Conceptual Design Review

Sponsor and General Project Information

Our senior design project sponsor is Harris Corporation. Our contact is an Engineer named Brent Stancil. Harris Corporation is an international communications and information technology company. They serve government and commercial markets in more than 150 countries. Headquartered in Melbourne, Florida, they receive annual revenues of $5.3 billion and provide work for 16,500 employees, including about 7,000 Engineers and Scientists.

Harris Corporation ran tests on bevel gears needed for a project and they did not achieve the expected standards. The possible problems included: misalignment, anodic coating failed, or the gears were overloaded. Some extended test bed issues we need to examine are vibration and heat generation. Our team needs to design a very accurate bevel gear test bed which can be used to test a variety of bevel gear sizes and materials. Some of our product specifications are in Table 1 below.

Specifications	U.S. Values	SI Values
Variable Torque	0 in.-lb. - 100 in.-lb	0 Nm - 11.3 Nm
Variable Speed	0 rpm - 1000 rpm	0 rad/s - 104.7 rad/s
Gear Size Range	1/3 in. to 5 in.	8.467 mm - 127 mm
Mounting Distance Accuracy	0.001 in.	.0254 mm
Variable Shaft Angle	+/- 0.5 degrees	+/- 0.00873 rad

Table 1

Concept Generation

Our concept generation included 6 different general design ideas. The focus was on how to adjust the walls supporting the gear shafts. The first concept is a drawer slider concept which operates on the same concept as a household drawer. The wall translates in one direction within a specific geometric design. The second concept incorporates the rotation of the walls. The wall will rotate along an angular slotted path. The third concept is a combination of the first two concepts, having the actual wall translate and rotate. Our fourth concept is similar to the drawer slider except instead of the wall being flat and the slider being similar to a drawer slider, the wall will be curved to make the angular movement of the shafts easier. In addition, the slider will be round to reduce the contact area between the slider and surrounding material, thus reducing friction. The fifth concept is a rack and pinion design. There are two different rack and pinion designs, one with a driving pinion and one with a driven pinion. The last conceptual design is a worm gear design. The worm gear is in mesh with a spur gear and will produce translational motion of the walls.

Drawer Slider Design

The drawer slider design is a simple translational motion design that is an imitation of the design of a drawer slider. The slider moves along a horizontal track. It moves with a decently smooth motion but will be hard to adjust within our desired 0.001 inch increments. In addition, the design does not consider the desired rotational motion. Figure 1 below is an illustration of the drawer slider design.

