoplastic is then injected into the mold, and the mold is compressed by applying force from a clamping unit (Figure 23). After compression, the thermoplastic takes the shape of the desired product. Although this process is fairly simple, creating the negative mold is expensive. The final product would also be made of a thermoplastic, which may provide durability issues, as is the case in the current prototype

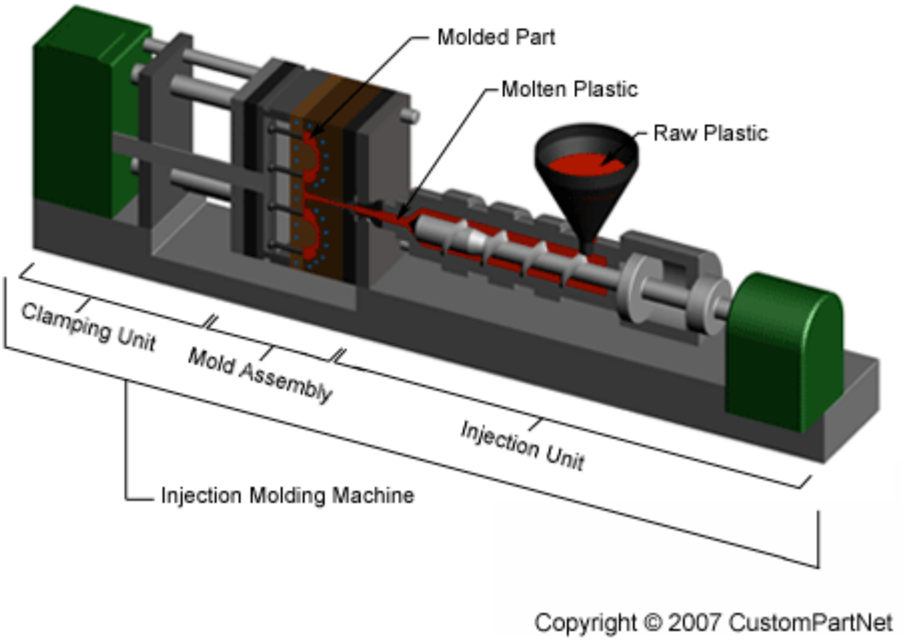


**Figure 23: Injection molding creates desired parts by filling a mold with molten plastic**

*Image courtesy of Custompartnet:*
http://www.custompartnet.com/wu/images/im/injectionMolding_machine_overview.png

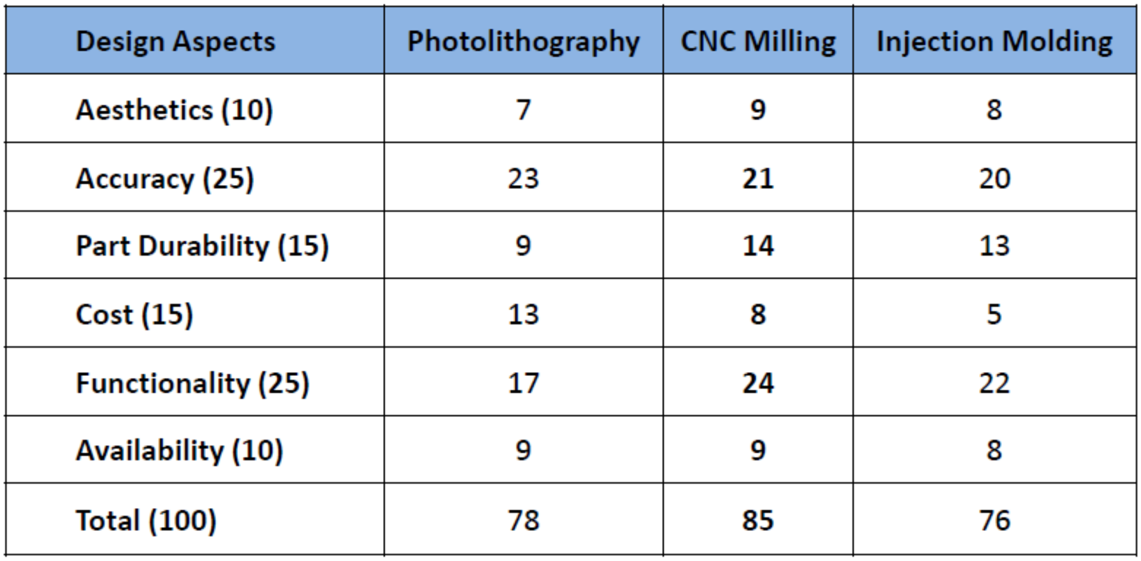
Since the final prototype must be durable, it is essential to manufacture the watch from strong materials. Although, thermoplastics have been widely used for injection molding, micro powder injection molding (μPIN) has been used to fabricate microstructures of 100 μm diameter and 200 μm height using a stainless steel powder[9]. μPIN offers another modality for fabricating durable and reliable parts.

