MECH 4860

Final Design Report:

Modular Hip Joint Testing Apparatus

Sponsor: Concordia Hip and Knee Institute

Contact: Dr. Urs Wyss

Advisor: Dr. Paul Labossiere

Team #4 - Hip Check

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Date of Submission: December 6, 2010

Greg Toews

Dec. 6, 2010

Professor Urs Wyss
Modular Hip Joint Testing Apparatus
Department of Mechanical Engineering
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Dear Professor Wyss:

On behalf of Team 4 in the MECH 4860 Engineering Design course, I would like to present the final report, “Modular Hip Joint Testing Apparatus”. The final report was submitted on Monday, December 6th, 2010.

The purpose of this report is to detail our design of a fixture to hold a variety of artificial hip stems in various orientations for fatigue testing. The report also contains the design for a fluid bath with the option to purchase an off-the-shelf system. Fatigue analysis was performed at the point deemed most likely to fail. However, this is a preliminary analysis. We recommend a more detailed analysis before proceeding with the manufacture of the design.

We would like to thank Professor Paul Labossiere for his technical expertise and support in his role as our advisor.

If there are any questions or concerns regarding the report, please do not hesitate to contact me at or umtoew21@cc.umanitoba.ca. All other team members can be reached through JUMP and will be eager to answer any questions or clarify any concerns.

Sincerely,

Greg Toews

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Abstract

This report details the design of a modular hip joint testing apparatus for the Concordia Hip and Knee Institute. Current methods of fatigue testing of artificial hip joints primarily focus on applying compressive axial loads onto the head of the hip joint in order examine the head/stem connection. Dr. Urs Wyss, in association with the Concordia Hip and Knee Institute, requires a testing apparatus capable of applying both compressive and tensile axial loads to the test specimen. The design of the testing apparatus focused on three aspects; mounting the top of hip joint, mounting the bottom of the hip joint, and the fluid bath that surrounds the hip joint. The top fixture consists of two plates made of 316 stainless steel that are secured together with three screws in a tripod configuration around the head of the hip joint. The bottom fixture consists of two main components; the stem holder and base, both of which are made of 316 stainless steel. The stem holder is an adjustable component that can slide along the length of the base in order to align the line of action between the top fixture and the bottom fixture. The fluid bath selected was an off-the-shelf component, a Bionix Environbath [3] courtesy of MTS Systems Corporation. The specifications for the Bionix Environbath were not available for compatibility test with the fixtures, therefore an alternative design, a fluid bath case made of acrylic glass and held together with aquarium adhesive is detailed as well. A preliminary analysis has shown that the diameter of the stem must increase in size from 14 mm to no less than 16 mm due to the high bending stress. Further analysis of the specimen and fixture using FEA software is needed to determine the actual stresses present within the stem and on the stem holder. Assuming it is compatible with the fixture, the Bionix Environbath is the best choice for the fluid bath because it incorporates the bath, circulating pump, reservoir, and temperature control in one off-the-shelf package.

1. Introduction: Problem Definition

Dr. Urs Wyss, in conjunction with the Concordia Hip and Knee Institute, is in need of a test apparatus capable of fatigue testing in a corrosive environment. As the population ages, artificial replacement of joints, hips in particular, have become more prevalent. Initial hip replacements were designed to be one-part constructions. One-part construction eliminates the metal on metal interface, and thus fretting and crevice corrosion. However, the disadvantage was that fitting the artificial hips was difficult, and adjusting the hip over time was near impossible. Newer hip designs are modular, allowing for better fit and adjustment, but the drawback is corrosion at the connections. Dr. Wyss and the Concordia Hip and Knee Institute hope to reduce fretting corrosion at the connections in newer hip designs, and the test apparatus will aid them in gathering useful data. An example of a modular hip replacement is shown below in Figure 1.

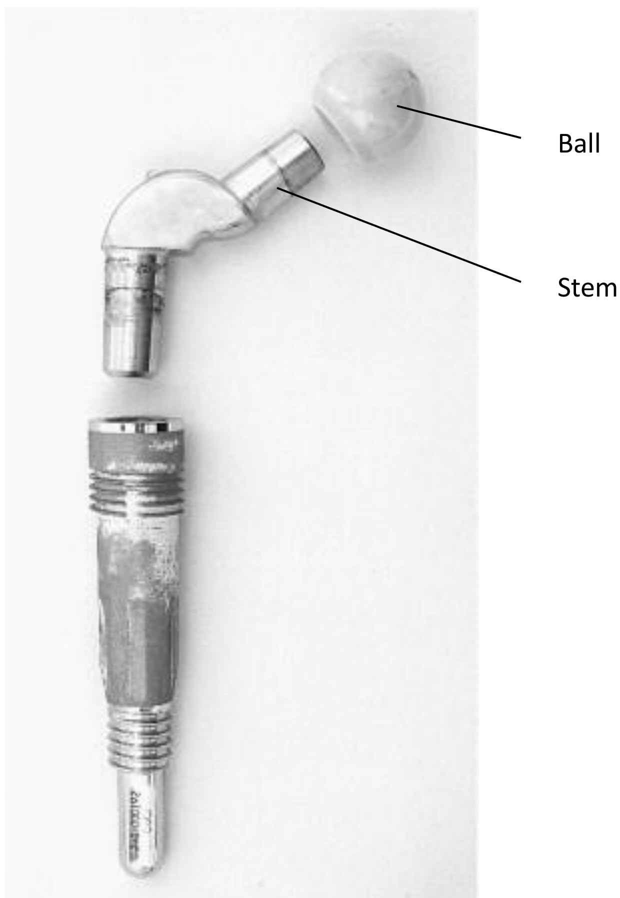


Figure 1. Exploded view of double tapered cone Margron Prosthesis. Head alumina, ASTM F603-00; stem and neck, ASTM F799-06 [1].

1.1 Problem Statement

Modular connections of artificial joints show signs of corrosion after a period of time. Crevice corrosion and/or fretting corrosion are the most common. While in the body, the joint is stressed axially in tension and compression. The artificial hip needs to be tested in an environment that can simulate the loads that will be placed on the hip 'in vivo' in order to determine the effects of fatigue loading in various directions on fretting corrosion of the stem.

1.2 Project Objectives

The primary objective of the project is to deliver a design that satisfies the client's needs as defined in Appendix A – 1 of this report. The expectations for the chosen concept design require that all of the necessary criteria in the target specifications are met, while attempting to fulfill the preferable criteria. Staying within the initial cost constraint of 2000 dollars will depend upon external factors such as material costs, machinist labour (time and wages), as well as any other unforeseen additional costs.

2. Background

Artificial hip replacements have been moving towards more modular designs, using a tapered neck and various head sizes. The advantages of a modular design include reduced cost of manufacture and the ability to adjust leg length. However, one major issue with increasing modularity is fretting and crevice corrosion at the interface of components. Stagnant areas develop at the interfaces, resulting in a depletion of oxygen. The dissolution of metal ions in these areas continues leading to increased concentrations of metal chloride within the crevice. Dissolution of metal ions increases causing accelerated corrosion in the stagnant area. An example of fretting corrosion of the stem can be seen below in Figure 2.

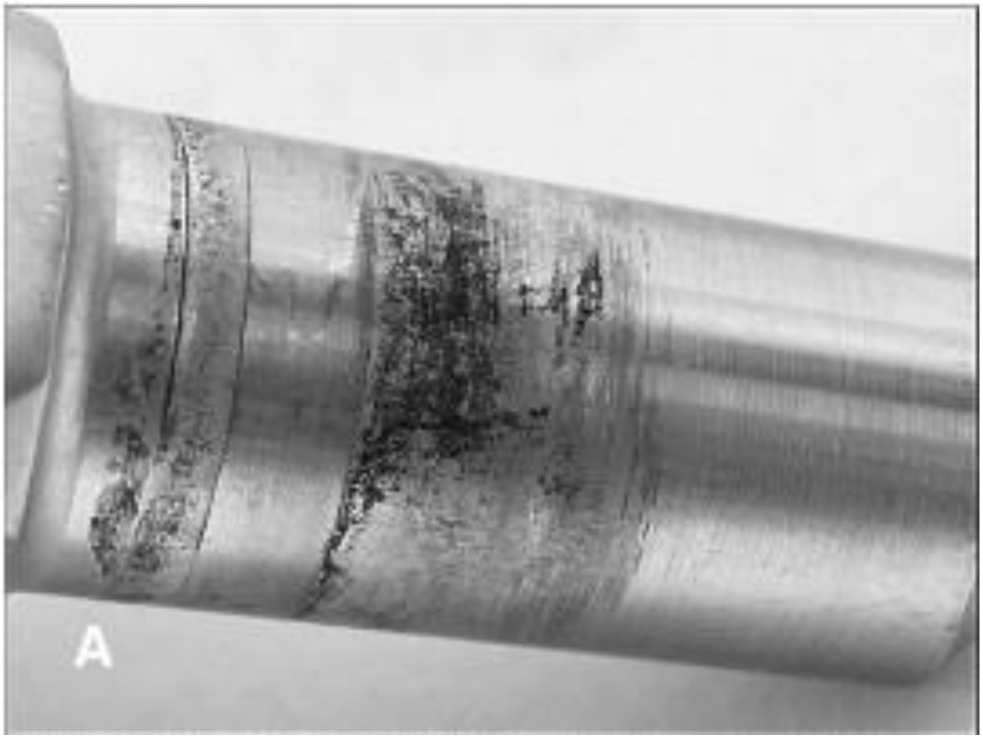


Figure 2. Macrostructure of neck-stem taper [1].

3. Details of Design

This section contains the details of the final design for the test apparatus, which discusses the main subsystems of the design, specifically the fixture and the fluid bath, as well as the work instructions needed to assemble the test apparatus.

3.1 Fixture

The fixture consists of three separate parts which hold the test sample. The three main components are shown and explained individually in the following sections.

3.1.1 Bottom Fixture

The bottom fixture is made from 316 stainless steel like the rest of the assembly. The base of this fixture must attach to the anvil of the load frame. There are two slots in this fixture. Screws will be used through these slots to secure the stem clamp to the bottom fixture. These slots allow the stem clamp to be adjusted so that the test sample is directly in the line of applied force of the load frame. A fillet is located at the inside corner of the fixture. This fillet significantly reduces the stress concentration in that area. Detailed drawings of the bottom fixture can be found in Appendix D.

3.1.2 Stem Clamp

There are 13 different Stem Clamps. Each stem clamp features a hole to be bored at a different angle, from 30° to 90° in increments of 5°. These stem clamps are made from 316 stainless steel and are all attached to the bottom fixture in the same way. The tolerances of the shaft hole must be very tight to the size of the shaft. Because these tolerances will be very tight, the slot can be reduced to a simple saw cut. The width of this cut can be very thin because the deflection from the clamping force on the sample will be extremely small. This is again because of the very tight tolerances between the hole and the shaft. The clamping force on the shaft will be provided by a number of horizontal screws through the base. Detailed drawings of the stem clamp can be found in Appendix D.

3.1.3 Top Fixture

The top fixture must attach securely to the cross head of the load frame. The top fixture consists of two parts. The bottom clamp of the top fixture is similar to the top side. The radii of curvature of the concave surfaces on the insides of the top fixtures have been oversized to match all required sizes of test ball. There are three screws which are used to clamp the fixture to the test ball. The slotted lower fixture allows for the test shaft to be rotated through all the required test angles. Because of these factors, these top fixtures will function for all test angles and ball diameters. Detailed drawings of the top fixture can be found in Appendix D.

3.2 Fluid Bath

This section discusses the main components of the fluid bath subsystem, specifically, the fluid bath casing and the fluid circulation system.

3.2.1 Fluid Bath Casing

The bath casing recommended for use with the apparatus is the MTS Bionix EnviroBath. More information on this product can be found in Appendix F.

In the event that the Bionix EnviroBath cannot be made to accommodate the apparatus, a casing can be made of acrylic glass. Acrylic glass has many advantages over glass. It is 17 times stronger, 50% lighter, and insulates 20% better than glass [2]. In addition, the resin used to seal sections together chemically bonds the surfaces together, making for a strong, leak-proof seal.

The construction features an open top. Floating plastic beads can be added to the bath to provide some degree of insulation. The primary reason for an open top is to allow the system to “breathe”, reducing the odours associated with stagnant pools of organic liquids. A secondary benefit is that it will simplify the addition of fluid as the fluid evaporates.

The bath should be constructed as laid out in the “Work Instructions” and as shown below in Figure 3.

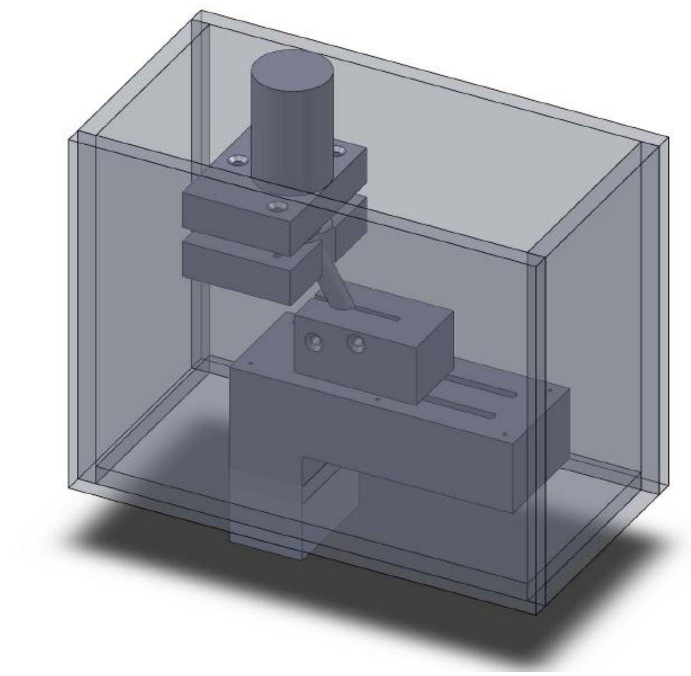


Figure 3. Design of fluid bath.

Aquarium glue should be used to bond the edges of the glass sections together, and caulking should be used to seal any areas that require it.

3.2.2 Hydraulic Power Unit - 505 G2

This is an off-the-shelf product supplied by MTS. It is provides functions of circulator pump, heater, and temperature sensor in one package. Detailed specifications for the HPU can be seen below in Table I.

TABLE I
HYDRAULIC POWER UNIT – 505 G2 [3]

Model	505 G2
Flow rates (60Hz model)	41.6 lpm
Reservoir capacity (maximum)	174 L
Width	71 cm
Height	107 cm
Length	99 cm
Weight with maximum oil	474 kg
Motor starter configuration	Wye-Delta
Motor size	18.5 Kw
Heat exchanger	Stainless steel plate style
Hydraulic connections	Pressure & Return: 12 ORFS
Cooling water connection	2 cm

3.3 Work Instructions

The following is the recommended procedure for assembling the test mechanism.

Step 1: Assemble all materials and tools as listed below.

Materials

- Bottom Fixture
- Top Fixture
- Top Fixture Bottom Clamp
- Stem Clamp
- Test Sample Ball
- Test Sample Shaft
- 5 sheets acrylic glass (bottom, 4 sides)
- MTS Bionix fluid bath accessories (heater, reservoir, pump & controls)

Tools

- Slotted screw driver
- Silicone Caulking
- Aquarium glue

Step 2: Attach test sample ball and shaft

Step 3: Place test piece in the Top Fixture and attach the Bottom Clamp with screws. Do not tighten the screws yet. The ball should be able to rotate will little force.

Step 4: Slide the shaft into the Stem Clamp Tighten the screws in the Stem Clamp securely.

Step 5: Fix bottom sheet of acrylic glass to bottom fixture. Seal with caulking.

Step 6: Attach Bottom Fixture to the load frame

Step 7: Attach the Stem Clamp to the Bottom Fixture. Do not tighten the screws yet. The Base should be able to slide will little effort.

Step 8: Align the ball with the load frame line of applied force and tighten all screws in the Top fixture and the Bottom Fixture.

Step 9: Double check the tightness of all screws and the alignment of the ball with the line of applied force.

Step 10: Assemble sides of bath case using remaining sheets of acrylic glass. Bond with aquarium glue and seal with caulking.

Step 11: MTS Bionix fluid bath accessories (heater, reservoir, pump & controls) should be assembled per manufacturer's instruction.

4. Conclusion and Recommendation

The loading fixture that was designed for fatigue testing, was designed for a 14 mm diameter stem. Preliminary stress calculations revealed that the stem diameter was insufficient to withstand the applied load, requiring an increase in stem diameter to at least 16 mm. This increase in stem diameter requires a change in the diameter of the bored hole in the stem holder. This increase in hole diameter may require a change in the positions of the screws that tighten and secure the stem to the bottom fixture. The stem holder may also need to be increased in size.

The fluid bath has two options; use the bath that MTS [3] supplies, or use the bath design that was developed by the design team, while incorporating the pump, heater, reservoir, temperature sensor, and the load frame from MTS.

Further analysis and design changes to the stem holder are required, specifically the use of FEA software. A compatibility test based on the dimensions and technical specifications for the MTS Bionix Environbath with respect to the loading fixture must be conducted. If the compatibility test fails, then the fluid bath casing that was designed should be used along with the accessories supplied by MTS.

Research and References

[1] A. M. Kop, and E. Swarts. (2009). "Corrosion of a hip stem with a modular neck taper junction," *The Journal of Arthroplasty* [Online], vol. 24 (7), pp. 1019-1023. Available: ScienceDirect [October 26, 2010].

