Work in Progress - Pickup Truck Work Station

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Abstract - **The objective of this capstone project was to design an inexpensive, automated pickup truck work station. The final product would provide workers with a mobile workspace that increases safety and efficiency. The truck bed holds two workbench toolboxes which extend the entire length of the truck bed. A mechanical linkage enables the two workbenches to move from within the truck bed to the outer sides of the truck. The mechanism is driven by a motor powered by the truck battery. The system only requires the user to operate the control that deploys the workbenches over the sides of the truck and make minimal adjustments to the benches so they are level. This provides a stable and efficient workspace that can be set up in minutes. When the workbenches are not deployed they reside securely in the truck bed for safe transportation. The device takes up minimal space inside the truck bed to allow for some functionality of the original bed space. Minimal modifications to the truck allow for mass production and effective marketability.**

Index Terms - Dynamic force analysis, finite element analysis, power loss, power transmission system

INTRODUCTION

Finding work space while out in the field can be difficult for landscapers and carpenters. Without having a work area supplied, it can be hard to complete the necessary tasks to get the job done. By transforming a pickup truck into a personal work station, that work area will go with the job, wherever it is. Contractors, carpenters, and landscapers would have the advantage of working comfortably at any job site by using the system. Jobs will be completed more quickly, more efficiently, and accurately, giving the company the opportunity to accomplish more in a workday and make a greater profit. The main benefit of this system will be the ability to finish jobs more quickly. A crew of people will have capability of working on different projects individually in their own areas. Time will be saved by having a flat, comfortable work station, and projects could also be completed with more accuracy. Improving the efficiency at a worksite is a major motivation of this project. However, safety and efficiency are two factors that are often critical to the success of a project. Usually when safety is increased, the project seems to lack efficiency, while the objective of this senior capstone project is to increase both safety and efficiency by developing an automated truck bed work station.

Currently there are no solutions to enable toolboxes to double as workbenches. Tailgates are usually used as workbenches when working in the field. This is very inconvenient and provides a limited workspace. While there are no solutions to this problem on the market, research has uncovered many different patents that try to satisfy the problem[1],[2]. The only toolboxes that double as workbenches are found as filed patents and are not manufactured. These patents describe systems that only fold out of the rear of the truck. They do not provide any added workspace because they just replace the tailgate. All of the systems employ the use of human power to deploy the work station. This results in a severe limitation for these systems because only a small amount of tools could be stored or else the user could not operate the apparatus. The only criterion that these systems satisfy would be that they provide better access to a limited number of tools.

SYSTEM SPECIFICATIONS

The system will turn a pickup truck into a full work station. The back of the bed will hold two workbench toolboxes which will extend the entire length of the truck bed. The toolboxes will be divided into three sections for easy tool access and organization. When the workbenches are not deployed they will sit securely in the truck bed for safe transportation. The workbenches will each be equipped with two 120 volt electrical outlets. The outlets will be optional and powered by a generator. This will allow the use of power tools at the workbenches. Each workbench will be able to automatically deploy over the side of the truck bed and be stable at a height of about three and a half feet from ground level. The truck battery will be able to power the motor that drives the workbenches outside of the truck bed. When the benches are deployed outside of the truck they will provide a stable workspace. The system will be able to move a maximum of 250 pounds of tools safely. Due to the many differing styles of pickup trucks the design must be able to work in all the different styles of trucks with minimal modification to the design. When the truck bed needs to be utilized for space the system will be able to be removed easily.

SYSTEM DESIGN

Three viable designs were created to satisfy the system specifications that were set forth. The three designs differed only in the linkage system that moves the system. The first design utilized a four bar linkage system with a spring loaded slider. This design deployed the toolboxes over the adjacent sides of the truck bed. The second design deployed the toolboxes over the opposite sides of the truck bed, which was done to reduce the extreme angles the toolboxes would have to travel. The design utilized a six bar linkage system. The third and final design was chosen based on the criteria of cost, size, and ease of manufacturability. The final design utilizes a four bar linkage system that is driven by a gear motor. In this design the toolboxes are raised above the floor of the truck bed by three steel brackets which lessen the vertical distance the toolbox has to travel and raises them above the wheel wells. Attached to the gear motor is a shaft that has a sprocket on it. The sprocket on the shaft is attached to a sprocket on a shaft that runs the length of the truck bed and is connected to the driving links of the mechanism located on both ends of the toolboxes. A chain connects the sprocket on the driving shaft of the motor to the sprocket on the driving shaft of the links. The user decides which direction the motor rotates through the use of a controller. When the motor turns to deploy the toolboxes the links are driven and the toolbox raises to the top of the side of the bed and rests there securely. The user can then fold out the workbench from this position. The side of the workbench is padded and rests against the side of the truck. When the user is finished the workbench can be folded back to its original position and the switch can be flipped in the opposite direction and the toolboxes will go back into the truck. They will reside there securely for transport and safe from the weather.

