MOREHEAD STATE UNIVERSITY

All-in-One Hex Wrench

ITCD 615 Final Report – Fall 2012

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The Allen wrench is a very simple tool designed to tighten and loosen hex head nuts. The tool being discussed in this article is called the All-In-One hex wrench and is designed to maintain the basic function of the Allen wrench while improving on the user ability. Instead of having a bulky kit of L-shaped Allen wrenches, one could replace them with the All-In-One hex wrench which would increase organization, ease of use, and the time spent changing tools would be significantly reduced.

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Company Profile

An Allen wrench or Allen key is a familiar brand name for a hex key or hex head wrench, a tool that drives a screw or bolt called a "socket head cap screw." This type of screw, with a recessed hexagonal head is common in all kinds of different products. The "Allen screw" name for the socket head cap screw and "Allen key" for the wrench originate from the products of the Allen Manufacturing Company of Hartford, Connecticut. According to Bates, it is widely reported that the company trademarked the name "Allen wrench or key" for its range of hex wrenches in 1943. (Pasquesi, 2012)

The benefit to using an Allen key as opposed to the conventional six-sided nut or bolt is that the hex head is less susceptible to wear and tear because the hexagonal socket is indented into the nut rather than around the outside of it. This feature not only increases the life span of the nut, but it also increases its rigidity and functionality.

The hex wrench is designed to be used with a driver that is connected to a long L-shaped tool as seen in *Figure 1*. If the shorter end is used torque is maximized and if the longer end is used leverage is maximized.

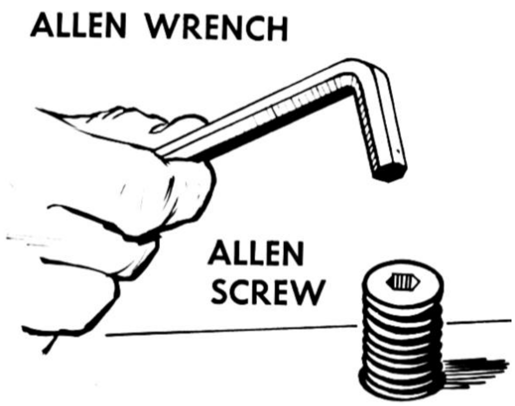


Figure 1: Example of a Standard Allen Wrench (Foresman, 2008)

The functionality of the hex wrench is stable, so the basic design is secured. Quality innovation for this tool lies in its design for ease of use, multi-function, and quick and easy tool change. The product design being presented here is called the "All-In-One Hex Wrench."

Company Name / Specializations

BFH Inc. (Bryan, Fisher, and Hamilton) is a growing company that specializes in the development and manufacturing of manual and electric hand tools. The newest product project to come out of BFH Inc. is an adjustable Allen wrench tool called the “All-in-One Hex Wrench.” BFH Inc. expects the product to be popular among electronic hobbyists and for small projects. Some specifics of the “All-in-One” tool are:

- A hex wrench that can adjust to multiple sizes of hex nuts quickly and easily.
- A functionally sound product that adheres to the general needs of any handyman.
- Denotes the need to own a bulky set of Allen wrenches and instead offers a much more convenient “*All-In-One”* tool.

Table 1: Company Mission Statement

Mission Statement – *All-In-One Hex Wrench*	
Product Description	• A multifaceted handheld hex wrench which is both functionally sound and faster and easier to use than the existing Allen wrench designs.
Benefit Proposition	• The *All-In-One* offers the functionality of the existing Allen wrench minus all the time spent changing tool sizes.
Primary Market	• The *All-In-One* would fit nicely into any tool box. Construction workers, mechanics, electricians and even stay-at-home moms could replace their bulky set of Allen wrenches with just one *All-In-One* hex wrench.
Key Business Goals	• Further simplify the Allen wrench design without sacrificing the structural integrity of the tool. • Gain speed of workmanship through the tools overall ease of use.
Stakeholders	• User

Profile of People Involved

The team behind the scenes of this product development in BFH Inc. consists of three employees: Bradley Bryan, Travis Fisher, and Samantha Hamilton. Samantha is one of the company founders and the team lead and primary organizer on the project and ran testing on the product. Bradley is one of the company co-founders and process engineer. He assisted in developing product goals, tolerances, project scope and other departments. Travis is the third co-founder of the company and the lead designer of the product. He created the product mission statement, product specializations, and the product design that has been determined as the product to be developed. (Please refer to the signature page for specific tasks completed by each team member, as well as the following figure).

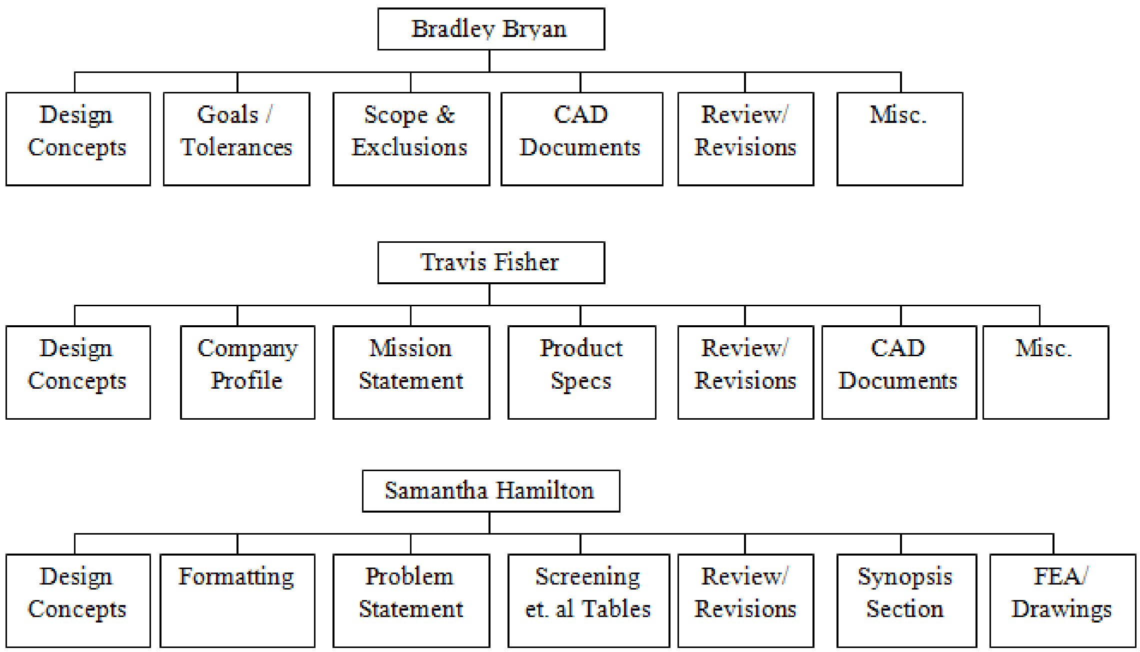


Figure 2: Project Management Team Structure

Problem Statement

Problem Description and Background

There are seemingly millions of tools available in our world today but the selection of Allen wrenches is pretty basic. There are few, if any, adjustable Allen wrenches available in the market today. There is a need for a new design that will allow for a user to carry a set of wrenches on his/her person, or store them, with the space taken up being minimal. BFH Incorporated's proposed design for the "All-in-One Hex Wrench" will allow someone to have access to a full metric or English set of Allen wrenches all in one piece. The set will properly adjust to the necessary size with little effort from the user for quick and easy use. With an all-in-one tool the time spent with trial and error of fitting different sizes to a hex bolt will no longer exist – the tool will do the work for the user.

Constraints and Assumptions

The assumptions and constraints for this product are as follows:

- Hand-held device
- Early models are limited to use for small projects (such as electronics, some home and office use, etc) where the hex bolts the product will be used on are not rusted and/or will required minimal forces to extract or tighten the bolts. Later models will be built and tested for more durability.
- Manual operation necessary
- More compact than competitor products
- The product will be used by consumers properly as instructed
- Durable product – on par with, or better than, competitors

Overall the constraints and assumptions of this product are that consumers will use the product as instructed and the product will maintain the advertised durability and strength. The product will be a functional Allen wrench that will compete with the standard set used so widely today. The adjustable set will be compact and portable that will help set it apart from the standard sets in existence.

Project Objectives

The objectives of this project include:

- Brainstorming multiple design possibilities for this product and then proceeding to the concept screening and scoring tables to assist in determining the best design for the product.
- To set and exceed the standards of durability set for the product.
- To sell the product for about the same, if not less than, competitor prices. The range would ideally be between $15 and $30.
- The product will weigh less than two pounds.
- To finalize the product design and submit the final plans on or before the December 7th deadline. Advertizing of the product could begin before the holidays.

- Product would begin production in January 2013.
- Work up to getting the company to being responsible for a minimum of 12% of the handheld tool market by the beginning of 2014.
- Expand on the adjustable wrench product and produce enhanced versions for more variety of uses further down the road.

Goals

Desired Outcomes

There are many desired outcomes/goals of this product development. One of the goals is to design the best product based off of various concept sketches of an adjustable Allen wrench. Another goal is to move on to designing the product concept in SolidWorks 3D CAD Software and then to create the dimensioned drawings of the components to demonstrate the standards and tolerances of the hand tool. An additional goal is to assemble the parts together in the CAD software and provide FEA analysis of the expected stresses on the tool for evaluation. Once that work is complete the next goal would be to setup for, and creation of, prototype of the wrench design for further review/testing. And overall to develop an adjustable wrench that meets customer needs of speed of use, ergonomic, and is also durable.

Due Dates

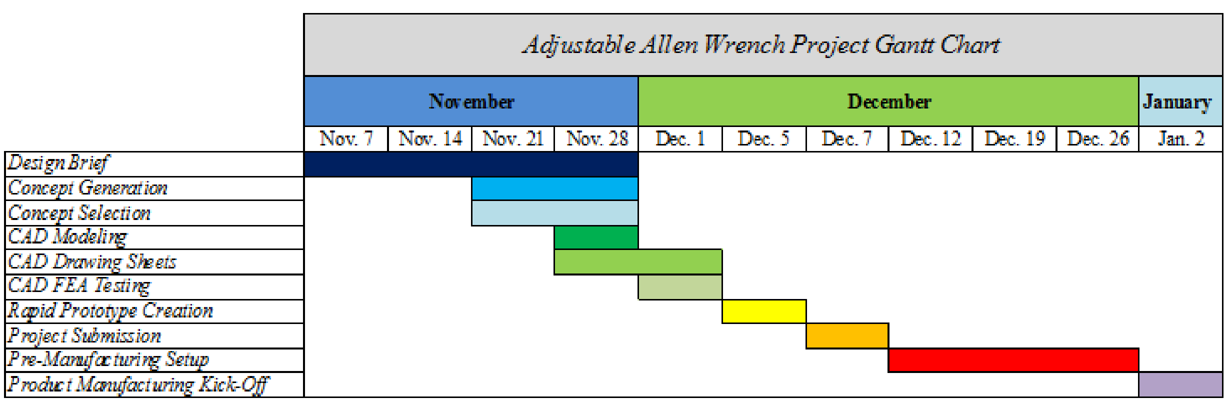


Figure 3: Project Timeline

Solution Analysis

This section covers the design variations that were discussed between team members. Some designs are more practical and durable than others, and these were two of the factors that went into deciding which design would be moved on to development.

Planned Solutions/ Brainstorming

Five preliminary designs were brainstormed in comparison to the reference product of the standard individual set of L-shaped Allen wrenches. Each of the brainstormed designs offer an adjustable feature to cut down on time needed for proper sizing and use. These designs are as follows:

- Design A: The most simple design concept. Pressure operated as the user applies pressure on the wrench handle and a stepped off pin pushes down on telescopic layered Allen wrenches to fit the properly sized wrench in the designated hex bolt head. This is a simple tool that will allow the proper fitting quickly.
- Design B: Based off the design of a multi-ink cartridge ink pen, this concept uses a sliding contact and the tension of a spring to slide the telescopic Allen wrench sizes into the hex bolt until the correct size and everything smaller fits within the bolt head. The notches on the slider lock the correct size into place. The extensions are released by pressing the button on the top of the shaft within the loop of the handle. This compresses the spring and tilts the slider slightly to release the notches from locked position.
- Design C: Similar to some existing designs for a screwdriver set, this concept stores the extra Allen wrench sizes within the handle and are locked into place until a rotating collar on the shaft is turned and the selected size Allen wrench falls from the handle down a tapered tunnel to the head of the tool and is then locked into place with the flick of a switch.
- Design D: This concept uses bits and pieces of the other designs as well as new concepts. The main shaft of the tool uses the telescopic extending Allen wrenches (similar to what is used with Designs A and B), but these are released through the lifting of a collar to release the different sized Allen wrenches and the necessary size will fit the bolt while the rest will recess back up into the tool when they do not extend as far as the rest. Releasing the collar will lock the wrenches into position. Larger wrench sizes are

stationary in the two arms of the handle for larger projects. This wrench set also has the makeup of a socket wrench feature as well. There is a switch on the handle to select the direction of rotation for the tool to assist in tightening or loosening to promote constant movement rather than having to completely twist the tool in full rotations.

- Design E: This design has two arms that swing out to create the handle as well as are storage for the extra wrench bits. These bits are held into the handles by small magnets and nested holders for the specific sizes. There is an opening on the base of the tool for the wrenches to be inserted for use. Since different sizes are going to be used the holder for the bits must be adjustable to hold each bit tightly. This adjustment is done through a rotating collar on the tool which will adjust the tightness around the tool. This adjustment is also what is used to release the bit.
- Reference: Standard Allen wrench set of the "L-shaped" wrenches that all slide into a plastic holder. (Refer to what is shown in *Figure 1*).

The brainstorming sketches of these designs follow.

Sketches

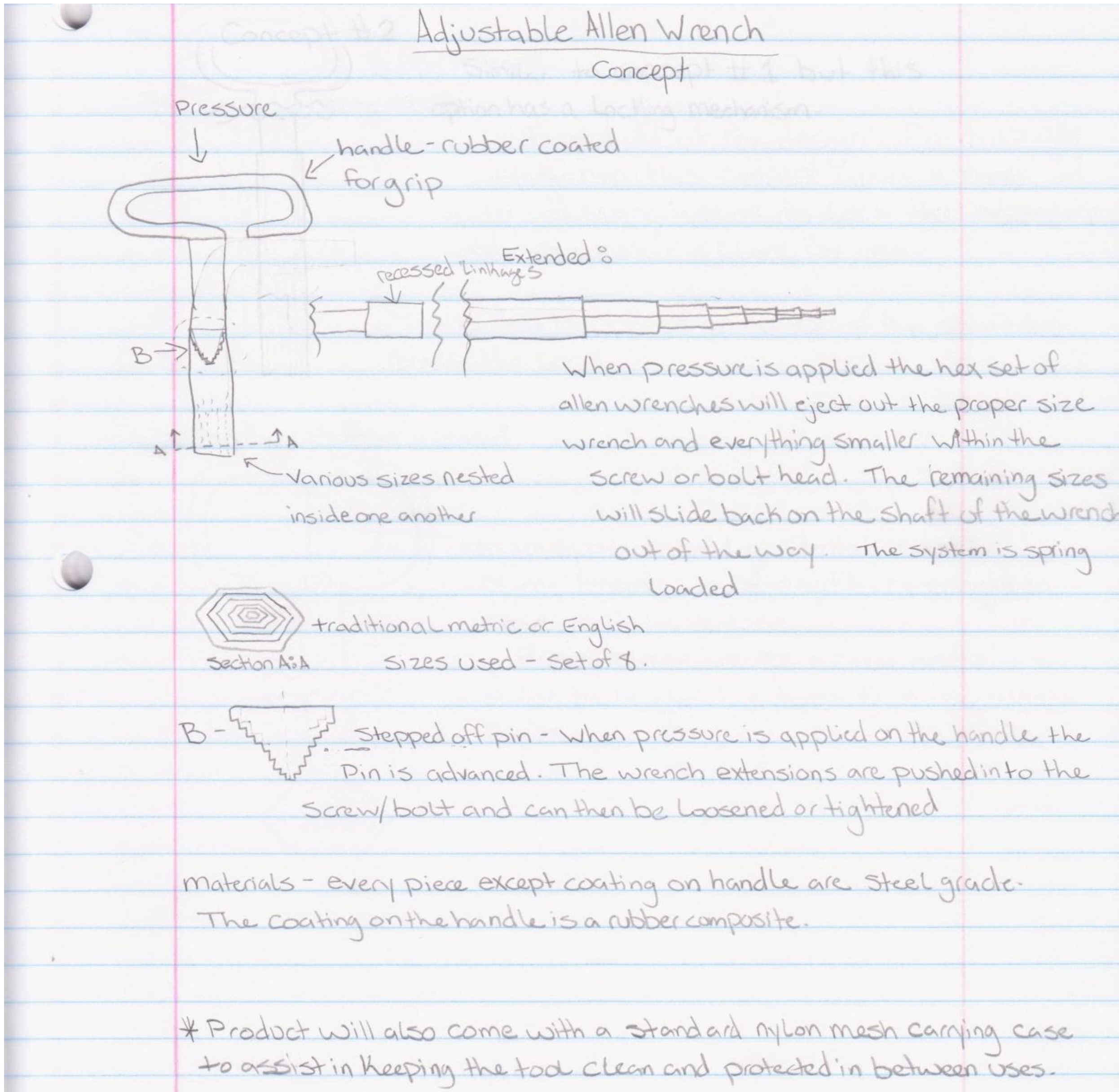


Figure 4: Design A

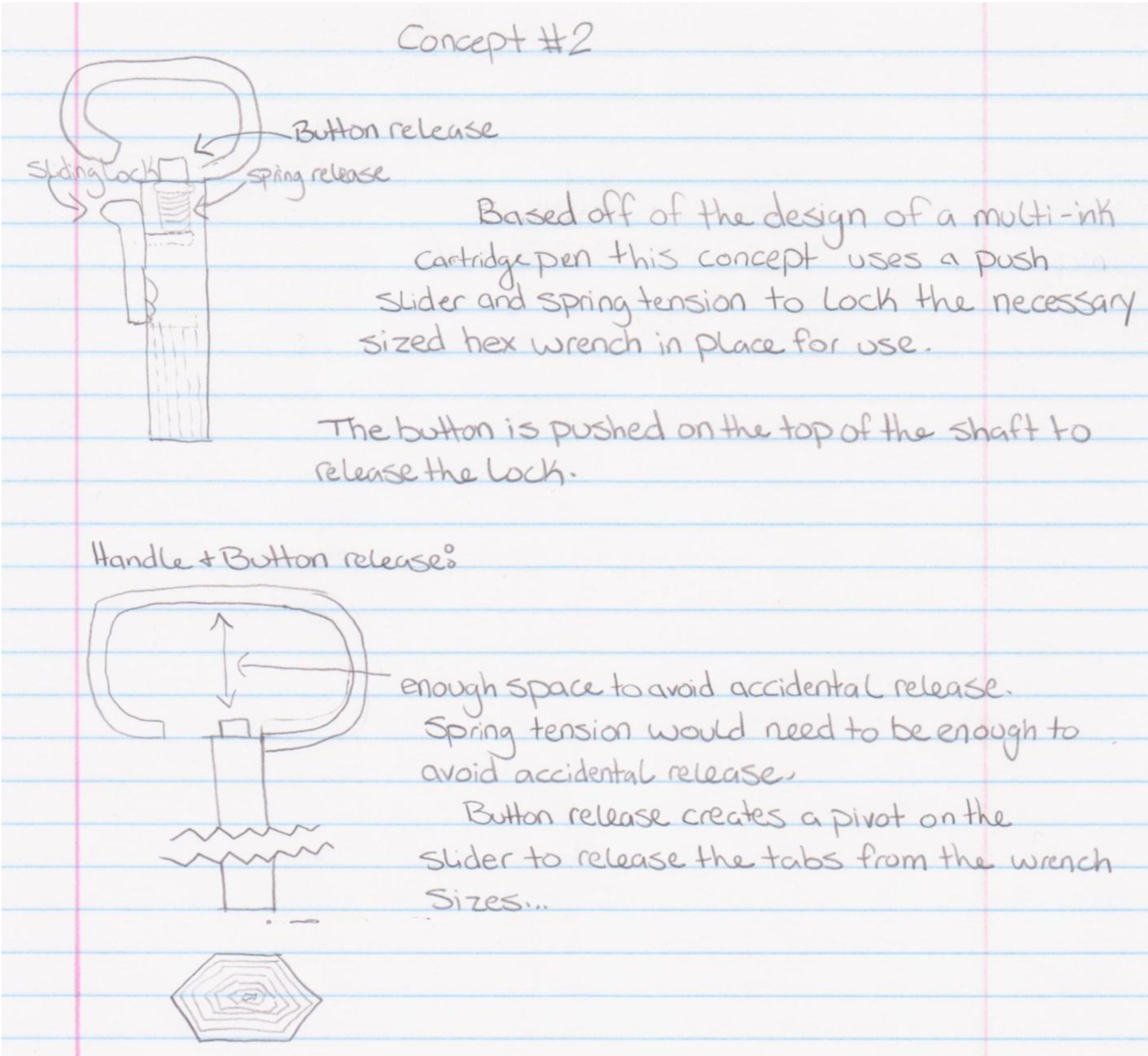


Figure 5: Design B

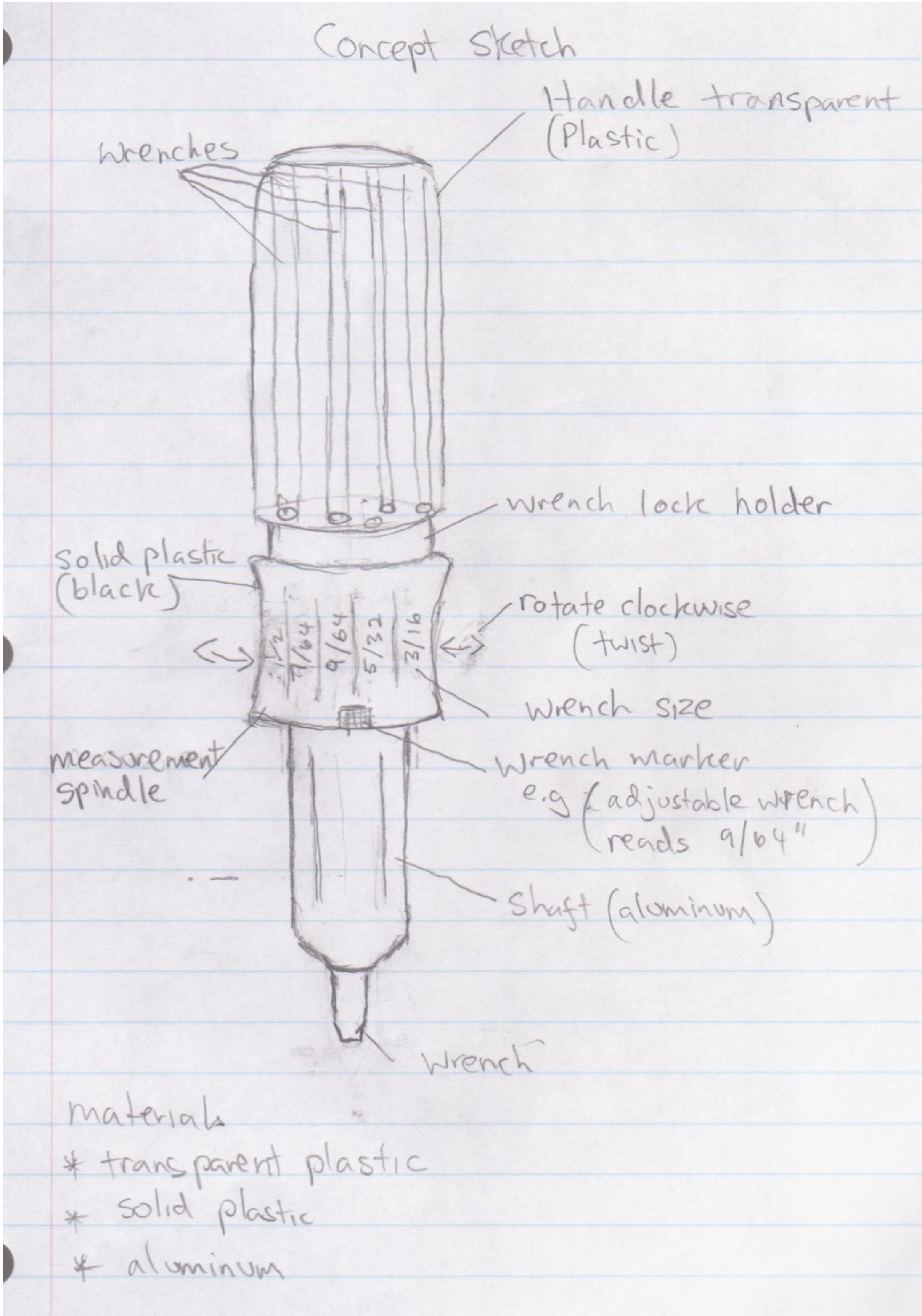


Figure 6: Design C

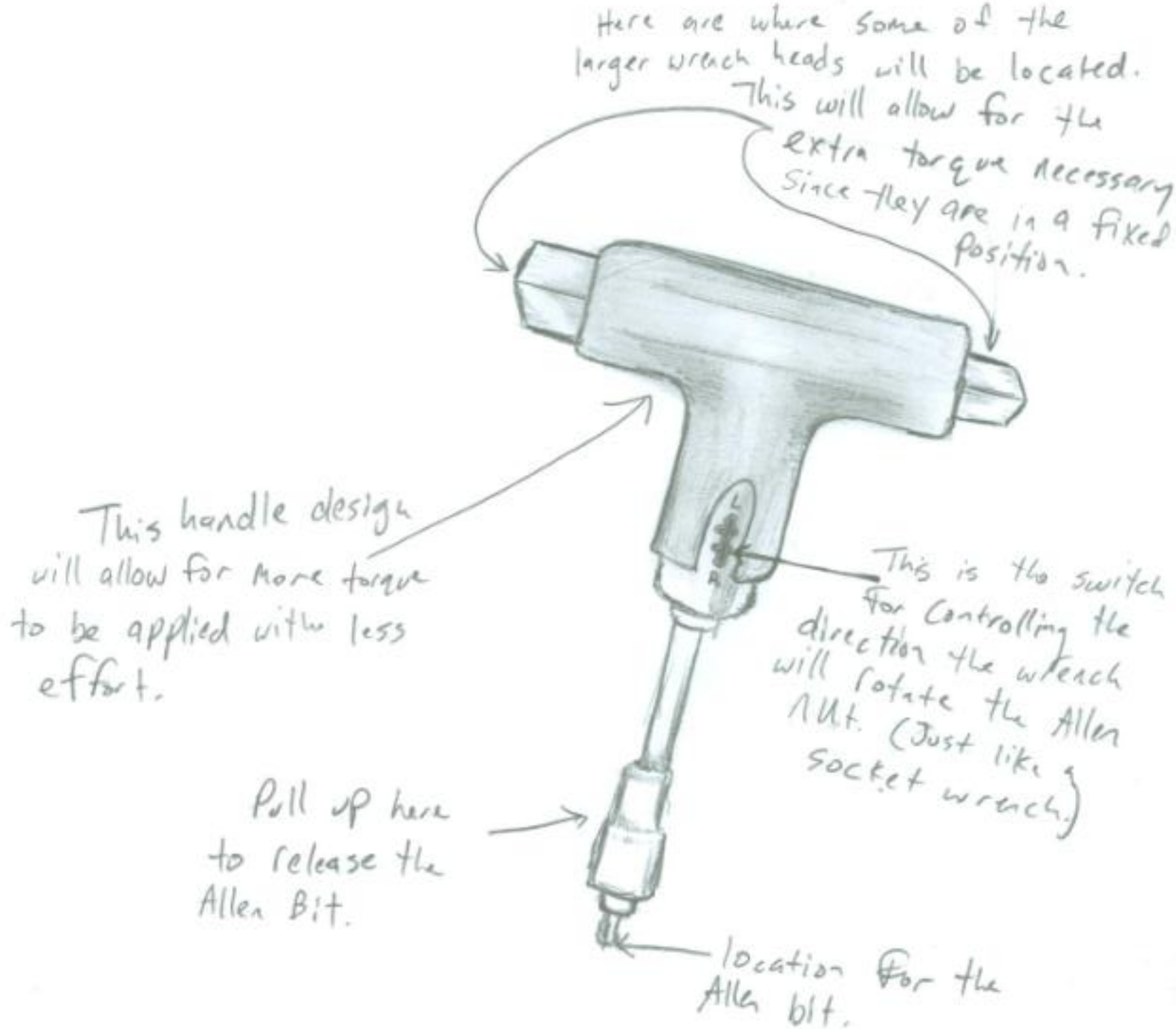


Figure 7: Design D

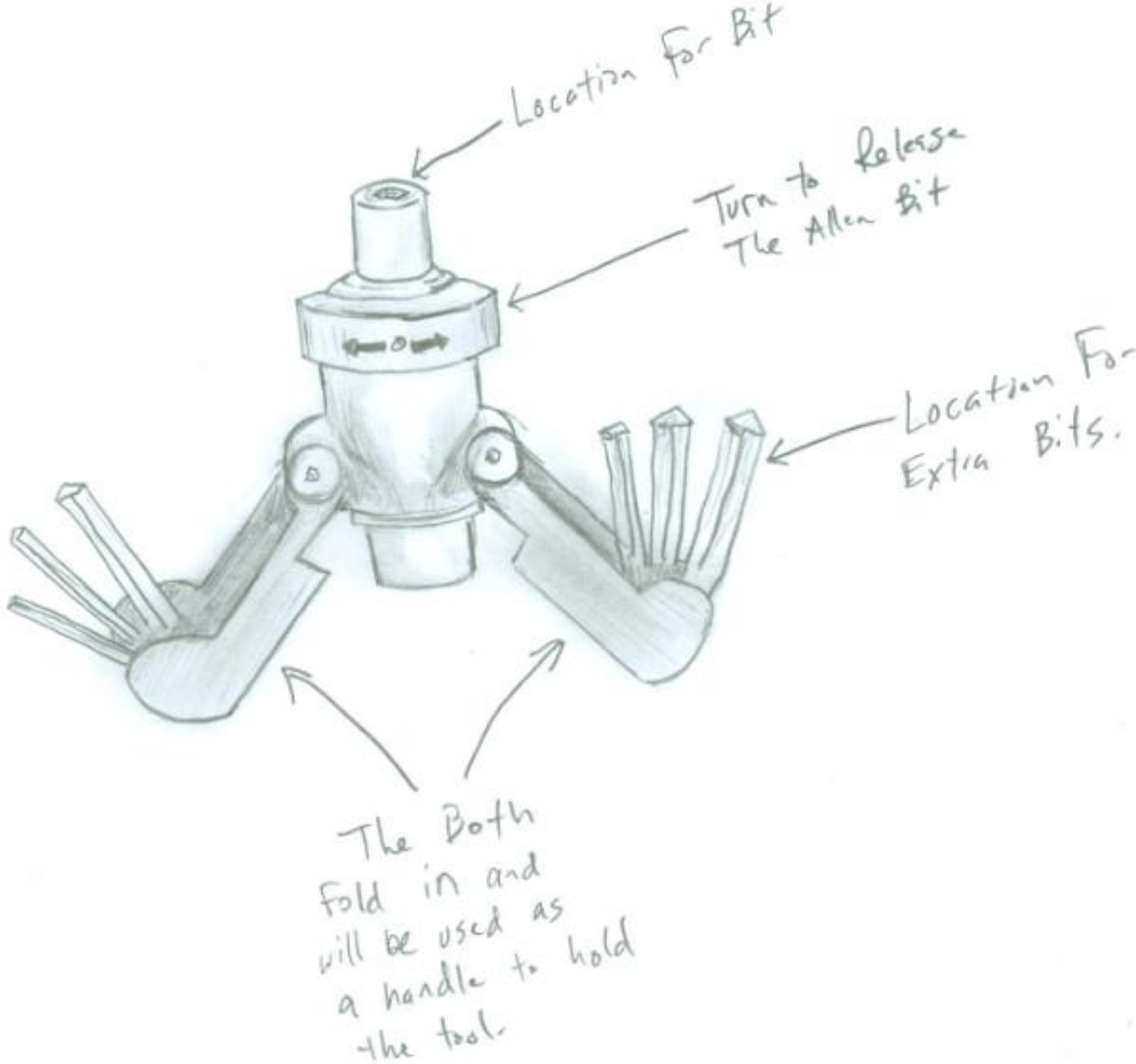


Figure 8: Design E

Concept Screening & Scoring Tables

Table 2: Concept Screening Table

	CONCEPT VARIANTS					
SELECTION	A	B	C	D	E	REF.
Ease of Use	+	0	-	+	-	0
Manufacturability	-	-	-	-	-	0
Speed of Use	+	+	+	+	0	0
Portability	+	+	-	-	+	0
Overall Weight	+	+	-	-	-	0
Durability	+	-	-	0	-	0
Ergonomic	+	+	+	+	+	0
Cost	-	0	-	-	0	0
PLUSES	6	4	2	3	2	
SAMES	0	2	0	1	2	
MINUSES	2	2	6	4	4	
NET	4	2	-4	-1	-2	
RANK	1	2	5	3	4	
CONTINUE?	Yes	Yes	No	Yes	No	

In the concept screening table above the screening factors were: ease of use of the device, manufacturability, the speed of use for the device (primarily the speed of bit changes), portability, overall weight of the product, durability, ergonomic features, and cost. The three concepts that proceeded on to the concept scoring table were designs A, B, and D.

Table 3: Concept Scoring Table

		Concepts							
		Reference		A		B		D	
Selction Criteria	Weight	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Ease of Use	15%	2	0.30	4	0.6	3	0.45	4	0.6
Manufacturability	10%	5	0.50	4	0.4	3	0.3	3	0.3
Speed of Use	15%	3	0.45	4	0.6	3	0.45	4	0.6
Portability	15%	2	0.30	4	0.6	4	0.6	4	0.6
Overall Weight	10%	3	0.30	4	0.4	5	0.5	4	0.4
Durability	10%	4	0.40	3	0.3	3	0.3	5	0.5
Ergonomic	10%	3	0.30	3	0.3	3	0.3	4	0.4
Cost	15%	4	0.60	4	0.6	4	0.6	3	0.45
	Total Score	3.15		3.80		3.50		3.85	
	Rank	4		2		3		1	
	Continue?	No		No		No		Yes	

The concept scoring table shows us that with the weights of each selection criteria applied, concept D came out on top, therefore this is the design that BFH Inc. proceeded to develop.

Concept Combination Table

Table 4: Concept Combination Table

Allen Wrench Size Selection (Fit)	Wrench Operation - Energy	Bit Size Reset
Force Fit	Manual Torque	Spring Load
Gravity Feed	Electric	Manual Pressure
Spring Load		Screw Mechanism

The concept combination table above shows us that the product will use more of a gravity feed system for the Allen wrench bit selection versus a force fit or a spring loaded mechanism. This is because the chuck on the design will be lifted and the bits will fall due to gravity and the bit that fits the bolt will go into the bolt and the rest will remain outside. The energy operation will be manual torque meaning the operator will have to provide the twisting motion versus an electric option. The bit size reset will require light manual pressure, meaning the chuck will again be lifted and the operator will either press lightly on a flat surface to reset the bits or elevate the tool upside down and allow gravity to do the work.

Project Tolerances

The tolerances for the "All-in-One Hex Wrench" are based off of some researched standard tolerances for basic Allen wrench sets. The table below shows some of the basic specifications met by an average hex key tool set. The following chart provides the hex bit and socket size, hex width across the flats of the maximum and minimum size, hex width across the corners of the maximum and minimum size, length of short arm of the maximum and minimum size, radius of bend as minimum and chamfer as a maximum with a tolerance of ±0.062 inch for the length.

Table 5: Hex Key Tolerances. Source: (Fastener Superstore, 2012).

