# Vibrational and Pressure Analysis of the Honeywell Oil Chip Detector Housing (OCDH)

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## INTRODUCTION

Team Honeywell is tasked with designing, testing, and producing a functional Oil Chip Detector Housing, from henceforth known as (OCDH), for use on prop engines for Honeywell. The OCDH needs to meet parameters that are set forth by Honeywell for guaranteed operation. The OCDH needs to withstand vibrations that range from 1 to about 10,000 Hz. A displacement will be calculated from the frequencies and the displacements must meet requirements set forth by Honeywell. Furthermore, the OCDH needs to withstand an undetermined amount of burst and operational pressure. Both internal and external pressures are required to be met.

The vibrational analysis consists of calculations and simulations run on solid modeling. The simulations will then be used to compare the calculated values to what the expected results are going to consist of. The solid modeling consists of a finite elemental analysis (FEA), and a frequency/vibrational simulation.

The pressure calculations are used to determine the maximum amount of internal burst pressure that the OCDH can take based upon wall thickness and material selection. Calculations will be completed for four different materials. Three different types of stainless steel: stainless steel 303, stainless steel 304, stainless steel 316; and a titanium alloy.

## METHOD & ASSUMPTIONS

The vibrational analysis consists of a one degree of freedom system, from here henceforth known as ODOF, that will be used to determine the amount of static deformation that the OCDH experiences at varying frequencies. The frequencies are bound from 1 to 10,000 Hz but calculations will be done for 1 to 2,000 Hz. The goal of the calculations is to determine the amount of static deformation that is experienced by the OCDH at every frequency. To calculate the deformation a stiffness value is needed to be calculated to from the given frequency. Equation 1 is used to calculate the stiffness coefficient [1].

$$k = m * {\omega_n}^2 \tag{1}$$

K in equation 1 is the stiffness coefficient in pounds per inch; m is the mass of the OCDH in lbs., based upon material properties; and $\omega_n$ is the natural frequency of the tests in radians per second. Equation 2 is the force equation, and this is calculated from gravity, area, and the natural frequencies [1].

$$F_o = \frac{g * m}{{\omega_n}^2} \tag{2}$$

In equation 2, g is the gravitational constant measured in in/$s^2$; m is the mass of the OCDH measured in lbs., and $\omega_n$ is the natural frequency. The force calculation allows the final deformation at each frequency to be calculated and measured in inches. Equation 3 is used to calculate the static deformation that OCDH experiences [1].

$$\delta_{st} = \frac{F_o}{k} \tag{3}$$

The deformation term is measured in inches and uses the stiffness coefficient and the calculated forces. The deformation is required to be below the maximum vibrational damage line seen in figure 1. Preliminary vibration calculations can be found in appendix A, but full calculations are included with the attached excel file.

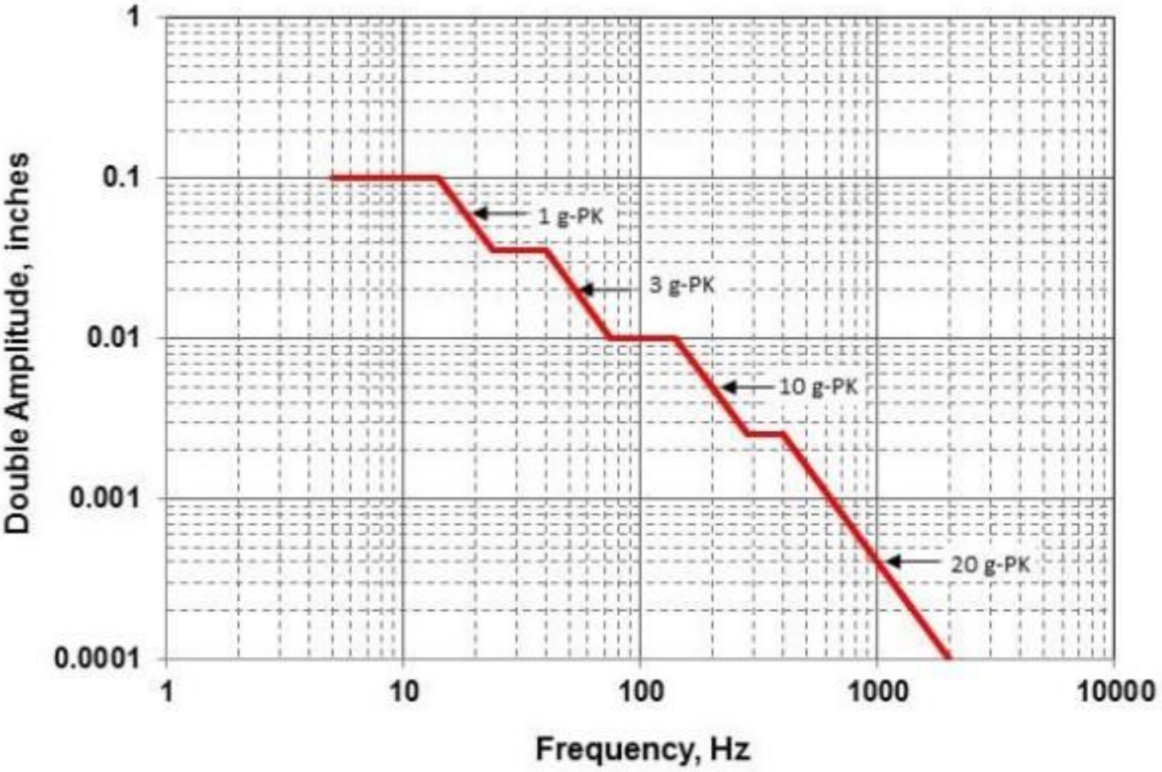

**Figure 1. Vibrational Limit for the OCDH [2]**

Figure 1 shows the maximum frequency and forces that the OCDH needs to withstand. The red line represents the amount of force that the OCDH experiences at the given frequencies. The x-axis is the provided frequencies measured in hertz. The y-axis the amplitude that the OCDH experiences during the vibrational test. The OCDH should not experience any damage during the vibrational analysis. For calculation purposes frequencies from 1 to 2,000 Hz are calculated which is within the frequency requirements.

The burst and proof pressure are calculated using the ultimate and yield strength of the materials respectively. The burst and proof pressure have not been determined yet but if the calculated pressures do not exceed the material properties the pressures are within limits. Pressure calculations will be calculated using the same four materials from the vibrational test. To properly calculate the burst pressure within a pipe the OCDH needed to be recalculated into am equivalent area. From the equivalent area the diameter of a pipe can be calculated. Equation 4 is the equivalent area equation that is used to determine the diameter of the pipe [3].

$$d = \frac{1.30 * (a * b)^{0.625}}{(a + b)^{0.25}} \tag{4}$$

Equation 4 consists of the equivalent diameter d; a which is measured as the length of the major side, and b which is the length of the minor side. The equivalent diameter can then be used in Barlow's formula to calculate the internal pressure. Equation 5 is the internal pressure calculation for the OCDH [4].

$$P = \frac{2 * t * S_y}{d_o} \tag{5}$$

In equation 5, t is the wall thickness in inches; $S_y$ is the yield strength of the given material measured in psi; and $d_o$ is the equivalent diameter. The burst pressure is calculated using equation 6 which is a derivation of the Barlow equation [4].

$$P_u = \frac{2 * S_t * t}{d_o} \qquad (6)[4]$$

In equation 6, t is the wall thickness measured in inches; $S_t$ is the ultimate tensile strength measured in psi; and $d_o$ is the equivalent diameter of the OCDH. Preliminary pressure calculation can be found in appendix B along with the preliminary equivalent diameter equations. Full calculations are included within the attached excel on the sheet titled Pressures.