## *Fabrication Evaluation*

Photolithography, CNC Milling, and Injection Molding were evaluated on a weighted scale ranging from zero to one hundred over a variety of design criteria (Table 1). The most important criteria were given more weight in the matrix and include accuracy, functionality, durability and cost. These aspects were determined to be the most important fabrication characteristics since each is critical in terms of manufacturing a functional final product.

Accuracy was a major concern because of the small features associated with the disk surfaces and the gears. It was essential that the chosen method of fabrication could provide high precision that, at the very least, would be greater than the 0.051 mm currently provided by the 3D printer[10]. Although photolithography received the most points for accuracy, this process could not provide a functional disk surface and, thus, received low points for functionality. CNC milling received the most points for functionality since this approach could accurately produce all parts.  Additionally, the metal parts would provide high durability. While injection molding could provide both durable and functional parts, the cost to create a mold is beyond the available funding.

**Table 1: The Design Matrix displays the design evaluation on a scale of zero to one hundred (zero=very poor, one hundred=excellent) and is weighted on a variety of criteria.**



| Design Aspects | Photolithography | CNC Milling | Injection Molding |
|---|---|---|---|
| Aesthetics (10) | 7 | 9 | 8 |
| Accuracy (25) | 23 | 21 | 20 |
| Part Durability (15) | 9 | 14 | 13 |
| Cost (15) | 13 | 8 | 5 |
| Functionality (25) | 17 | 24 | 22 |
| Availability (10) | 9 | 9 | 8 |
| Total (100) | 78 | 85 | 76 |

The design matrix revealed that CNC milling would be the best fabrication method to pursue. As was previously mentioned, the team has already contacted Tosa Tool, a rapid prototyping company that utilizes CNC milling[11], as well as other CNC specialists. With CNC milling, a durable, functional and accurate Braille watch prototype can be manufactured.

# Testing and Results

## *Client Testing*

In order to gain feedback on the functionality, practicality and necessity of the Braille watch, six blind students, including Colton, and a blind teacher from the Wisconsin School for the Visually Handicapped tested the prototype. Initially, they tested the prototype developed during the Fall 2010 semester (Figure 8). This device was difficult for them to read, as the display does not utilize standard Braille spacing. After they had critiqued the fall semester prototype, they were given the prototype developed in Spring 2011 (Figure 16). Although it took time to individually locate each character, due to the standard Braille spacing within each character, all of the testers were able to correctly read the time. Colton was extremely pleased with the prototype, saying, "This is exactly what I wanted."

When asked if any of them would be willing to buy a device with the functionality and size of the prototype, the answer was a unanimous yes. The students, all of whom used the talking watch, desired a product that was less disruptive; while the teacher, who used the analog watch, wanted a watch that was easier to use and read. Based on these results, it was concluded that the design sufficiently met Holly and Colton’s needs, as well as those of the blind community. Furthermore, if the prototype was developed into a fully functional watch, a significant market potential would exist.

Once the prototype from this semester had been fabricated (Figure 20), Colton was once again asked to test the prototype. This time, with a swipe of his finger, he was able to read the displayed time. Since standard Braille spacing was achieved between and within each character, the display provided a natural and similar feel to standard written Braille.

## *Force Calculations*

When completing the force calculations, several design features had to be considered. There are four main forces functioning within the watch: the frictional force between the surfaces of the bottom of the gears and the bottom casing, the frictional force between interacting gears, the frictional force between the axels and the gears and the force applied by the disk surfaces in order to raise the pins. It is critical to determine the maximum internal force that occurs at the drive gear, as the chosen rotating mechanism must be able to overcome this force.

The force between the bottom of the gears and the bottom casing will be discussed first. Ignoring the pins, one of these forces can be calculated by multiplying the weight of a disk ($F_N$) by the coefficient of static friction between the disk and casing ($u_s$). The resulting value is the force required to move the disk due to static friction ($F_f = u_s \cdot F_N$). This force can be decreased by applying a lubricant between the surfaces or by ensuring that these surfaces are smooth. Both would reduce the coefficient of friction. The calculation for the frictional force between interacting gears is very similar, except the coefficient of friction may vary (this depends on the material and smoothness of the individual parts) and the forces are acting within different planes.