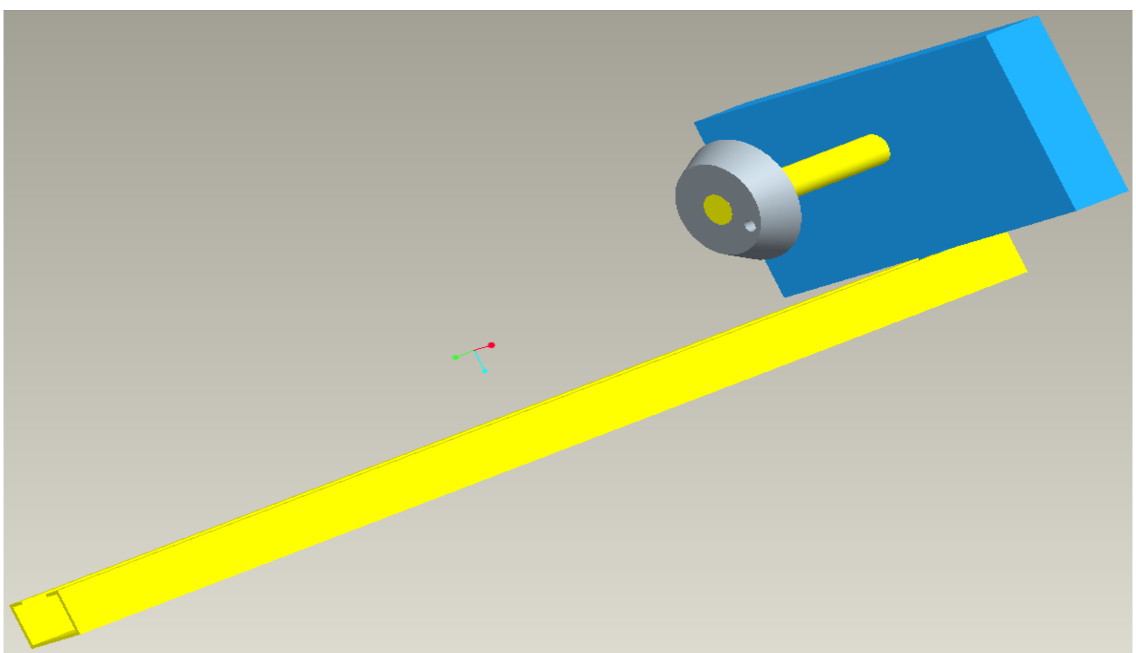

Figure 1: Drawer Slider Design

Rotator Design

The rotator design is a simple rotational motion design. The rotator moves along a circular track in the horizontal plane. It moves with a relatively smooth motion but fails to incorporate the desired translational motion. Figure 2 below is an illustration of the rotator design.

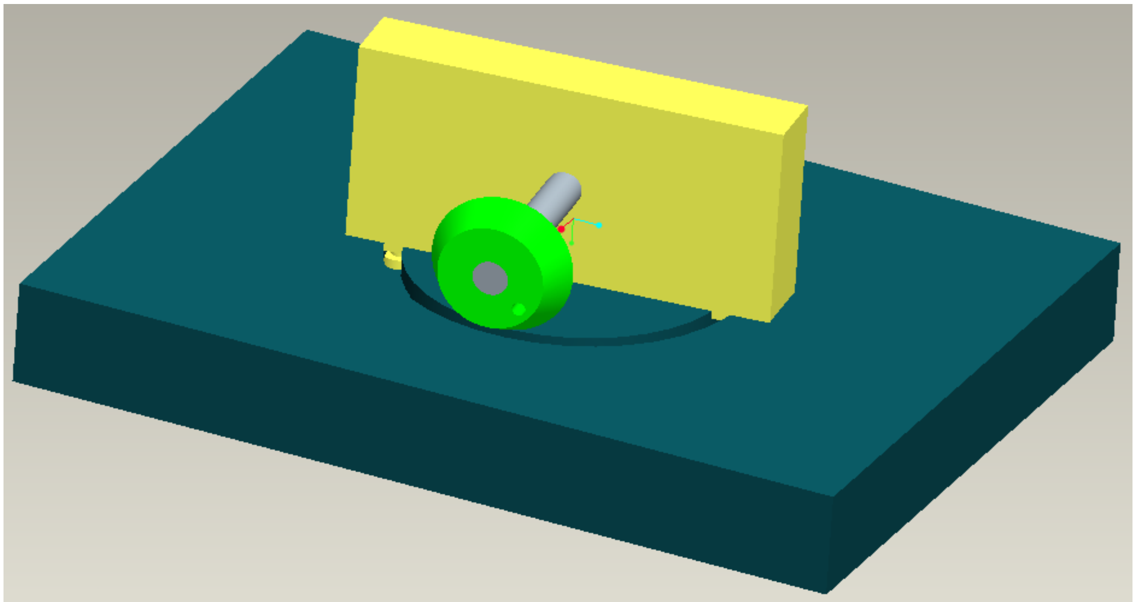

Figure 2: Rotator Design

Rotator-Slider Design

The rotator-slider design is a combination of the rotator and slider design. The translational portion of the motion is accomplished by a horizontal slot in the lower base plate. The rotational portion of the motion is achieved through a circular slot in the upper base plate. Figure 3 on the following page is an illustration of the rotator-slider design.