[2] "What is the Difference Between Acrylic and Glass Aquariums?" in *Wisegeek* [Online]. Available: http://www.wisegeek.com/what-is-the-difference-between-acrylic-and-glass-aquariums.htm [December 4, 2010].

[3] J. Shoust. (2010, Nov. 18). "RE: MTS EnviroBath Options." Personal e-mail.

[4] "Erosion corrosion," in *Wikipedia,the Free Encyclopedia* [Online],September 10, 2010. Available: http://en.wikipedia.org/wiki/Erosion_corrosion [October 27, 2010].

[5] "Crevice corrosion," in *Wikipedia the Free Encyclopedia* [Online], October 24, 2010. Available: http://en.wikipedia.org/wiki/Crevice_corrosion [October 27, 2010].

Appendix A - Concepts

In this section, the various concepts that were thought of by the design team are presented, discussed and ranked in a decision matrix.

1. Client Needs

In order to improve the joints, a test apparatus is required. The apparatus would simulate the use of the joint in the human body for several years in a controlled manner. The client's needs, ranked in order of importance are as follows:

1. The ball joint needs to be stressed axially with both a positive and negative force (push and pull).
2. The force must be applied in different directions (orientation angle).
3. Testing must simulate an 'in vivo' environment.
4. Different sized ball joints must be accommodated.
5. Joint must be visible during test.
6. Load curve must be sinusoidal.
7. Apparatus must be able to exert a variety of loads.
8. Apparatus must not corrode during testing.

2. Target Specifications

In order to provide a design that meets the client's needs, the following is a list of specifications that the final design must comply with in order to satisfy the client.

1. Angle of load must be adjustable, from 0° to 45° in 10° increments. A range of 0° to 60° in 5° increments would be preferable.
2. Applied load must be up to 4000N positive, 100N negative.
3. Load curve must be sinusoidal.
4. Fluid bath must be a 0.9% saline solution at 37°C, ±2°C. An accuracy of ±1°C would be preferable.
5. Load must cycle at varying speeds from 2-10Hz.
6. Load must be able to cycle 5-10 million times.
7. Apparatus must accommodate ball diameters of 28-60mm in 4mm increments.
8. Case around test piece must be made of transparent material.

9. Apparatus must accommodate balls of different materials such as cobalt-chromium alloy and stainless steel.
10. Apparatus shall be constructed from a material that will not corrode in a saltwater environment, such as 316 stainless steel.

3. Discussions with Experts and Lead Users

Don Mardis, a technician with many years of experience working with laboratory equipment found in the faculty of engineering, answered questions regarding the implementation of adding a test apparatus onto existing load frames. The Instron 8502, a load frame that can be found in Room E1-269 of the Engineering Information and Technology Centre, was shown to connect with specimens via two coarse threaded, one inch, male bolts. Don said that there must be no lateral (horizontal) load applied to the load frame, otherwise damage can occur.

Dr. Urs Wyss and Dr. Olanrewaju Ojo discussed the corrosion of the hip joint, specifically corrosion of the stem near the head of the hip joint. Dr. Olanrewaju Ojo briefly mentioned that erosion corrosion, which is the degradation of the surface of a material due to relative fluid motion over the surface of the material [4], is not a significant factor when considering the corrosion of the stem of the hip joint. Crevice corrosion, which is the degradation of a material surface occurring in spaces where a working fluid has access but no relative movement [5], is the dominant mechanism of corrosion. Dr. Urs Wyss mentioned that the corrosion by-products have been known to cause severe health hazards, such as inflammation of surrounding tissue and the formation of pseudo tumors. Dr. Urs Wyss also mentioned that the force applied during the “tapping of the head” has an effect on the crevice corrosion later on in the lifecycle of the hip joint.

4. Bottom Fixture

The purpose of the bottom fixture is to attach to the anvil of the load frame and provide a base to which the stem/clamp can be fixed.

4.1 Concept A – Circular Base

- Base is one piece
- Test sample is threaded and screws into base
- Large solid base is capable of handling minor side loads and eccentric loading

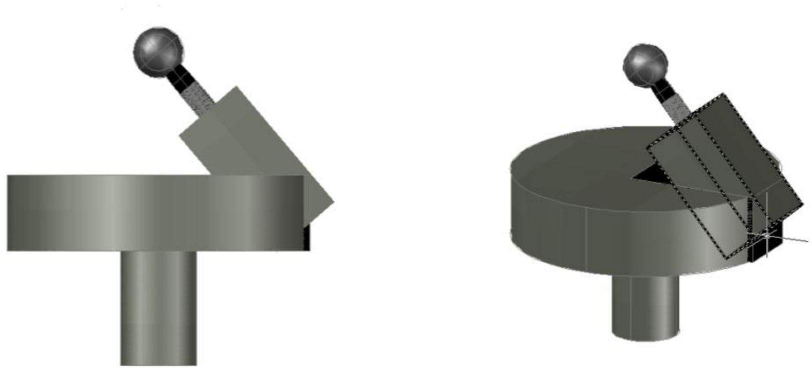


Figure 4. Concept A – Bottom Fixture Circular Base.

4.2 Concept B – Screw in Test Sample

- Base is one piece
- Test sample is threaded and screws into base
- Excess material is removed from the base design

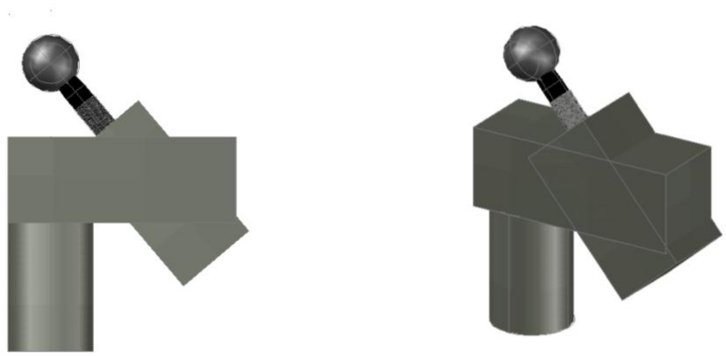


Figure 5. Concept B – Bottom Fixture Screw in Test Sample.

4.3 Concept C –Variable Angle

- Base consists of 4 pieces + test sample
- Test sample is screwed into the holder, which is then clamped between two of the base pieces, which are then bolted to the base machine attachment
- Allows one base fixture to handle a large range of angles
- The range of testable angles is large, and small changes to the angle can be made

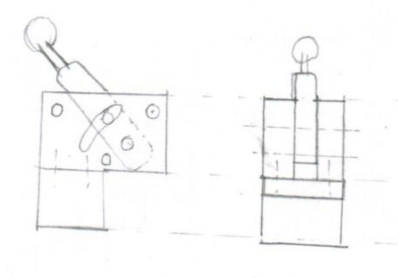


Figure 6. Concept C – Lower Fixture Variable Angle.

4.4 Concept D –L-Shape Test Sample

- One- piece base + Test sample
- One base piece can be used for all testing angles

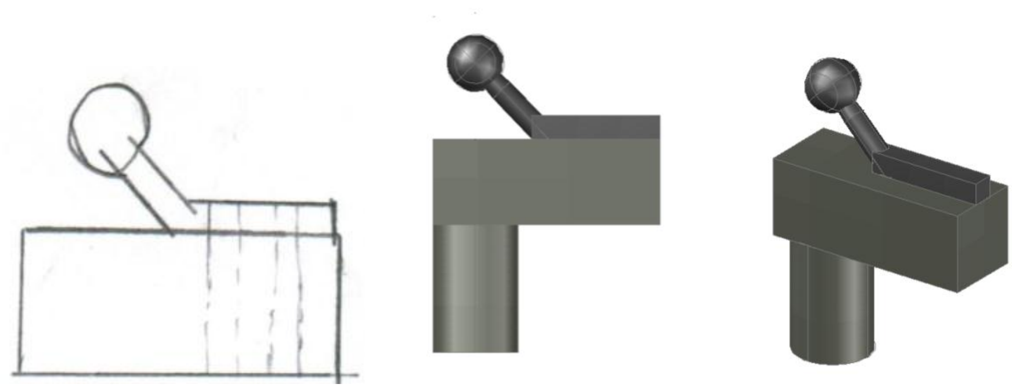


Figure 7. Concept D – Bottom Fixture L-Shape Test Sample.

4.5 Concept E–L-Shape Test Sample sunk into Base

- Notched base allows for test sample to be in contact with two or three surfaces
- Allows for horizontal bolts to secure sample
- May create a more stable grip due to surface clamping

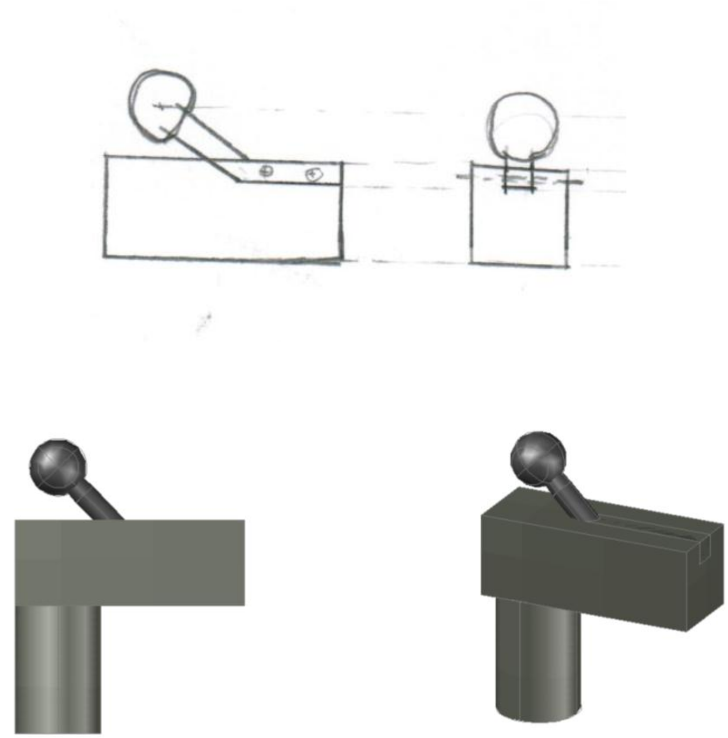


Figure 8. Concept E– L-Shape Test Sample sunk into Base.

4.6 Concept F– Square Base Attachment

- Square base requires less machining
- May affect the ease of bath attachment

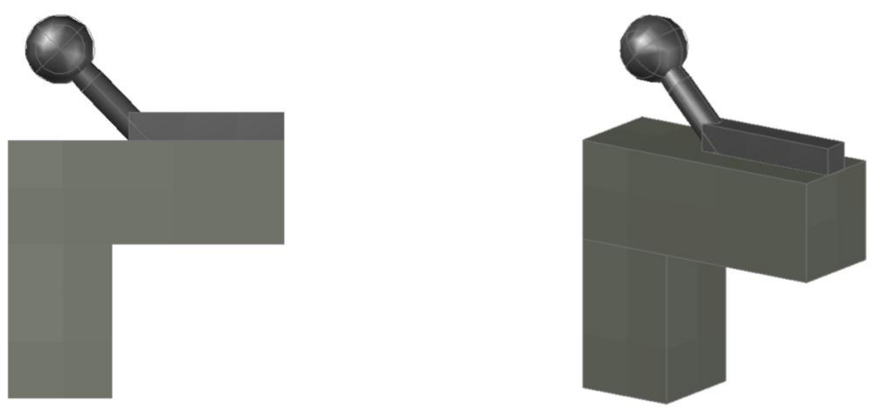


Figure 9. Concept F – Bottom Fixture Square Base Attachment.

4.7 Concept G – L-Shape with Threaded Base

- Requires the base to be threaded

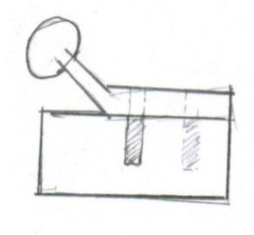


Figure 10. Concept G – Lower Fixture L-Shape with Threaded Base.

4.8 Concept H – L-Shape attached by Bolt, Washer & Nut

- Requires bolt holes to be drilled through base
- Eliminates plastic deformation of base due to sample attachment via screw threads

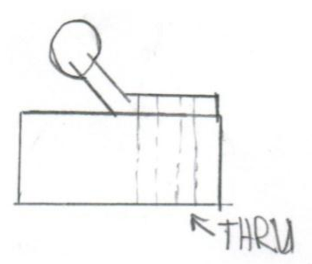


Figure 11. Concept H – Lower Fixture L-Shape attached by Bolt, Washer & Nut.

5. Top fixture

The purpose of the top fixture is to clamp the ball and allow the forces applied by the crosshead of the load frame to be transmitted through the test specimen.

5.1 Concept A – Side Clamp

- Consists of a three part top fixture + test sample
- Allows for gripping of the test sample by the sides; may provide a more realistic simulation

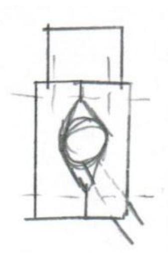


Figure 12. Concept A – Side Clamp.

5.2 Concept B – Matching Diameter Clamp

- Clamp diameter matches the test sample ball diameter
- Allows for the applied load to be distributed to the test ball

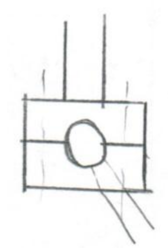


Figure 13. Concept B – Matching Diameter Clamp.

5.3 Concept C – Angled Clamp

- Allows for possibly more secure clamping at an angle
- Eliminates need for notch in lower test piece

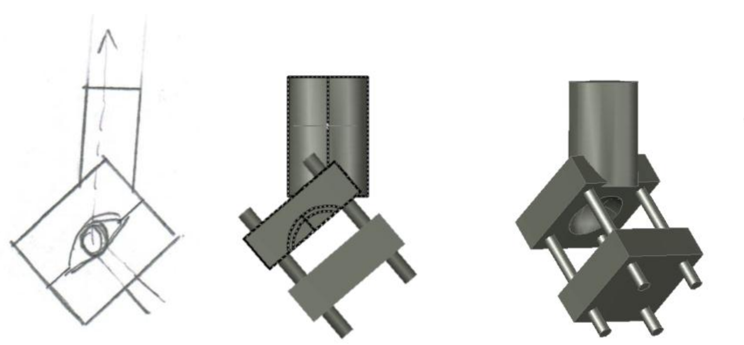


Figure 14.Concept C – Angled Clamp.

5.4 Concepts D–Oversized Cavity and Horizontal Orientation

- Grips test sample with less components than side clamp
- Will accommodate more ball sizes

- Requires notch (not shown) for different angles

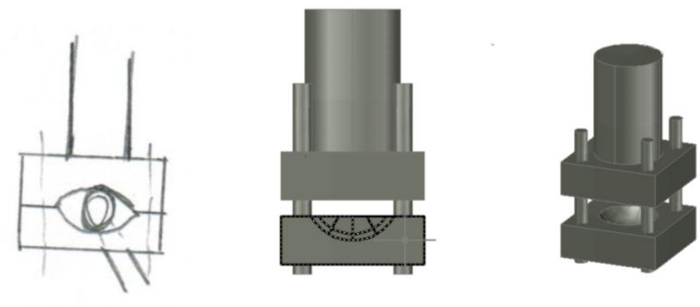


Figure 15. Concepts D –Oversized Cavity and Horizontal Orientation .

5.5 Concept E – Square Base Attachment

- Square base requires less machining
- May affect the ease of bath attachment

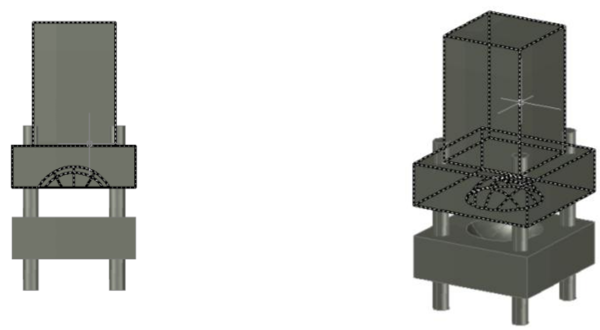


Figure 16. Concept E – Square Base Attachment.

6. Fluid Bath

The purpose of the fluid bath is to allow the test specimen to be immersed in a fluid, simulating ‘in vivo’ conditions.

6.1 Concept A –Integrated with Fixture

- Does not require pump, piping, and holes drilled into casing
- May not allow as much control over fluid temperature and level

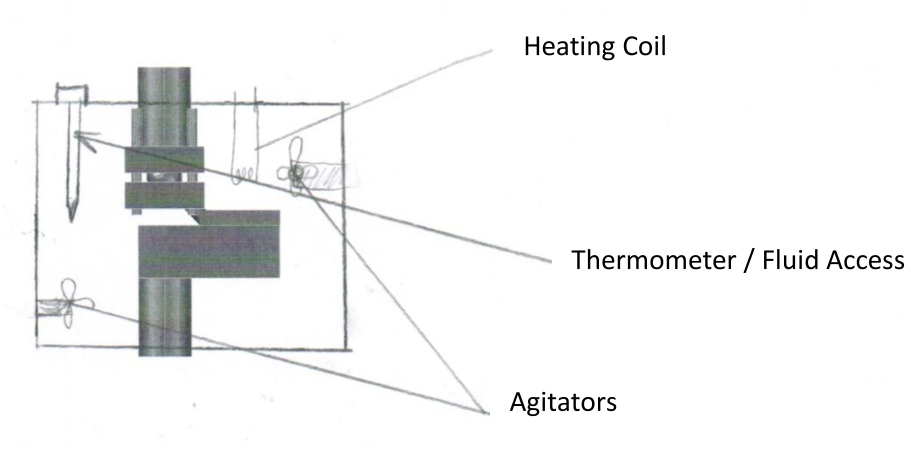


Figure 17.Concept A – Fluid Bath Integrated with Fixture.

