MEEN-442 Computer Aided Engineering

Final Project

Flexible Pipe Riser Internal Inspection Tool

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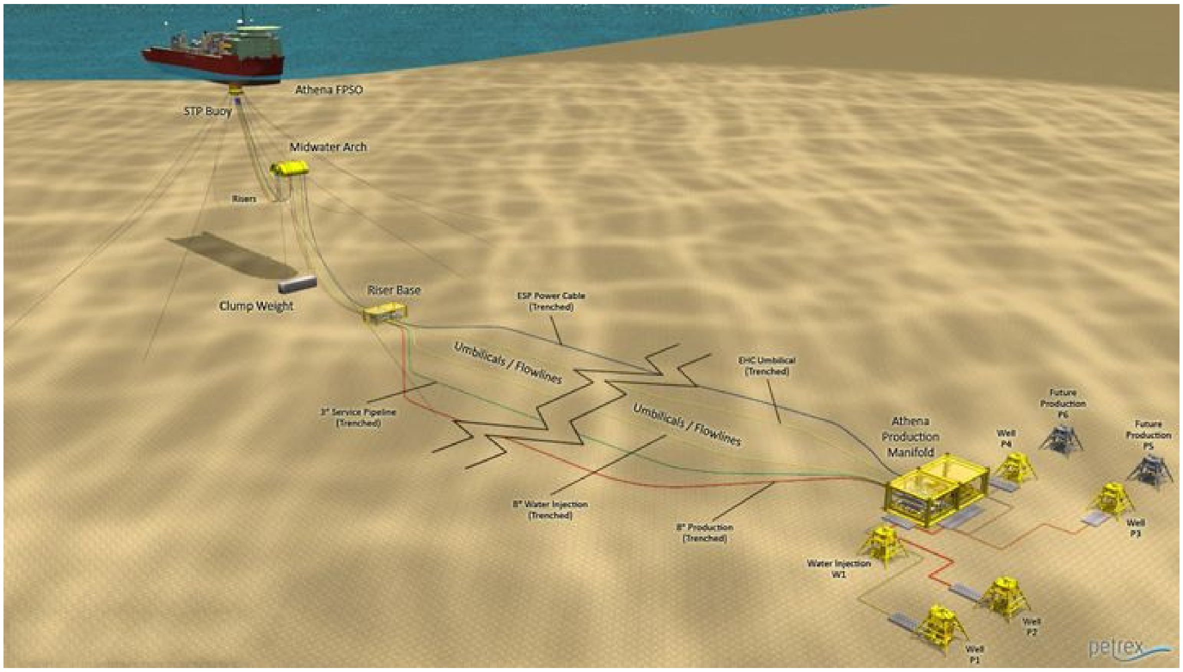

[6]

5/4/2018

Abstract

The team was tasked with designing a new flexible riser inspection tool meant to scan for defects in flexible pipe risers on offshore drilling rigs. This device must be able to move up and down pipes ranging from 6 to 9 inches in diameter across horizontal, vertical, and 20-D bends in various environments including hydrocarbons and seawater. In addition, it had to inspect the full 360 degrees of the pipe for defects and report the location of said defects without damaging the pipe in the process. After various design changes and supporting calculations, a final modular design was decided upon. This new design consisted of two sections. The first one contains multiple adjustable legs with motorized wheels attached to the end of them allowing the device to move up and down any size of pipe within the required range. The second section of pipe contains ultrasonic sensors that can also be adjusted depending on the pipe size to optimize data gathering. Both sections also serves as the battery and data storage housing for the entire device.

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1 PROJECT DESCRIPTION

1.1 Introduction

This project is the culmination of the design of a inspection device for flexible pipe risers on offshore oil rigs. This problem was given to the design team by Professors Doron and Ingram, the latter having worked in the energy industry for many years before joining Texas A&M faculty. In the following figure, a set of flexible pipe risers can be seen as the yellow hoses connecting the oil rig to the seafloor.

Figure 1.1.1. Example of flexible pipe risers working[3]

The product had to be able to satisfy several requirements which contributed to the selection of materials, sensors, method of transportation, and size. The team also focused on making the inspection tool as effective as possible all the while not over complicating its duty, which could cause additional problems. The specifications, design, and technology of the inspection tool designed by the team can be found in the following report.

1.2 Background

Offshore drilling is a very profitable yet expensive segment of the energy industry that is constantly making advances in processes and technology. One of the most important aspects of this segment is the flexible pipe risers that connects the crude in the sea floor to the oil rigs on top of the water. These flexible pipe risers have several layers of interlocking metal ribbings and polymer that allow for dynamic movement within the water while protecting the crude. By having these interlocking metal layers and polymer, the pipe is able to bend over a certain length as the wires inside slide around ever so slightly. An example of this construction can be seen in the figure below.

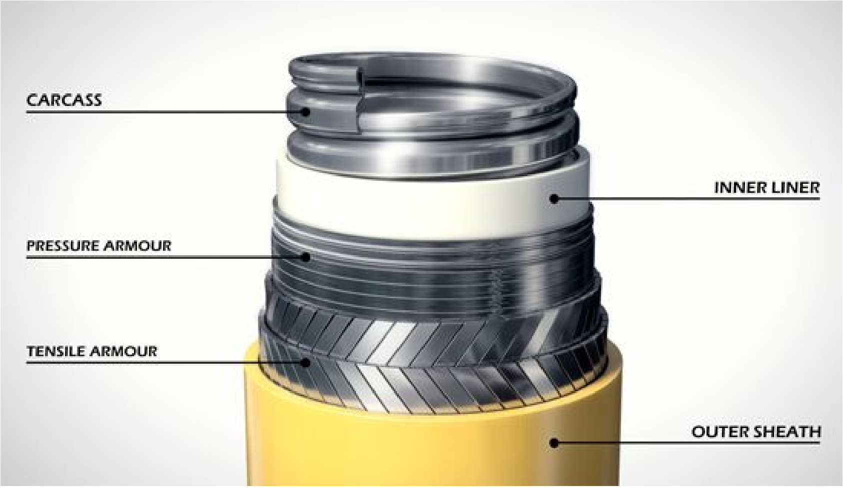

Figure 1.2.1. Flexible pipe riser construction[6]

Each layer of the pipe was designed to support one function of the pipe. The inner carcass is made of interlocking stainless steel to seal in the process fluids and be corrosion resistant. The inner layer, or pressure sheath, is a polymer layer designed to improve the pipes ability to prevent leaks of the internal fluid. The pressure armour layer is another layer of interlocking metal wires that, when under internal pressure, buckle together to prevent pipe bursting. A few examples of pipe armour wires can be seen in the figure below.

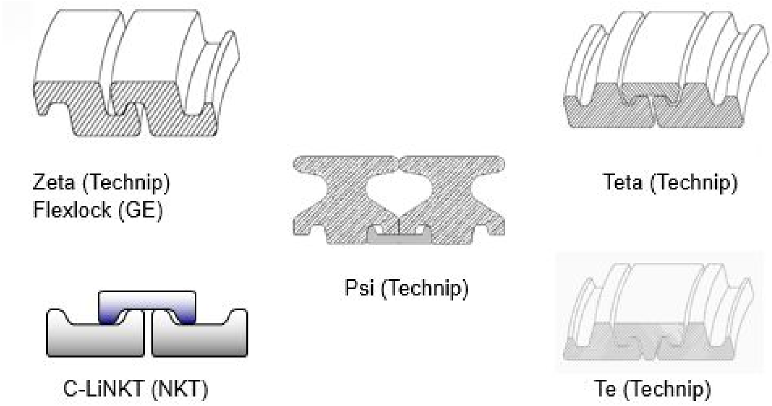

Figure 1.2.2. Pressure armour variations[6]

The tensile armour layer is made up durable steel wires and are designed to support tensile loads resulting from both the internal fluids and the actual weight of the riser. Finally the outer sheath layer is an additional polymer layer designed to protect the riser from the salt water of the ocean, scratches and other external defects.

Many modern oil rigs float in the ocean and are attached to the sea floor using cables tethered across the entire circumference of the rig. These tethers however must allow for motion during events such as storms, currents, or winds. Therefore the entire oil rig can move around on top of the water as seen in the figures below.

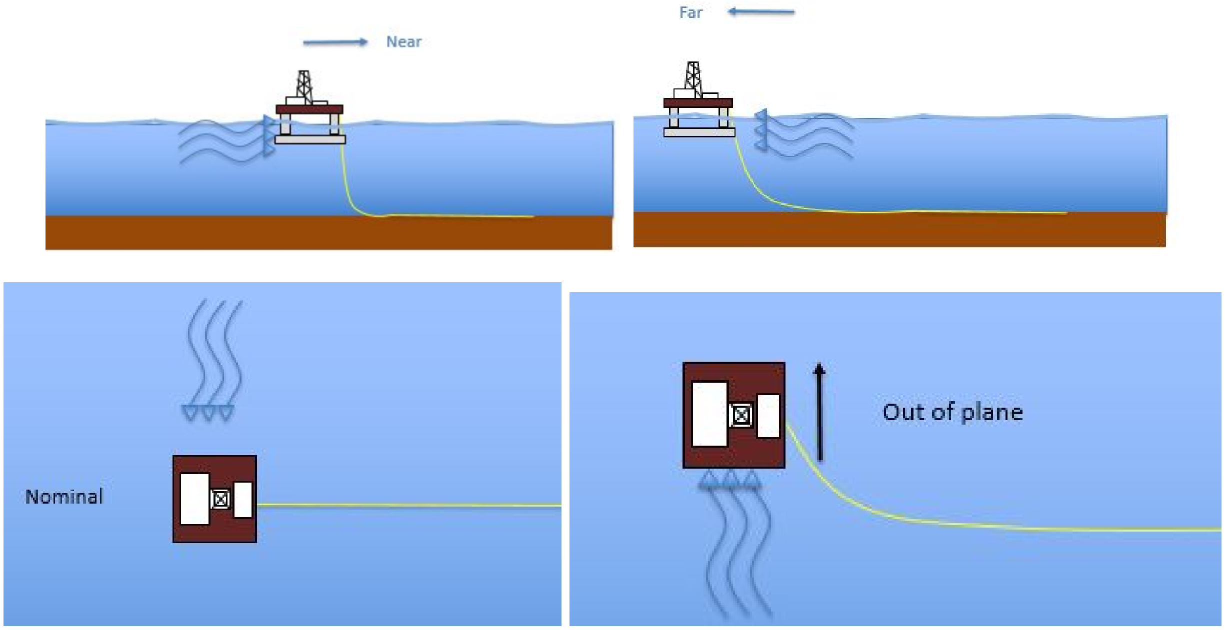

Figure 1.2.3. Dynamics of a moving oil rig[6]

As a result, the risers, depicted as the yellow lines in the previous figure, must also have a high range of motion and account for the movement of its connection points.

The last aspect of pipe risers that needs to be covered in the background is the end fittings of the risers. They are designed to bring each layer to an end while also supporting what each layer was designed to support. An example of an end fitting can be seen in the following figure.

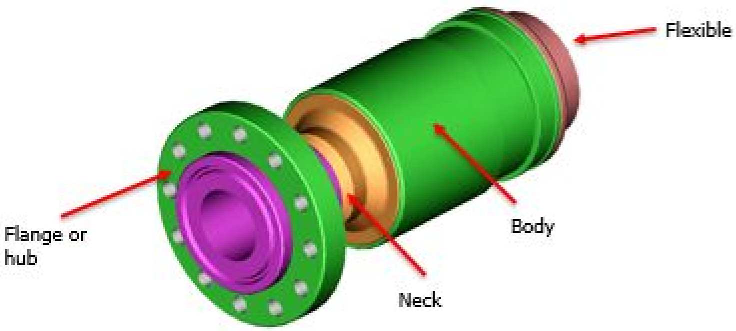

Figure 1.2.4. Example of a end fitting[6]

The body of the end fitting is long so that way it can bring each layer to a solid end and ease the stress at the beginning of the end fitting where the flexible pipe first enters. By making that connection more tangential, the less stress is applied to both parts. This end fitting is located at both ends of the pipe, but the group is much more interested in the fitting at the top of the rig due to it being where the inspection tool will be inserted. This process of insertion is described in later sections of this report.

Being the only connection to transport crude oil to the top of the rig, it is very important to make sure that these flexible pipes are up to code and will not fail. If the flexible pipe riser were to fail, not only will the company lose capital with lost crude oil, but also there would be an environmental impact because of the oil spill. We as engineers are bound to the Fundamental Canons set forth by the National Society of Professional Engineers (NSPE) and in following these canons must act ethically and minimize negative impact on others. Which is why this problem is important and requires a suitable product to maintain the safety and reliability of the flexible pipe risers.

1.3 Objectives

The main objective for this project is to design a pipe riser inspection tool that must meet many specifications set forth from the clients. These twelve specifications are listed on the following page:

1. Work on pipe sizes from 6" to 9" ID with a total length of 4500 ft installed in water depths of up to 3300 ft.
2. Be hydraulically powered.
3. Be able to traverse along the vertical and horizontal sections of the pipe with ease,
4. including around a 20-D bend.
5. Be able to return to the top of the riser.
6. Be constructed from materials compatible with seawater, trace amounts of hydrocarbons, CO2, H2S and corrosion inhibitors.
7. Tool must not scratch or otherwise damage pipe wall.
8. Internal layer may be:304L or 316L stainless steel or
   2304 or 2205 duplex steel.
9. Be able to inspect the full 360 degrees of surface all along the riser.
10. Be able to report the location of an anomaly.
11. Tool body must have structural integrity to support self weight and working pieces.
12. Be installable.

The above list of specifications are all individual problems in themselves and are solved by the team in a variety of different methods. Each of these solutions are documents in this report in their appropriate sections.

2 PROJECT TASKS

In this section of the report, every specification set forth in the objectives are discussed and a solution for each is presented by the team. Included are both former and current design decisions to demonstrate the evolution of the final product and why the team made the decision that it did. This section also contains figures from the SolidWorks files that demonstrate the teams design of each part.

2.1 Motion of the Device

As specified in the design objectives, the riser inspection tool must be able to "traverse along the vertical and horizontal sections of the pipe with ease." Thus the motion of the tool cannot solely depend on gravity or other external factors. Thus the team iterated multiple design options where the tool could power itself down the riser in a manner controlled by the user. Another important factor in this design, was that it was stated in the objectives that the tool must not "scratch or otherwise damage pipe wall." This impacts the what kind of materials were selected to come into contact with the inner pipe walls and what kind of methods that would prevent the most damage. The last objective that the motion of the device deals with is that the tool must fit in pipes sizes ranging from 6 to 9 inches. So the method of transportation must be able to fit and accommodate this range of size.

