Design of a High Pressure System to Aid Horizontal Directional Drill Bit Steering

Dustin Holden
Curtis Johnson
Brandon Kimbrell
Kristin Stephens

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Hole Mole
The West Central Pump Works, Inc.

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Project Introduction

Horizontal Directional Drilling (HDD) is a technique that provides a means of installing underground utilities without cutting a trench in the soil (i.e. trenchless). Several equipment manufacturers have been successful in designing, manufacturing, and marketing units for this task. HDD equipment typically performs well unless the soil is very hard and dry. A senior design team, The West Central Pump Works, Inc., under the direction of Dr. Paul Weckler, has been challenged with this problem by one of the equipment manufacturers and has been asked to develop a creative solution.

Statement of Work

The Charles Machine Works, Inc. (Perry, OK) is the manufacturer of the high quality Ditch Witch™ product line, which includes: compact utility products, trenchless products, trenchers and plows, vacuum excavation systems, pipe bursting systems, electronic products, and trailers. The Charles Machine Works, Inc. (Ditch Witch) recently came to the Biosystems and Agricultural Engineering (BAE) department with a need to enhance the performance capabilities of one of their trenchless products. Past agreements between the company and department have resulted in positive outcomes, and The West Central Pump Works intends to continue building that relationship.

The West Central Pump Works, Inc. is composed of four Biosystems and Agricultural Engineering Senior students interested in the field of mechanical design. Ditch Witch has come to the team, looking for creative solutions to their design problem.

Figure 1: JT520 (CMW, 2001)

Ditch Witch JT520 units (Figure 1) are used for compact horizontal directional drilling (HDD) tasks. They are ideal for shallow product installations and are commonly used in residential areas. Relative to larger Jet Trac units, the JT520 is a comparatively low powered unit. The problem presented to the team involves complications the unit encounters when steering the drill head through compacted soils.

Current operation of the unit involves a rotating bit (beacon) that is continually lubricated with drilling fluid. When steering of the beacon is required, rotational motion is stopped and the bit is forced (pushed or thrust) through the soil. When it reaches the desired position, rotational motion is resumed. A problem arises when the soil is too solid for the beacon to push through during the steering process. Ditch Witch is requesting a design that solves the need of injecting a high pressure fluid through the drill string for a short period of time to aid in steering the beacon in hard, dry soil conditions. Ultimately, the team will be concerned with producing high pressure down the drill pipe to achieve a high velocity stream of fluid to erode material in the drill path.

While the ultimate design factor controlling the problem solution is a high pressure, high velocity jet of water, other factors play a key role in the design process. The following list describes many of these factors.

- Current Conditions
  - Typically 150 ft of pipe on a machine.
  - Two to five feet typical boring depth.
  - Steering in characteristic soil conditions takes about 15 seconds.
  - An operator will steer approximately 15 times per bore on average.
  - The current mud pump can pump a maximum of 5 GPM.
- Power Supply
  - The power required by the high pressure system determines if an additional power source will be required.
  - The power available by the current unit may constrain the design of the high pressure system.
- Fluid
  - Water is acceptable as the high pressure fluid.
  - Drilling fluid (mud) is also acceptable.
- Model Application
  - The team's design should be specifically applicable to the JT520 model.
  - Although beneficial, it is not necessary that it be applicable to the JT920 or other models.

- Kit
    - One point of interest that will be kept as a high priority is Ditch Witch's desire for the system to be produced as a kit.
    - The team would like to see a package that can be sent to the dealer, who can install it on a current unit with minimal training needed.
- Considerations
    - Fifty gallon tanks are readily available. Other sizes may be considered as options.
    - Any high pressure hoses within three feet of the operator must be shielded.
    - If high pressure hose is used, its strength should be adequate to handle the design pressures so that it does not need to be replaced often.
    - Weight and space limitations on the trailer and unit.
    - An electronic control system, preferably wireless, is required for the implemented design solution.