DESIGN PROCESS AND VALIDATION

The validation included but was not limited to the construction of a prototype. When going through the design process the same procedures were completed for a full scale design and for a third scale design. After all validations were completed the prototype was constructed. If a test of the prototype at a scaled maximum weight was successful it was assumed that a full scale design could be manufactured. The following subsections outline the design process and the validation checks that have been completed.

I. Linkage Design

The linkage was designed using a three-position synthesis with specified fixed pivots [3]. This type of analysis allowed for the ground points to be specified, as well as the three positions of the moving link. The synthesis was done graphically through the use of Pro Engineer. The process involved linkage inversion. Linkage inversion is used to find the required moving pivots that correspond with the chosen fixed pivots and three desired coupler positions [3]. The lengths of the links were determined from this synthesis and from there a computer animation was created in Pro Engineer to check the clearances and range of motion of the linkage system. The computer model used a three dimensional drawing of the truck, toolboxes, and the linkage system. The linkage was then set into motion and from the animation the toolboxes had no clearance issues and followed the path that was set.

II. Dynamic Force Analysis

After the linkage was designed it was necessary to determine the forces present at each linkage point. In order to perform the dynamic force analysis the link lengths, positions, locations of the center of gravity of the links, the linear accelerations of the centers of gravity, and link accelerations and velocities must be determined through a kinematic analysis. The position vectors could be determined from the Pro Engineer drawing of the linkage system. Once the position vectors are determined they can be plugged into the matrix shown below, which will be called matrix A (1).

$$\begin{bmatrix} 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ -R_{12y} & R_{12x} & -R_{32y} & R_{32x} & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & -1 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & R_{23y} & -R_{23x} & -R_{43y} & R_{43x} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -1 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & -1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & R_{34y} & -R_{34x} & -R_{14y} & R_{14x} & 0 \end{bmatrix} \quad (1)$$

The position vector matrix is then multiplied by the force matrix shown below, which will be called matrix B.

$$\begin{matrix} F_{12x} \\ F_{12y} \\ F_{32x} \\ F_{32y} \\ F_{43x} \\ F_{43y} \\ F_{14x} \\ F_{14y} \\ T_{12} \end{matrix} \quad (2)$$

These two matrices when multiplied can be set equal to the following matrix, which will be called matrix C.

$$\begin{matrix} m_2 a_{G2x} \\ m_2 a_{G2y} \\ I_{G2}\alpha_2 \\ m_3 a_{G3x} - F_{Px} \\ m_3 a_{G3y} - F_{Py} \\ I_{G3}R_{Px} - R_{Px}F_{Py} + R_{Py}F_{Px} \\ m_4 a_{G4x} \\ m_4 a_{G4y} \\ I_{G4}\alpha_4 - T_4 \end{matrix} \quad (3)$$

In order to solve for the unknown values of the forces in matrix B, matrix A must be inverted and multiplied by matrix C [3].

$$[A]^{-1} \times [C] = [B] \qquad (4)$$

These forces were calculated through the use of a computer program Norton: Design of Machinery. In the program the linkage was modeled the centers of gravity were determined and the weight on the coupler link was input. The program then goes through the necessary calculations to determine the maximum forces at each linkage point. The only inputs that are necessary are the speed of the sprocket and the starting angles of the links which were determined from the drawing of the linkage system in ProEngineer. Figure 1 shows a drawing of the linkage system drawn in ProEngineer.