HEX KEYS & BITS, LONG AND SHORT ARM													ASME B18.3-1998
Nominal Key or Bit and Socket Size		W		Y		B		C				R	K
		Hex Width Across the Flats		Hex Width Across the Corners		Length of Short Arm		Length of Long Arm				Radius of Bend	Chamfer
								Short Series		Long Series			
		Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Min	Max
-	0.028	0.0280	0.0275	0.0314	0.0300	0.312	0.125	1.312	1.125	2.688	2.500	0.062	0.003
-	0.035	0.0350	0.0345	0.0393	0.0378	0.438	0.250	1.312	1.125	2.766	2.578	0.062	0.004
-	0.050	0.0500	0.0490	0.0560	0.0540	0.625	0.438	1.750	1.562	2.938	2.750	0.062	0.006
1/16	0.062	0.0625	0.0615	0.0701	0.0680	0.656	0.469	1.844	1.656	3.094	2.906	0.062	0.008
5/64	0.078	0.0781	0.0771	0.0880	0.0859	0.703	0.516	1.969	1.781	3.281	3.094	0.078	0.008
3/32	0.094	0.0937	0.0927	0.1058	0.1035	0.750	0.562	2.094	1.906	3.469	3.281	0.094	0.009
7/64	0.109	0.1094	0.1079	0.1238	0.1210	0.797	0.609	2.219	2.031	3.656	3.469	0.109	0.014
1/8	0.125	0.1250	0.1235	0.1418	0.1390	0.844	0.656	2.344	2.156	3.844	3.656	0.125	0.015
9/64	0.141	0.1406	0.1391	0.1593	0.1566	0.891	0.703	2.469	2.281	4.031	3.844	0.141	0.016
5/32	0.156	0.1562	0.1547	0.1774	0.1745	0.938	0.750	2.594	2.406	4.219	4.031	0.156	0.016
3/16	0.188	0.1875	0.1860	0.2135	0.2105	1.031	0.844	2.844	2.656	4.594	4.406	0.188	0.022
7/32	0.219	0.2187	0.2172	0.2490	0.2460	1.125	0.938	3.094	2.906	4.969	4.781	0.219	0.024
1/4	0.250	0.2500	0.2485	0.2845	0.2815	1.219	1.031	3.344	3.156	5.344	5.156	0.250	0.030
5/16	0.312	0.3125	0.3110	0.3570	0.3531	1.344	1.156	3.844	3.656	6.094	5.906	0.312	0.032
3/8	0.375	0.3750	0.3735	0.4285	0.4238	1.469	1.281	4.344	4.156	6.844	6.656	0.375	0.044
7/16	0.438	0.4375	0.4355	0.5005	0.4944	1.594	1.406	4.844	4.656	7.594	7.406	0.438	0.047
1/2	0.500	0.5000	0.4975	0.5715	0.5650	1.719	1.531	5.344	5.156	8.344	8.156	0.500	0.050
9/16	0.562	0.5625	0.5600	0.6420	0.6356	1.844	1.656	5.844	5.656	9.094	8.906	0.562	0.053
5/8	0.625	0.6250	0.6225	0.7146	0.7080	1.969	1.781	6.344	6.156	9.844	9.656	0.625	0.055
3/4	0.750	0.7500	0.7470	0.8580	0.8512	2.219	2.031	7.344	7.156	11.344	11.156	0.750	0.070
7/8	0.875	0.8750	0.8720	1.0020	0.9931	2.469	2.281	8.344	8.156	12.844	12.656	0.875	0.076
1	1.000	1.0000	0.9970	1.1470	1.1350	2.719	2.531	9.344	9.156	14.344	14.156	1.000	0.081
Tolerance on Length of Key Bits						±0.062							

Based off the information this chart and Table 6 (located in the appendix), the adjustable "All-in-One Hex Wrench" will have higher tolerances to allow for a more affordable product for our hex bit sizes which range from 1/8" to 1". The tolerances will be ±0.063 inches.

Below is a table illustrating some of the metrics and units that will be essential to this product design.

Table 6: Metrics and Units

Metrics and Units

Metric #	Metric	Imp.	Units
1	Manufacturing cost	4	$
2	Material gives without breaking	5	N
3	Height of adjustment for hex bits	3	in.
4	Weight - how much it can withstand	3	Lbs.
5	Total weight of assembly	2	Lbs.
6	Max torque hex bits can withstand before failing	5	lbf-in
7	Amount of pressure assembly and components can withstand	4	psi
8	Time to change bit sizes	5	seconds
9	Tighten/loosen bit cycles to failure	2	Cycles
10	Amount of deformation of assembly during use (minimal preferred)	4	in.

For the forces tested on the components and assembly of the All-in-One Wrench some research was done to determine what range of forces would be good to test. In the end what was decided was in the middle to high end of the ranges found online, which turned out to be 10 psi of pressure and 10 lbf-in for torque. (Bondhus Corp., 2009)

Project Scope and Exclusions

PROJECT SCOPE STATEMENT

PROJECT OBJECTIVE

To design an adjustable Allen wrench using CAD software, FEA Analysis, Rapid Prototyping, project submission and pre-manufacturing of the product.

TECHNICAL REQUIREMENTS

1. Wrench must meet required tolerances of an average wrench tool set.
2. Wrench must be easy for portability.
3. Exterior must be shock resistant for Durability.

LIMITS AND EXCLUSIONS

1. Design should be able to work as a prototype.
2. Final product should be cost efficient.

3. Design should have access to following sizes of the basic Allen wrench (1/8” to 1” sizes).
4. Easy to use.
5. 1-year product warranty included.

Critical Success Factors

One of the major success factors for our product will be its ability to easily, and properly, fit various sizes of hex bolts as well as be able to withstand the torque and other forces needed to loosen/tighten bolts in use. If the adjustable Allen wrench cannot hold up to average wrench use then the product is a failure and will not be able to compete with competitor products. Another critical success factor would be if the product is bought by consumers once the product passes testing. If the tool isn’t bought then the company will fail. If early customers are satisfied with the product word-of-mouth will assist in spreading word about the product and in turn help the customer base grow. Once this version of the product hits the market the data of the sales can be evaluated and customer feedback will be evaluated to assist in determining what future models can be developed.

Interfaces

This product must interface easily with standard metric and English sizes of hex bolts to make the use of the product easy for the customer. The tolerance for the adjustable Allen wrench must fit within the standard tolerances of the bolts for proper use. Another factor in consideration is the fit within the user’s hand. The tool must not be too large or too small in the customer’s hand or use of the product will be more difficult.

CAD Documents

The following section is a collection of the drawing sheets, 3D part images, and FEA (finite element analysis) documentation for the assembly and components. Some narrative is provided where necessary.

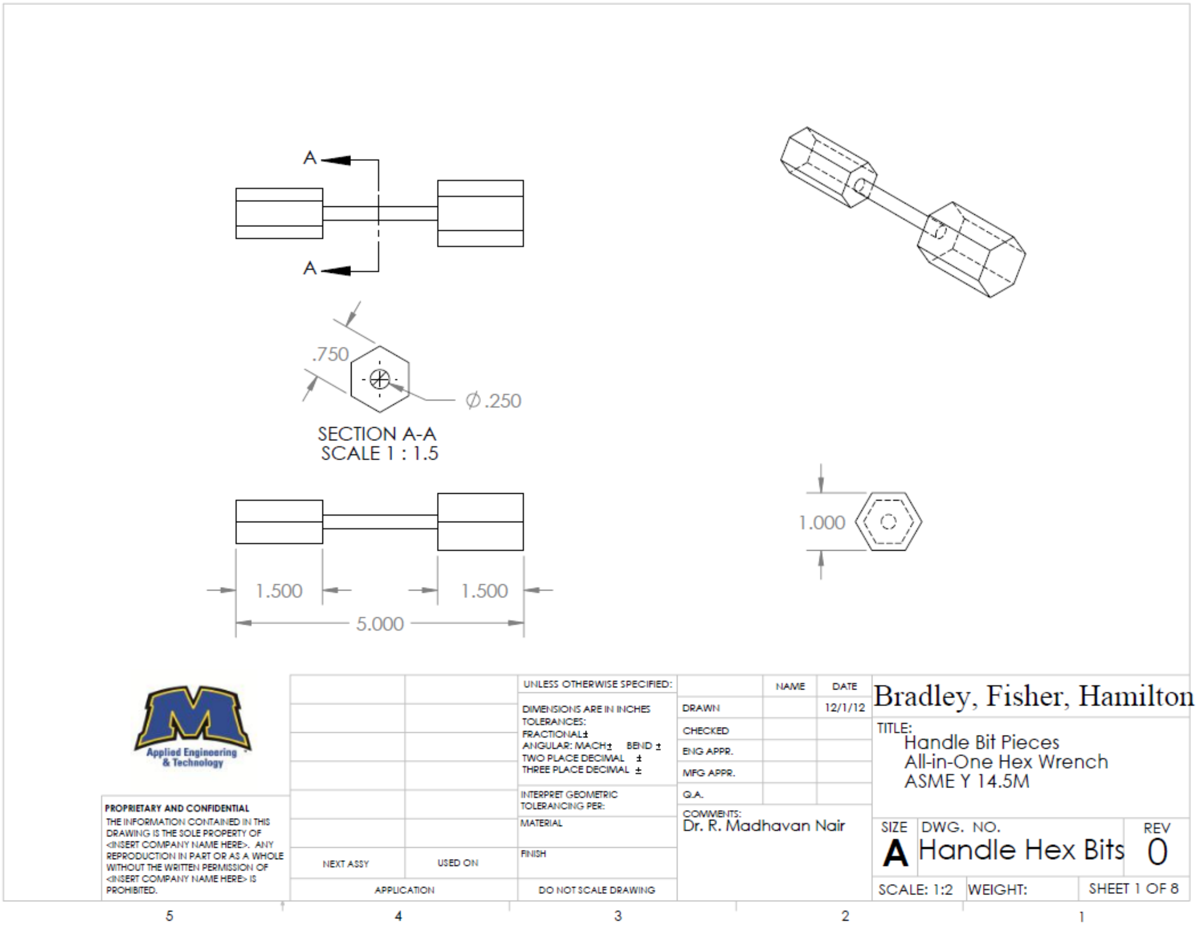


Figure 9: Handle Bit Piece Dimensioned Drawing

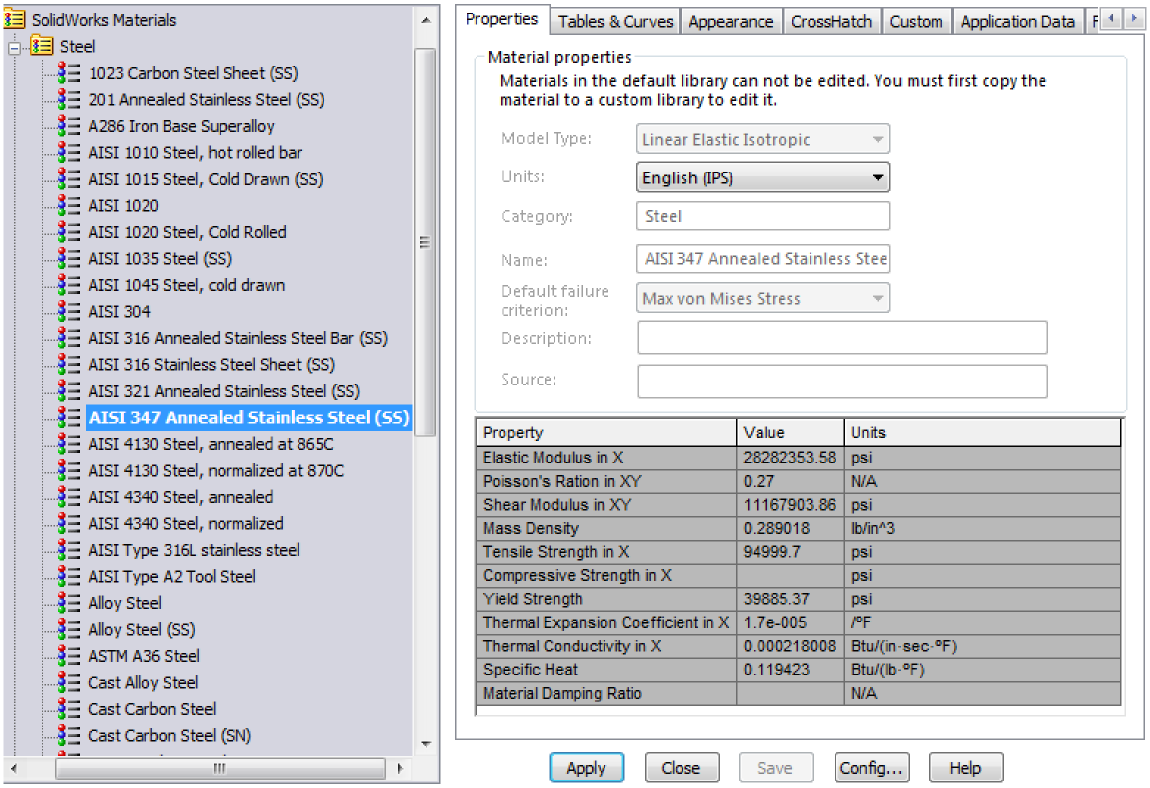


Figure 10: AISI 347 Annealed Stainless Steel (SS) Material Properties

The material AISI 347 Annealed Stainless Steel shown above was used for the all hex bits in the assembly. A stainless steel material was desired for the hex bits due to the stainless properties and it will not corrode as well as the high yield strength (higher than the 316 annealed stainless steel used on the wrench pin and chuck).