The team spent most of the fall semester concentrating on concept generation and performing theoretical calculations of design characteristics. The design variable of concern is the exit velocity of the jet of fluid out of the drill string nozzle. However, there currently is no data available. It is known that when the pressure at the nozzle is above 1500 PSI, there tends to be cutting action in the soil. Faster and more penetrating soil erosion occurs with higher pressures. Ditch Witch engineers state that the smallest nozzle that would be used with a high pressure system is a 0.070 in nozzle.

A detailed list of initial design alternatives was presented to the sponsor during the fall semester. After discussing some of these alternatives the team decided to continue an evaluation of the more feasible alternatives. The theoretical calculations were used to determine the most physically and economically reasonable solutions to the design problem. These solutions will be presented to Ditch Witch, who will be prompted to ask questions and discuss issues with the team. Ditch Witch and the team will collaborate to determine which solution will be pursued for the remainder of the design process.

Final adjustments will be made to the overall design and components will be ordered during the spring semester. When all components have arrived, the team will assemble the design and test the final product. A design report and presentation will be given to the sponsor covering the team's recommendation for a final product.

Investigation

The West Central Pump Works, Inc. spent considerable time conducting background research as part of the investigation of the assigned project. This research included a literature review, an extensive US and European patent research, an investigation of competitive companies and products, and an analysis of current solutions to the problem. The team concentrated on subsurface drilling with the use of high pressure fluid to assist in below ground horizontal boring. It is the team's goal to produce a high pressure flow through the system that will in turn, produce a high velocity fluid jet at the nozzle. This high velocity jet will be used to erode away material to aid in steering the drill bit through the bore path.

Background Literature Review

Extensive searching through multiple indexes and databases provided no relative information to the use of high pressure fluid to assist in the steering of horizontal directional drilling machines. However, the fifth edition of Fluid Mechanics by Frank M. White became an important resource for the pressure and fluid flow analysis of the pipe and beacon head. Useful information from this text included the Bernoulli and Reynolds Number equations, coefficients of friction for pipe flow, head loses in pipes and fittings, and the kinetic energy correction factor.

Patent Research

The US Patent and Trademark Office (USPTO, 2006) and the European Patent Office (EPO, 2006) were used for patent research for this design project. A search of the recent US patent applications was conducted and nothing of relevance to the project was found. The search of the European Patent Office produced no results of interest to the project.

Five patents were chosen from the list found in the US Patent and Trademark Office database for further consideration: US4957173, US5054565, US4674579, US4714118, and US4306627. These patents were chosen after the team felt that their relevancy to the project produced the greatest concern. The following descriptions are the team's understanding of the relevant patents researched. Appendix A contains the full patents, including figures.

- US4957173 – Method and Apparatus for Subsoil Drilling

  This patent is for a method and apparatus that creates an underground bore hole using high pressure fluid within a drill string to disturb and displace the subsoil (Kinnan, 1990). Underground Technologies, Inc. has patented a flexible drill head that improves the steering capabilities of the drill string by responding to an increase in fluid pressure through the head. The unique steering capabilities are accomplished by applying different fluid pressures inside the drill string so that the flexible head bends in the desired direction.

  If no steering of the head is necessary, the fluid pressure in the drill string is maintained at a predetermined pressure that is adequate for the cutting fluid nozzles to properly function while the head rotates. When a change in direction is desired, rotation and forward progression are stopped and the orientation of the head is determined. The head is then oriented to steer the drill string in the proper direction. Fluid pressure through the drill string and head is then increased above the predetermined pressure for normal cutting. The degree of movement of the head from the longitudinal axis is directly proportional to the back pressure of the liquid that builds in the piston cavity of the head. The pressure is then dropped to the first predetermined level and the flexible head deflects from its normal position to the direction of desired movement. Normal operating conditions are then resumed to continue the bore.

