Energy Harnessing Speed Hump

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INTRODUCTION

Speed humps can be found on roads all around the world. Currently, these humps only serve to slow down vehicles on the road. Slowing down and traversing the speed humps wastes the kinetic energy of the car without receiving any energy in return. This project focuses on converting the everyday speed hump into an energy harnessing speed hump, capable of using the force exerted by a vehicle passing over the speed hump to generate electricity. This project was chosen to create an alternative way of harnessing clean sustainable energy from an otherwise unnoticed device currently deployed in modern day roadways. The energy gathered from the device can be used in various applications including outdoor lighting and tollbooths.

OBJECTIVE

The focus of this project is to collect energy from a vehicle passing over a speed hump and to use this energy for powering devices such as the following: lighting in a parking lot, garage doors in residential spaces, and tollbooth gates. This device was developed to help society become more sustainable and environmentally friendly. The idea for this device originally was derived from potential and kinetic energy principles in classical mechanics. A solution is to design an energy harvesting speed hump device. An important challenge in the design process is to capture the energy efficiently. These losses can range from the major losses due to the length and material of the piping, and the minor losses associated with valves and fittings. Also some important factors that will contribute to energy losses are due to friction, heat, and fluid compressibility. This system includes a series of plates, and each plate displaces a pair of pistons containing hydraulic fluid. This fluid is forced into another piston acting as a two-way hydraulic cylinder. One side of the cylinder contains hydraulic fluid and the other side contains air. The side that contains air is connected to a pneumatic pressure vessel. This stores the compressed air. The stored air creates electrical energy via a pneumatic-electrical generator. A reliable method to reset the system after a car traverses the device would be ideal; however, it is currently our biggest challenge. The key aspects to the design are the valves in the system, which provides a method of returning the plates to their initial positions by supplying a negative pressure in the pistons. Many factors go into the spring design such as coil diameter, spring life, spring constant, and estimated displacement. A scaled prototype, CAD model, and Simulink model will assist in the proof of concept, and provide a solid basis for material and stress analysis.

MODELING

Premodeling

In order to implement further analysis of this design project, the energy-harnessing speed hump was modeled with Siemens NX 8.0 computer-aided design software. However, since the system is innovative and without precedent, preliminary ideation and diagrams were taken care of before beginning the modeling process. Thus, a simplified two-dimensional schematic of the system can be found in Figure 1.

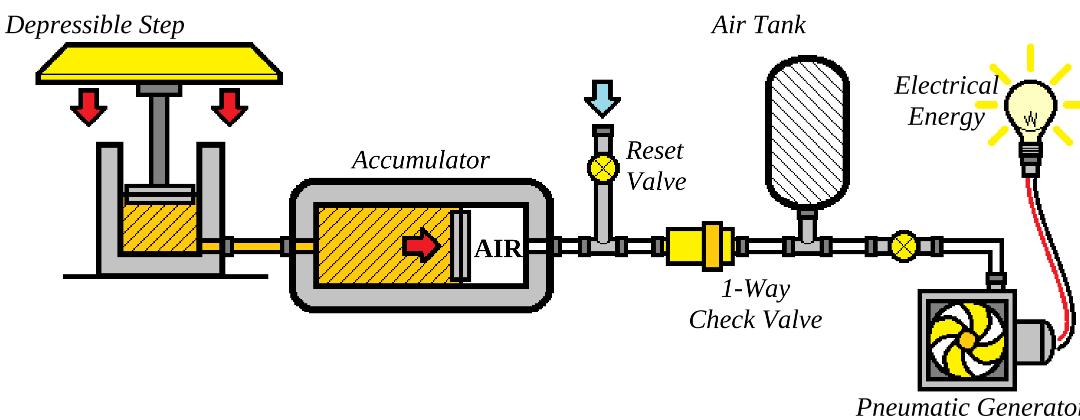

Figure 1. Simplified Schematic of Hydraulic/Pneumatic Speed Hump System

Once the above idea was translated into the proper layout for the energy-harnessing speed hump, all modeling was done and redone before analysis. Although the specific architecture and aesthetic design of the speed hump was not given much attention, the primary system was given adequate detail. The speed hump is constructed with four different assemblies comprised of over forty individual parts: a piston assembly, support assembly, accumulator assembly, and hosing.

Piston Assembly

The piston assembly was the first to be modeled, as it is the trigger to the system. Using a suitable bore size of five inches, the actual piston and rod assembly were created, as seen in Figure 2.

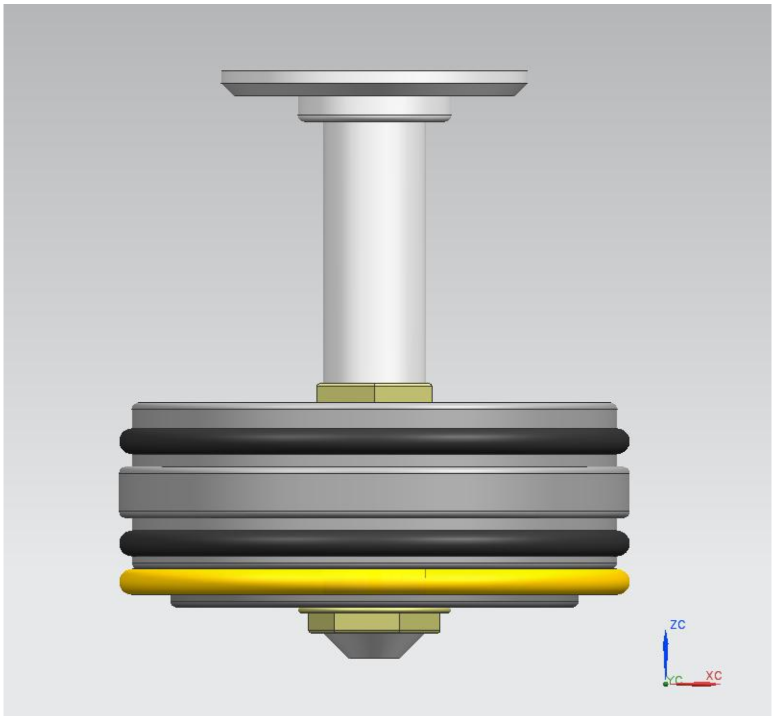

Figure 2. Hydraulic Piston and Rod

Similar to a piston and rod within an internal combustion engine, Figure 2 illustrates the multiple seals and varying cross-sectional diameter of the piston implemented in the design process. Modeling consisted of a simple circular geometry with mostly extrusions, cuts, and edge blends. The piston was then secured with proper housing, seen in Figure 3.

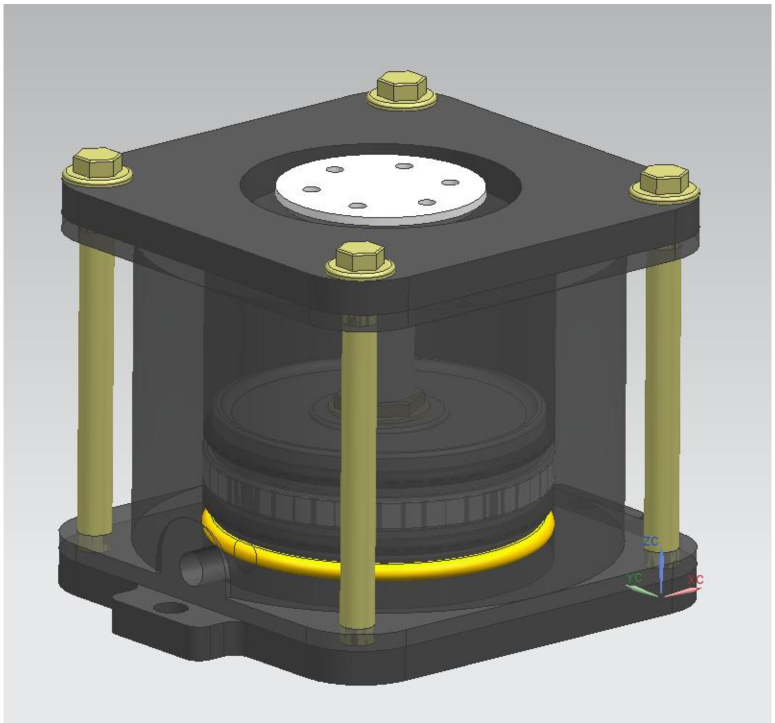

Figure 3. Piston Housing

The housing was formed using a compression cylinder, top plate, bottom plate, and four housing bolts. A one-inch wall thickness was given to the cylinder, all appropriate mounting locations were placed around the bottom plate, and the top plate was given a slightly oversized diameter to relieve pressure. Once the outlet hole for hydraulic fluid was tapped, the housing was completed. All modeling was done with extrusions, cuts, and edge blends, using simple circular and square geometry.

The piston assembly was next encased in an accompanying support bracket, providing a modular capability in consideration of maintenance. This is seen in Figure 4.