## PHYSICAL MODELING

The vibrational models were simulated in Solidworks for the purpose of modelling the base calculations. Finite elemental analysis can be seen via the mesh grid in the figures. Stainless steel 304, stainless steel 316, and titanium are modeled. The amount of deformation on the walls is shown. Figure 2 is the vibrational model for stainless steel 303.

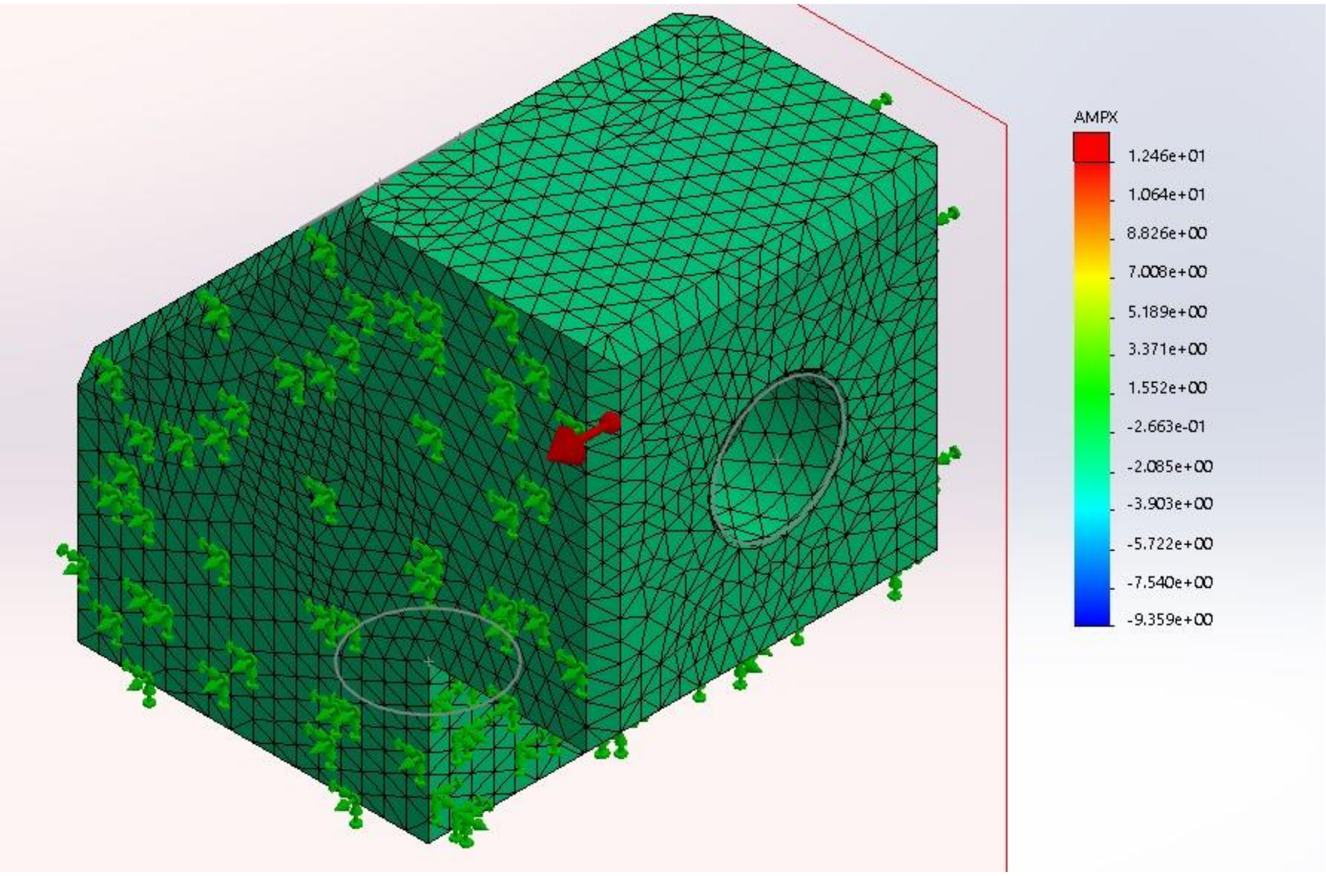

**Figure 2. Stainless Steel 304 Vibrational Deformation**

The stainless steel 303 vibrational deformation model is displayed in figure 2. The green on all sides of vibrational model represent the amount of deformation on the model based upon high frequencies. The model did not see deformation until 8,081 Hz. The model experiences deformation at about four times the required frequency. Figure 3 is the stainless steel 304 vibrational model.

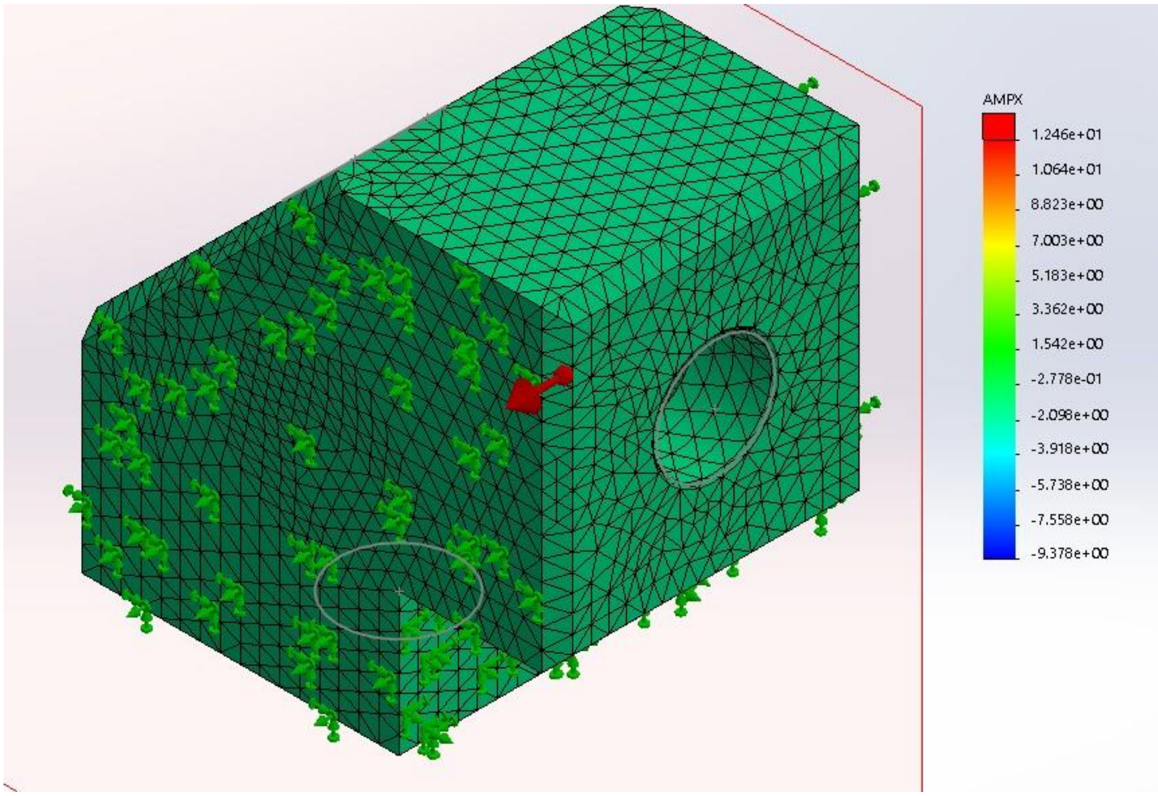

**Figure 3. Stainless Steel 316 Deformation**

The stainless steel 316 vibrational deformation graph can be seen in figure 3. The vibrational model experiences no deformation until 8,155 Hz. This model experiences about the same amount of deformation as the previous model. Figure 4 is the titanium solid model.