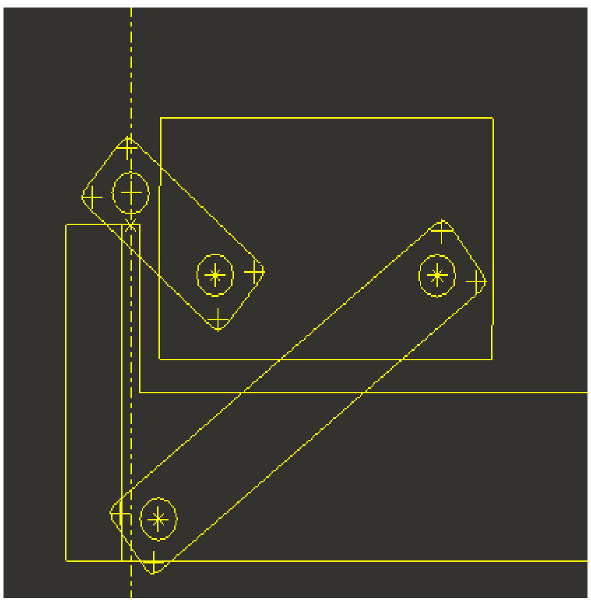

FIGURE 1
DRAWING OF THE LINKAGE SYSTEM

III. Finite Element Analysis (FEA)

Determining the maximum forces on the linkage allowed for the FEA to be conducted using ANSYS Workbench. The FEA would be used to determine the maximum stresses on the links. The width and thickness of the links were varied to find the dimensions necessary to avoid failure of the linkage system. Figure 2 shows the driving link of the system. The driving link is the link that is connected to the shaft and drives the linkage system.

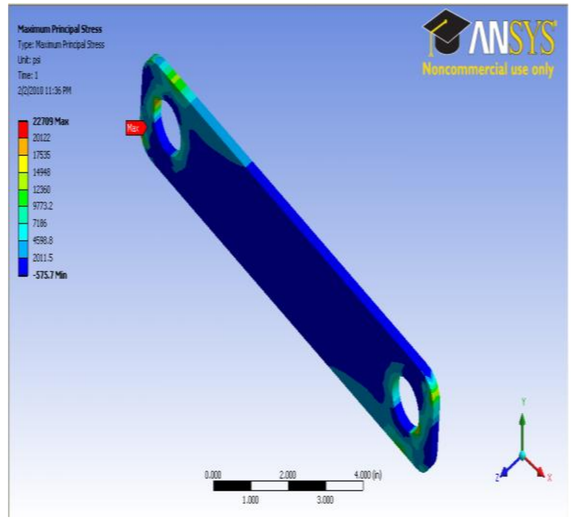

FIGURE 2
FEA OF DRIVING LINK

From the simulation the maximum stress was found to be 22.7 kpsi. The allowable stress for the steel being used was 36 kpsi, so the maximum stress on the link was far below the allowable stress. Figure 3 shows the finite element analysis on the coupler link. The coupler link is the link on the toolbox that remains stationary during the movement of the system.

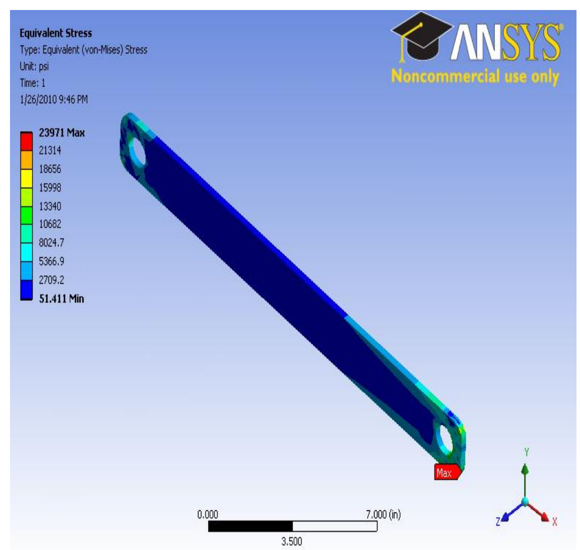

FIGURE 3
FEA OF COUPLER LINK

This analysis calculated the maximum stress to be 24 kpsi which was also far below the allowable stress. Figure 4 shows the analysis on the output link. The output link is the link that stabilizes the system as it moves from point A to point B.

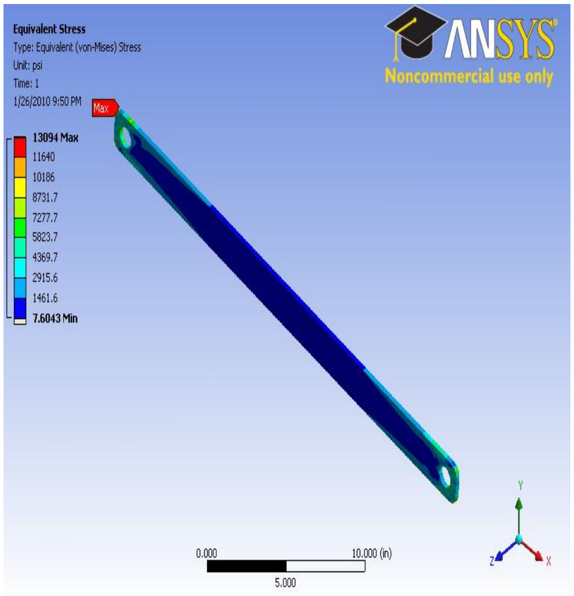

FIGURE 4
FEA OF OUTPUT LINK

This analysis showed the maximum stress to be at 13.1 kpsi, so the stress on the output link would be far below the allowable stress. In all three links the maximum stress was found to be on the corner of the link. In order to lower the maximum stress in this area the corners of the links were rounded until a satisfactory stress was calculated.