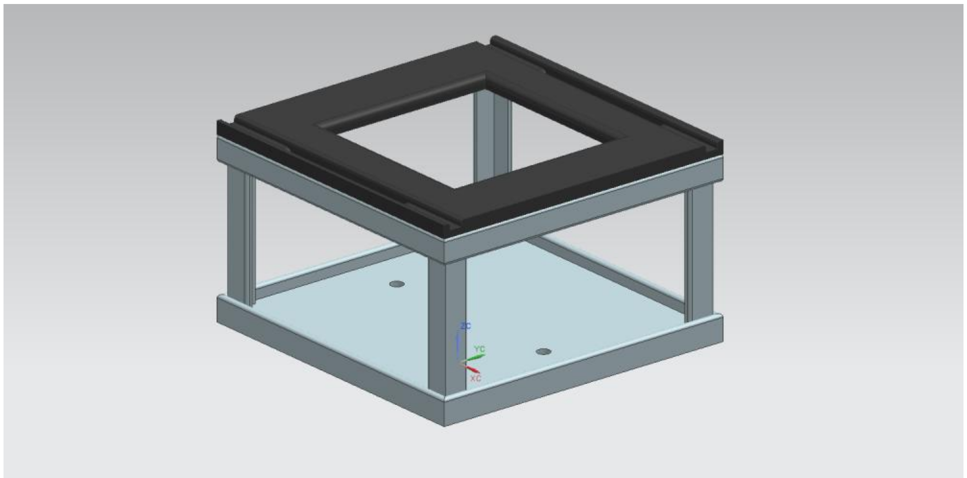

Figure 4. Piston Assembly Support Bracket

This support, made of a simple metal frame with a hard and rubberized landing mat atop, was designed to dissipate a portion of the force created by a vehicle's weight. The mat has slit indentations along two edges for the alignment of the depressible platform.

Lastly, the depressible platform itself was designed to perfectly fit atop the piston assembly and support. It was modeled using extrusions, cuts, chamfers, and edge blends. Its depressed position and bolting mechanism are displayed in Figures 5 and 6.

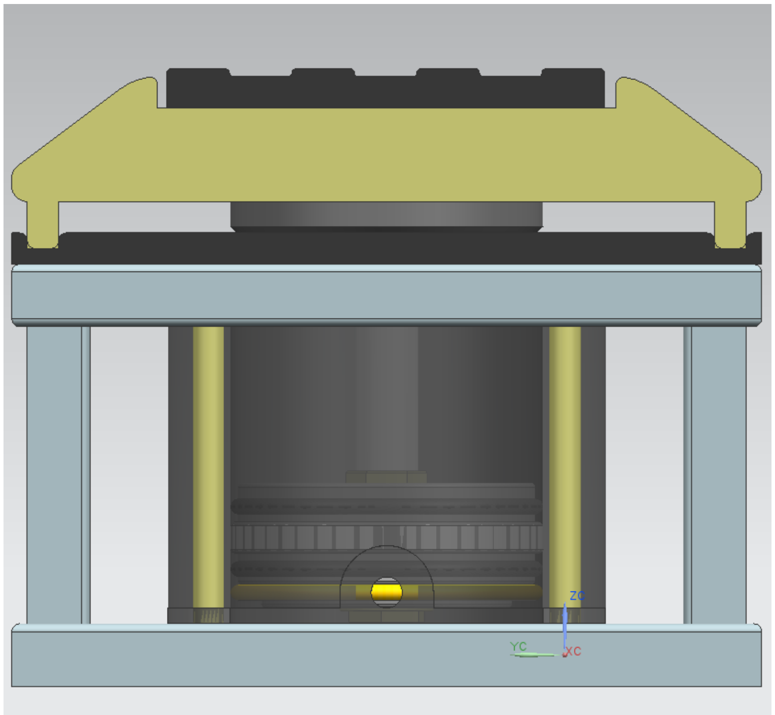

Figure 5. Side View of Depressible Platform

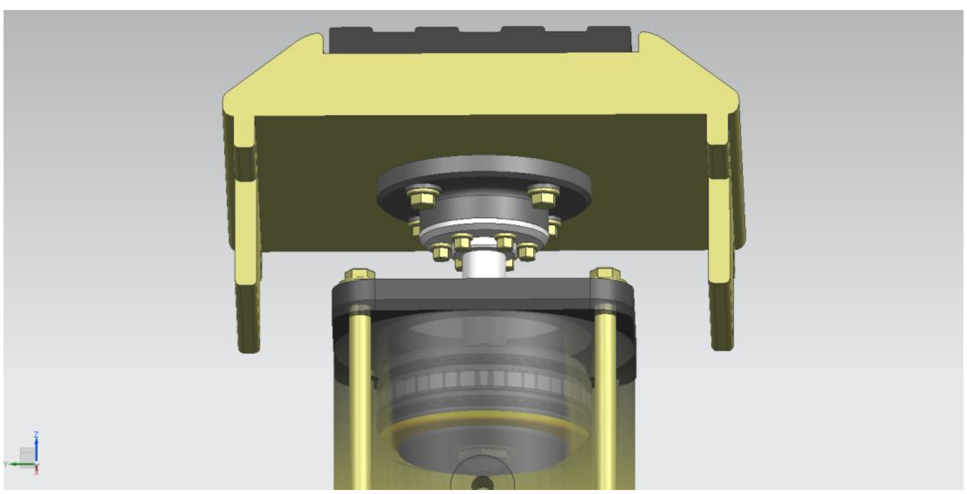

Figure 6. Bolt Connection of Depressible Platform

Thus, the piston assembly was completed and can be seen in Figure 7. Although hosing is discussed in a later section, it is also displayed in the figure.

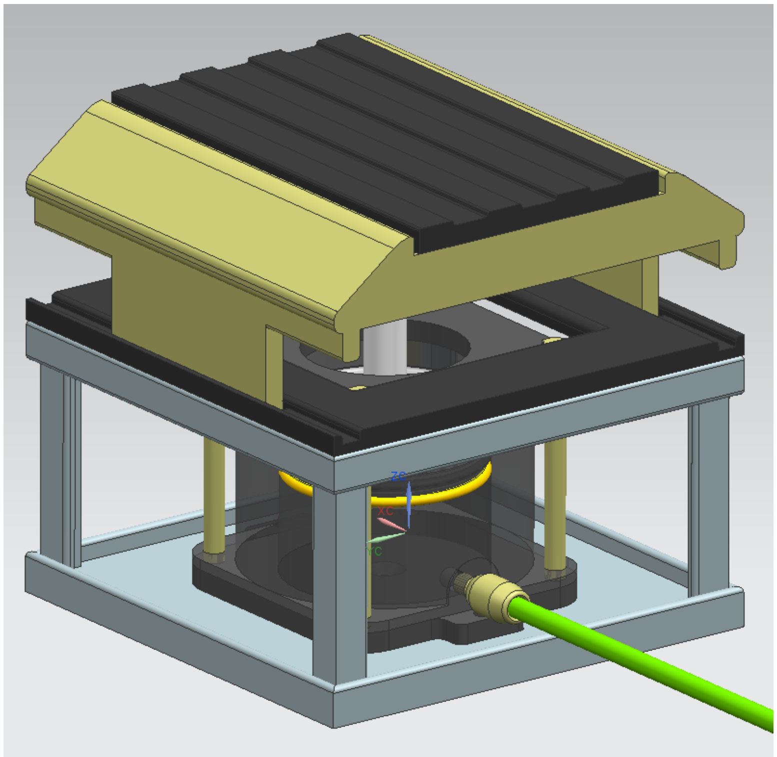

Figure 7. Complete Piston Assembly

Support Assembly

Although not seen in the simplified schematic, the support assembly is bundled along the piston assembly. It is an assist to failure of the depressible platform. The support assembly is comprised of two simple springs enclosed similarly to the piston assembly. The spring assembly, shown in Figure 8, was designed to mimic the exact height of the piston assembly.

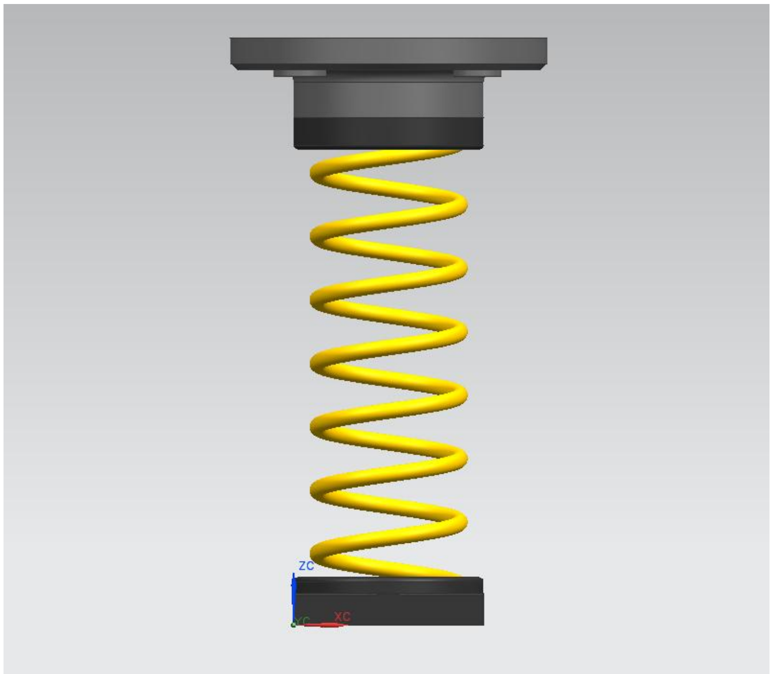

Figure 8. Spring Assembly

The spring assembly was modeled with a basic helix and sweep function, while the top and bottom hats were created using simply extrusions, cuts, and edge blends. In order to see the resemblance to the piston assembly, a side view illustration of the full support assembly is shown in Figure 9.