6.2 Concept B –External Pump

- Requires pump, piping, and holes drilled into casing
- May allow more control over fluid temperature

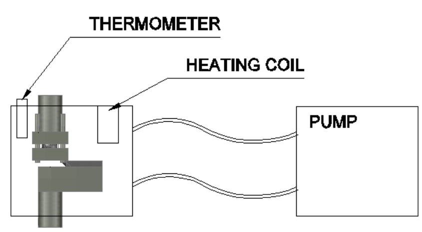


Figure 18.Concept B – Fluid Bath with External Pump.

6.3 Concept C – External Pump and Reservoir

- Requires pump, piping, and holes drilled into casing
- May allow more stable fluid temperature and level

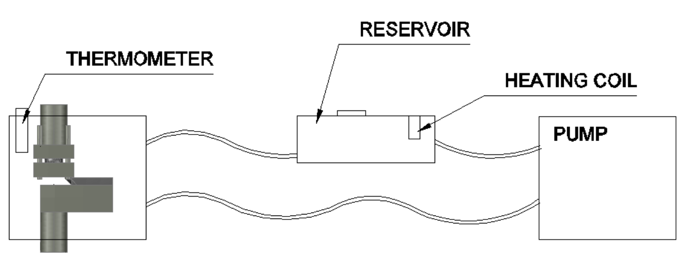


Figure 19.Concept C – Fluid Bath with External Pump and Reservoir.

6.4 Concept D – Mini-Bath with External Pump and Reservoir

- Requires pump, piping, and holes drilled into casing
- May allow more stable fluid temperature and level
- May be more difficult to fit over fixture
- Minimum exposure of fixture to corrosive bath

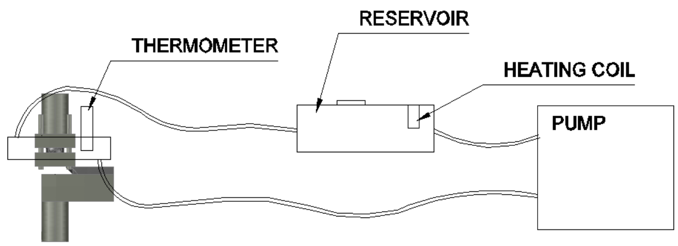


Figure 20. Concept D – Mini-Bath with External Pump and Reservoir.

7. General Constraints and Limitations

This section contains only the constraints and limitations for the design of the test apparatus.

- Apparatus must fit in a load frame available at the University of Manitoba.
- Cost of apparatus should ideally be under $2000.
- Design must be completed by December 6, 2010.

8. Decision Matrix

This section contains the analysis and selection for each of the main components including the bottom fixture, top fixture and fluid bath.

8.1 Analysis and Selection of Bottom Fixture

The criteria used for the selection of the bottom fixture were 1) accuracy, 2) adaptability to angle, 3) cost, 4) ease of use, 5) installation difficulty, 6) ease of manufacture, 7) resistance to fatigue, and 8) stability. A weight from 1 to 5 was given to each criteria, with 5 meaning it was very important, and 1 meaning it was less important. Each concept was then rated from 1 to 5 with 5 being a good rating, and 1 being a poor rating. It is important to note that a high cost is not good, so a high rating indicates a relatively low cost, and a low rating indicates a relatively high cost. The weight and rating were multiplied together to give a weighted score for each criteria, and the weighted scores were added together to give a net score for each concept. A higher net score indicates the relative suitability of the concept. The rank shows how each concept ranks among the others. Table II below shows the decision matrix for the bottom fixture.

As can be seen by the weighting of the criteria, accuracy and adaptability to angle are among the most important criteria. Cost was also rated fairly high as our client indicated a strong desire to have manufacturing done as cheaply as possible. Ease of use and installation difficulty were given lower weights because of the relatively small time required for setup compared to the time required for testing. In some cases the time required for one test is upwards of 3 weeks, so an hour or two spent setting up the equipment is not critical. Manufacture difficulty was not given a very high rating because of the relative simplicity of the designs in general. Stability and resistance to fatigue were also given fairly low ratings because in all cases the apparatus itself is not likely to fail; failure will occur at the stem, and stability is not seen as a major issue because all designs strive to eliminate side loading.

Based on the results in Table II below, Concept H should be selected for further design, and Concepts E and F should be looked into further as possibilities for further design, or merging with each other or Concept H.

TABLE II

DECISION MATRIX – BOTTOM FIXTURE

Selection Criteria	Weight	Concept A		Concept B		Concept C	
		Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Accuracy	5	5	25	5	25	4	20
Adaptability to Angle	5	5	25	5	25	5	25
Cost	4	1	4	2	8	1	4
Ease of use	3	4	12	4	12	5	15
Installation Difficulty	2	2	4	2	4	1	2
Manufacture Difficulty	2	2	4	2	4	1	2
Resistance to Fatigue	1	4	4	4	4	4	4
Stability	2	3	6	3	6	3	6
Net Score		84		88		78	
Rank		5		4		6	
Selection Criteria	Weight	Concept D		Concept E		Concept F	
		Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Accuracy	5	5	25	5	25	5	25
Adaptability to Angle	5	5	25	5	25	5	25
Cost	4	4	16	4	16	5	20
Ease of use	3	4	12	4	12	4	12
Installation Difficulty	2	4	8	4	8	5	10
Manufacture Difficulty	2	4	8	4	8	5	10
Resistance to Fatigue	1	3	3	3	3	1	1
Stability	2	3	6	4	8	1	2
Net Score		103		105		105	
Rank		3		2		2	
Selection Criteria	Weight	Concept G		Concept H			
		Rating	Weighted Score	Rating	Weighted Score		
Accuracy	5	5	25	5	25		
Adaptability to Angle	5	5	25	5	25		
Cost	4	4	16	4	16		
Ease of use	3	4	12	4	12		
Installation Difficulty	2	4	8	4	8		
Manufacture Difficulty	2	4	8	4	8		
Resistance to Fatigue	1	3	3	4	4		
Stability	2	3	6	4	8		
Net Score		103		106			
Rank		3		1			

8.2 Analysis and Selection of Top Fixture

The criteria and weights for the top fixture are the same as for the bottom fixture. The top fixture serves a similar function, will be made of the same materials, and will work together with the bottom fixture. Based on the results below in Table III, Concepts A and D should be selected for further design, and Concept E should be looked into further as an alternative, or for merging with Concept A and/or D.

TABLE III

DECISION MATRIX – TOP FIXTURE

Selection Criteria	Weight	Concept A Rating	Concept A Weighted Score	Concept B Rating	Concept B Weighted Score	Concept C Rating	Concept C Weighted Score
Accuracy	5	3	15	5	25	4	20
Adaptability to Angle	5	4	20	3	15	5	25
Cost	4	4	16	1	4	3	12
Ease of use	3	5	15	2	6	3	9
Installation Difficulty	2	4	8	1	2	2	4
Manufacture Difficulty	2	5	10	1	2	2	4
Resistance to Fatigue	1	4	4	5	5	3	3
Stability	2	4	8	5	10	3	6
Net Score		96		69		83	
Rank		1		4		3	

Selection Criteria	Weight	Concept D Rating	Concept D Weighted Score	Concept E Rating	Concept E Weighted Score
Accuracy	5	3	15	3	15
Adaptability to Angle	5	4	20	4	20
Cost	4	4	16	2	8
Ease of use	3	5	15	5	15
Installation Difficulty	2	4	8	3	6
Manufacture Difficulty	2	5	10	5	10
Resistance to Fatigue	1	4	4	4	4
Stability	2	4	8	4	8
Net Score		96		86	
Rank		1		2	

8.3 Analysis and Selection of Fluid Bath

The criteria used for the selection of the bath were 1) cost, 2) ease of adding fluid, 3) energy consumption, 4) evaporation, 5) installation difficulty, 6) manufacture difficulty, 7) size, 8) stability of temperature, and 9) visibility. The procedure for rating and ranking each concept is similar to the method used for the top and bottom fixture.

As can be seen by the weighting of the criteria, cost and visibility are the most important criteria. Cost is important due to the client wanting to keep costs down. Visibility is weighted high because the entire apparatus needs to be visible at all times during testing. Important data will be gathered based on observations of what is happening to the joint under the loading conditions to be tested. Evaporation was given an average rating as this will cause the concentration of the solution to rise as water evaporates. Evaporation should be kept as low as possible, but adding more fluid on a regular basis is an acceptable means of dealing with the problem. The rest of the criteria are all weighed fairly low because none of them are critical to the success of the design, and all designs are quite similar in how they will perform with respect to these criteria.

Based on the results in TABLE IV below, Concept C should be selected for further design, and Concept A should be looked into as a possibility for further design.

TABLE IV

DECISION MATRIX – FLUID BATH

Selection Criteria	Weight	Concept A		Concept B	
		Rating	Weighted Score	Rating	Weighted Score
Cost	5	5	25	4	20
Ease to add Fluid	2	4	8	5	10
Energy Consumption	2	5	10	3	6
Evaporation	3	5	15	4	12
Installation Difficulty	2	2	4	3	6
Manufacture Difficulty	2	2	4	3	6
Size	2	5	10	3	6
Stability of Temperature	2	5	10	4	8
Visibility	5	4	20	5	25
Net Score		106		99	
Rank		2		3	
Selection Criteria	Weight	Concept C		Concept D	
		Rating	Weighted Score	Rating	Weighted Score
Cost	3	5	15	4	12
Ease to add Fluid	2	4	8	3	6
Energy Consumption	2	4	8	3	6
Evaporation	3	5	15	4	12
Installation Difficulty	2	2	4	1	2
Manufacture Difficulty	2	2	4	2	4
Size	2	5	10	5	10
Stability of Temperature	5	5	25	3	15
Visibility	5	4	20	4	20
Net Score		109		87	
Rank		1		4	

Appendix B – Discussion

1. Calculations for maximum allowable stem length

In order to determine whether the stem would fail under the proposed fatigue loading conditions of 10 million cycles at -100 N to 4000 N, the Goodman Method for determining fluctuating normal stresses was used. The governing equation states that:

$$\frac{K_t \sigma_a}{S'_n} + \frac{\sigma_m}{S_u} = \frac{1}{N}$$

Where:

- K_t is the value of the stress concentration. A conservative value of 2 was chosen.
- σ_a is the alternating stress.
- σ_m is the mean stress.
- N is the design factor. A design factor of 1.5 was chosen.
- S_u is the tensile strength of the material.
- S'_n is the actual endurance strength of the material.

S'_n is the product of the material's endurance strength and several factors. The factors used were:

- A type-of-stress factor, C_{st}. A value of 1.0 is used for bending stress, and a value of 0.8 for axial tension. As bending stresses during the compression phase of the loading was predicted to be the cause of failure, a C_{st} of 1.0 was used.
- A reliability factor, C_R. A reliability of 0.99 was desired, so a C_R of 0.81 was used.
- A size factor, C_s. For diameters, *D*, ranging from 7.62 mm to 50 mm, the size factor can be found by $C_s = (D/7.62)^{-0.11}$.

The material properties used for the calculations can be seen in Table V below.

TABLE V
PROPERTIES OF STEM MATERIAL

	Cobalt Chromium	Titanium Alloy
Tensile Strength [Pa]	8.00E+08	8.50E+08
Endurance Strength [Pa]	4.00E+08	4.00E+08
Diameter [m]	0.014	0.014

The actual endurance strength, S_n', was found by:

$$S_n' = S_n(C_{st})(C_R)(C_s) = (4.00 \times 10^8(1.0)(0.81)(14/7.62)^{-0.11} = 3.03 \times 10^8$$

When the orientation of the stem is straight up and down (θ = 90°) then the stress is purely axial. In any other orientation (θ = 30° to 85°) there are bending stresses as well. A diagram showing the maximum forces on the stem can be found below in Figure #.

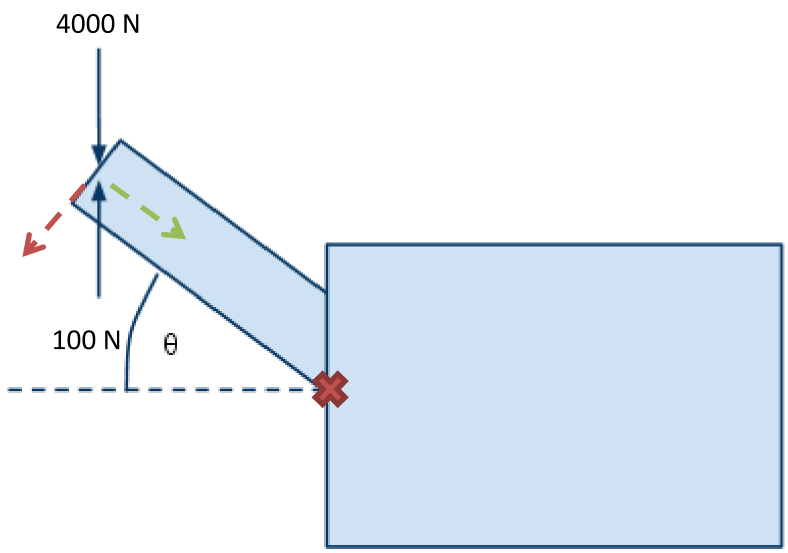


Figure 21. Diagram of Maximum Forces on Stem

The maximum stress will occur at the  during the compression phase as the axial forces and the bending forces add together. This point is the one that will be examined. The axial (green arrow) and bending components (red arrow) of the compressive and tensile forces can be found by:

$$F_{axial} = F \sin\theta$$

$$F_{bending} = F \cos\theta$$

For the compressive phase, the axial stresses, σ_{ca}, can be found by:

$$\sigma_{ca} = \frac{F_{ca}}{A_c} = \frac{F \sin\theta}{\pi D^2/4} = \frac{4000 \sin 30}{\pi(0.014)^2/4} = 1.2992 \times 10^7 \; Pa$$

The bending stresses, $\sigma_{bending}$, can be found by:

$$\sigma_{cb} = \frac{-M_y}{I} = \frac{LF_{cb}\left(\frac{D}{2}\right)}{\pi D^4/64} = \frac{LF \cos\theta}{\pi D^3/32} = \frac{L(4000 \cos 30)}{\pi(0.014)^3/32} = L(1.2859 \times 10^{10}) \; Pa$$

The total stress, σ_{ct}, can be found by:

$$\sigma_{ct} = \sigma_{cb} + \sigma_{ca} = L(1.2859 \times 10^{10}) + 1.2992 \times 10^7 \; Pa$$

The same process was used to find the total tensile stress, σ_{tt}. The mean stress, σ_m, and alternating stress, σ_a, were found by:

$$\sigma_m = \frac{\sigma_{ct} + \sigma_{tt}}{2}$$
$$= \frac{[\,L(1.2859 \times 10^{10}) + 1.2992 \times 10^7] + [L(-3.2147 \times 10^8) + (-3.2451 \times 10^5)]}{2}$$
$$= L(6.2688 \times 10^9) + 6.3337 \times 10^6 \; Pa$$

$$\sigma_a = \frac{\sigma_{ct} - \sigma_{tt}}{2}$$
$$= \frac{[\,L(1.2859 \times 10^{10}) + 1.2992 \times 10^7] - [L(-3.2147 \times 10^8) + (-3.2451 \times 10^5)]}{2}$$
$$= L(6.5902 \times 10^9) + 1.3317 \times 10^7 \; Pa$$

The Goodman equation was then used to solve for the maximum stem length, L:

$$\frac{K_t \sigma_a}{S_n'} + \frac{\sigma_m}{S_u} = \frac{1}{N}$$

$$\frac{2[L(6.5902 \times 10^9) + 1.3317 \times 10^7]}{3.03 \times 10^8} + \frac{L(6.2688 \times 10^9) + 6.3337 \times 10^6}{8.50 \times 10^8} = \frac{1}{1.5}$$

$$L = 0.01123 \; m$$

Rounding *L* down to the nearest millimeter gives a maximum stem length of 11 mm. This is the longest the stem can be without risk of failure for 10 million cycles in the worst case orientation of θ = 30°.

2. Meeting the requirements

The project requirements and the ways in which they were met are detailed below.

1. **The ball joint needs to be stressed axially with both a positive and negative force (push and pull).**

   The load frame used with the apparatus is capable of applying both tension and compression. The upper fixture holds the ball in a manner capable of transmitting both forces.

2. **The force must be able to be applied in different directions.**

   The angle of the stem is adjustable by the changing the lower fixture. The angle will range from 30° to 90° in 5° increments. A separate clamp will be manufactured for each orientation.

3. **Testing must simulate an 'in vivo' environment.**

   The test will take place within a bath fill with liquid. The temperature will be set to 37°C degrees to simulate body temperature. The bath can accommodate both saline and protein solutions.

4. **Different sized ball joints must be accommodated.**

   The upper fixture can accommodate all required ball sized, from 28mm to 60mm in diameter.

5. **Joint must be visible during test.**

   The Bionix Envirobath provided by MTS features transparent doors. The alternative solution of building the bath casing by acrylic glass is also transparent.

6. **Load curve must be sinusoidal.**

   The load frame can be programmed to generate sinusoidal load curves.

7. **Apparatus must be able to exert a variety of loads.**

The force applied by the load frame is adjustable within the range specified, from -100N to 4000N.

8. **Apparatus must not corrode during testing.**

   The material used for the fixtures are stainless steel 316. This material will not corrode appreciably during testing.