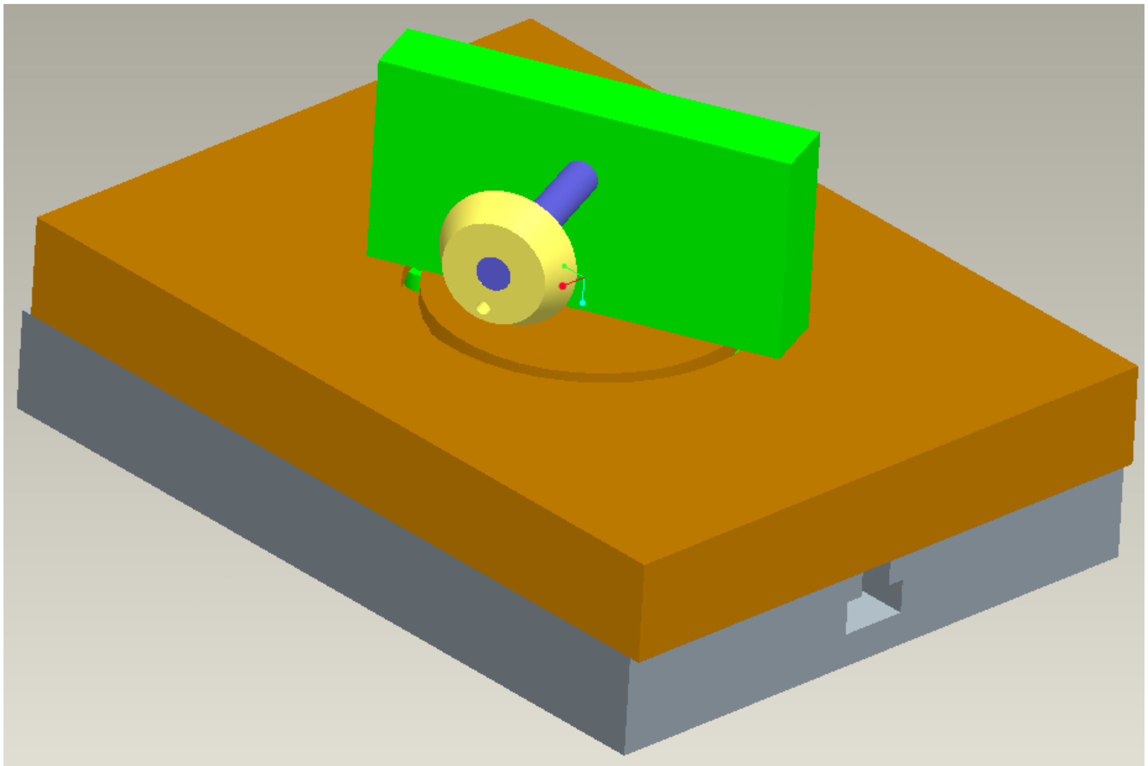

Figure 3: Rotator-Slider Design

Curved Wall Design

The curved wall design is closely based on the design concept of the drawer slider wall idea. This design concept will use the same type of slider concept to adjust the mounting distance of the testing gears. Instead of a square cross section being used for the slider piece, a rounded slider piece will be used. This is because a rounded slider piece should be less difficult to machine to within a 0.001 in. tolerance. The drawer slider concept will achieve the rotational motion by some method of rotating the wall while still being able to adjust mounting distance. The problem with this is that it adds extra parts to the overall system, which will increase the degree of difficulty for the machining and assembly of the test bed.

By adding curvature to the wall, the need for extra parts that allow the wall to rotate will be eliminated. Based on a calculated radius of curvature and a rectangular shaft slot, the gear shaft can be set to a pivot point to achieve the slight shaft angles requested by the client. Machining a curved wall with an exact radius of curvature parts for rotational walls will increase the difficulty level for the test bed; the assembly difficulty level will decrease. This design will probably be very difficult in this design. Figure 4 below shows how the curved wall design will look.