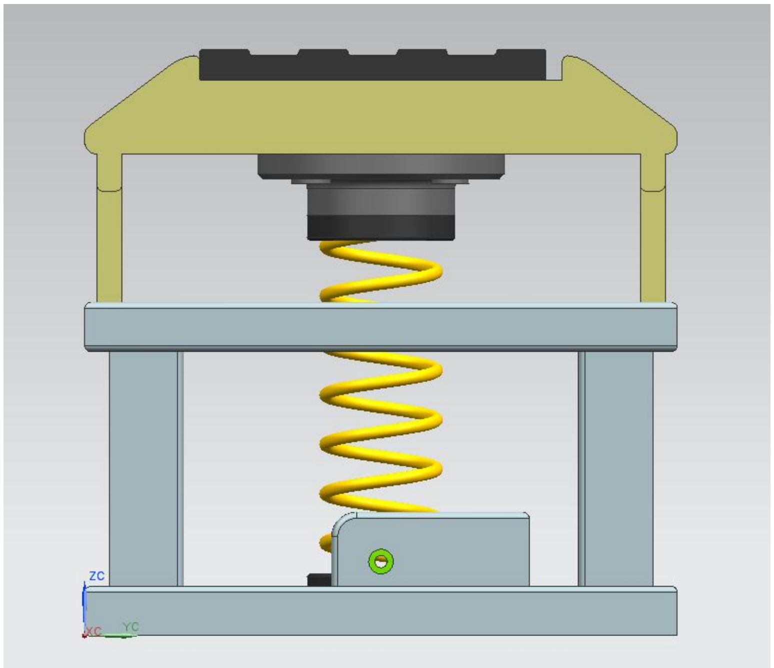

Figure 9. Side View of Support Assembly

In contrast to the piston assembly, the support assembly is designed as a four-module combination with thicker vertical posts. Although not as significant as that of the piston, the complete support structure must still dissipate a considerable amount of force from a vehicle's weight, thus providing a reason for these changes. The inner two modules feature spring assemblies, whereas the outer two are left for hose organization. The setup of the modules and an overall view of the support assembly can be found in Figures 9 and 10.

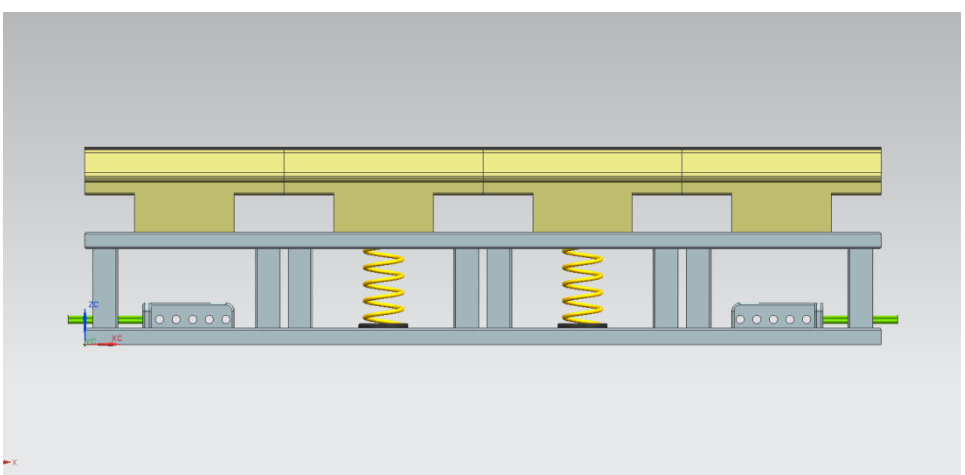

Figure 9. Four Modules of Support Assembly

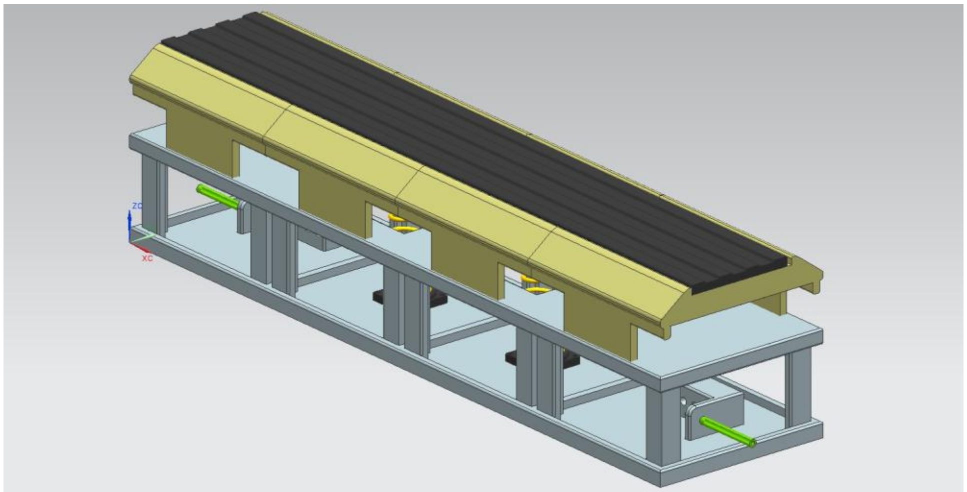

Figure 11. Overall View of Support Assembly

Accumulator Assembly

Moving on to the final side of the system, the hydraulic accumulator and pneumatic generator were modeled based on experimental and hand-written results. The hydraulic accumulator was simply modeled by extrusions and cuts using the basic square and circular geometry, and given the same basic cylindrical housing assembly as the piston. Both the inlet and outlet were tapped to a quarter-inch diameter. The modeling of the hydraulic cylinder was kept basic for further flow analysis. The component is found in Figure 12.

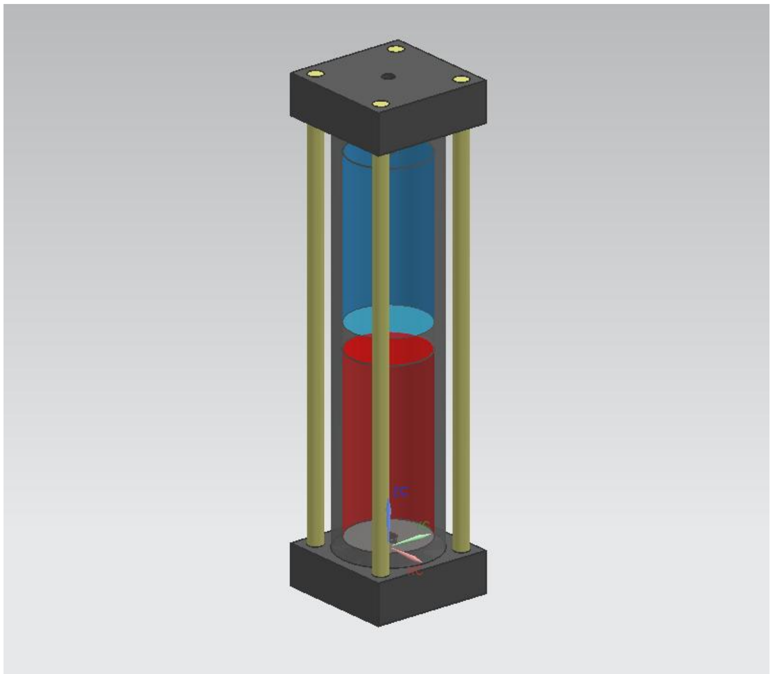

Figure 12. Hydraulic Accumulator

As for the pneumatic generator, it was modeled using a more complex geometry. Meshing was used to create a single surface of each fan blade before extruding the feature radially around the inner rod. The fan element is housed with both a small inlet and outlet to receive pressurized air and relieve the housing of pressure. The pneumatic generator can be seen in Figure 13.