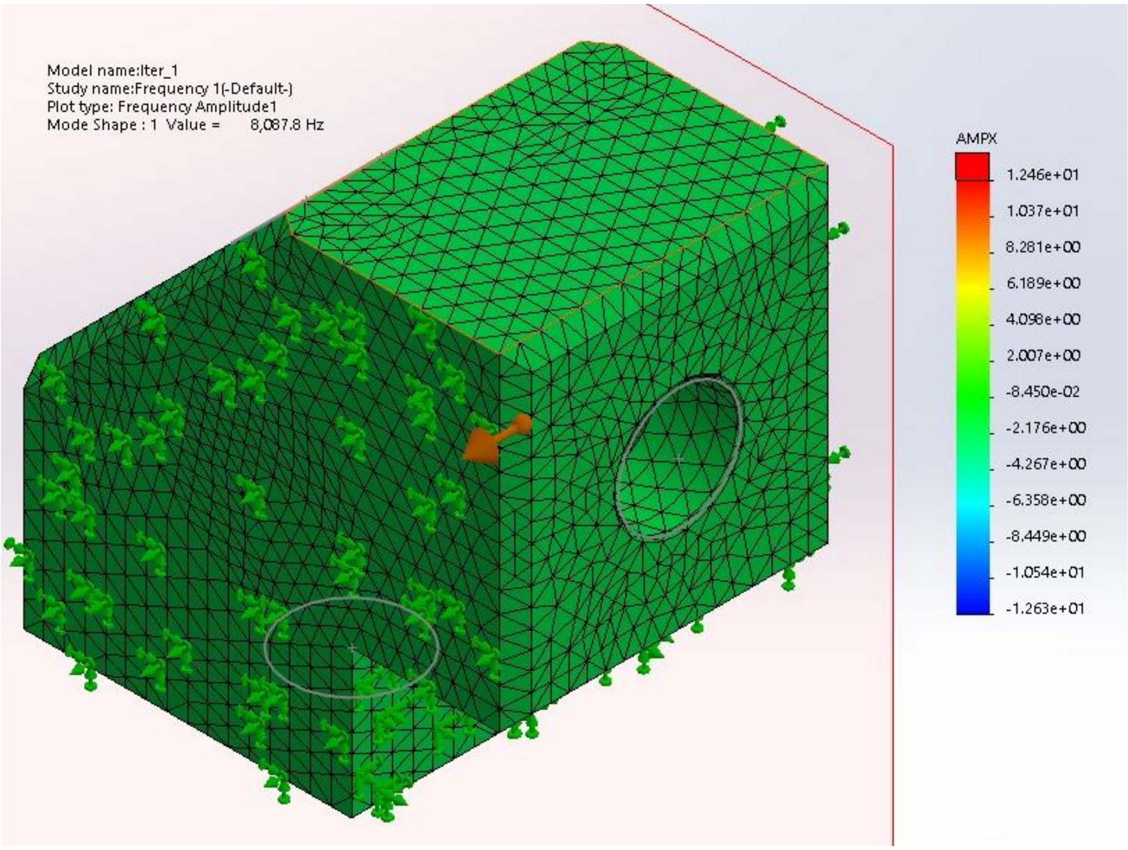

**Figure 4. Titanium Deformation**

The titanium vibrational deformation graph is like the previous models. The model did no experience deformation until 8,087 Hz. Like the previous models the location where deformation first occurs is around the sensor inlet.

The vibrational FEA models all began deforming around 8000 Hz. Because this value is much higher than the operating frequency model can be safe to use and well within operating conditions. Figure 5 displays the location around the sensor inlet where deformation takes place for all models.

