Cableless Dredge Design

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Problem Introduction

Allied Engineering has been assigned the task of redesigning the propulsion system for a mid-sized dredge manufactured by VMI Dredges, Cushing, OK. Currently a majority of their dredges are propelled using a cable stretched across the body of water in which the dredge is working. The cable is attached at opposite ends of the water body to anchors staked in the ground. Heavy trucks or tractors are typically used for these anchors. The dredge pulls itself back and forth using a hydraulic motor attached to the cable. The hydraulic drive provides an infinite variation of forward and reverse speeds, easily adjustable by valve positioning. While quite operable in forward and reverse, the dredge is limited in lateral movement due to the semi-permanent affixation of the cable anchors.

A considerable amount of time is spent moving the cable anchors, often over one hour per move. In addition to the inefficient use of time, the practice of using vehicles as anchors obviously ties up expensive equipment that are more useful for their intended purpose. A desirable design solution would decrease the overall time spent per job by focusing on improving the current propulsion system. This project involves designing a cableless dredge propulsion system for VMI’s horizontal dredges.
Statement of Work

It is obviously too large an undertaking for one senior design team to build a full scale working dredge in one year. The finances, time and space would not be feasible to build a full size dredge. Because of this limitation, the scope of the project has been constrained to building scale models of probable final designs. This will present some difficulties such as finding the properly scaled components. However, scaled models will allow development and testing of the most feasible designs under simulated conditions. Upon VMI’s approval, scaled models are the plan of action.

The use of hydraulic controls is desired by VMI’s customers. Hydraulic controls have been the standard for many years in the dredging industry. However, the use of electric controls is growing and VMI looks to move in that direction. This new technology has been met with some customer resistance because of the new expertise required for working on the systems. Instituting an electrical control system would require experienced operators to become accustomed to a different type of control system and would also force operators to learn how to perform repairs on the new machinery. Most dredge operators perform their own repair and maintenance. This is especially important since VMI ships their products worldwide and paying travel expenses for a VMI technician would be prohibitive.

When instituting new technology, such as electric controls, it is important to make it as user friendly as possible to minimize the learning curve. VMI has already made the first step towards this goal because their newest machines do have electronics on the hydraulic pumps.

One important design consideration is the location of use. Current VMI dredges are designed for use in marinas, small lakes, rivers and lagoons. Each location presents unique difficulties. Lagoons present a special design problem because of the consistency and density of the sludge. This sludge is very different from sediment and other dredged materials. Also, cable systems in marinas are difficult to implement due to the fact that boats are located in the
water. In this case, cable systems are possible but may require underwater anchors. This variety of uses presents an important limitation for the design.

Another limitation brought to our attention by a working dredge’s crew is the unavoidable need of the discharge pipe leading from the dredge to the deposit site. While it may be possible to eliminate the need for cable, this pipe will always be necessary for dredges of this scope. This pipe is a very important part of the system and typically requires its own trailer for transportation.

Propulsion driving force is perhaps the most important design constraint. Depending on the material on the bottom of the water body, it may be hard to support and propel tracks or star wheels. The dredge needs a sturdy propulsion system because of the stability needed for the pump and cutterhead.

![Conceptual Design of Dredge Propulsion](image)

**Figure 2: Conceptual Design of Dredge Propulsion**

Placement of the propulsion device will greatly determine the design of the overall system. Keeping with VMI’s current design, the cutter head will be located at the bow or front of the vessel. This creates a cleared channel or path behind the cutter head. The pathway could provide the propulsion system direct contact to the water body’s floor eliminating the need to drive through the undisturbed material. This concept would only be feasible if the style of dredging was like that of Figure 2.
For this scenario, the propulsion unit will be located within the range of the cutter head. The other configuration would be to place the unit on the sides of the dredging vessel outside the range of the cutter head. This setup would require driving through the undisturbed material. This would pose a rolling resistance on the driving mechanism which would require either a larger driving force or a larger footprint such as wider tires.

There needs to be minimal design changes to the actual dredging equipment. Changing only the propulsion system will make it easier for VMI to implement our recommended design into their existing one. It will also be easier for them to fabricate without a number of major design changes. Also, the design must be realistic for their budget. If they choose to implement Allied Design’s recommendations, the cost of the design must be feasible for them to fabricate. In any final recommendation, it is important to remember VMI’s manpower resources and shop size.

One main caveat deals with a specific use of dredges. As mentioned above, many of VMI’s dredges are used in lagoons. Lagoons of this sort typically have either rubber liners or concrete bottoms. With any sort of propulsion system that touches the bottom, there is concern of the liner tearing. The tearing of the liner should be avoided at all costs. This phenomenon may force the exclusion of lined lagoons from the proposed design.

**Patent Search Information**

There are many different designs for dredge propulsion. Patents have already been issued to several novel ideas. While this is somewhat unfortunate, this does give Allied Design a starting point. For abstracts and images of the listed patents, see Appendix A.