- US5054565 – Steering Mechanism for a Subsoil Boring Apparatus

  Underground Technologies, Inc. has also patented a percussive device that improves the steering of a boring device that uses a high pressure fluid to disturb and displace the subsoil. They have found that the presence of hard materials or soft spots in the soil may prevent the nose member from moving in the desired direction when normal operation is resumed after steering. To ensure that the nose member, or head, advances in the proper direction, they have also found it advantageous to apply one or more impact strokes to the pipe string before normal operation is resumed (Kinnan, 1991). This design incorporates a percussive device that hammers the drill string forward after the desired steering has taken place. Due to this hammering, the boring head becomes properly seated in the media being bored and will accurately advance when rotation of the drill head resumes.

- US4674579 – Method and Apparatus for Installment of Underground Utilities

  FlowMole Corporation has patented a method and apparatus for installing underground utilities using an offset head fluid jet drilling and reaming apparatus (Geller et al., 1987). Their invention also pertains to the drilling of soft materials with the use of high pressure fluids. At the time this patent was written, no boring methods had been met with widespread commercial adoption.

  FlowMole Corporation claims to have developed an economical method of drilling through unconsolidated material by the use of jet cutting techniques. Electronic devices are utilized to guide the boring tool to form either a hole in a predetermined path or to follow an existing utility line using a source of high pressure fluid. Steering of the bore head involves stopping the rotation of the head and orienting the drill so that the bent tip is pointed in the proper direction. The bore head is then pushed without rotation until it is pointed in the desired direction. During this push, a slight oscillation of the drill can be used to maneuver the tip around rocks and increase the cutting capability. The reported pressure at the drilling unit is 1500-4000 PSI, which is produced by a conventional high pressure pump.

The team feels that this patent is relevant to the goal of the design project. It is recommended that Ditch Witch further evaluate this patent and its relevance if they decide to implement the team's design.

- US4714118 – Technique for Steering and Monitoring the Orientation of a Powered Underground Boring Device

  FlowMole Corporation has also patented an elongated boring device that incorporates a forward facing, off-axis high pressure fluid jet that is rotated about the elongated axis of the device while the device is pushed through the soil. A pressurized fluid that is sufficiently strong to bore through the soil is supplied to the nozzle, which under normal operation, is rotated at a constant speed. When steering is required, the rotational speed of the bit is modulated so that the fluid jet spends more time along a particular segment of its rotation path. The roll angle of the device and the position of its off-axis jet are monitored to control the precise position of the jet relative to its roll position. At the same time, the overall bore head is being urged forward by the drill string. FlowMole Corporation claims they have developed an uncomplicated, yet reliable means for and method of steering and boring.

- US4306627 – Fluid Jet Drilling Nozzle and Method

  Flow Industries, Inc. has patented a nozzle that is to be connected to a source of high pressure fluid and rotated about a rotation axis (Cheung and Veenhuizen, 1981). The nozzle comprises a body formed so that it partially encloses a cavity that is in direct contact with the source of high pressure fluid. The nozzle also allows the high pressure fluid to exit the nozzle as a high velocity fluid jet that intersects the axis of rotation of the nozzle.

They have found that one problem in fluid jet drilling is that fluid jets lose their cutting ability if the jet forming nozzle is too far from the surface being cut. This invention supposedly provides a fluid jet drilling nozzle and a drilling method that will allow a single fluid jet to drill a hole of large enough diameter that the drilling nozzle can enter and be closer to the surface being cut. In this design, an electric motor drives a hydraulic pump, which supplies a comparatively low pressure fluid (e.g. 3000 PSI) to an intensifier. The intensifier draws fluid such as water from a reservoir and discharges the fluid at a high pressure, typically 20000 to 60000 PSI. This high pressure fluid is supplied to a high pressure swivel, where it passes through a rotating, tubular drill stem to the nozzle. The nozzle allows the high pressure fluid to be emitted in the form of a high velocity (e.g. 1200 ft/sec) fluid jet.

