BioHorizons:
Fatigue Test Machine

Felicia Craig
Jonathan Hill
Chris Howell
Bradley Johnson
Allen Lindsay
John Maddox
Crichton Neal

October 12, 2006

Abstract

The general concept of our fatigue testing machine concerns a base with a U-shaped steel frame from which the jig is attached at the appropriate angle. The base holds the linear servo-motor, which actuates in tandem with a load cell to apply the load to the dental implant. The implant is submerged in a saline solution held in a container above the motor. Each dental implant size has its own holder, tapped specifically for their respective thread sizes. A combination of a heating element, temperature switch, and fluid level indicator keep the solution at the appropriate level and temperature. The signal from the load cell will be processed by a computer and then fed back to a driver that controls the servo-motor. LabView will process the signal and record the data necessary for the creation of the S-N curves.

Contents

List of Figures

1 Introduction

Thus far into the design process, Corp 3 has developed a primary concept covering all necessary components of the dental implant fatigue testing machine. The concept is manufacturable, reasonably economical, and simple enough to be completed within the allotted time frame. The initial task of the senior design project team was to review the sponsors objectives and specifications, as well as those established in the ISO 14801 standard. From this point, the team brainstormed to develop several concepts, each of which was given an initial feasibility screening. From this screening, the team selected the primary design concept.

The general concept of our fatigue testing machine concerns a base with a U-shaped steel frame from which the jig is attached at the appropriate angle. The base holds the linear servo-motor, which actuates in tandem with a load cell to apply the load to the dental implant. The implant is submerged in a .09% saline solution held in a container above the motor. Each dental implant size has its own holder, tapped specifically for their respective thread sizes. The holder for the implant size to be tested is placed into the jig and held with a horizontal screw-lock mechanism to allow for the required uniaxial loading, as specified in the ISO standard. A combination of a heating element, temperature switch, and fluid level indicator keep the solution at the appropriate level and temperature. The signal from the load cell will be processed by a computer and then fed back to a driver that controls the servo-motor. LabView will process the signal and record the data necessary for the creation of the S-N curves.

Upon approval by BioHorizons, and making any improvements to meet their recommendations, several tasks need to be completed during the rest of the semester. The team will acquire several more quotes for linear motors to drive down costs, as well as finalize and dimension the design parts for machining. Finally, additional preparations need to be made for the linkage of controls, computers, and sensors to enable the controls process to run smoothly in the spring semester.

2 Specifications and Constraints

Consideration should be given to multiple categories of constraints and specifications during the concepts stage of the design process. The first of these to be adhered to is more of the general and feasible nature. During the introductory presentation, BioHorizons established several project requirements. Among these is the desire to have the fatigue testing machine sit on a table top indoors at the company's worksite to perform tests. This establishes size, weight and environmental constraints, as the final product must be small and light enough to rest on a table as well as be reasonably transportable. Furthermore, since BioHorizons operates within an office-building, no emissions or excessive noise levels are permissible. While no weight or decibel levels are specifically given, the more general constraints of light enough and quiet enough prevail and significantly affect our concepts.

The majority of the more exact, measurable constraints concerning this project are contained within the International Standard ISO 14801: Dentistry —Fatigue test for endosseous dental implants. The fact that a standard strictly regulates the design and operation of our fatigue tester makes the applicable specifications and constraints fairly straight-forward. The ISO standards that specifically applied to our design concept can be found in the Standards section (page 17). It should also be noted that the machine should also be able to perform a static load failure test in addition to the fatigue test.

Finally it should be noted that referenced standards below were and will continue to be examined as the design process continues for additional applicable constraints on the fatigue testing machine: The main economic constraint is to produce a fatigue testing machine that can be reproduced and used by BioHorizons for less than it currently costs the company to send off its dental implants for testing. Economic constraints are elaborated in the Economic Analysis Section of the report. At this stage of the design process, quotes and approximations of costs for motors, software, and sensors are the main goal, as more exact cost constraints and cost comparisons will be determined after the concepts presentation.

3 Primary Concept Presentation

The machine will be built with a solid square plate as the base. The frame will be mounted to the base and extend vertically. A load cell and linear actuator will be mounted on the base so that the load cell is in the line of the applied force. There will then be a liquid bath container mounted on top of the linear actuator and load cell, which will be pressed against the test piece. The base of the container will be what actually applies the force to the test piece. The frame will be made to hold the test piece at a 30° angle. See Figures 1 and 2.