IV.Motor Requirements

It was determined that the torque required to drive the system would be 4860 inch pounds. This was calculated by multiplying the maximum weight of 250 lbs by a safety factor of two and then multiplying the 500 lbs by the length of the driving link. Equation (5) was the equation used to determine the torque.

$$\tau = r \; x \; F \qquad (5)$$

A truck winch was found to have a motor that would supply the right amount of power for this application. It would also be able to be easily powered by the trucks existing electrical system.

V. Power Transmission System

The design that is currently being worked on uses a shaft that runs the whole length of the bed connected to the driving links on each end of the toolbox. A sprocket is attached to the shaft and a chain runs from that sprocket to a sprocket on the driving shaft of the motor. Analysis has been done on the shaft to determine the thickness needed to keep it from twisting too much. The thickness of the shaft was determined to be ¾ inch in diameter. Analysis has also been completed on the chain and sprocket design. The chain that was selected to drive the mechanism at the required torque without failing, is a number 41 chain. A quick preliminary analysis of the sprockets revealed that the stresses were well within the tolerances of the steel. However, the analysis still needs to be refined.

VI. Scale Model

The final validation technique is the construction of a one third scale prototype. At this time a truck bed and a toolbox have been constructed out of wood. The linkage system has also been made from eighth inch steel plate and has been connected to the toolbox and truck bed. The linkage system can be driven by hand and works smoothly. As soon as the analysis is completed on the shaft and sprockets the motor can be connected and a test of the system at a scaled maximum weight can be conducted.

POTENTIAL PROBLEMS

I. Power Loss

If power is lost while the system is in motion there are currently no safety measures in place to stop the toolbox in its place. The motor itself should provide enough braking force to hold the system in place to keep it from crashing down, but further investigation of this will be done to ensure safety. If it is found that the motor does not have enough braking force a will have to be designed and installed in the system.

Once the braking problem is solved a way of safely getting the system back in place will have to be devised. As of now investigations are being done into a crank handle that will be able to be attached to move the system securely in the truck.

II. Safety Hazards

There are a few potential safety risks that still need to be addressed. The first involves the linkage system being exposed. The amount of weight that will be driven creates a substantial force on the linkage system and if an operator or unsuspecting person was to get their finger caught in between they could lose it. As of now the only safety precaution is that the remote controller must be depressed for the motor to operate. Therefore if it is not depressed it will stop immediately and can be reversed quickly. However, the investigation of the braking system, mentioned earlier, is crucial for this to work properly. If the system comes crashing down it could cause damage to the truck or hurt the operator.

The other safety risk involves the chain and sprocket system being exposed. The same safety risks are present here as with the linkage. The chain and sprocket could be very dangerous to the operator and others around should something get caught in it.

Currently we are looking into a way to house the linkage and the chain and sprocket system to eliminate these hazards.

III. Shaft Twisting

The driving system currently uses a shaft which runs the entire length of the truck bed. The large torques that will be on the shaft could cause it to twist. If the shaft was to twist drastically it would throw the sprockets out of alignment. This would cause the motion of the linkage to be different on each side and cause the whole system to bind up. If the shaft was to twist enough to shear it would render the whole system useless. We have done the necessary analysis using FEA and ANSYS workbench and determined that the shaft should not twist a significant amount.

IV. Overloading

As of now the system is being designed under the assumption that the toolbox will not be overloaded on one side. In other words the mass of the toolbox is evenly distributed. It is foreseeable that in practical application this may not be the case. If the toolbox is overloaded on one side it could potentially cause a multitude of problems. One side of the linkage would be under greater stress and could possibly fail. One side of the linkage could move slower and cause the system to bind up. The shaft may have a higher potential of twisting. The chain could be placed under a higher stress and break. All of these problems could result in the system not working or worse injury to the user.

CONCLUSIONS

In conclusion, the project is well under way and major problems have been identified. The final design has been determined and the driving system has been analyzed. The addition of the driving system was the last step in the completion of our prototype. The proper steps are being taken to solve all of the problems with the current system. The project is on track to be completed by the conference on March 26, 2010. However, many of the issues are still unresolved. The weeks following the conference will be used for further testing and analysis and finding solutions to the aforementioned problems.

ACKNOWLEDGMENTS

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REFERENCES

[1] Patent number 5823595

[2] Patent number 5169202

[3]. Norton, R, L, "*Design of Machinery*", Fourth edition, 2008