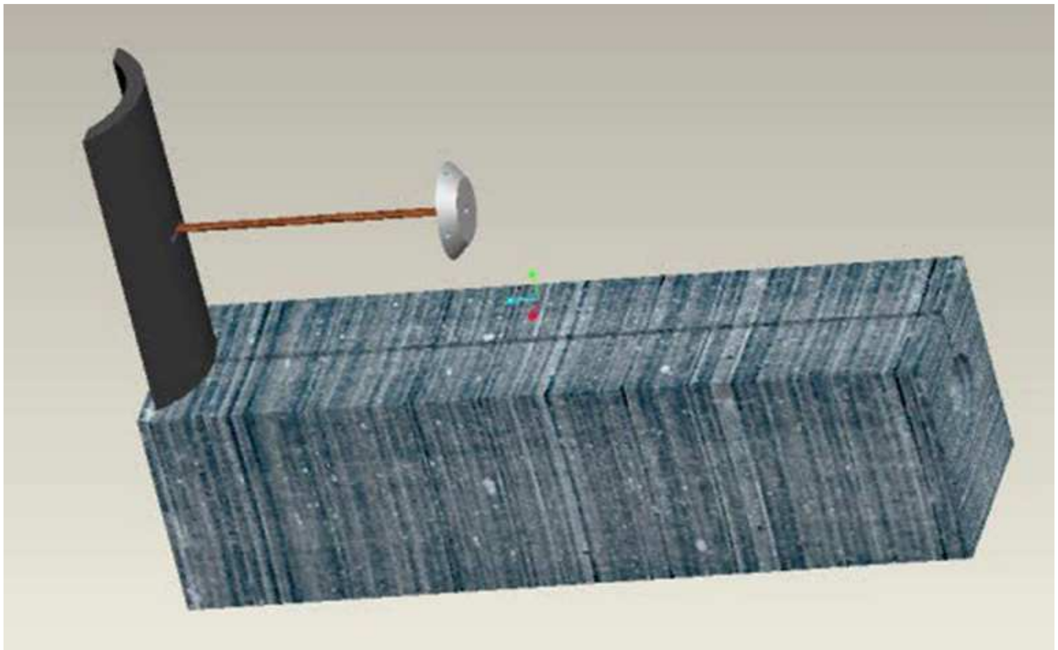

Figure 4: Curved Wall Design

Rack-and-Pinion Concepts

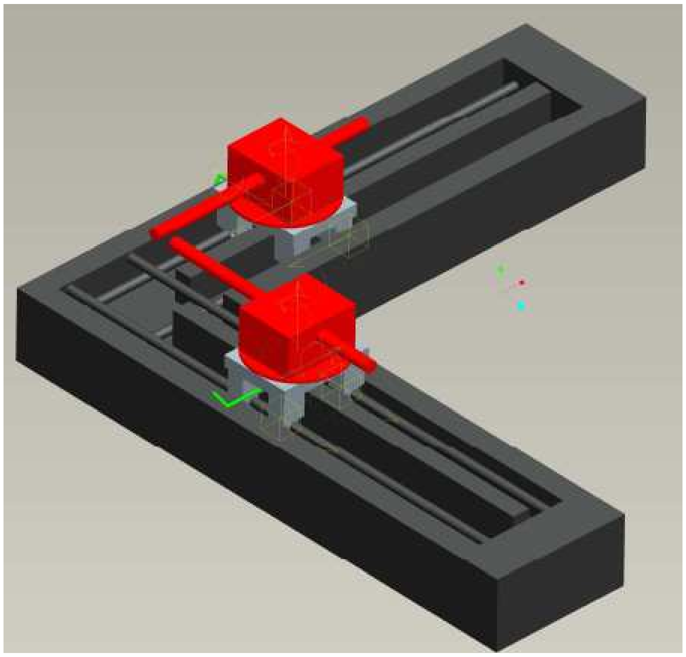

Figure 5: Rack-and-Pinion - Concept A

Rack-and-Pinion - Concept A

The first idea is to mount each gear-shaft housing on a rack-and-pinion style gear assembly. This design is split into two different methods. The first of the two methods is to mount a pinion underneath the gear-shaft housing in mesh with a static rack mounted to the base of the gearbox. To move the gear-shaft housing there will be a crank connected directly to the pinion which allows for translational movement with an excellent degree of control along the stationary pinion based on the translational rotation. The precise translational movement associated with a particular rotation of the crank can be determined empirically, or can be achieved through the use of a digital sensor to measure the displacement of the gear-shaft housing. The benefit of this system is that it would be relatively simple to assemble as there is only one moving part in the gear train to translate the housing. However this is also the biggest disadvantage of the system, as having a pinion being both the driving and driven gear poses reliability concerns and may produce a lot of backlash and unnecessary wear on the teeth of the gears.