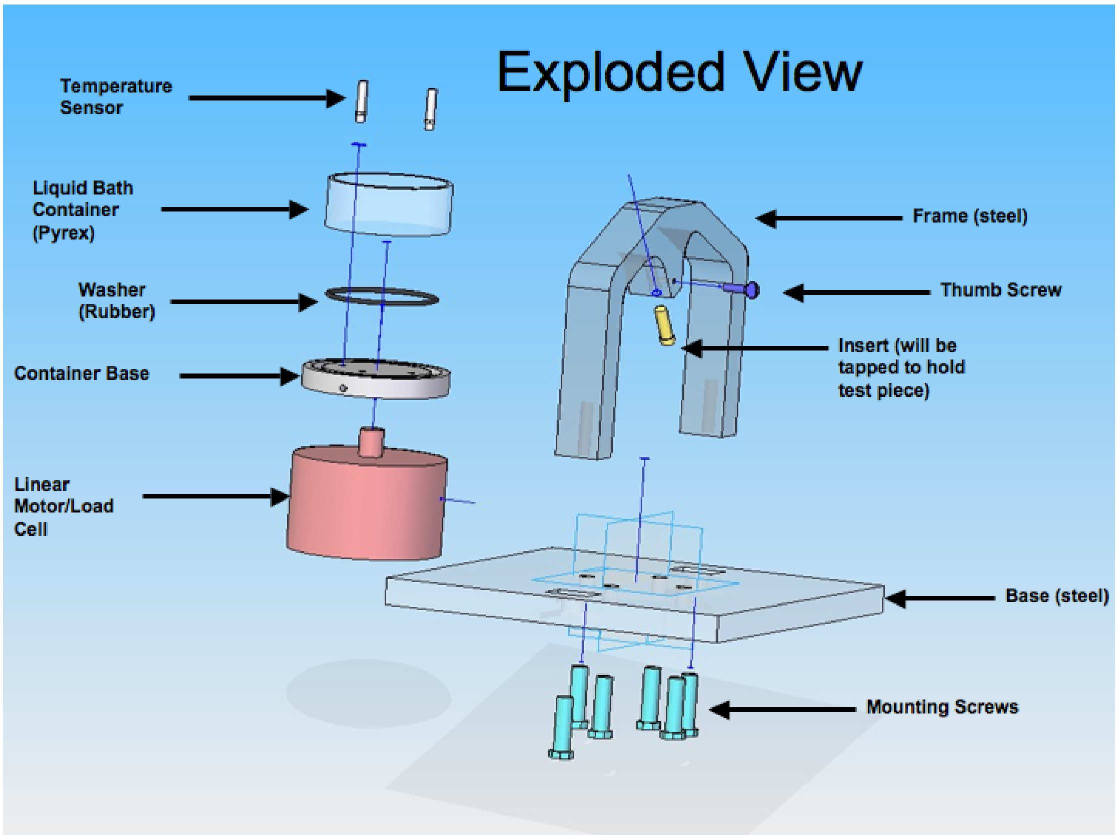

Figure 1: Exploded View with Labels

3.1 Base

A square metal plate will serve as the base onto which the frame and linear motor will me mounted. Bolts from underneath will attach the frame and motor to the base. The under side on the base will be machined out so that the heads of the bolts will be flush base bottom. The base will rest on rubber feet, which will act as vibration isolators. See Figure 3

3.2 Frame

The frame will be machined out of steel. There will be a hole machined into the frame at a 30° angle relative to the plane at which the frame contacts the base. Having this hole machined into the frame will make the angle accurate and reliable. The extension of the frame, in which the implant is inserted, will be cut so that there will not be a moment acting on the main part of the frame. The shape of the frame will also help to counteract any bending force that would contribute to altering the angle of the hole. The frame design will also decrease the localized stress points at the bends and the jig. See Figure 4

3.3 Insert

An insert will be placed into a hole in the frame and it will be held in place by a hand-tightened screw. The screw will only keep the piece from falling out of the hole; it will not be withstanding any of the applied force. All of the force applied by the linear actuator will be distributed to the frame. An insert will need to be tapped to fit each different line of test pieces. See Figures 5 and 6 .

3.4 Water Bath

The water bath is required by ISO 14801:2003 section 5.4, which can be found in the Standards section (page 17). The water bath design must meet these requirements and allow for the tester to address the testing environment, including medium (saline, water, or air) and temperature in the test report.

The design for the water bath will consist of 4 major components: heating element, the temperature switch, the dish, and the water level switch. See Figure 7

3.4.1 Heating Element

In order to meet the ISO 14801:2003 standards, the fluid and the test specimen must be maintained at 37°C±2°C. For this to be maintained, a heating element must be utilized to raise the temperature of the fluid to the required standard. Also, the heater must fit into the design requirements. The design requirements for the heating element are that the element fit into the dish or be able to create a flow to move fluid from the dish, across the element, and back to the dish. The element must also work with a small amount of fluid. Several elements were considered, ranging from fish tank heaters to engine pre heaters. In the case of the fish tank