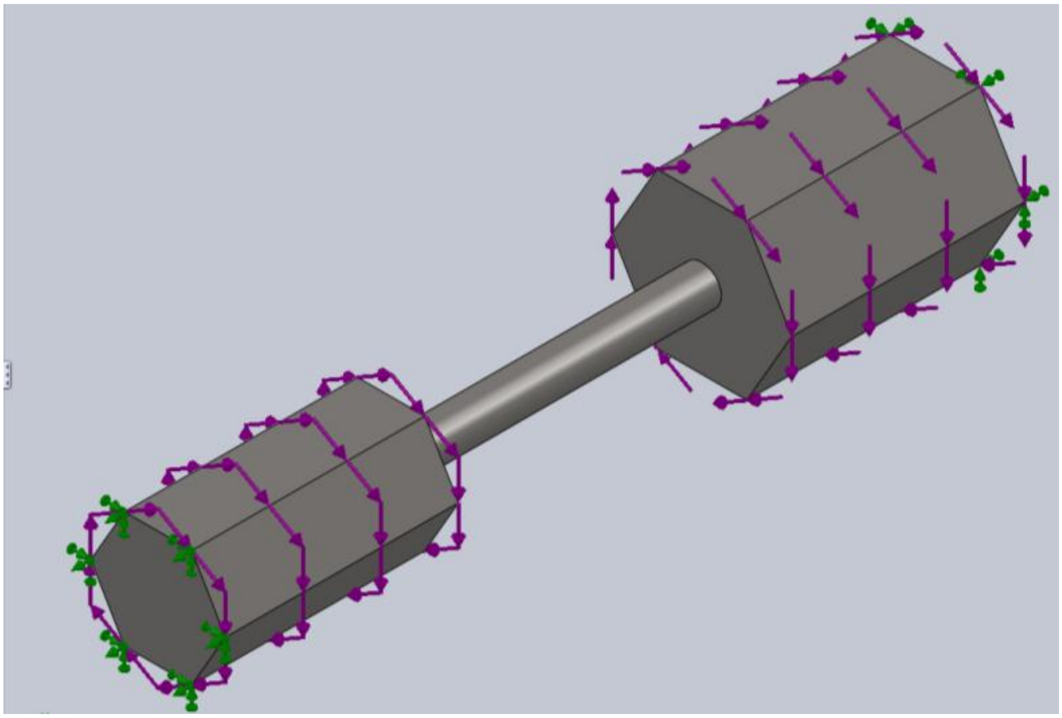


Figure 11: Handle Bit Piece Forces Pre FEA

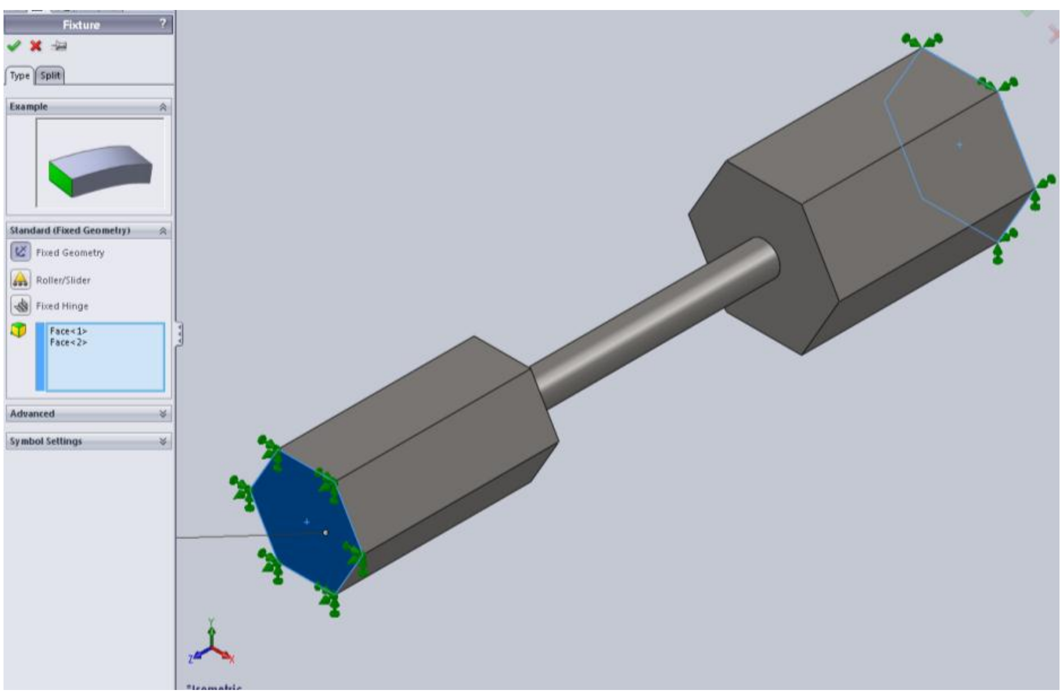


Figure 12: Handle Bit Piece Applied Fixtures

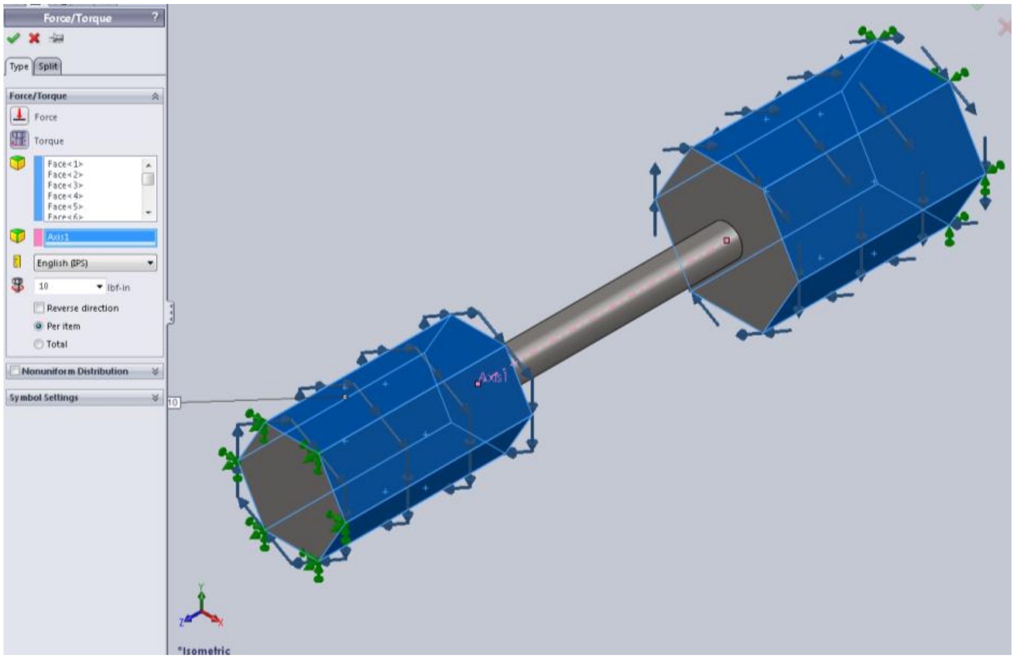


Figure 13: Handle Bit Piece Applied Torque

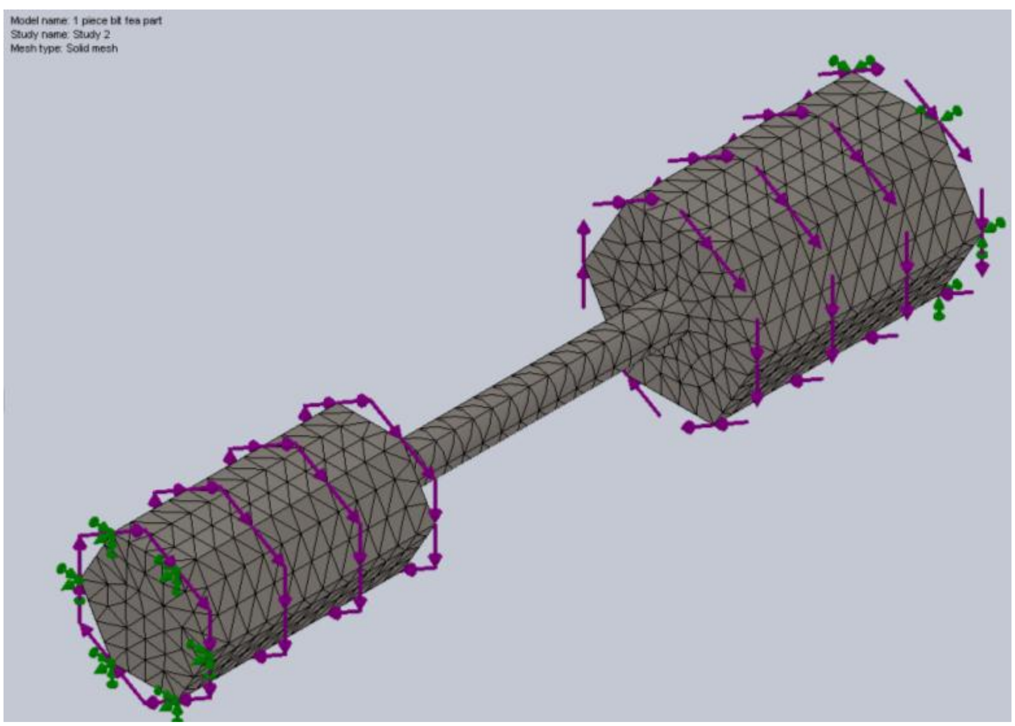


Figure 14: Handle Bit Piece Meshed

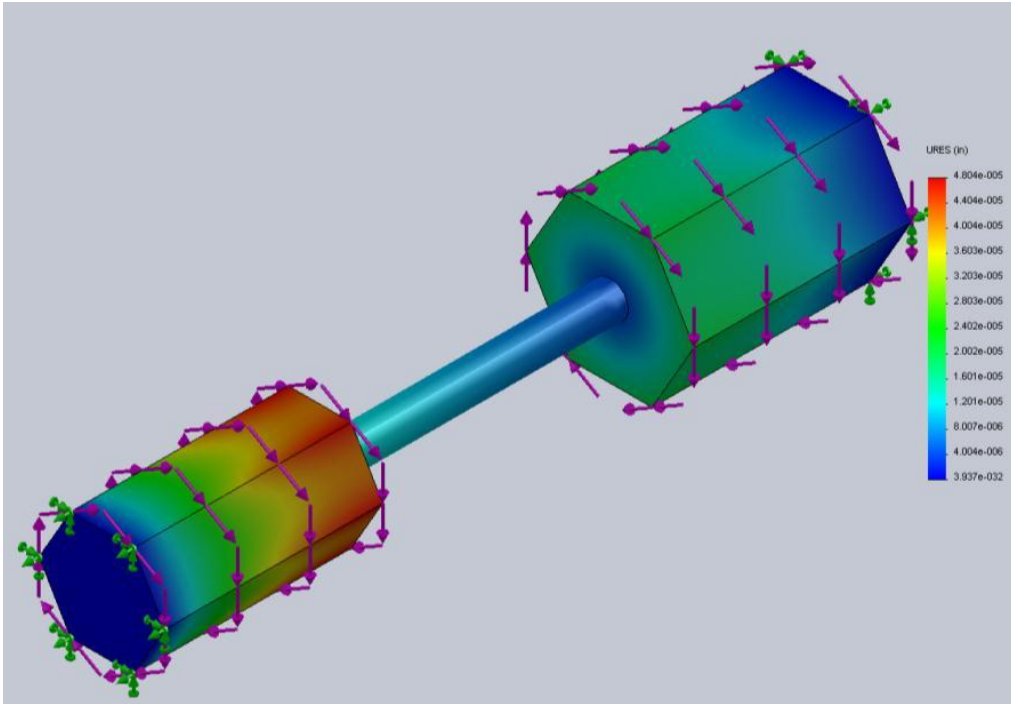


Figure 15: Handle Bit Piece - Resultant Displacement

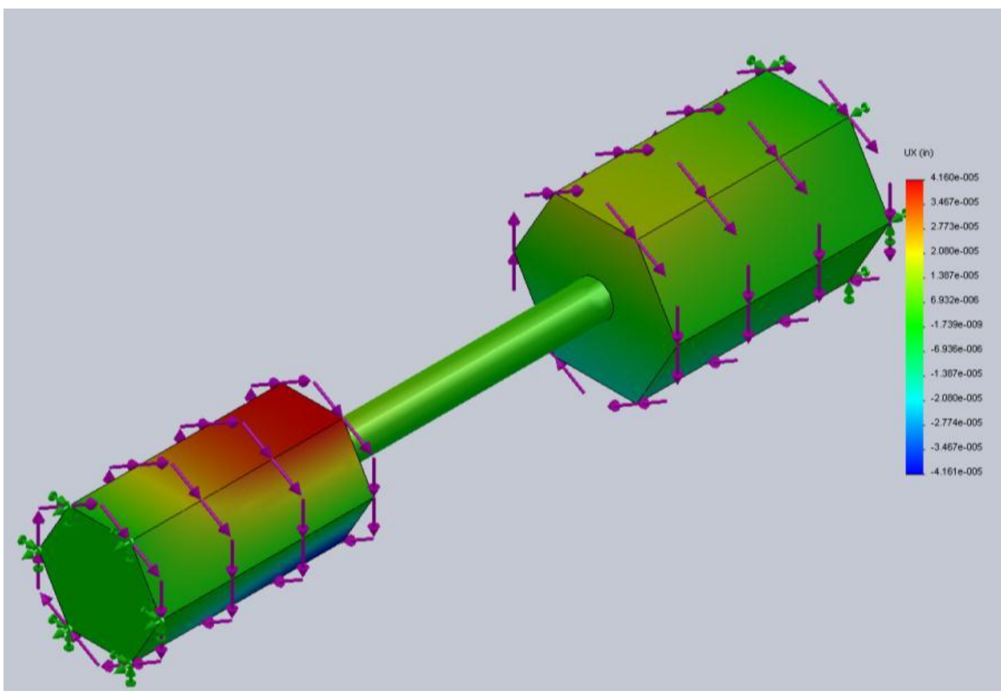


Figure 16: Handle Bit Piece - Displacement in the X-Direction

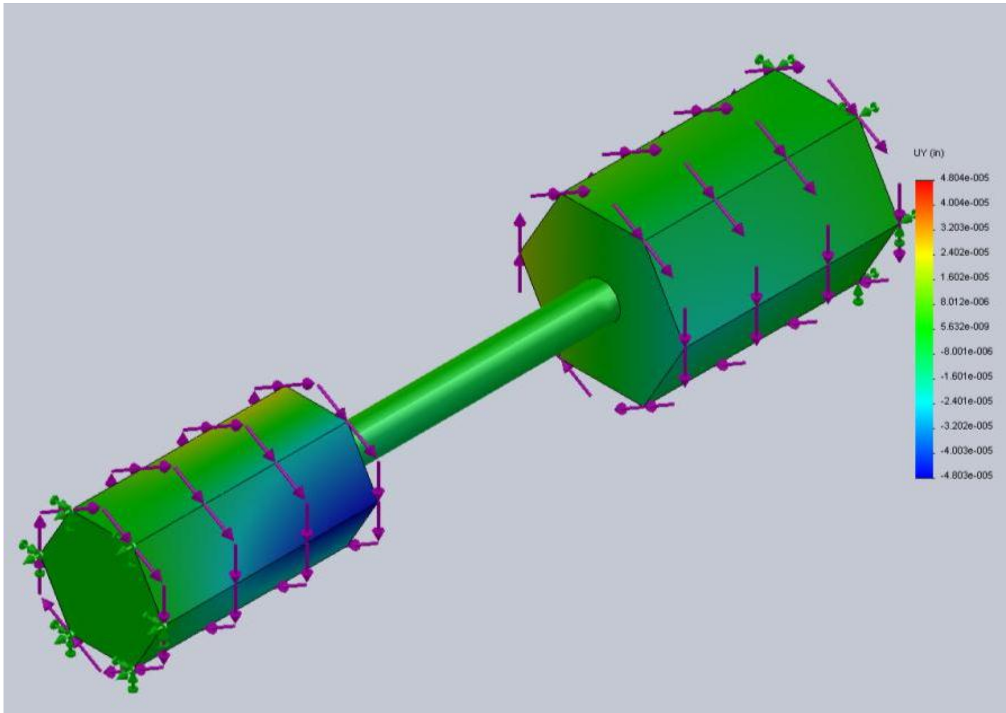


Figure 17: Handle Bit Piece - Displacement in the Y-Direction

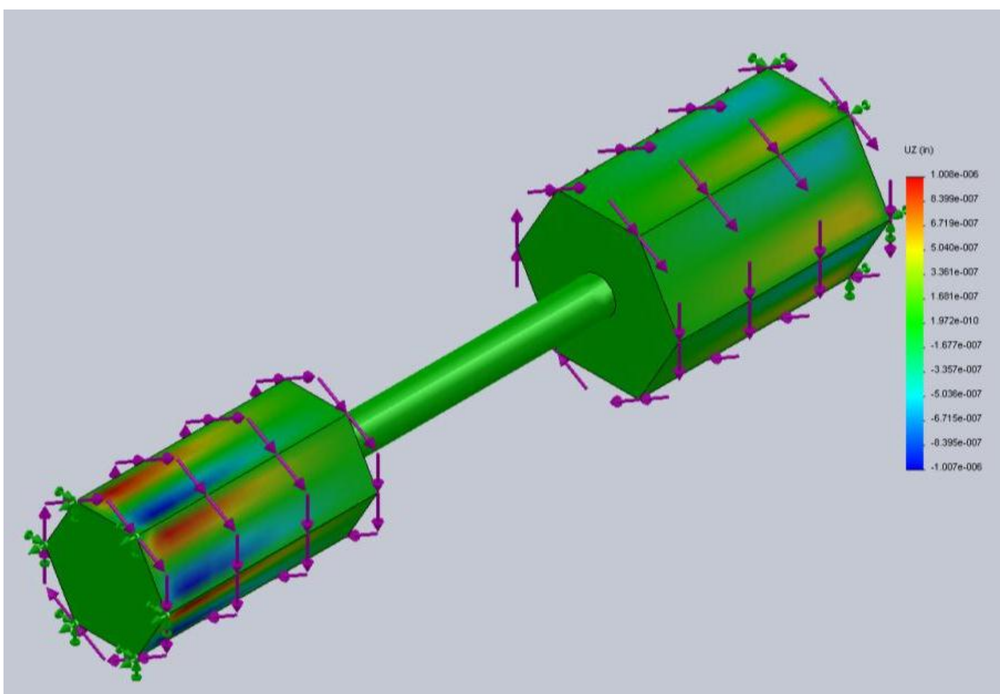


Figure 18: Handle Bit Piece - Displacement in the Z-Direction

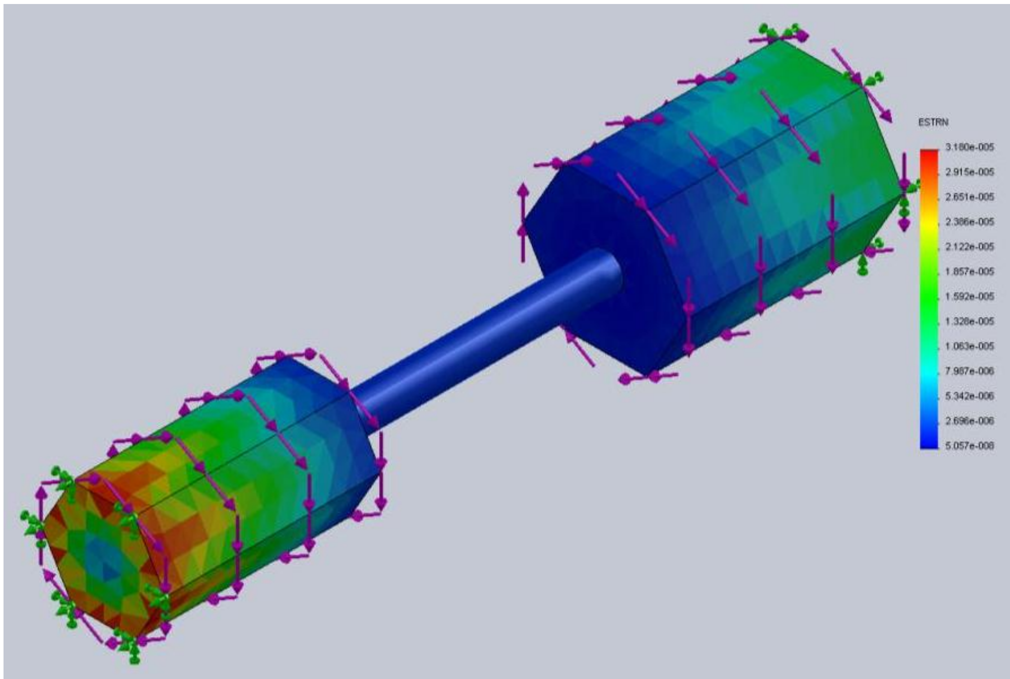


Figure 19: Handle Bit Piece - Resultant Strain

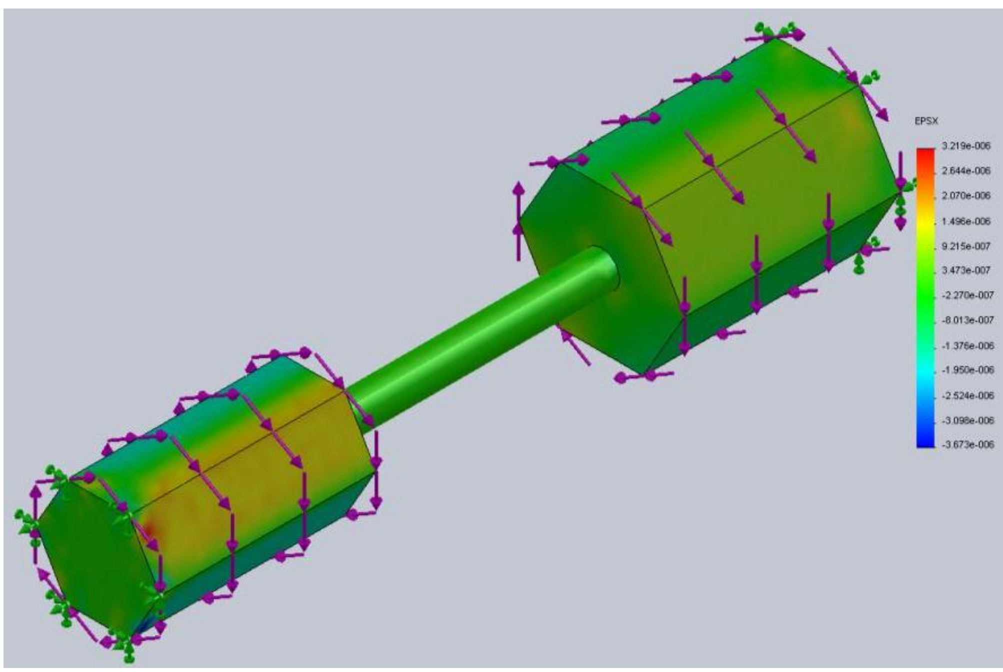


Figure 20: Handle Bit Piece - Strain in the X-Direction

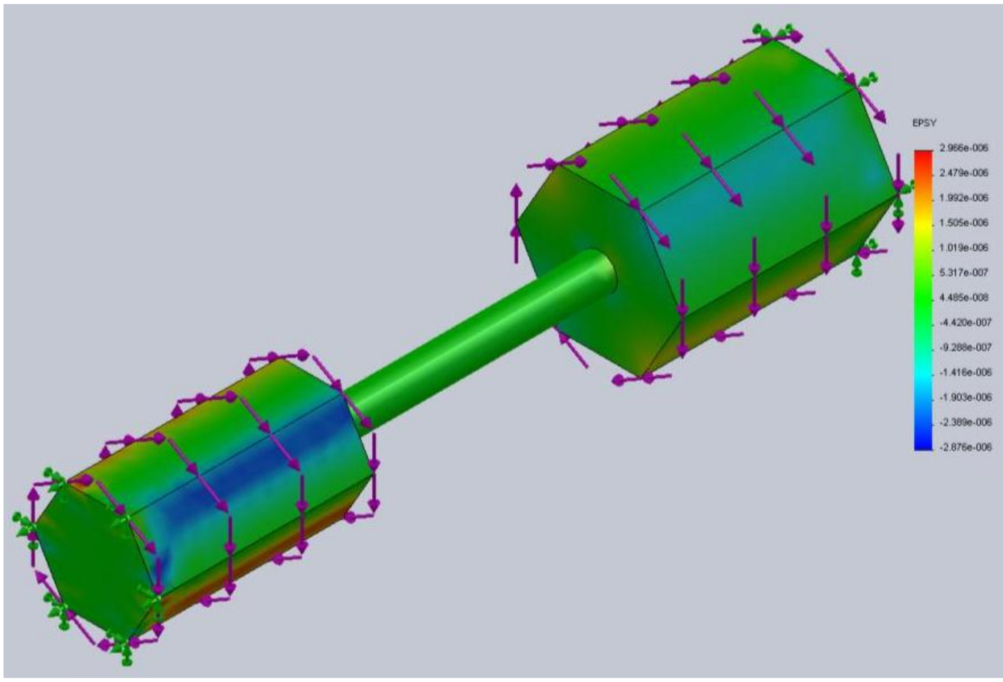


Figure 21: Handle Bit Piece - Strain in the Y-Direction

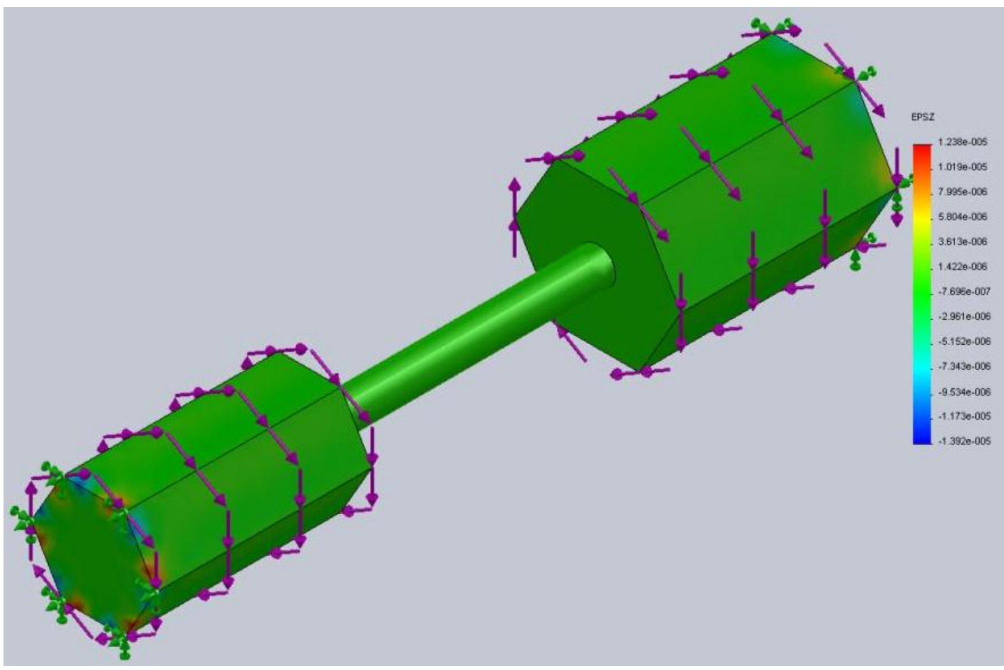


Figure 22: Handle Bit Piece - Strain in the Z-Direction

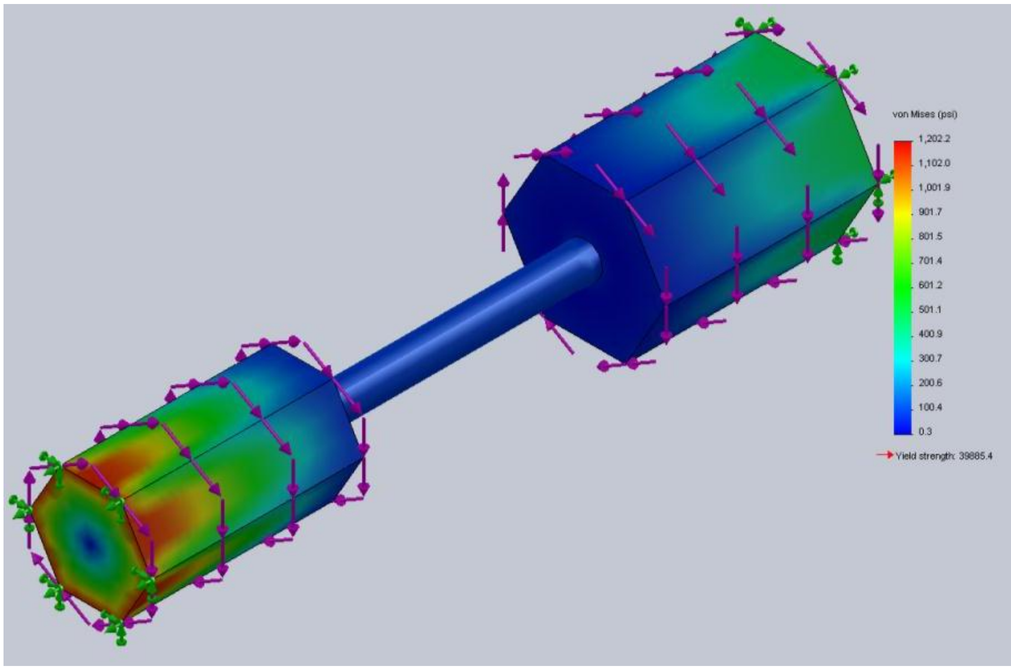


Figure 23: Handle Bit Piece - Resultant Stress

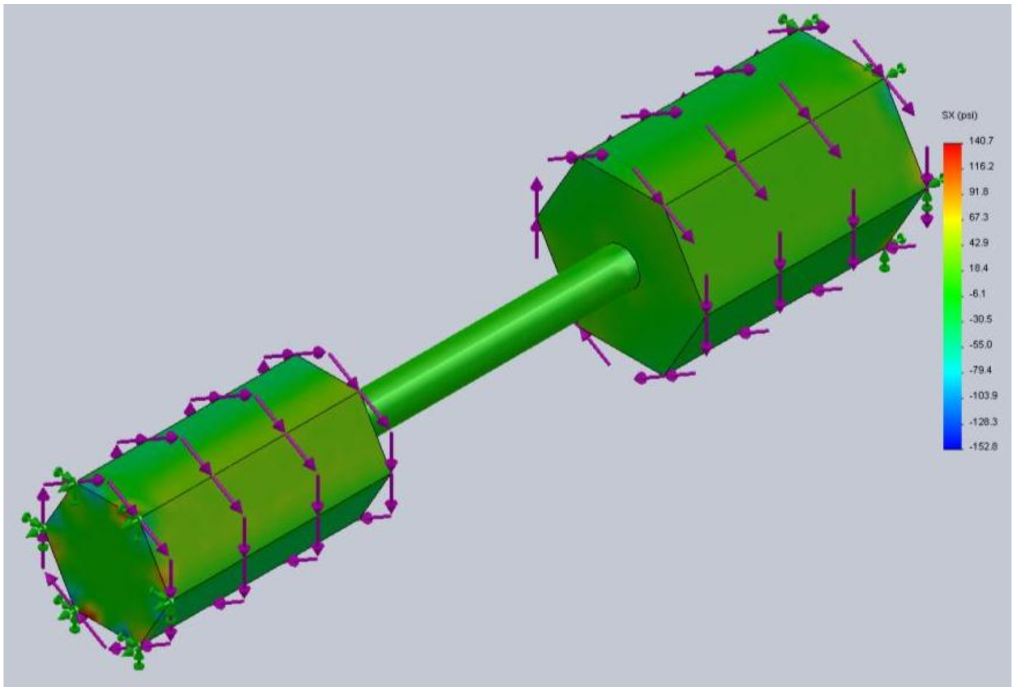


Figure 24: Handle Bit Piece - Stress in the X-Direction

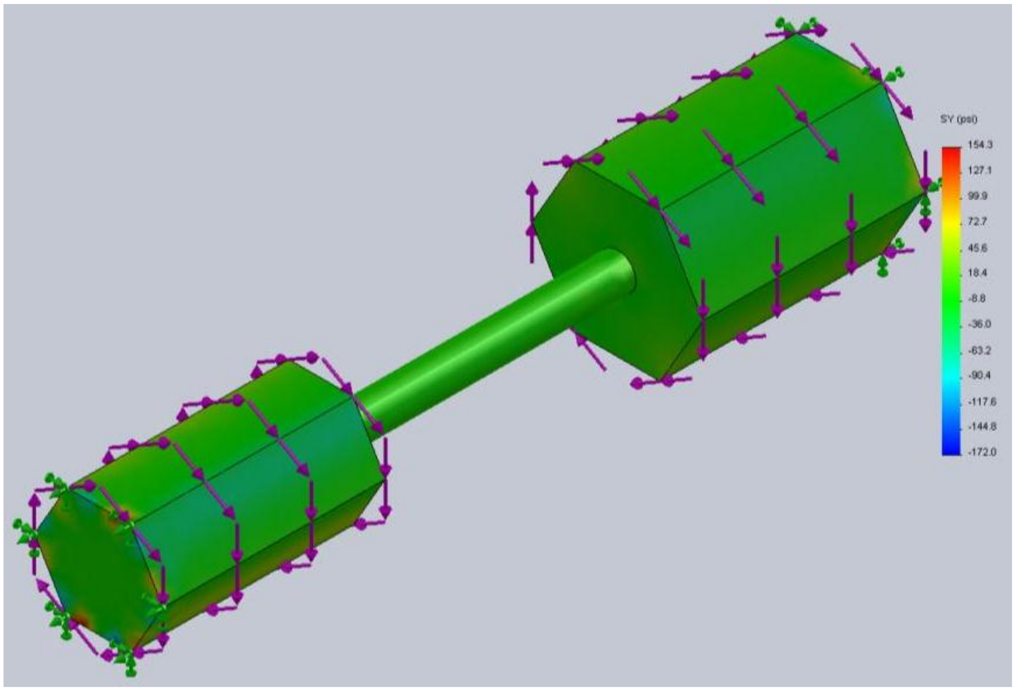


Figure 25: Handle Bit Piece - Stress in the Y-Direction

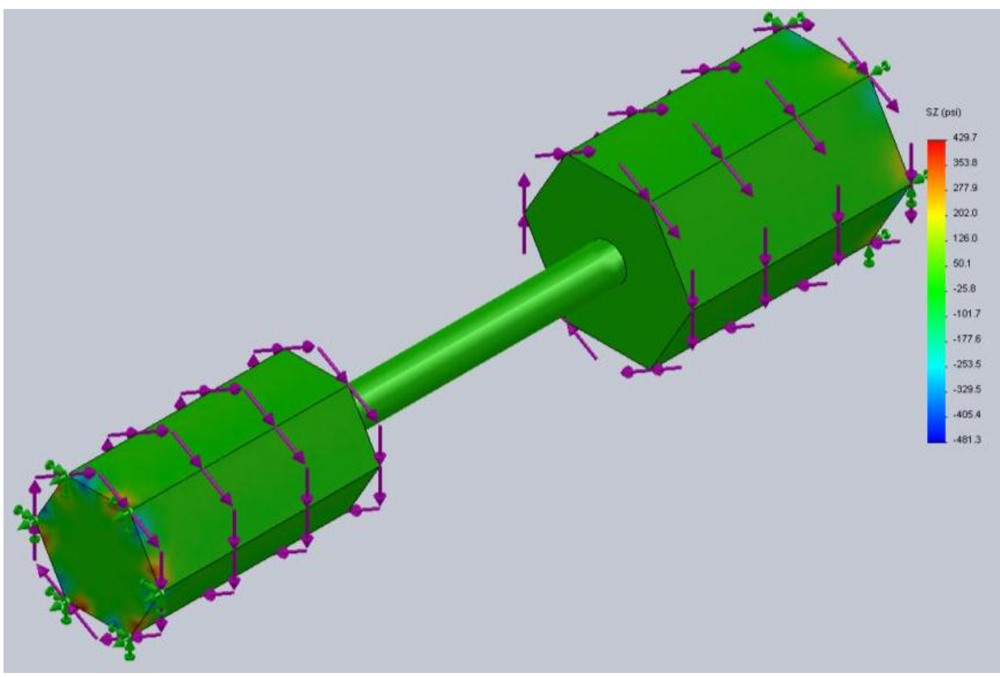


Figure 26: Handle Bit Piece - Stress in the Z-Direction

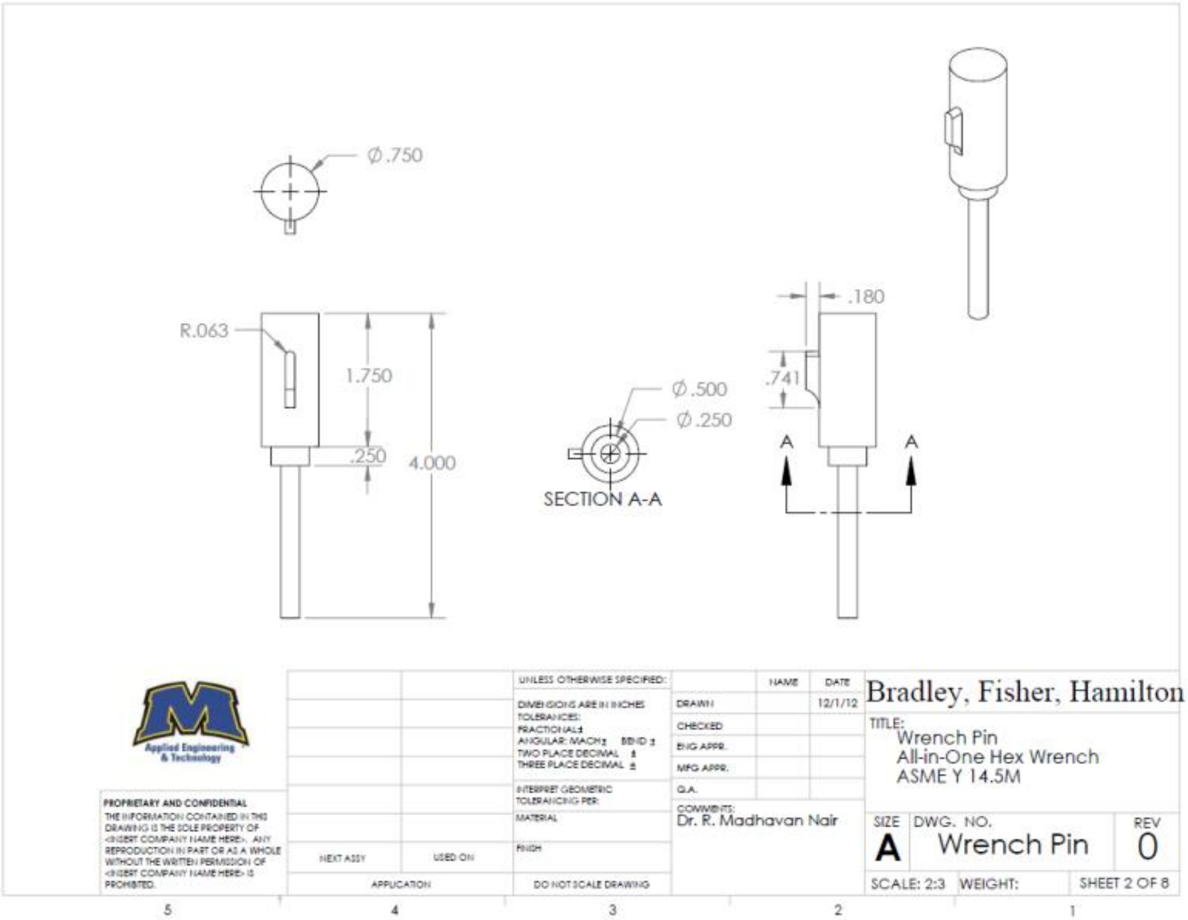


Figure 27: Wrench Pin Dimensioned Drawing

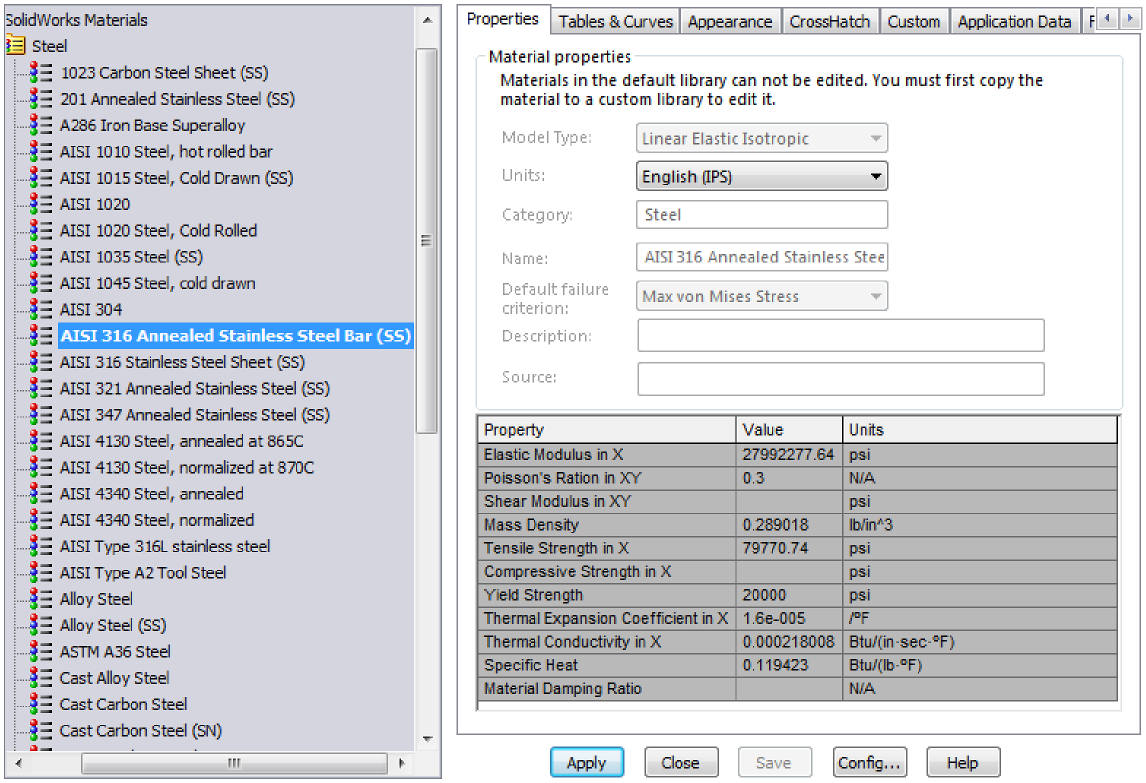


Figure 28: AISI 316 Annealed Stainless Steel Bar (SS) Material Properties

The material AISI 316 Annealed Stainless Steel Bar shown above is used on the wrench pin as well as the chuck component. This material was selected for both due to it being stainless and will not corrode. Also the high yield strength was desired.