2.1.1 Hydraulics

The first method discussed amongst the team was to hydraulically power the inspection tool by adding a pump to the device and have it displace water from the front end to the back end to create a pressure difference, pushing the tool forward down the riser. The reason as to why this idea was first brought up was because of the specification to have the tool be hydraulically powered. To be able to perform this method of transportation, There must be watertight head seals on the device, blocking off the front from the back of the tool, so that a pressure difference could be made in the first place. These seals must also come in various sizes so that the range of pipe diameters specified in the project objectives would be met. The following figure is a hand drawing of said head seals.

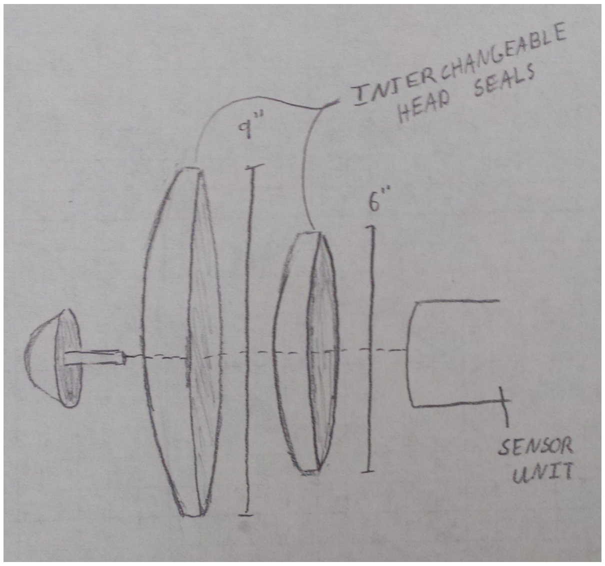

Figure 2.1.1.1. Interchangeable head seals for hydraulically power

However after internal discussion and verification from Prof. Doron, it was decided that hydraulic power was not a valid option. This decision was made because of the difficulty to keep a watertight seal at extreme depths of 3300 ft and the cost of having multiple seals for the various riser diameters. Another factor leading to this decision is that in other hydraulically powered devices, such as PIG pipeline cleaners, there are pump houses that push the device forward in the pipe. Whereas in the riser system, the pump must be mounted onto the inspection tool itself. This causes a great deal of complication as now a rotating piece of machinery must travel down the pipe riser and maintain enough power to continue its motion. It was deemed that too much effort would have to go into planning around this objective than instead of picking another method of transportation. The group was then told by Prof. Doron himself in class that this decision was acceptable in the project.

2.1.2 Servo Motors and Wheels

The next method of transportation became a part of the final design due to its ease of use. The servo motor and wheels methods rings with Prof. Doron's analogy of a "choo-choo train" where the motorized wheels will be pressed against the inner diameter of the riser and power it forward.

In the figure below, a SolidWorks screenshot is available to see what is meant by the motorized wheel with a scissor-lift expansion system.

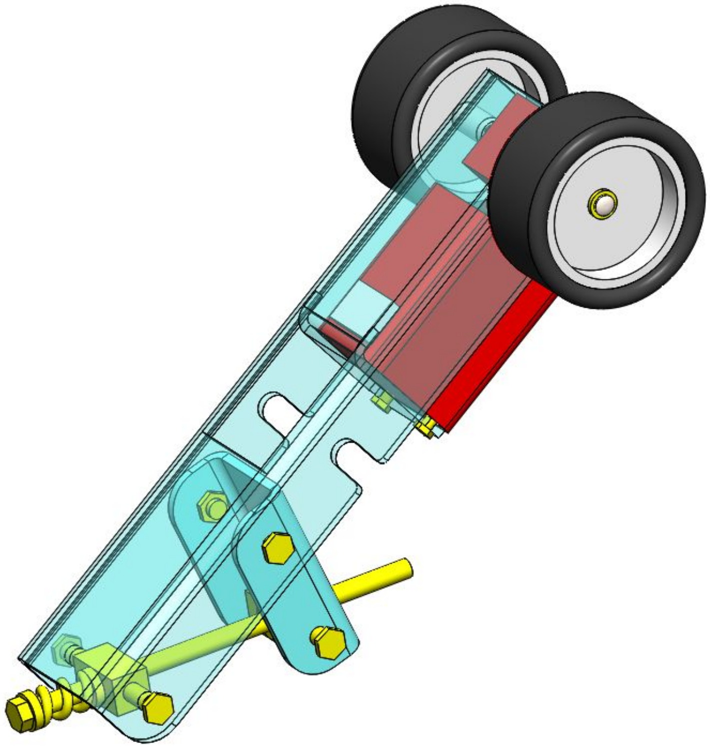

Figure 2.1.2.1. Servo motor, wheel, and scissor-lift assembly for transportation

The scissor-lift expansion system's purpose is to be able to expand the wheels arm radius so that way it can fit the range of riser diameters without having to resize parts. This sub assembly is discussed further in Section 2.4.1 of this report. The red rectangular prism in Figure 2.1.2.1 signifies the servo motor and is connected to the axle powering the two black nitrile rubber wheels. The reason as to why nitrile rubber was selected as the wheel material is that it will not scratch or damage the inner riser walls. It is also chemically resistant to seawater, trace amounts of hydrocarbons, CO2, H2S and corrosion inhibitors that could be present in the pipe riser, which is an additional objective of this project.

2.2 Return Method

With the hydraulic system determined to be ineffective, it was determined that the system would need to be able to hoist up and down the pipe with onboard power. Torque and power requirements were calculated and an appropriate motor, gearbox, and battery system were selected. During the design process, the possibility of a catastrophic onboard system failure was brought up. To solve this, it is possible to tether the flexible riser inspection tool to a wench system at the head of the pipe, where in the case of emergency, the system can be hoisted through and up the pipe. To ensure the steel cable would not scratch the surface of the pipe riser, it would need to be coated with nitrile. The anchor points for the tether on the inspection tool can be seen in the following figure.

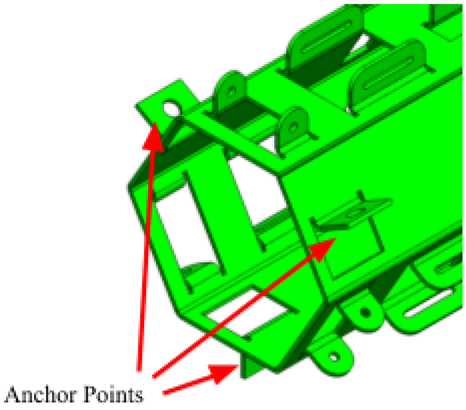

Figure 2.2.1. Emergency return tether anchor system

2.3 Sensors

2.3.1 Hall Sensor

Based on research of other pipeline inspection gadgets, it was thought that a magnetic flux leakage sensor would be the most effective way to measure corrosion inside the pipe. This was because so called Hall sensors are very effective at determining defects in the walls of pipes. However, these sensors require a great deal of electrical current as well as created electromagnetic drag in the system. These two things, combined with the soft requirement that the system have onboard power made the use of Hall sensors infeasible.

2.3.2 Calipers

The original design included calipers for determining large defects along the pipe. During the design process, it was determined that this would be beyond the immediate scope of this project, and that small corrosion defects would be the focus of this tool. However, the modular design of the tool does allow for the addition of calipers at a later date without much change to the system.

2.3.3 Odometer

The original design was hydraulically powered. This meant that there was no direct way for the system to determine where along the pipe it was. Therefore, it was necessary that on the centering wheels there would be an odometer that could track the horizontal distance travelled by the system. The removal of the hydraulic power and switching over to electric motor wheels made the odometer redundant. This is because using the servomotor enabled the system to calculate distance travelled without an odometer.

2.3.4 Ultrasonic Sensor

The sensors used in the final design are ultrasonic. It has been shown that ultrasonic sensors are adequate in detecting defects in the wall of a pipe.[7] These ultrasonic sensors require much less power than the Hall sensors, which satisfies the onboard power issue. Additionally, these sensors do not require contact with the wall, so variations in the pipe diameter will not be an issue to a much higher degree than a Hall sensor would be.

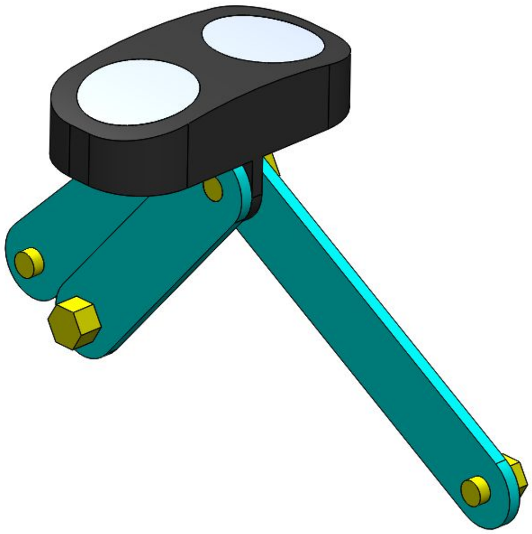

Figure 2.3.4.1. The ultrasonic sensors in their housing

2.4 CAD Design

This section of the report dives into the detailing of the main sub-assemblies used in the CAD design. The main features and relevant manufacturing methods will be discussed with material selection kept into consideration too.

2.4.1 Extendable Wheel

The following sub-assembly focuses on the mechanics of motion along the internal surface of the pipe riser. As mentioned in section 2.1.2, the assembly uses a scissor-lift expansion technique to expand the wheel arm radius. These arms are each attached to a compressed spring trying to push the arm out as far as possible. This allows for the wheels to stay in contact with the internal surface of the pipe throughout the entire inspection. All of the nuts, bolts, and the arms themselves are constructed out of 316 stainless steel due to its great chemical resistance to seawater, hydrocarbons, and other such environments that this device could come in contact with during service. The nuts and bolts being manufactured via hot forged and die forged respectively followed by a thread rolling process. The arms are made out of sheet metal that has been cut and bent to shape following the design. As for the wheels, they will be made from nitrile rubber due to its chemical resistance as well but also because it will be able to grip firmly onto the internal surface of the pipe, preventing the device from plummeting uncontrollably down the pipe, while not damaging this surface during the inspection. The motor and the gearbox will be purchased from an outside source with information regarding these devices located in Appendix 4.3 and 4.4 respectively.

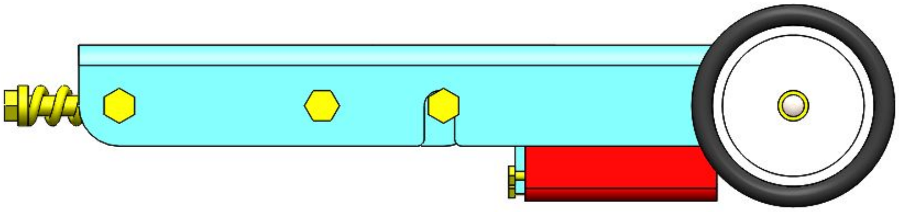

Figure 2.4.1.1. Drive arm fully retracted position

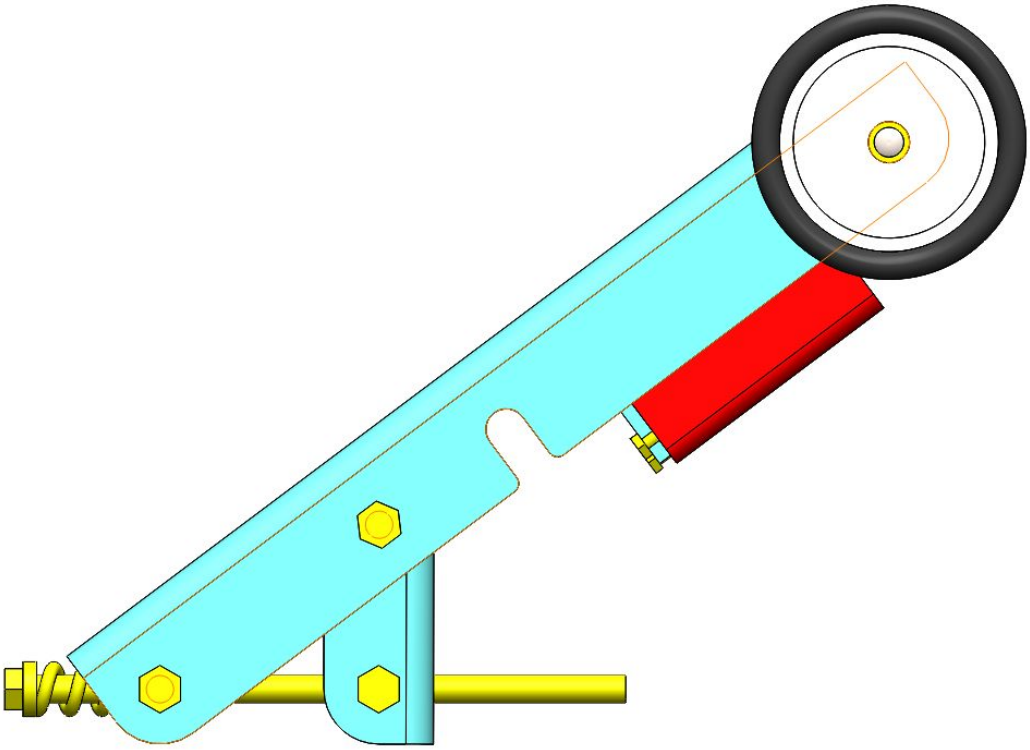

Figure 2.4.1.2. Drive arm fully extended position

2.4.2 Sensor Array

The following sub-assembly involves the sensor array arrangement used to perform the function of gathering data of the internal surfaces of the wall for any concerning defects. The design allows for 360° detection, as many sensing units are attached around the entire design. The sensor mounting ring and scissor-lift arms will be manufactured from 316 stainless steel sheet metal. The design utilises an assortment of folded tabs used to connect the scissor-lift mechanisms but also ensure correct alignment with respect to the main body. Additionally, there are folded tabs with slots. This design feature was included to allow for the pin to move and provide motion for the scissor-lift. It should also be noted that these tabs have relief sections to prevent warping during the bend process. The scissor-lift mechanisms are used to adjust the radial positioning of the ultrasonic sensors. This design feature was included to compensate for changes in internal pipe sizes. Attached to the end of the scissor lift mechanisms are the sensor housing units. These units are made from high-density polyethylene (HDPE), which is commonly used today for corrosion protection with steel pipelines. The ultrasonic sensors will be sourced externally, whereas the housing units will be manufactured by conventional machining.