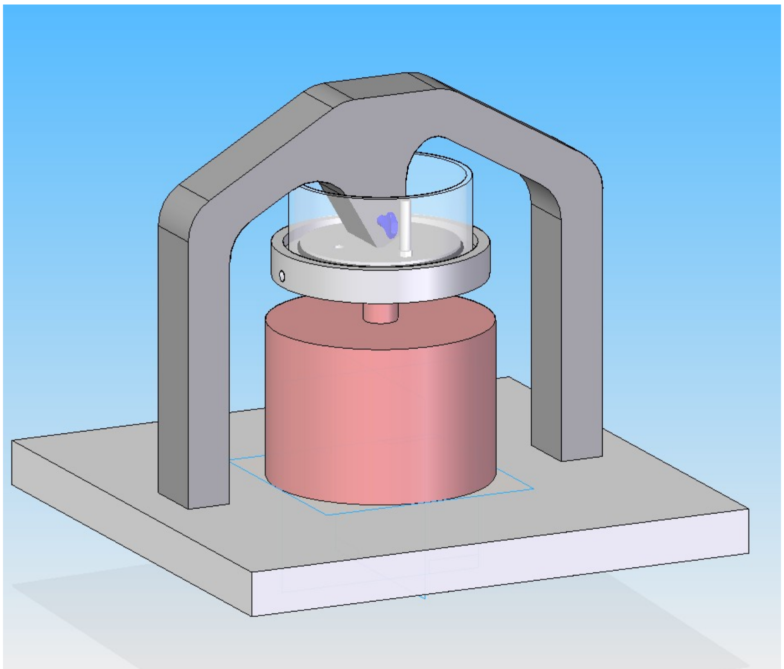

Figure 2: Solid Assembly

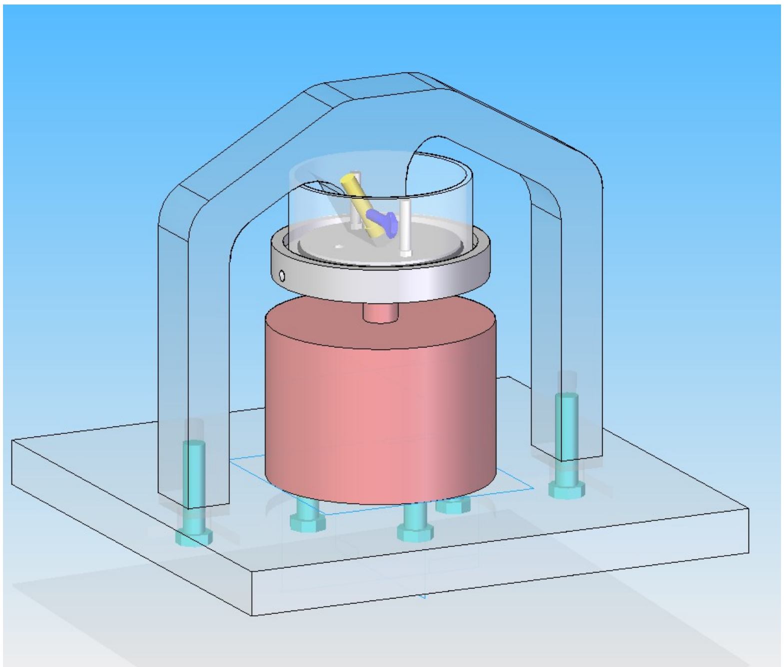

Figure 3: Transparent Assembly

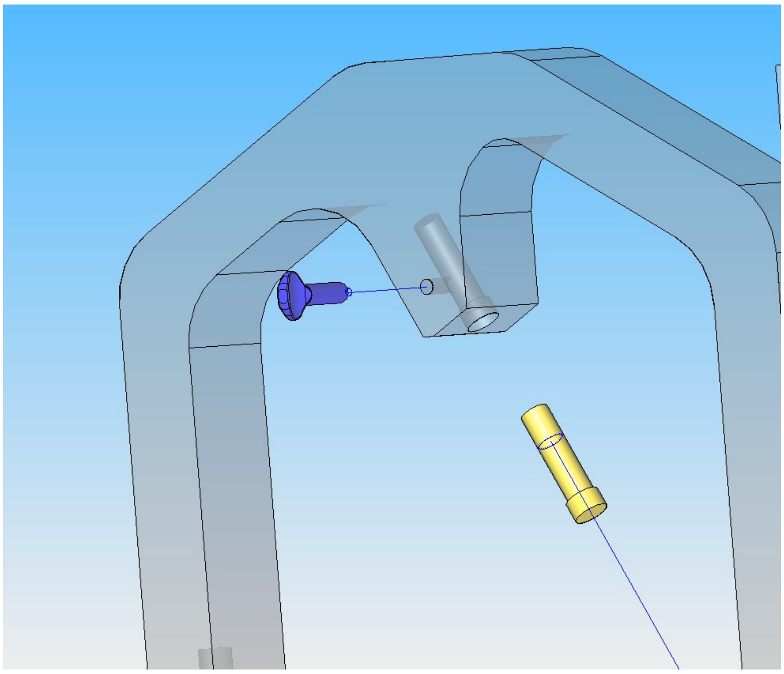

Figure 4: Exploded View of Insert

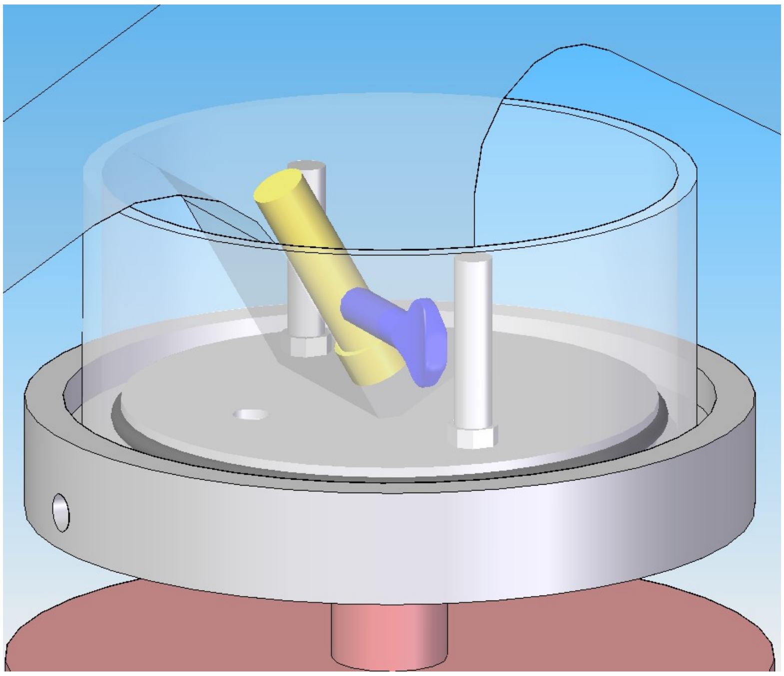

Figure 5: Angled View of Insert

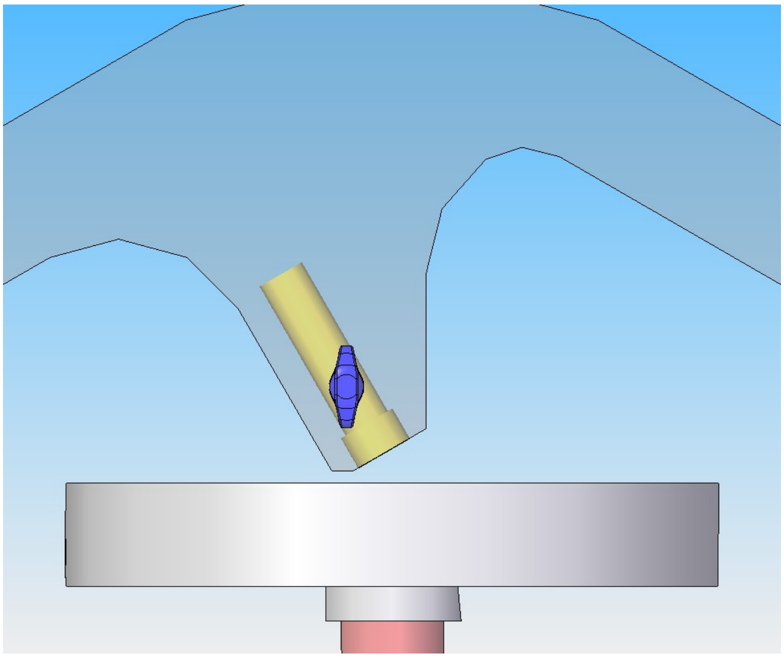

Figure 6: Side View of Insert

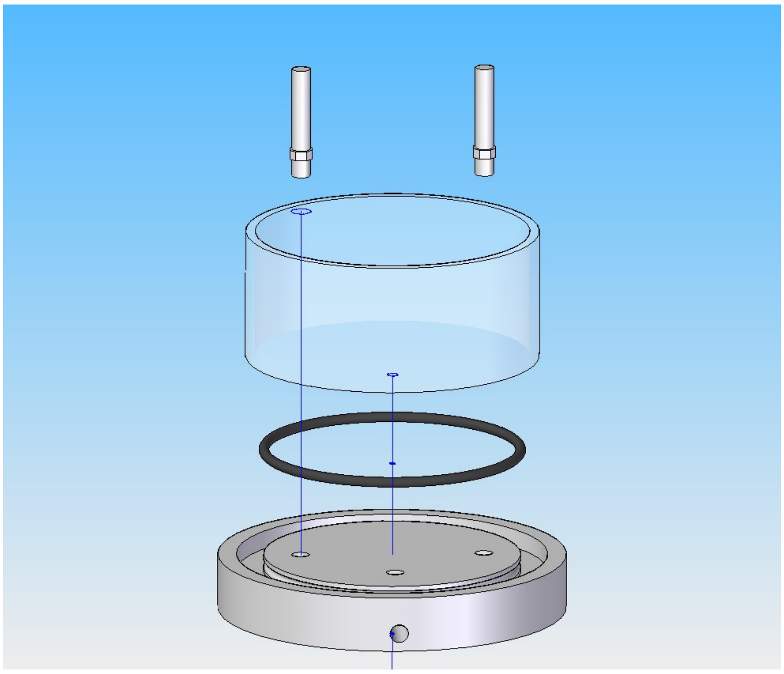

Figure 7: Exploded View of Water Bath

heaters, most need a minimum volume of fluid which often far excide the design requirements. Also, a concern for engine per heaters ability to create natural convection to circulate the fluid to and from the dish pulled them from contention. The element chosen is a compact cartridge-style immersion heater. This heater is more compact than screw-plug immersion heaters, but has similar heat-transfer properties. The heater can be used with water and 90% water-soluble liquids and can be mounted horizontally or vertically. It has a maximum temperature of 100 C. The heater has a 1 5/8" long type 316 stainless steel element and is a UL-recognized and CSA-certified element. The screw plug is NPT male and made of Type 316 stainless steel. This heater is ideal for the design; however it will need a way to regulate the temperature.