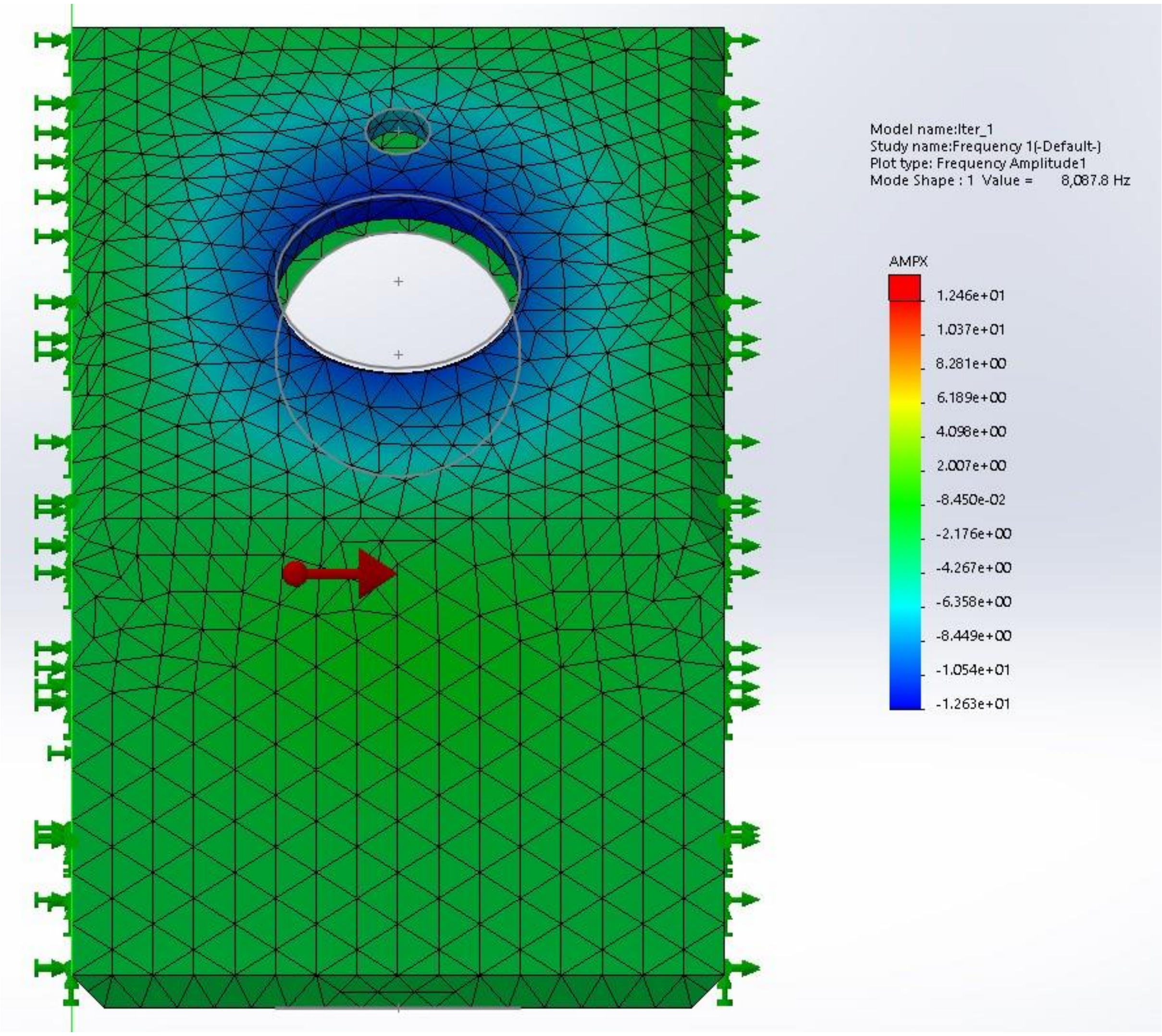

**Figure 5. Sensor Inlet Deformation Location**

The measured value of deformation for the models is in AMPX which is like displacement measurements. Much like the calculations the models performed within expected values and within the expected parameters. Main deformation always occurs around sensor inlet because the wall thickness in that location is the smallest. The FEA models allow for deformation to measured in all individual mesh locations allowing for accurate measurements.

A lone pressure model was created using a nonlinear test model. This allowed for the stress within the OCDH's sensor housings to be measured. The nonlinear model shows the weakest portions of the sensor housing within its original format. This allows for the wall thickness to be analyzed based upon burst pressure and operational pressure along the walls. Figure 6 is the nonlinear stress model used for pressure calculations.

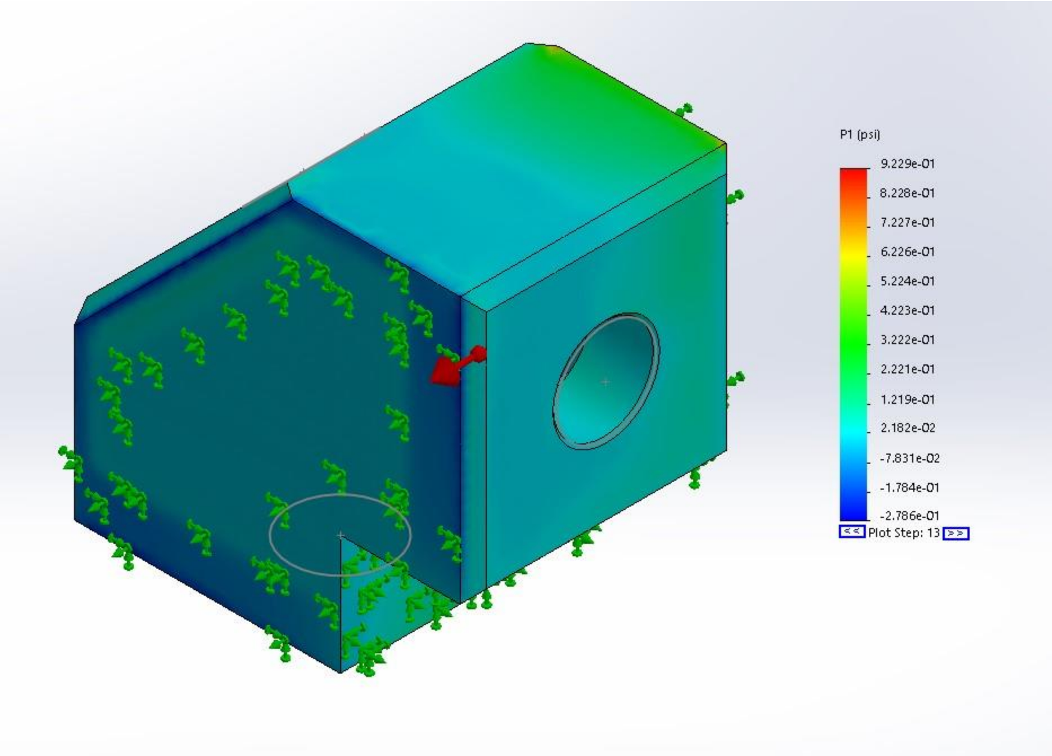

Figure 6. Principal pressures (psi)

The amount of pressure across the OCDH is equivalently distributed when placed in a high-pressure environment. This basic principal pressure figure shows the pressure present across the whole of the OCDH. Figure 7 is the location along the OCDH where the most pressure concentrates.

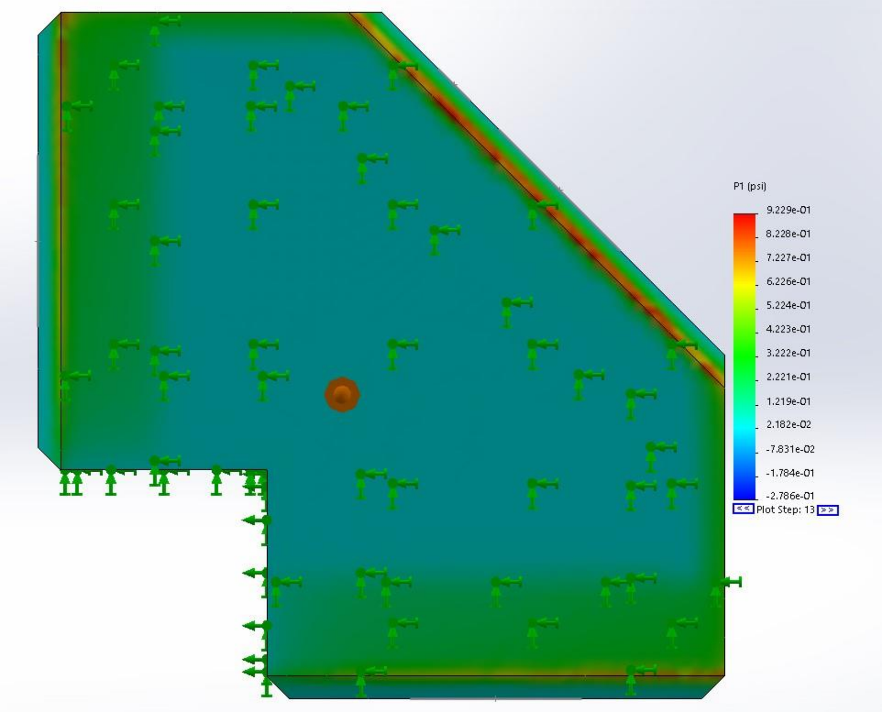

Figure 7. High pressure locations on the OCDH

Figure 7 displays the locations of the highest pressure on the model. This changes with the material and with the thickness of the walls. This model is made of titanium but because the mechanical properties are like stainless steel the model holds. Calculations for all materials can be found in the attached excel.