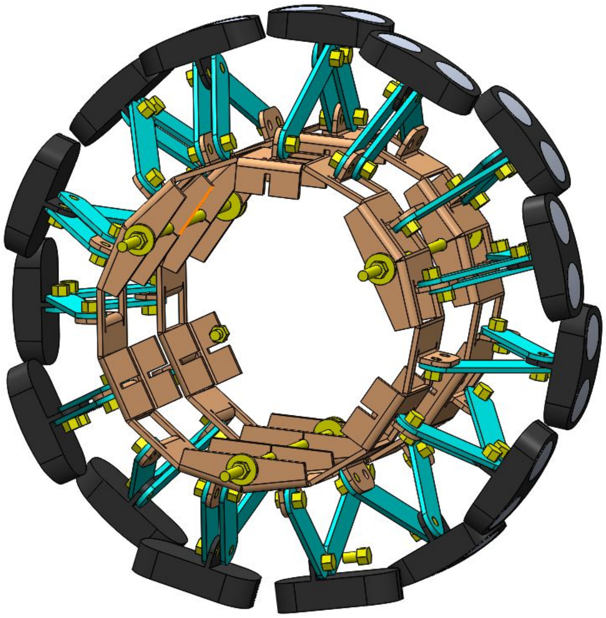

Figure 2.4.2.3. 360° ultrasonic sensor unit

2.4.3 Universal Joint

The universal joint serves as a way to connect the two main bodies together and address the issue of moving through bends within the pipe riser. The universal joint is formed from two identical parts, rotated at different orientations to allow for rotational movement in two different planes. The parts used in this sub-assembly are manufactured from sheet metal, with exception to the machined screws which are sourced externally. The design features a flange used to connect the joint assembly to the main body of the device. The flange plate replicates the hexagonal nature of the body instead of a typical circular shape. Additionally, the flange plate features folded tabs to secure the hinged arm feature. At the center of the design, four individual pins are used to connect the arms, providing a point of rotation. The joint will be manufactured using 316 stainless steel as it will be in contact with other components of the inspection tool that are also made from stainless steel.

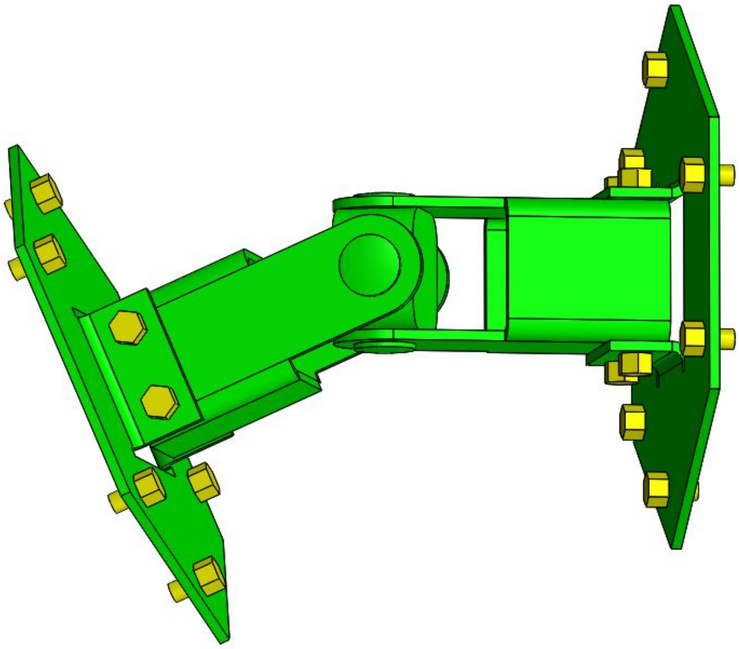

Figure 2.4.3.1. Universal joint connecting the two modules

2.4.4 Main Bodies

The main bodies of the device are manufactured from sheet metal. The part requires to be cut using a flat pattern and any suitable method such as laser cutting. This is followed by bending processes to form all the required features. The body incorporates folded tabs in the design to attach the armatures revolving around the hexagonal body. These folded tabs have been designed for ease of manufacturing, with reliefs to prevent the metal from warping during the bending process. It is also evident that the folds located towards the center of the body include slots, as depicted in *Figures 2.4.4.1-2*. These slots were included in the design to allow the pins of the extendable wheel assemblies to translate horizontally, which helps the flexibility of the device when operating on different pipe sizes. The hexagonal shape of the body allows for the device to house any relevant electronics and batteries used to power the sensors and motors. As the body must be compatible with seawater, trace amounts of hydrocarbons, CO2, and H2S; the material should be corrosive resistant. The selected material for the main body parts will be 316 stainless steel, which is common throughout the design where sheet metal is incorporated. By utilising a common material, the device will not incur galvanic corrosion between the body and the armatures, improving the longevity of the body itself.

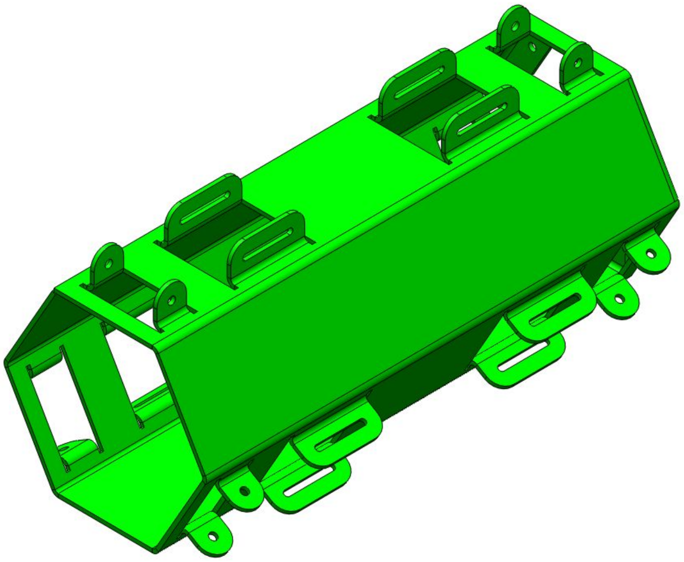

Figure 2.4.4.1 Main Power Body

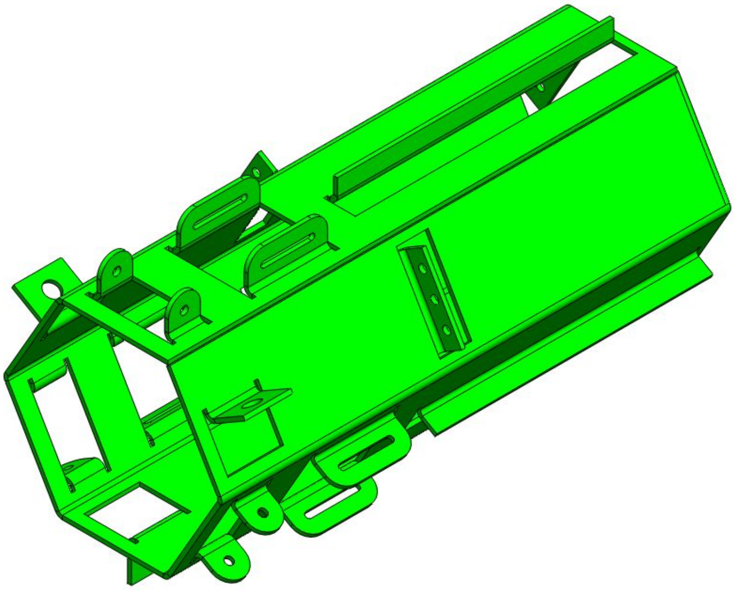

Figure 2.4.4.2 Main Sensor Body

3 RESULTS

3.1 Complete Pipe Inspector Design

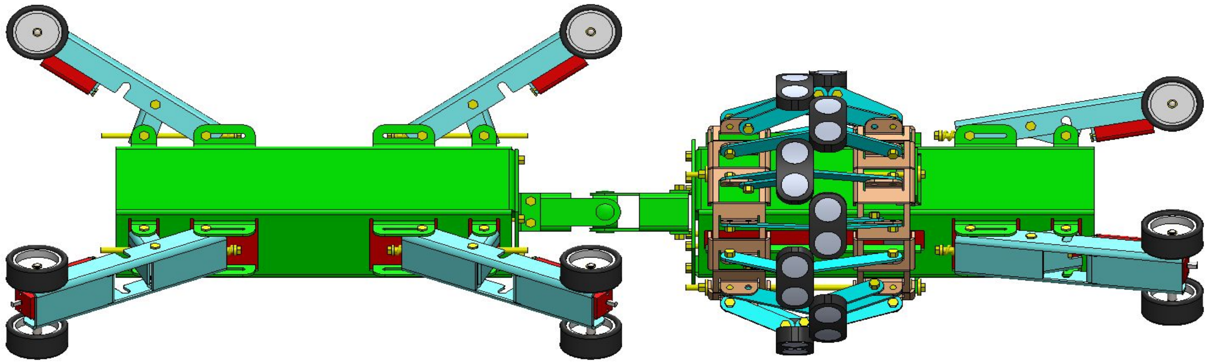

Figure 3.1.1. Overall Design

As stated in previous sections, the overall design has a focus on manufacturability. With most pieces made of sheet metal, the design is very simple to manufacture by requiring no metal forging. The hardware was kept to Unified Thread standards and all complex or electronic parts were sourced. The modular design allows for future designs to use different sensing techniques and the simple adjustment method simplifies the process for switching between pipe sizes.

3.2 Finite Element Analysis

To determine the structural integrity of the design, finite element analysis was performed on all the load bearing parts. *Figure 3.2.1-4* shows the stress analysis done on the fully extended arm with the factors of safety calculated to be 3.3, 9.2, 75, and 3 for the long arm, short arm, adjustment block, and body, respectively. Under the same conditions but completely retracted, the long arm had a factor of safety of 2.9, with the stress analysis shown in *Figure 3.2.5*. This shows the design is adequate in supporting the stresses required to support the system in the pipe.