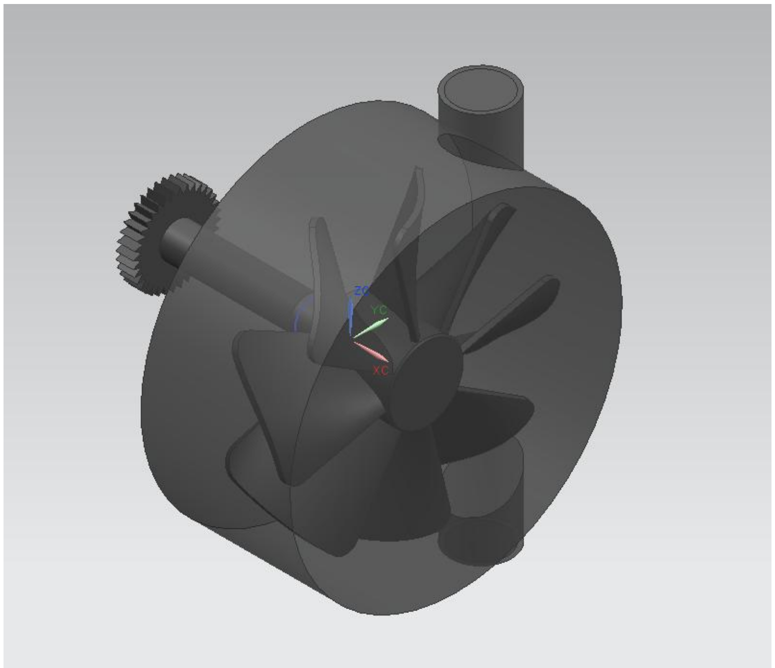

Figure 13. Pneumatic Generator

Although both these components are not clearly seen in the final assembly, they remain housed at the uppermost level of the speed hump.

Hosing

Once all mechanical aspects of the system were assembled, each component had to be connected with hosing. The design of the hosing featured a simple quarter-inch inner diameter, half-inch outer diameter, and varying length depending on the connection. The hoses were modeled using either simple linear geometry or planar splines before sweeping. One of the used hoses is shown in Figure 14.

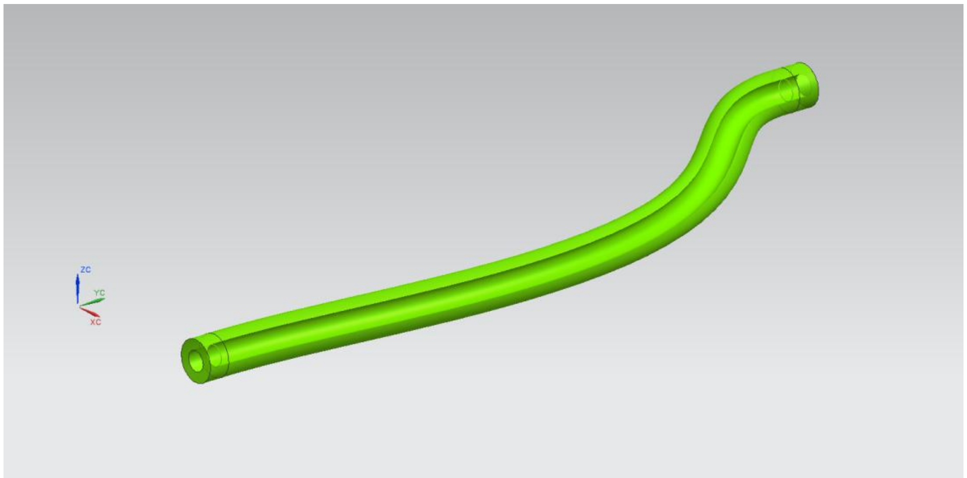

Figure 14. General Hydraulic Connection Hose

In regards to the ends of each hose connection, simple brass hose ends or one-way check valves were used, both of which can be seen in Figures 15 and 16.

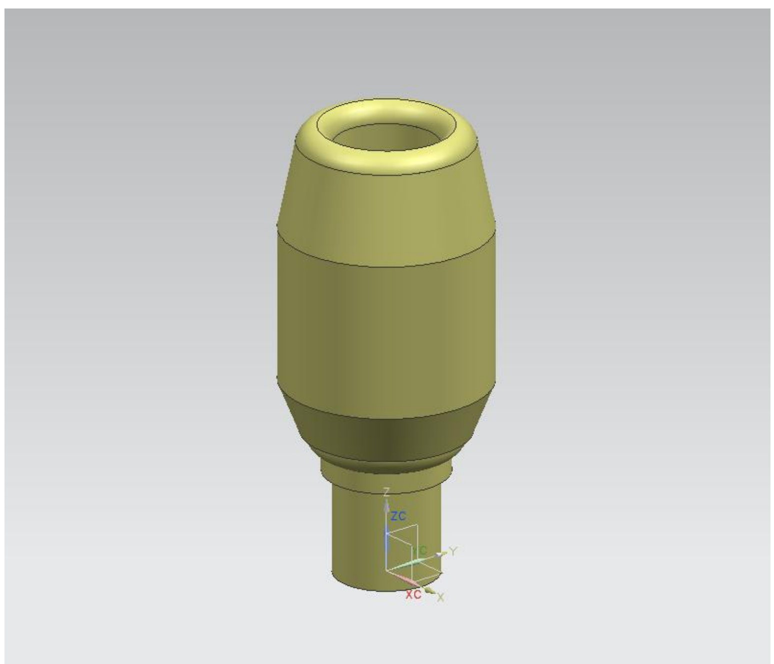

Figure 15. Hydraulic Hose End Connector

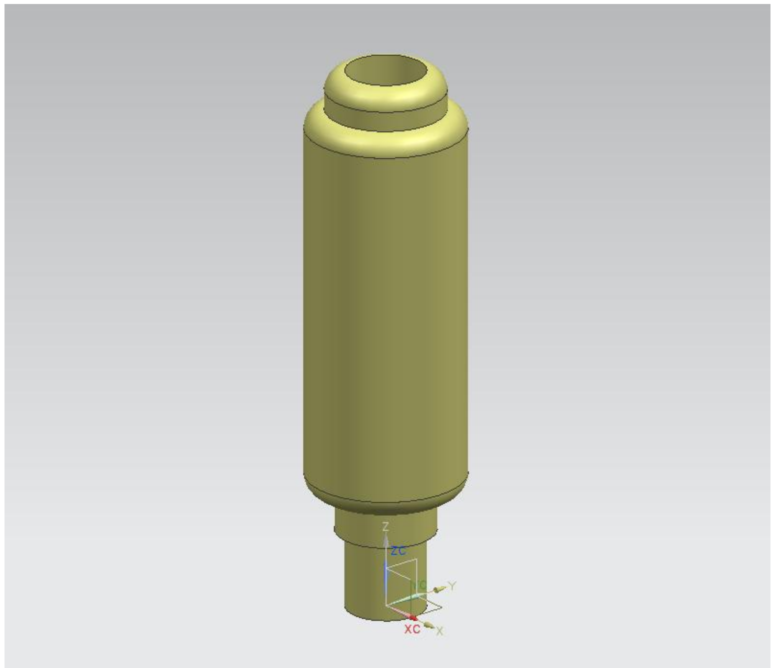

Figure 16. One-Way Check Valve

The important aspect of hosing is the manner in which the hosing is organized within the system. Although not shown earlier, the support assembly features hose organization brackets within its outer two modules. These brackets allow all hydraulic lines to follow the same general path without overlapping. The hose organizations can be seen in four different views in Figures 17 to 20.