3. Assembly & manufacturing principles

During brainstorming sessions the team brought up many ideas. Some of these ideas were rejected due to expected difficulties in assembly and manufacturing. Some examples are explained in detail below.

3.1 Top fixture

3.1.1 Arm

The cross section of the arm is designed to be round. It may be cheaper to manufacture a square arm, however, since the arm may have to pass through the bath casing it may be easier to seal a round opening than a square one.

3.1.2 Ball Clamp

The clamp is designed to be square for ease manufacturing. It is also designed to be fixed together by bolts. Depending on how far the bolts are screwed together, the gap on the clamp varies. Only one clamp will need to be manufactured to accommodate all required ball diameters.

3.2 Lower fixture

3.2.1 Stem Clamp

Initially, a one piece stem/clamp was designed to give more stability (as can be seen in Figure 7). However, the complex shape would be difficult and expensive to manufacture. To address this issue, a clamp was designed to allow separate stems to be fitted. This allows the clamp to be re-used and simplifies manufacture of the stem to a straight cylinder.

3.3 Fluid Bath

The fluid bath design used off-the-shelf components provided by a single distributer, eliminating manufacturing completely and simplifying assembly. Should compatibility issues be found between the fixture and the bath, an optional bath casing has been designed which can be built out of readily available acrylic glass.

Appendix C – Cost Analysis

As the design's purpose is to aid in medical experimentation and not save or earn money, there is no break even analysis. Meeting the client's needs is more important than saving money, but this does not mean that saving money was not considered in the design. Several design decisions were made to save money. For example, the arm of the bottom fixture was designed to have a square cross section rather than a circular cross section as this makes manufacturing easier. Another example is the bath system. The bath system that was chosen for this project is an off the shelf product from MTS company. It would be much cheaper to build a case out of acrylic glass even though using an off-the-shelf system would be simpler and more robust. An alternative design featuring an acrylic glass casing was submitted not only as a cost savings basis, but also in case the apparatus could not be fit into the MTS Bionix EnviroBath.

TABLE VI
COST OF FLUID BATH COMPONENTS

Item	**Cost (CAD)**
Bionix Servohydralic Test System - MTS Model 370 Load Frame - Cylinder-Centric Actuator - Close-Coupled Hydraulic Service Manifold - Closed-Housing Coaxial LVDT - Load Cell – 661 - Crosshead Positioning and Locks - Frame-Integrated Hydraulic Grip Controls - Other Load Frame Options - Integral Test Area Enclosure - Controller – Flextest 40 - MTS Supplied PC - Software – 793 Controller - S/W Flextest 40 Key - Software – Testsuite ™ - Testsuite Multipur Elite Software Key - Hydraulic Hose Set - Service – Onsite Installation/Training	$78,688
Bionix Envirobath – 6L - Service – Onsite	$18,700
Hydraulic Power Unit – 505 G2 - Hydraulic Hose Set	$21,750
Bottom Fixture	$269
Top Fixtures	$390
Stem Clamps (15 pieces)	$670
Total	**$120,467**

Appendix D – Detailed Drawings

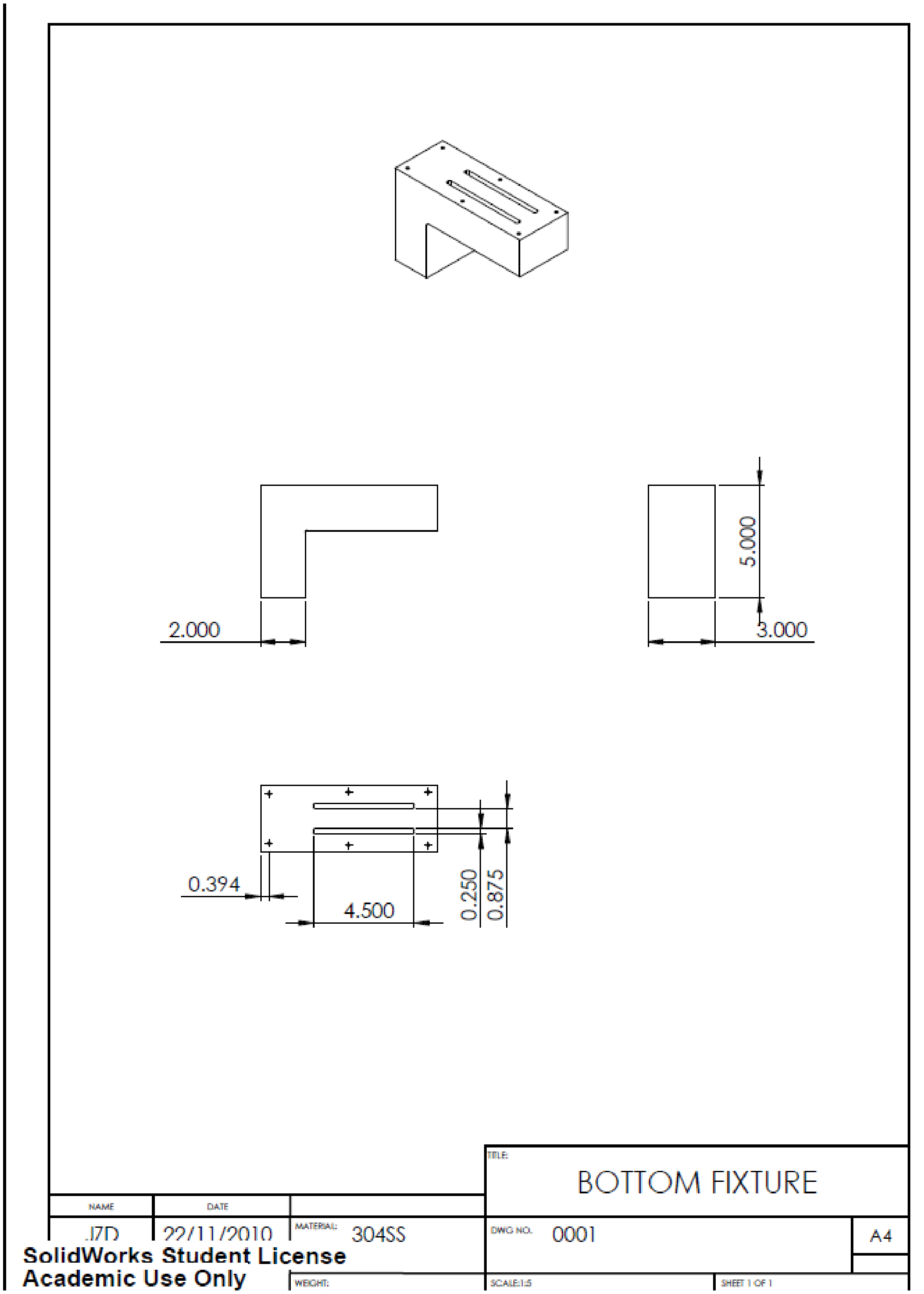


Figure 22. Bottom fixture detailed drawing.

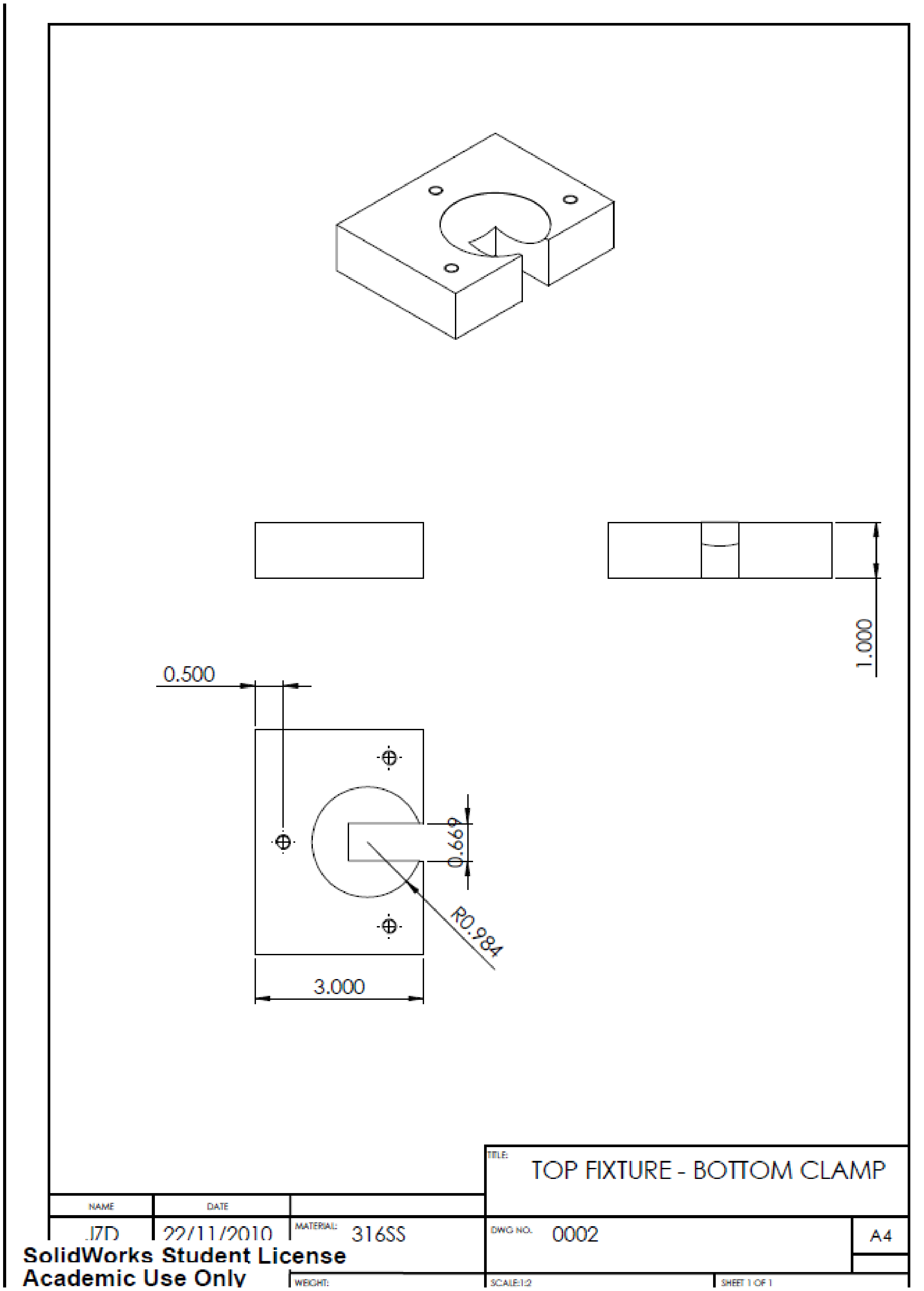


Figure 23. Top fixture bottom clamp.

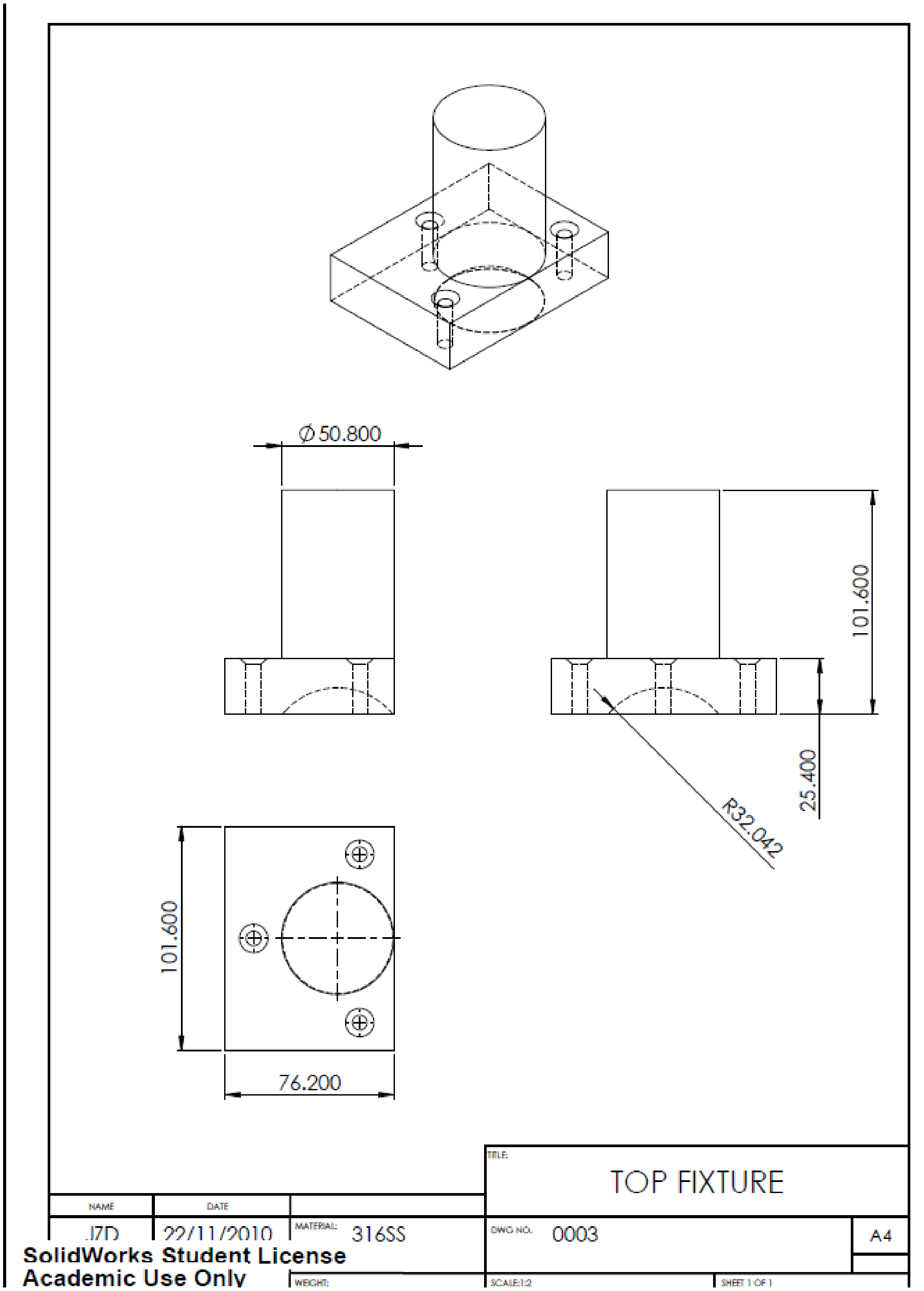
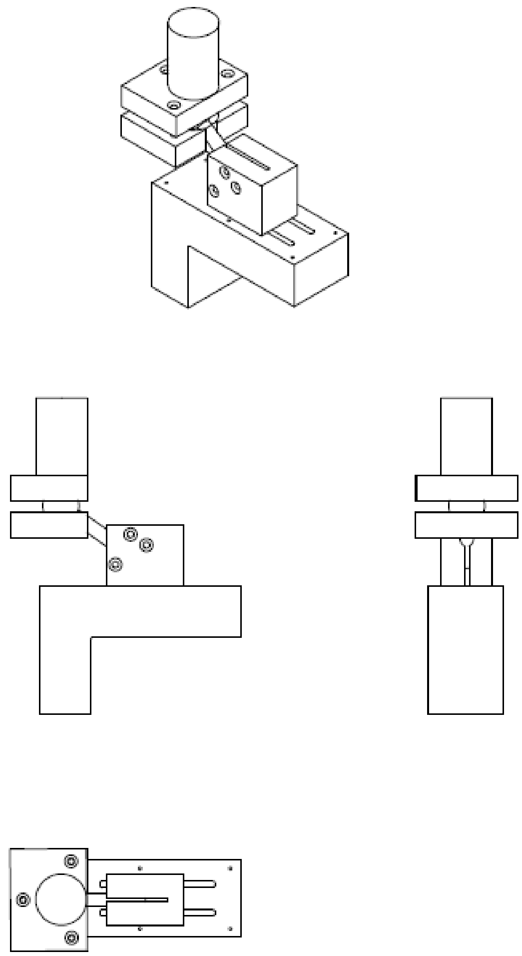


Figure 24. Top fixture top clamp.



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	bottom fixture		1
2	Top fixture bottom clamp		1
3	Top fixture		1
4	ball		1
5	shaft		1
6	A55		1

TITLE: ASSEMBLY

NAME: J7D
DATE: 22/11/2010
MATERIAL: 316SS
DWG NO.
A4
WEIGHT:
SCALE:1:5
SHEET 1 OF 1

SolidWorks Student License
Academic Use Only

Figure 25. Fixture assembly.