## RESULTS

Vibration calculations for frequencies ranging from 1 to 2,000 Hz for four different materials yielded a deformation graph for each material. Stainless steel 303, stainless steel 304, stainless steel 316, and titanium all have deformation graphs. Figure 8 is the stainless 303 deformation graph.

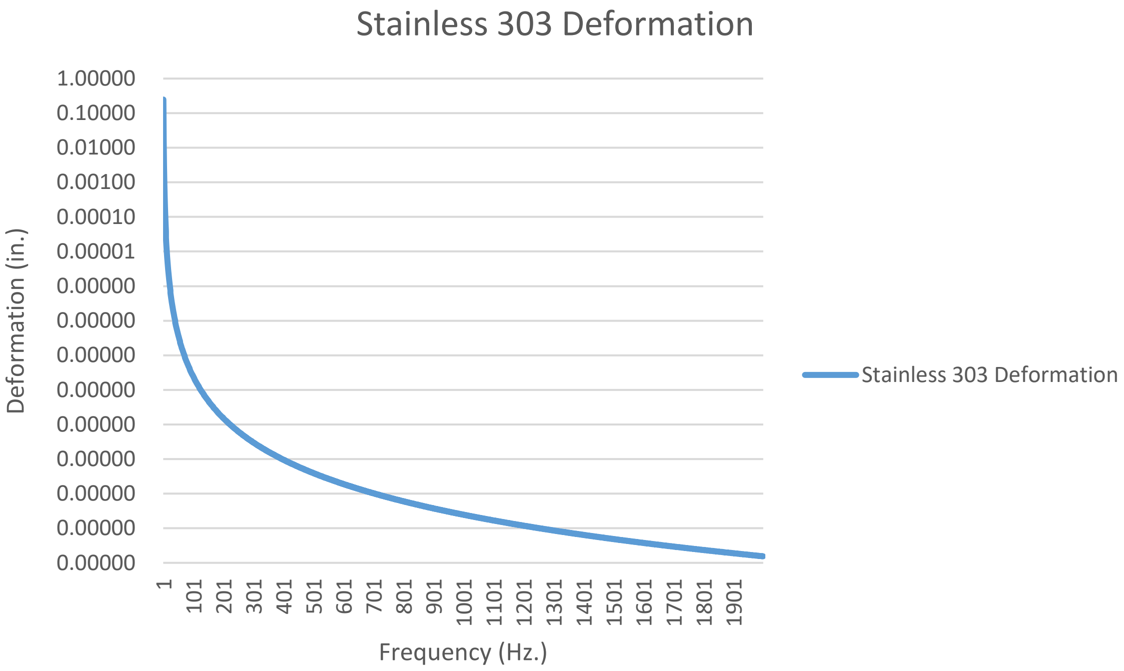

**Figure 8. Stainless steel 303 deformation log graph**

The deformation frequency graph displays the amount of deformation at frequencies from 1 to 2,000 Hz. The amplitude of deformation begins to decrease as the frequency increases. This is due to the frequency reaching a point of high resonance where the material is no longer affected by the large amounts of vibration. This graph when analyzed with figure 1 shows the validity of the design with stainless steel 303. Figure 9 is the stainless steel 304 deformation graph.

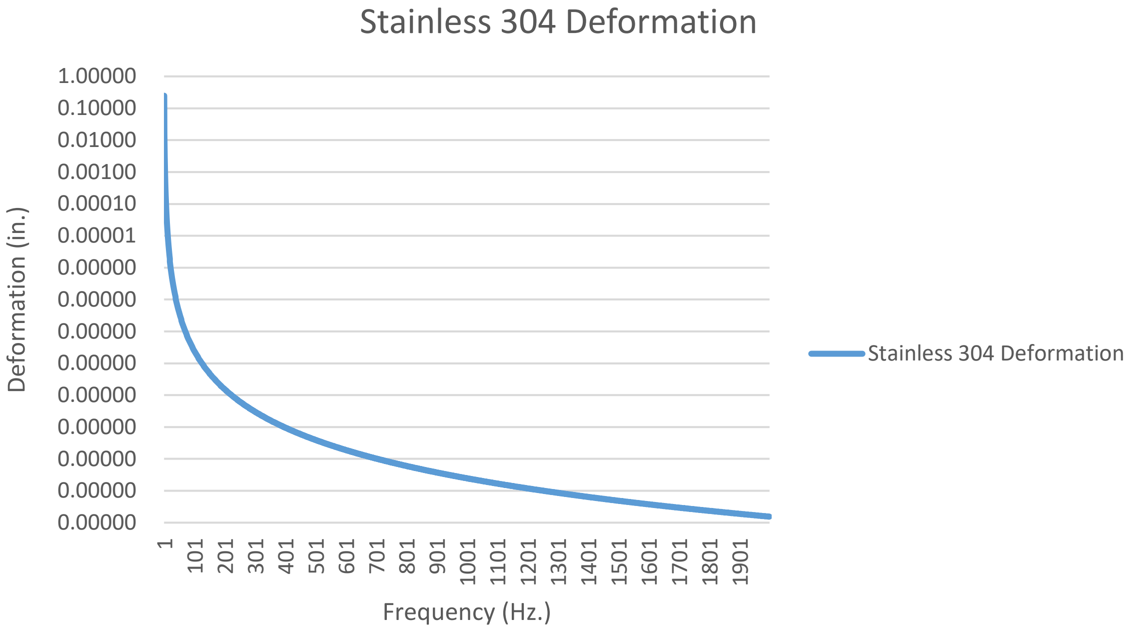

**Figure 9. Stainless steel 304 deformation log graph**

The deformation frequency graph is like figure 8. Because the mechanical properties of stainless steel 303 and 304 are similar the amount of deformation is consistent within the graph. As the frequency increase the amount of deformation decrease. When compared to figure 1 this graph shows that stainless steel 304 is a viable choice because the amount of deformation in inches is lower than the expected vibrational curve. Figure 10 is the stainless steel 316 deformation graph.

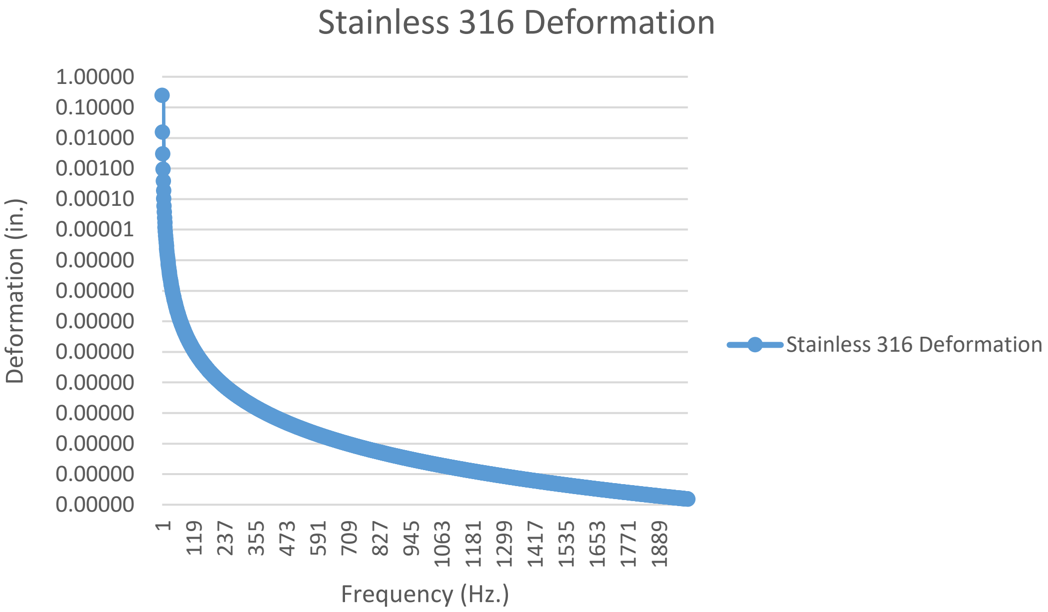

**Figure 10. Stainless steel 316 deformation log graph**

The deformation frequency graph of stainless steel 316 has similar properties to the stainless-steel deformation graphs from before. As the frequency increases the amount of deformation within the part begins to decrease. Figure 11 is the deformation graph for titanium.