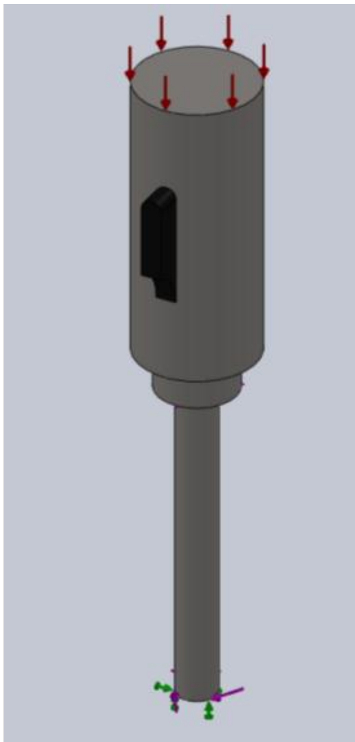


Figure 29: Wrench Pin Forces Pre FEA

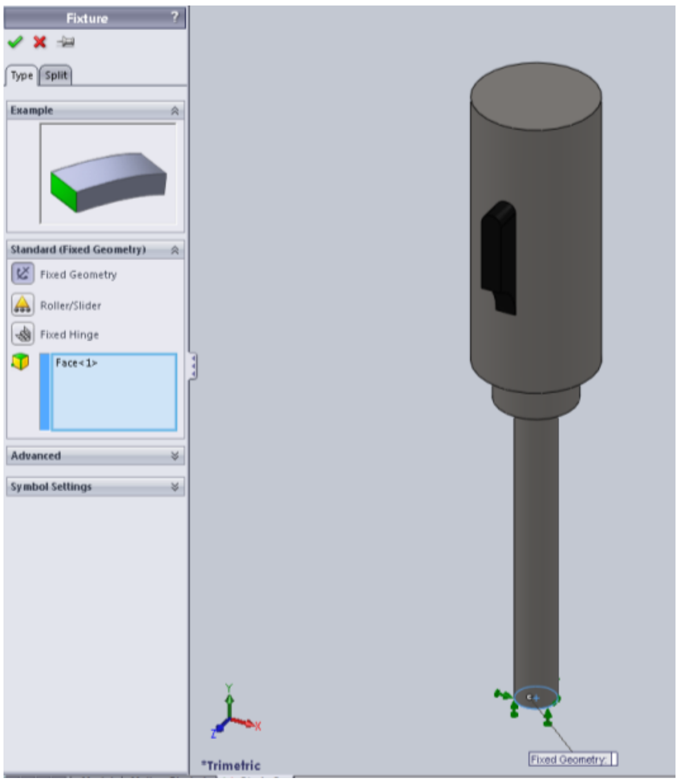


Figure 30: Wrench Pin Applied Fixtures

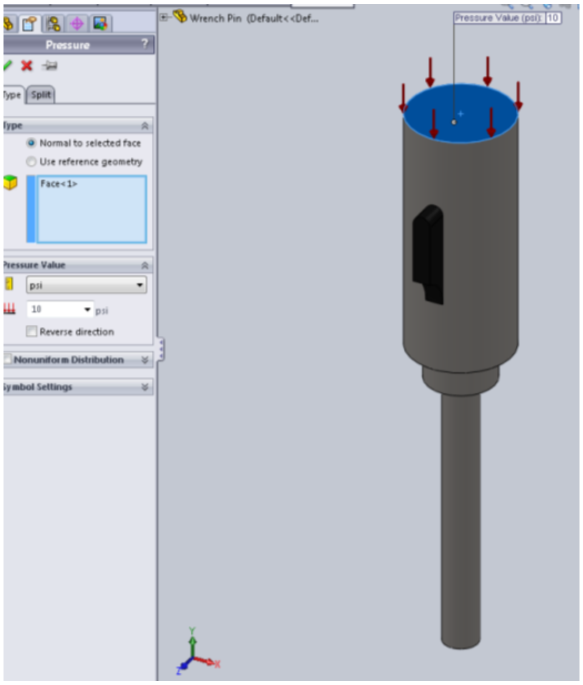


Figure 31: Wrench Pin Applied Pressure

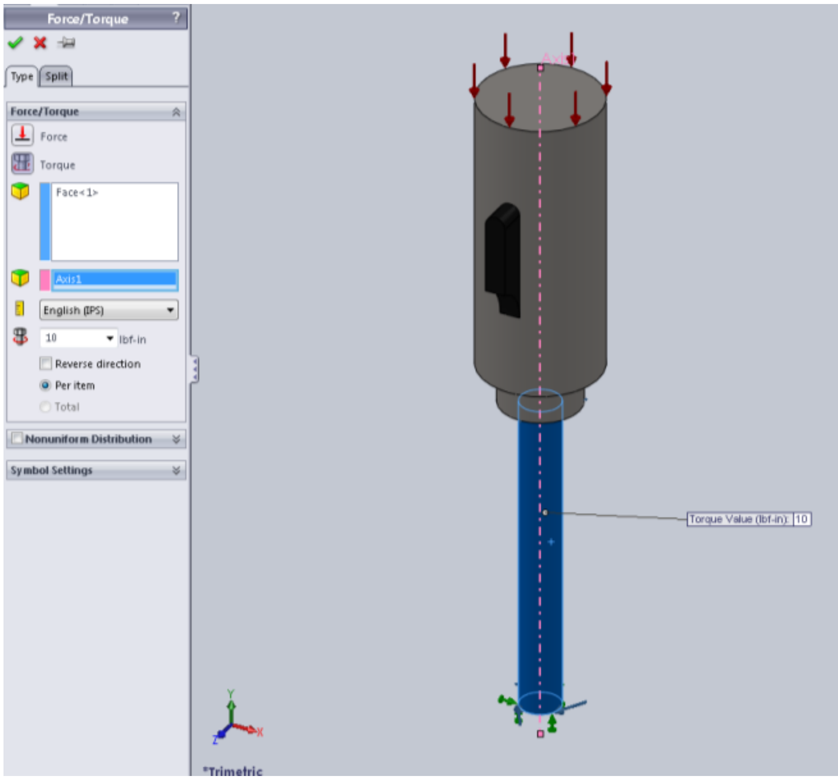


Figure 32: Wrench Pin Applied Torque

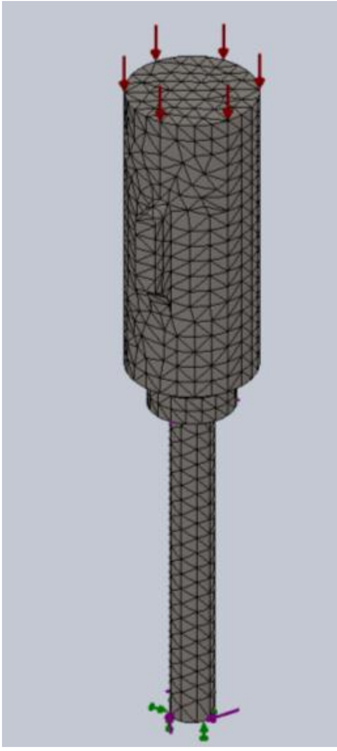


Figure 33: Wrench Pin Meshed

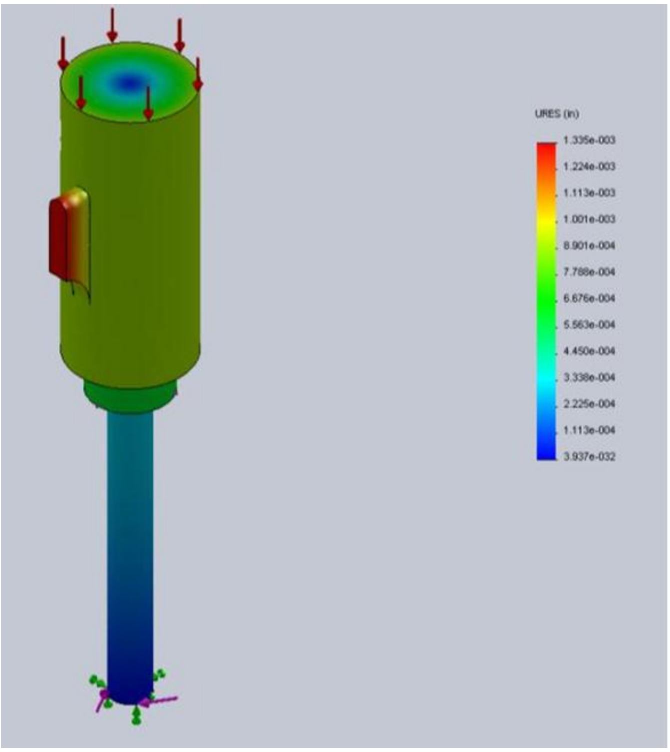


Figure 34: Wrench Pin - Resultant Displacement

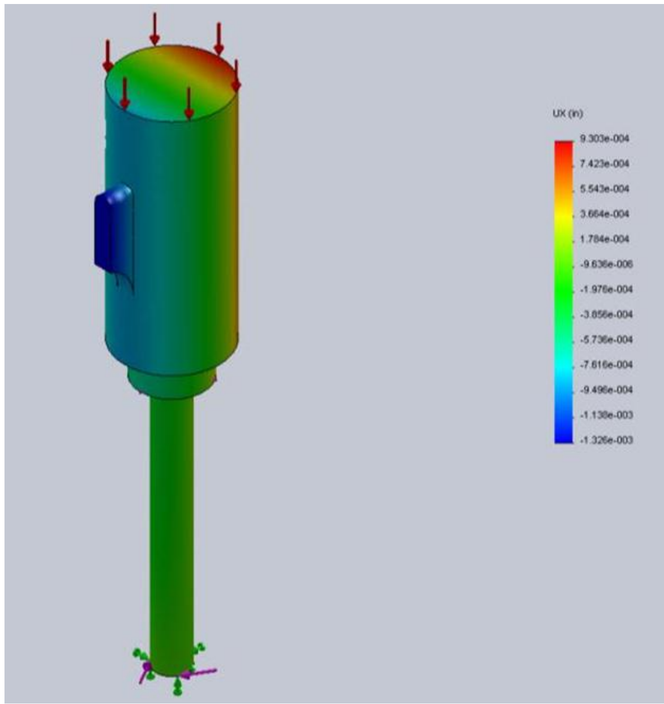


Figure 35: Wrench Pin - Displacement in the X-Direction

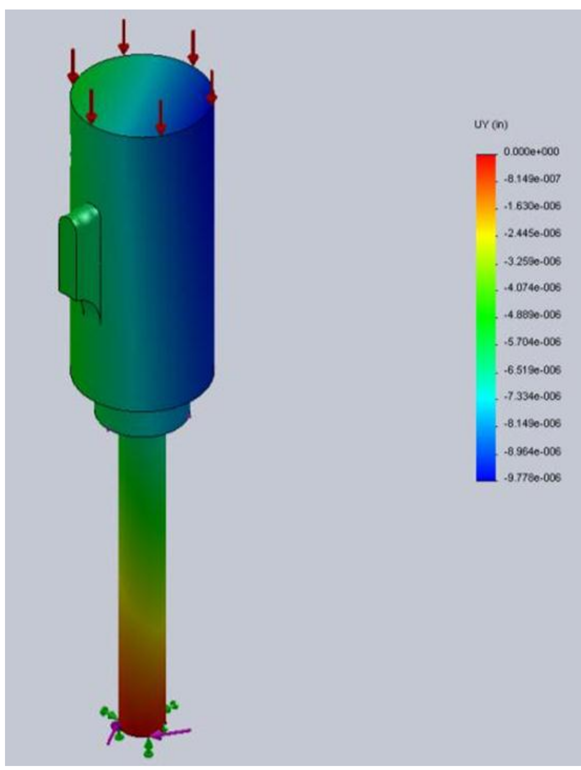


Figure 36: Wrench Pin - Displacement in the Y-Direction

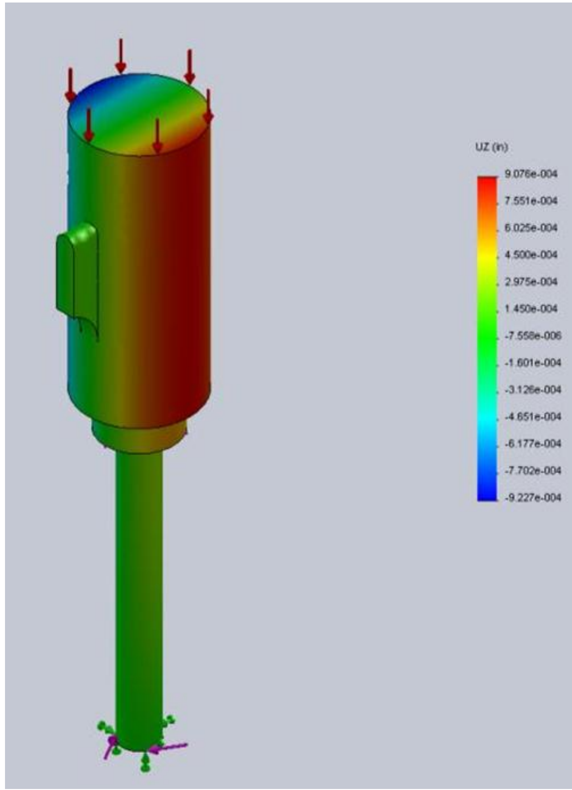


Figure 37: Wrench Pin - Displacement in the Z-Direction

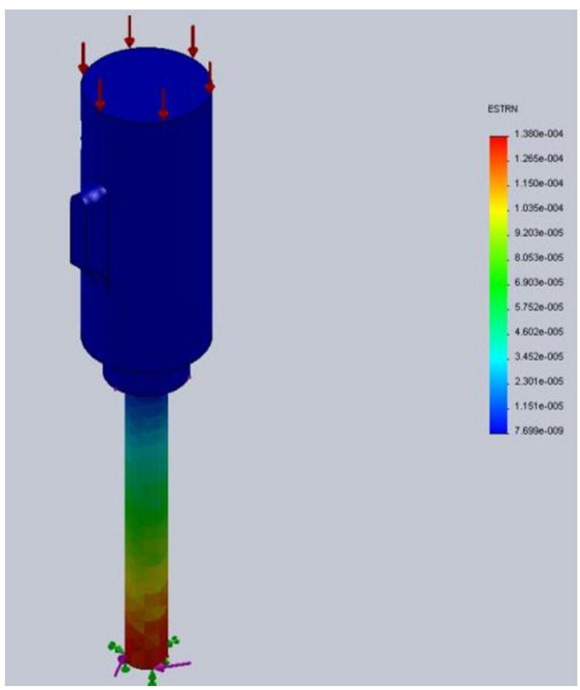


Figure 38: Wrench Pin - Resultant Strain

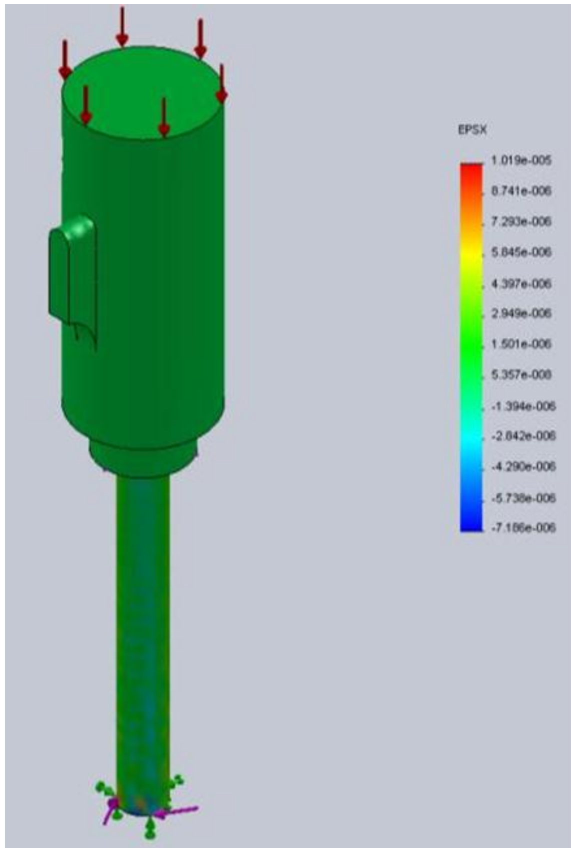


Figure 39: Wrench Pin - Strain in the X-Direction

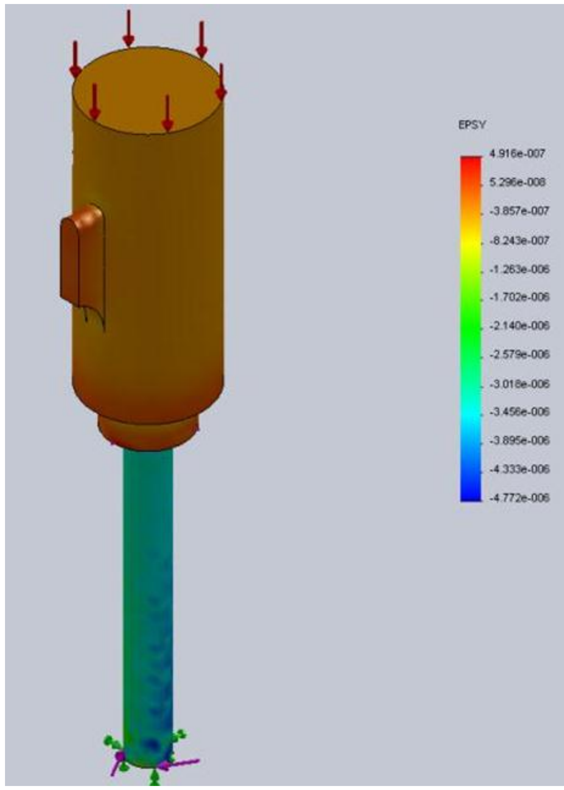


Figure 40: Wrench Pin - Strain in the Y-Direction

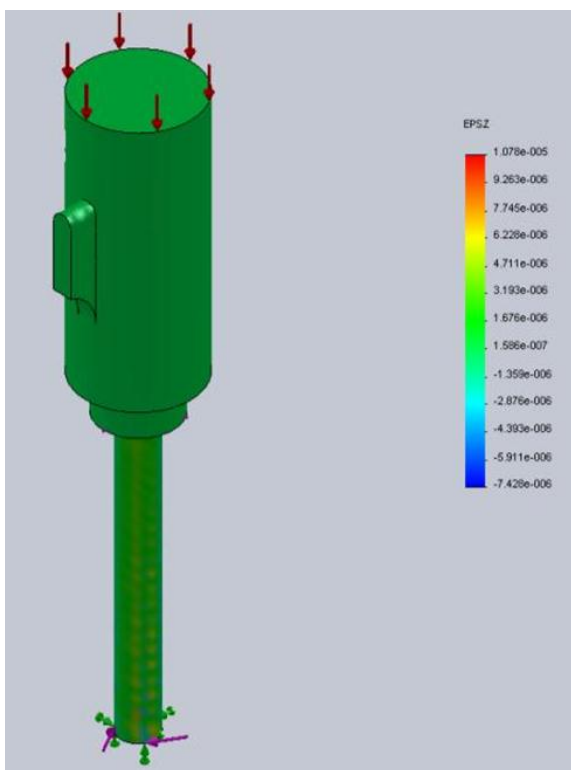


Figure 41: Wrench Pin - Strain in the Z-Direction

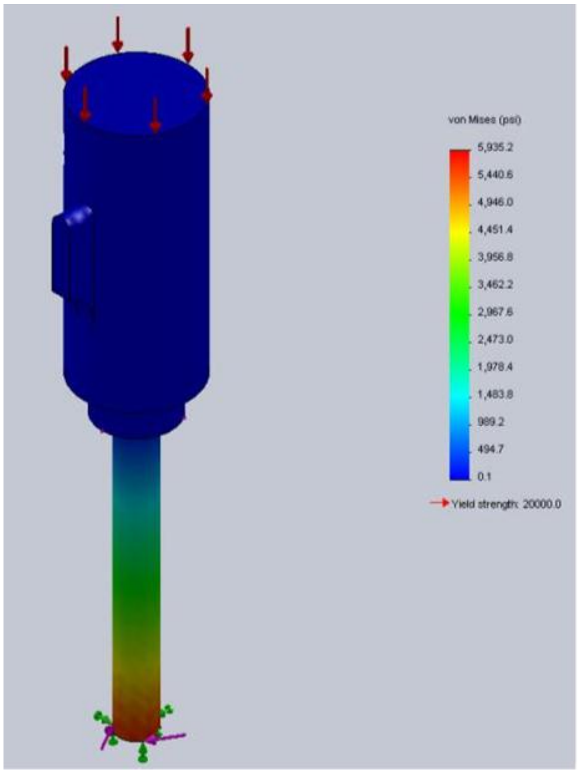


Figure 42: Wrench Pin - Resultant Stress

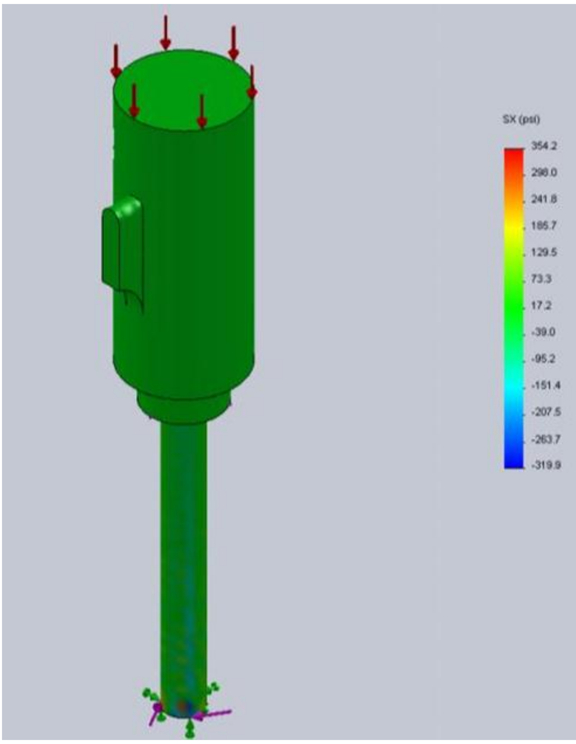


Figure 43: Wrench Pin - Stress in the X-Direction

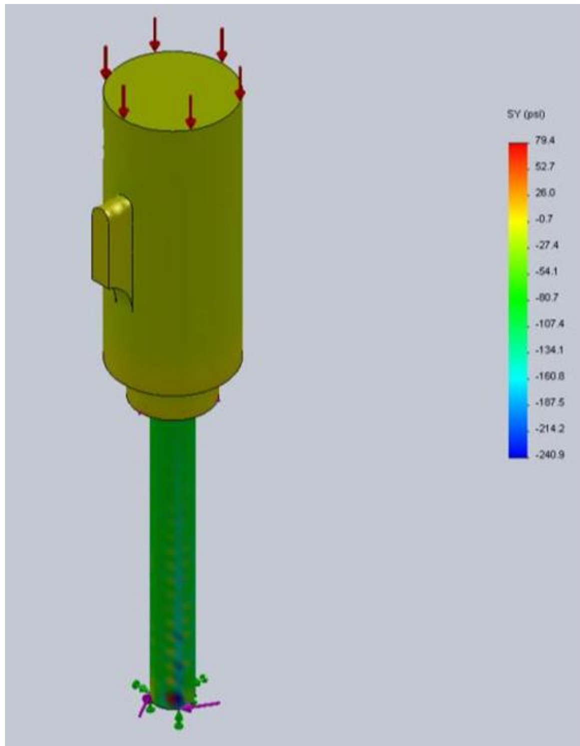


Figure 44: Wrench Pin - Stress in the Y-Direction

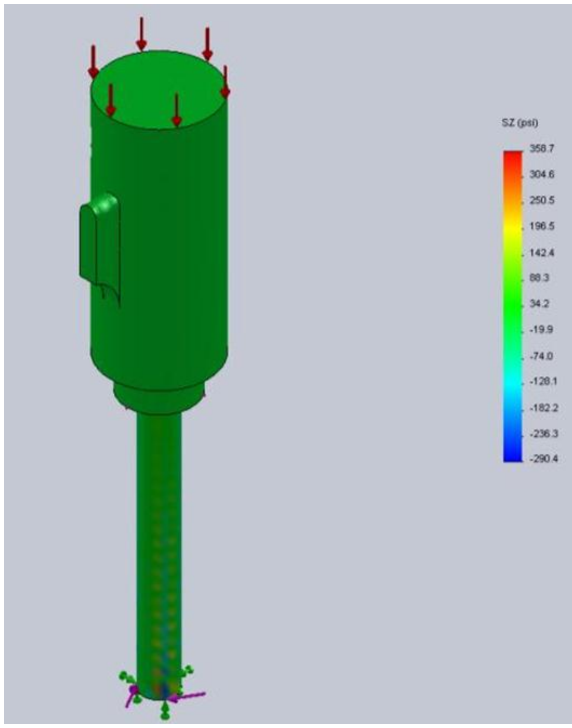


Figure 45: Wrench Pin - Stress in the Z-Direction

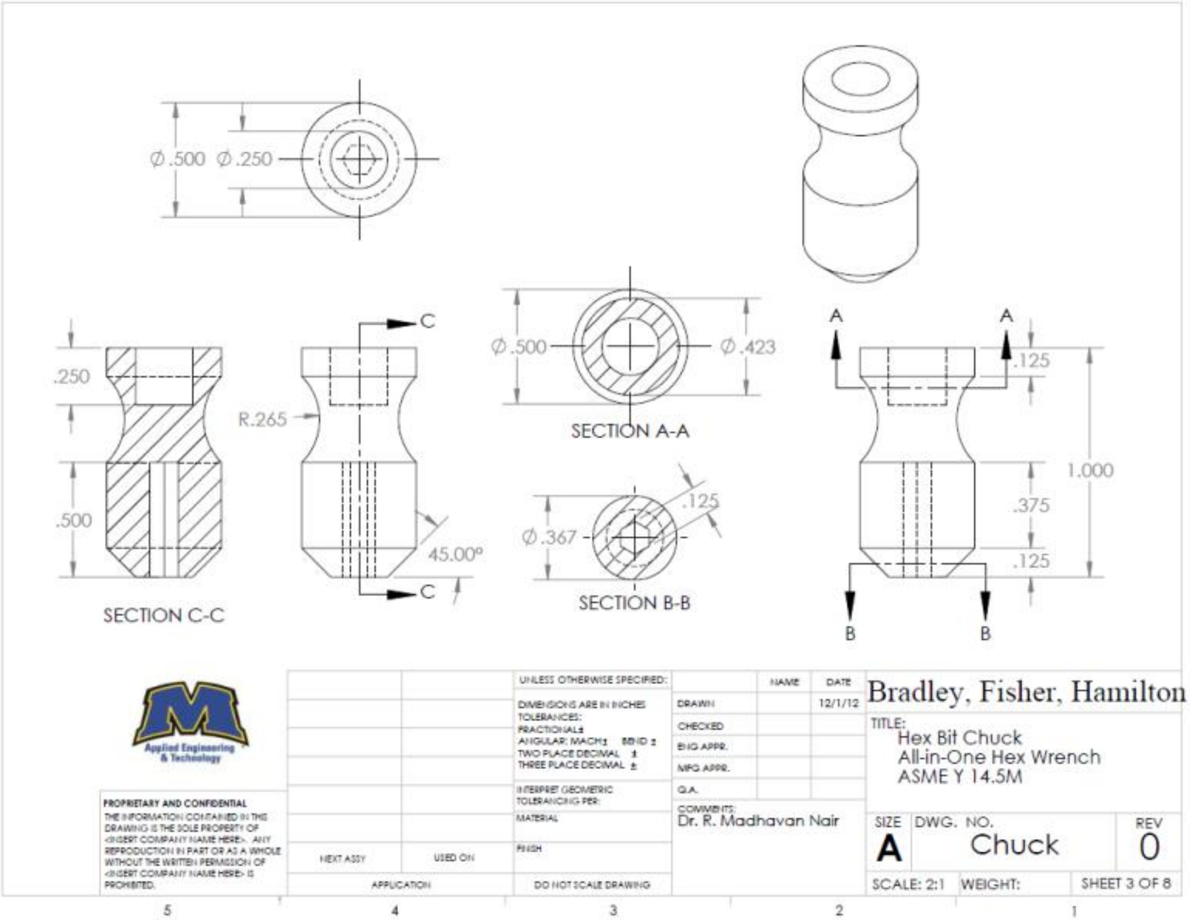


Figure 46: Chuck Dimensioned Drawing

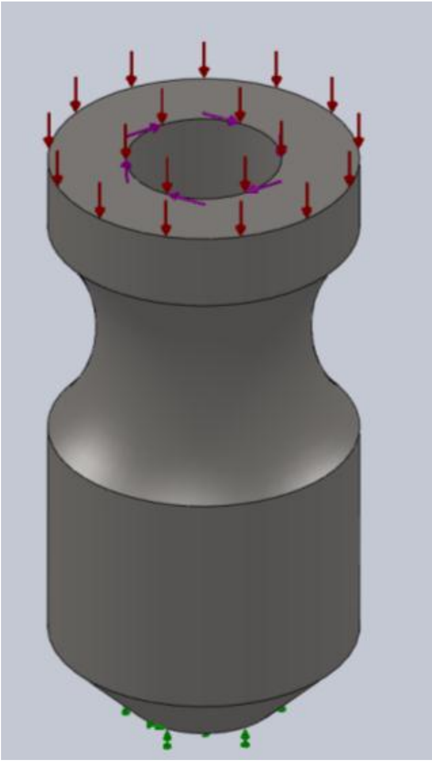


Figure 47: Chuck Forces Pre FEA

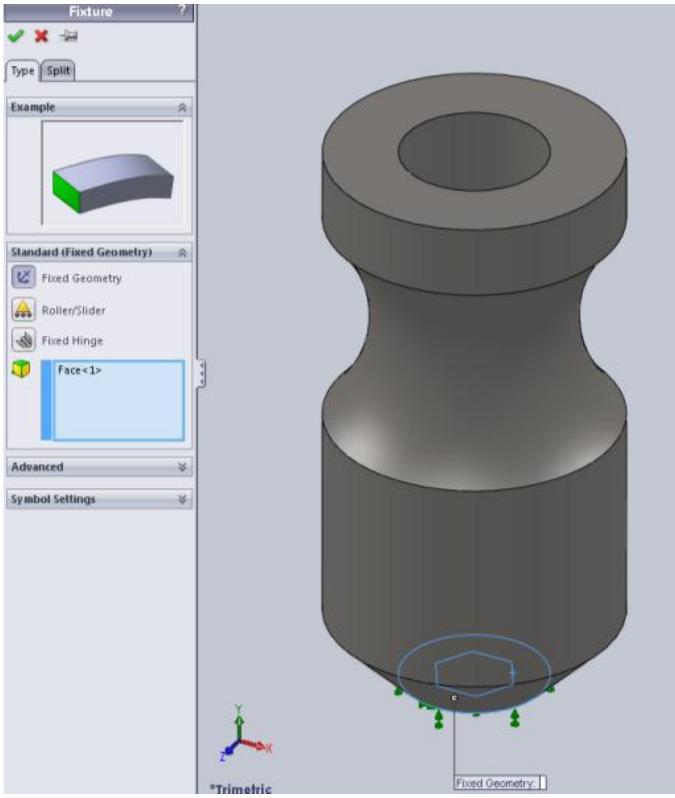