U.S. Patent # 5,782,660 (filed on July 21, 1998) incorporates the star wheel design. This patent has a large star wheel connected to the end of a boom. One of Allied Design’s concerns regarding this design is its stability. It is not apparent that there are any stability considerations made in the design to allow the two drive wheels to move independently of each other. This poses a concern that inconsistencies of the pond floor may cause the dredger to tip.
Secondly, several patents have been issued that implement a track system. Patent # 4,713,896 (Dec. 22, 1987) uses a track system that is raised and lowered by a scissor jack application. Patent # 6,755,701 (June 29, 2004) has a track system that is attached to a boom that will raise and lower like an arm. The most promising design is included in Patent # 5,970,634 (Oct. 26, 1999). This patent has two hydraulic cylinders attached to the track system that will keep the dredge level on the surface. This allows the track system to follow the contour of the bottom more naturally thus reducing the risk of tipping. Each of these patents has a desirable component to the final design.

Several patents VMI referred to Allied Design are patent numbers 4,676,052 (granted June 30, 1987) and 3,755,932 (granted September 4, 1973). The former implements a paddle wheel propulsion system much like a paddle wheel river boat. This self propelled dredge incorporates a floating hull with a pair of independently controlled paddle wheels in the rear. In the second patent, number 3,755,932, the dredge is suspended by retractable legs. Large wheels are attached at the bottom of the legs for propulsion on top of the dredged material.

**Engineering Specifications**

Some specifications for VMI’s current dredges can be founding Appendix B. This information was taken from VMI’s website, [www.vmi-dredges.com](http://www.vmi-dredges.com). Eventually, a drive system and various building materials will be specified for the design prototype. The model will be 1’ x 3’, approximately one-tenth scale.

**Testing**

Two major tests were performed to discern properties of several dredged materials. First, viscosity testing was executed to establish properties of dredged material in a liquid stated or in a disturbed saturated state. Secondly, soil shear testing was performed to understand properties of dredged material under compaction. Several materials were tested including fly ash, river sand, swine lagoon sludge, lake sediment, marsh sediment, a Teller soil, and crystalline
silica. The river sand was taken from the North Canadian River, the Teller soil is a soil native to Oklahoma, and the crystalline silica is a fine powder used in pool filters. A wide variety of materials were tested to obtain a range of data.

According to Stroshine, when a semisolid is subjected to a constant shearing force, it deforms continuously at a velocity that increases as the applied shearing force increases. Viscosity is used to quantify the resistance of the fluid to flow. According to Wikipedia.com, Newton’s theory states that the “thicker” the fluid, the greater its resistance to shear stress. This shear stress resistance is a resistance of the fluid’s movement. This provides a resultant force equal and opposite to the direction of fluid motion. This resultant force can be harnessed for the propulsion on the auger and cage wheel design. The viscosity testing was done with a Brookfield viscometer in the Food and Agricultural Products Center. The tests were completed with Dr. Dani Bellmer’s help. Results are shown in Figure 3. It can be concluded from the tests that as the speed of mixing increases, the material gets increasingly easier to stir.

![Disturbed Viscosity’s of Dredged Materials](image)

**Figure 3: Viscosity Testing**

The shear testing was performed in Dr. Glenn Brown’s groundwater laboratory. Again, according to Wikipedia.com, the definition of shear stress is a stress state where the shape of a material tends to change without particular volume change. The term change refers to sliding forces and directional shear. In
a laboratory setting, as is the case here, shear stress is achieved by torsion of a material. Direct shear of a material by a moment induces shear stress, along with tensile and compressive stress. Several sediment and sludge samples were tested under saturated conditions. Calculations were performed to determine stress and strain curves using the equations below.

\[
\text{Strain} = \frac{\Delta L}{L}
\]

\[
\text{Stress} = \frac{P}{A}
\]

The change in length was read from the testing equipment. The original length was the diameter of the core sample. In the stress equation, \( P \) represents the force applied. This was read from a dial on the machine and then converted using the machine’s calibration equations. The area was the cross sectional area of the sample. A normal force of 10kg was used to simulate 10ft of settlement plus 1ft of water head. The graphical results can be seen in Figure 4. The results of Figure 4 indicate that our design must be designed for a maximum stress of approximately \( 0.35\text{N/cm}^2 \). This figure provides a force per area that is required for the propulsion system to propel the cutterhead through the wall of undisturbed material.

![Stress vs. Strain Curves for Dredged Material](image)

**Figure 4: Stress Strain Curves**
Definition of Customer Requirements

VMI has left many of the design decisions to the group. This allows great flexibility in Allied Design’s research and testing. However, the one major design requirement is that the system be cableless. This is, in fact the purpose of the entire project.

Another VMI request included the use of hydraulic controls. As mentioned above, hydraulic controls are currently the standard in the dredging industry. While this may change in the future, hydraulic and not electric controls will be implemented in the design recommendation. It is also important that existing dredges could be retrofitted to work with the cableless design. Lastly, Allied Design has identified that the design should not be overly complex. This is so that design will be relatively easy to fabricate and will be easily serviceable.