Further analysis of the above patents did not bring much concern over patent infringement regarding the team's design. Patent US4674579 is relevant to the goal that the sponsor is trying to achieve, but not necessarily relevant to the team's recommended design. The team recommends that if Ditch Witch desires to implement the team's final design, that it perform a more in-depth patent research.

Current Relevant Products

The following information includes not only Ditch Witch products that will be relevant to the team's design project, but also information on competitive products currently available that are relative to the team's design.

- DitchWitch (CMW, 2001)
    - JT520 – The JT520 HDD (Figure 2) is the target product for the team's design. The JT520 is equipped with 150 ft of drill pipe and an onboard variable flow drilling fluid system that operates in the range of 0 to 5 GPM at 500 PSI and a 26 HP engine. The completely equipped unit weighs approximately 2980 lbs.

Figure 2: JT520 (CMW, 2001)

    - FT5 – The compact FT5 (Figure 3) is the current fluid management system that will accompany a JT520. The FT5 has a total unit length of 84 in and weighs 402 lbs empty and 2071 lbs when loaded with 200 gal of water.

Figure 3: FT5 and T9B (CMW, 2001)

    - T9B – The T9B is the current trailer that accommodates the JT520 and FT5. The bed dimensions are 156 in long and 76 in wide. Load ratings for the trailer are as follows: maximum tongue load of 1650 lbs and maximum load weight rating of 8650 lbs. The empty trailer weighs 2350 lbs.

    - FX60 – The FX60 (Figure 4) is a large vacuum excavation system that uses high pressure water to excavate the ground. The water pump system consists of a pump rated at 5.2 GPM at 3500 PSI and 100 ft of high pressure hose.

Figure 4: FX60 (CMW, 2001)

- Vermeer (VMC, 2004)
    - D6X6 NAVIGATOR – The D6X6 (Figure 5) is a competing HDD unit to the JT520. It has a 25 HP engine and an onboard mud pump that operates at 5 GPM at 500 PSI.

Figure 5: D6x6 NAVIGATOR (VMC, 2004)

    - ST250 – The ST250 is a 250 gal modular drilling fluid system that is used with the D6X6.

    - HP250 – The HP250 is a 250 gal modular high pressure drilling fluid system that is used with HDD units that are not equipped with an onboard mud pump. The system operates at 9.5 GPM at 550 PSI.

    - HP300 – The HP300 (Figure 6) is a 300 gal modular high pressure drilling fluid system that is used with HDD units that are not equipped with an onboard mud pump. The system operates at 18 GPM at 700 PSI.

Figure 6: HP300 (VMC, 2004)

- Astec (Astec, 2005)
    - EarthPro™ Series DD-65 *MiniMax* – The DD-65 *MiniMax* (Figure 7) is another competing HDD unit to the JT520. The DD-65 *MiniMax* has a 26 HP engine and an onboard mud pump that operates at 5 GPM at 650 PSI.

Figure 7: DD-65 MiniMax (Astec, 2005)

- Robbins HDD (Robbins, 2000)
    - Midi HDD – The Midi HDD (Figure 8) is a much larger HDD unit than the JT520, with the smallest model having a 125 HP engine.

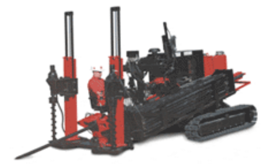

Figure 8: Midi HDD (Robbins, 2000)

- StraightLine (StraightLine, 2004)
    - SL2020 – The SL2020 is a slightly larger HDD unit than the JT520. It has a 99 HP engine and utilizes up to 30 GPM of drilling fluid.

- Kerr Pump (Kerr Pumps, 2006) – Kerr Pumps offers a large line of positive displacement pumps ranging from 2000 to 10000 PSI and 0 to 205.6 GPM.

- FMC Pump (FMC Technologies, 2006) – FMC Pumps are currently being used by Ditch Witch. The positive displacement pumps range in size from 800 to 1500 PSI.

- F.E. Meyers (Meyers, 2002) – F.E. Myers offers a large line of positive displacement pumps ranging up to 5500 PSI and 600 GPM.