Now the force applied by the disk surfaces in order to raise the pins will be discussed. Since pins are located at different distances away from the center of the disk, the torque needed to move each pin is different. Thus, calculations for each pin will vary.  As the disks rotate, the slanted surfaces of the disk cause the pins to move in a vertical direction (Figure 24). Considering the force of one pin acting on a disk, the force keeping the pin in a lowered position is the force due to the pin's weight ($F_w$) plus the force of the spring on the pin ($F_{spring} = k\Delta x$, where k is the spring constant, 5.357 g/mm, and $\Delta x$ is the total change in height, which ranges from 0 mm. to 0.48 mm. as the pin is being raised). The total force of the pin on the disk can be described by $F_{total}=F_w+F_{spring}$.  Since the pins associated with each disk are different sizes (Figure 16), their weights will vary.

Considering the force of the disk acting on the pin, only the y-component of $F_{slanted}$ moves the pin in the vertical direction. Therefore, in the case of only one pin, $F_{surface}=F_{desired}/\cos(45^\circ)$ (where $F_{desired}=F_{total}$ and $45^\circ$ refers to the angle the slanted surface

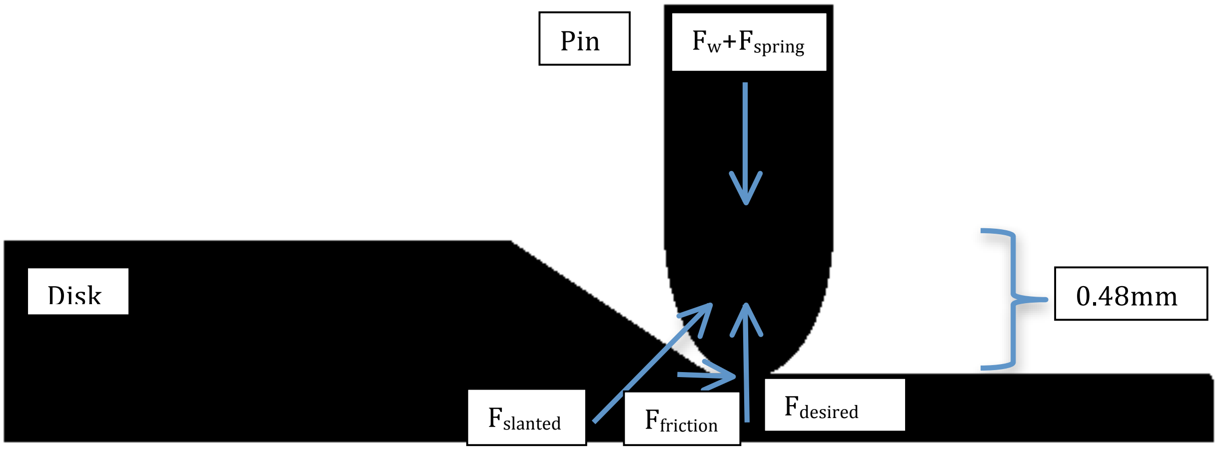


**Figure 24: Forces acting during movement of pins in vertical direction**

makes with the lowered surface). However, this is an idealization since multiple pins are often raised simultaneously. Furthermore, although it was considered negligible in this discussion, the frictional force between the pin and the disk surface ($F_{friction}$) will need to be taken into consideration. It is this force that currently prevents the pins from smoothly interacting with the disk surfaces.

Many of the forces in this section have been idealized, and the additive effect of these forces has yet to be analyzed. While models like these are helpful in determining the internal forces of the watch, physically measuring the forces on a completed prototype will best reveal the actual forces. Once the maximum force needed to control the watch is calculated, a motor that can provide at least one and a half times this force should be implemented in order to ensure that the watch maintains functionality. Once the material of the final prototype is known, the coefficients of friction can be solved for and these calculations can be completed.

## Management and Planning

At the beginning of the semester, the Gantt chart found in Appendix C was created as a work and time management tool. It was roughly followed throughout the semester to ensure that the project was on track and deliverables were finished on time. All expenses were recorded throughout the semester as well. The cost for manufacturing all parts using the Viper si2 SLA rapid prototyping was $97.75, while the 17 springs cost $13.22. This results in a total cost of $110.97. A detailed list of expenses can be found in Appendix D.

# Future Work

While this semester's design was a large improvement on past designs, many steps are still required to produce a fully functional prototype. First, the watch must be manufactured using a more precise method that can produce durable parts. Ideally CNC milling will be used. A major obstacle to this approach will be manufacturing the complex features of the disk surfaces. Additionally, the disks and gears may need to be broken into separate parts, manufactured, and then reassembled into a single part. If CNC milling is unable to meet the necessities of this design, other fabrication methods will be pursued.