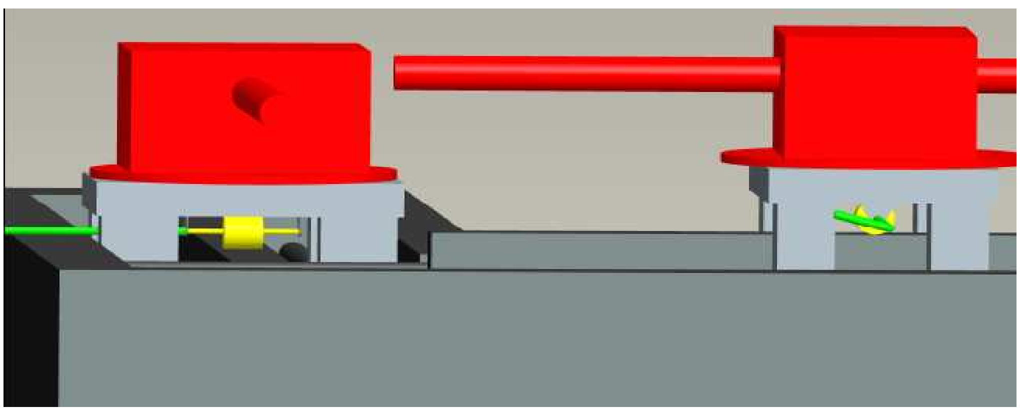

Figure 6: Close up of Rack-and-Pinion - Concept A

Rack-and-Pinion – Concept B

The second of the two ideas is a more traditional rack-and-pinion where the pinion is mounted onto the gearbox base plate and the rack in this case will be attached underneath the gear-shaft housing. A crank will remain attached to the pinion to control the translational motion of the housing, although instead of a driving pinion rotating and translating on a stationary rack, this concept has a rack being driven by a pinion to achieve translational motion. The advantage of this concept is that it is a more traditional use of a rack-and-pinion and would thus not pose as large of a reliability concern. The drawback of this design is that the rack needs to be much longer than the housing wall to achieve the full range of motion necessary for the mounting and interchanging of different gear sets within the test bed.

Worm Gear Concept

The alternative to the rack-and-pinion ideas is to replace the rack-and-pinion with a worm gear and an accompanying pinion. The worm gear would be mounted within the baseplate of the gearbox with a crank to control the translational motion of the pinion, which would be mounted underneath the gear-shaft housing, similarly to the first idea listed above. The difference from this concept and the first idea above is that in this concept, the worm gear is the driving gear and the pinion need only be driven. Since the worm gear is always in direct contact with its mating pinion, there is absolutely no backlash in the gear set and therefore, extremely high precision can be achieved with repeatability. The displacement associated with each revolution of the crank can be determined empirically or via a digital sensor, both of which would be simple enough to execute and as such, the digital sensor will most likely be preferred.

The biggest advantage of the worm gear assembly over the rack-and-pinion assembly is the repeatability of motion without compromising accuracy. Since there is no backlash in the worm gear, interchanging and re-aligning different gears and/or shafts can be done with a high degree of precision. The biggest disadvantage of the worm gear is that it will likely cost more than the rack-and-pinion, since it requires its own bearings and alignment, whereas the rack-and-pinion needs only one set of bearings for the pinion. Despite these differences, both gear sets can provide highly accurate methods of producing translational motion for the gear-shaft housing. However, the worm gear seems to be more

Additional Concept Considerations

Gear to Shaft Connections

In the design of the gearbox, every connection and alignment must be done with a high degree of precision. To ensure that each bevel gear being tested is connected to its accompanying shaft precisely and is able to be run within the gear-shaft housing, several connection methods have been produced and investigated. The different types of connections are as follows:

Concept 1 – Variable shaft diameters using an adjustable chuck

The first concept design for gear connection is to allow for variable shaft diameters as per variable gear sizes. This will be achieved by mounting an adjustable chuck, similar to those found in milling machines, into the bearing for the shaft, and running the shaft within the chuck. This would allow for the gearbox to integrate any sized gear-shaft pair into the test bed as long as it fits within the space provided, and the shaft fits inside the chuck. This method requires that the chuck be directly mounted to the motor and inside a large accompanying bearing to account for the added weight of the chuck, to ensure reliability. This is a highly accurate and very simple method of interchanging different sized shafts. The biggest drawback for this idea is the added cost and complexity. Upon further investigation, it was found that a chuck would be quite difficult to find and afford, while the manufacturing of a custom chuck would be much too complex and time-consuming for the group to take on.

Concept 2 – Constant shaft diameter using variable shaft adapters

The second concept is to use a constant diameter large stock shaft and supplementary bearings. However, instead of mounting an adjustable chuck within the bearings to account for variable mounting diameters between different gears, variable diameter adapters will be machined to mount onto the constant diameter shaft to fit any size bevel gear being tested. This method would require that a new adapter be machined for each size gear-shaft to be tested, which costs time and money, however it will cost much less of both than the designing and manufacturing of an adjustable chuck. In addition, if done properly, this method can be just as accurate as an adjustable chuck, but it is not as simple, since multiple extra pieces need to be designed, manufactured, and then assembled as needed. Within this concept there are different methods to attach the adapter to the shaft:

a) The first of the ideas under consideration is to drill a clearance hole into the adapter with an accompanying tapped hole on the shaft that will be connected via a threaded bolt, to act as a set screw. This approach will be simple to machine and should be very accurate. However it is possible that the set screw might not make the adapter completely rigid to the main shaft, and the extra un-centered weight of a set screw can add wobble to the shaft and cause added wear on the gears.