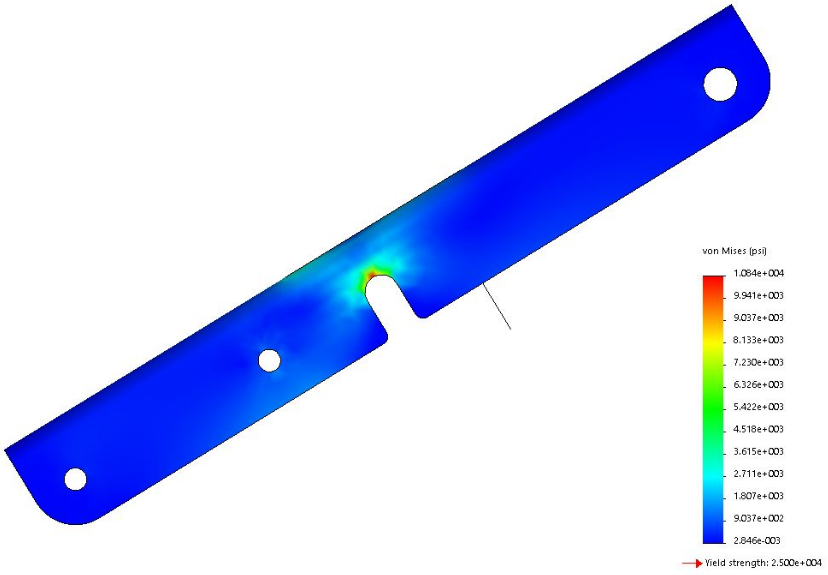

Figure 3.2.1. FEA of extended long arm

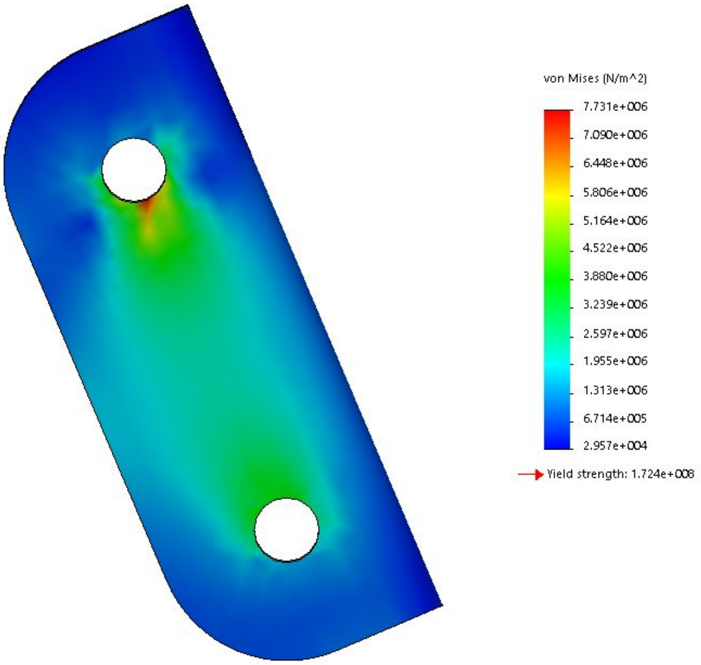

Figure 3.2.2. FEA of extended short arm

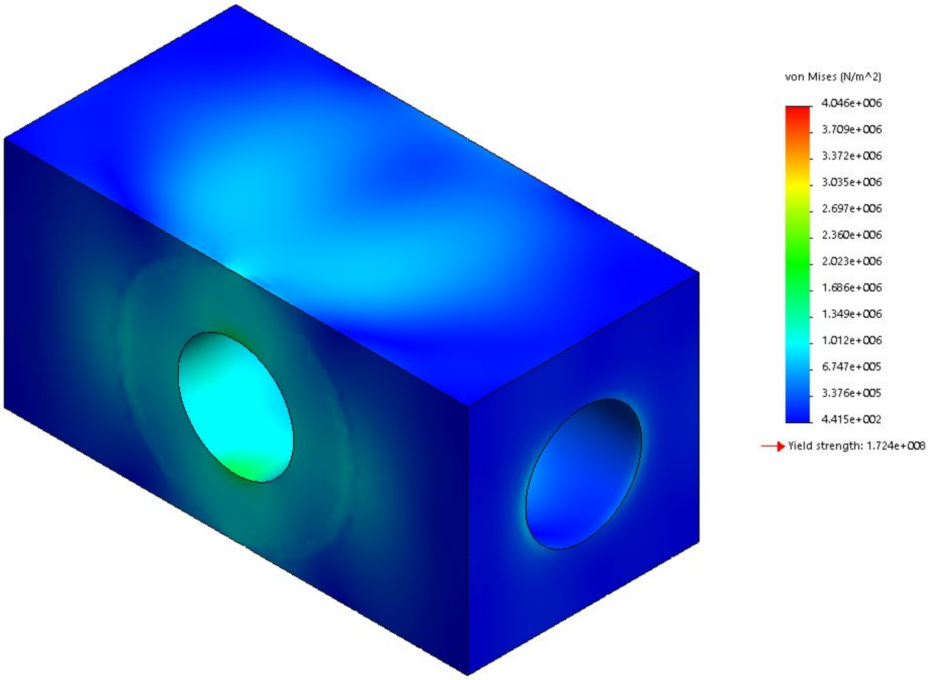

Figure 3.2.3. FEA of adjustment block under extended loading

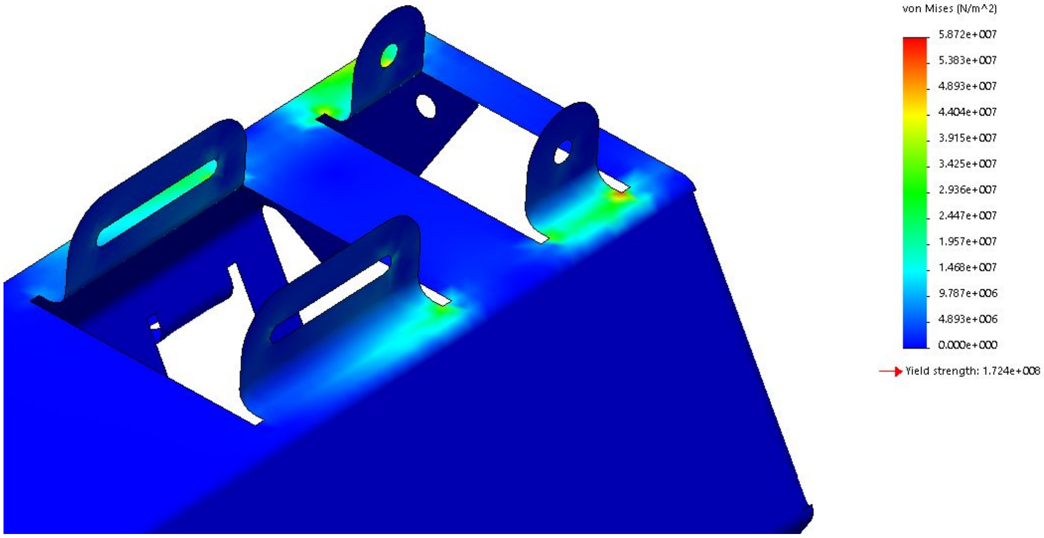

Figure 3.2.4. FEA of body under extended condition

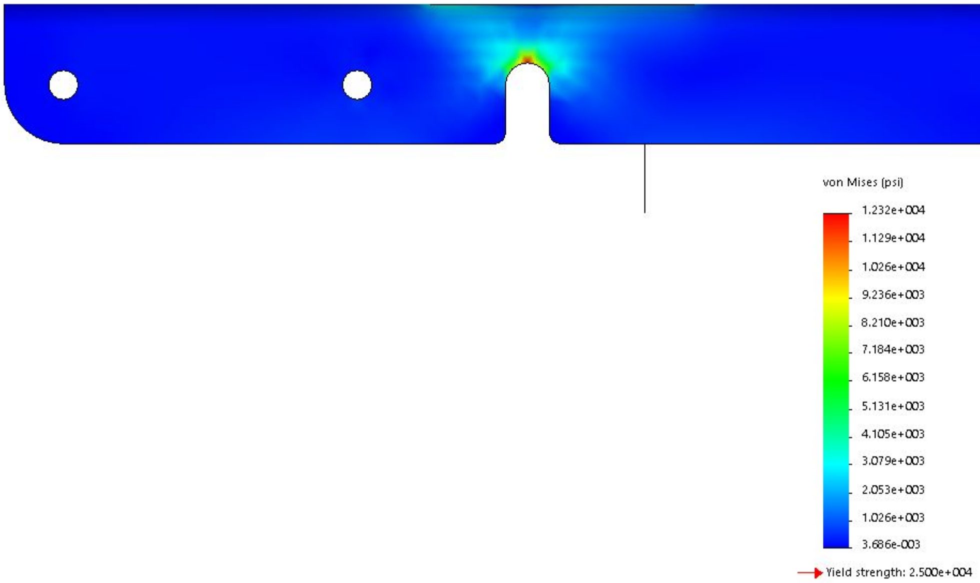

Figure 3.2.5. FEA of retracted long arm

In the case the system must be hoisted, analysis was done on the flanges and the body. The stress analysis performed on the flanges and bodies are shown in *Figures 3.2.6-7* where the factors of safety were found to be 5.2 and 20 for the flange and hoisting hook, respectively. This shows that the design is sufficient to bear the loads required to hoist the system vertically via the hoisting hooks.

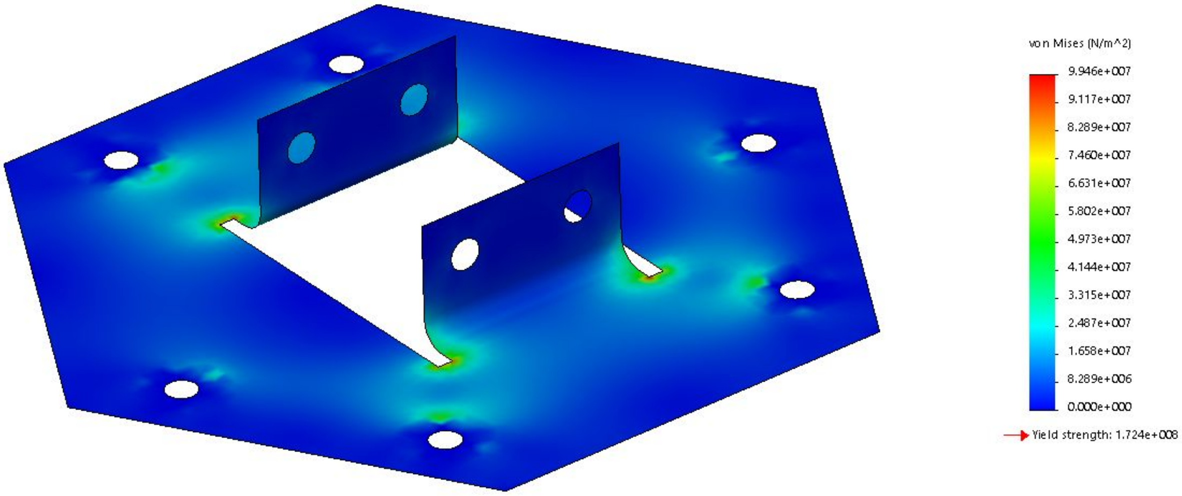

Figure 3.2.6. FEA of flange while body is suspended

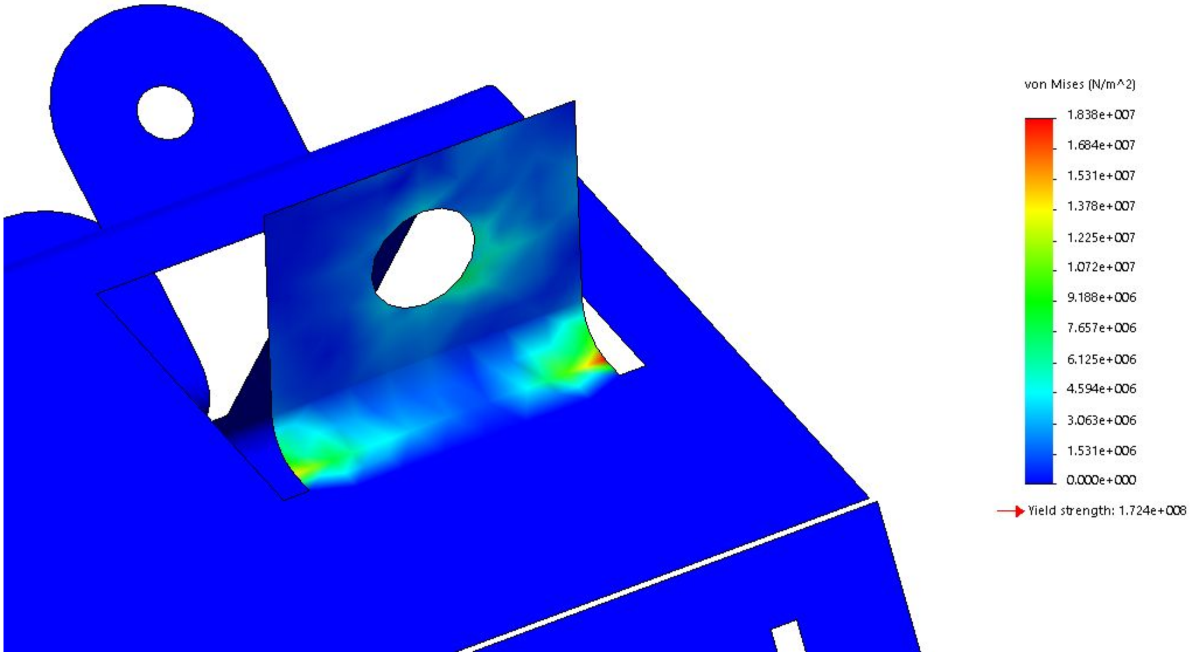

Figure 3.2.7. FEA of fully suspended body

3.3 Conclusion

This flexible riser inspection tool design fitted all of the needs required from it. It was able to fit any size pipe with an internal diameter between 6 and 9 inches and move up and down said pipe. Though this device was not hydraulically powered, as was requested, it has been justified that the electric motor design selected here with provide the tool with a lighter design and allow it to move up and down the pipe in a simpler way than the alternative could have done. In addition, it was able to inspect the full 360 degrees of the pipe's inner surface within any environment, specifically hydrocarbon and seawater without damaging the pipe. The ultrasonic sensor was the best suited sensor for this design as it provided a simple way for the tool to inspect the pipe without having additional sensors, require an enormous amount of power, or cause significant drag as sensors in previous versions for this tool had done. The combination of nitrile rubber, 316 stainless steel, and HDPE as the material makeup of this design allowed it to be able to be chemically resistant to all potential environments that the tool may be used in during its service. Finally, due to this design, this tool can be easily manufacturable as a result of it being constructed entirely out of sheet metal and machined, polymer casted, die forged, thread rolled, and purchased components. Due to these manufacturing processes, any part of the tool can be easily replaced by a new piece allowing the lifespan of this tool to grow. While a physical prototype of the design has not been created, multiple FEA's have been run on the various structural pieces of the design that will carry a load. From these FEA's, it can be determined that this device should be able to withstand the stresses that it will operate under with a high enough factor of safety to satisfy the requirements. Moving forward with this design process, a prototype should be built in order to conduct physical testing. This is so that this model can be refined even further until a final design has been created and sent out to industry.

4 APPENDICES

4.1 Individual Contributions

Table 4.1.1. Teammate contributions to this project

Team Member	Contribution
Aden Cracknell	● Design Discussions ● Sensor Specifications
Jacob Hartzer	● Original Drawings ● CAD Design ● FEA
Colin Michels	● Created Original Presentation ● Design Discussions ● Created Final Presentation
Connor Michels	● Created Original Presentation ● Created Design Discussions

4.2 Calculations

4.2.1 Wheel Contact Pressure Requirements

$$weight = 31.56\ lbs$$

$$coef.\ of\ friction = 0.56^{[1-2,\ 4-5,\ 8-9]}$$

$$contact\ force = \frac{31.56\ lbs}{0.56 * 9\ wheels} = 6.26\ lbs$$

4.2.2 Motor Torque Requirements

$$\tau = \frac{31.56 lbs * 0.75 in}{9\ wheels * 12{:}1\ gear\ ratio} = 0.2192\ in - lbs$$