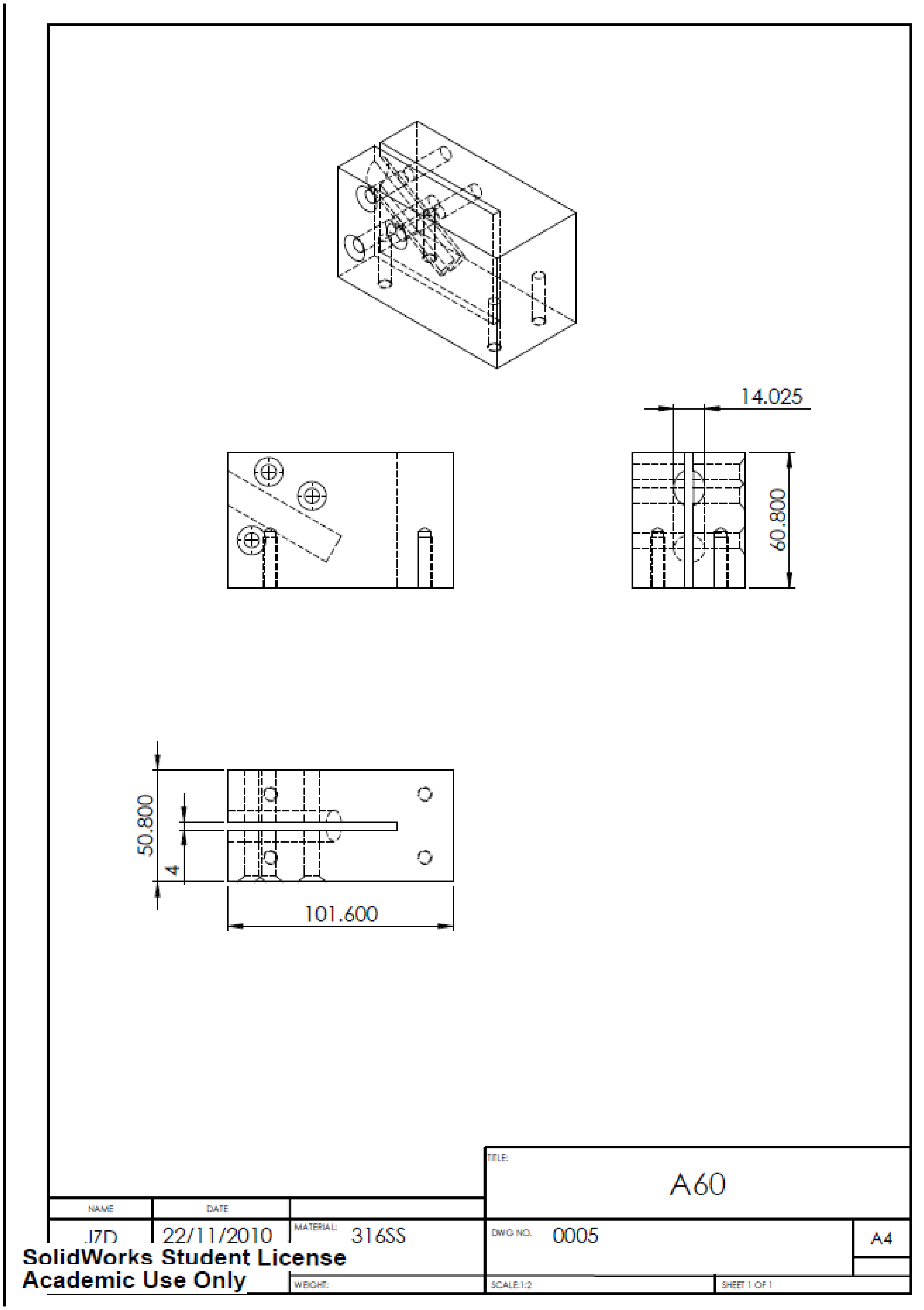


Figure 26. Stem clamp for 30 degree angle.

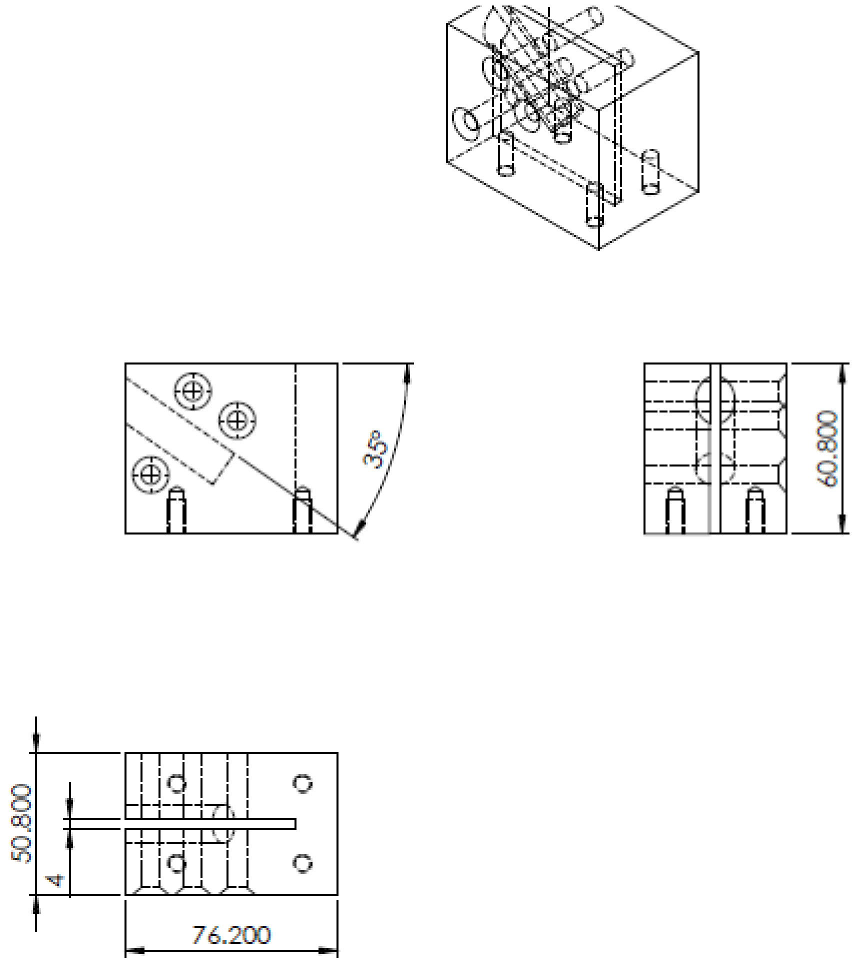


Figure 27. Stem clamp for 35 degree angle.

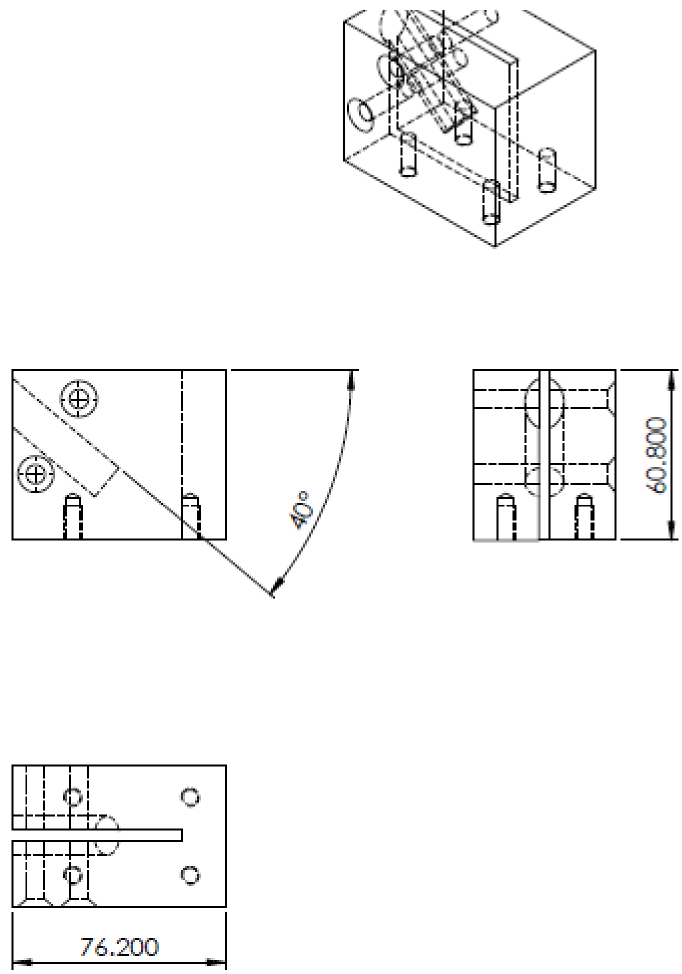


Figure 28. Stem clamp for 40 degree angle.

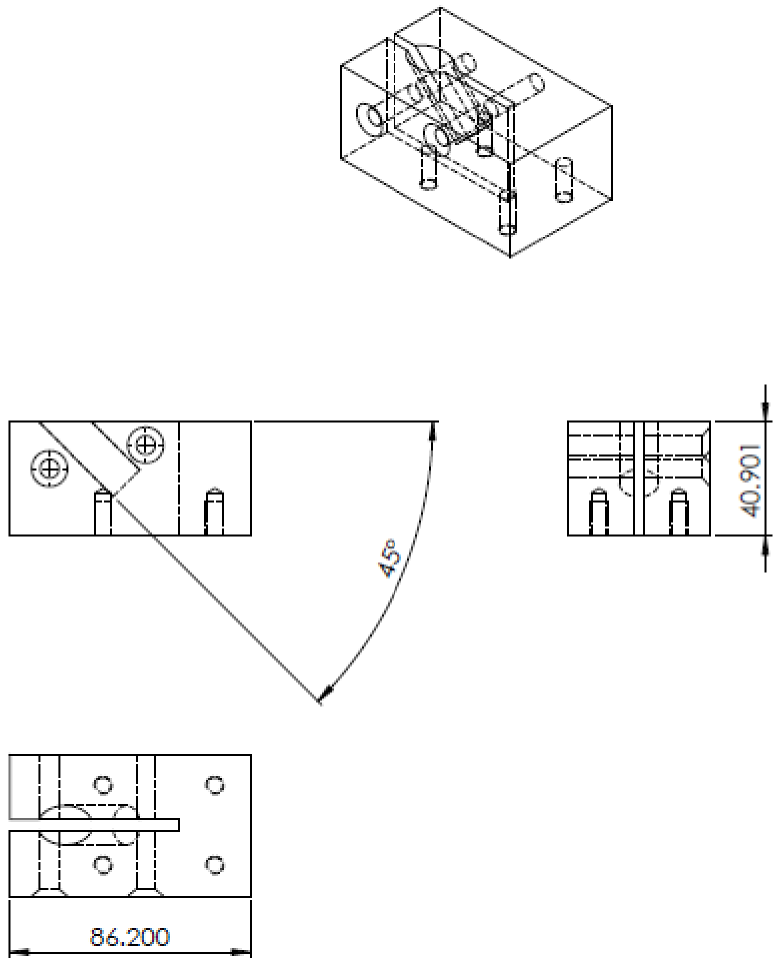


Figure 29. Stem clamp for 45 degree angle.

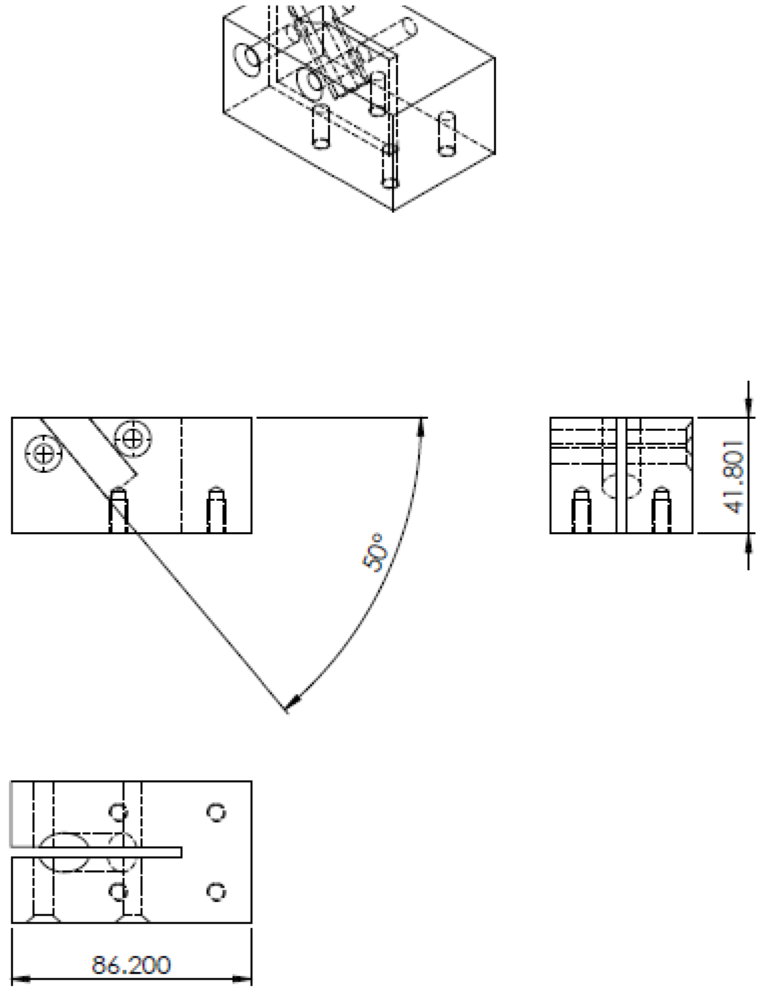


Figure 30. Stem clamp for 50 degree angle.

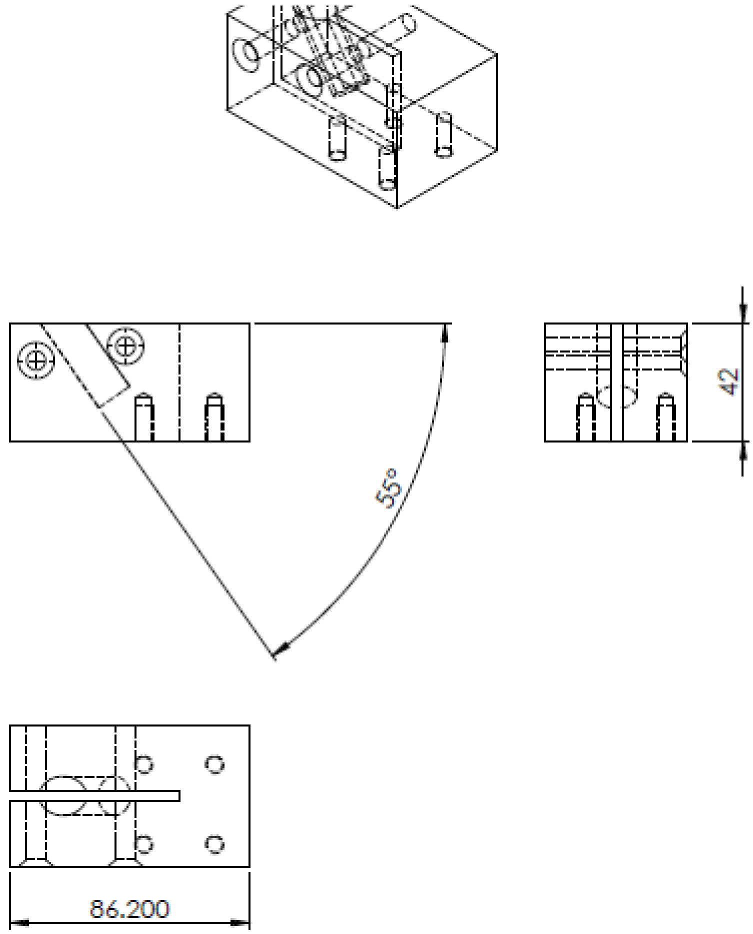


Figure 31. Stem clamp for 55 degree angle.

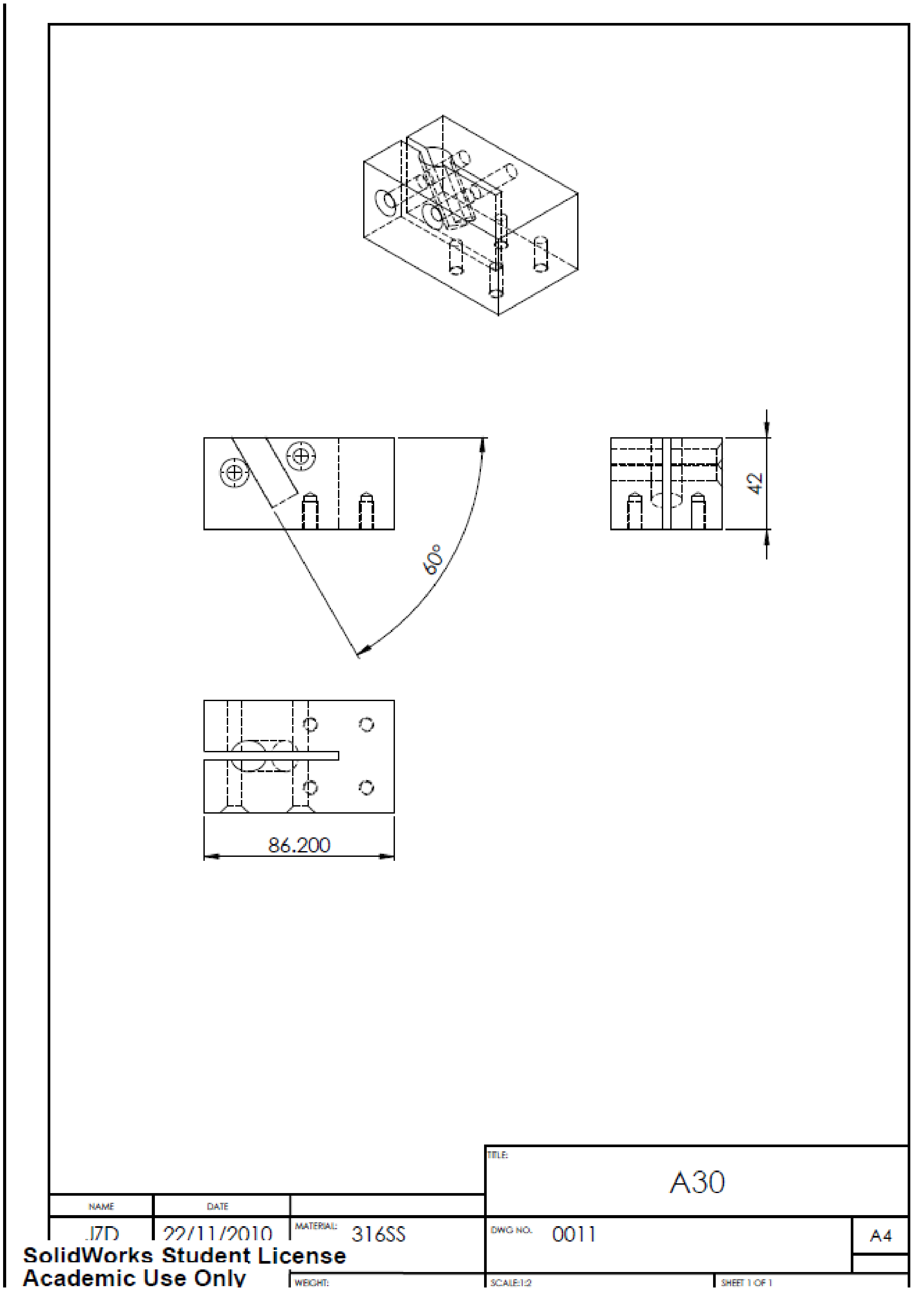


Figure 32. Stem clamp for 60 degree angle.