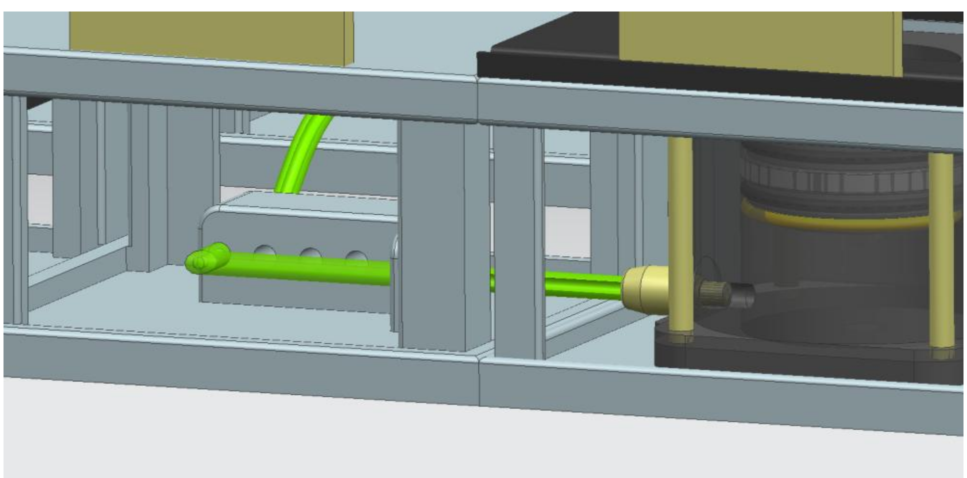

Figure 17. Hose Organization Near Piston Outlet

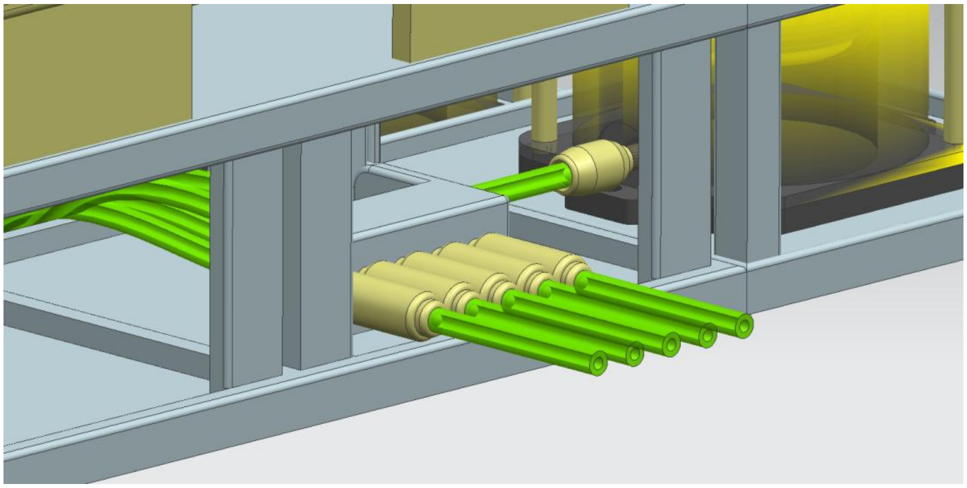

Figure 18. Hose Organization to Accumulator Inlet

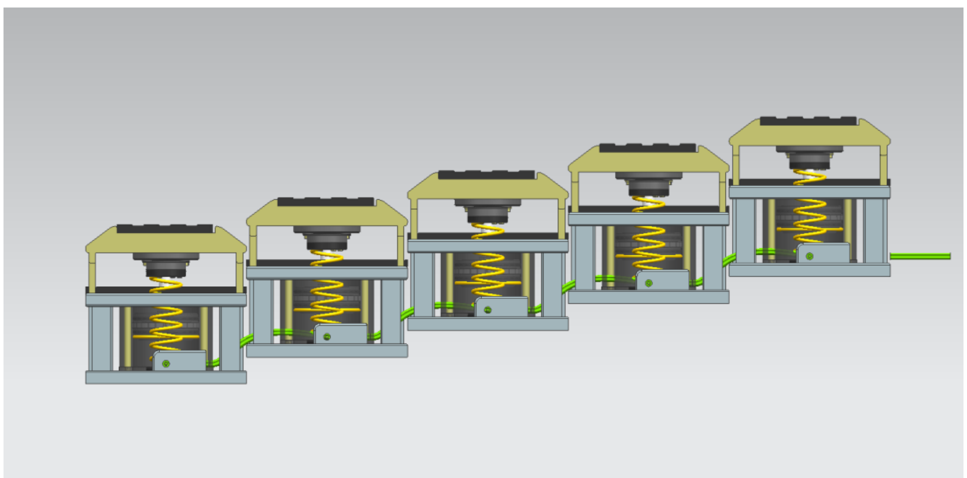

Figure 19. System Side View of Hose Organization

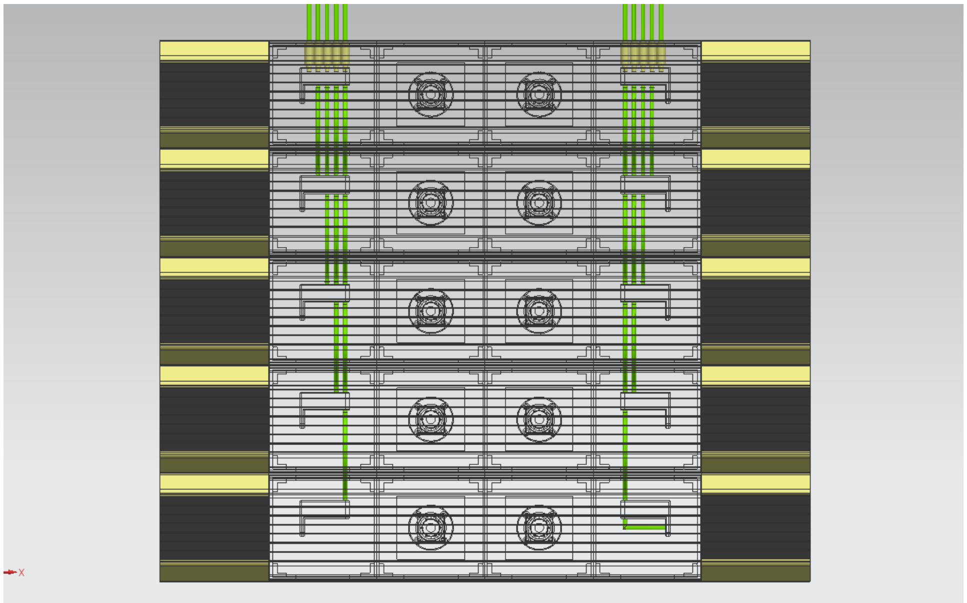

Figure 20. Top View of Overall Hose Organization

Complete Assembly

Finally, after all modeling and assembling of the four separate systems was completed, the assembly of the speed hump was constructed. Although the modeling focuses on the hydraulic and pneumatic system components, simple ramps were also modeled for visual purposes. Two views of the complete system are shown in Figures 21 and 22.

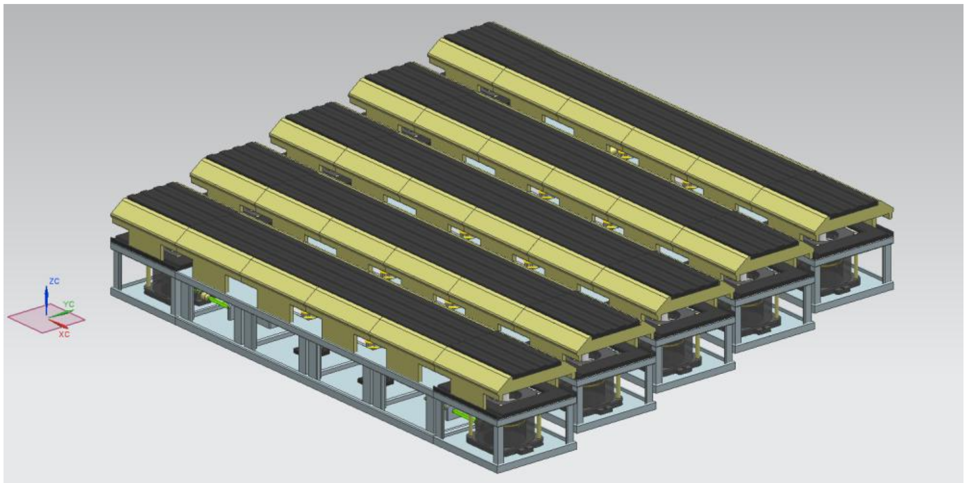

Figure 21. Completed Speed Hump Hydraulic System

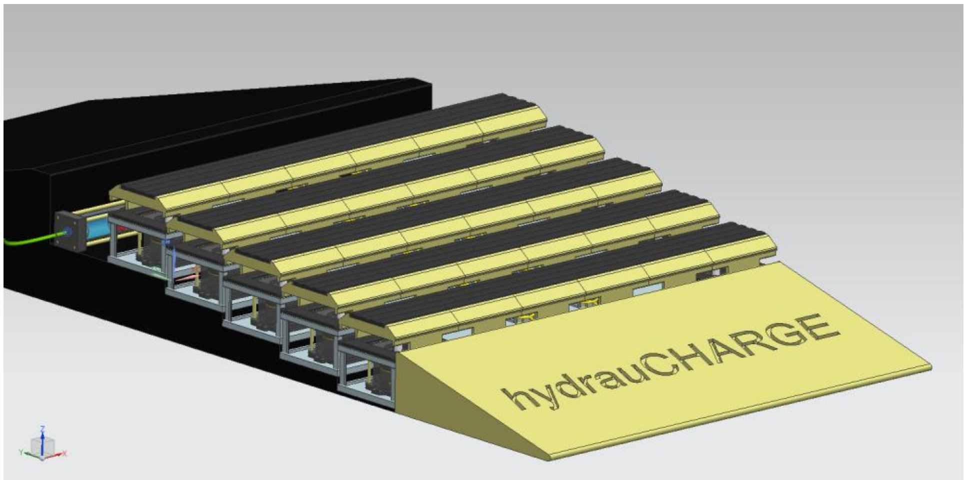

Figure 22. Completed Speed Hump with Ramping Mechanisms

ANALYSIS

The precharged pressure was calculated to be 40 psi according to Figure 23 and Table 1. Important assumptions that should be noted are the frictional force between the piston and the housing is negligible.