4.2.3 System Energy Requirements

$$PE = 1005.84m * 9.81m/s/s * 14.315kg/0.85 = 166\ kJ$$

$$Sensor\ E = (24V)^2/100M\Omega * 1080s = 6.22\ J$$

$$Total\ Energy\ Requirement\ =\ 166\ kJ$$

$$Battery\ Energy = 12V\ *\ 11A * hr * 3600s/hr * 12 = 5.7\ MJ$$

4.2.4 Free Body Diagrams

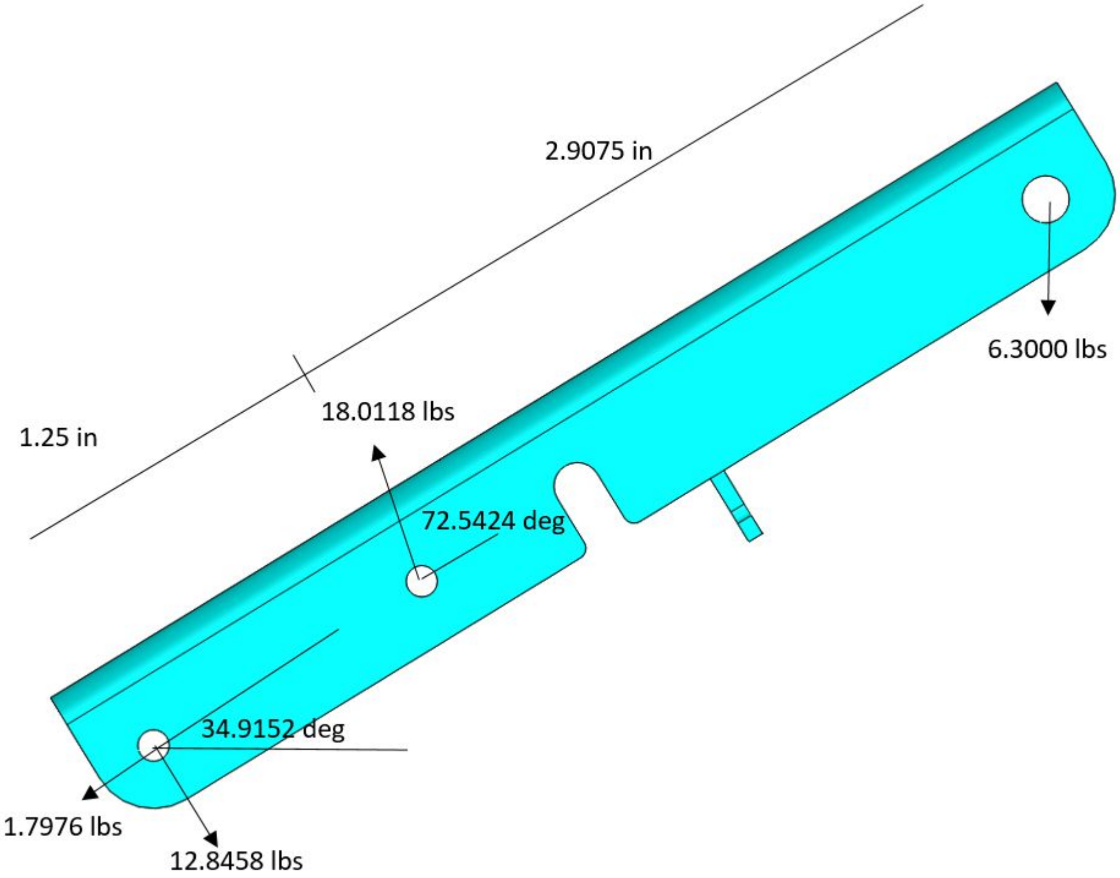

Figure 4.2.4.1. Free Body Diagram of fully extended arm

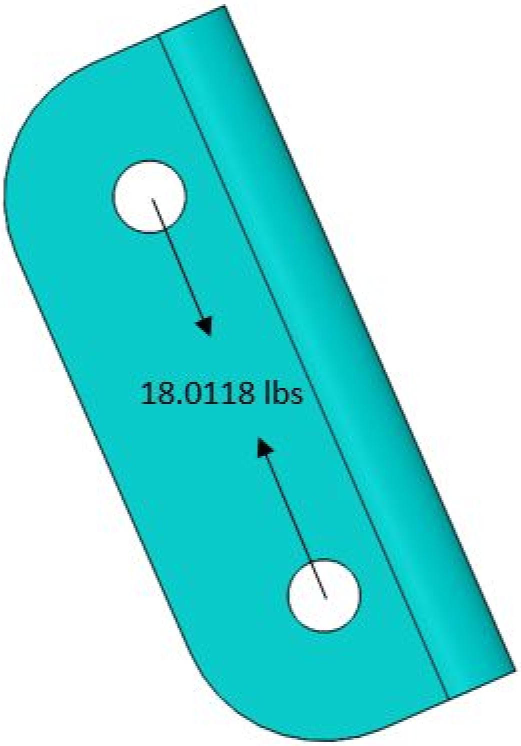

Figure 4.2.4.2. Free Body Diagram of fully extended short arm

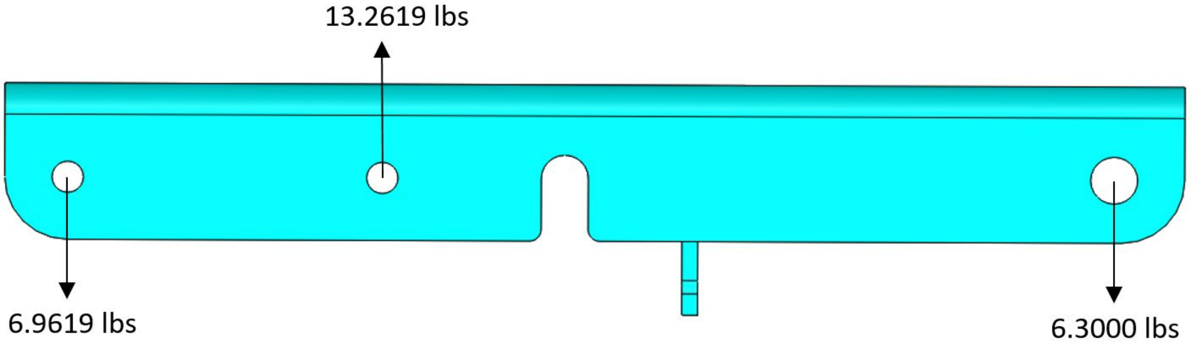

Figure 4.2.4.3. Free Body Diagram of fully retracted arm

4.2 Ultrasonic Sensor Specifications

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Product Specification for Reference Only

Issued Date: 18 July 2013
Rev. :

Part Description: Ultrasonic Sensor

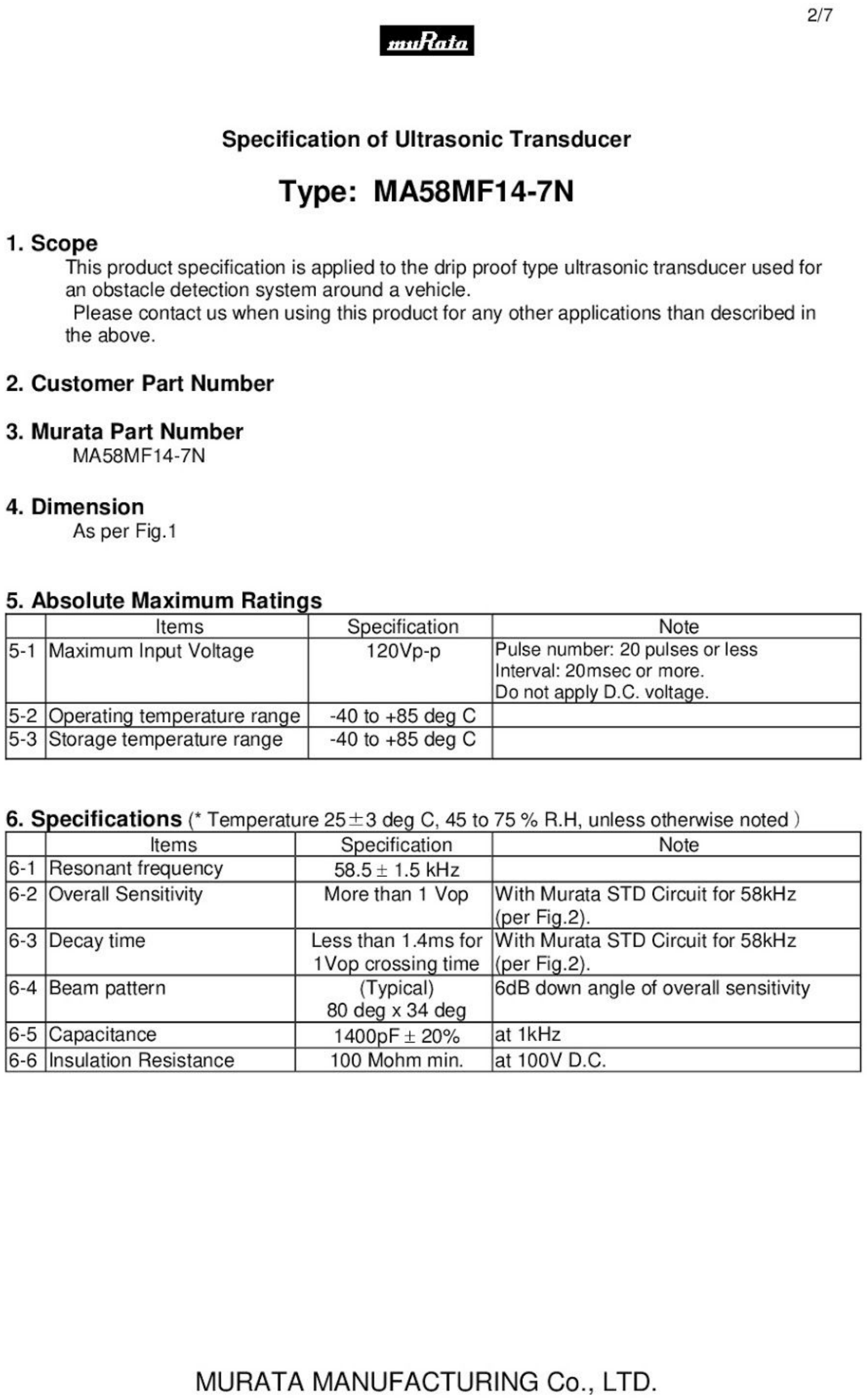
MURATA Part No.: MA58MF14-7N

The product specification in this sheet is for reference only.
The contents of this specification are subject to change.

You are requested to receive the latest specification and to return one copy of the specification to us with your receipt signature before going into mass production.

Product Promotion Sec. 1
Sensor Products Dept. 1
Sensor Products Division
Device Business Unit
Murata MFG. Co., Ltd.

MURATA MANUFACTURING Co., LTD.



muRata

Specification of Ultrasonic Transducer

Type: MA58MF14-7N

1. Scope

This product specification is applied to the drip proof type ultrasonic transducer used for an obstacle detection system around a vehicle.

Please contact us when using this product for any other applications than described in the above.

2. Customer Part Number

3. Murata Part Number

MA58MF14-7N

4. Dimension

As per Fig.1

5. Absolute Maximum Ratings

	Items	Specification	Note
5-1	Maximum Input Voltage	120Vp-p	Pulse number: 20 pulses or less Interval: 20msec or more. Do not apply D.C. voltage.
5-2	Operating temperature range	-40 to +85 deg C	
5-3	Storage temperature range	-40 to +85 deg C	

6. Specifications (* Temperature 25±3 deg C, 45 to 75 % R.H, unless otherwise noted)

	Items	Specification	Note
6-1	Resonant frequency	58.5 ± 1.5 kHz	
6-2	Overall Sensitivity	More than 1 Vop	With Murata STD Circuit for 58kHz (per Fig.2).
6-3	Decay time	Less than 1.4ms for 1Vop crossing time	With Murata STD Circuit for 58kHz (per Fig.2).
6-4	Beam pattern	(Typical) 80 deg x 34 deg	6dB down angle of overall sensitivity
6-5	Capacitance	1400pF ± 20%	at 1kHz
6-6	Insulation Resistance	100 Mohm min.	at 100V D.C.

7. Environmental Tests (Standard Test Condition: 25 ± 3 deg C, 45 to 75 % R.H)

7.1 Shock Test

The variation of the Overall sensitivity at 58 kHz is within ±3dB compared with initial figures at 25 deg C after following test conditions

Acceleration : sine 980 m/s^2 (100G), 6ms
Direction : 3 directions
Shock time : 3 times / directions

7.2 Vibration Test

The variation of the Overall sensitivity at 58 kHz is within ±3dB compared with initial figures at 25 deg C after following test conditions

Vibration frequency: 10 to 200 Hz
Sweep Period : 15 min.
Acceleration : 43.12 m/s^2 (4.4G)
Directions : 3 directions
Time : 96 hours / direction

7.3 Drop Test

The variation of the Overall sensitivity at 58 kHz is within ±3dB compared with initial figures at 25 deg C after following test conditions

Height : 1 meter onto concrete floor
Times : 3 times

7.4 Pull Strength

There should be no substantial damage after 2.45 N of force.

7.5 High Temperature Test

The variation of the Overall sensitivity at 58 kHz is within ±3dB compared with initial figures at 25 deg C in 24 hours after following test conditions

Temperature : +85 ± 2 deg C
Time : 1000 hours

7.6 Low Temperature Test

The variation of the Overall sensitivity at 58 kHz is within ±3dB compared with initial figures at 25 deg C in 24 hours after following test conditions

Temperature : -40 ± 3 deg C
Time : 1000 hours

7.7 Humidity Test

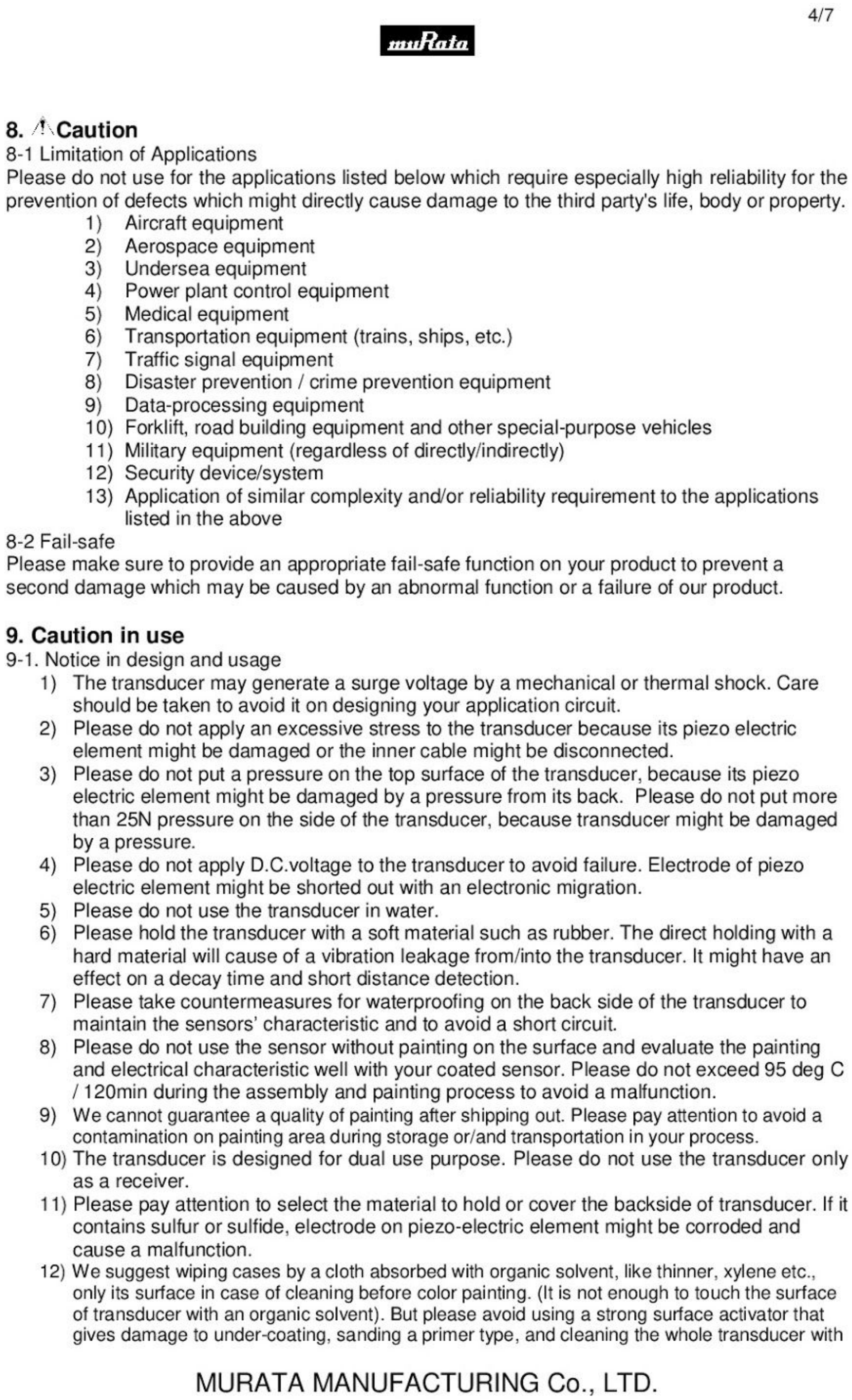
The variation of the Overall sensitivity at 58 kHz is within ±3dB compared with initial figures at 25 deg C in 24hours after following test conditions

Temperature : +85 ± 2 deg C
Humidity : 85 % R.H.
Time : 1000 hours

7.8 Heat Cycle Test

The variation of the Overall sensitivity at 58 kHz is within ±3dB compared with initial figures at 25 deg C in 24hours after following test conditions

Temperature : +85 ± 3 deg C, 30 min
-40 ± 3 deg C, 30 min
*heat up and pull down time are less than 5min.
Cycles : 1000 cycles



8. ⚠Caution

8-1 Limitation of Applications

Please do not use for the applications listed below which require especially high reliability for the prevention of defects which might directly cause damage to the third party's life, body or property.