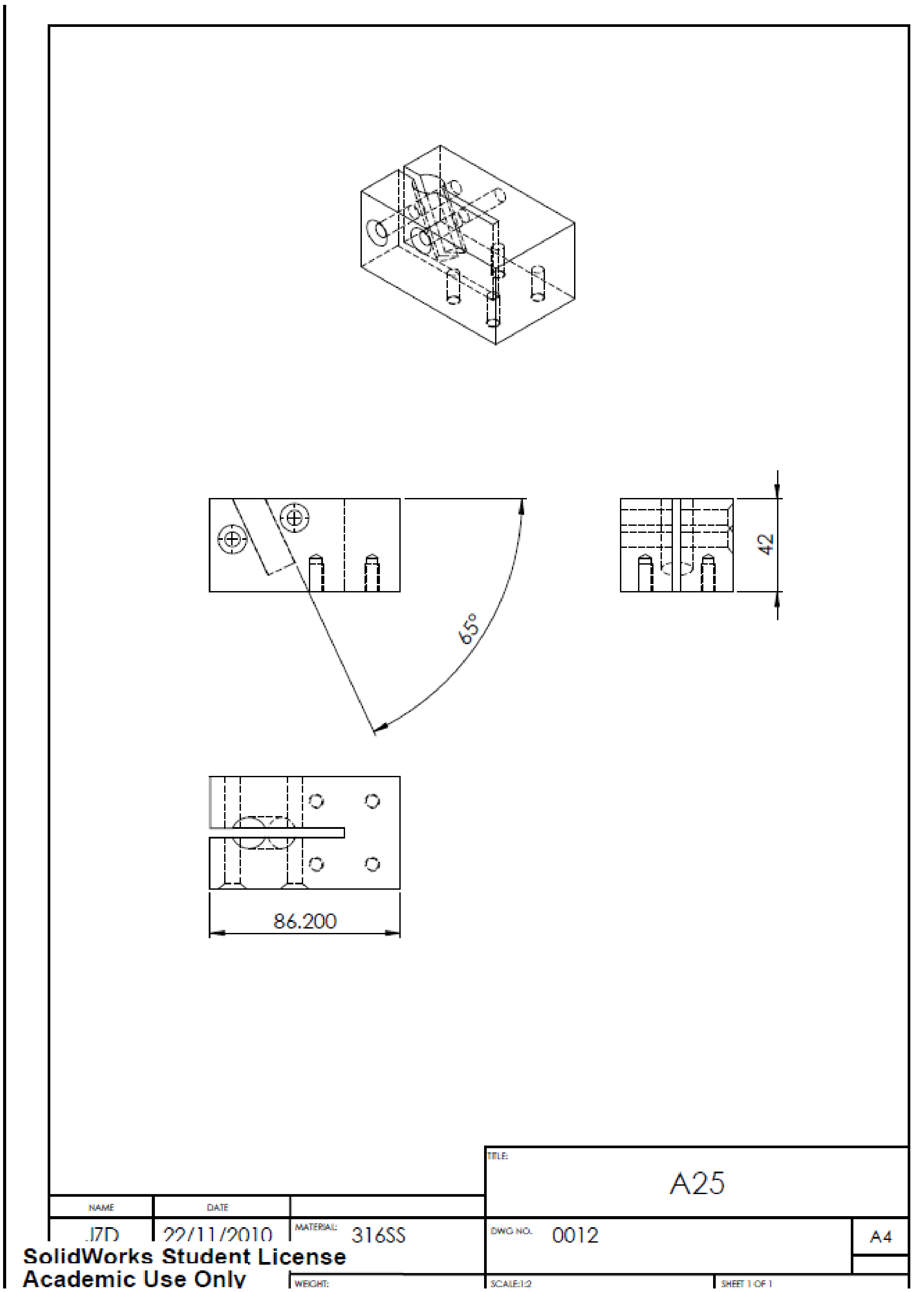


Figure 33. Stem clamp for 65 degree angle.

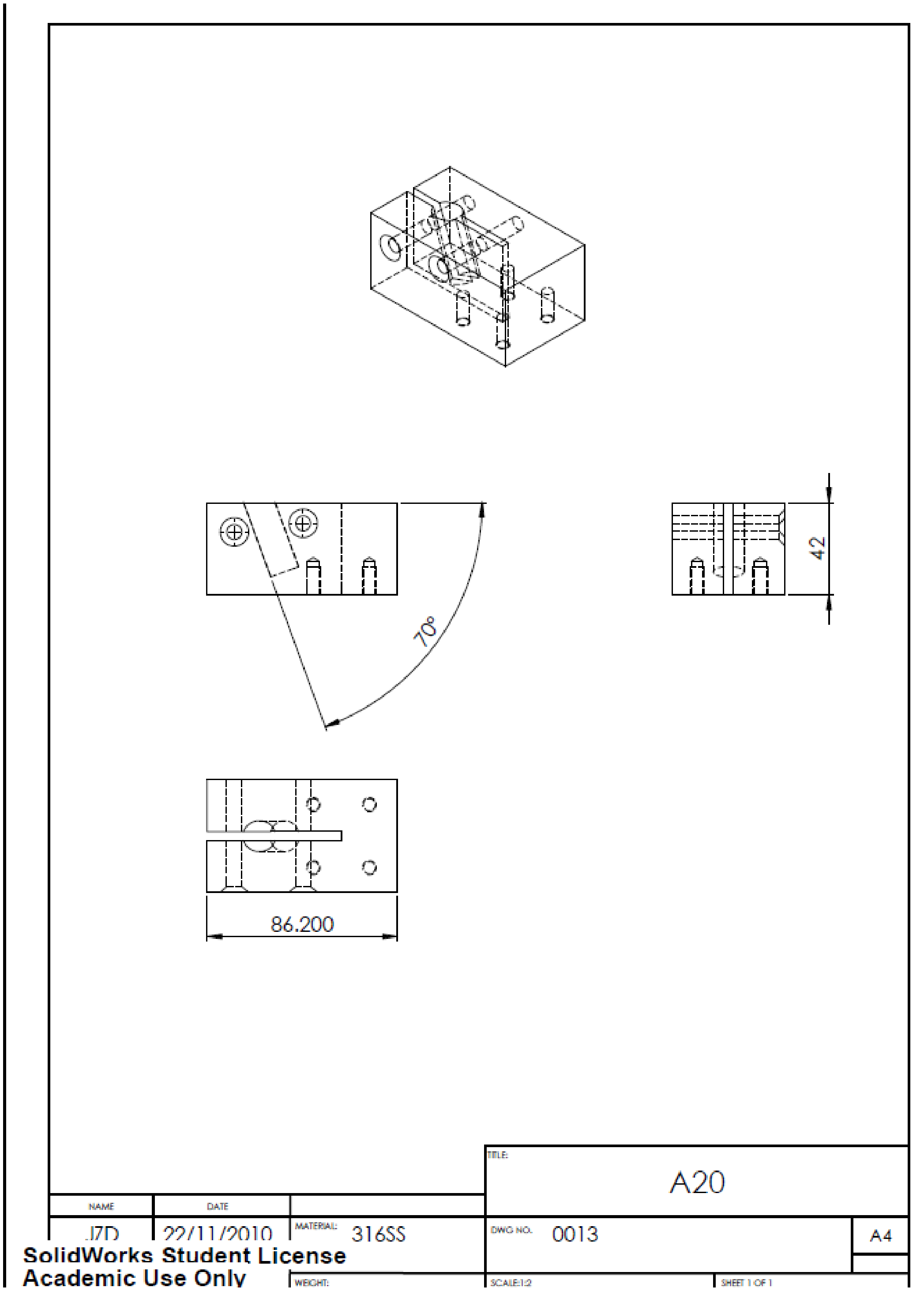


Figure 34. Stem clamp for 70 degree angle.

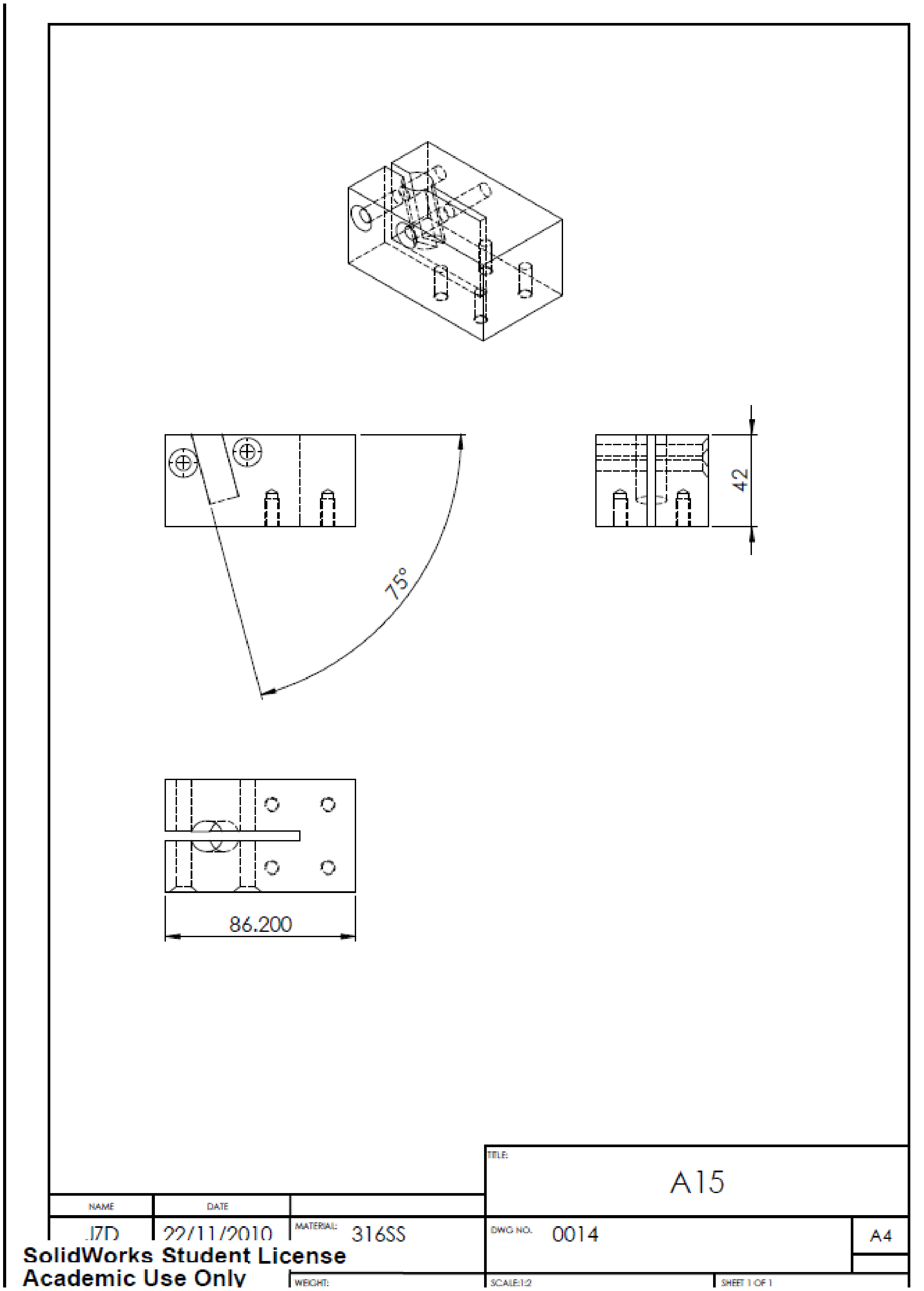


Figure 35. Stem clamp for 75 degree angle.

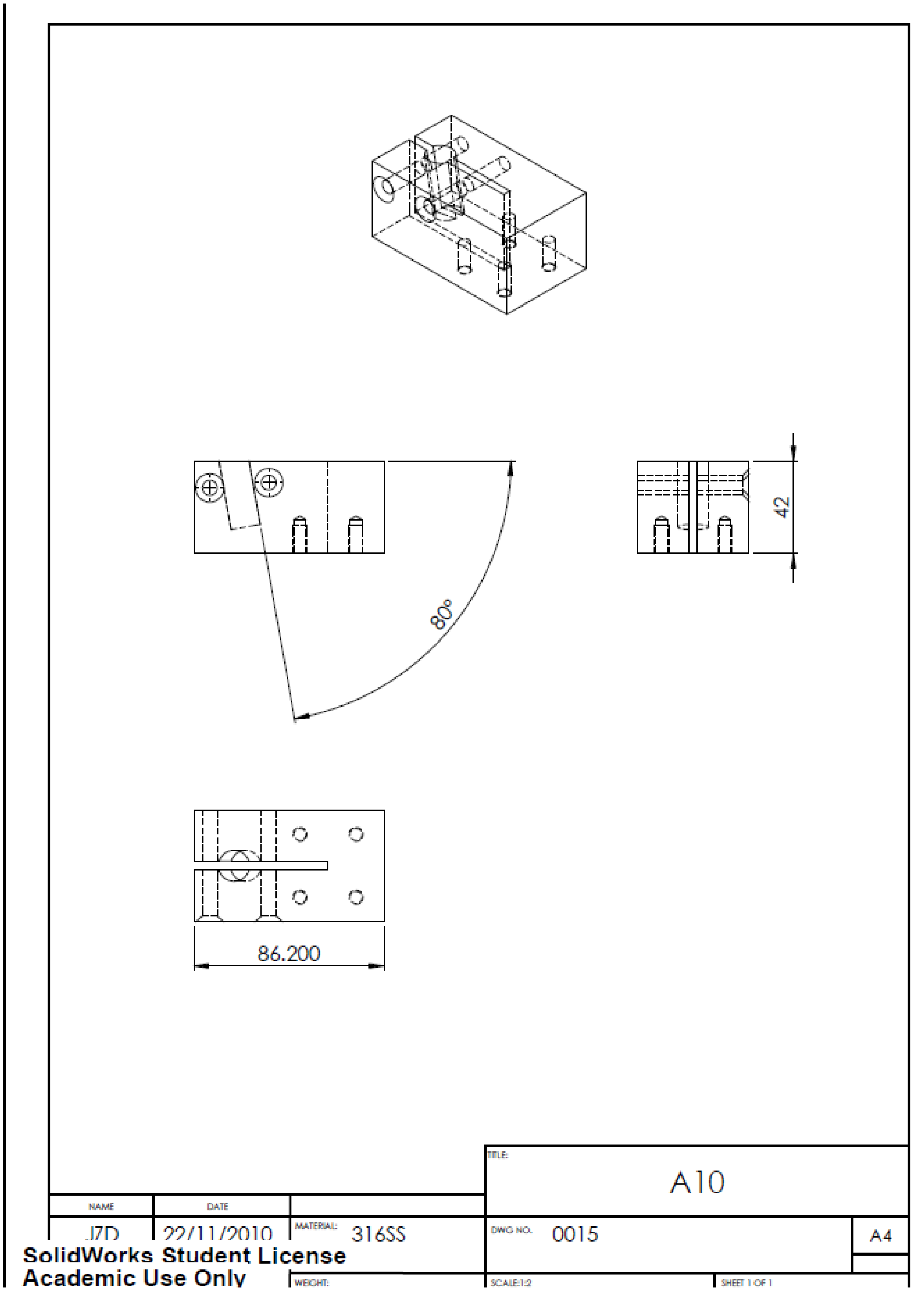


Figure 36. Stem clamp for 80 degree angle.