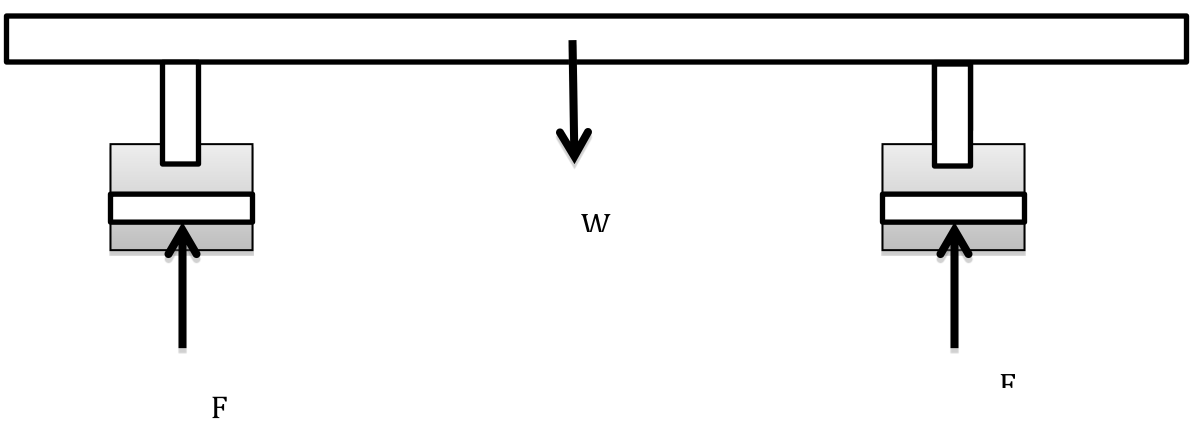

Figure 23. Static Forces on the platform and piston.

Table 1. Static values for the platform and pistons

Volume of beam	0.0929 m^3
Force (weight)	6999 N
F per piston	3499 N
Area of Piston	0.0126 m^2
Precharged Pressure	40.3 psi

The maximum stress in the platform was at the outside of the plate that connects the connecting rod to the platform and is 1.35 Kpsi. The yield strength for steel is around 40 Kpsi, so failure will not likely occur in the platform. The force applied to the beam was 12000 N.

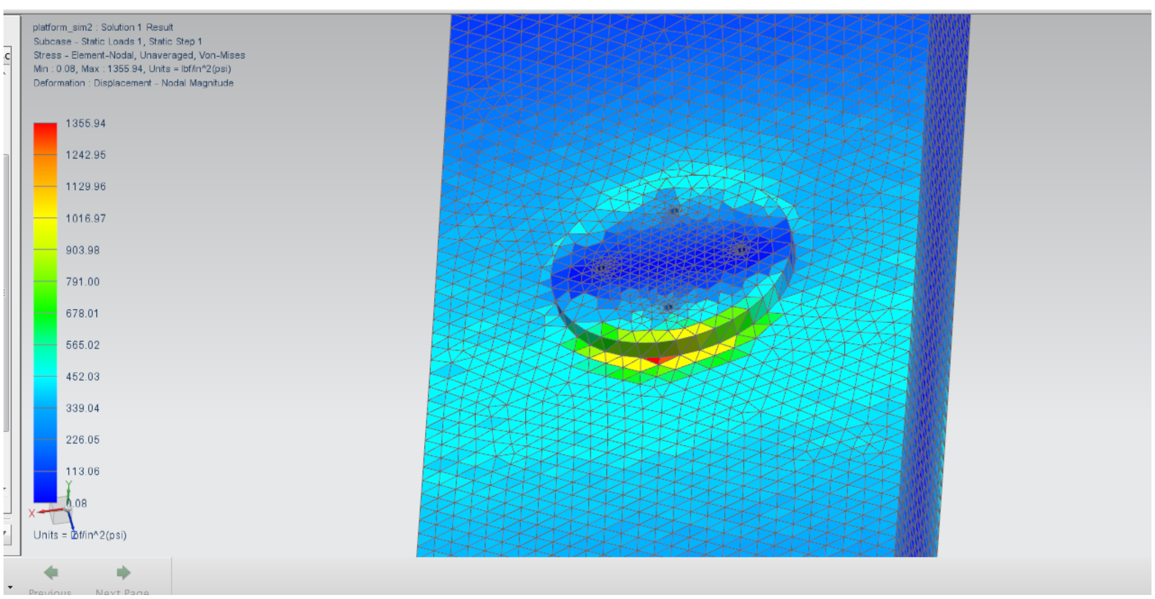

Figure 24. Von-Mises Nodal Stress

FEA on the piston was first calculated using NX 8. Figure 24 shows the nodal displacement of the piston with the force exerted by a car. This model was verified using

$$\begin{bmatrix} f1 \\ f2 \\ f3 \\ f4 \\ f5 \\ f6 \\ f7 \\ f8 \\ f9 \\ f10 \end{bmatrix} = \begin{bmatrix} K1 & -K1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -K1 & K1+K2 & -K2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -K2 & K2+K3 & -K3 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -K3 & K3+K4 & -K4 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -K4 & K4+K5 & -K5 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -K5 & K5+K6 & -K6 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & -K6 & K6+K7 & -K7 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -K7 & K7+K8 & -K8 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & -K8 & K8+K9 & -K9 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -K9 & K9 \end{bmatrix} * \begin{bmatrix} d1 \\ d2 \\ d3 \\ d4 \\ d5 \\ d6 \\ d7 \\ d8 \\ d9 \\ d10 \end{bmatrix}$$

where f_i is the external load applied to that section, K_i is the spring constant of the section and d_i and d_{i+1} are the displacements at the beginning and end of each section respectively.

The maximum displacement was found to be 0.0043 inches in NX. A basic assumption for the boundary conditions of the piston was that the bottom of the piston was a fixed body. If the hydraulic fittings burst, the piston would bottom out causing a fixed boundary inside the piston housing. Since the bottom piston face would no longer have a fluid interface, the stress and displacement can be assumed to be at a maximum under this condition.

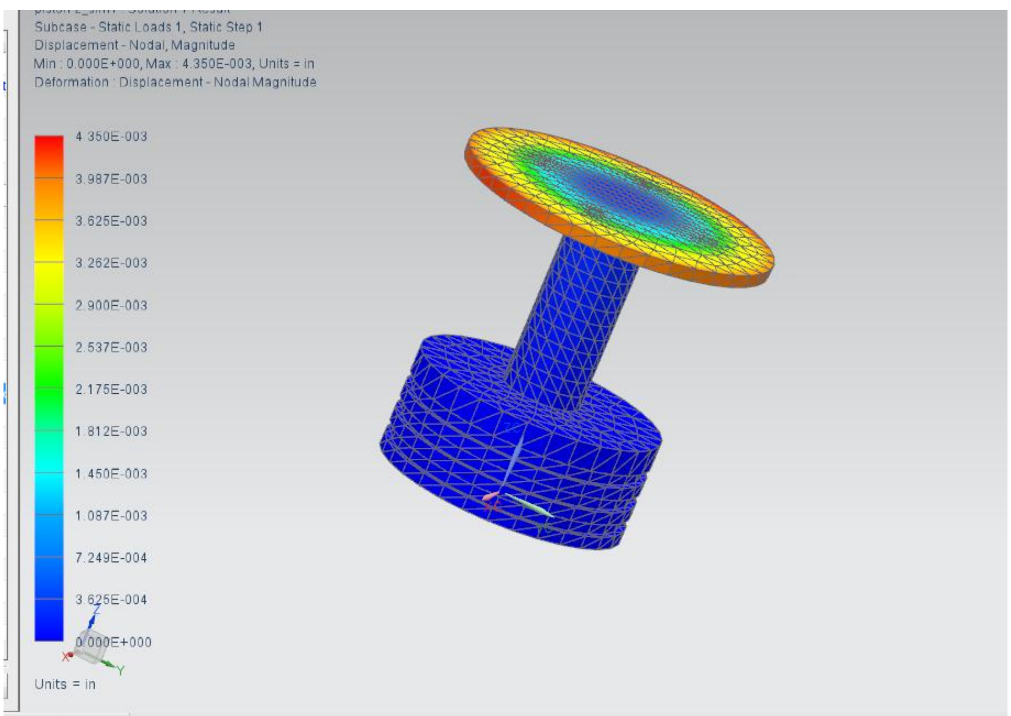

Figure 25. Nodal Displacement of the Piston

The spring constants were calculated using

$$K_i = \frac{A_i * E}{L_i}$$

where A_i is the cross sectional area, E is the Young's modulus, and L_i is the length of the section. Since Steel was used, the first equation can be simplified to:

$$D = K^{-1} * F$$

The stress was then analyzed on the piston. As can be seen in Figure 25, the maximum stress is 15.2 Kpsi. So the part will not yield. However the geometry of the piston is of concern because of fatigue. This is a weak part in the model.