1) Aircraft equipment
2) Aerospace equipment
3) Undersea equipment
4) Power plant control equipment
5) Medical equipment
6) Transportation equipment (trains, ships, etc.)
7) Traffic signal equipment
8) Disaster prevention / crime prevention equipment
9) Data-processing equipment
10) Forklift, road building equipment and other special-purpose vehicles
11) Military equipment (regardless of directly/indirectly)
12) Security device/system
13) Application of similar complexity and/or reliability requirement to the applications listed in the above

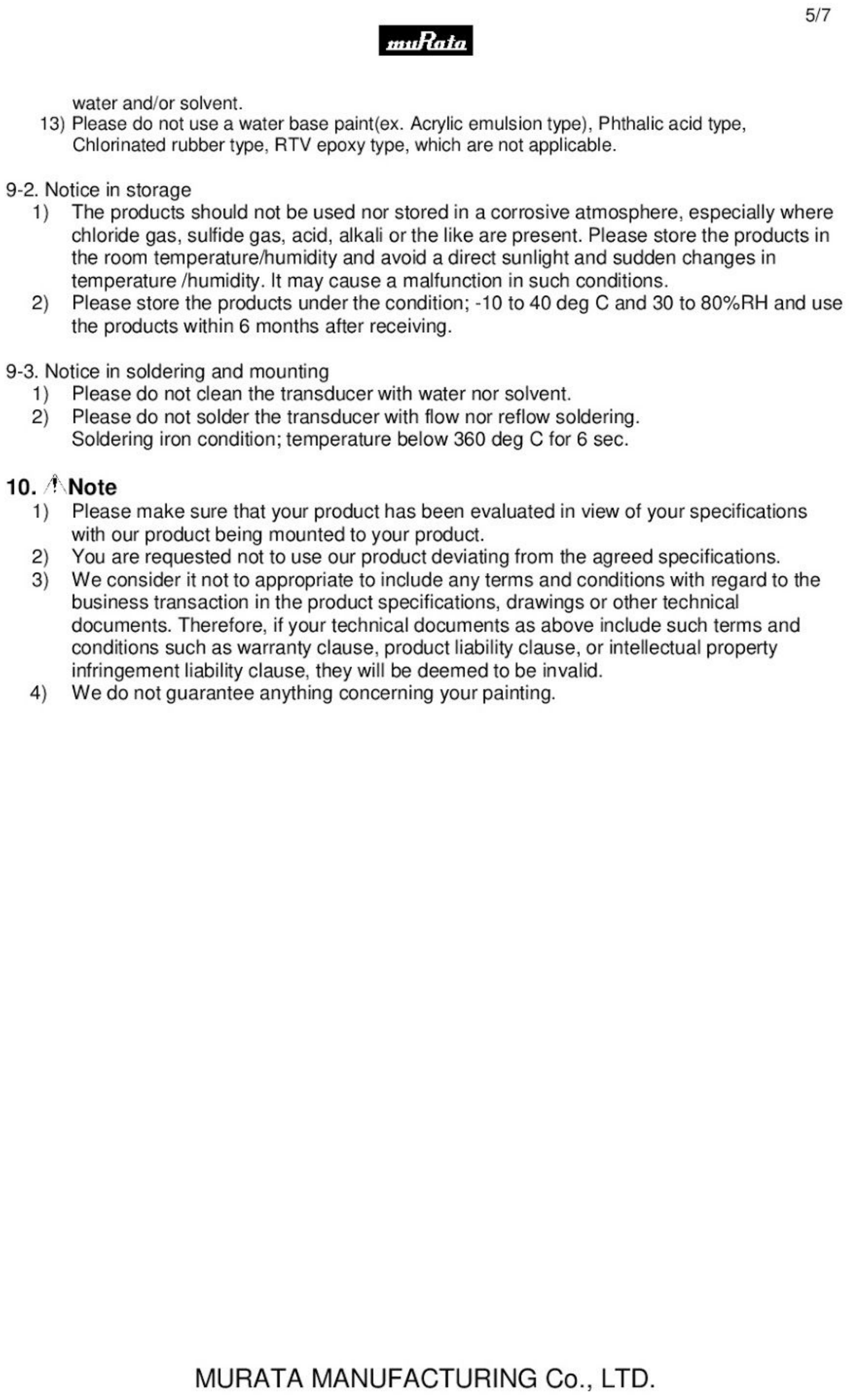
8-2 Fail-safe

Please make sure to provide an appropriate fail-safe function on your product to prevent a second damage which may be caused by an abnormal function or a failure of our product.

9. Caution in use

9-1. Notice in design and usage

1) The transducer may generate a surge voltage by a mechanical or thermal shock. Care should be taken to avoid it on designing your application circuit.
2) Please do not apply an excessive stress to the transducer because its piezo electric element might be damaged or the inner cable might be disconnected.
3) Please do not put a pressure on the top surface of the transducer, because its piezo electric element might be damaged by a pressure from its back. Please do not put more than 25N pressure on the side of the transducer, because transducer might be damaged by a pressure.
4) Please do not apply D.C.voltage to the transducer to avoid failure. Electrode of piezo electric element might be shorted out with an electronic migration.
5) Please do not use the transducer in water.
6) Please hold the transducer with a soft material such as rubber. The direct holding with a hard material will cause of a vibration leakage from/into the transducer. It might have an effect on a decay time and short distance detection.
7) Please take countermeasures for waterproofing on the back side of the transducer to maintain the sensors' characteristic and to avoid a short circuit.
8) Please do not use the sensor without painting on the surface and evaluate the painting and electrical characteristic well with your coated sensor. Please do not exceed 95 deg C / 120min during the assembly and painting process to avoid a malfunction.
9) We cannot guarantee a quality of painting after shipping out. Please pay attention to avoid a contamination on painting area during storage or/and transportation in your process.
10) The transducer is designed for dual use purpose. Please do not use the transducer only as a receiver.
11) Please pay attention to select the material to hold or cover the backside of transducer. If it contains sulfur or sulfide, electrode on piezo-electric element might be corroded and cause a malfunction.
12) We suggest wiping cases by a cloth absorbed with organic solvent, like thinner, xylene etc., only its surface in case of cleaning before color painting. (It is not enough to touch the surface of transducer with an organic solvent). But please avoid using a strong surface activator that gives damage to under-coating, sanding a primer type, and cleaning the whole transducer with



water and/or solvent.

13) Please do not use a water base paint(ex. Acrylic emulsion type), Phthalic acid type, Chlorinated rubber type, RTV epoxy type, which are not applicable.

9-2. Notice in storage

1) The products should not be used nor stored in a corrosive atmosphere, especially where chloride gas, sulfide gas, acid, alkali or the like are present. Please store the products in the room temperature/humidity and avoid a direct sunlight and sudden changes in temperature /humidity. It may cause a malfunction in such conditions.
2) Please store the products under the condition; -10 to 40 deg C and 30 to 80%RH and use the products within 6 months after receiving.

9-3. Notice in soldering and mounting

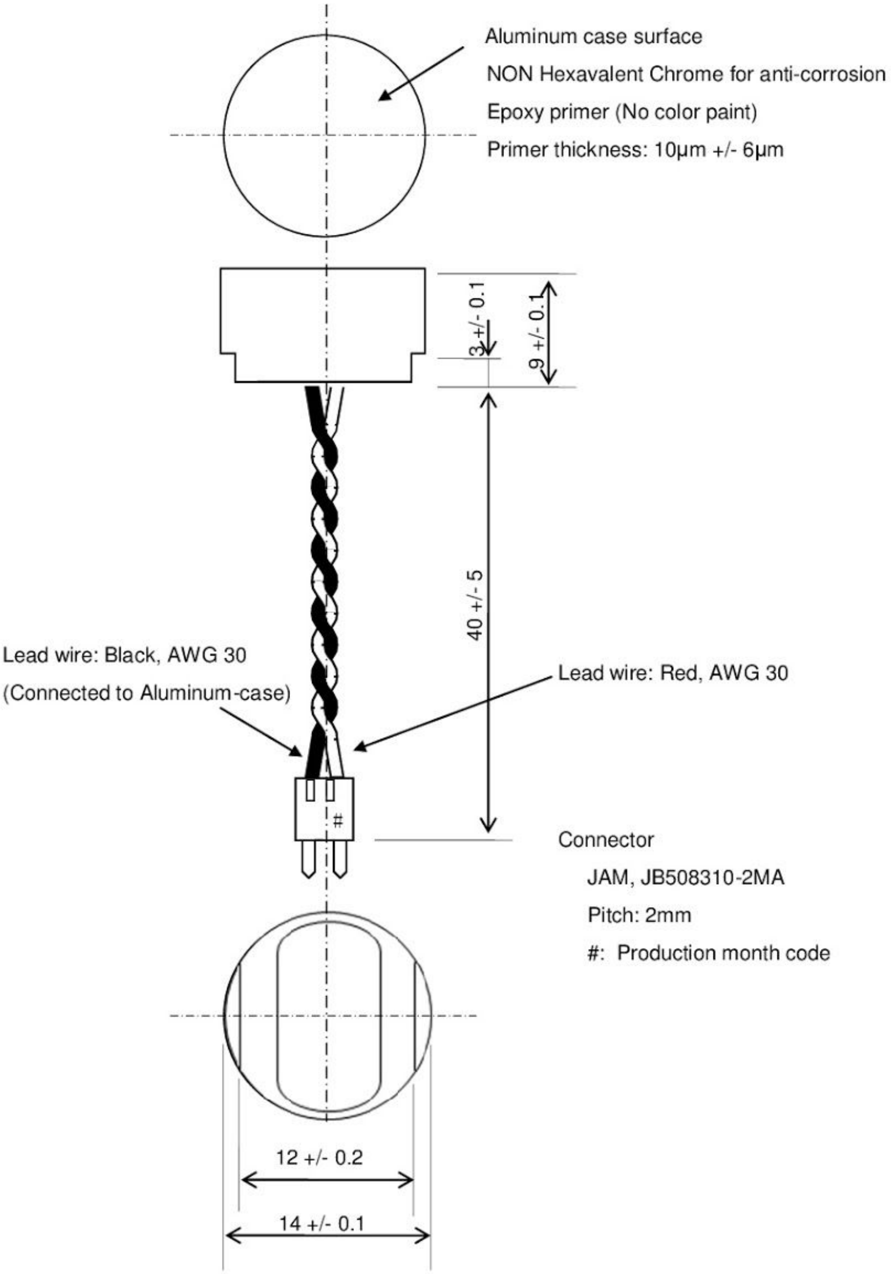
1) Please do not clean the transducer with water nor solvent.
2) Please do not solder the transducer with flow nor reflow soldering. Soldering iron condition; temperature below 360 deg C for 6 sec.

10. ⚠Note

1) Please make sure that your product has been evaluated in view of your specifications with our product being mounted to your product.
2) You are requested not to use our product deviating from the agreed specifications.
3) We consider it not to appropriate to include any terms and conditions with regard to the business transaction in the product specifications, drawings or other technical documents. Therefore, if your technical documents as above include such terms and conditions such as warranty clause, product liability clause, or intellectual property infringement liability clause, they will be deemed to be invalid.
4) We do not guarantee anything concerning your painting.