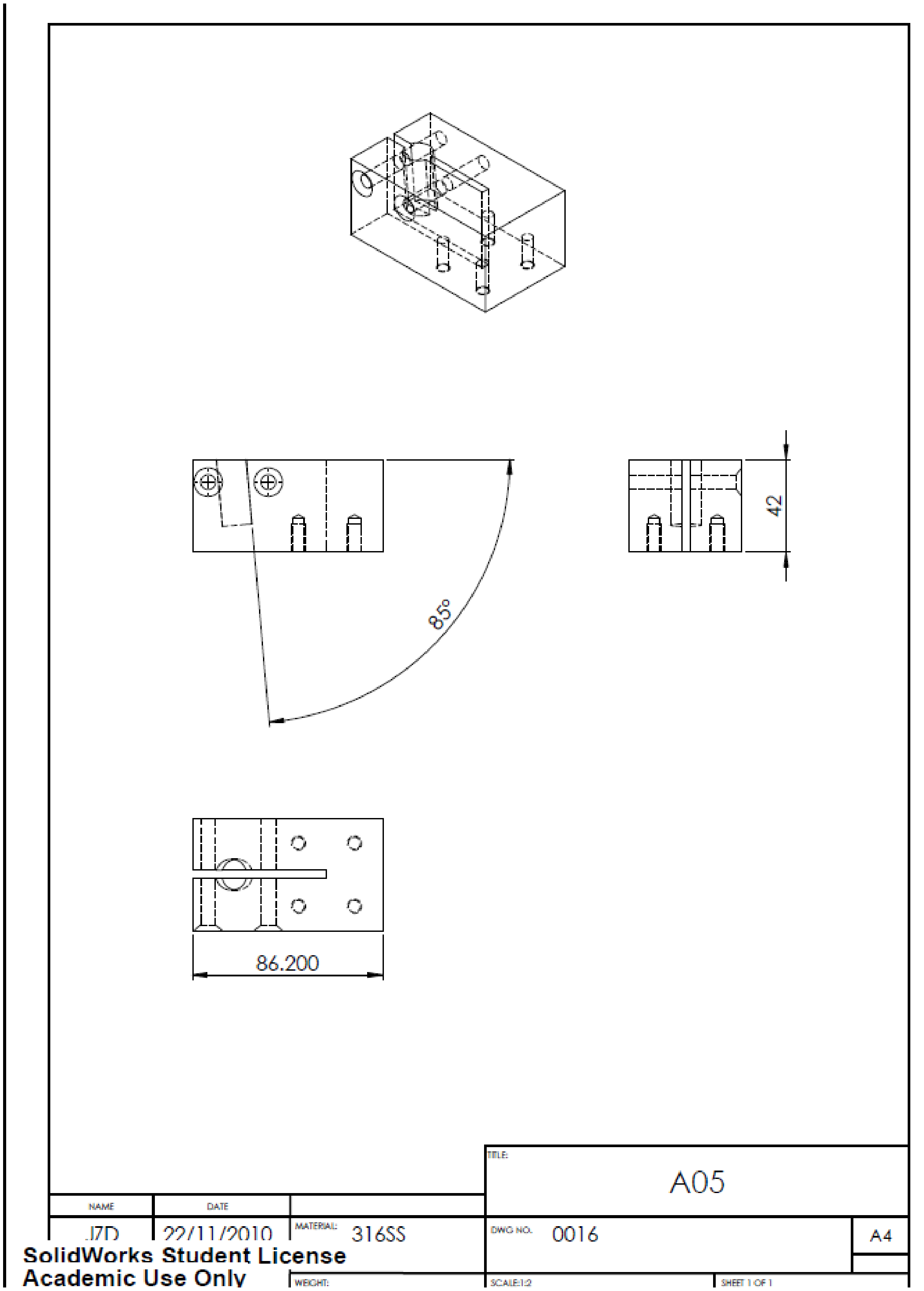


Figure 37. Stem clamp for 85 degree angle.

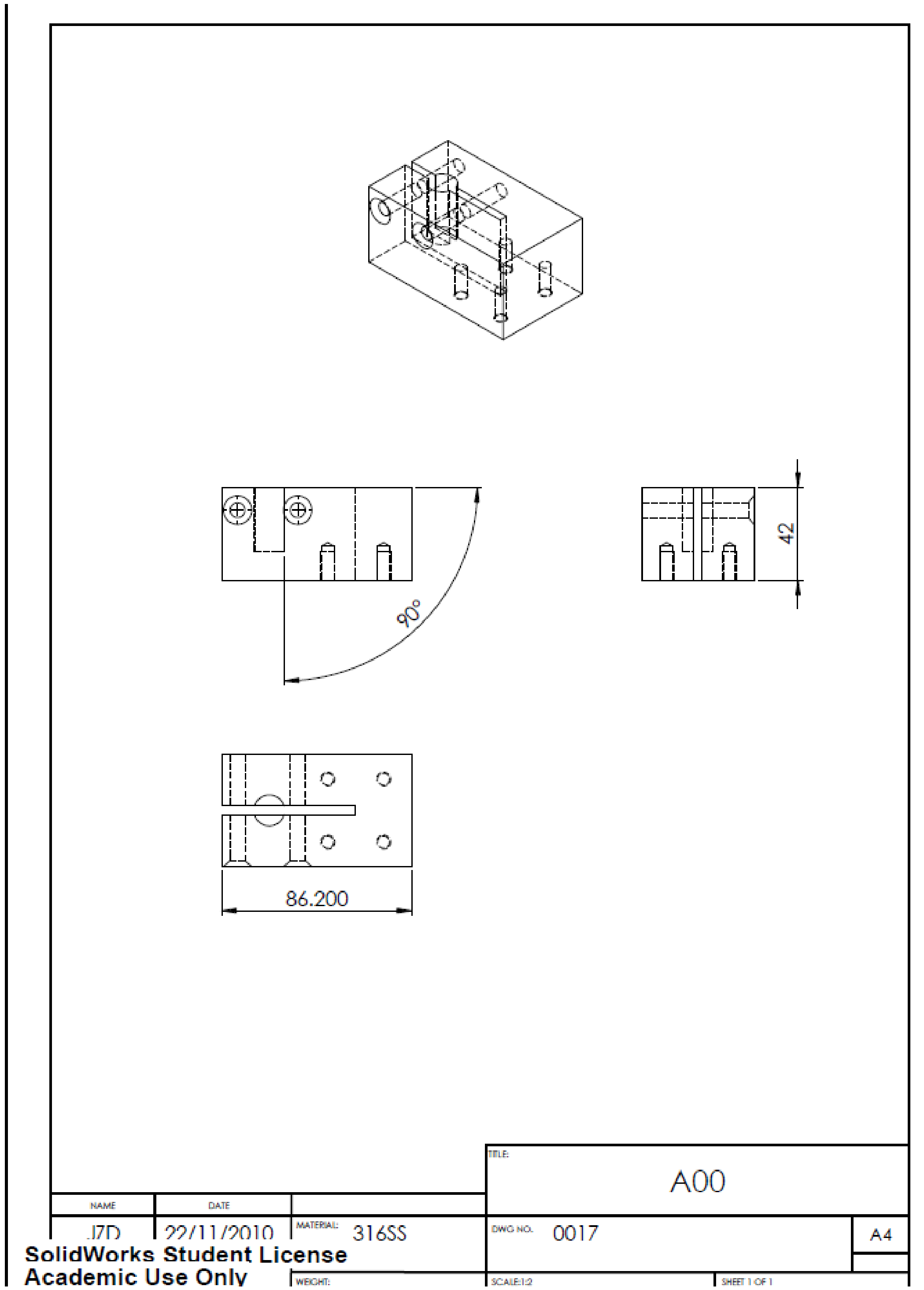


Figure 38. Stem clamp for 90 degree angle.

Appendix E – Email Correspondence with MTS

Date: Mon, 29 Nov 2010 16:49:34 -0600 [11/29/10 16:49:34 CST]
From: Greg Toews <umtoew21@cc.umanitoba.ca>
To: Stephen Toth <umtoths@cc.umanitoba.ca>
Subject: Fwd: MTS EnviroBath Options
Part(s): 2 QJDS1000BG2a-MTS Bionix and BioBaths-01.pdf [application/pdf] 345 KB

1 unnamed [text/html] 5.14 KB

---------- Forwarded message ----------
From: **Shoust, John**
Date: 18 November 2010 11:30
Subject: RE: MTS EnviroBath Options
To: Greg Toews <umtoew21@cc.umanitoba.ca>

Greg,

Please see attached for a quotation containing all of the discussed items.

You did not specify the needs for a pump so I've added one in as an option. Each system or product is broken out by the pricing on the righthand side.

Give me a call to clarify any points or make adjustments.

Regards,

John Shoust - P. Eng
Field Account Manager - Ontario, Manitoba, Saskatchewan
MTS Systems Corp.
137 Niagara Street
Toronto, ON M5V-1C6
O: 647-477-5665

C: 416-356-7310

F: 416-352-0174

http://www.mts.com

From: **On Behalf Of** Greg Toews

Sent: November 16, 2010 8:55 PM
To: Shoust, John
Subject: Re: MTS EnviroBath Options

John,

Thanks for getting back to me. We've got several Instron and MTS load frames around the department. I'm not sure which one we'll be using for testing, or if we'll be buying new equipment. Perhaps you could send me a quote on a load frame as well?

The load frame would need to be servo-hydraulic, capable of loads from 100-4000 N, both in compression and tension, and cycle from 2-10 Hz. This is bare minimum requirements.

About the bath, where are the temperature and heater located? Are they all integrated within the bath itself?

Regards,

Greg

On 16 November 2010 09:42, Shoust, John <John.Shoust@mts.com> wrote:

Greg,

Good morning, I wanted to take a quick moment to introduce myself as the local MTS field engineer here in Canada (based in Ontario).

I am attaching our EnviroBath brochure if you have not seen it yet and will generate some pricing for you in the next day or so. They do in fact come with pump and reservoir if needed.

Is there a particular frame you will be using this with?

Best regards,

John Shoust - P. Eng
Field Account Manager - Ontario, Manitoba, Saskatchewan
MTS Systems Corp.
137 Niagara Street
Toronto, ON M5V-1C6
O: 647-477-5665

C: 416-356-7310

F: 416-352-0174

http://www.mts.com

Appendix F – Load Frame & Bath Quotation from MTS

MTS SYSTEMS CORPORATION
14000 TECHNOLOGY DRIVE
EDEN PRAIRIE, MN 55344

www.mts.com

MTS TEST SOLUTIONS
be certain.

MTS QUOTATION

MTS Quotation for a Servo Hydraulic Test System

Prepared For
Univ of Manitoba Mech Engrg Dept
E2-262 EITC
Winnipeg, MB R3T 5V6

Customer Contact: Greg Toews
Fax:
Phone:
Email: umtoew21@cc.umanitoba.ca

Quote Number: QJDS1000BG
Quote Date: 11/18/2010
Valid Until Date: 2/16/2011
Estimated Shipment Schedule: 60 Days
Payment Terms: Net 30
Shipping Terms: FOB Free on board (fr.collect) EDEN PRAIRIE
Equipment Packed For: Ground Transport

Prepared By
John Shoust
MTS Systems Corporation Sales Office
137 Niagra St
Toronto ON M5V 1C6
Email: john.shoust@mts.com
Office: 647-477-5665
Fax: 952-974-8518

Signed:

Any contract resulting from this quotation shall incorporate the MTS general terms and conditions

MTS Systems Corporation - 137 Niagra St, Toronto, ON, M5V 1C6
john.shoust@mts.com - Office: 647-477-5665 - Fax: 952-974-8518

We thank you for the above inquiry and offer you, subject to our valid delivery conditions, the following items:

Item	Product Description	Qty	Price
1000	BIONIX SERVOHYDRAULIC TEST SYSTEM	1	**$78,688**
1010	MTS MODEL 370 LOAD FRAME	1	
1020	CYLINDER-CENTRIC ACTUATOR	1	
1030	CLOSE-COUPLED HYDRAULIC SERVICE MANIFOLD	1	
1040	CLOSED-HOUSING COAXIAL LVDT	1	
1050	LOAD CELL - 661	1	
1060	CROSSHEAD POSITIONING AND LOCKS	1	
1070	FRAME-INTEGRATED HYDRAULIC GRIP CONTROLS	1	
1080	OTHER LOAD FRAME OPTIONS	1	
1090	INTEGRAL TEST AREA ENCLOSURE	1	
1100	CONTROLLER - FLEXTEST 40	1	
1110	MTS SUPPLIED PC	1	
1120	SOFTWARE - 793 CONTROLLER	1	
1130	S/W FLEXTEST 40 KEY	1	
1140	SOFTWARE - TESTSUITE (TM)	1	
1150	TESTSUITE MULTIPUR ELITE SOFTWARE KEY	1	
1160	HYDRAULIC HOSE SET	1	
1170	SERVICE – ONSITE INSTALLATION/TRAINING	1	
2000	BIONIX ENVIROBATH – 1L	1	**$14,100**
2010	SERVICE - ONSITE	1	
3000	BIONIX ENVIROBATH – 6L	1	**$18,700**
4000	BIONIX ENVIROBATH – 10L	1	**$21,250**
5000	HYDRAULIC POWER UNIT - 505 G2	1	**$21,750**
5010	HYDRAULIC HOSE SET	1	

Note: Any photos provided in this quotation may not depict your specific product or system configuration.

Item	Config #	Product Description	Qty	Price
1000	**SYLMK002**	**BIONIX SERVOHYDRAULIC TEST SYSTEM**	**1**	

Bionix Servohydraulic Test Systems are ideal for determining the mechanical properties of biomaterials, medical devices and orthopedic constructs. Available in both axial and axial/torsional tabletop configurations, these compact systems combine the latest in MTS servohydraulic load frame technology, versatile FlexTest controls, proven MTS application software, and a complete selection of grips, fixtures and test environments to meet a full spectrum of dynamic testing and simulation needs. The axial configuration of this system is designed to perform accurate and repeatable fatigue life studies, and tension, bending, and compression tests of biomaterials and components. The axial/torsional configuration is well-suited for testing the durability and wear properties of components such as knee, hip, and spine implants, and studying surgical techniques and conducting complex kinematics studies of joints, tissues, and other orthopedic constructs. The culmination of decades of MTS testing expertise, years of in-depth customer research, and a world-class industrial design program, the Bionix Servohydraulic Test System delivers:

- MTS Performance - the global standard for test system precision, reliability, and flexibility.
- Innovative Cylinder-Centric Design - minimal joints to yield the stiffest, best aligned system on the market.
- Leading-edge ergonomics - intuitive controls, enhanced operator safety features, and a highly efficient workspace.
- Streamlined system procurement - broad selection from a single product family and easy system configurability.

End Use Geographic Area	North America
Load Frame	370
Actuator Type	Axial
Hydraulic Power Unit (HPU)	Not Included
Hose Length to Load Frame	4.5 m (15 ft)
Controller	FlexTest 40
Power Supply Voltage	115V
Cable Length - Frame	7.5 m (25 ft)
Cable Length - HPU	7.5 m (25 ft)
Installation	On-site

1010 TF370001 MTS MODEL 370 LOAD FRAME 1

Available in tabletop and floor standing configurations, MTS Series 370 Servohydraulic Load Frames are extremely stiff and easy-to-maintain. They feature an innovative, cylinder-centric actuator design, precision-machined columns, lightweight crossheads and laser-guided factory alignment to ensure unprecedented static and dynamic test performance. Engineered to enhance ease-of-use and operator safety, MTS Series 370 Load Frames employ leading-edge ergonomic features such as:

- Conveniently positioned system controls for efficient installation of specimens and setup of tests.
- Easy-to-turn control handles labeled with clear, universally-understood symbols.
- A repositionable crosshead that accommodates a variety of specimen sizes.
- Consolidated electrical connections that simplify cable connections.
- T-slot grooves in the load-reacting surface of tabletop models that allow for easy attachment of test fixtures.
- Channels in the load-reacting surface of tabletop models that contain and collect fluid spilled from test fixtures.

End Use Geographic Area	North America
Load Frame Model Number	370.02 - 25 kN (5.5 Kip) Cap.
Project System Type	Bionix
Power Supply Voltage	115V
Actuator Type	Axial
Vert. Test Space (min/max)	Std 144/827 mm (5.7/32.6 in)
Load Frame Column Spacing	460 mm (18.1 in)
Load Frame Column Diameter	76.2 mm (3.0 in)
Actuator Location	Integral to Crosshead
Actuator Force Rating	15 kN (3.3 kip)
Load Cell Force Rating	5 kN (1.1 kip)
Actuator Dynamic Stroke	100 mm (4 in)
Crosshead Positioning	Hydraulic Powered Adjustment
Crosshead Locks	Hydraulic Powered Adjustment
HSM Maximum Flow Rating	57 lpm (15 gpm) 1 servovalve

Controller Platform	494 Platform
Calibration - Site	Standard Factory Calibration
Calibration - Electronics	494.16/494.25/494.26
Calibration - Cable Length	7.5 m (25 ft)
Calibration - Output Polarity	Tension (+), Compression (-)
Calibration - Full Scale	100 mm, +/- 65 mm

1020 AC370001 CYLINDER-CENTRIC ACTUATOR 1

The MTS Series 370 Load Frame employs an innovative, cylinder-centric design that integrates fatigue-rated MTS actuators directly into the cross-beam to comprise an integrated actuator beam. Regardless of whether the actuator beam is mounted in the base or crosshead of a load frame, this design minimizes the number of required joints, yielding a frame that exhibits high axial and lateral stiffness, superior reliability and a high degree of uptime.

- Symmetric end caps grant easy access to piston rod seals without removal of the actuator from the load frame.
- Precision machining on end-cap flanges provides automatic realignment of the end cap to the piston rod.
- MTS Annular Step Bearings supply large side-load capacity through hydrostatically-fed strut pressure.
- MTS-proprietary direct-bonded polymer ensures high-durability and tight alignment of actuator bearings.
- Optional, actively-fed hydrostatic pad bearings are available for applications with severe side-loads.

Actuator Location	Integral to Crosshead
Actuator Force Rating	15 kN (3.3 kip)
Actuator Dynamic Stroke	100 mm (4 in)
Actuator Total Stroke	114 mm (4 in)
Actuator Bearing Type	MTS-proprietary Annular Step
Piston Hub Seal	Not Included

1030 HD370001 CLOSE-COUPLED HYDRAULIC SERVICE MANIFOLD 1

The MTS Series 370 Load Frame features a close-coupled Hydraulic Service Manifold (HSM) with a direct, high-integrity connection to the integrated actuator beam. This design eliminates the need for additional flanges or manifolds and ensures optimal servovalve performance. The HSM provides local, proportional hydraulic station control allowing for first-on/last-off management of hydraulic power.