b) To account for the possible problems associated with the above concept, the adapter and the shaft can connect by having one side threaded on its outer diameter and the other side threaded on its inner diameter. The threads will be designated the appropriate hand (right-hand or left-hand threads) as to allow the two pieces to self-tighten from the rotation of the shaft by the motor. This will be an extremely simple connection method, and would also mesh the two components quite rigidly. The only drawback is that it will be difficult to control the length of the adapters on the shaft to ± 0.001 in., although it is possible. Also since there is no set screw, there is no worry of extra weight on the shaft.

The most likely approach is to go with Concept 2b since it will be simplest to machine and assemble, and also the most reliable without too much unnecessary cost. It will be very rigid, and the mounting distance is capable of being controlled to the necessary tolerance. It also is not very expensive in comparison to purchasing or machining a chuck, and allows for variable gear-shaft sizes.

Concept Selection

When deciding which design to use, we first wanted to set up a Quality Function Deployment chart to relate our customer requirements to our engineering requirements. Our customer requirements include the following: machinability, durability, looks good, accuracy, reliability, ease of assembly, and our power source. Our engineering requirements include the following: rotational velocity, resistive torque, elastic modulus, anodic coating thickness, weight, deflection, yield strength, shaft mounting distance, and cost. These relationships are demonstrated in Table 2 on the following page.

	Engineering Requirements								
Customer Requirements	rotational velocity	resistive torque	elastic modulus	anodic coating thickness	weight	deflection	yield strength	Mounting Shaft Distance	cost
Machinability			X	X	X		X		X
Durability						X	X		X
Looks Good			X	X					X
Accuracy				X	X	X	X	X	X
Reliability	X	X			X	X	X	X	X
Assembled	X	X	X	X					
Power Source	X	X							X
Units									
	rpm	in.-lb.	MPa	μm	lb.	mm	MPa	in.	$
	1000	100							≤1500
	Engineering Targets								

Table 2

Next, we wanted to compare our different concepts by using 6 different criterions to judge which concept will be suit our project. The overall concept selection was based upon the total rating of each concept using our discretion as to scaling each criterion to a specific importance percentage and rating each criterion from each concept from 1 to 5. We arranged our concept grading in the concept screening matrix in Table 3 on the next page.

Criteria	Weight	Concepts													
		Drawer Slider		Rotator		Slider-Rotator		Curved Wall		Rack and Pinion (Pinion Driven)		Rack and Pinion (Rack Driven)		Worm Gear	
		Rating	Rating x Weight	Rating	Rating x Weight	Rating	Rating x Weight	Rating	Rating x Weight	Rating	Rating x Weight	Rating	Rating x Weight	Rating	Rating x Weight
Machinability	10%	4	0.40	3	0.30	3	0.30	1	0.10	4	0.40	4	0.40	4	0.40
Looks Good	5%	3	0.15	3	0.15	2	0.10	4	0.20	4	0.20	4	0.20	5	0.25
Cost	10%	3	0.30	2	0.20	1	0.10	2	0.20	2	0.20	2	0.20	2	0.20
Reliability	25%	2	0.50	2	0.50	2	0.50	2	0.50	4	1.00	3	0.75	4	1.00
Ease of Assembly	10%	4	0.40	4	0.40	3	0.30	3	0.30	2	0.20	2	0.20	3	0.30
Accuracy	40%	2	0.80	2	0.80	2	0.80	2	0.80	4	1.60	4	1.60	5	2.00
Total Score		2.55		2.35		2.1		2.1		3.6		3.35		4.15	

Table 3

As seen in Table 3 above, the worm gear design will be the most appropriate choice from the 7 conceptual ideas. The worm gear's rating ties for the highest machinability and the highest reliability. It scored the highest for visual looks and for accuracy. It faired well in its ease of assembly. The only bad grading occurred in the realm of cost. Due to the highly detailed and attentive design needed for a worm gear assembly, the cost of manufacturing the gear set will be high. In closing, the worm gear is the best overall design and is our chosen design concept.

Things to DO

- Everyone proof-read
- Maybe put animation links on website
- Upload presentation to website
- Practice Presentations
- Table of Contents: yes or no?
- Check all figure and write up references
- References?