Figure 48: Chuck Applied Fixture

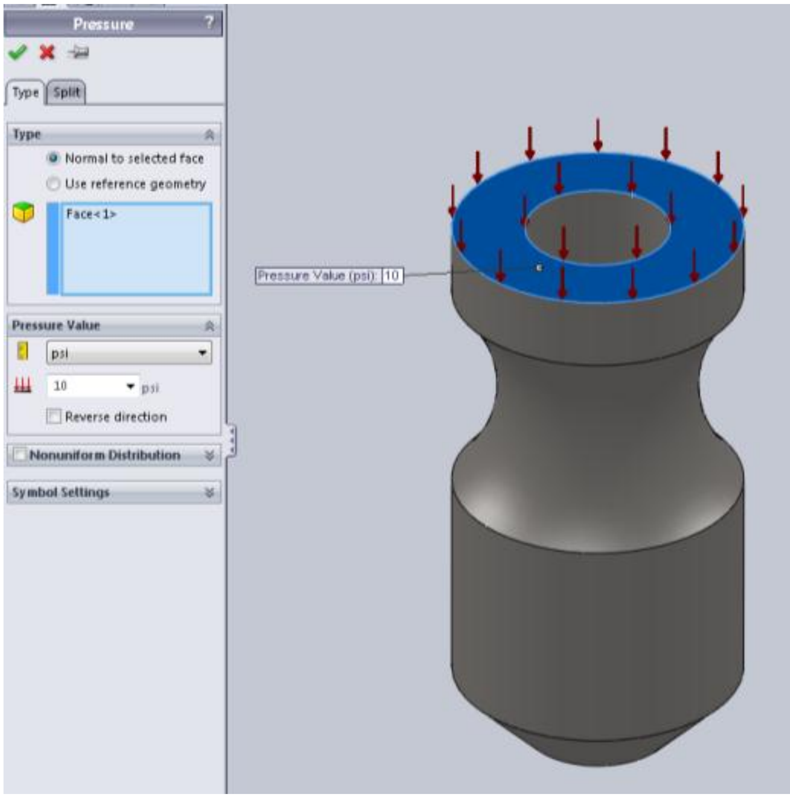


Figure 49: Chuck Applied Pressure

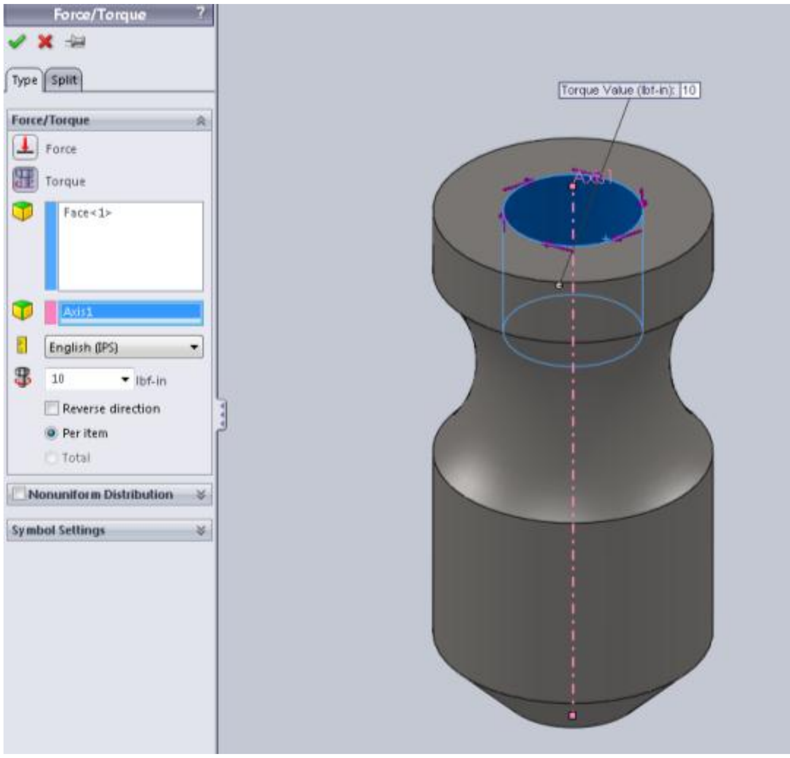


Figure 50: Chuck Applied Torque

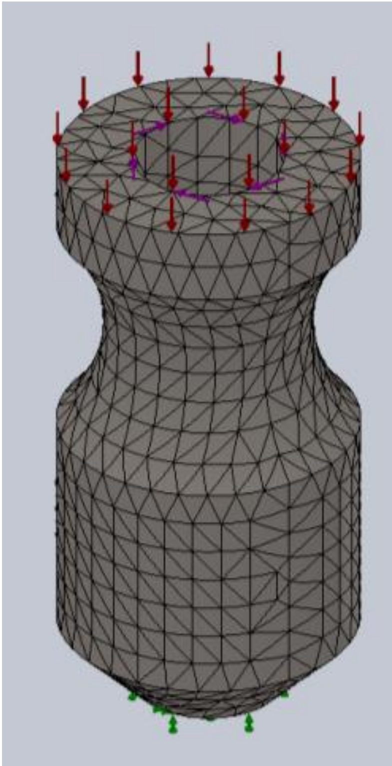


Figure 51: Chuck Meshed

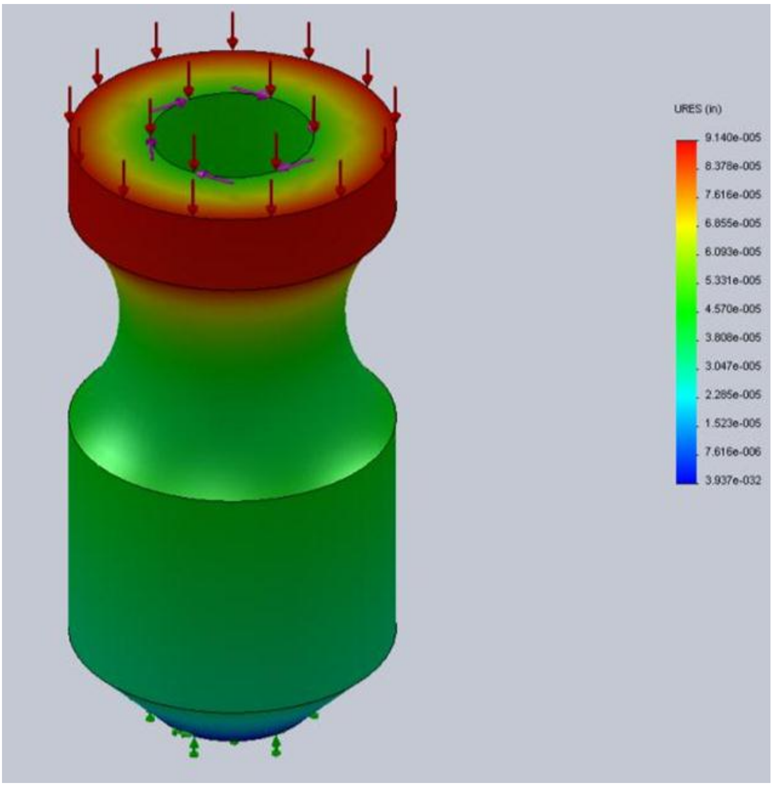


Figure 52: Chuck - Resultant Displacement

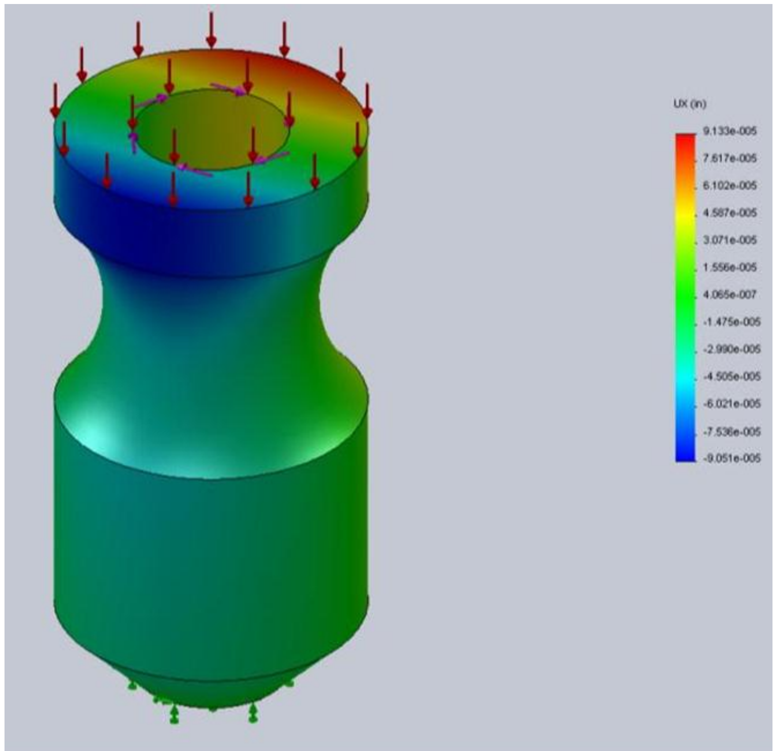


Figure 53: Chuck - Displacement in the X-Direction

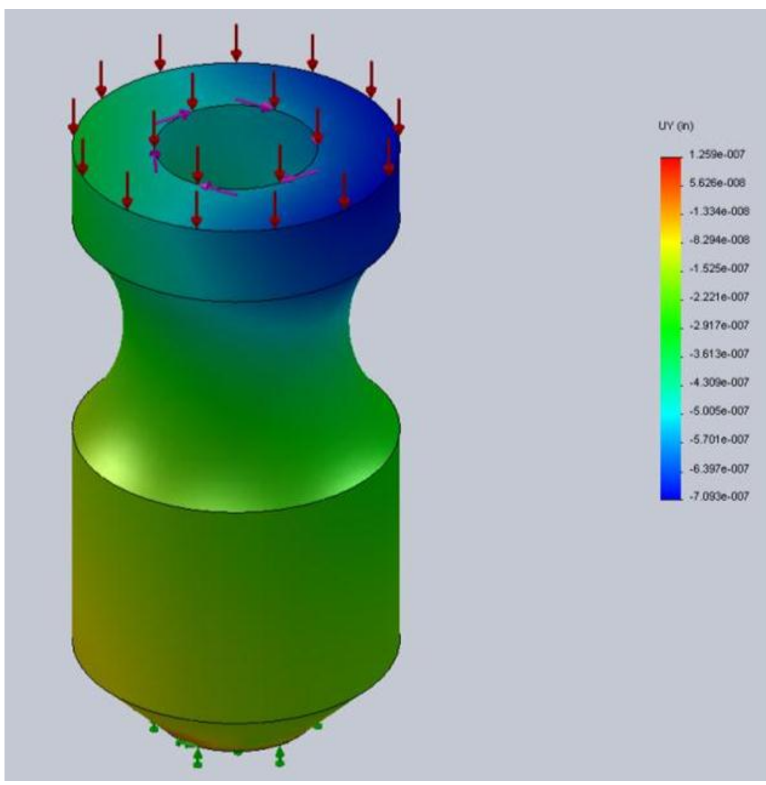


Figure 54: Chuck - Displacement in the Y-Direction

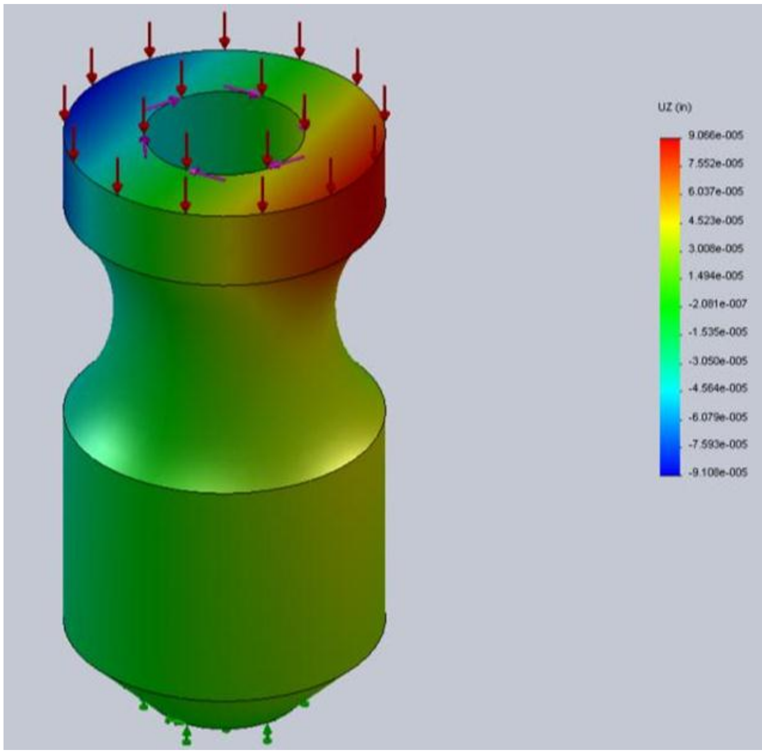


Figure 55: Chuck - Displacement in the Z-Direction

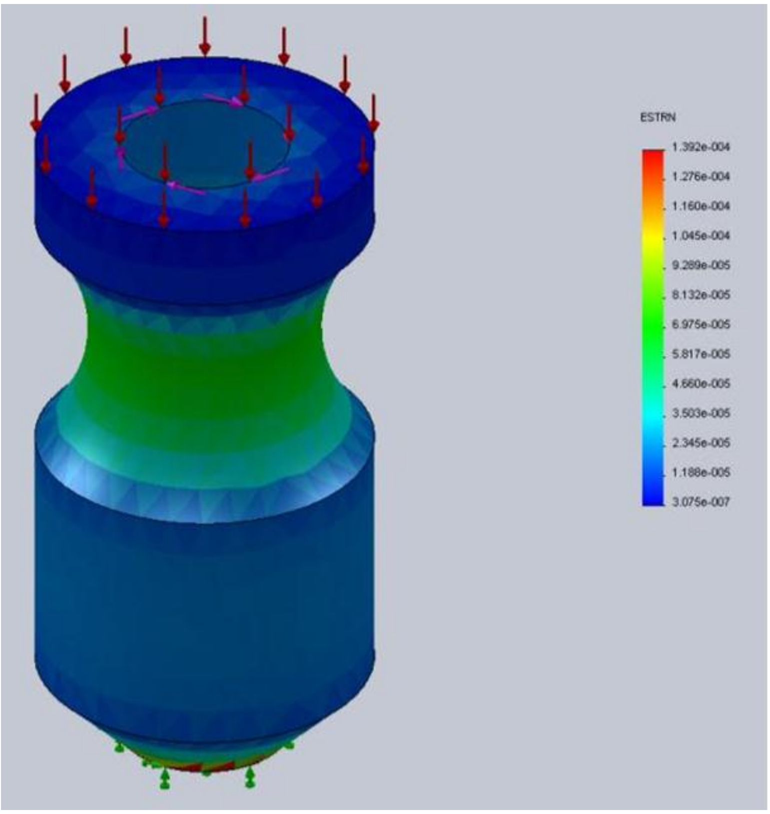


Figure 56: Chuck - Resultant Strain

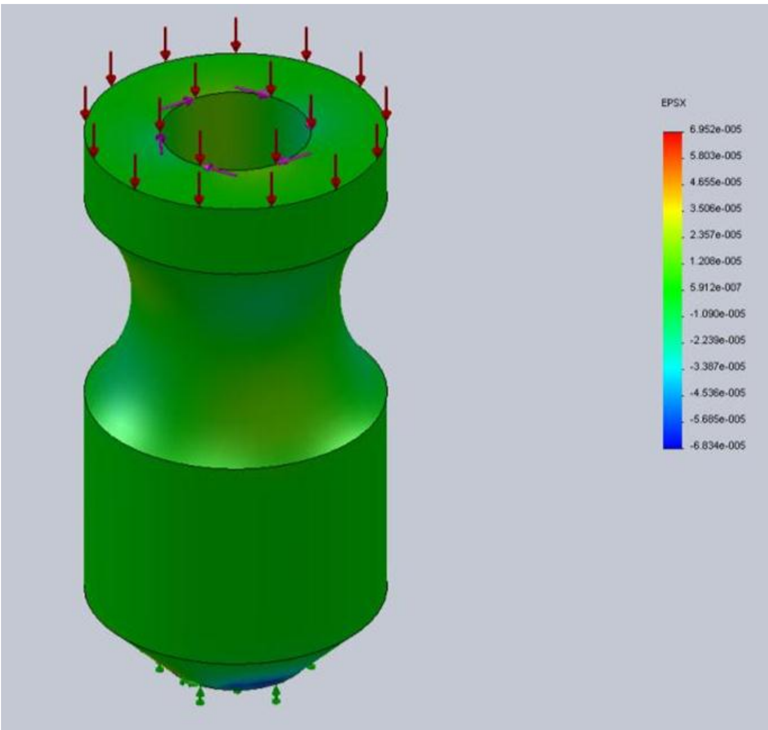


Figure 57: Chuck - Strain in the X-Direction

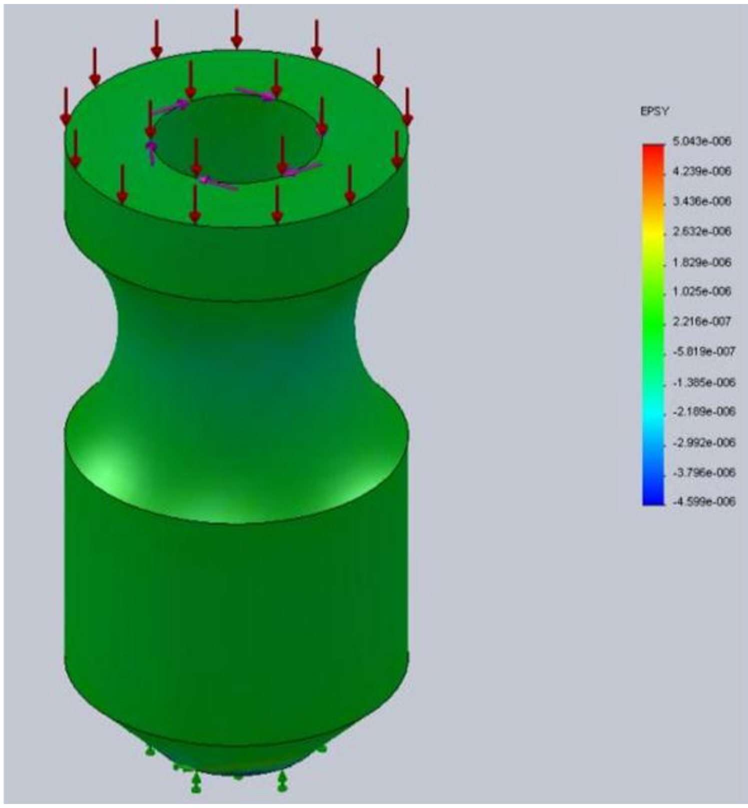


Figure 58: Chuck - Strain in the Y-Direction

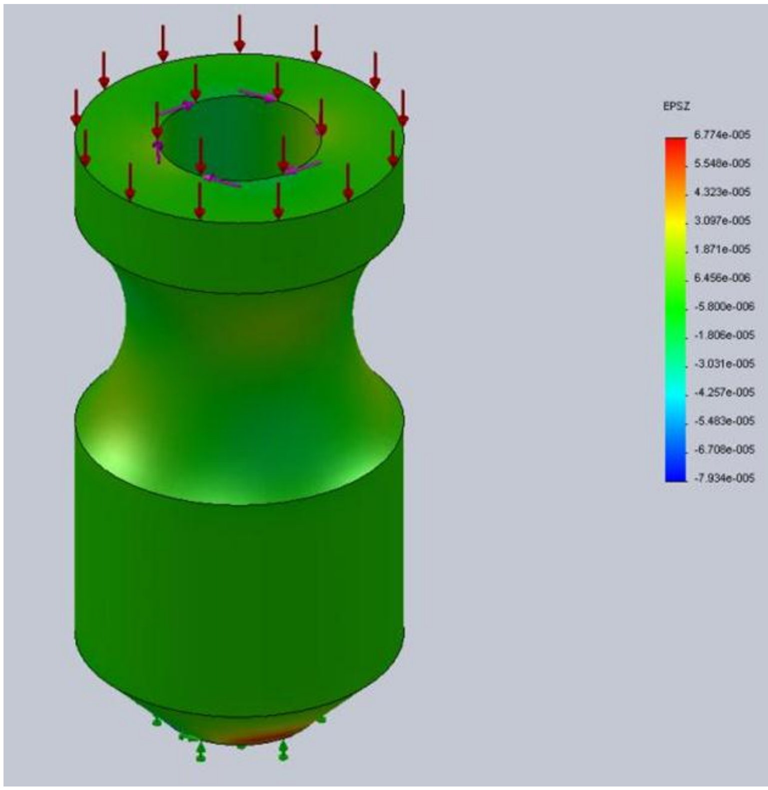


Figure 59: Chuck - Strain in the Z-Direction

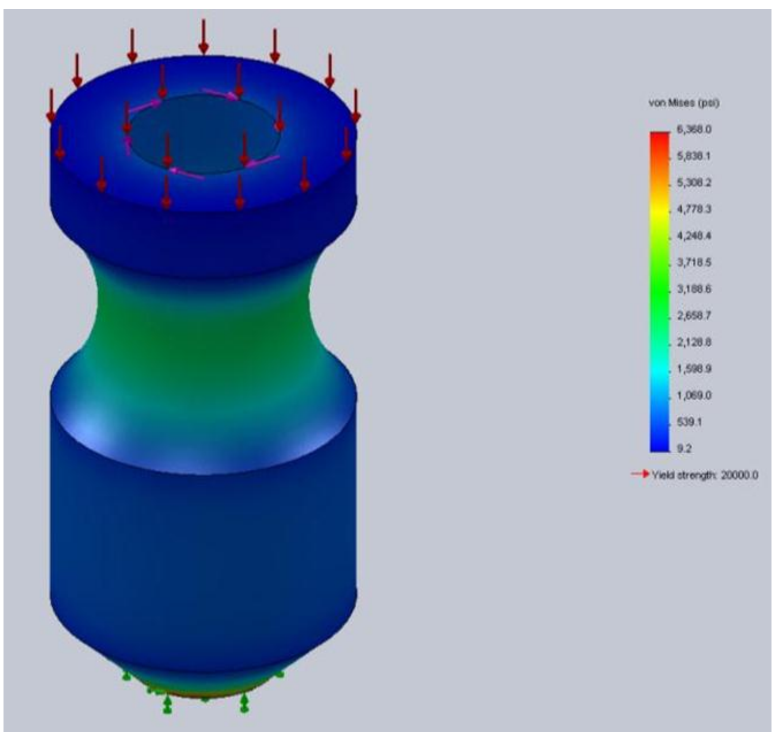


Figure 60: Chuck - Resultant Stress

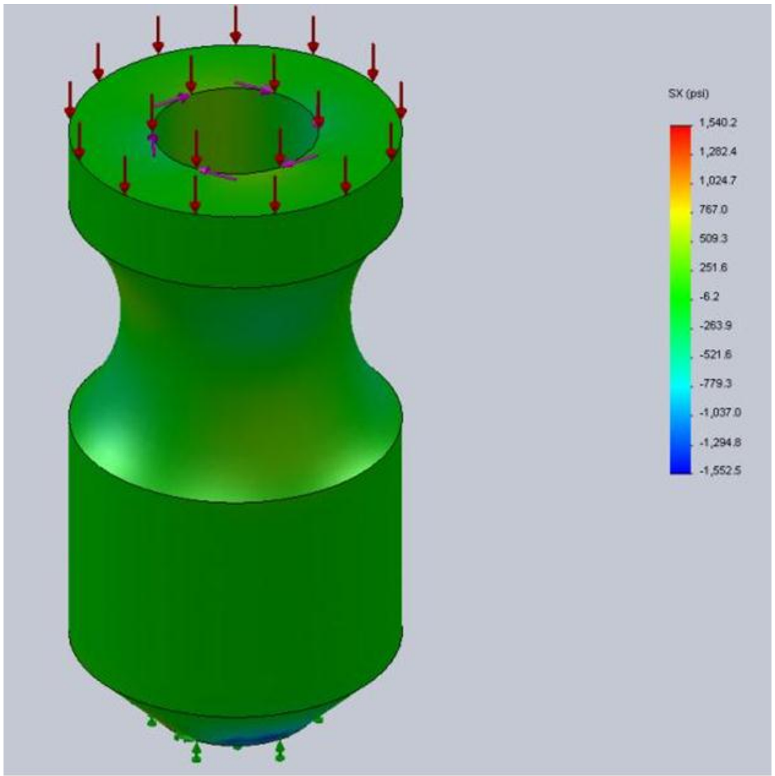


Figure 61: Chuck - Stress in the X-Direction

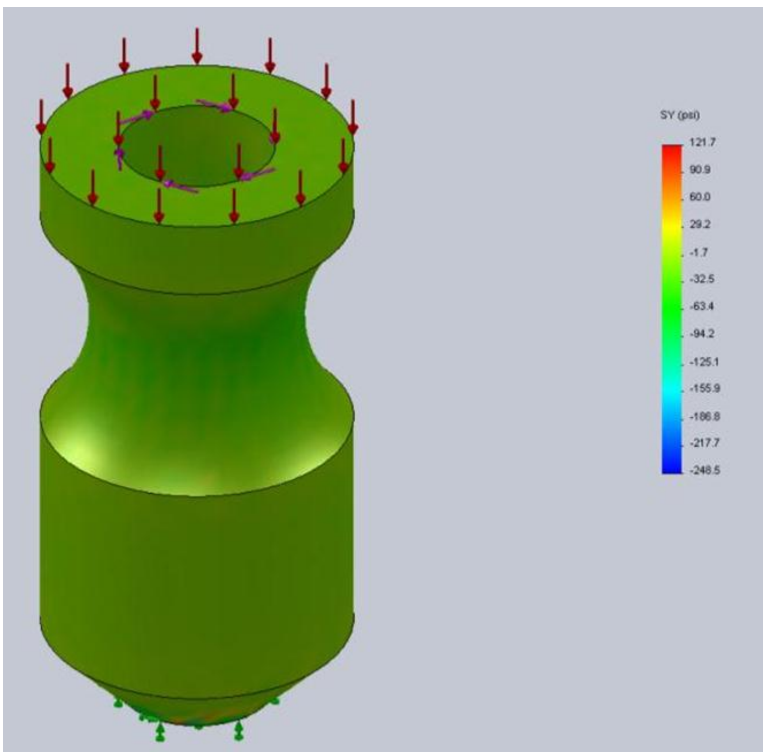


Figure 62: Chuck - Stress in the Y-Direction

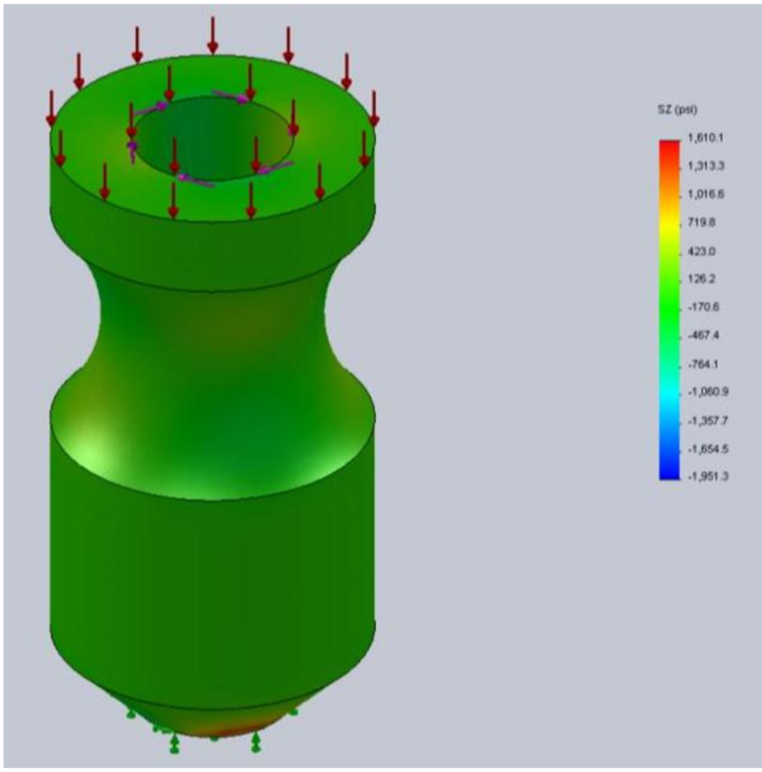


Figure 63:Chuck - Stress in the Z-Direction

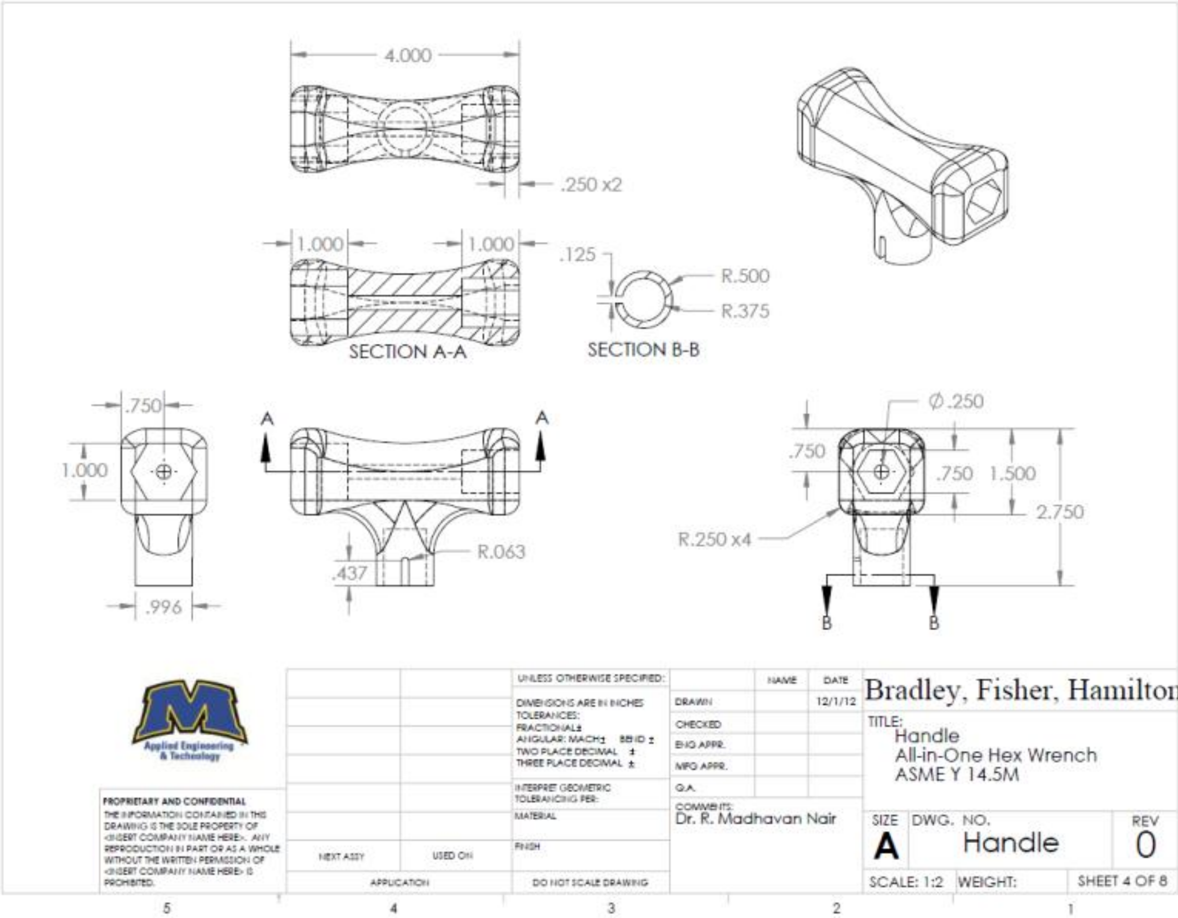


Figure 64: Handle Dimensioned Drawing

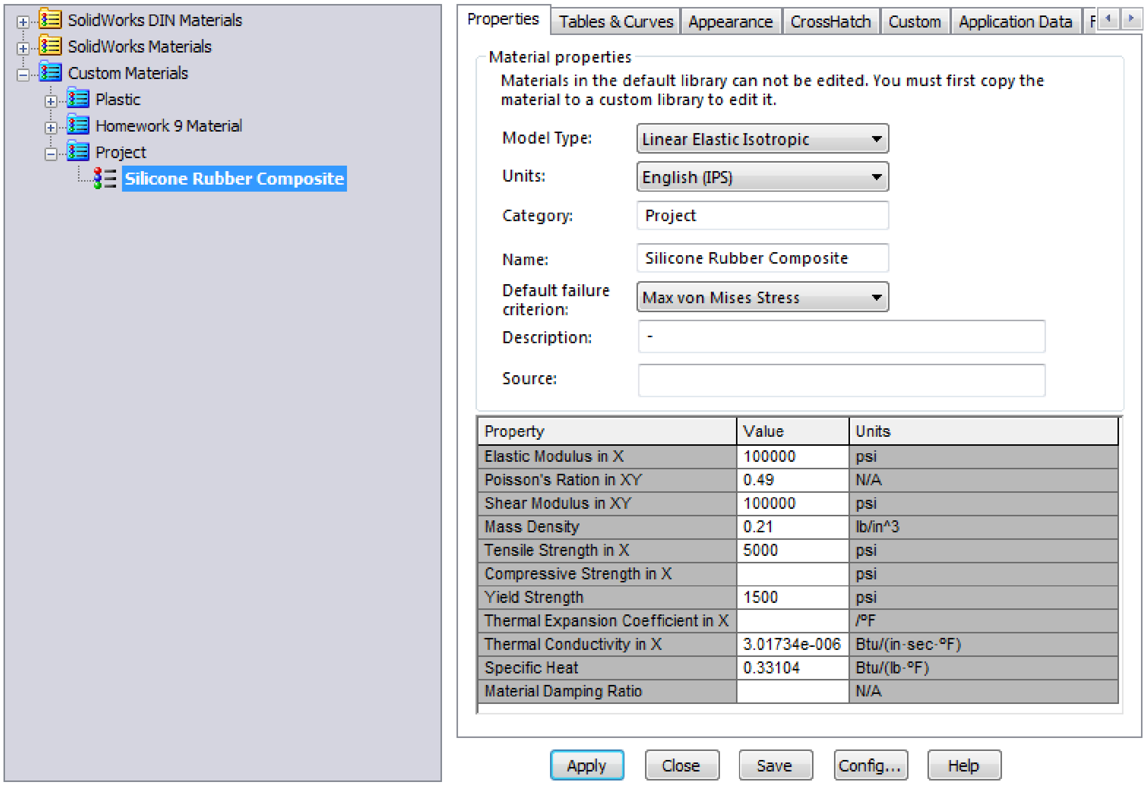


Figure 65: Silicone Rubber Material Properties

Unsure of what specific silicone rubber would work best for this design we used values that were at the midpoint to high point in the ranges provided in an overview section of silicone rubber. Specific materials will be narrowed down in future work. (MatWeb, 2012)