3.4.2 Temperature Switch

In order to maintain the temperature of the fluid, a submersible cartridge temperature switch will be utilized. This switch will open when temperature rises above set point, and close when it falls below set point. The switch is submersible to the top of the 300 series stainless steel outer shell. Its set point can be adjusted between -73° and +315°C. Although this is well beyond the required set point for the design, the switch does meet the requirement of a 37°C set point. However the search for a more refined switch is still ongoing. The current considered switch has a 1/2" diameter and a 2" length and is UL recognized. This switch will be used to turn on and off the heater to maintain the set temperature within the dish.

3.4.3 Dish

The dish will consist of four main components. First the base will me made of metal and will be the mounting point for the heating element, the temperature switch, the water level switch, and a small ball valve. A circular indention in the base will house a rubber washer and a glass tube. The glass tube will form the sides and the washer, or sealant as of yet to be determined, will seal the base to the glass. Glass must be used because most immersion heaters are not rated for plastic containers. A small hole in the bottom of the base will provide a way, in conjunction with the ball valve, will allow for draining of the fluid from the dish as needed

3.4.4 Water Level Switch

The final need for the dish design is a way of maintaining a safe water level for the immersion heating element. The element must remain immersed in the fluid in order to function properly and to keep the element from being damaged. A vertical-mount liquid-level switch will provide the needed safety valve to protect the design. The switch will mount to the base of the dish and will be set for normally closed operation. The float travel is about half the length of the float. The float length is 5/8". Switches are rated for 120/240 VAC. The switch is UR and CSA rated and is UL recognized. The connections are NPT male with a diameter of 37/64". The switch has an over all length of 1 7/8" and is rated for a max temperature of 105°C. This switch will cut power to the heating element when the fluid level drops too low for safe heating and turn on a warning light or trigger a system warning in the testing program letting the tester know to add more fluid.

The design detailed here satisfies the requirements of the water bath, and with some refining the design will be a stable, robust, and safe system.

3.5 Discussion of Primary Design Concept

3.5.1 Advantages

The advantages for the linear motor setup are numerous. The machine will have long life; in other words, it will over all have a small chance of wearing out due to fatigue in the parts as a whole. The machine will have excellent precision and reliability. Over a long run, the cost of operation will not be significant due to the extended life of the components as a whole. When doing the tests, the operator will be able to vary the frequencies of testing and the pressure loads easily. In addition, there will be virtually no maintenance and low calibration needs both in the motor and load cell. There will be no need to change parts when performing a static test versus an actuating test; everything will be controlled by computer programs that send signals to the linear motor. A unique advantage of our jig-frame combination is the fact that the forces will be distributed more evenly throughout the frame with a decrease in pressure points. In addition, the combination of the jig and frame will allow the project to have a lack in high momentary tendencies that would be associated with a shaft that could be used for the placement of the jig. The largest advantage is the overall small number of parts that are in the machine as a whole. The small number of parts allows for an open design/easy access of critical parts and a reduction in the possibilities of failure due to excessive parts. In addition the reduction in parts allows for easy disassembly and transportation of the machine.

3.5.2 Disadvantages

Disadvantages of the linear motor setup primarily deal with the initial operating costs. Due to the components in the machine, building costs will probably run higher than what they could with other project types. The jig-frame combination could be among the most expensive and hardest to produce machining portions of the project. The insert hole and angles that are on the frame are crucial and if any portion of the frame is not exact an entire new frame will need to be produced. In addition, each insert that will be put in the jig portion of the frame will have to be specially machined to meet the specifications of the new dental implant. Similarly, if one of the components should expire, the replacement costs will be high. Training someone to run the machine could be easy or difficult depending on the technical skill of the operator. Finally, the motor could have cooling needs that might need to be addressed if the operation is done in a warmer environment.

4 Economic Analysis

When considering economics with the fatigue tester, several components tend to bring higher amounts of consideration than others. The linear motor, which will be custom designed and built to meet our specifications, cooling jacket, control box, and the driver, which will send voltage signals to the motor, will cost roughly $19,600. The load cell will cost an additional $1,000. The heater needed for the saline bath will run around $300. For the data acquisition side of the project, a one-year license agreement for LabView will cost $1,200 for a base package and up to $4,400 for the premium package. The DAC card will cost a maximum of $500. The jig-frame and the base for the project if machined by Corp 3 in the Auburn Machine Shop would cost practically nothing other than the materials. However, if the parts were to be machined in a professional machine shop the price could be $2,000. Also, the project will probably need around $600 for a stand-alone computer for the data acquisition and controller and an additional $500 for incidental cabling.

Total costs could run $25,000 if machined in a professional machine shop.

5 Alternate Design Concepts

We considered alternate concepts for both the structure of the machine and the motor used to apply the force. We considered using a rotary motor instead of the linear motor, and we also considered a horizontal design for the structure which could be used with the linear motor or the rotary motor.

5.1 Horizontal Structure

The horizontal structure we considered uses two legs mounted to a base using translational joints with bearings. See Figures 8 - 6. One of the legs would be permanently affixed to a load cell which would be permanently affixed to the base. The other leg would be affixed to a motor which would apply the force. The implant would be mounted into one of the legs and pressed against the other while submerged in the saline bath. The force could either be applied with a linear motor (Figure 9)or a rotary motor (Figure 11).