Design Concepts

Three major concepts have been identified as possible solutions. They include a track system, a paddle wheel system and, at VMI’s recommendation, an auger system.

The track system can be seen in Figure 5. Much like a tank, this option would have tracks to maneuver through the sediment. These tracks would be rubber and would connect to the dredge with a hydraulically controlled boom. This would enable the dredge to be on the water surface while the tracks move along the bottom of the water body. A problem arises if the bottom of the water body is not solid. In this scenario, the entire dredge would sink when the boom has reached full extension. Therefore, the dredge must be sufficiently buoyant to support its weight as well as the weight of the tracks.
The paddle/cage wheel design is similar to rice harvesters and can be seen in Figure 6. A potential design uses large tires with an attached cage wheel. These wheels are attached to the dredge similarly to the track system with a hydraulic boom. This attached cage wheel would provide additional traction by pushing the sediment simulating a paddle wheel. The vanes on the cage wheel provide additional propulsion.

This extra propulsion is proportional to the density of the sediment. As mentioned earlier in the testing section, the denser the fluid, the greater its resistance to shear stress. The resultant force can be harnessed for the propulsion on the cage wheel design. This design has been used on rice farming equipment. Because of the saturated conditions of rice paddies, this extra traction and propulsion is necessary. The extra traction provided by the cage wheel could provide sufficient driving force to operate a dredge. Like the track system, the sinking of the dredge may be an issue. With a cage wheel design, the weight of the dredge would be spread over a smaller surface area than the track system which may cause the problem of sinking to be exacerbated. In this case, additional power or larger tires would be needed.
Figure 6: Paddle wheel/cage wheel system

The auger system can be seen in Figure 7 and would also use the sediment at the bottom of the body. The screw augers would be lowered to the bottom of the body and rotate through the sediment. This rotation would provide the propulsion for the dredge. This system would provide a great amount of forward force because of the high torque capabilities associated with augers. Top speed for this design would be relatively slow. However, stability may be an issue with this system. If the bottom of the water body were sloped perpendicular to the direction of travel, the augers could tend to slide since the traction of the auger flighting is effective only in the direction of travel.

Figure 7: Auger system
Feasibility Evaluation

Several criteria must be considered to determine feasibility. These include cost, maintenance, controllability, and ease of fabrication. Note that until prototypes of the designs are built in the spring, these criteria cannot be fully identified and evaluated.

The cost of the various solutions will be relatively small compared to the cost of a dredge. All design will require a hydraulic boom to raise and lower the dredge. This boom will require a motor and controls. Individual designs each have their own associated costs. For example, the track system will involve purchasing rubber tracks. The cage wheel design will require large agricultural tires, metal for vanes, and a drum for floatation. For the auger design, large screw augers will be needed. All these items and other additional necessities will be priced before the final recommendation is made.

All solutions will have to be considered from a maintenance viewpoint. Like existing dredges, this is a factor that can not be eliminated with any amount of design work. However, Allied Design strives to minimize the maintenance of any recommended design. The hydraulic boom on all the possible designs will have a small level of maintenance to keep it running properly. The track system will require repair on or replacement for the rubber. The cage wheel system will occasionally require new tires as well as mending any bent or broken vanes. The auger system will also require mending of broken or bent flighting. Of the three options, the track system will likely have the highest maintenance costs due to the cost of the rubber tracks. Of course, it is important to keep the dredge clean while not operating in order to minimize undue wear.

As discussed above in the Client Requirement section, serviceability is an important consideration. This, along with operation and controllability, makes up a third important design criteria. These factors fall under the category of usability. Regarding controllability, it is ideal to have each of the propulsion mechanisms operating independently. If this is not feasible, stability issues could arise which in turn decreases the controllability of the dredge. This is a potential problem for all the dredge designs but the augers in particular would be prone to
this type of failure. The similar boom design that is standard on each solution would occasionally need to be serviced either by the contractor or an experienced mechanic. The cage wheel system would be the most easily serviced because the design is least complex.

The various solutions will each require significant fabrication. Obviously, all designs will require fabrication of a hydraulic boom. The track design will require fabrication similar to that of a Caterpillar track system or a tank. Rubber tracks and metal parts will be necessary for this. For the paddle design, cage wheels and vanes will need to be made out of steel. Regarding the auger design, large screw conveyors will need to be bought or made.

**Determination of Designs**

As mentioned earlier in this report, three designs have been chosen for testing. Upon testing, Allied Design anticipates selecting one final design for large scale fabrication. The three potential designs include a track system, a paddle wheel/cage wheel design and an auger design. A model of each will be fabricated and tested under simulated conditions. The final recommendation will be made at the end of the spring semester.

**Project Schedule**

See Attached Appendix C
**Proposed Budget**

The proposed budget is shown in the figure below. The total estimated expense at this time is $1000.

![Figure 8: Proposed Budget](image)

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References


Appendix A: Patent Search Information

See attached.
## Appendix B: VMI Dredge Specifications

### Mini-Dredge Specifications

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Appendix C: Project Schedule
See attached Gantt Chart.