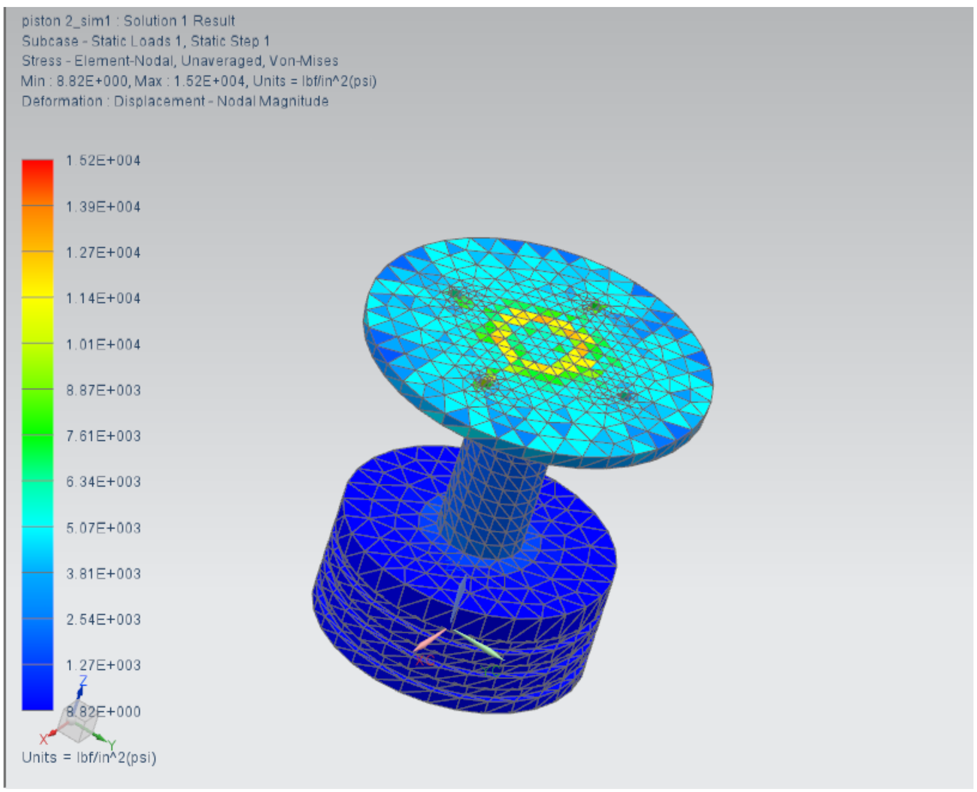

Figure 26. Von-Mises Stress on the piston

The pressure loss was negligible in the first flow analysis of the pipe that connects the piston to the hydraulic accumulator. The stress is not a large concern in the failure analysis for the model. However, leaks in fittings are a problematic area. The Reynolds number was calculated to be 534 using

$$Re = \frac{VD}{\nu}$$

where *V* is the velocity, *D* is the diameter, and ν is the kinematic viscosity. This shows that the flow is laminar. Also the hydraulic fluid is assumed to be incompressible. And the friction factor for the pipe was calculated to be 0.12 using

$$f = \frac{64}{Re}$$

The pressure drop across the pipe that connects the piston to the hydraulic accumulator can be seen in Figure 26 with the indicated friction factor. This model is very closely related to the first flow model.

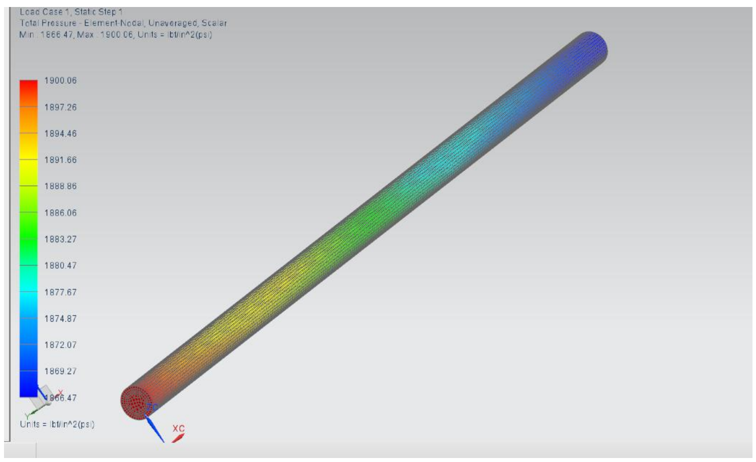

Figure 27. Pressure drop across pipe connecting the hydraulic piston an accumulator

Figure 27 shows the velocity streamlines in the pipe connecting the hydraulic piston and accumulator. The maximum velocity is located in the centered because of the boundary layer assumption. The fluid is not fully developed through the entire tube. The length to achieve a fully developed flow profile is .32 m and the length of the tube is .54 m as

$$0.06ReD = l_{FD}$$

where D is the diameter of the pipe. The flow becomes fully developed before it enters the hydraulic accumulator.

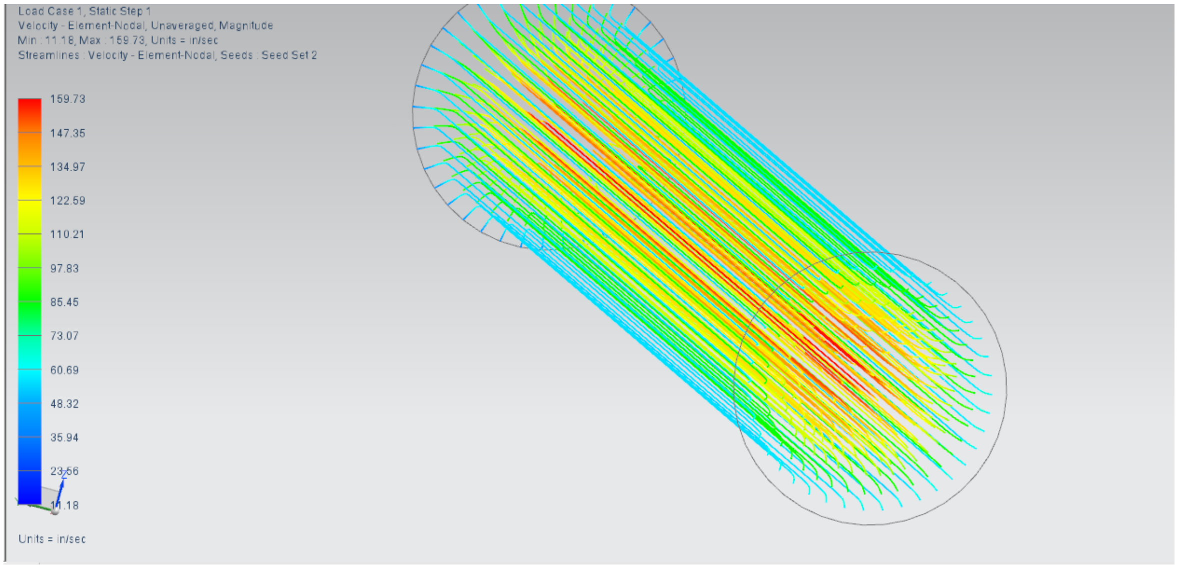

Figure 28. Streamline Velocities across pipe connecting the hydraulic piston an accumulator

Figure 28 shows a simple pressure convergence given the input force on the hydraulic cylinder and the diameters inside of the cylinder. The pressure from the graph is estimated to be about 1885 psi. Again this model is an ideal model with the same parameters as described above using the quick convergence may imply an accurate model.

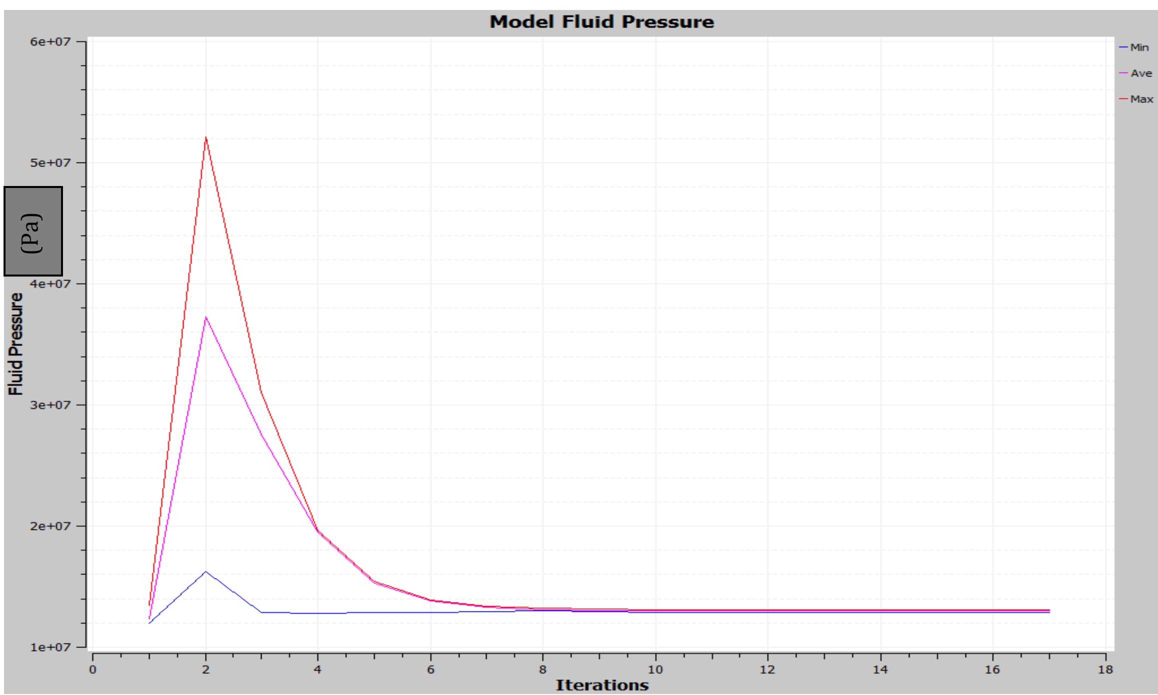

Figure 29. Fluid pressure convergence for the hydraulic pipe

An analysis was performed on the hydraulic side of the system using Simulink. The goal for the Simulink model was to show the ideal pressure values under different conditions. The reason for this was to manipulate different geometrical values and observe the flow rate, pressure change, and verify the piston displacement was correct. The constant head tank was put in the model in order to calculate the volumetric flow rate. This model assumes the hydraulic fluid is incompressible and there are minor losses from the pipe. These kinds of losses would be due to the friction factor. The model at one point did include a 90 degree pipe bends, but the pressure loss was negligible. The pressure calculated by the Simulink model was verified by hand in order to confirm the results. The hydraulic Simulink Model is shown in Figure 30. The Simulink was a helpful tool because initial conditions could be easily verified between the models. For instance the check valve component was replaced with a tube and the pressure change was measured across the pipe to be about 60 psi.