6/7

Fig.1 Dimensions



Aluminum case surface
NON Hexavalent Chrome for anti-corrosion
Epoxy primer (No color paint)
Primer thickness: 10μm +/- 6μm

Lead wire: Black, AWG 30
(Connected to Aluminum-case)

Lead wire: Red, AWG 30

Connector
JAM, JB508310-2MA
Pitch: 2mm
#: Production month code

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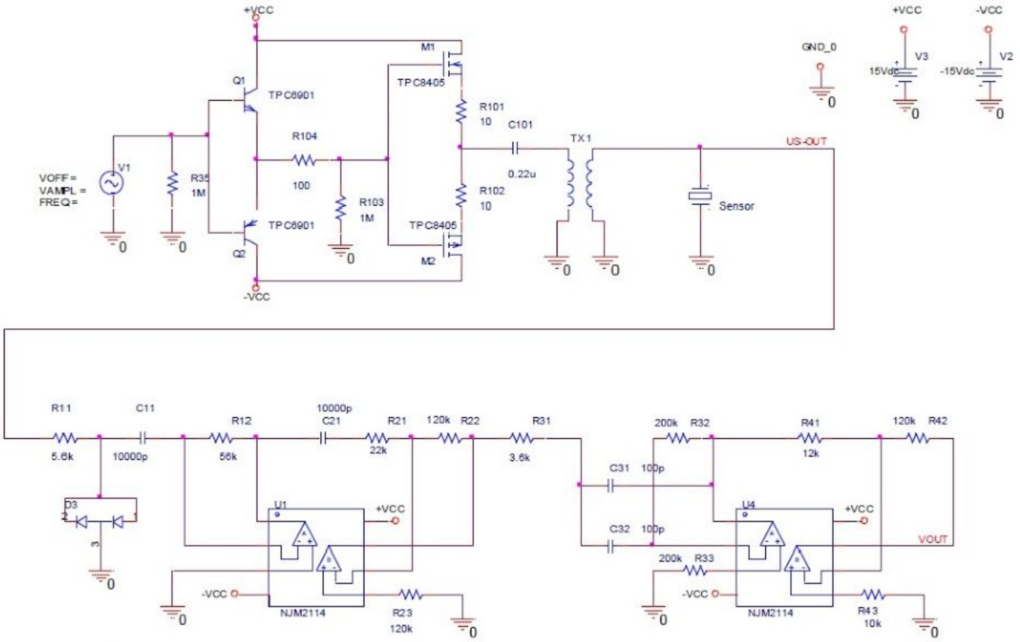
Fig.2 Murata Standard Circuit



<u>Circuit condition</u>

Input Voltage: Vcc=15V, －Vcc= -15V

Input signal V1: burst waveform (58kHz, 8pulses), 7.5Vpp

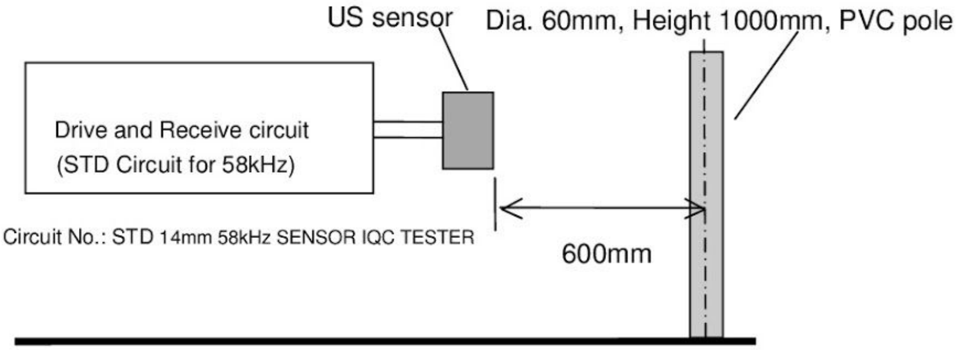
Amplifier gain: 83dB

Trance: Primary inductance: 68μH

Secondary inductance: typ. 5.8mH

Q value is more than 75 at 252 kHz

Fig.3 Test Condition for Overall Sensitivity



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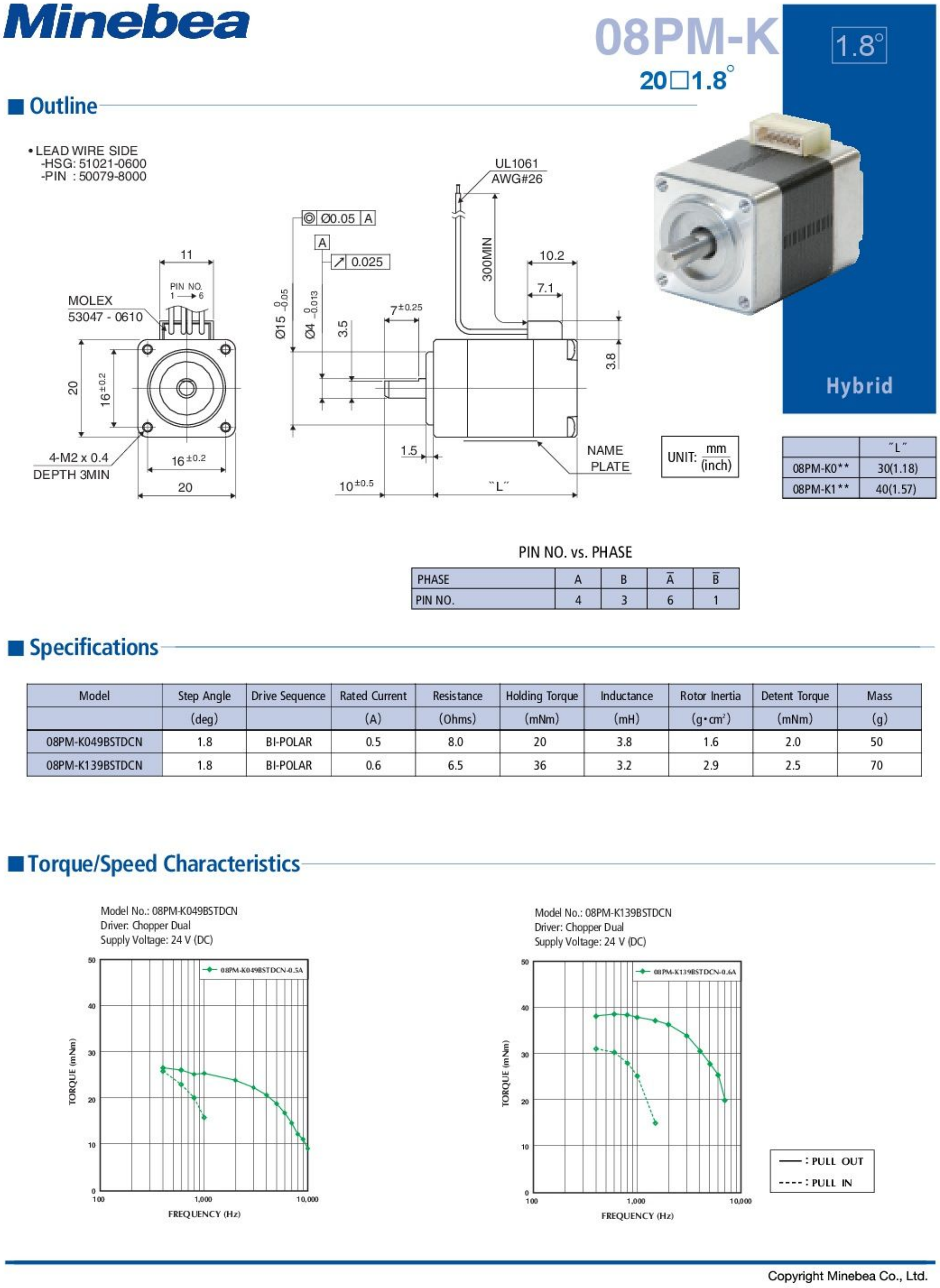
4.3 Motor Specifications



08PM-K

20□1.8°

Outline

	"L"
08PM-K0**	30(1.18)
08PM-K1**	40(1.57)

PIN NO. vs. PHASE

PHASE	A	B	$\bar{A}$	$\bar{B}$
PIN NO.	4	3	6	1

Specifications

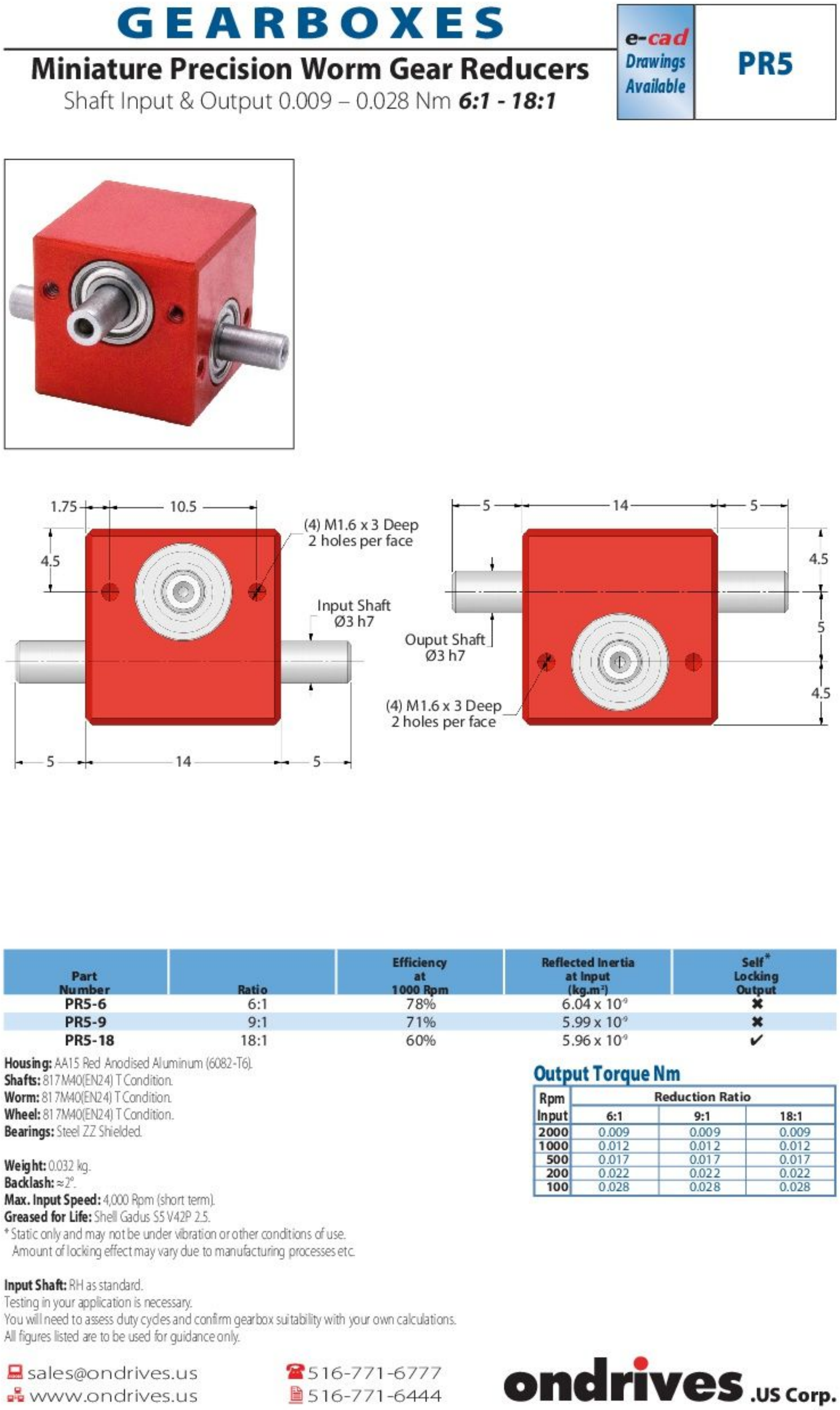
Model	Step Angle	Drive Sequence	Rated Current	Resistance	Holding Torque	Inductance	Rotor Inertia	Detent Torque	Mass
	(deg)		(A)	(Ohms)	(mNm)	(mH)	(g・cm²)	(mNm)	(g)
08PM-K049BSTDCN	1.8	BI-POLAR	0.5	8.0	20	3.8	1.6	2.0	50
08PM-K139BSTDCN	1.8	BI-POLAR	0.6	6.5	36	3.2	2.9	2.5	70

Torque/Speed Characteristics

Model No.: 08PM-K049BSTDCN
Driver: Chopper Dual
Supply Voltage: 24 V (DC)

Model No.: 08PM-K139BSTDCN
Driver: Chopper Dual
Supply Voltage: 24 V (DC)

4.4 Gearbox Specifications



GEARBOXES

Miniature Precision Worm Gear Reducers

Shaft Input & Output 0.009 – 0.028 Nm ***6:1 - 18:1***

e-cad Drawings Available

PR5

Part Number	Ratio	Efficiency at 1000 Rpm	Reflected Inertia at Input (kg.m²)	Self* Locking Output
PR5-6	6:1	78%	6.04 x 10^{9}	✖
PR5-9	9:1	71%	5.99 x 10^{9}	✖
PR5-18	18:1	60%	5.96 x 10^{9}	✓

Housing: AA15 Red Anodised Aluminum (6082-T6).
Shafts: 817M40(EN24) T Condition.
Worm: 817M40(EN24) T Condition.
Wheel: 817M40(EN24) T Condition.
Bearings: Steel ZZ Shielded.

Weight: 0.032 kg.
Backlash: ≈2°.
Max. Input Speed: 4,000 Rpm (short term).
Greased for Life: Shell Gadus S5 V42P 2.5.
* Static only and may not be under vibration or other conditions of use.
Amount of locking effect may vary due to manufacturing processes etc.

Input Shaft: RH as standard.
Testing in your application is necessary.
You will need to assess duty cycles and confirm gearbox suitability with your own calculations.
All figures listed are to be used for guidance only.

Output Torque Nm

Rpm Input	Reduction Ratio		
	6:1	9:1	18:1
2000	0.009	0.009	0.009
1000	0.012	0.012	0.012
500	0.017	0.017	0.017
200	0.022	0.022	0.022
100	0.028	0.028	0.028

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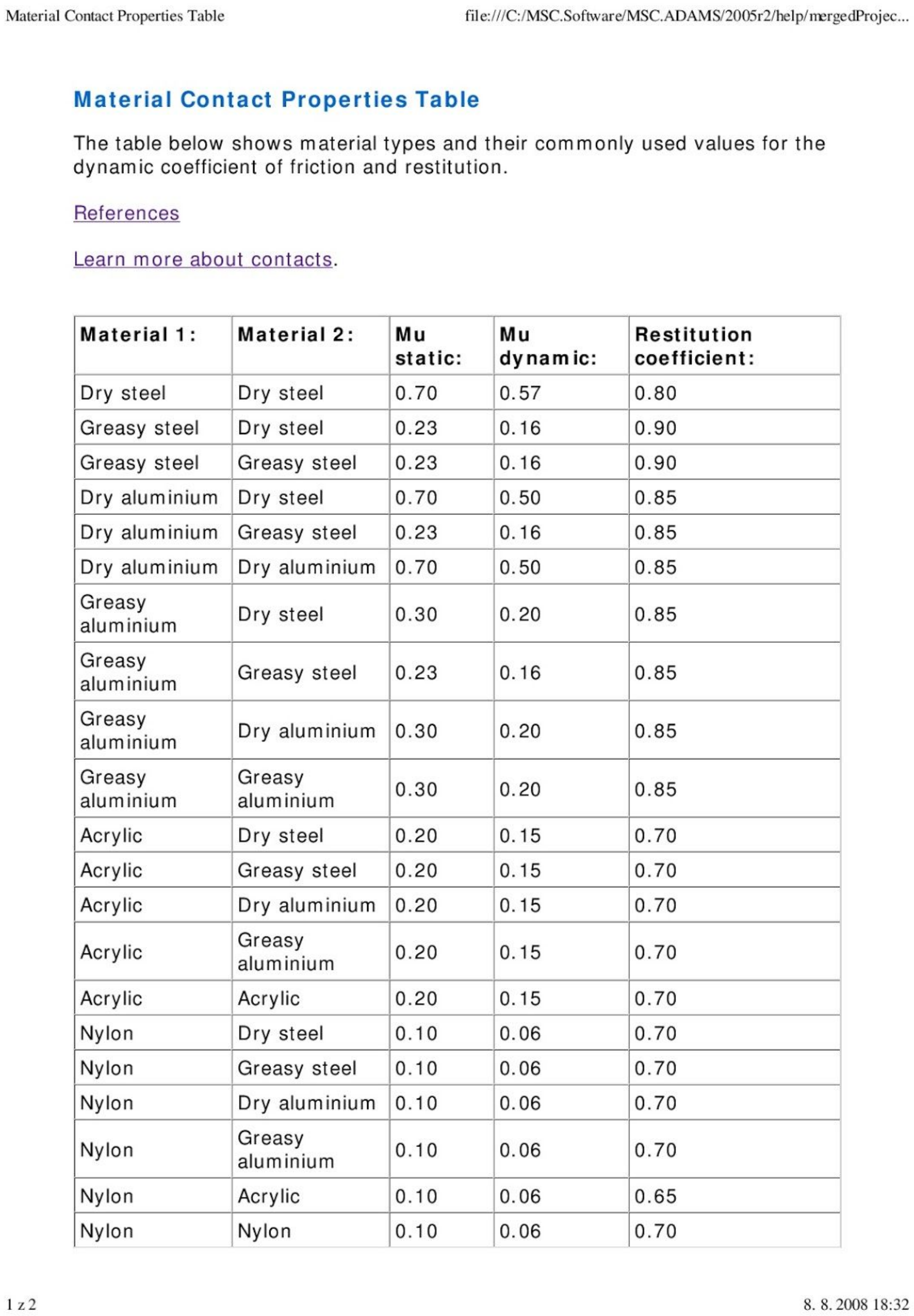
4.5 Coefficient of Friction Table

Table 4.5.1. Table of various coefficients of friction



Material Contact Properties Table file:///C:/MSC.Software/MSC.ADAMS/2005r2/help/mergedProjec...