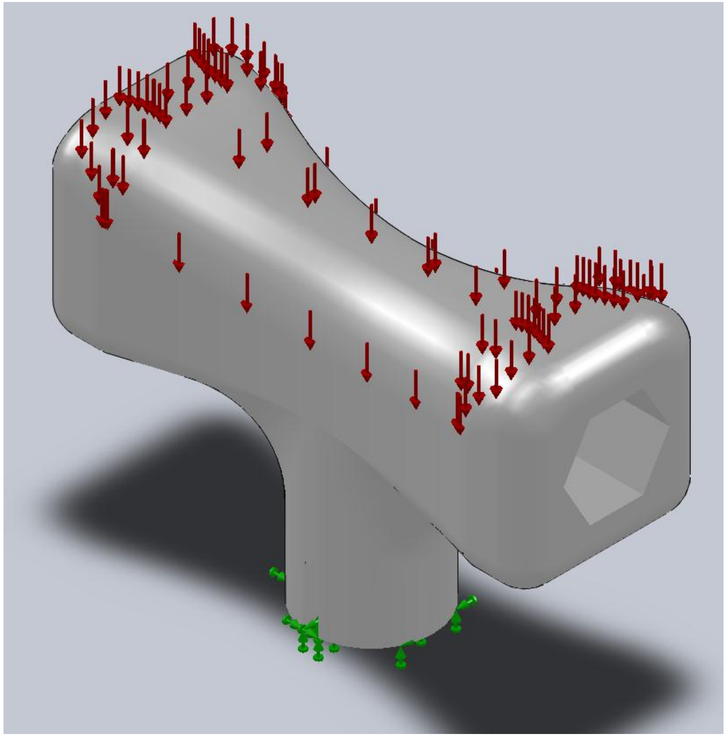


Figure 66: Handle Forces Pre FEA

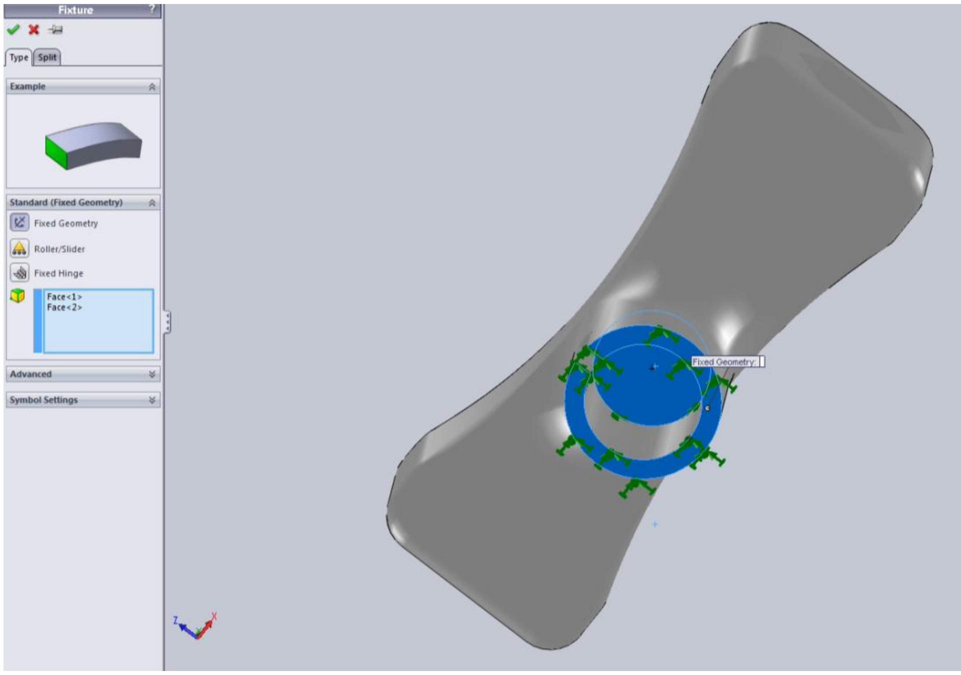


Figure 67: Handle Applied Fixtures

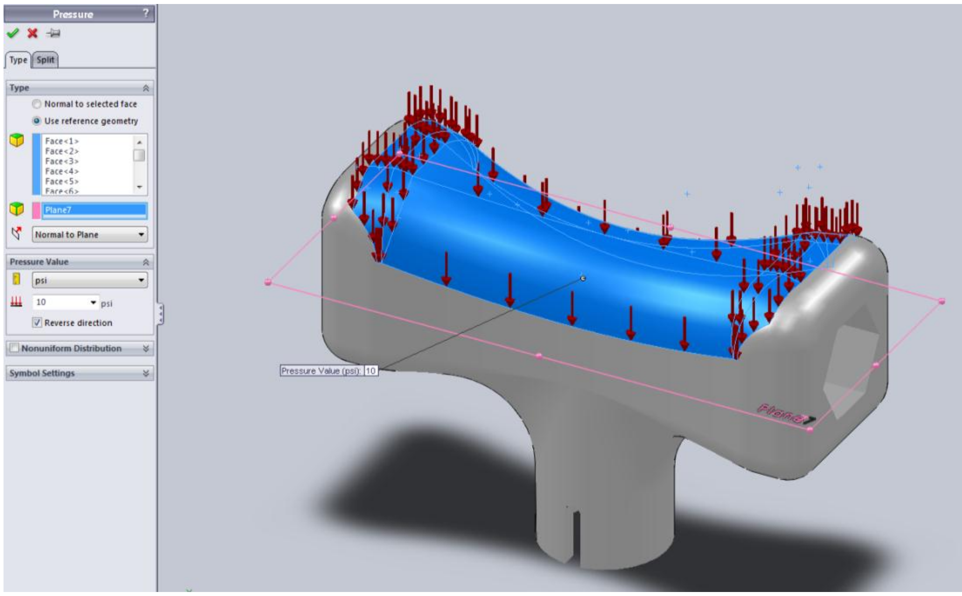


Figure 68: Handle Applied Pressure

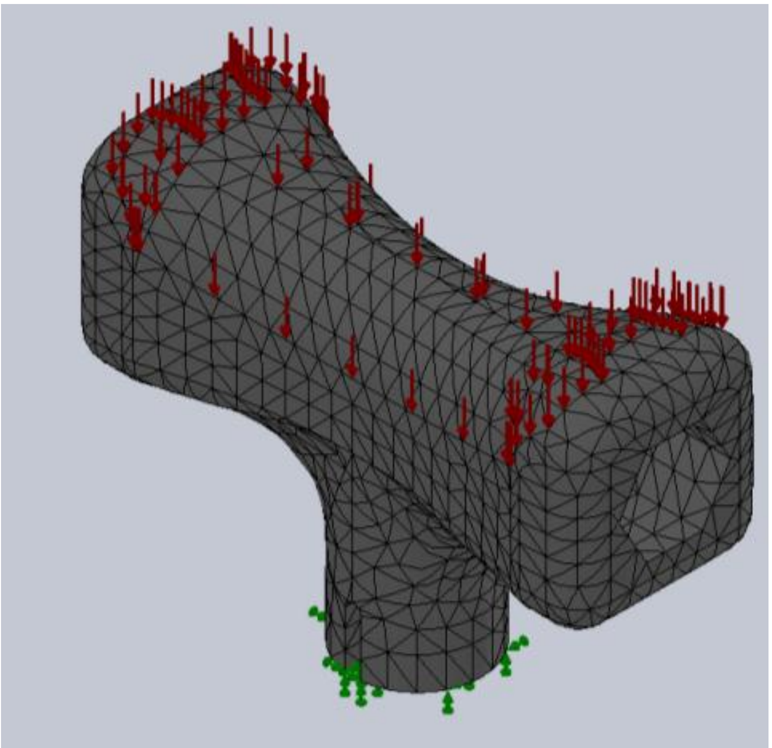


Figure 69: Handle Meshed

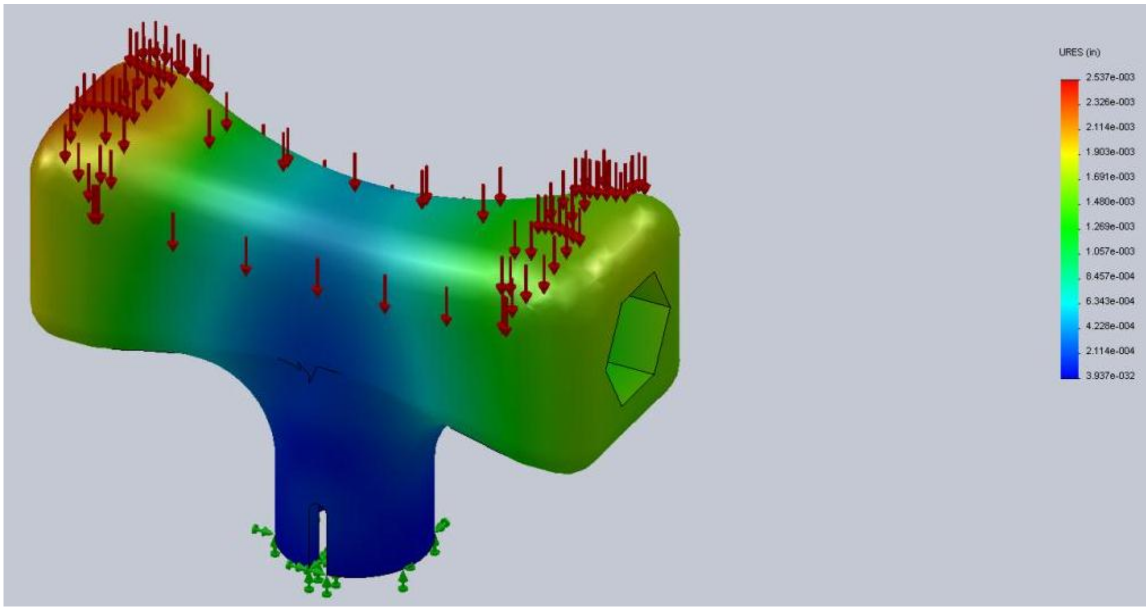


Figure 70: Handle - Resultant Displacement

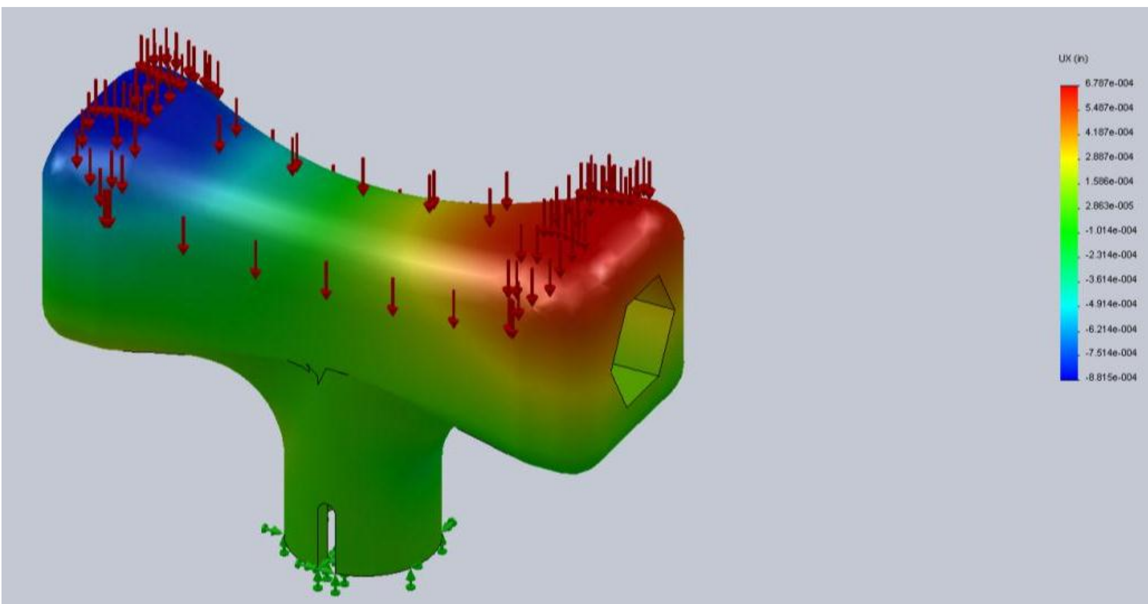


Figure 71: Handle - Displacement in the X-Direction

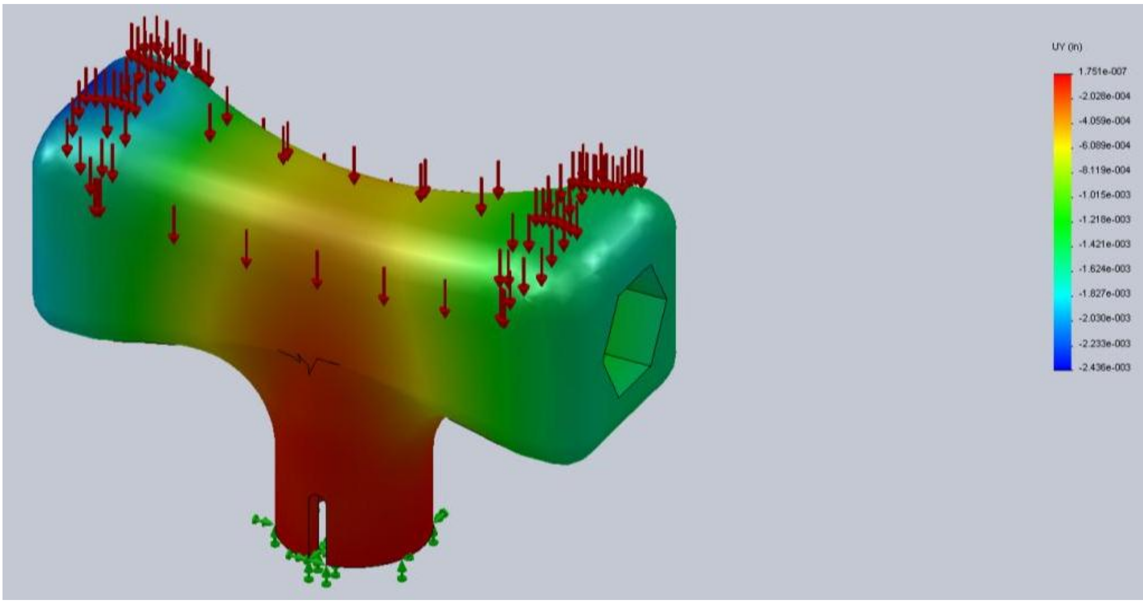


Figure 72: Handle - Displacement in the Y-Direction

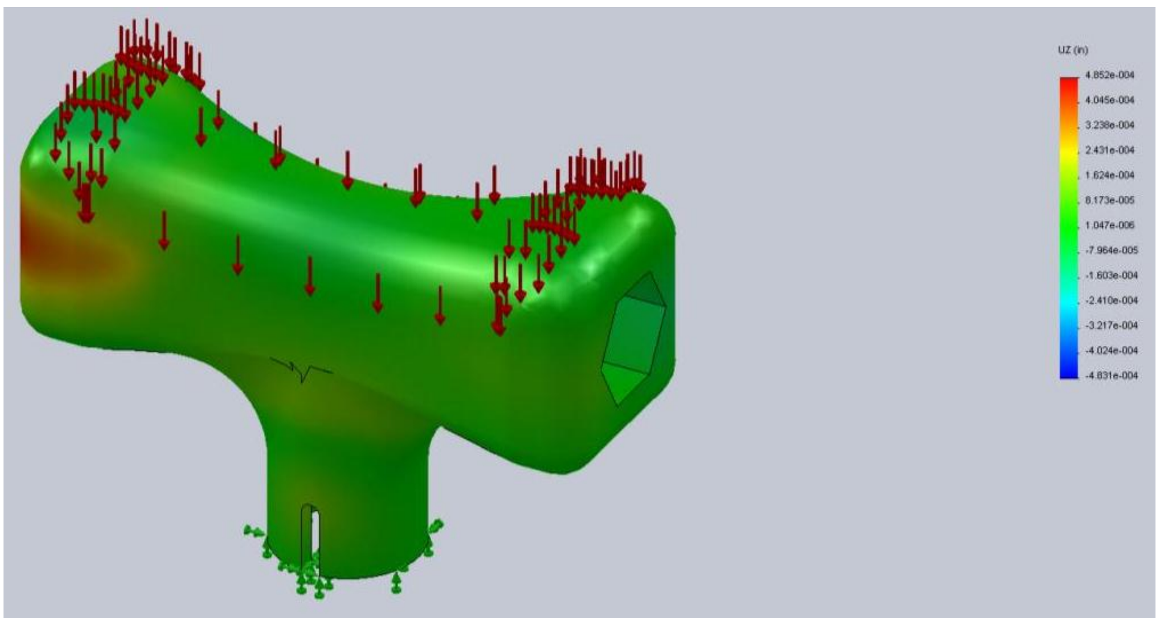


Figure 73: Handle - Displacement in the Z-Direction

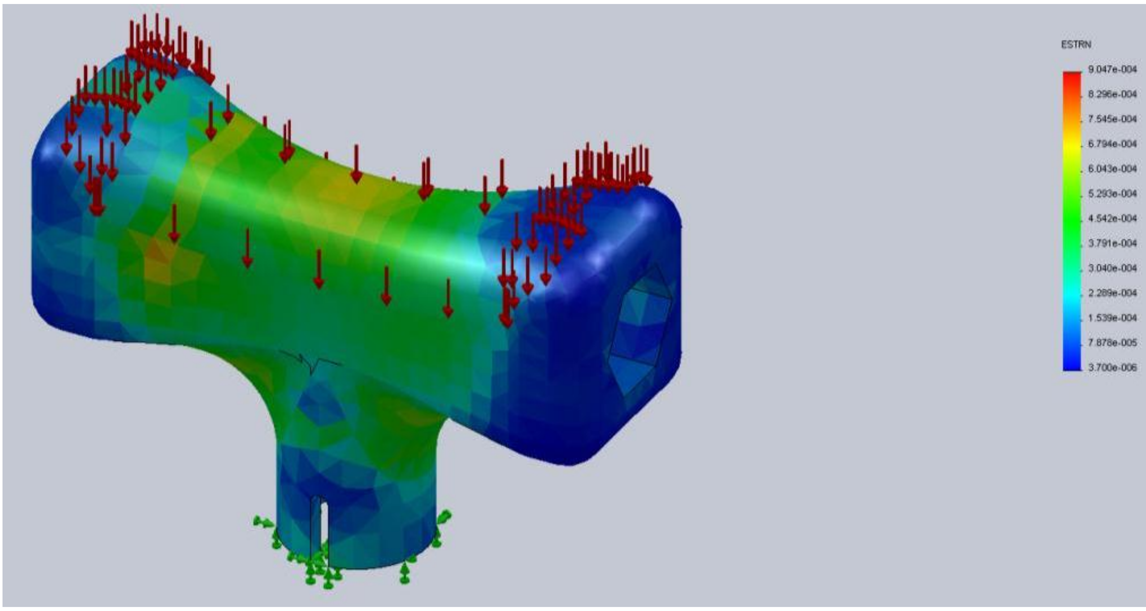


Figure 74: Handle - Resultant Strain

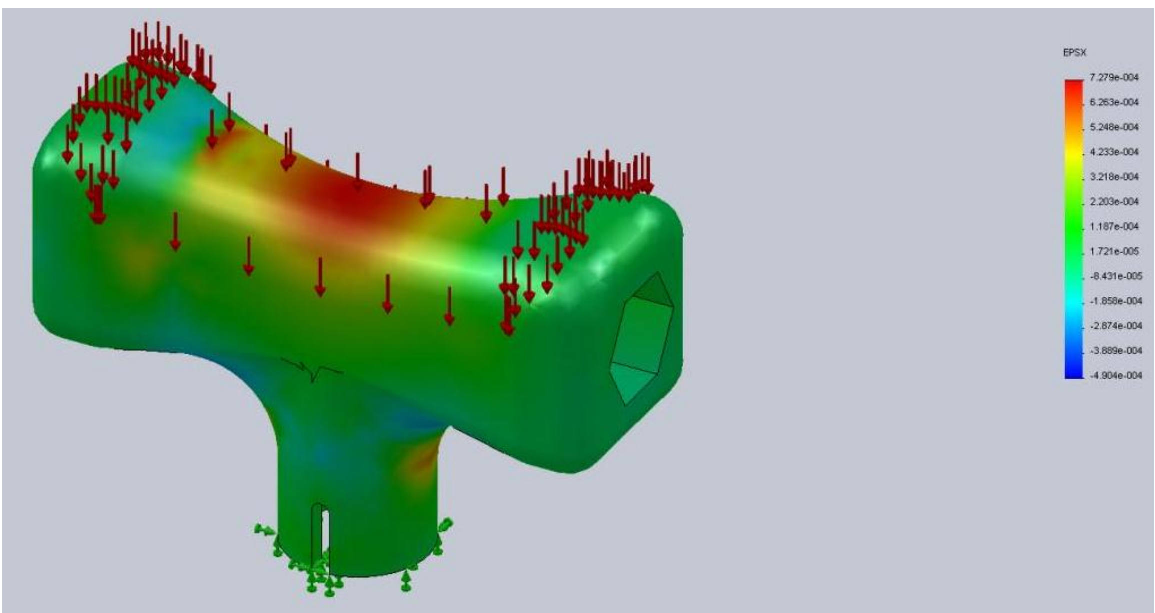


Figure 75: Handle - Strain in the X-Direction

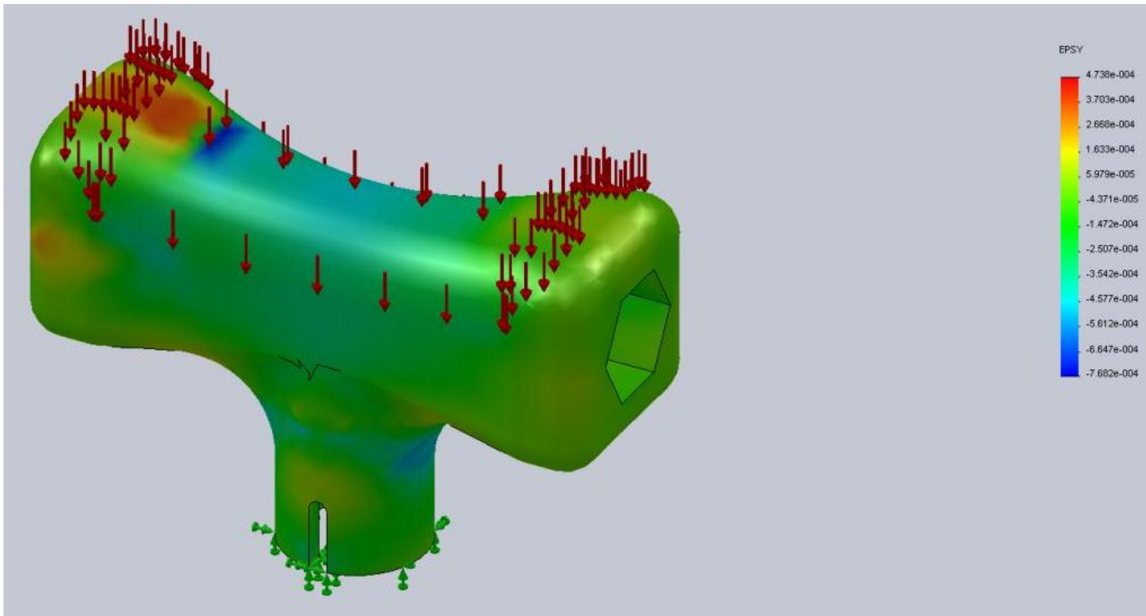


Figure 76: Handle - Strain in the Y-Direction

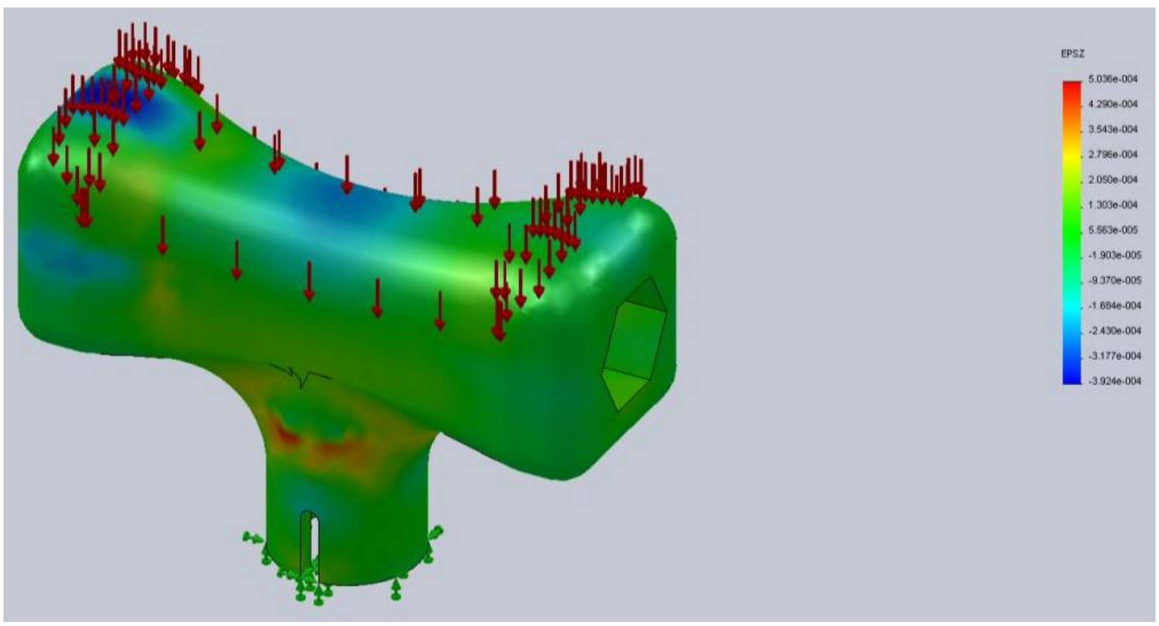


Figure 77: Handle - Strain in the Z-Direction

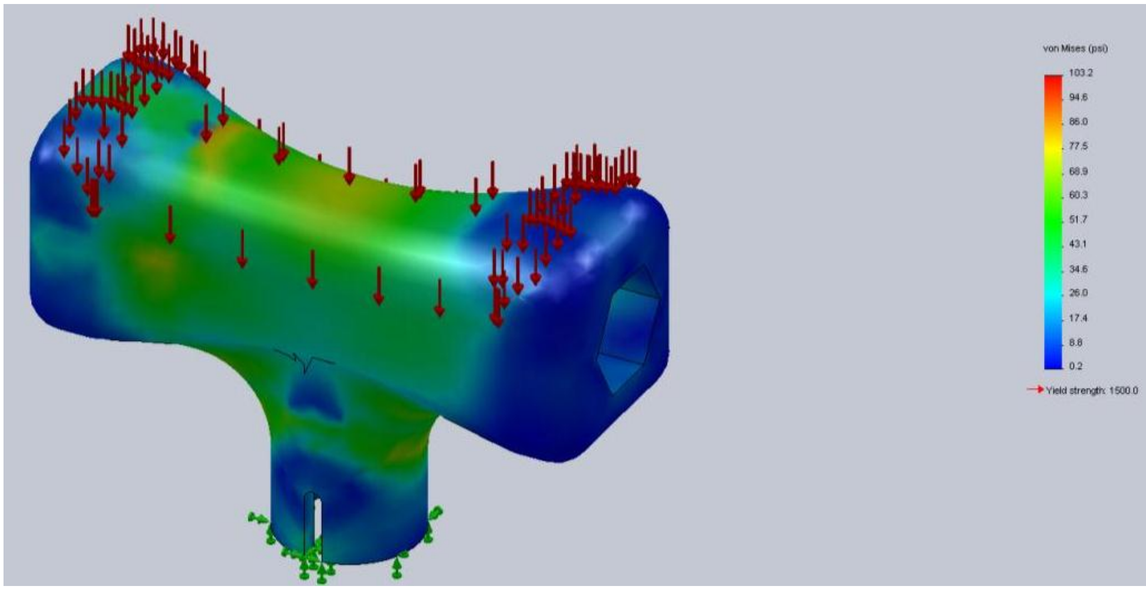


Figure 78: Handle - Resultant Stress

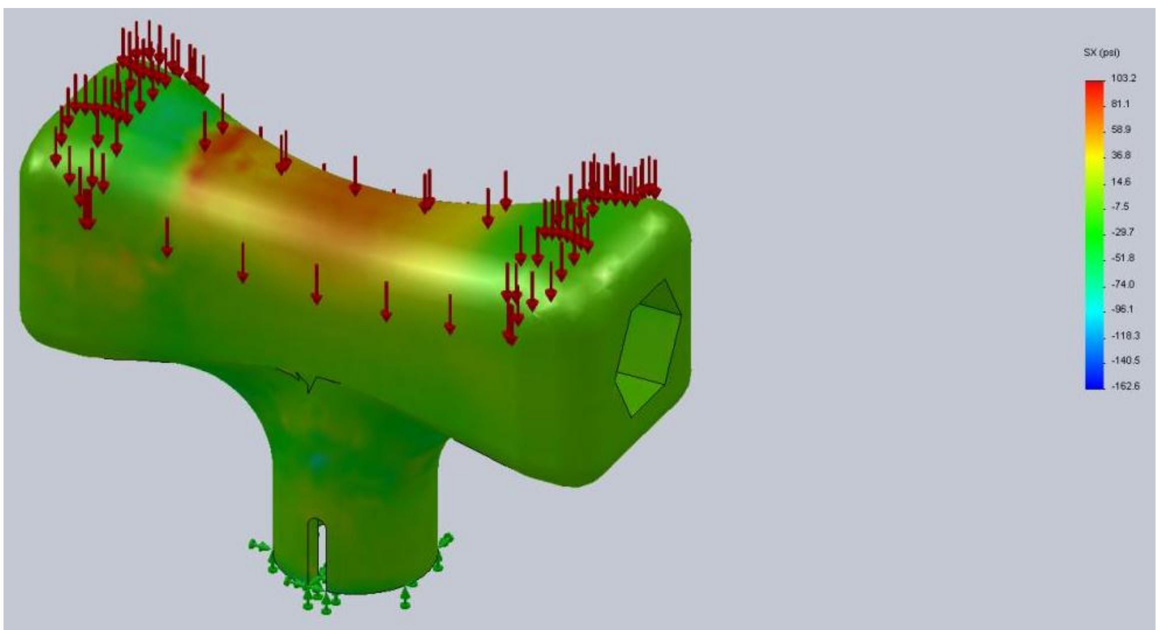


Figure 79: Handle - Stress in the X-Direction

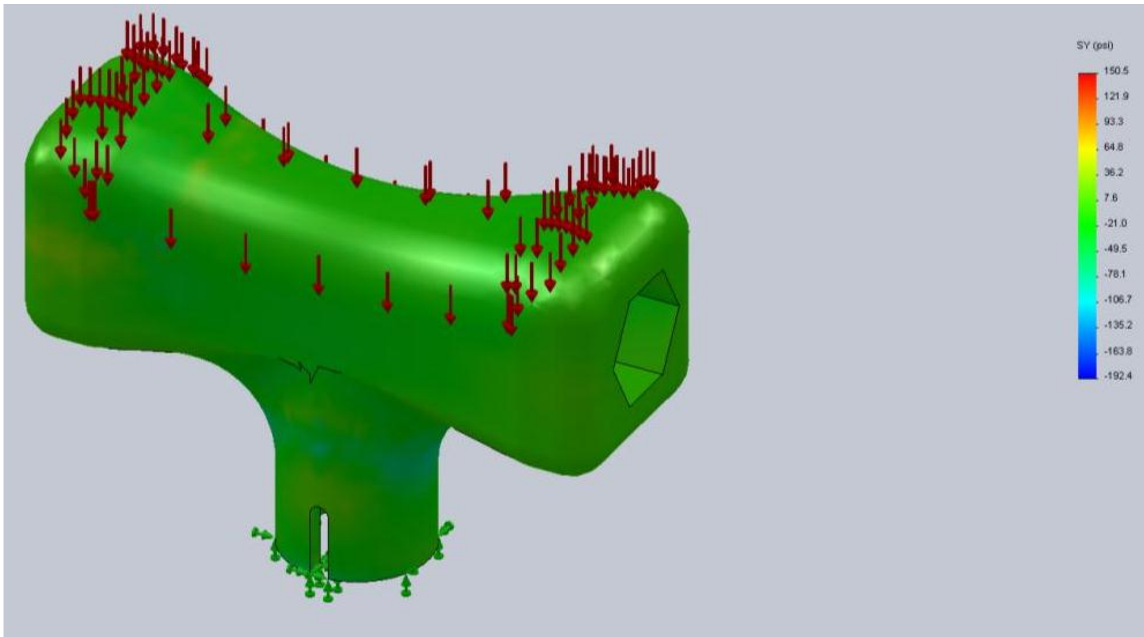


Figure 80: Handle - Stress in the Y-Direction

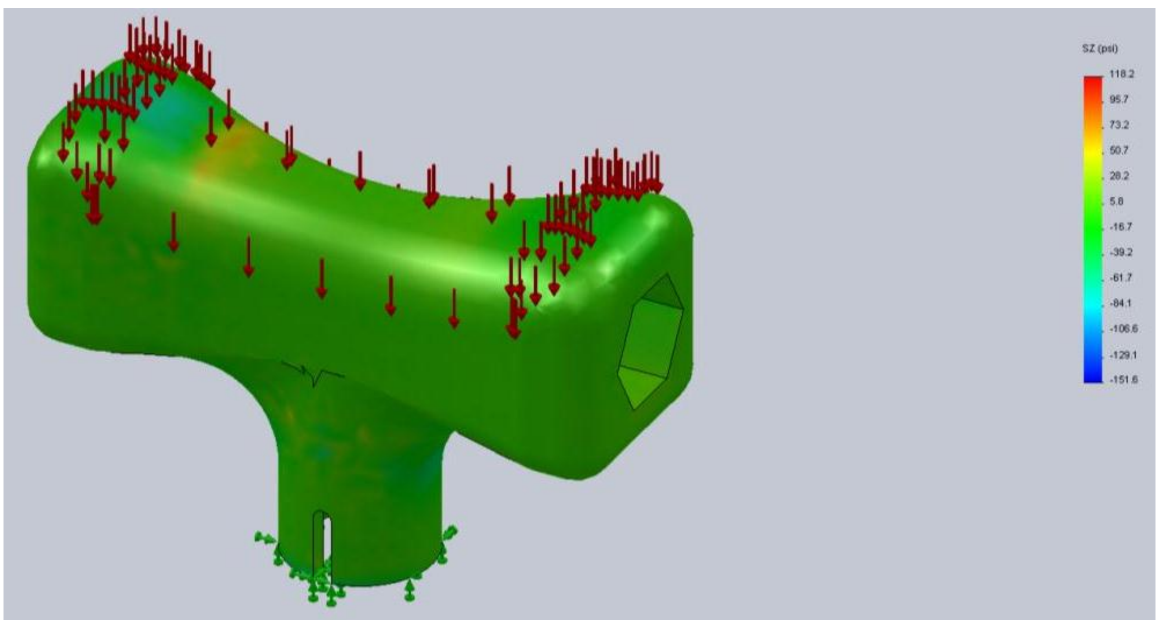


Figure 81: Handle - Stress in the Z-Direction

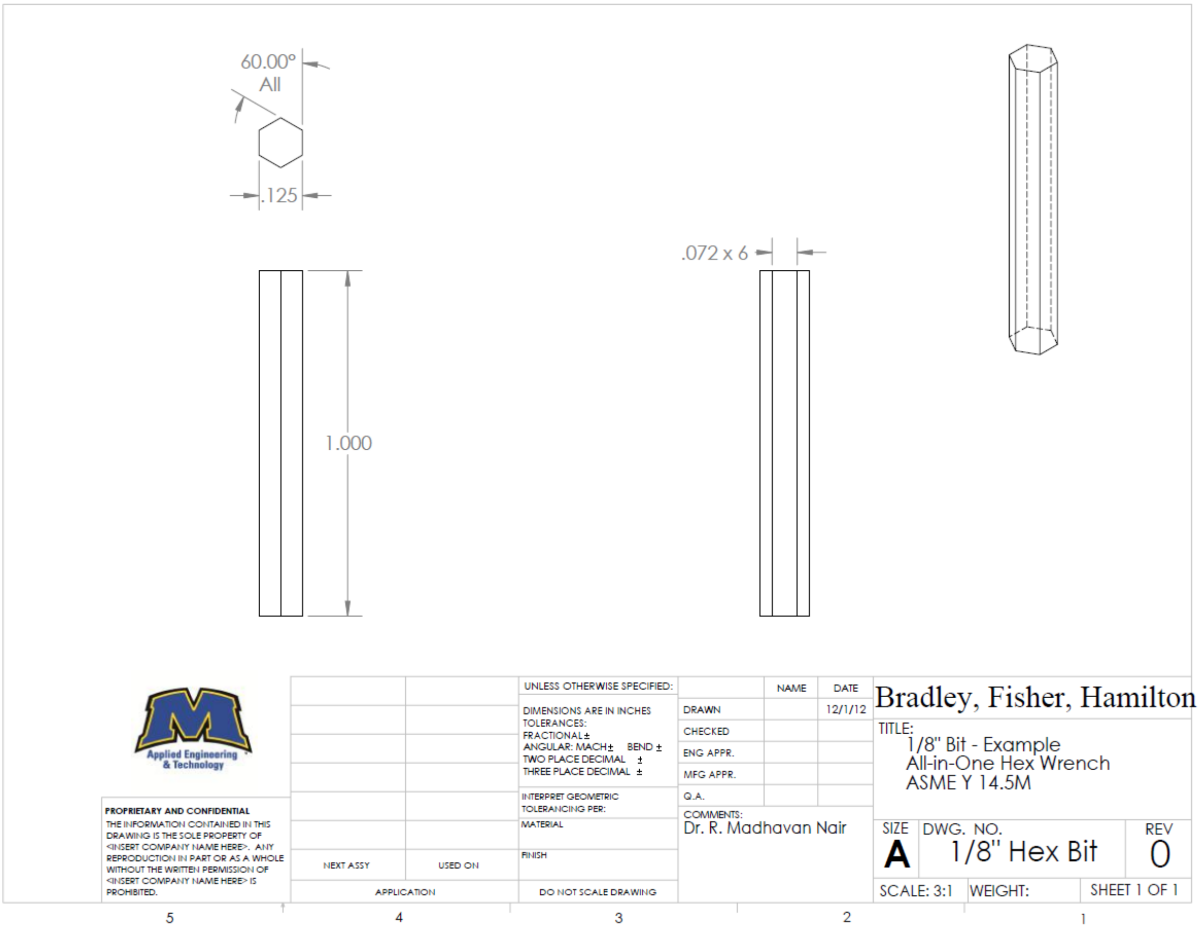


Figure 82: 1/8" Bit Dimensioned Drawing

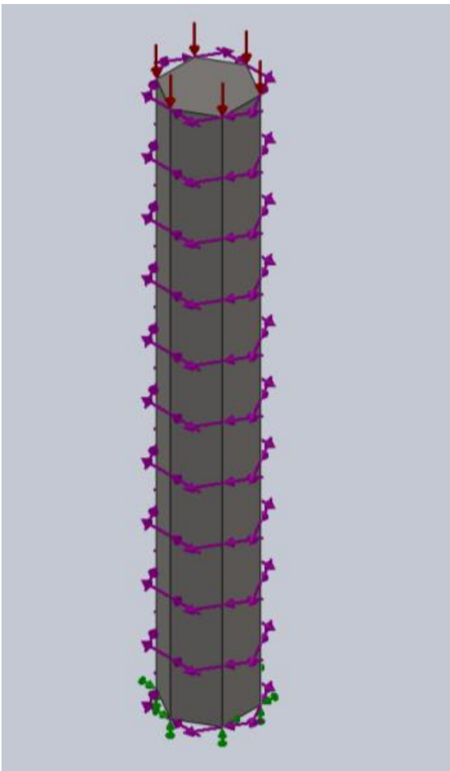


Figure 83: 1/8" Bit Forces Pre FEA

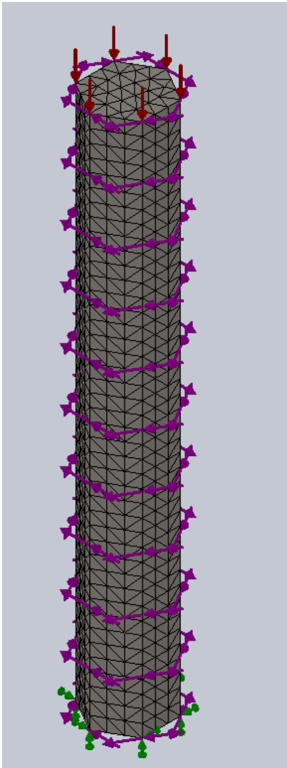


Figure 84: 1/8" Meshed

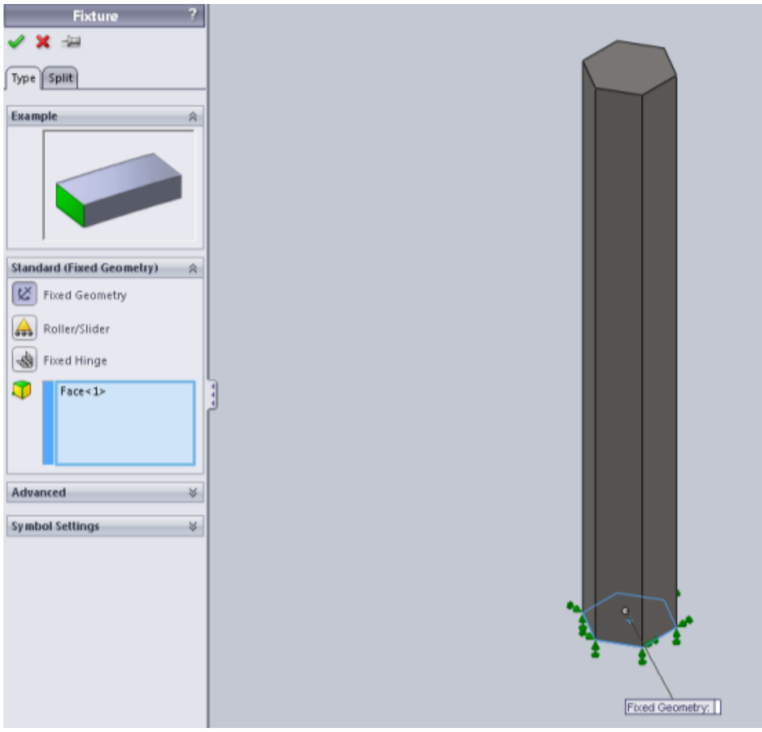


Figure 85: 1/8" Bit Applied Fixture

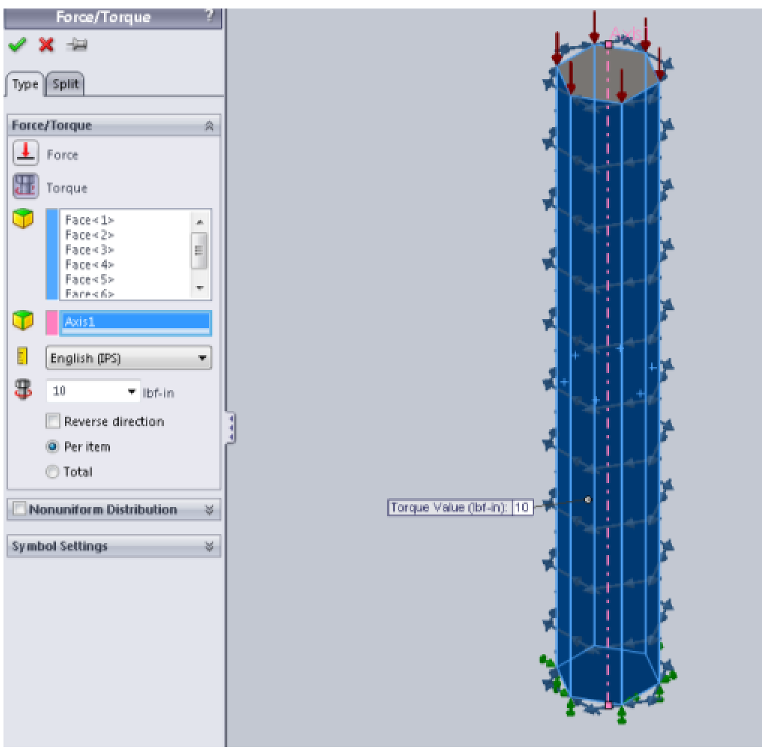


Figure 86: 1/8" Bit Applied Torque

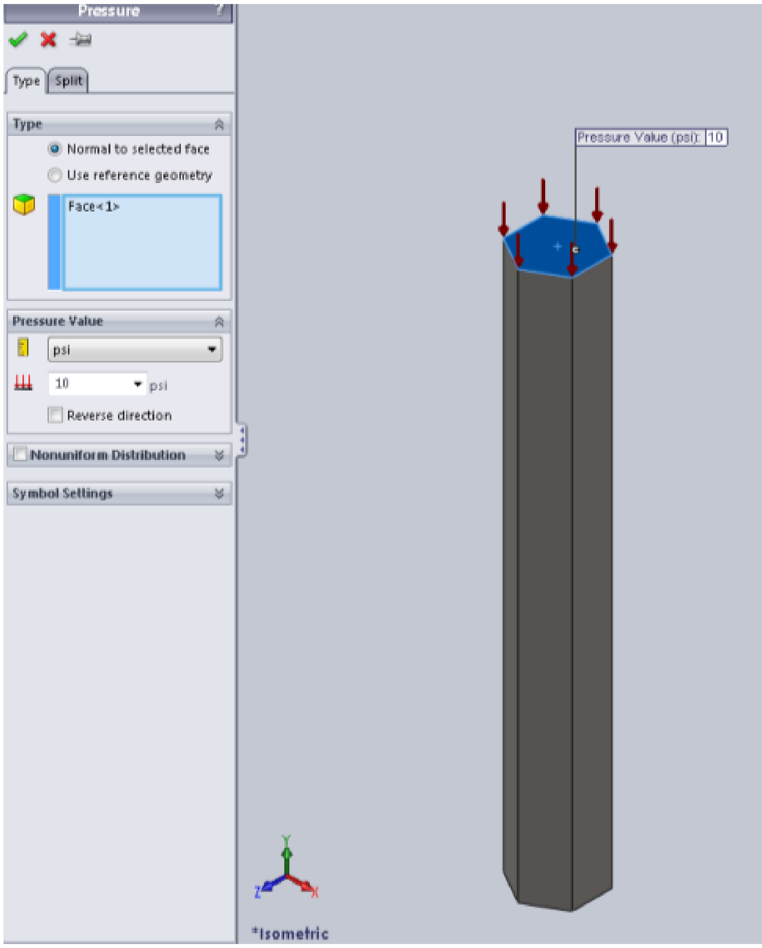


Figure 87: 1/8" Bit Applied Pressure

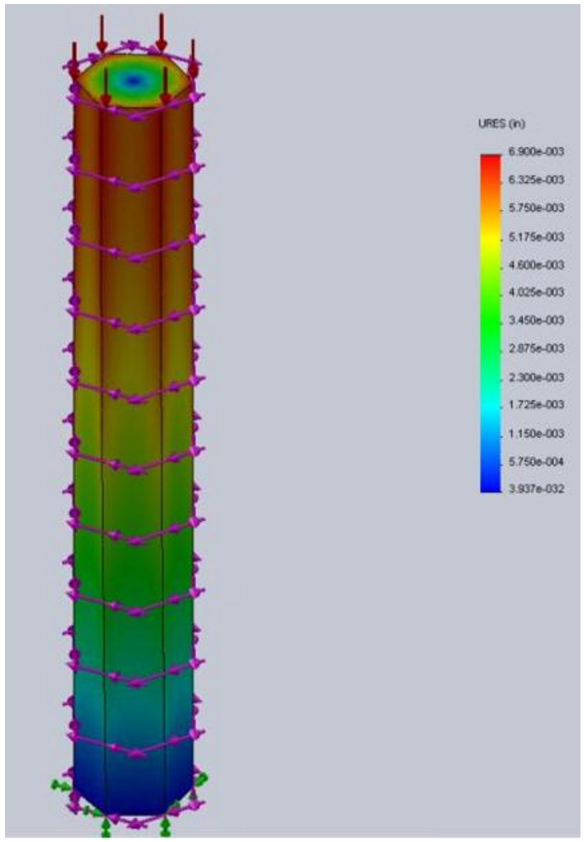


Figure 88: 1/8" Bit - Resultant Displacement

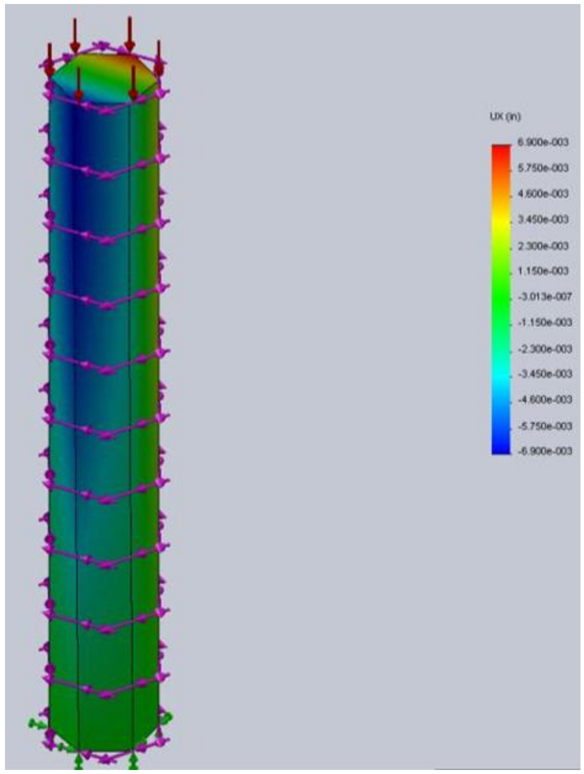


Figure 89: 1/8" Bit - Displacement in the X-Direction

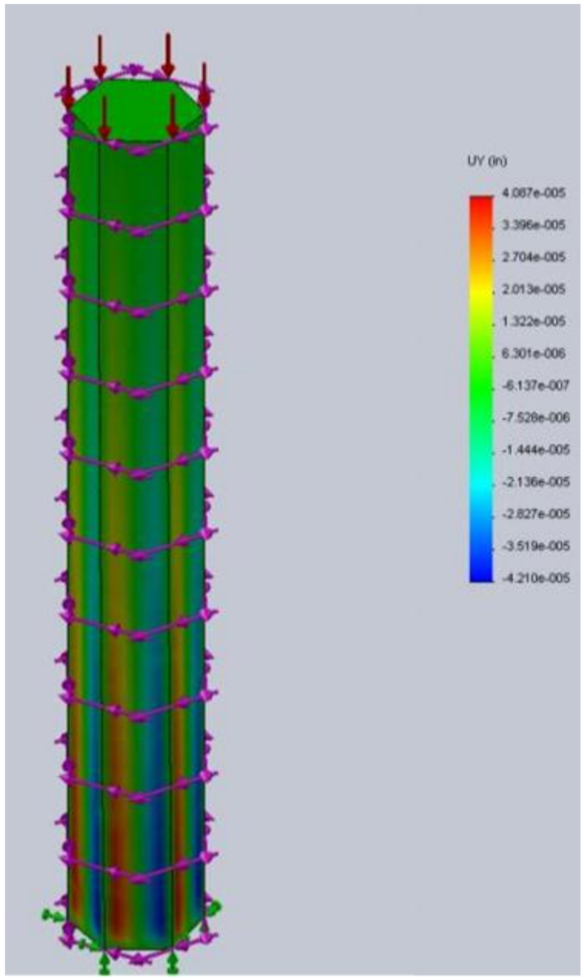