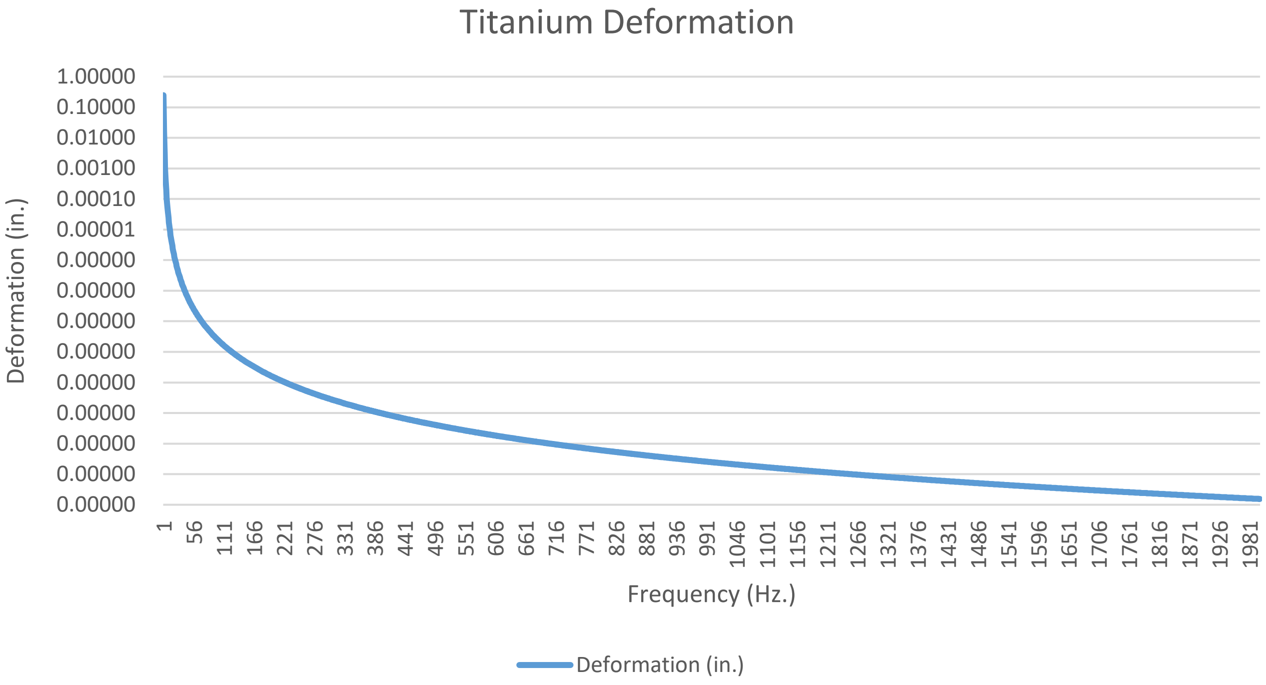

**Figure 11. Titanium deformation log graph**

Figure 11 is the deformation frequency log graph. As the frequency increase the amount of deformation decreases extremely fast. This is due to the material properties of titanium. When compared to figure 1 titanium is a viable option based upon figure 11.

All materials as well as the design are feasible for Team Honeywell. The price of the materials is the only limiting factor for this design iteration. It can be assumed that the deformation graphs are well within expected values because all values are within one hundred thousandths. The terms are ever decreasing and well within the graph of vibrational limits.

Internal operating and burst pressures are calculated based upon the material properties of the design. The internal pressure is important and calculated from 0.01 to 1 inch. Operating pressures are important for this design because it can allow for optimization of wall thicknesses. Figure 12 is the internal pressure graphs for the four selected materials. The wall thickness shows the amount of operating pressure that the sensor housing walls can withstand before deformation begins.

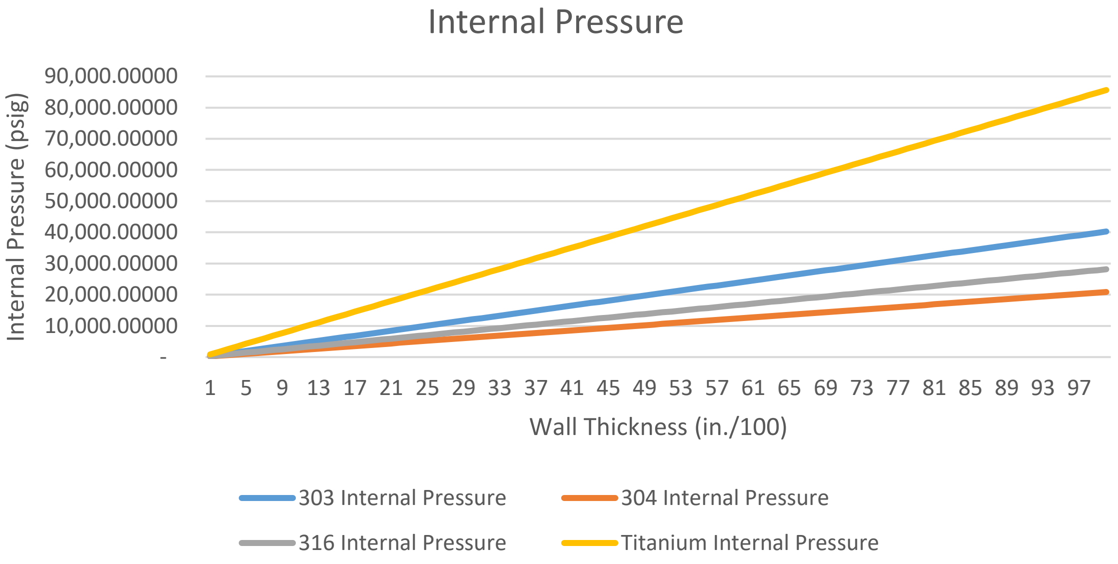

**Figure 12. Internal pressures for given materials**

The internal operating pressure is measured in gauge pressure psi. As wall thickness increase the amount of internal pressure can increase. Wall thickness was measured up to 1 inch thick, but the design is rated for many thicknesses below. Figure 13 is the total burst pressure that the design can take before failure.