5.1.1 Advantages

- The saline bath container will be cheaper than the one used in the primary concept
- The saline bath could be easily removed for the static load

5.1.2 Disadvantages

- The angle of the implant will be less reliable
- The bearings will need regular maintenance
- Larger footprint than the primary concept
- There will be a small error introduced by the friction of the bearings
- It is complicated and there are many places for possible failure

5.2 Rotary Motor

The rotary motor concept uses a jointed arm and a spring to convert the rotary force into a linear force. The motor would be attached to a rotating disc. The disc would have an arm attached to it. The arm would also be attached to a shaft with a spring in it (See Figure 12). Applying force to the arm would apply force to

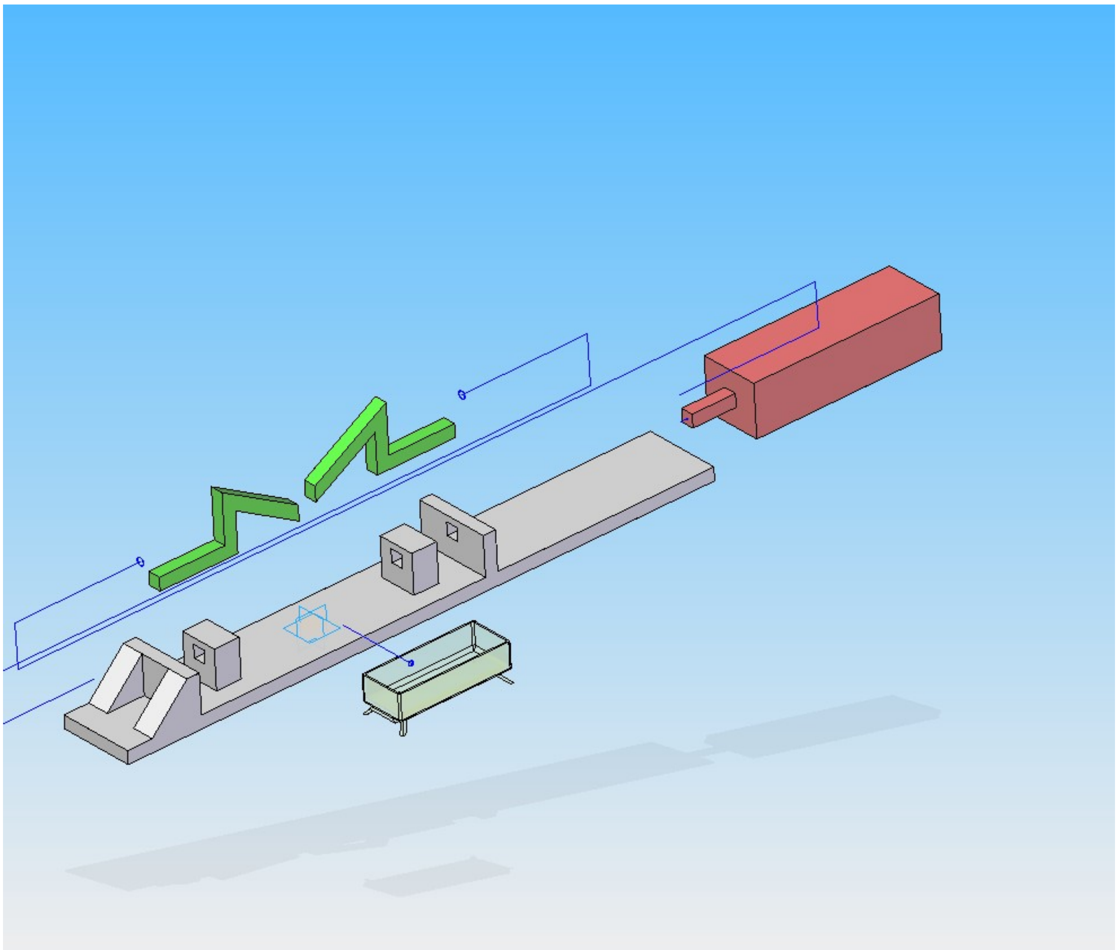

Figure 8: Exploded view of Horizontal Structure

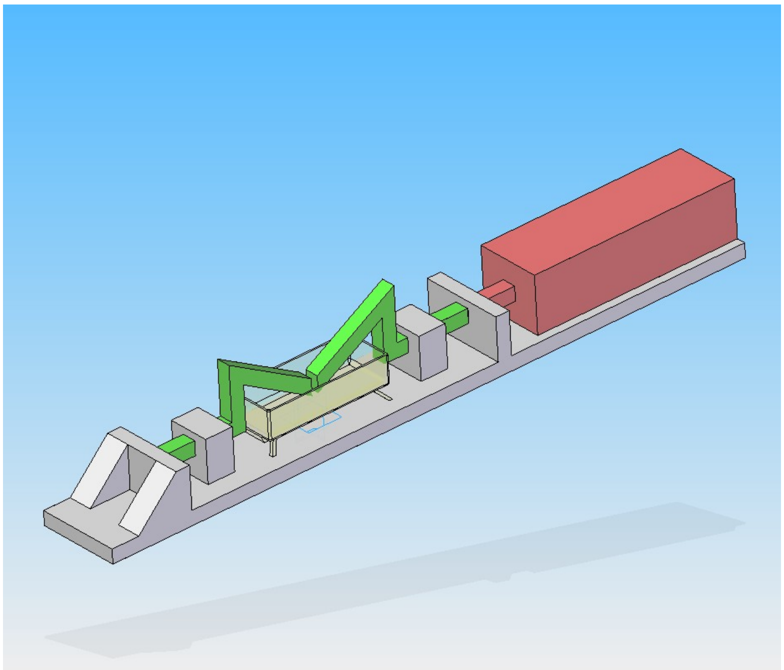