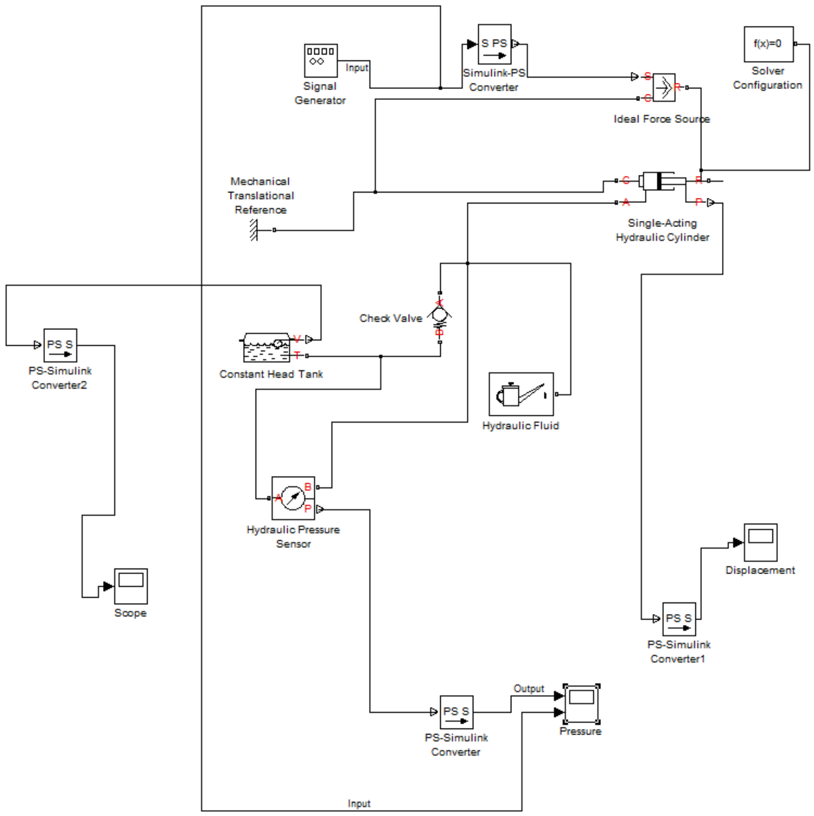

Figure 30. Simulink Model for the Hydraulic side of the System

The pneumatic Simulink model is shown in Figure 31. The pneumatic Simulink model was not able to converge to a reliable solution for the electricity generated in the system. However, the model helps conclude the cause for this may be a large amount of heat transfer that occurs in the system.

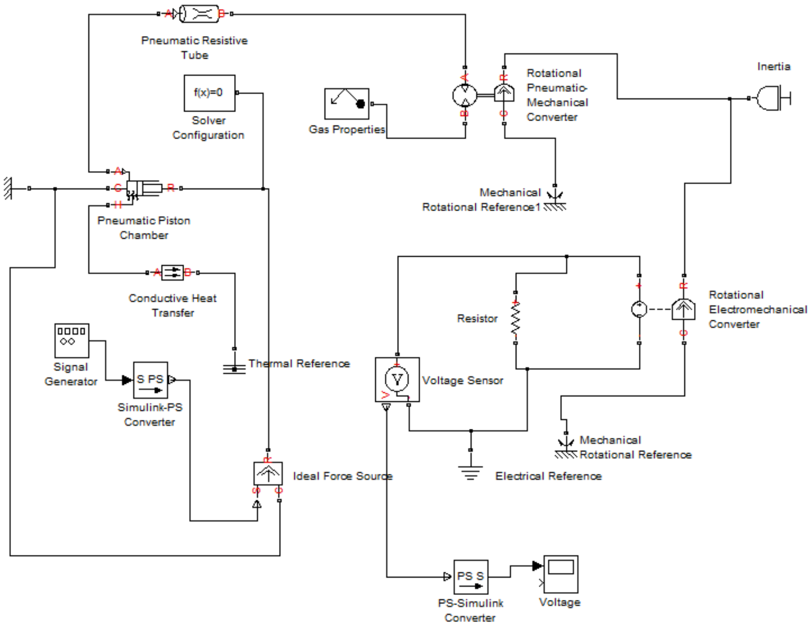

Figure 31. Pneumatic side of the Simulink model

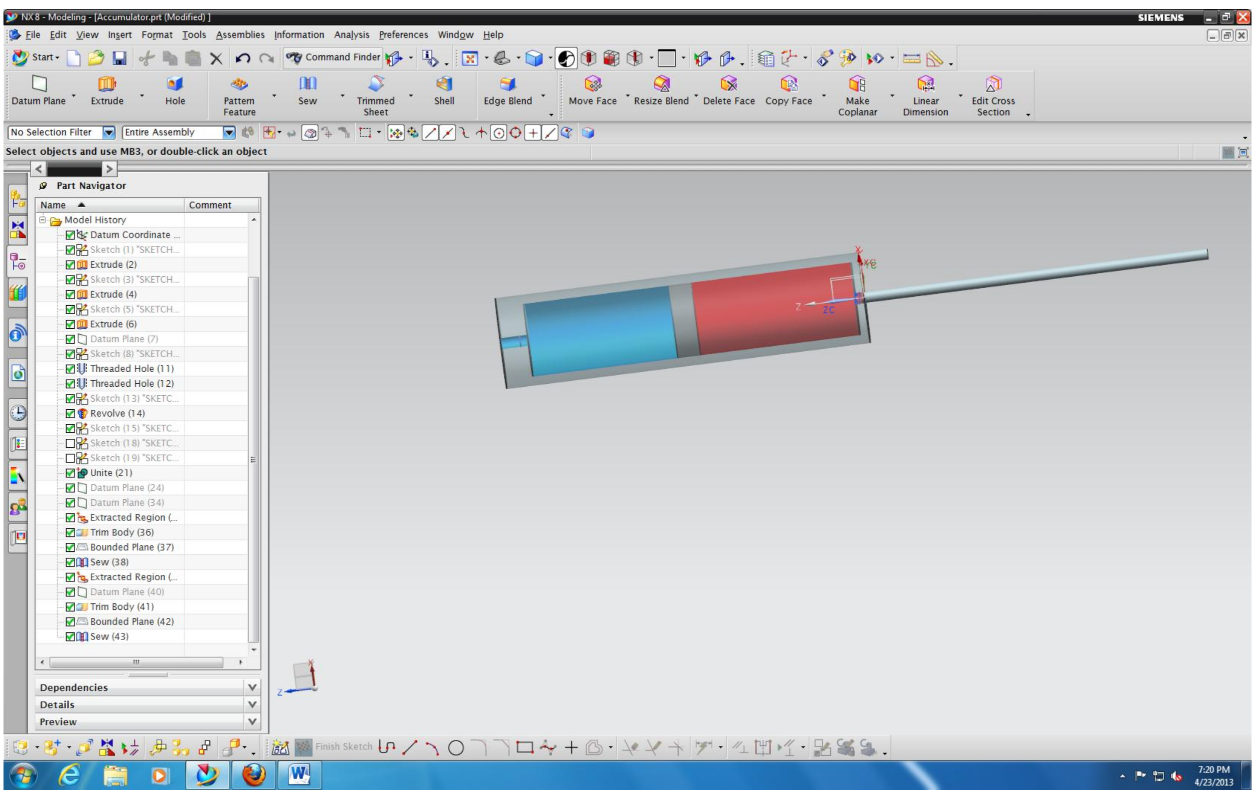

Figure 32. Modeling Process for the Hydraulic Cylinder

The separate fluid domains were constructed using extracted region, trim body, bounded plane, and sewn.

Figure 33. Pneumatic fan

CONCLUSION

In conclusion, speed humps currently used on streets today just waste energy in causing vehicles to slow down. This proposed system capitalizes on this decrease in kinetic energy by transferring some of this energy into usable energy. This project focuses on converting the everyday speed hump into an energy harnessing speed hump, capable of using the force exerted by a vehicle passing over the speed hump to generate electricity. This project was chosen to create an alternative way of harnessing clean sustainable energy from an otherwise unnoticed device currently deployed in modern day roadways. The energy gathered from the device can be used in various applications including outdoor lighting and tollbooths.