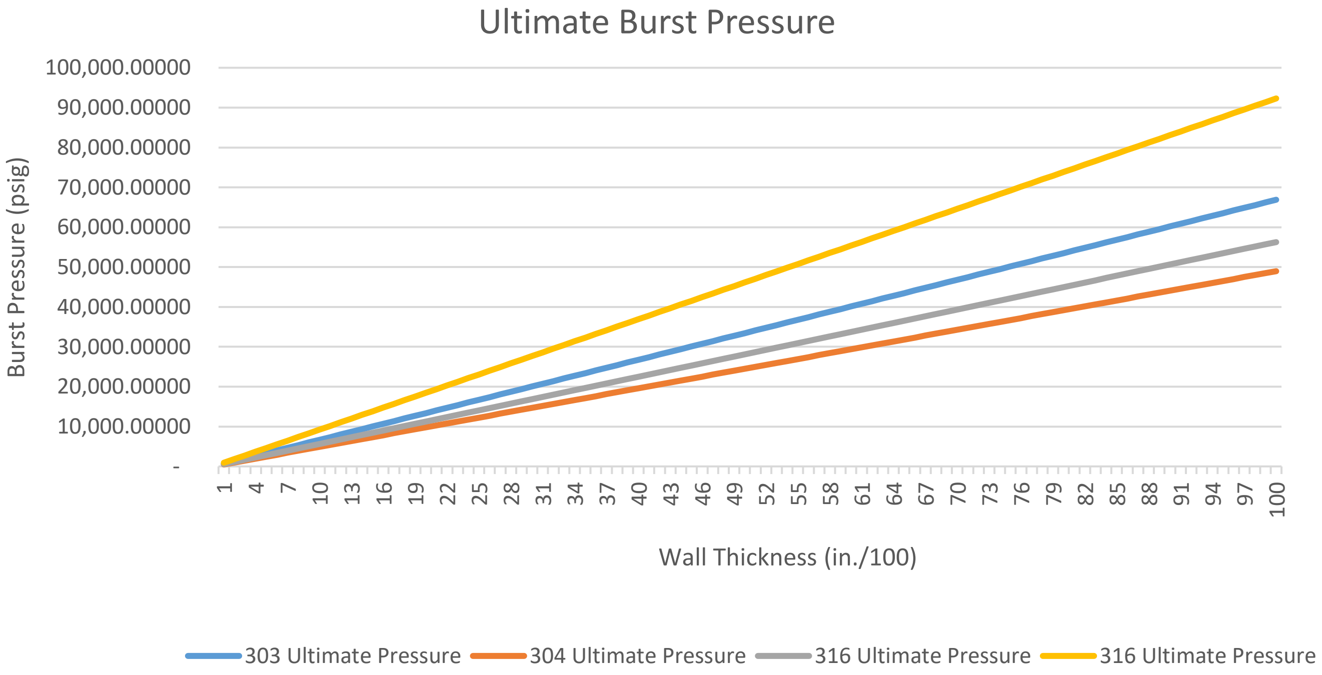

**Figure 13. Ultimate burst pressure**

The ultimate burst pressure calculations show the material properties and how they effect wall thickness and the amount of total pressure the design can take. The amount of burst pressure the design can take depends on the material properties. As the wall thickness increases the amount of burst pressure the design can take. Wall thickness can then be optimized for the design based upon the burst pressure graphs.

The operational and burst pressure allow for optimization of the design based upon wall thickness and the amount of pressure the walls can take. The pressures are preliminary calculations that can be used to adjust the wall thickness to the burst pressure and operational pressure when they are determined.

## CONCLUSIONS

Vibrational damage within the OCDH depends upon the amount of frequency and the mechanical properties of the materials. The design is determined to be viable with any of the four materials that are discussed. Because the deformation does not occur until frequencies that are much higher than test frequencies it is determined that the design will succeed based upon the parameters set forth by Honeywell.

Internal and burst pressure can be used to adjust the wall thickness within the sensor housing based upon requirements that will be set forth later. The pressures allow for a proper wall thickness to be determined based upon the mechanical properties of the materials. The design is also verified based upon the pressures because all materials can guarantee the validity of the design.

## REFERENCES

[1] S. S. Rao, Mechanical Vibrations, Pearson Education, 2017.

[2] Honeywell, "Procurement Specifications for the Oil Chip Detector Housing," Honeywell Aerospace, Phoenix, 2019.

[3] The Engineering ToolBox, "Equivalent Diameter," EngineeringToolBox.com, 20013. [Online]. Available: https://www.engineeringtoolbox.com/equivalent-diameter-d_205.html. [Accessed 25 11 2019].

[4] The Engienering ToolBox, "Barlow's Formula - Internal, Allowable and Bursting Pressure," EngineeringToolBox.com, 2005. [Online]. Available: https://www.engineeringtoolbox.com/barlow-d_1003.html. [Accessed 25 11 2019].

[5] MatWeb LLC., "Material Property Data," MatWeb, 2019. [Online]. Available: http://www.matweb.com/. [Accessed 25 11 2019].[1]

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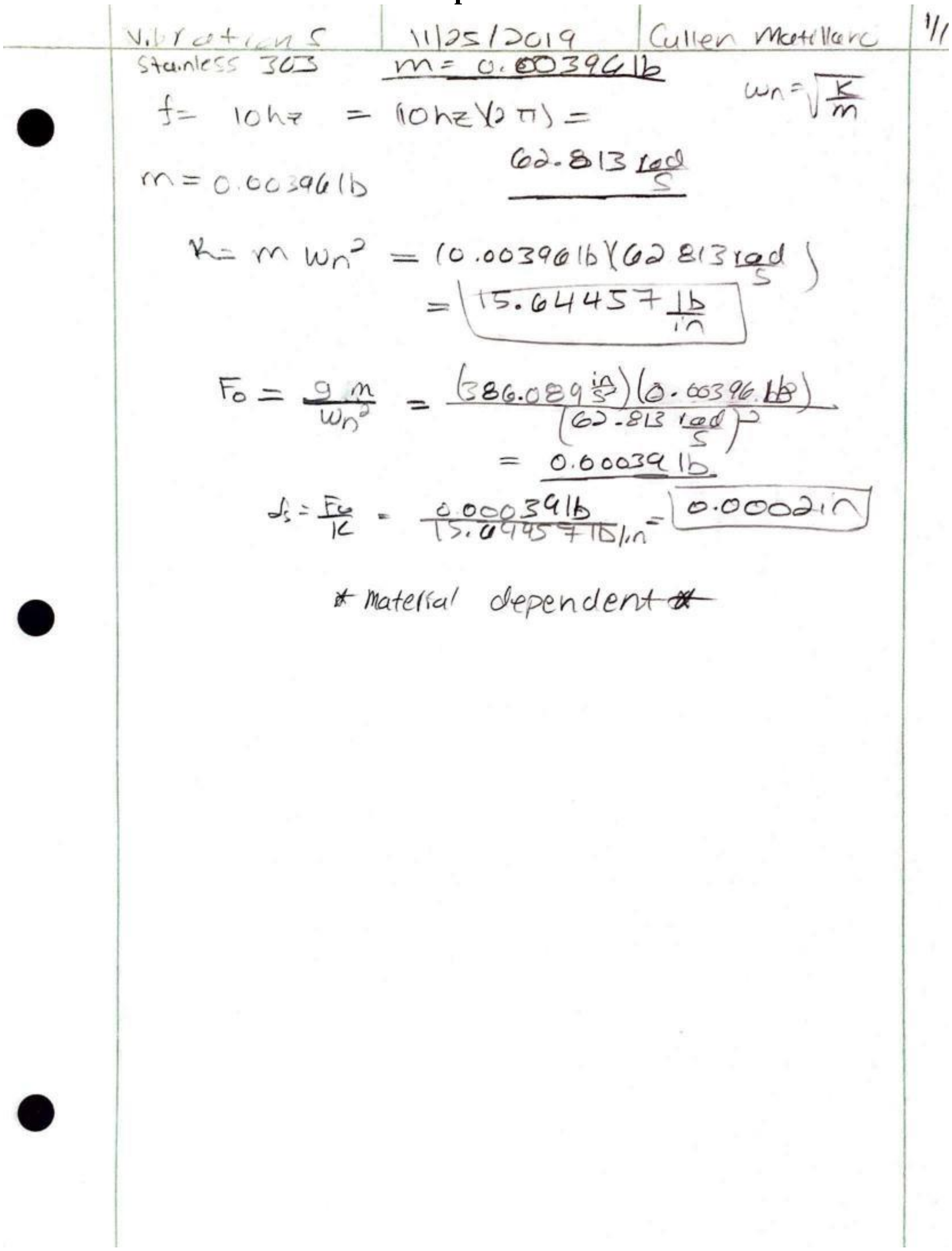
[1] All material properties have been procured through MatWeb; Stainless steel 303, 304, 316, and Titanium