Figure 9: Angled View of Horizontal Structure

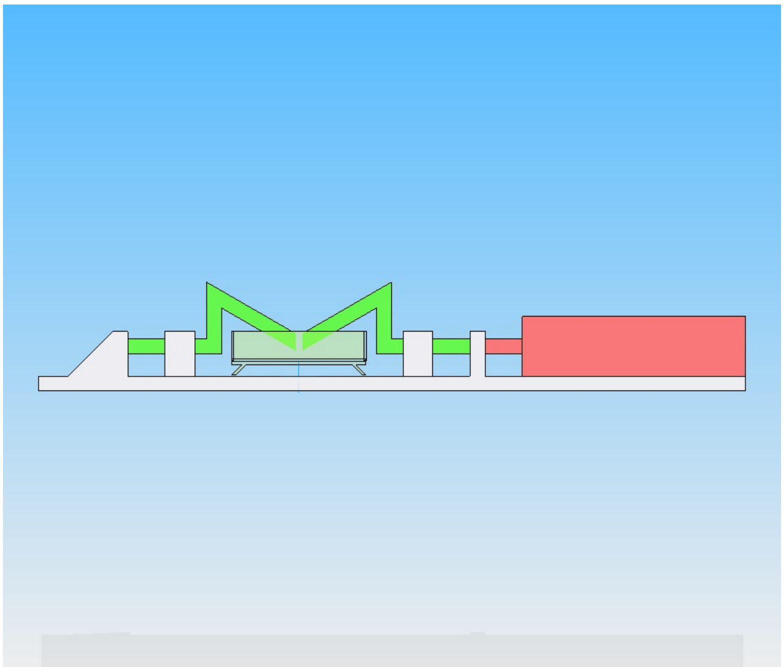

Figure 10: Side View of Horizontal Structure

the spring. The spring would then transmit the force to the implant. The system would be set up to deal with the different loading in one of three ways.

- by inserting the a spring with a corresponding stiffness for the desired load
- changing how far away from the center of the disc the arm is attached
- changing the length of the arm so that it presses the spring in a different distance

5.2.1 Advantages

- Lower initial cost than a linear motor
- Lower repair cost, in case of failure

5.2.2 Disadvantages

- Complicated, better chance of failure than the linear motor
- Not capable of performing static test without major changes to the setup
- Physical adjustments will need to be made to the elements of the system in order to vary the loading
- It would be difficult to calibrate