Figure 90: 1/8" Bit - Displacement in the Y-Direction

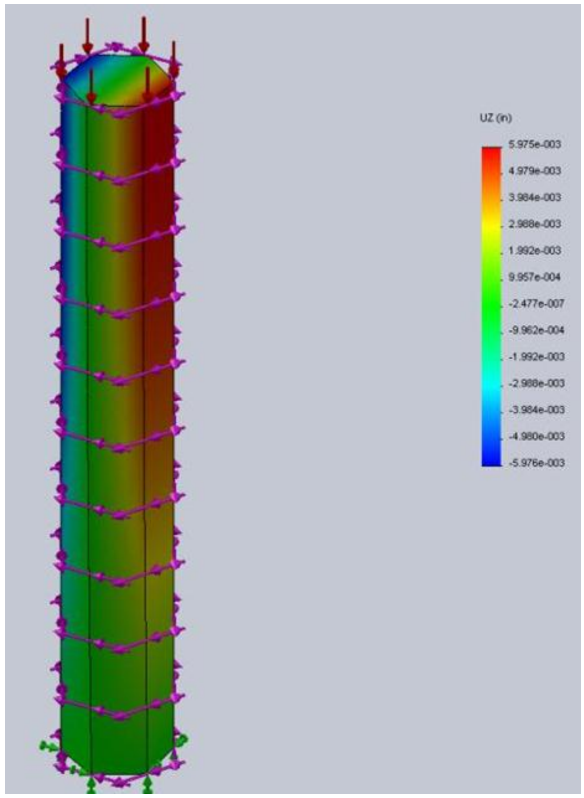


Figure 91: 1/8" Bit - Displacement in the Z-Direction

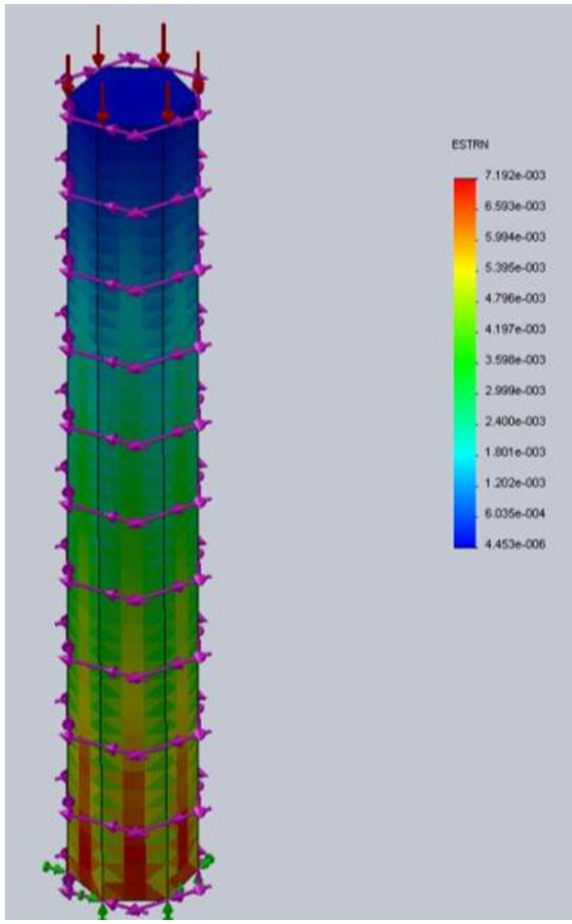


Figure 92: 1/8" Bit - Resultant Strain

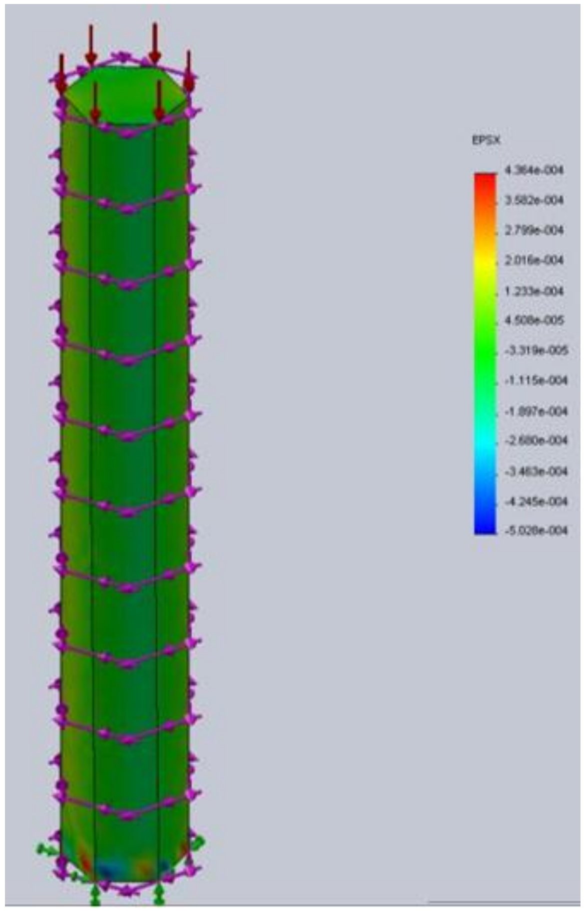


Figure 93: 1/8" Bit - Strain in the X-Direction

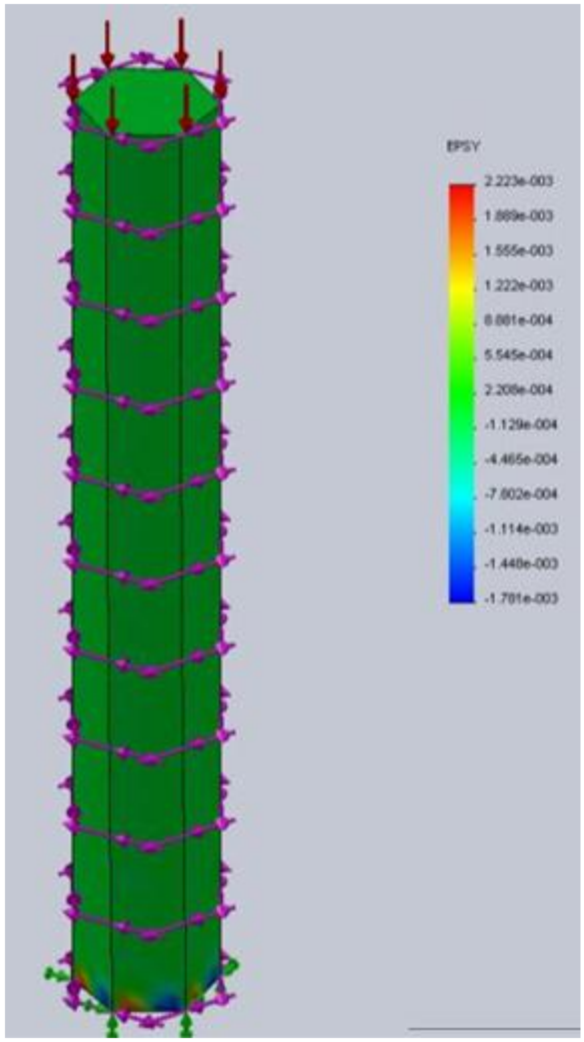


Figure 94: 1/8" Bit - Strain in the Y-Direction

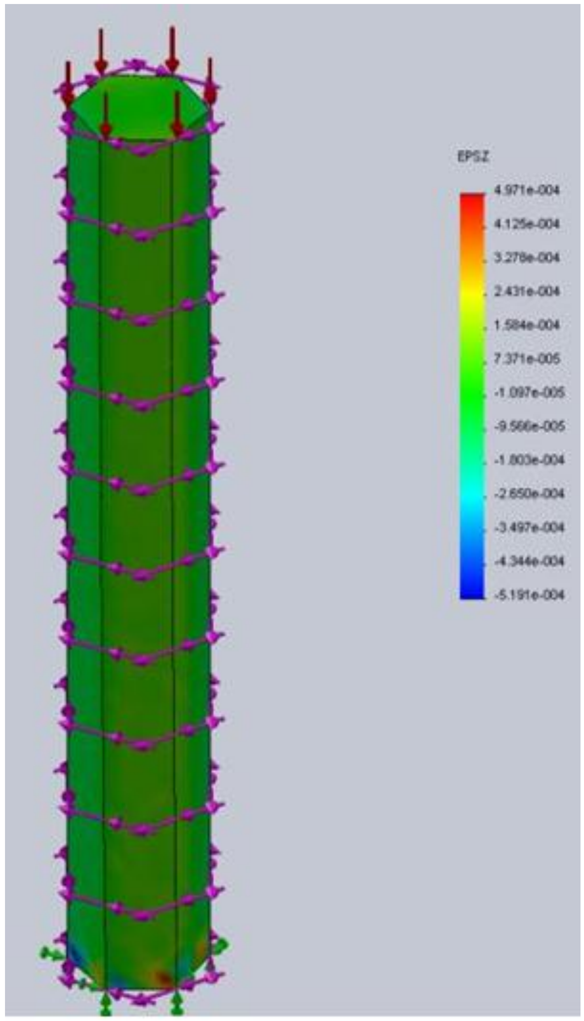


Figure 95: 1/8" Bit - Strain in the Z-Direction

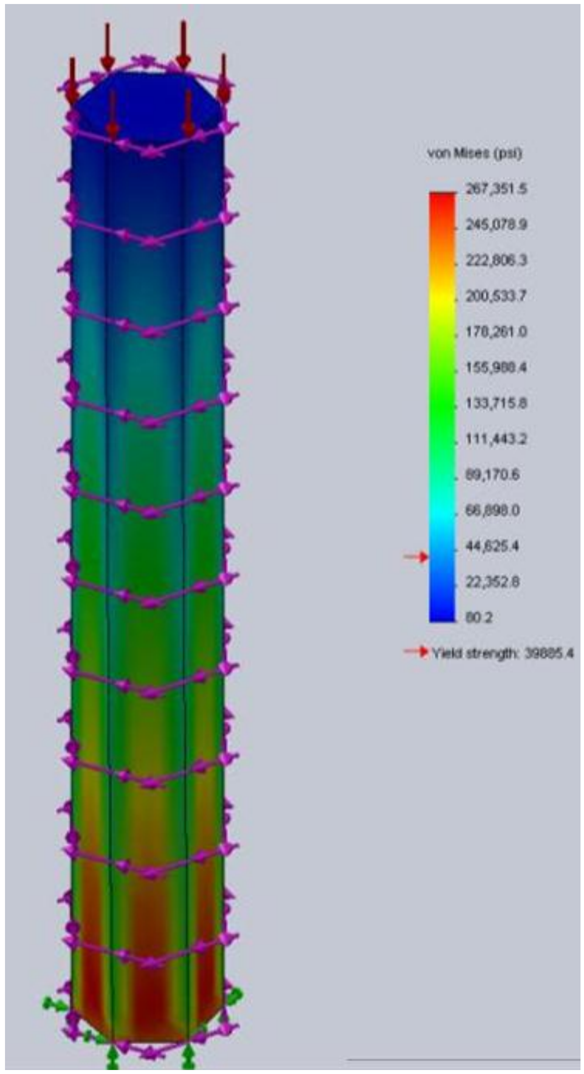


Figure 96: 1/8" Bit - Resultant Stress

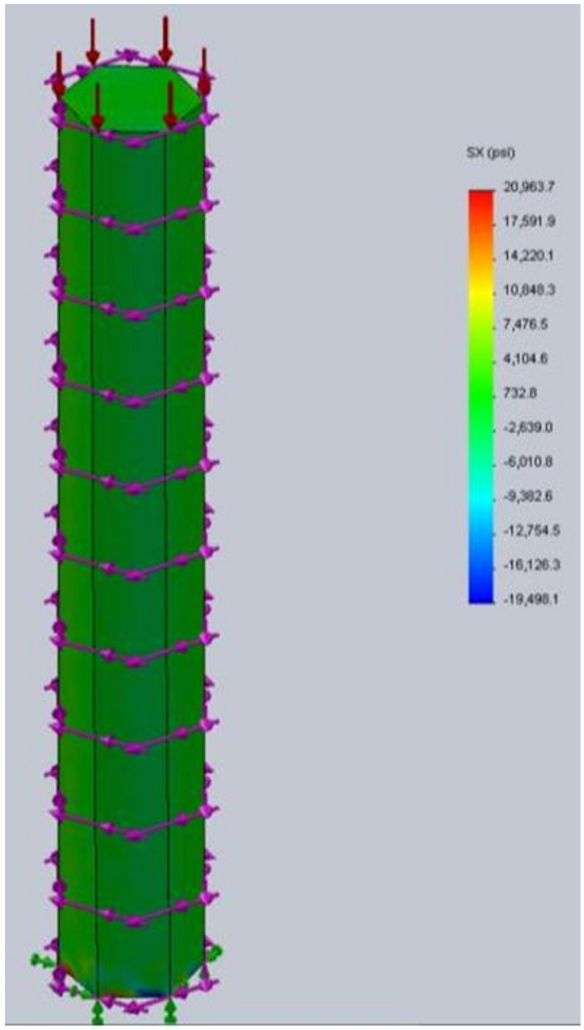


Figure 97: 1/8" Bit - Stress in the X-Direction

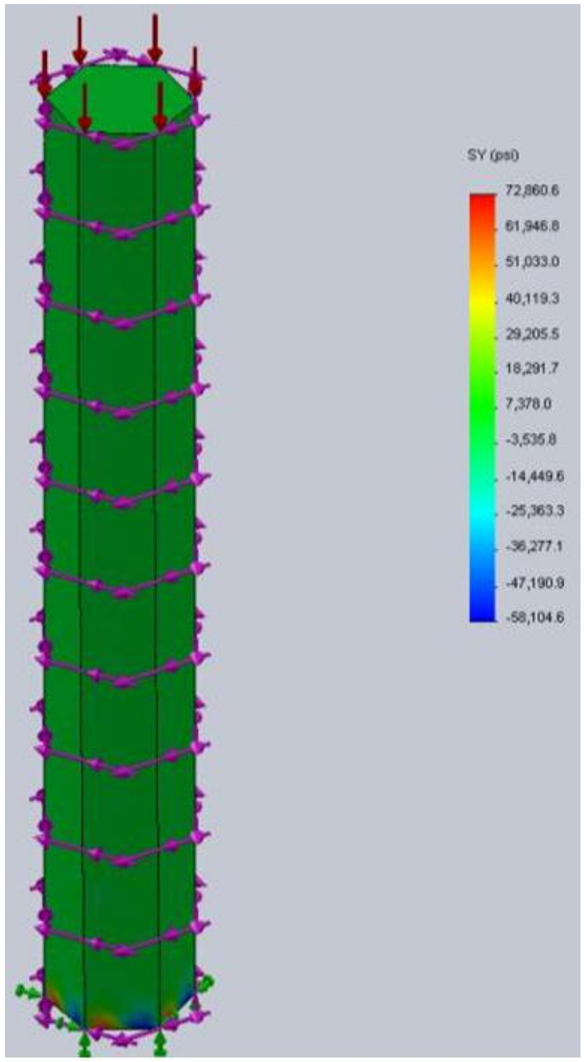


Figure 98: 1/8" Bit - Stress in the Y-Direction

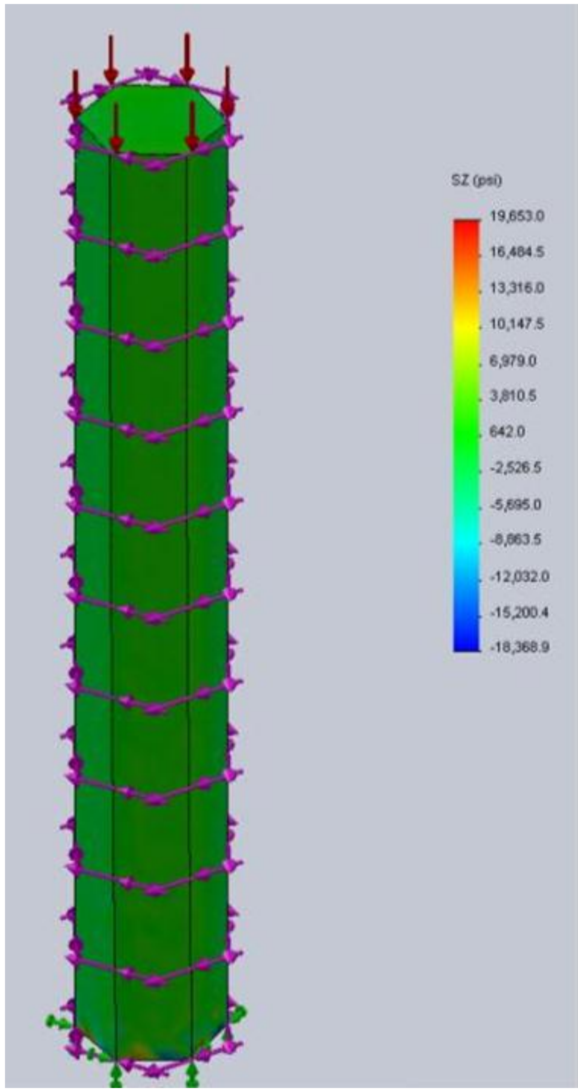


Figure 99: 1/8" Bit - Stress in the Z-Direction

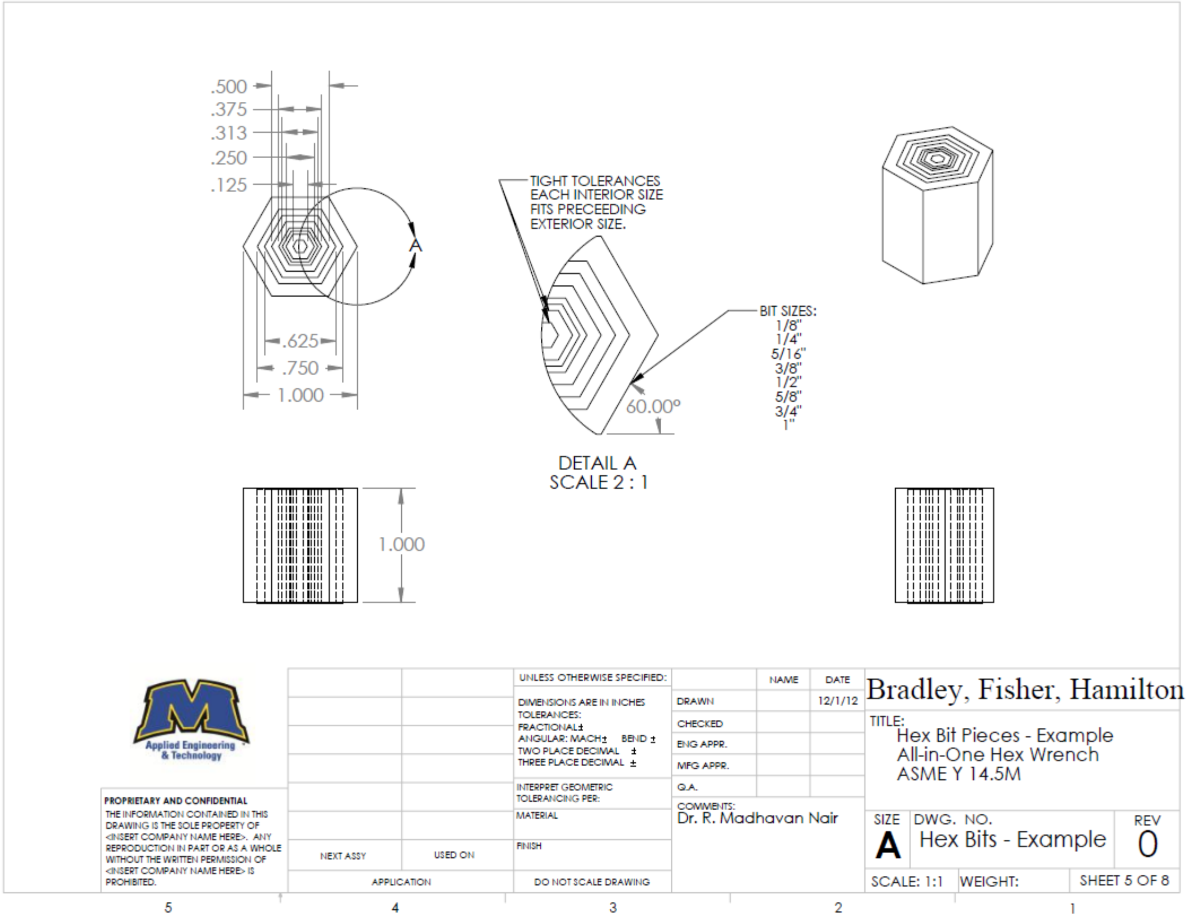
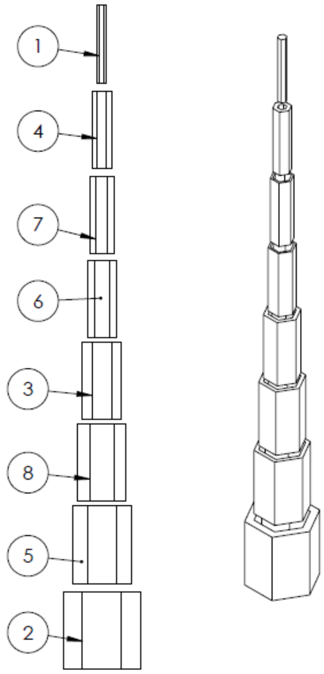


Figure 100: Hex Bit Subassembly Illustration

Note: The figure above and the following figure are for demonstration purposes. The "All-in-One Hex Wrench" uses a chuck piece to change hex bit sizes, but these figures are used to illustrate how the bit sizes will fit within one another and when a size is selected all the preceding sizes will provide the interior support for the bit as it is used. For our initial testing during this stage of the product development we have tested using the 1/8" hex bit only.



ITEM NO.	PART NUMBER	MATERIAL	QTY.
1	1-8 inch bit	AISI 347 ANNEALED STAINLESS STEEL	1
2	1 inch bit	AISI 347 ANNEALED STAINLESS STEEL	1
3	1-2 inch bit	AISI 347 ANNEALED STAINLESS STEEL	1
4	1-4 inch bit	AISI 347 ANNEALED STAINLESS STEEL	1
5	3-4 inch bit	AISI 347 ANNEALED STAINLESS STEEL	1
6	3-8 inch bit	AISI 347 ANNEALED STAINLESS STEEL	1
7	5-16 inch bit	AISI 347 ANNEALED STAINLESS STEEL	1
8	5-8 inch bit	AISI 347 ANNEALED STAINLESS STEEL	1

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TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		12/1/12
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:
Dr. R. Madhavan Nair