# APPENDIX A: Vibrational Back of the Envelope Calculation



Vibrations | 11/25/2019 | Cullen Matellaro | 1/1

Stainless 303 $\underline{m = 0.00396\,\text{lb}}$

$w_n = \sqrt{\frac{k}{m}}$

$f = 10\,\text{hz} = (10\,\text{hz})(2\pi) = \underline{62.813\,\frac{\text{rad}}{\text{s}}}$

$m = 0.00396\,\text{lb}$

$$k = m\,w_n^2 = (0.00396\,\text{lb})(62.813\,\tfrac{\text{rad}}{\text{s}})^2$$

$$= \boxed{15.64457\,\frac{\text{lb}}{\text{in}}}$$

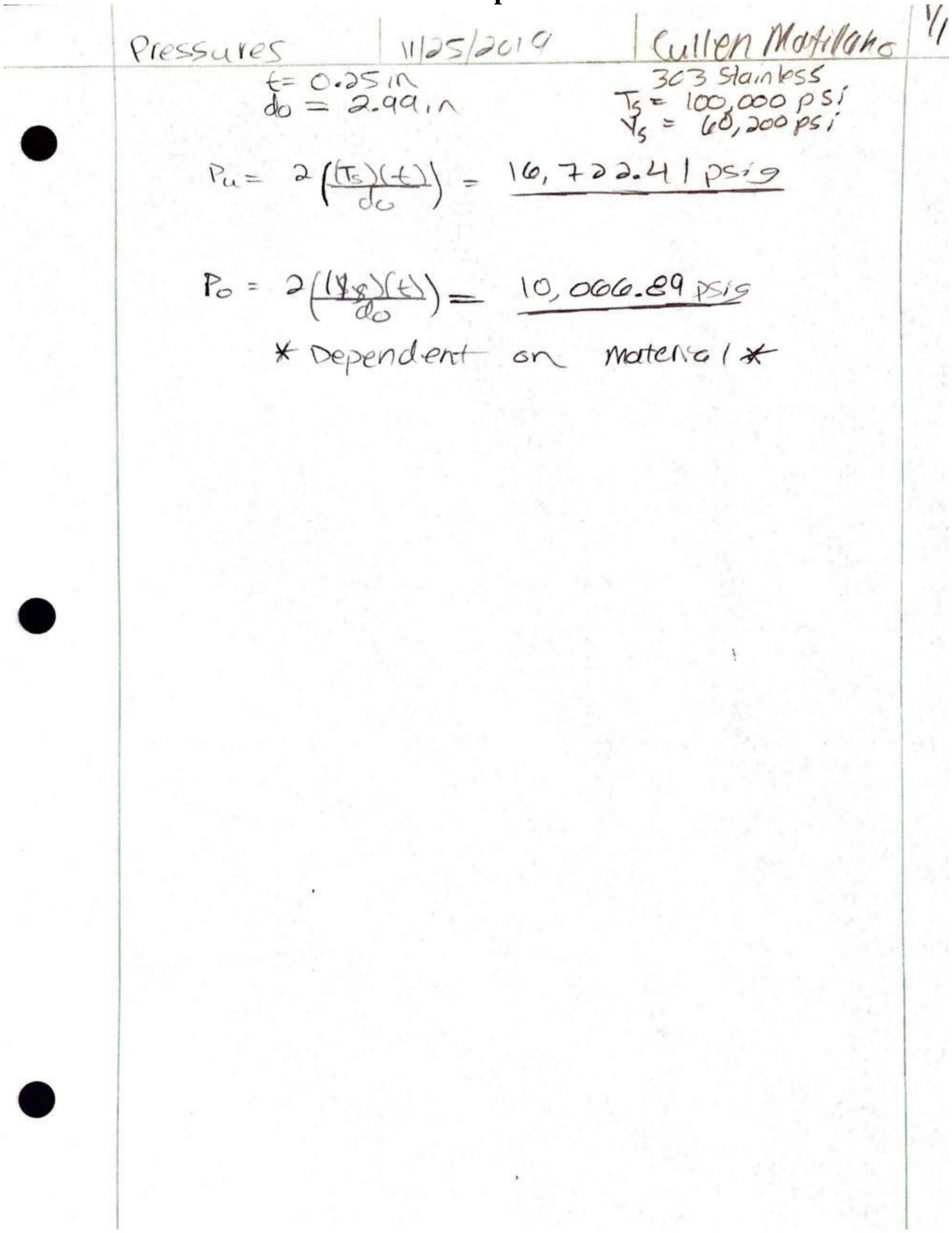
$$F_o = \frac{g\,m}{w_n^2} = \frac{(386.089\,\frac{\text{in}}{\text{s}^2})(0.00396\,\text{lb})}{(62.813\,\frac{\text{rad}}{\text{s}})^2}$$

$$= \underline{0.00039\,\text{lb}}$$

$$\delta_s = \frac{F_o}{k} = \frac{0.00039\,\text{lb}}{15.64457\,\text{lb/in}} = \boxed{0.0002\,\text{in}}$$

* material dependent *

## APPENDIX B: Pressure Back of the Envelope Calculations



Pressures | 11/25/2019 | Cullen Matilano | 1/1

$t = 0.25 \text{ in}$
$d_o = 2.99 \text{ in}$

303 Stainless
$T_s = 100{,}000 \text{ psi}$
$Y_s = 60{,}200 \text{ psi}$

$$P_u = 2\left(\frac{(T_s)(t)}{d_o}\right) = \underline{16{,}722.41 \text{ psig}}$$

$$P_o = 2\left(\frac{(Y_s)(t)}{d_o}\right) = \underline{10{,}066.89 \text{ psig}}$$

* Dependent on material *