- Five-port servovalves ensure that pressure transitions and shutoffs proceed smoothly and under system control.
- Actuator velocity limiting circuit limits actuator speed to 10 mm/sec during test setup.
- Optional close-coupled accumulators provide high frequency response, low distortion, and low noise levels.
- Optional local filter captures particle contamination and enhances maintenance by allowing visual inspection of filter cleanliness.

HSM Maximum Flow Rating	57 lpm (15 gpm) 1 servovalve
HSM Close-coupled Accumulator	Not Included
Axial Servovalve	19 lpm (5 gpm) 5-port
HSM Pressure In	-08 JIC
HSM Return Out	-08 JIC
Load Frame Drain 1 Out	-06 JIC
Load Frame Drain 2 Out	N/A

1040 AC370003 CLOSED-HOUSING COAXIAL LVDT 1

Designed for both static and dynamic testing, the Linear Variable Differential Transducer (LVDT) provides piston rod displacement feedback to the test system controller. A closed housing protects the LVDT from dust, oil, debris, and damage. The LVDT is coaxially mounted within the hollow piston rod for increased accuracy and added protection.

- Transducer Electronic Data Sheet (TEDS) provides automatic identification when connected to an appropriately equipped controller.
- Optional anti-rotation mechanism is integrated into the LVDT housing.

Actuator Coaxial Mounted LVDT	Standard High Accuracy
Actuator Anti-rotation	Not Included
Controller Platform	494 Platform
Calibration - Site	Standard Factory Calibration
Calibration - Electronics	494.16/494.25/494.26
Calibration - Cable Length	7.5 m (25 ft)
Calibration - Output Polarity	Tension (+), Compression (-)
Calibration - Full Scale	100 mm, +/- 65 mm

1050 XD661001 LOAD CELL - 661 **1**

MTS 661 Series Load Cells are designed for a wide array of static and dynamic testing applications. The cells are designed for cyclic operation in through zero tension/compression modes.

- Low deflection and high degree of stiffness gives better dynamic performance.
- High output shear web design resists off-axis loading and moments, increasing accuracy and resolution.
- Proprietary wiring techniques reduce electrical noise.
- Temperature compensation helps ensure stability.
- Designed for easy integration with other accessories, platens, and fixtures.
- Manufactured with aircraft-quality steels, specially heat-treated to minimize distortion.

Controller Platform	494 Platform
TEDS	Included
Load Cell Model Number	661.19H-01
Thread Type	Metric
Load Cell Force Rating	5 kN (1.1 kip)
Load Cell Thread Form	M12 X 1.25MM
Load Cell Cable Connector Type	JT
Electronics	494.16/494.25/494.26
Calibration - Site	Standard Factory Calibration
Cable Length	7.5 m (25 ft)
Calibration - Output Polarity	Tension (+), Compression (-)
Calibration - Full Scale	5 kN (1.1 kip)

1060 TF370004 CROSSHEAD POSITIONING AND LOCKS **1**

Optional hydraulic-powered crosshead positioning and locks facilitate the automated repositioning of the MTS Series 370 Load Frame crosshead to quickly and safely accommodate specimens of varying lengths. The optional hydraulic locks are in addition to the standard manual locking mechanism and provide the high clamping forces suitable for most tests. Other crosshead positioning features include:

- Double-acting cylinders that drive the crosshead up and down and maintain its position in case of hydraulic pressure loss.
- Adjustable crosshead speed that allows the rate of repositioning to be customized for typical test setup changes.
- Easy-to-turn control handles that are conveniently integrated into the load frame stand.

Crosshead Positioning	Hydraulic Powered Adjustment

Crosshead Locks | Hydraulic Powered Adjustment

1070 TF370002 FRAME-INTEGRATED HYDRAULIC GRIP CONTROLS 1

Optional hydraulic grip controls integrated into the MTS Series 370 Load Frame enable automated operation of a variety of MTS hydraulic-powered specimen grips. These optional controls provide the most convenient way to open and close the upper and lower grips during test setup. Gripping pressure is adjusted jointly for both grips, but is activated and monitored via independent controls and pressure gages; the rate of grip closing can be set independently for each grip. Additional features include:

- Cross-ported check-valves that eliminate cross-talk between grips during clamping and unclamping.
- Independent booster pumps that extend the life of high pressure grip systems.
- Conveniently located system control handles.
- Easy-to-turn valve knobs that require low activation force, even with high pressure grip systems.

Integrated Hyd Grip Control | Not Included

1080 TF370003 OTHER LOAD FRAME OPTIONS 1

An MTS Model 609 Alignment Fixture can be added to the load frame, allowing alignment adjustments to be made while the load-train is fully preloaded. Multilayer Fabcel pads or optional MTS elastomeric/pneumatic mounts are employed to isolate the load frame and decrease the amount of vibration transmitted to and from the surrounding environment. A tie bar that connects the tops of the load frame columns can be purchased to increase the stiffness and natural frequency of the system. An optional holder provides a secure and convenient port for the ergonomic FlexTest Handset.

Load Frame Alignment Fixture	Not Included
Load Frame Isolation	Multilayer Fabcel® Pads
Column Stiffening Tie Bar	Not Included
FlexTest Handset Holder	Included
Load Frame Mounting Options	Not Included

1090 TF370005 INTEGRAL TEST AREA ENCLOSURE 1

MTS recommends that the MTS Series 370 Load Frame be equipped with an integral test area enclosure that provides protection against hazards and containment of ejected material. The enclosure also enhances the security and integrity of tests by preventing unintended specimen contact by operators and observers. The enclosure is interlocking and features a uniquely-keyed latch mechanism that is integrated with the actuator velocity limiting circuit to prevent the starting of tests until the test area has been secured. Other test area enclosure features include:

- High-impact-strength, polycarbonate panels that provide clear visibility to test area.
- Automatically locking front and rear doors that provide easy access to specimens and fixtures during test setup.
- CE mark with compliance to the European Machinery Directive when integrated with an MTS Landmark System.

Test Area Enclosure | Declined

1100 EL494001 CONTROLLER - FLEXTEST 40 1

MTS FlexTest® 40 Control System is a versatile, easy-to-use servo-controller for general testing applications. It provides real-time closed-loop control, with transducer conditioning and function generation to drive various types of servo-actuators. The FlexTest 40 controller can support up to four control channels and one or two test stations, depending on the model type. It is fully configurable to meet your current and future needs, so you can run new tests without changing cables. Free from configuration constraints, you can use any resource for any channel.

- The One-Station Models contain the 494.41 system board which includes 3 pair of user-definable DIO.
- The Two Station Models contain the 494.44 system board which support an option for 8 pair of user-definable DIO when the 494.32 DIO Breakout Box is ordered.
- Includes PC and MTS Model 793.00 System Software.
- Basic TestWare® software provides the easiest way to set up and run simple tests.
- Optional MultiPurpose TestWare (MPT™) software automates virtually any test procedure.
- Compensation techniques optimize control, even for challenging tests and "difficult" specimens.
- Two analog D/A outputs are included on the FlexTest 40 chassis (optional BNC adapter is available for easy access to these outputs).
- Digital Universal Conditioners (DUCs) accommodate a wide range of transducers.
- Model 494.16 VD/DUC card supports one transducer and a 2-stage valve or drives a 3-stage valve.
- Excitation sensing verifies proper voltage to the transducer, regardless of cable length.
- Excitation loss detection minimizes errors in testing data and protects specimen integrity.

Controller Platform	494 Platform
FlexTest Model	FlexTest 40
Current FT40 model type	494.42 - 1 Station
Controller Input Voltage	115V
Control Mount Configuration	Desktop
Qty Control Channels	1
Controller Processor Type	Upgrade Processor
Controller PC Source	MTS Supplied
Qty 2 Stage Valve Drivers	1
Qty 3 Stage Valve Drivers	
Qty Transducers	2
Qty 494.16 VD/DUC cards	1
Qty 494.25 Single DUC cards	1
Qty 494.26 Dual DUC cards	
Shunt Cal Kits Included	1
Qty Handsets	1
Cable Length - Handsets	7.5 m (25 ft)
Qty E-Stop (Univ) w/15' cable	1
Qty E-Stop (Univ) w/25' cable	
Qty E-Stop (Univ) w/50' cable	
Dual UART/Enc Interface Card	1
Add'l Dual UART/Enc Intf Card	
Qty 8-Input A/D Pkg	
BNC Adapter for 2 D/A Outputs	Not Included
Qty 8-Output D/A Pkg	
HSM (9pin D) Cable Qty	1
Uninterruptible Power Supply	Declined
TestSuite (TM) Software	Included
Maint, Enhance & Support-ME&S	Included

1110 ELCMP001 MTS SUPPLIED PC 1

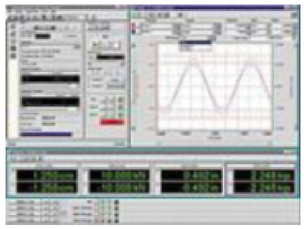
Computer Model	HP - SYS-6000
Computer Processor Type	Intel Core 2 Duo E8400
Computer Processor Speed	3 GHz
Computer RAM	4 Gb
Computer Hard Drive Size	2x250Gb
Computer Operating System	Win7
Input Voltage	115V 50/60Hz
PC Monitor Model	HP L2245WG
PC Monitor Size	22" Diagonal

PC Monitor Type LCD

1120 SW793001 SOFTWARE - 793 CONTROLLER 1

FlexTest Model	FlexTest 40
Current FT40 model type	494.42 - 1 Station
Controller Automation	Yes
Controller Processor Type	Std Processor

1130 100182611 S/W FLEXTEST 40 KEY 1



MTS 793 System Software including:
- Station Builder Software -- Provides a software interface for reconfiguring the controller.
- Station Manager Software -- Provides the main user interface to the test station.
- Station Desktop Organizer Software -- Switches the monitor from one station to another.
- Basic TestWare -- Allows the user to define, save and execute simple test procedures.
- Null Pacing -- Enables desired levels on initial pass without over-programming. Can be used to reproduce waveshape or to maximize test speed.
- Peak Valley Control (PVC) -- Corrects for peaks and mean levels in cyclic waveforms. PVC is our most popular and widely used compensation tool.

1140 SWTSS001 SOFTWARE - TESTSUITE (TM) 1

Software Version	v2.0
FlexTest Model	FlexTest 40
Applications	Fatigue
Unique TestSuite SW Configs	1
Configuration 1: TestSuite TM	mp Elite License
Configuration 1: PC Qty	1
ME&S TestSuite (TM)	Included

1150 100205351 TESTSUITE MULTIPUR ELITE SOFTWARE KEY 1

MTS TestSuite Multipurpose Testing Software lets you graphically build and run monotonic and cyclic tests. Features and functions include:
- Graphical drag-and-drop test layout design
- Test template creation
- Data acquisition (timed, P/V, level crossing, cyclic/logarithmic)
- Function generation up to 100 Hz on all channels
- Sine, square, triangle, ramp, hold processes
- Parallel branches for test execution and logical operators (if/then, while)
- Limit sensing, sequencing triggers, and interface to digital I/O
- Data export to ASCII

Component quantity 1

1160 HDHOS001 HYDRAULIC HOSE SET 1

Hose set for optimal flow.

Hose Length	4.5 m (15 ft)
HOSE END FROM COMPONENT...	HPU
HOSE END TO COMPONENT...	FRAME
Hose End - Pressure (IN)	-08 JIC
Hose End - Return (OUT)	-08 JIC
Hose End - Drain (OUT)	-06 JIC
Hose End - Drain2 (OUT)	N/A
Hose - Drain 2	N/A

1170 SRONS001 SERVICE - ONSITE 1

A properly trained and equipped MTS Field Service Engineer will visit your facility to perform the required work. The tasks performed during this visit may include installation, calibration, or preventive maintenance as called out in the original order. Informal operator instruction may also be offered if it can be performed within the time allotted for the original requested task.

Service	Onsite

2000 EVBTH001 BIONIX ENVIROBATH 1

Easy to set up, operate, and maintain, the Bionix EnviroBath facilitates accurate and efficient mechanical testing of medical device and biomaterial specimens in fluids heated to body temperatures. Bionix EnviroBaths are available in one, six, and ten-liter volume configurations and are compatible with MTS electromechanical and servohydraulic load frames, a wide selection of Bionix grips and fixtures, and electromechanical test systems from other manufacturers. Optional features include a protein-based fluid system, a bath-mounted digital temperature monitor, a mist spray, and a horizontal mounting kit.

Application	Servohydraulic
Servohydraulic Frame	370.02 - 25 kN (5.5 Kip) Cap.
Chamber Model Number	1
Actuator Type	Axial
Actuator Location	Integral to Crosshead
Column Length	Standard
Controller Input Voltage	115V USA (Straight Plug)
Volume	1 liter
Internal Width Depth Height	100x200x56 mm (4x8x2.2 in)
External Width Depth Height	180x295x95mm (7x11.5x3.7in)
Fluid Type	Saline
Digital Temperature	Included
Extension Rod	Included
Upper Attachment Type	Force Transducer
Installation	On-site

2010 SRONS001 SERVICE - ONSITE 1

A properly trained and equipped MTS Field Service Engineer will visit your facility to perform the required work. The tasks performed during this visit may include installation, calibration, or preventive maintenance as called out in the original order. Informal operator instruction may also be offered if it can be performed within the time allotted for the original requested task.

Service	Onsite

3000 EVBTH001 BIONIX ENVIROBATH 1

Easy to set up, operate, and maintain, the Bionix EnviroBath facilitates accurate and efficient mechanical testing of medical device and biomaterial specimens in fluids heated to body temperatures. Bionix EnviroBaths are available in one, six, and ten-liter volume configurations and are compatible with MTS electromechanical and servohydraulic load frames, a wide selection of Bionix grips and fixtures, and electromechanical test systems from other manufacturers. Optional features include a protein-based fluid system, a bath-mounted digital temperature monitor, a mist spray, and a horizontal mounting kit.

Application	Servohydraulic
Servohydraulic Frame	370.02 - 25 kN (5.5 Kip) Cap.
Chamber Model Number	6
Actuator Type	Axial
Actuator Location	Integral to Crosshead
Column Length	Extended
Controller Input Voltage	115V USA (Straight Plug)
Volume	6 liter
Internal Width Depth Height	130x480x100 mm (5x19x3.9 in)
External Width Depth Height	205x575x140mm (8x22.5x5.5in)
Fluid Type	Saline
Spray Option	Included
Digital Temperature	Included
Extension Rod	Included
Upper Attachment Type	Force Transducer
Installation	Not Included

4000 EVBTH001 BIONIX ENVIROBATH 1

Easy to set up, operate, and maintain, the Bionix EnviroBath facilitates accurate and efficient mechanical testing of medical device and biomaterial specimens in fluids heated to body temperatures. Bionix EnviroBaths are available in one, six, and ten-liter volume configurations and are compatible with MTS electromechanical and servohydraulic load frames, a wide selection of Bionix grips and fixtures, and electromechanical test systems from other manufacturers. Optional features include a protein-based fluid system, a bath-mounted digital temperature monitor, a mist spray, and a horizontal mounting kit.

Application	Servohydraulic
Servohydraulic Frame	370.02 - 25 kN (5.5 Kip) Cap.
Chamber Model Number	10
Actuator Type	Axial
Actuator Location	Integral to Crosshead
Column Length	Standard
Controller Input Voltage	115V USA (Straight Plug)
Volume	10 liter
Internal Width Depth Height	215x305x150 mm (8.5x12x5.8 in)
External Width Depth Height	295x395x190mm(11.5x15.5x7.4in)
Fluid Type	Saline
Spray Option	Included
Digital Temperature	Included
Extension Rod	Included
Installation	Not Included

5000 HD505002 HYDRAULIC POWER UNIT - 505 G2 1

HPU Model Number	SilentFlo Model 505.11
HPU Flow Delivery	41.6 l/min (11 g/min)
HPU Electrical Service	220V/3phase/60Hz
Sound Pressure Level	60 dB(A)
Hydraulic Fluid	160 liters (42 gallons)
Hydraulic Fluid Source	Ship in HPU
HPU High Pressure Filter	Not included
HPU Surge Suppressor	Not included
HPU Trolley	Not included
ORFS to JIC Adapter Kit	No
HPU Pressure Out	-12 ORFS
HPU Return In	-12 ORFS
HPU Drain In 1	-08 ORFS
HPU Drain In 2	-06 ORFS
Hose Length	4.5 m (15 ft)
Installation	Not Included

5010 HDHOS001 HYDRAULIC HOSE SET 1

Hose set for optimal flow.

Hose Length	4.5 m (15 ft)
HOSE END FROM COMPONENT...	HPU
Hose End - Pressure (OUT)	-12 ORFS
Hose End - Return (IN)	-12 ORFS
Hose End - Drain (IN)	-08 ORFS
Hose End - Drain2 (IN)	-06 ORFS
HOSE END TO COMPONENT...	Customer Supp. or Aftermarket

NOTE: The prices quoted above are expressed in US Dollars, unless otherwise noted. Prices do not include any local, state, or federal taxes if applicable.:

For increased safety, such as to address the European Machinery Directive, an acceptable Uninterruptible Power Supply (UPS) should be properly integrated in hydraulic test systems. The UPS should be wired to provide power to the servo controller and any peripheral equipment that is instrumental in safe system operation and shut-down. For more information, see UPS Quote Text document at http://www.mts.com/ups