Material Contact Properties Table

The table below shows material types and their commonly used values for the dynamic coefficient of friction and restitution.

References

Learn more about contacts.

Material 1:	**Material 2:**	**Mu static:**	**Mu dynamic:**	**Restitution coefficient:**
Dry steel	Dry steel	0.70	0.57	0.80
Greasy steel	Dry steel	0.23	0.16	0.90
Greasy steel	Greasy steel	0.23	0.16	0.90
Dry aluminium	Dry steel	0.70	0.50	0.85
Dry aluminium	Greasy steel	0.23	0.16	0.85
Dry aluminium	Dry aluminium	0.70	0.50	0.85
Greasy aluminium	Dry steel	0.30	0.20	0.85
Greasy aluminium	Greasy steel	0.23	0.16	0.85
Greasy aluminium	Dry aluminium	0.30	0.20	0.85
Greasy aluminium	Greasy aluminium	0.30	0.20	0.85
Acrylic	Dry steel	0.20	0.15	0.70
Acrylic	Greasy steel	0.20	0.15	0.70
Acrylic	Dry aluminium	0.20	0.15	0.70
Acrylic	Greasy aluminium	0.20	0.15	0.70
Acrylic	Acrylic	0.20	0.15	0.70
Nylon	Dry steel	0.10	0.06	0.70
Nylon	Greasy steel	0.10	0.06	0.70
Nylon	Dry aluminium	0.10	0.06	0.70
Nylon	Greasy aluminium	0.10	0.06	0.70
Nylon	Acrylic	0.10	0.06	0.65
Nylon	Nylon	0.10	0.06	0.70

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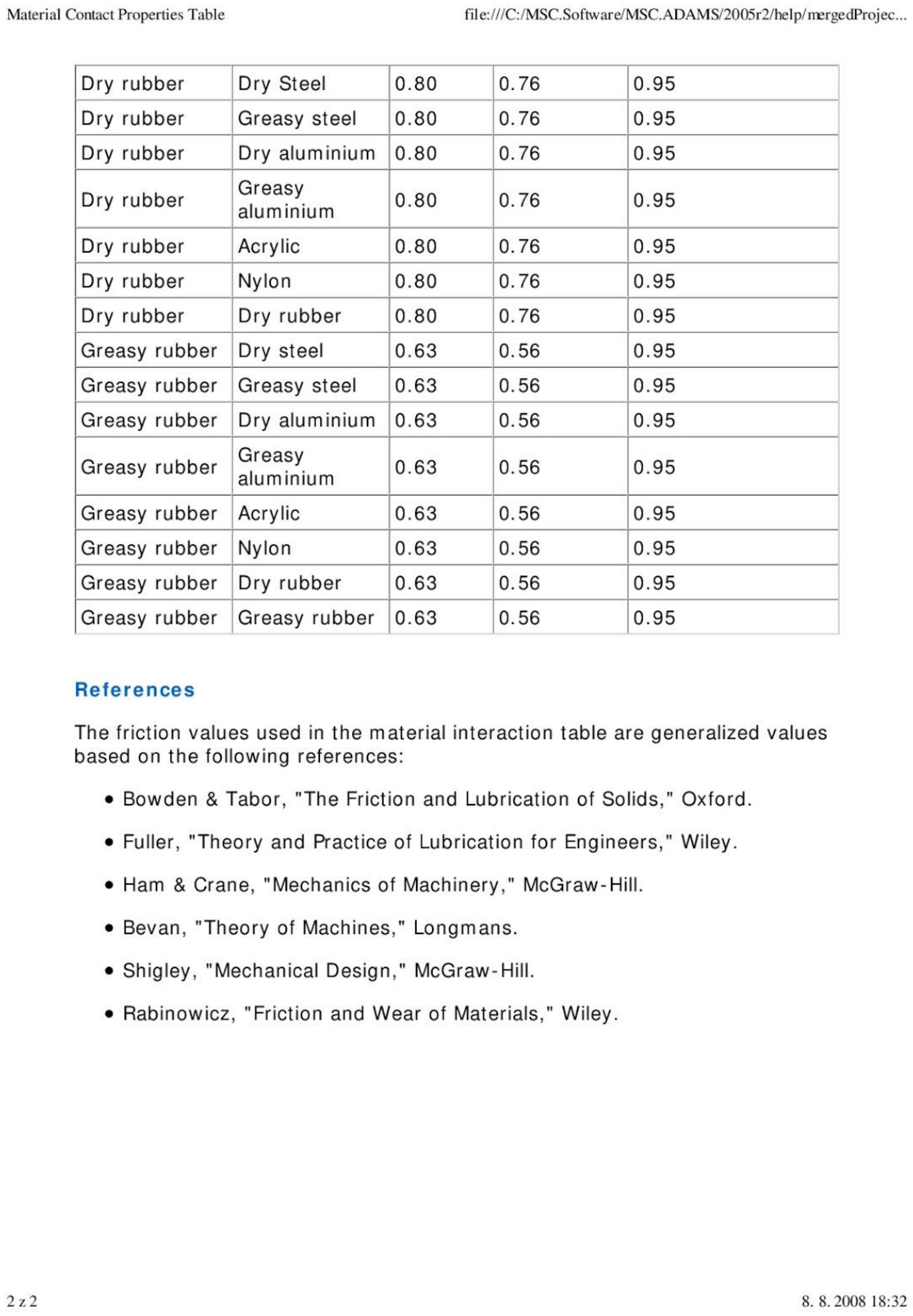

Material Contact Properties Table file:///C:/MSC.Software/MSC.ADAMS/2005r2/help/mergedProjec...

Dry rubber	Dry Steel	0.80	0.76	0.95
Dry rubber	Greasy steel	0.80	0.76	0.95
Dry rubber	Dry aluminium	0.80	0.76	0.95
Dry rubber	Greasy aluminium	0.80	0.76	0.95
Dry rubber	Acrylic	0.80	0.76	0.95
Dry rubber	Nylon	0.80	0.76	0.95
Dry rubber	Dry rubber	0.80	0.76	0.95
Greasy rubber	Dry steel	0.63	0.56	0.95
Greasy rubber	Greasy steel	0.63	0.56	0.95
Greasy rubber	Dry aluminium	0.63	0.56	0.95
Greasy rubber	Greasy aluminium	0.63	0.56	0.95
Greasy rubber	Acrylic	0.63	0.56	0.95
Greasy rubber	Nylon	0.63	0.56	0.95
Greasy rubber	Dry rubber	0.63	0.56	0.95
Greasy rubber	Greasy rubber	0.63	0.56	0.95

References

The friction values used in the material interaction table are generalized values based on the following references:

- Bowden & Tabor, "The Friction and Lubrication of Solids," Oxford.
- Fuller, "Theory and Practice of Lubrication for Engineers," Wiley.
- Ham & Crane, "Mechanics of Machinery," McGraw-Hill.
- Bevan, "Theory of Machines," Longmans.
- Shigley, "Mechanical Design," McGraw-Hill.
- Rabinowicz, "Friction and Wear of Materials," Wiley.

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4.6 Bill of Materials

Table 4.6.1 Bill of Materials

ITEM NO.	PART NUMBER	ASM. QTY.	TOTAL QTY.	MANUFACTURING METHOD
1	PowerCart_assem	1		
1.1	Body_power	1	1	Sheetmetal
1.2	DriveArm_assem	6		
1.2.1	AdjustBlock_assem	2		
1.2.1.1	AdjustBlock	1	12	Conventional Machining
1.2.1.2	Screw_1_8x7_16	2	24	Die Forging & Thread Rolling
1.2.2	DriveArm_Short	1	6	Sheetmetal
1.2.3	DriveArm_Long	1	6	Sheetmetal
1.2.4	AdjustScrew_275	1	6	Die Forging & Thread Rolling
1.2.5	ScrewNut1_8x1_8	2	12	Hot Forging
1.2.6	Spring	1	6	Wound Wire
1.2.7	Gearbox_assem	1		
1.2.7.1	Motor_08PM_K0	1	6	Purchased
1.2.7.2	ServoAxle	2	12	Turning
1.2.7.3	ServoWheel	2	12	Turning
1.2.7.4	MiniGearbox_PR5_9	1	6	Purchased
1.2.7.5	Set Screw	3	18	Die Forging & Thread Rolling
1.2.7.6	MachineScrew_0_0625_125	2	12	Die Forging & Thread Rolling
1.2.7.7	Washer_0625	2	12	Sheetmetal
1.2.7.8	ServoWheelTread	2	12	Polymer Casting
1.2.8	M2bolt	2	12	Die Forging & Thread Rolling
1.3	Power Pack	1		
1.3.1	ElectronicsHousing	1	1	Polymer Casting
1.3.2	Lipo	6	6	Purchased
1.3.3	Hard Drive	1	1	Purchased
1.3.4	MachineScrew_0_125_375	2	2	Die Forging & Thread Rolling
1.3.5	EndCap	2	2	Polymer Casting
2	SensorCart_assem	1		
2.1	SensorBody	1	1	Sheetmetal
2.2	DriveArm_assem	3		

2.2.1	AdjustBlock_assem	2		
2.2.1.1	AdjustBlock	1	6	Conventional Machining
2.2.1.2	Screw_1_8x7_16	2	12	Die Forging & Thread Rolling
2.2.2	DriveArm_Short	1	3	Sheetmetal
2.2.3	DriveArm_Long	1	3	Sheetmetal
2.2.4	AdjustScrew_275	1	3	Die Forging & Thread Rolling
2.2.5	ScrewNut1_8x1_8	2	6	Die Forging & Thread Rolling
2.2.6	Spring	1	3	Wound Wire
2.2.7	Gearbox_assem	1		
2.2.7.1	Motor_08PM_K0	1	3	Purchased
2.2.7.2	ServoAxle	2	6	Turning
2.2.7.3	ServoWheel	2	6	Turning
2.2.7.4	MiniGearbox_PR5_9	1	3	Purchased
2.2.7.5	Set Screw	3	9	Die Forging & Thread Rolling
2.2.7.6	MachineScrew_0_0625_125	2	6	Die Forging & Thread Rolling
2.2.7.7	Washer_0625	2	6	Sheetmetal
2.2.7.8	ServoWheelTread	2	6	Polymer Casting
2.2.8	M2bolt	2	6	Die Forging & Thread Rolling
2.3	Sensor Array_assem	1		
2.3.1	Sensor MountRing	2	2	Sheetmetal
2.3.2	AdjustScrew_475	3	3	Die Forging & Thread Rolling
2.3.3	Washer_0125	9	9	Sheetmetal
2.3.4	Nut_0125	3	3	Hot Forging
2.3.5	Sensor Arm_assem	13		
2.3.5.1	Ultrasonic Sensor	2	26	Purchased
2.3.5.2	SensorHousing	1	13	Conventional Machining
2.3.5.3	Long SensorArm	1	13	Sheetmetal
2.3.5.4	Short SensorArm	2	26	Sheetmetal
2.3.5.5	MachineScrew_0_125_125	4	52	Die Forging & Thread Rolling
2.3.5.6	MachineScrew_0_125_1875	1	13	Die Forging & Thread Rolling
2.3.6	Short SensorArm	4	4	Sheetmetal
2.3.7	Long SensorArm	2	2	Sheetmetal
2.3.8	SensorHousing_offset	2	2	Conventional Machining
2.3.9	Ultrasonic Sensor	4	4	Purchased
2.3.10	MachineScrew_0_125_125	9	9	Die Forging & Thread Rolling
2.3.11	MachineScrew_0_125_1875	2	2	Die Forging & Thread Rolling

2.4	Power Pack	1		
2.4.1	ElectronicsHousing	1	1	Polymer Casting
2.4.2	Lipo	6	6	Purchased
2.4.3	Hard Drive	1	1	Purchased
2.4.4	MachineScrew_0_125_375	2	2	Die Forging & Thread Rolling
2.4.5	EndCap	2	2	Polymer Casting
3	UJoint_assem	1		
3.1	UJoint_Middle	1	1	Sheetmetal
3.2	UJoint_Pin	4	4	Die Forging

5 REFERENCES

1. Bevan, "Theory of Machines," Longmans.
2. Bowden & Tabor, "The Friction and Lubrication of Solids," Oxford.
3. Flexible Pipe Engineering - Advanced Subsea Engineering. (n.d.). Retrieved from https://www.4subsea.com/solutions/flexible-risers/flexible-pipeline-engineering/
4. Fuller, "Theory and Practice of Lubrication for Engineers," Wiley.
5. Ham & Crane, "Mechanics of Machinery," McGraw-Hill.
6. Ingram, Doron (2018), “Flexible Pipe Riser Internal Inspection Tool.” PowerPoint presentation. Texas A&M University. College Station, TX. Spring 2018
7. Mazraeh, Ali, et. al. (2017). Development of Ultrasonic Crack Detection System on Multi-diameter PIG Robots
8. Rabinowicz, "Friction and Wear of Materials," Wiley.
9. Shigley, "Mechanical Design," McGraw-Hill.