Second, in order to be fully functional, the watch needs to have a self-powered rotating mechanism. This mechanism will ideally fit inside the current design so that the dimensions of the watch do not change significantly. The power source for this mechanism must be long-lasting and reliable. Additionally, the rotating mechanism must be able to overcome any internal forces restricting the movement of the gears and pins. The group will need to contact watch companies or other technical specialists in order to discuss potential options for this mechanism.

Once a fully functional product has been manufactured, product testing will need to be conducted. This would first include testing that every combination of time can be correctly displayed by the current design mechanism. Another round of testing would measure any accumulation of undesired debris (e.g., dirt, dust, etc.) in the various compartments and the wear that occurs at the pins and the surface of the disks to make sure that the product remains reliable over time. If applicable, battery life for the design will need to be determined as well.

Finally, the team would like to market the final product. A patent application was recently filed at the patent office for the Braille watch mechanism, and various companies that may have interest in a Braille watch product have been identified. Additionally, the market size is larger than previously believed. Not only could a Braille watch be helpful to the blind, but it could have applications for the military and elderly as well. This increased applicability should make the Braille watch even more appealing to companies. Ultimately, gaining the interest of a company will lead to the mass production and distribution of Braille watches all over the world.

# Conclusion

A fully functional Digital Braille Watch was successfully created using a rotating disk and gear mechanism. The final prototype met all of the major design specifications, with the exception of having a self-contained power supply and a rotating mechanism. Next semester, a rotating mechanism will be integrated into the watch, and the final prototype will be fabricated using CNC milling. Based on the results of the testing, it was determined that the watch would be well received by the blind public. Upon completing the patenting process with the Wisconsin Alumni Research Foundation, the team will search for a company that is willing to help commercially market the watch. This innovative prototype demonstrates that it is possible to create a Digital Braille Watch that is silent and easy to read, thus, improving the daily life of the blind.

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# Appendix A: Product Design Specifications

## Product Design Specifications—Digital Braille Watch

Team: Chandresh Singh, Nick Anderson, Luke Juckett
Client: Holly and Colton Albrecht
Advisor: John Puccinelli

**Problem Statement:**
In order to determine the time, the blind currently depend on talking or tactile watches. However, talking watches are disruptive, while tactile watches are difficult to read and fragile. Developing a watch that displays the time using the standard Braille number system would allow blind individuals to discretely, accurately and independently check the time. This device should be fabricated using durable and precise parts, have a self-contained power supply, use standard Braille spacing, and be the size of a standard wristwatch.

**Client Requirements:**

- Digital time display using Standard Braille Spacing
- Silent and without vibrations
- A functioning prototype that the client can use on the daily basis