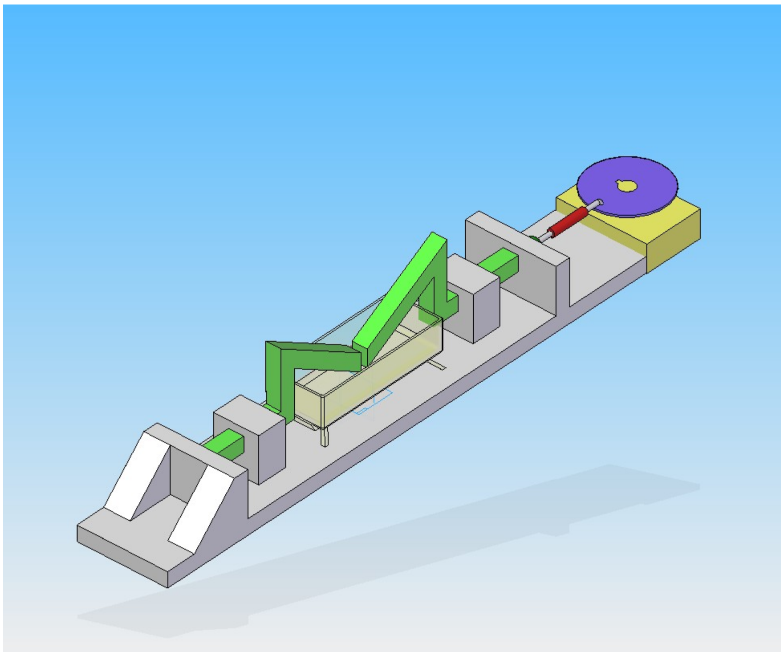

Figure 11: Angled View of Rotary Motor and Horizontal Structure

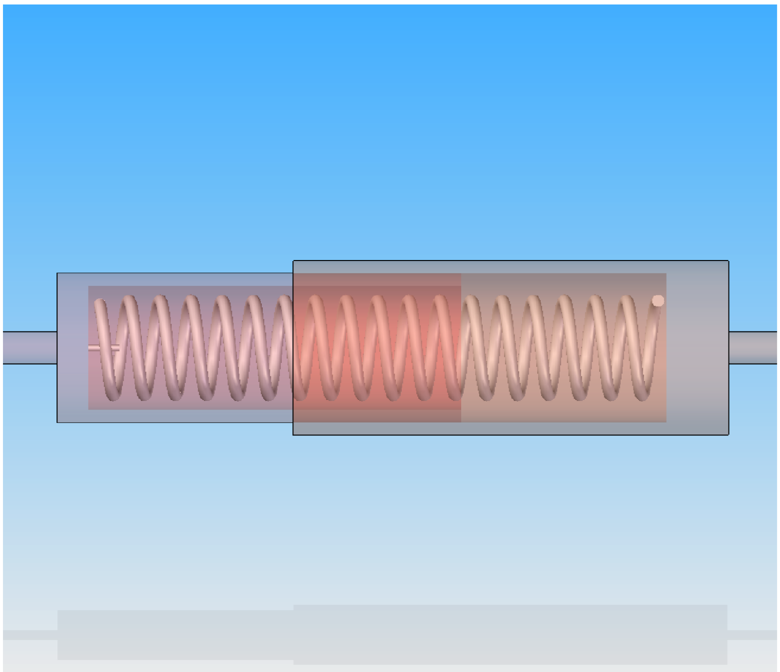

Figure 12: View of Spring and Shaft

6 Standards

6.1 ISO 14801:

The following standards all fall under ISO 14801

- 4.2 Multi-part endosseous dental implants: ...If a multi-part device is assembled by means of screw joints, then these shall be tightened to the manufacturers recommended torque using a device that provides torque within $\pm5\%$ of the recommended value.
- 5.1 Testing Machine: The testing machine shall have the following characteristics:
  - Be capable of applying the specified load with an error not exceeding $\pm5\%$ at maximum load
  - Be capable of applying the load at the specified frequency
  - Include instrumentation to monitor the values of maximum and minimum loads and loading frequency and to detect failure of the specimen
  - Be capable of recording the number of loading cycles during the test
- 5.2: Loading Geometry
- 5.2.1: The loading force of the testing machine shall be applied is such a way that no lateral constraint occurs and the loading centre is well defined.
- 5.2.2: The endosseous dental implant shall be clamped such that it makes a $30°\pm1°$ angle with the loading direction of the testing machine.
- 5.2.3: The loading force of the testing machine shall be applied through a hemispherical loading member attached to or placed over the free end of the endosseous dental implant. The loading centre, which is the centre of the hemisphere, shall be on the axis of the endosseous dental implant.
- 5.2.4: The loading force shall be applied to the hemispherical loading member by a plane surface normal to the loading direction of the machine. The member containing the plane surface that applies the loading force to the hemispherical loading member shall be unconstrained in the transverse direction, so as to not reduce the magnitude of the applied load. This shall be accomplished by means of a universal joint or a pin at the junction of the loading member and the test machine structure. The junction shall be located at least 50 mm from the hemispherical loading member.

- 5.3: Specimen Holder
- 5.3.1: The bone-anchoring part of the specimen shall be fixed in a rigid clamping device. If an embedding material is used, it should have a modulus of elasticity higher than 3 GPa. The geometry of the clamping device shall be such that the testing geometry specified in 5.2 is achieved. The clamping device shall be designed so as to not deform the test specimen.
- 5.3.2: The device shall clamp the specimen at a distance 3.0 mm ± 0.1 mm apically from the nominal bone level as specified in the manufacturers instruction for use.
- 5.3.3: The free end of the endosseous dental implant shall be provided with a hemispherical loading member to achieve load application as specified in 5.2The dimensions of the loading member shall be chosen to define a distance l = 11.0 mm ± 0.1 mm from the centre of the hemisphere to the clamping plane. In the case of a long endosseous dental implant, for which l = 11.0 mm cannot be readily achieved, a larger value for l may be chosen. The choice shall be justified and documented.
- 5.4: Testing Environment: For endosseous dental implants that include materials in which corrosion fatigue has been reported or is expected to occur, or for systems that include polymeric components, testing shall be carried out in water of Grade 2 according to ISO 3696, in normal saline [.09%]* or in physiologic medium. The fluid and the test specimen shall be kept at 37°C±2°C during the testing.
- 5.5: Loading frequency and wave form: Fatigue testing shall be carried out with a unidirectional load. The load shall vary sinusoidally between a nominal peak value and 10% of this value. The loading frequency shall be $\leq$ 15 Hz. Testing in liquid media shall be conducted at frequencies $\leq$ 2 Hz.

6.2 Other ISO Standards

- ISO 1099: Metallic materials —Fatigue testing—Axial force controlled method
- ISO 1942-1: Dental vocabulary—Part 1: General and clinical terms
- ISO 3696: Water for analytical laboratory use—Specification and test methods
- ISO 4965: Axial load fatigue testing machines—Dynamic force calibration—Strain gauge technique

- ISO 7500-1: Metallic materials—Verification of static uniaxial testing machines—Part 1: Tension/compression testing machines—Verification and calibration of the force-measuring system