Bradley, Fisher, Hamilton

TITLE:
Hex Bit Pieces - Illustration
All-in-One Hex Wrench
ASME Y 14.5M

SIZE A | DWG. NO. Hex Bits | REV 0
SCALE: 2:3 | WEIGHT: | SHEET 6 OF 8

5 4 3 2 1

Figure 101: Hex Bit Subassembly Illustration - Exploded

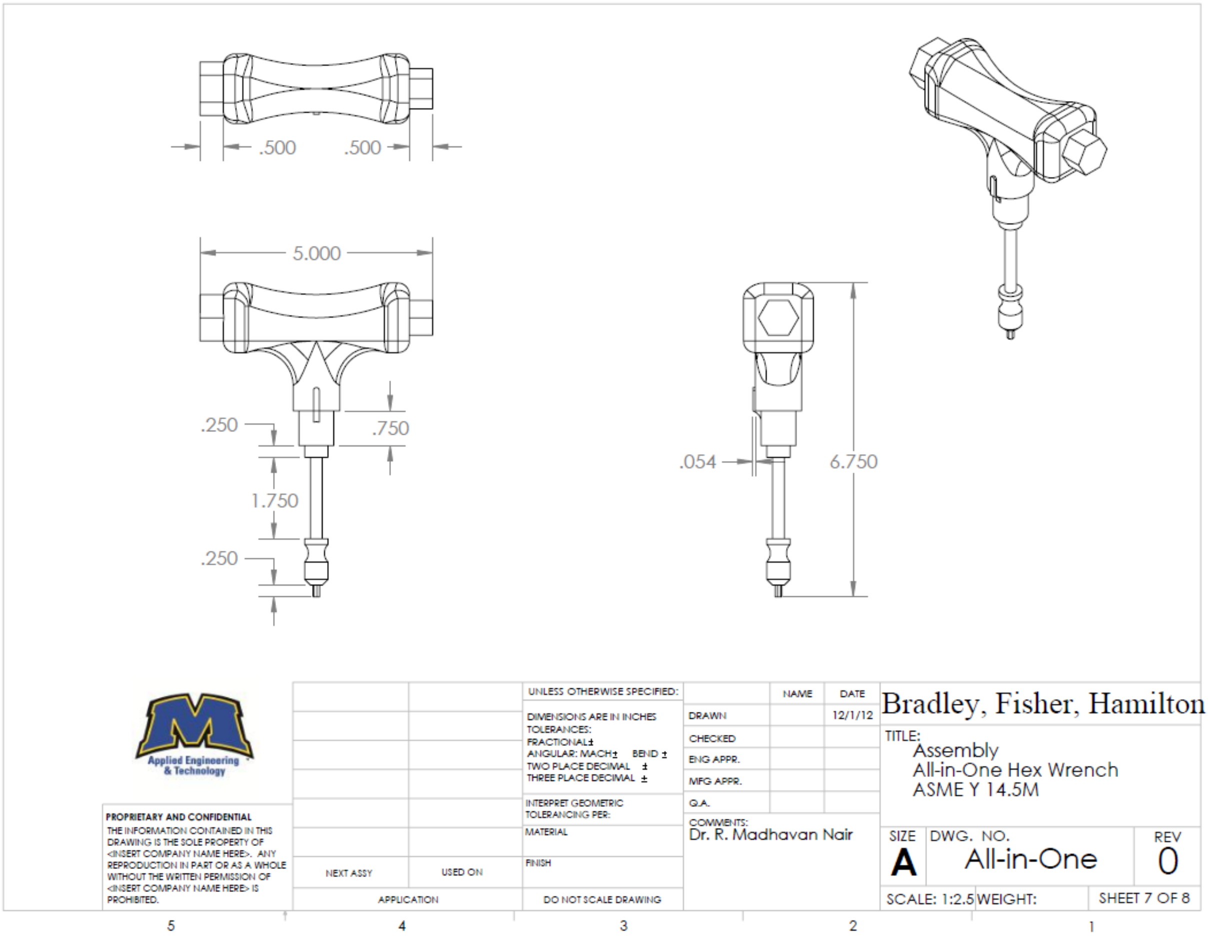


Figure 102: Assembly Dimensioned Drawing

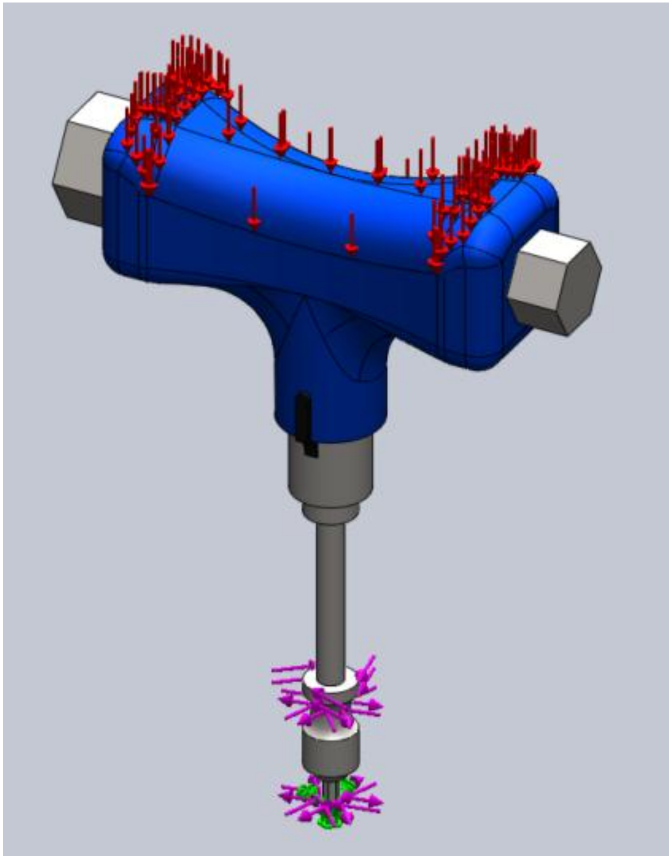


Figure 103: Assembly Forces Pre FEA

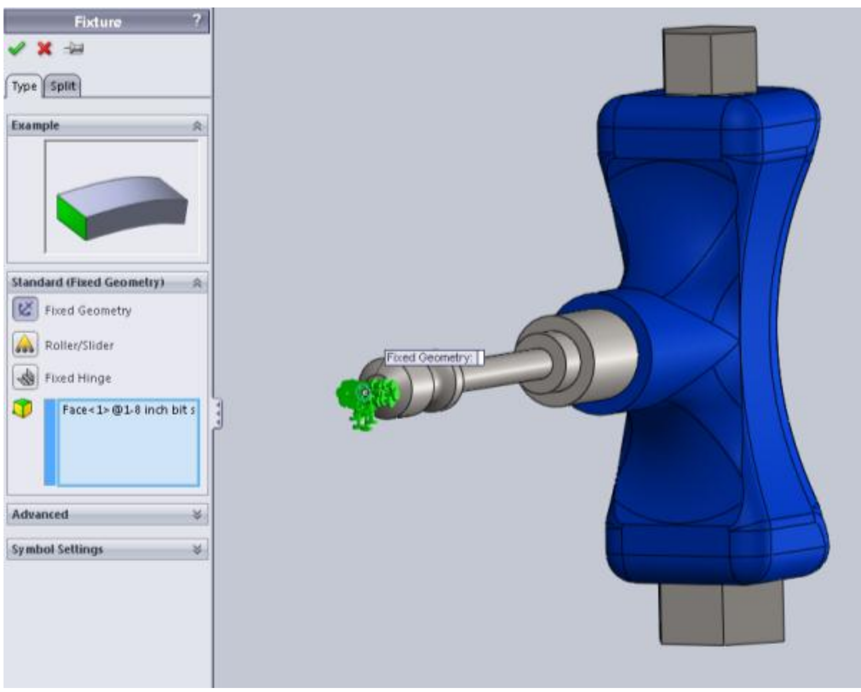


Figure 104: Assembly Applied Fixture

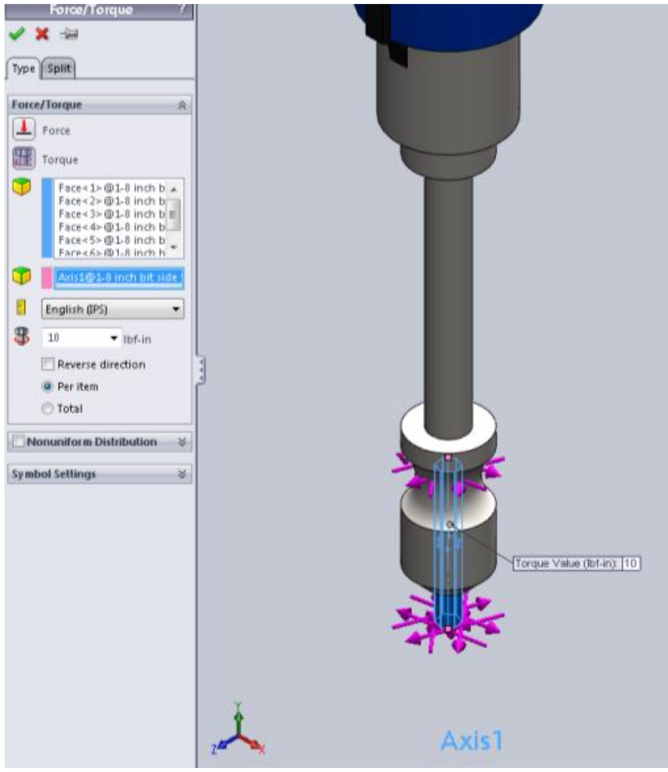


Figure 105: Assembly Applied Torque on 1/8" Bit

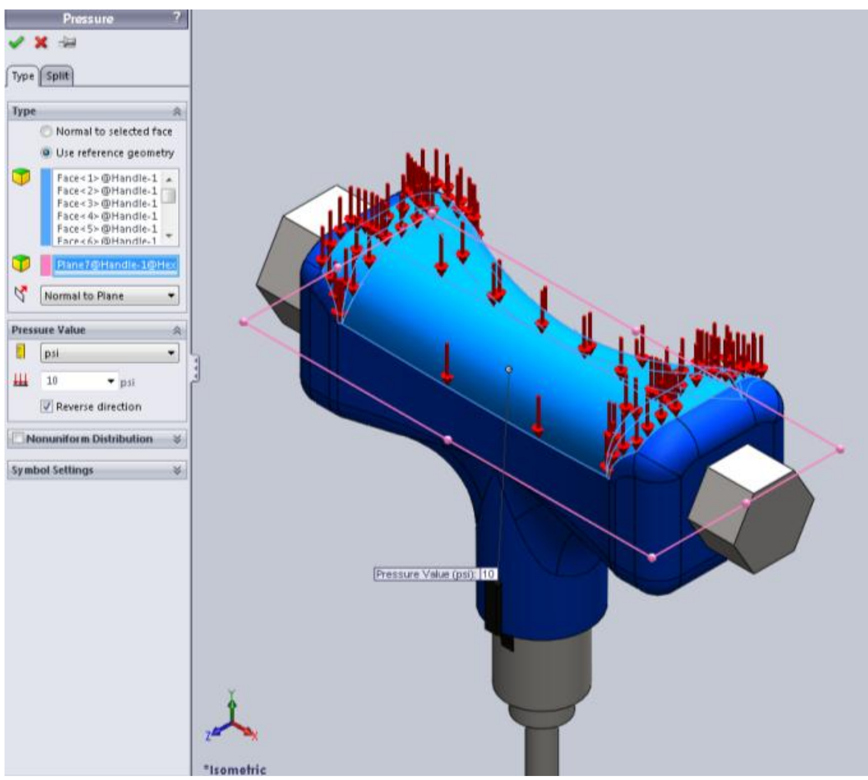


Figure 106: Assembly Applied Pressure

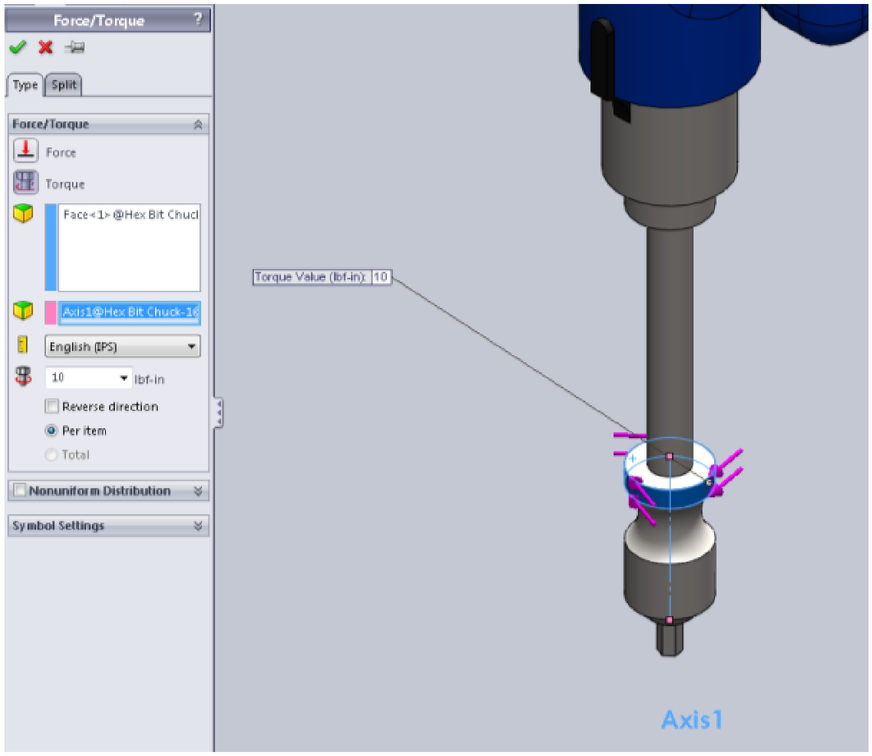


Figure 107: Assembly Applied Torque on Chuck

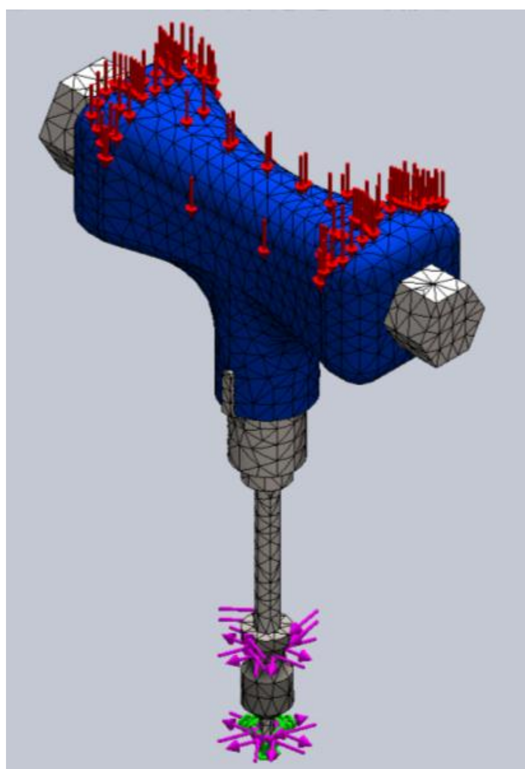


Figure 108: Assembly Meshed

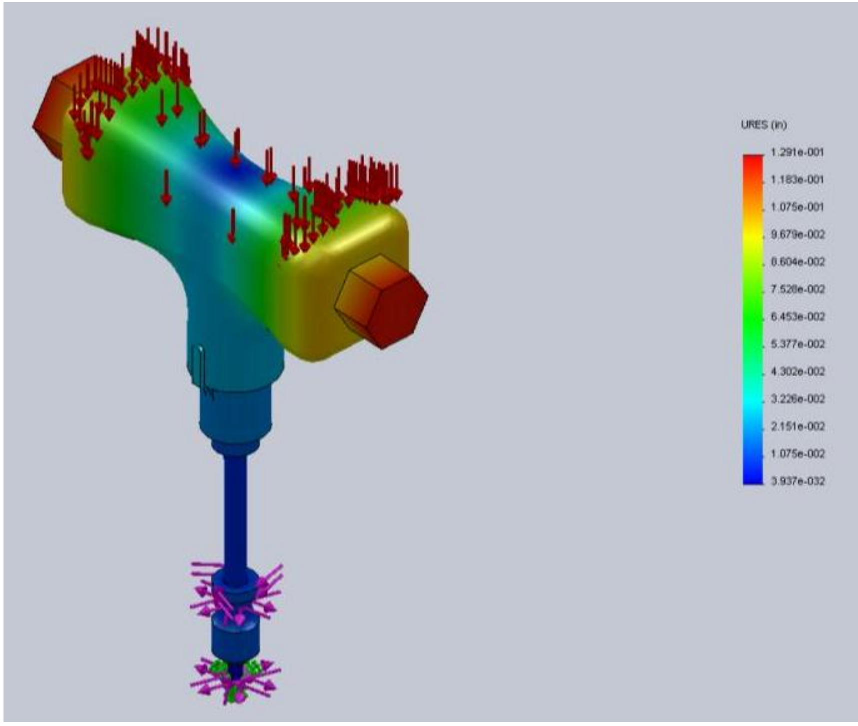


Figure 109: Assembly - Resultant Displacement

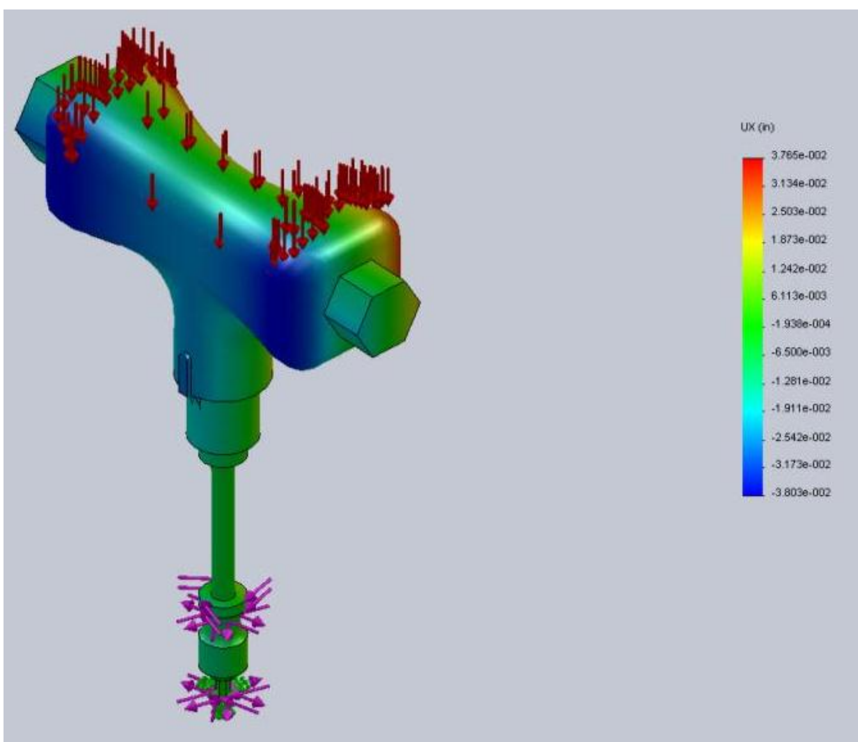


Figure 110: Assembly - Displacement in the X-Direction

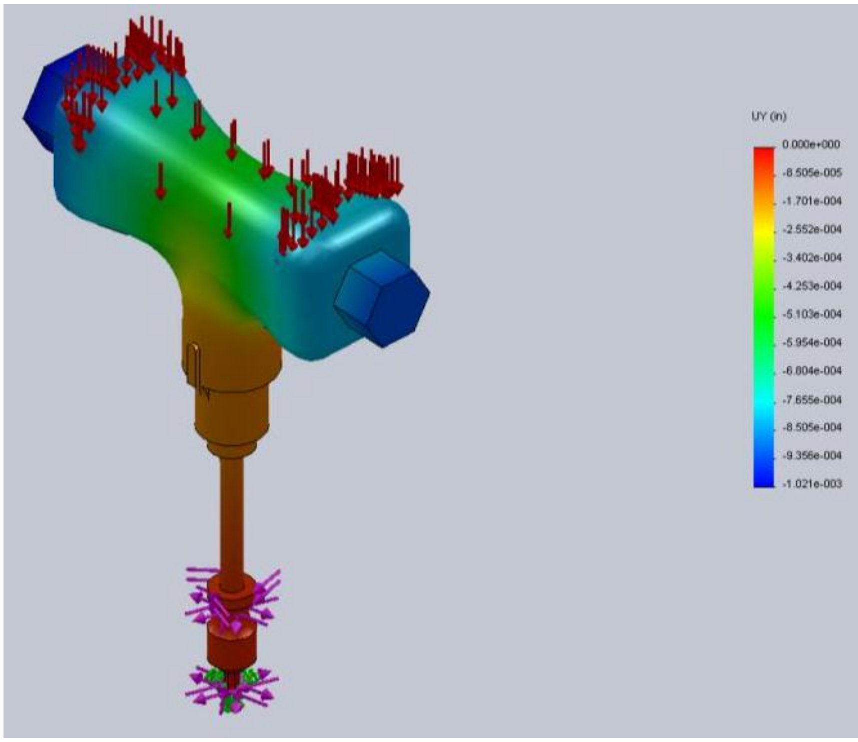


Figure 111: Assembly - Displacement in the Y-Direction

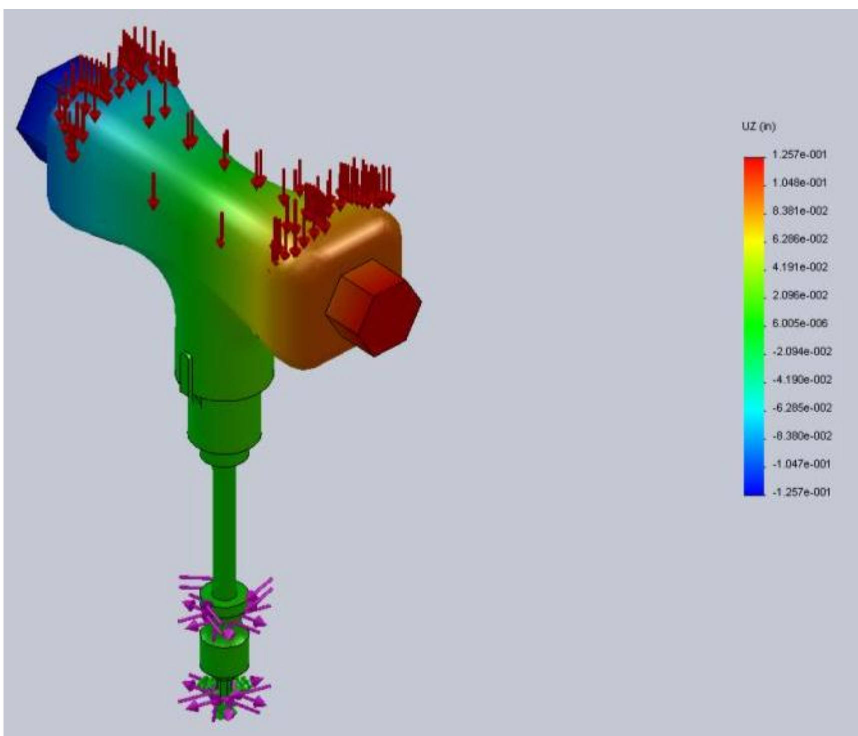


Figure 112: Assembly - Displacement in the Z-Direction

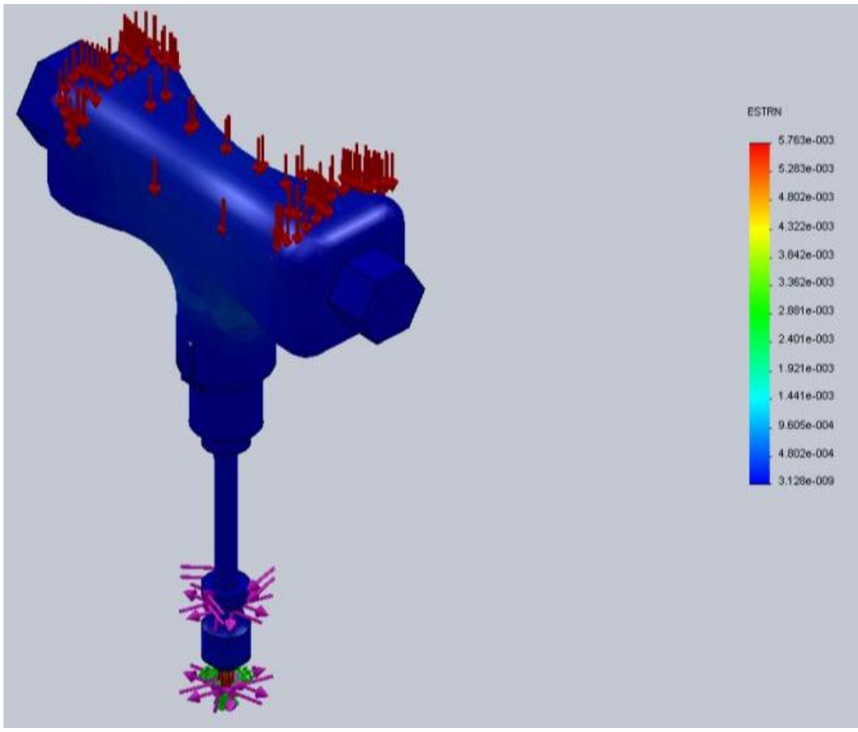


Figure 113: Assembly - Resultant Strain

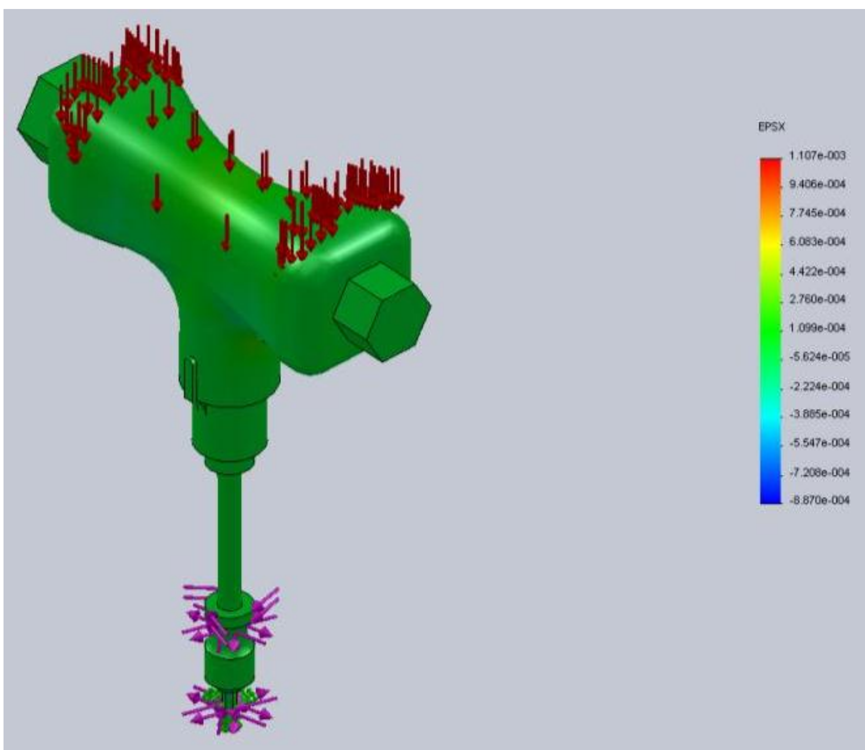


Figure 114: Assembly - Strain in the X-Direction

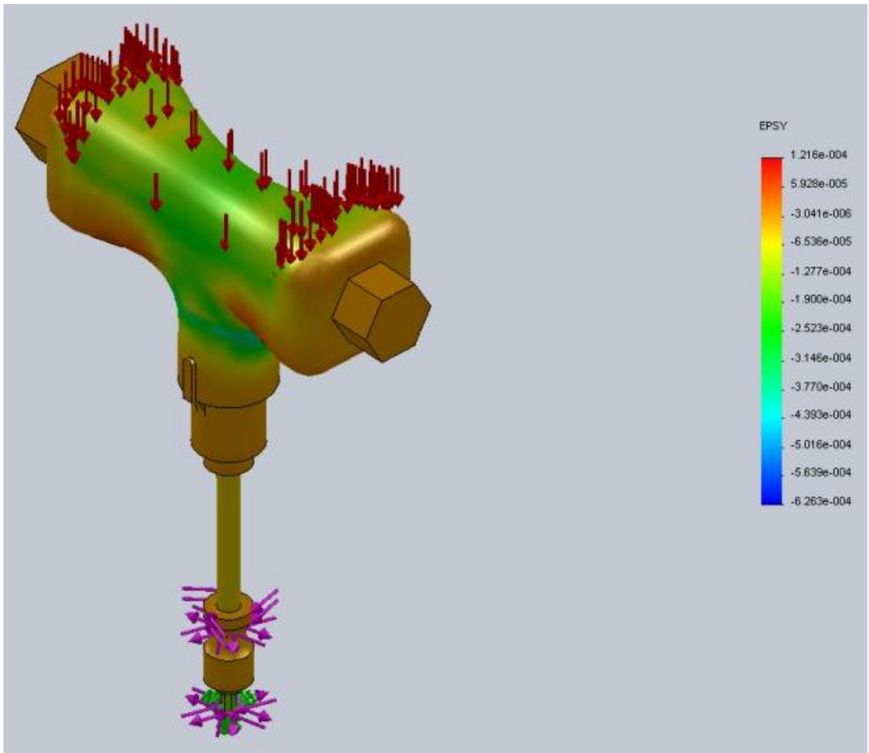


Figure 115: Assembly - Strain in the Y-Direction

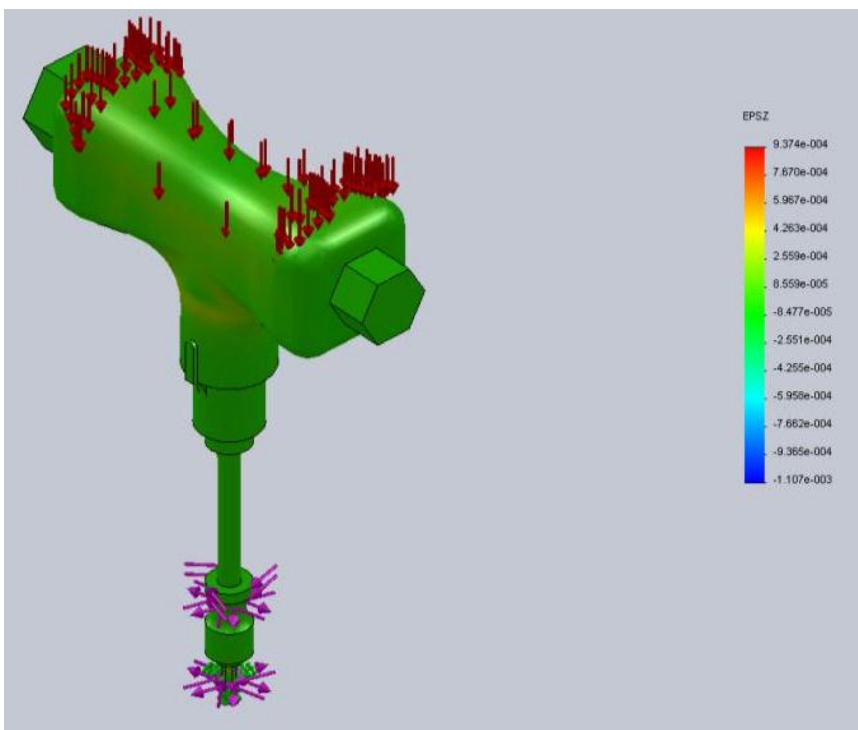


Figure 116: Assembly - Strain in the Z-Direction

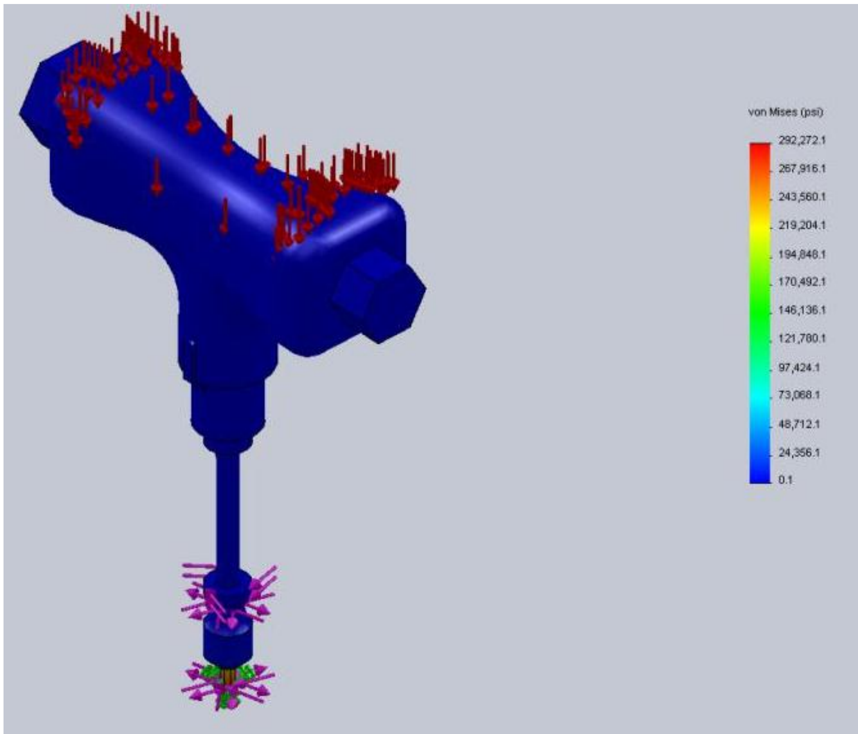


Figure 117: Assembly - Resultant Stress

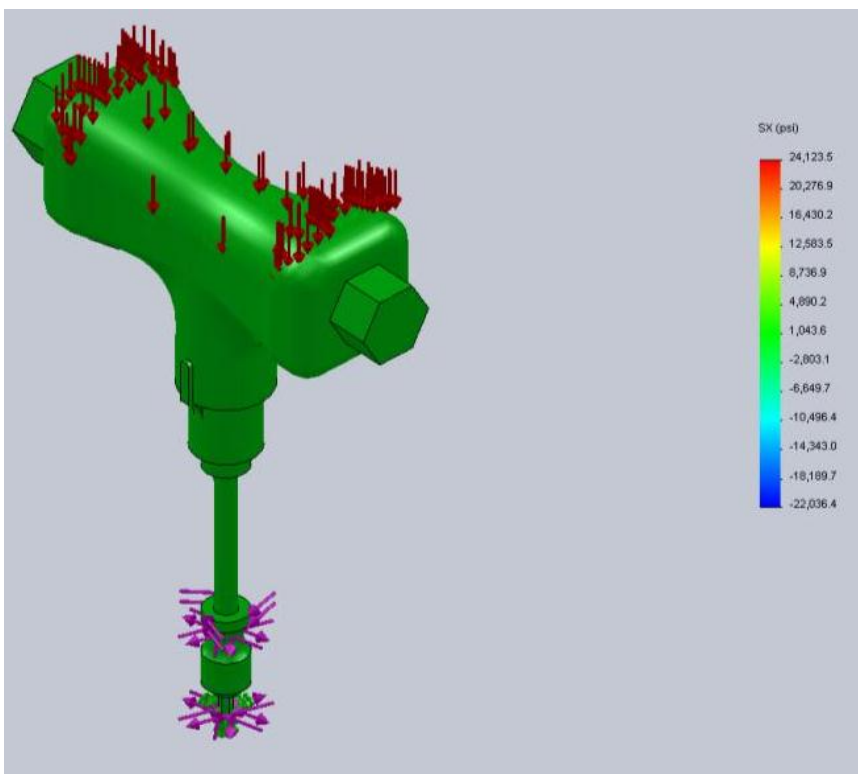


Figure 118: Assembly - Stress in the X-Direction

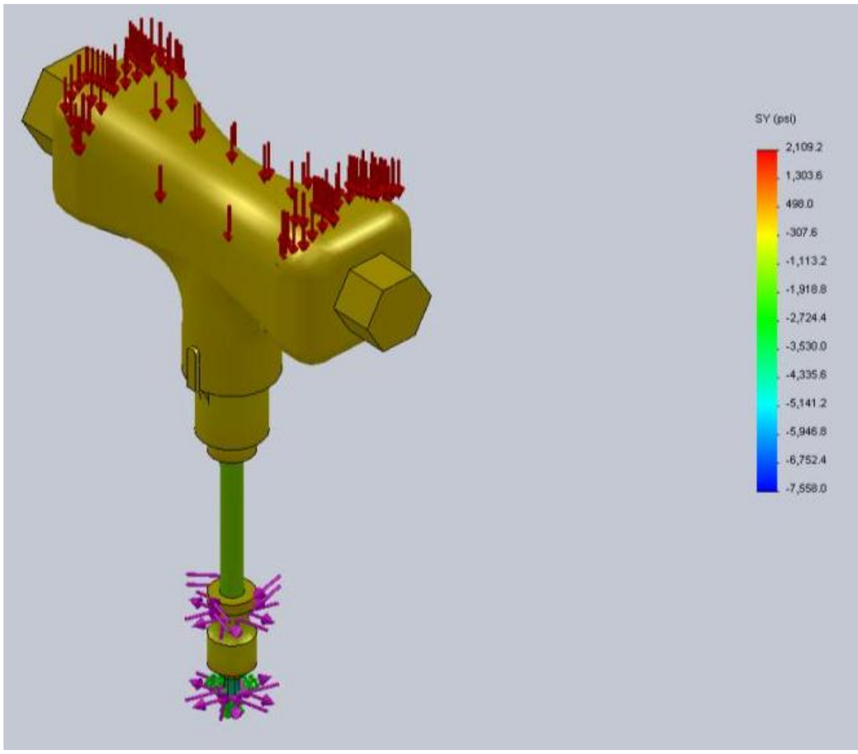


Figure 119: Assembly - Stress in the Y-Direction

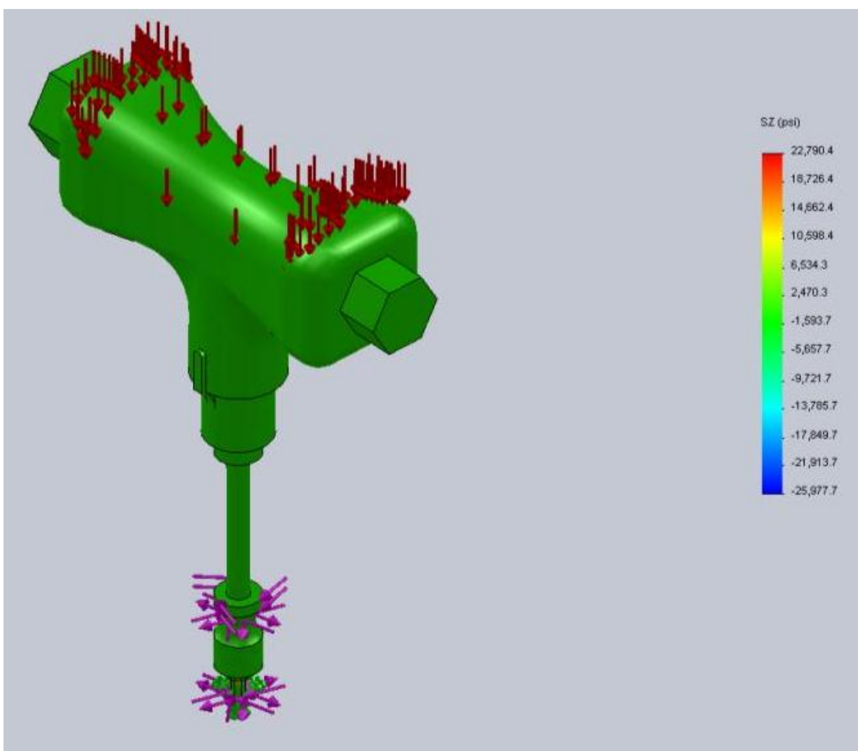
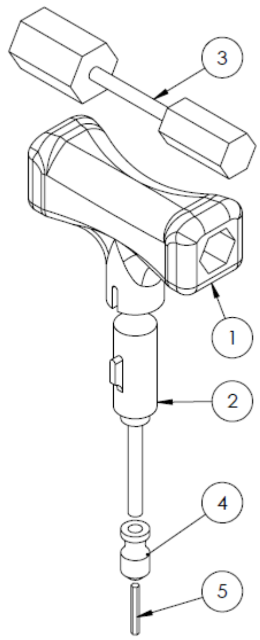


Figure 120: Assembly - Stress in the Z-Direction



ITEM NO.	PART NAME	DESCRIPTION	QTY.
1	HANDLE	SILICONE RUBBER	1
2	WRENCH PIN	AISI 316 ANNEALED STAINLESS STEEL	1
3	HANDLE BITS	AISI 347 ANNEALED STAINLESS STEEL	1
4	HEX BIT CHUCK	AISI 316 ANNEALED STAINLESS STEEL	1
5	1/8 INCH HEX BIT	AISI 347 ANNEALED STAINLESS STEEL	1

NOTE:
CHUCK ALLOWS FOR ADJUSTMENT
FOR VARIOUS HEX BIT SIZES SHOWN
HERE IS A 1/8" BIT FOR EXAMPLE PURPOSES.

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THREE PLACE DECIMAL ±
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MATERIAL
FINISH
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	NAME	DATE
DRAWN		12/1/12
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:
Dr. R. Madhavan Nair

Bradley, Fisher, Hamilton

TITLE:
Bill of Materials - Assembly
All-in-One Hex Wrench
ASME Y 14.5M

SIZE A | DWG. NO. All-in-One Assembly | REV 0

SCALE: 1:2 | WEIGHT: | SHEET 8 OF 8

5 4 3 2 1

Figure 121: Assembly Drawing with Bill of Materials

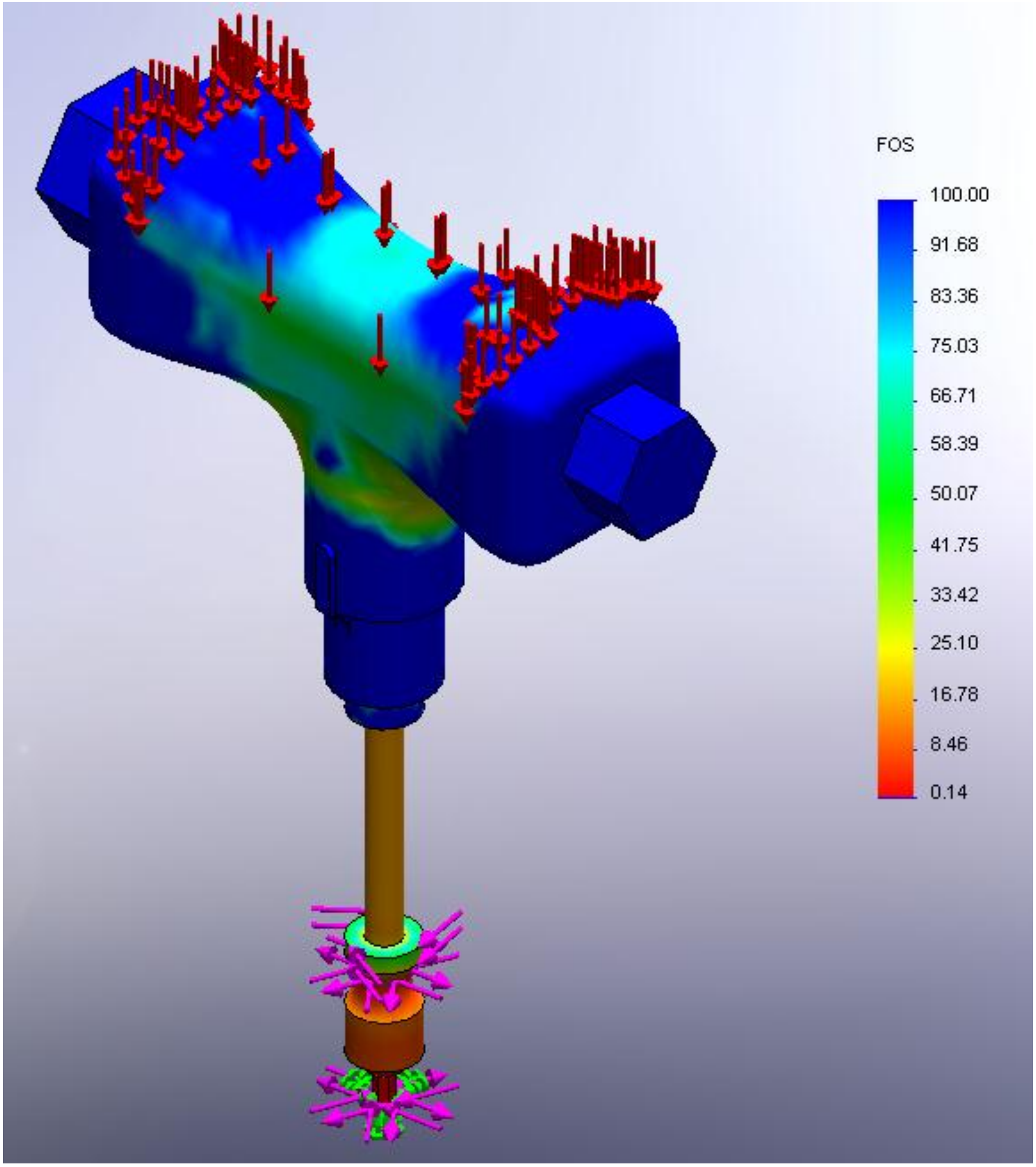

Figure 122: Factor of Safety Results

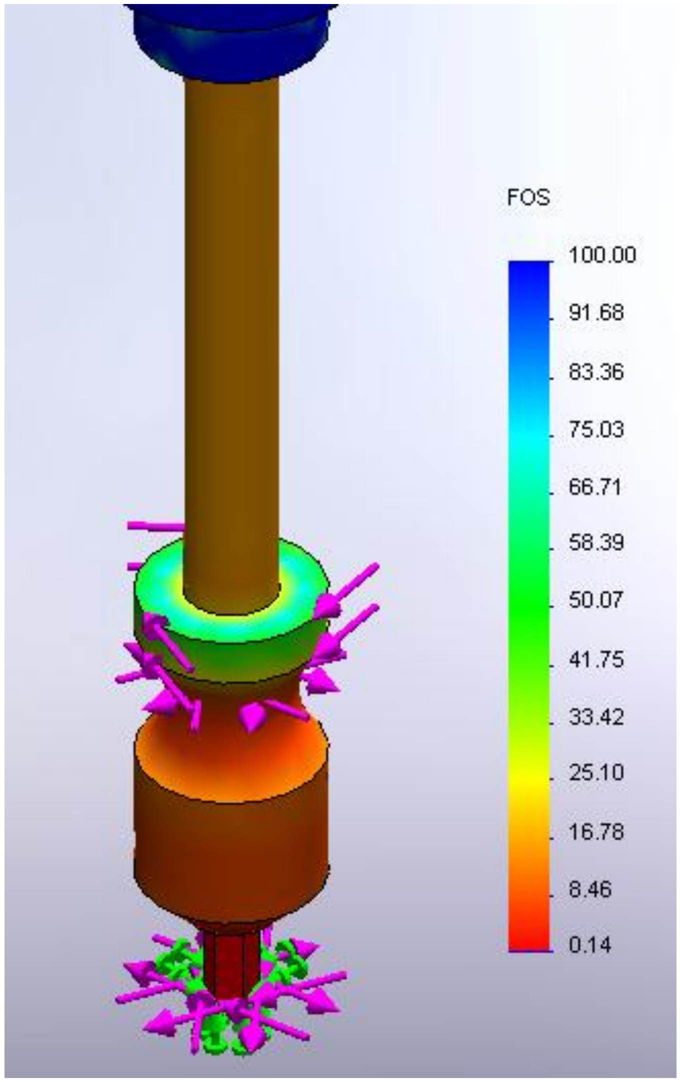

Figure 123: Close Up of Bit and Chuck - Factor of Safety

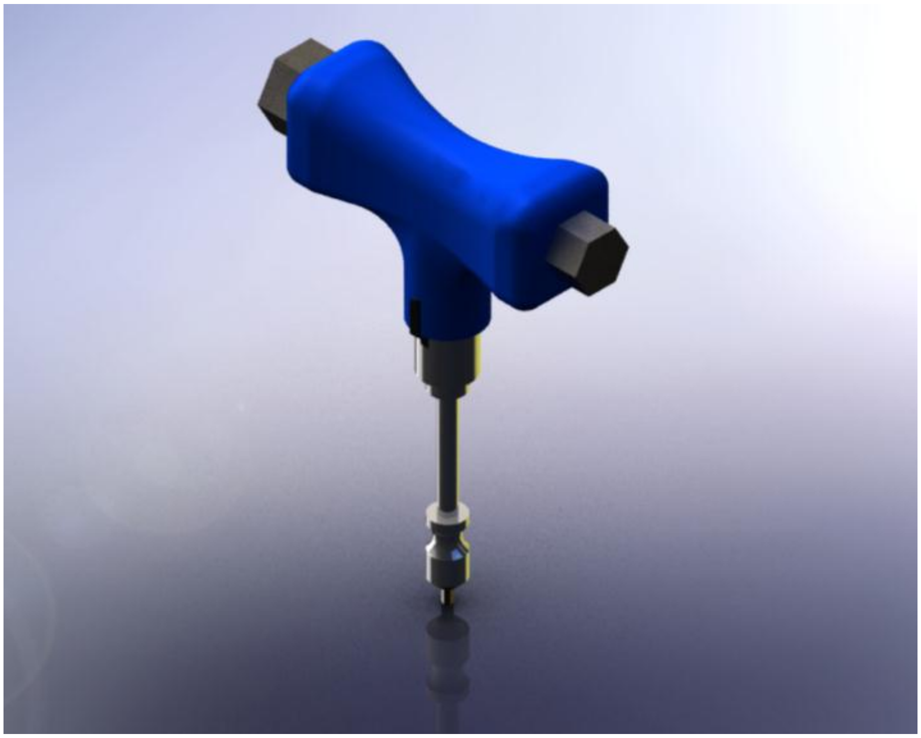

Figure 124: Rendered Isometric View of Assembly

Figure 125: Rendered Front View of Assembly

Figure 126: Rendered Right View of Assembly

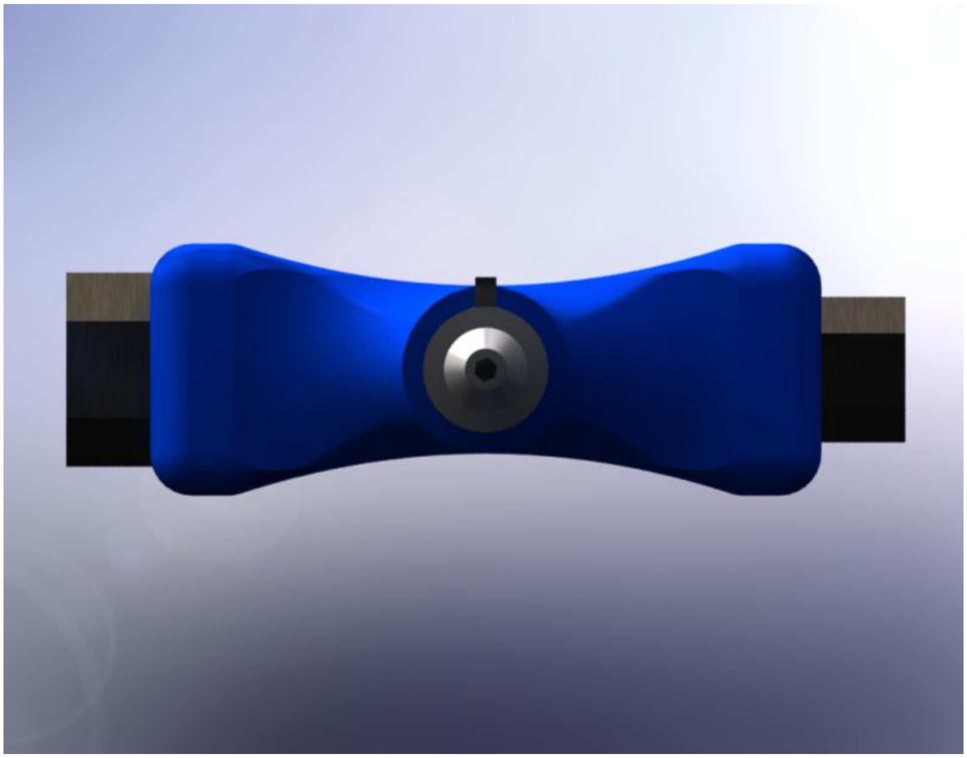

Figure 127: Rendered Bottom View of Assembly

Figure 128: Rendered Top View of Assembly

Figure 129: Rendered Trimetric View of Assembly

Figure 130: Close Up Rendering of Handle and Bit Piece

The FEA testing and results told us that all the individual components, with the exception of the 1/8" bit, passed testing. The smallest bit offered could not withstand the forces applied to it. This was also evident in the testing of the assembly. The bit was the only part of the assembly that appeared to fail. This was evident in our factor of safety test as well.

Rapid Prototyping

To further evaluate this product BFH Inc. would create a prototype of the assembly. The rapid prototyping method we would use for our product would be Fused-deposition modeling (FDM) for our initial prototype. We would use this type of RP process because the prototype would have basic mechanical properties and allow the company to review some basic movement properties of the prototype. Plus FDM produces a stronger prototype than some other methods such as laminated object modeling (LOM) or three-dimensional printing (3DP). We would use this model to get a hands-on idea of the overall size and grip of the product. (Dieter & Schmidt, 2009)

Once FDM is used and evaluated we would move on to a true working model of the wrench, and this would be initially produced using CNC lathe and mill methods to give us a more sturdy prototype to further evaluate.

The following image is the .stl file of our assembly that would be used to print the design.

Figure 131: STL File for Rapid Prototyping

<u>Synopsis</u>

This project goal is to develop an “All-in-One Hex Wrench” tool that will improve upon the basic Allen wrench design that is commonly used today. Our product will help increase the speed of use, be a durable product to last, and is a more compact design than most Allen wrench sets. The best design of five brainstormed design concepts was “developed” in this project.

Evaluation

The best design for this project was selected from our initial five brainstormed ideas and 3D models were created and evaluated using FEA within SolidWorks. During the FEA testing 10 psi of pressure was applied to necessary areas as was 10 lbf-in. All of the components except the 1/8" hex bit passed testing, which was due to the forces applied were too great for that small of a bit made of AISI 347 Annealed Stainless Steel. The rest of the assembly passed testing, therefore in future work the bit materials and forces for testing such a small bit would be reevaluated but the design itself would continue further to the creation of a rapid prototype (once the bit situation was solved) and further testing would occur. Overall we are happy with our design and believe it would be successful in the hand tool market.

Conclusion/Summary

BFH Incorporated's design of the "All-in-One Hex Wrench" is a product that will soon sweep the hand tool market. Multiple designs have been considered for the project but the strongest continued through the development phases. The tool is an affordable Allen wrench option for many types of users and as this project continues we will determine how sturdy of a product we have currently developed.

Once the FEA was completed it was determined that all of the components except the 1/8" bit passed testing, as all of the material's yield strengths (except the 1/8" bit) were greater than the highest amount of force on the components in the stress tests. The 1/8" bit is the smallest bit size BFH uses in the "All-in-One Hex Wrench." We decided to test the smallest size to see how it would hold up to greater forces than what are actually recommended for such size, and in turn the bit couldn't withstand them. Therefore we applied too much stress on the smallest tool and should have stepped it down as well as tried larger sizes. However overall the "All-in-One Hex Wrench" reached expectation as the rest of the components separately, and assembled, passed FEA testing. We believe if we were to product this product after reevaluating some of the bit properties that it would do well in the market.

<u>Future Work</u>

As stated in the conclusion, all components separately and in the assembly passed testing with the exception of the 1/8" hex bit. This tells us that we applied too great of forces to such a small bit. Therefore for future work we will do some more testing on other bit sizes to see if they can withstand the 10 psi torque and 10 lbf-in pressure, as well as test some other materials and step down the forces on the smallest bit to see how it does.

Signature Page

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Responsible for:

- Design Concepts
- Goals Section
- Project Tolerances
- Project Scope and Exclusions
- CAD Component Creation
- Part Drawings
- FEA
- Review/Revision
- Misc.

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- Design Concepts
- Company Profile Section
    - Product Specializations
    - Company Name
    - Mission Statement
- Product Specializations
- CAD Component Creation
- Part Drawings
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Samantha Hamilton

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- Project Organization/Formatting
- Design Concepts
- Problem Statement Section

- Planned Solutions
- Concept Screening, Scoring, and Combination Tables
- Synopsis Section
- Part/Assembly Drawings & Revisions
- FEA
- Renderings
- Rapid Prototype Section
- Review/Revision
- Misc.

References

Bondhus Corp. (2009). *Hex Key Comparisons*. Retrieved November 30, 2012, from Bondhus: http://www.bondhus.com/tech-library/body-10.htm

Dieter, G. E., & Schmidt, L. C. (2009). *Engineering Design* (4th ed.). New York, New York: McGraw-Hill.

Fastener Superstore. (2012). *Sockets Hex Keys & Bits*. Retrieved November 26, 2012, from Fastener Superstore: http://www.fastenersuperstore.com/productSheets/SocketsHexKeys.pdf

Foresman, P. S. (2008, February 24). *Allen Wrench and Screw (Image)*. Retrieved November 26, 2012, from Wikipedia: http://en.wikipedia.org/wiki/File:Allen_wrench_and_screw_(PSF).png

MatWeb. (2012). *Overview of Materials for Silicone Rubber*. Retrieved November 24, 2012, from MatWed Material Property Data: http://matweb.com/search/DataSheet.aspx?MatGUID=cbe7a469897a47eda563816c86a73520&ckck=1

Pasquesi, A. (2012). *How Are Allen Wrenches Made?* Retrieved November 26, 2012, from eHow: http://www.ehow.com/how-does_5768909_allen-wrenches-made_.html

Appendix

The following chart provides the Torsion Shear Average and Torque Rating of standard hex key wrenches. This information will be referenced for our FEA analysis.

Table 7: Torsional Sheer and Torque Ratings for Typical Allen Wrenches. Source: (Fastener Superstore, 2012)

HEX KEYS AND BITS		Blue Devil®
Nominal Size	Torsional Shear Average (Inch-Pounds)	Torque Rating (Inch-Pounds)
.028	1.1	.86
.035	2.3	1.80
.050	6.5	5.00
1/16	11.9	9.50
5/64	25.0	19.40
3/32	43.0	33.50
7/64	68.0	52.90
1/8	98.0	77.90
9/64	146.0	117.00
5/32	195.0	156.00
3/16	342.0	273.00
7/32	535.0	428.00
1/4	770.0	615.00
5/16	1,600.0	1,315.00
3/8	2,500.0	2,150.00
7/16	4,500.0	3,665.00
1/2	6,300.0	5,130.00
9/16	8,750.0	7,010.00
5/8	12,000.0	9,810.00
3/4	19,500.0	15,570.00
7/8	29,000.0	23,400.00
1	43,500.0	35,100.00