**Design Requirements:**

1) Design Requirements

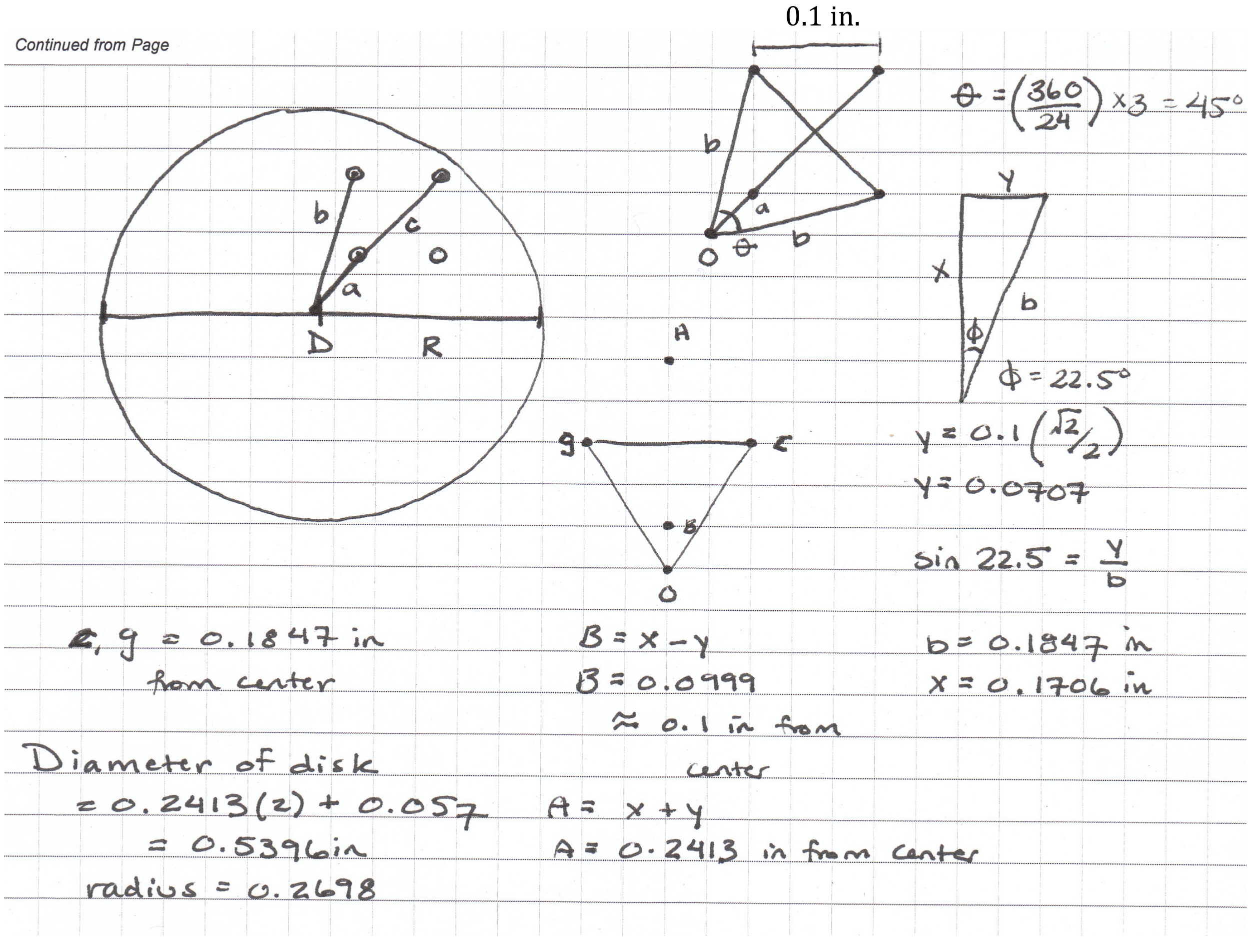
   a) *Performance requirements:* See Client Requirements above, in addition to being self-contained, using standard Braille spacing, and of sufficient size. The battery should last at least a month and should be rechargeable
   b) *Safety:* All electronics must be contained and the watch must not contain hazardous materials. In order to ensure the user is not harmed in any condition, no component of the part should be unsafe
   c) *Accuracy and Reliability*: The watch must accurately display military time within the minute for the duration of its life
   d) *Life in Service*: The watch must be able function continuously using a self-contained power source for at least five years
   e) *Shelf Life*: Similar or superior to audible or tactile watches in the market
   f) *Operating Environment*: The device must be able to operate reliably in a dry environment without being affected by perspiration
   g) *Ergonomics*: The watch should not contain rough edges or loose components and the display surface should be easy to read. The watch should not make its user aware of the fact that he/she is wearing something on his/her wrist.
   h) *Size*: The prototype should have a display area of less than 50x50 mm and a height of less than 25mm
   i) *Weight*: Less than 500 grams
   j) *Materials*: The device must comprise of non-toxic metal components
   k) *Aesthetics, Appearance, and Finish*: The watch should be aesthetically pleasing

2) Product Characteristics
   a) *Quantity*: One working prototype
   b) *Target Product Cost*: $100 or less when mass-produced

3) Miscellaneous
   a) *Standards and Specifications*: Must display time according to the standard Braille language
   b) *Customer*: The customer would like a device that physically displays the time using Braille technology
   c) *Patient Related Concerns*: None
   d) *Competition*: Audible and tactile analog watches are commercially available for the visually-impaired

# Appendix B: Calculations

Example calculation showing how disk size was determined:



$\theta = \left(\frac{360}{24}\right) \times 3 = 45°$

$\phi = 22.5°$

$y = 0.1\left(\frac{\sqrt{2}}{2}\right)$

$y = 0.0707$

$\sin 22.5 = \frac{y}{b}$

c, g = 0.1847 in from center

$B = x - y$

$B = 0.0999$

≈ 0.1 in from center

b = 0.1847 in

x = 0.1706 in

Diameter of disk

= 0.2413(2) + 0.057

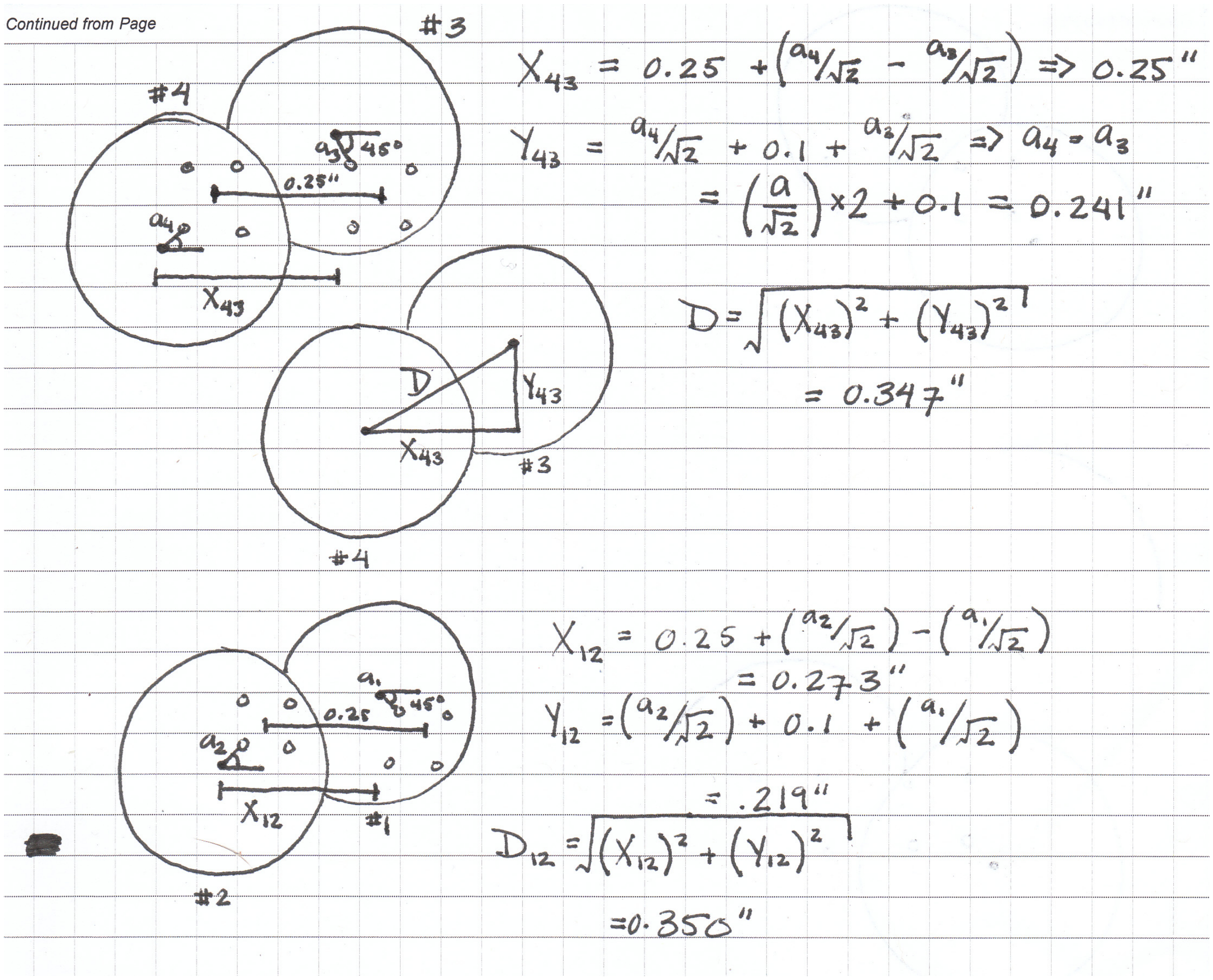
= 0.5396in

radius = 0.2698

$A = x + y$

A = 0.2413 in from center

Example calculation showing how disk spacing was determined:



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$$X_{43} = 0.25 + \left(\frac{a_4}{\sqrt{2}} - \frac{a_3}{\sqrt{2}}\right) \Rightarrow 0.25''$$

$$Y_{43} = \frac{a_4}{\sqrt{2}} + 0.1 + \frac{a_3}{\sqrt{2}} \Rightarrow a_4 = a_3$$

$$= \left(\frac{a}{\sqrt{2}}\right) \times 2 + 0.1 = 0.241''$$

$$D = \sqrt{(X_{43})^2 + (Y_{43})^2}$$

$$= 0.347''$$

$$X_{12} = 0.25 + \left(\frac{a_2}{\sqrt{2}}\right) - \left(\frac{a_1}{\sqrt{2}}\right)$$

$$= 0.273''$$

$$Y_{12} = \left(\frac{a_2}{\sqrt{2}}\right) + 0.1 + \left(\frac{a_1}{\sqrt{2}}\right)$$

$$= .219''$$

$$D_{12} = \sqrt{(X_{12})^2 + (Y_{12})^2}$$

$$= 0.350''$$

Example calculation showing how gear length and angles were determined:

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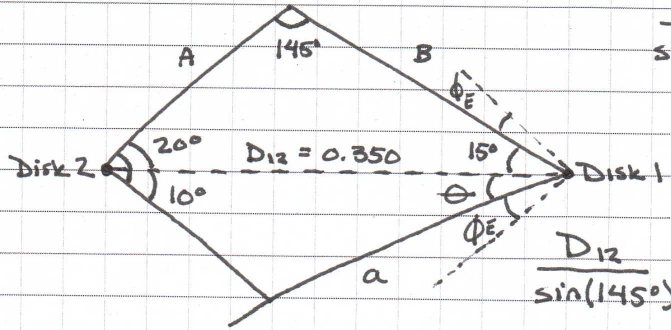


$$\frac{D_{12}}{\sin(145^\circ)} = \frac{B}{\sin(20^\circ)}$$

B = 0.209"

B = length of long gear on disk 1

$$\frac{D_{12}}{\sin(145^\circ)} = \frac{A}{\sin(15^\circ)}$$

A = 0.158"

A = length of short gear on disk 2

$$a = \sqrt{(.35^2)+(A^2)-2(.35)(A)\cos(10^\circ)}$$

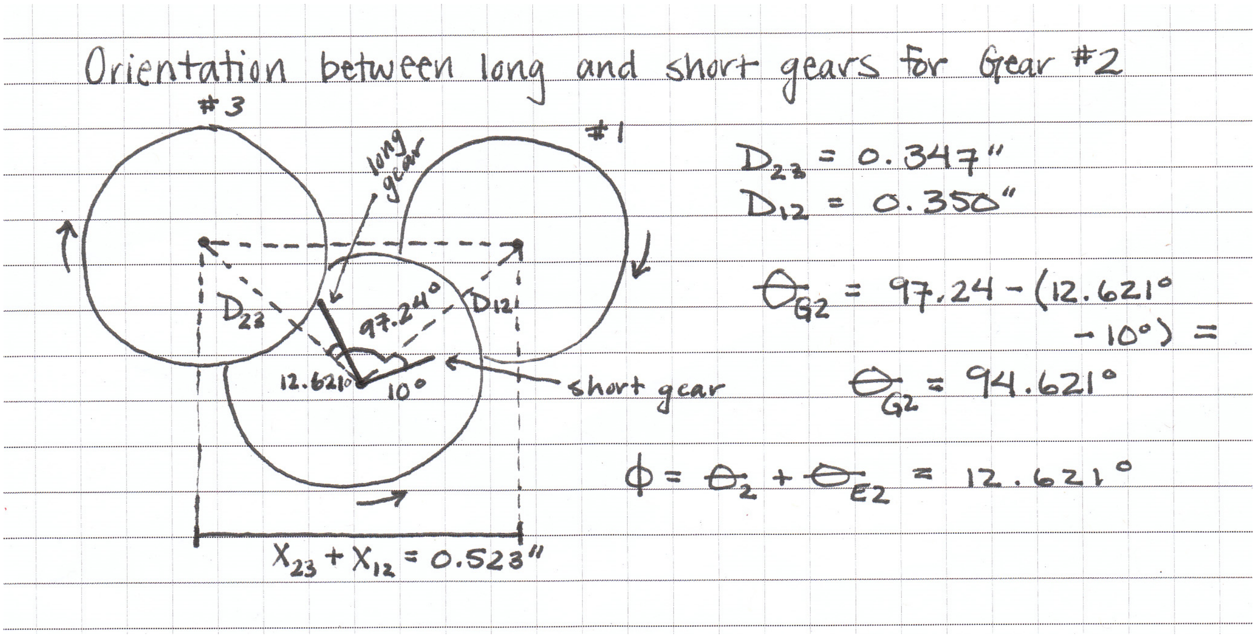
a = .1963"

$$\theta = \cos^{-1}\left(\frac{(.35^2)+(.1963^2)-(A^2)}{2(.35)(.1963)}\right) \qquad \theta = 8.01^\circ$$

$$\phi_E = \frac{(36^\circ - (15^\circ + \theta))}{2} = 6.495^\circ$$

$\phi_E$ = represents the angle of the long gear before and after contact with the short gear. Represents one complete rotation of long gear.

Example calculation showing how the orientation between the long and short gears was determined:



Orientation between long and short gears for Gear #2

$D_{23} = 0.347''$

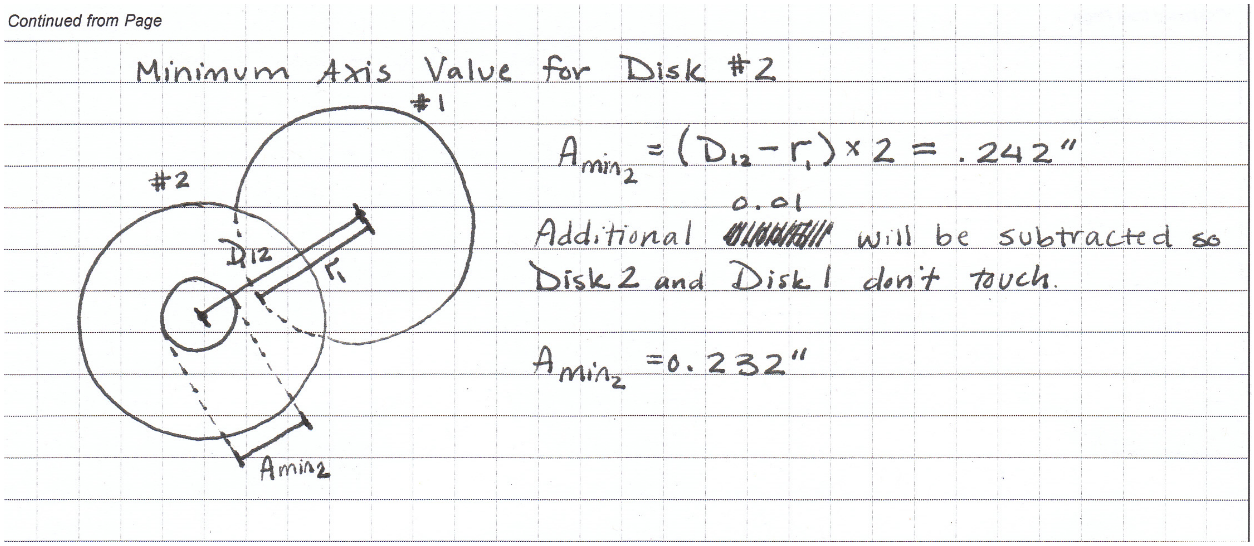
$D_{12} = 0.350''$

$\theta_{G2} = 97.24 - (12.621° - 10°) =$

$\theta_{G2} = 94.621°$

$\phi = \theta_2 + \theta_{E2} = 12.621°$

Example calculation showing how the minimum axis of an overlapping disk was determined:



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Minimum Axis Value for Disk #2

$A_{min_2} = (D_{12} - r_1) \times 2 = .242''$

Additional ~~[illegible]~~ 0.01 will be subtracted so Disk 2 and Disk 1 don't touch.

$A_{min_2} = 0.232''$

# Appendix C: Gantt Chart

| Task | September | | | | | October | | | | November | | | | December | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2 | 9 | 16 | 23 | 30 | 7 | 14 | 21 | 28 | 4 | 11 | 18 | 25 | 2 | 9 |
| **Project R&D** | | | | | | | | | | | | | | | |
| Researching | X | X | X | X | X | X | X | | | | | | | | |
| Brainstorming | X | X | X | X | X | X | X | | | | | | | | |
| Design Matrix/Cost Estimation | | | | | | ■ | X | | | | | | | | |
| Design Selection | | | | | | | X | X | X | | | | | | |
| Ordering Materials | | | | | | | | X | X | X | | | | | |
| Prototyping | | | | | | | | | X | X | X | X | X | X | X |
| Testing | | | | | | | | | | | | | X | X | X |
| Final Prototype | | | | | | | | | | | | | | X | X |
| **Deliverables** | | | | | | | | | | | | | | | |
| Progress Reports | X | X | X | X | X | X | X | X | X | X | X | ■ | X | X | X |
| PDS | ■ | ■ | ■ | X | ■ | | | | | | | | | | |
| Mid-semester Presentation | | | | | | X | X | X | | | | | | | |
| Final Presentation | | | | | | | | | | | | | | X | X |
| Final Paper | | | | | | | | | | | | | | X | X |
| **Meetings** | | | | | | | | | | | | | | | |
| Client | | ■ | | | | ■ | | | | ■ | | | | ■ | |
| Team | X | X | X | X | X | X | X | X | X | X | X | X | | X | X |
| Advisor | | X | X | X | X | X | | X | X | X | X | X | X | | |
| **Website** | | | | | | | | | | | | | | | |
| Update | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |

# Appendix D: Expenses

| **Date** | **Item** | **Per Unit Cost** | **Extended Cost** |
|---|---|---|---|
| 3/11/11 | Mini Compression Springs (x50) | $1.00 | $38.87* |
| 11/14/11 | Prototype printed using Viper SLA printer | $97.75 | $97.75 |
| | | **TOTAL** | $136.62 |

*Although 50 springs were ordered, only 17 springs were used in the final prototype. The cost presented in the paper only includes the cost of 17 springs, which was determined by multiplying $38.87 by 17/50.