Current Solutions

In select areas of the United States the problem of drilling diversion has become more prevalent. Ditch Witch dealers in these areas have attempted solutions in the absence of one provided by the company. These solutions are presented in the following:

- High Pressure Power Washer

  The most elemental solution to the problem is the attachment of a high pressure power washer to the JT520 unit. High pressure power washers (Figure 9) can be purchased at Home Depot and other suppliers, in ranges of 1500 PSI and 1.3 GPM to 3000 PSI and 4.4 GPM. The price of one of these pressure

Figure 9: High Pressure Power Washer (Home Depot, 2006)

washers is around $1000, depending on the size (Home Depot, 2006). To implement this solution, the nozzle is removed from the pressure washer and the outlet hose is attached to the unit to provide the high pressure flow. The team believes that although this attachment can provide a high pressure flow, it is unable to produce a high enough flow rate to substantially contribute a high velocity jet of water out of the JT520 drill bit.

- FX60 Pump Attachment

  A more sophisticated solution came from a California dealer who is implementing a high pressure pump from another Ditch Witch product (FX60) by pumping a high pressure flow from a reservoir to the unit. This pump can provide a maximum flow rate of 5.5 GPM and a maximum pressure of 3500 PSI. A specification sheet on this pump is located in Appendix B. This solution is readily available and economical to dealers, as it is already a Ditch Witch supplied product and no outside supplier for components is needed. Like the pressure washer, it is also very easy for dealers to install this attachment to a unit, with minimal training required.

While operators have found both of these solutions to produce satisfactory results, the team feels that it can develop a much more predictable solution to the problem based on engineering analysis, design testing, and product validation.

Concept Generation and Evaluation

As a team, The West Central Pump Works, Inc. spent time developing a broad variety of design alternative solutions to the problem. These alternatives were presented to Ditch Witch in a format that described each alternative and its advantages and disadvantages. The team then weighed the advantages, disadvantages, and feasibility of the alternatives and selected two alternatives to further evaluate. This selection process was based on preliminary calculations and engineering analysis. The team feels that its decisions were appropriate in response to the information available. The following is a compiled list of the team's envisioned alternatives. More detailed descriptions of each alternative can be found in Appendix C.

- Kit assembly with water pump on the trailer – This concept alternative was chosen as one of the two alternatives for further evaluation. A description of this evaluation is included in a later portion of this report titled HM2500z.
- Kit assembly with water pump on the trailer and beside the JT520 unit
- Enhance the current mud pump on the JT520 unit
- Replace the current mud pump on the JT520 unit
- High pressure water pump installed on the JT520 unit
- Pressure intensifier or crank drive pump
- Accumulator
- Hydraulic cylinder application – This is the second creative alternative deemed worthy of further evaluation. More information is provided in the section titled HM5x20z.

High pressure hose options were also considered and found to be:

- Hydraulic hose
- Oil field hose
- Flexible pipe

Oil field hose and flexible pipe are more costly and less convenient to handle. The team will only consider hydraulic hose for high pressure needs in its final design.

Testing

Initially, the team wished to perform testing during the fall semester to determine characteristics of the drill pipe and a length of hydraulic hose. These tests would provide data that could be used to perform theoretical calculations to determine specifications for the team's design solution. However, after working with the sponsor, it was determined that assuming certain values would provide reasonable results to continue through the design process. It was also determined that, time permitting, testing could be performed early in the spring semester to verify these calculations, if desired by the team and sponsor. The team is also planning on conducting tests on the finished product at the end of the spring semester. Availability of a JT520 unit for most of the spring semester for the team's utilization for finishing the design and testing would be ideal.

Recommended Designs

Analysis of High Pressure System Requirements

Before analyzing the two design alternatives chosen, the team performed a thorough analysis of the current system and its requirements of a high pressure pumping attachment. As mentioned previously, the team utilized the fifth edition of Fluid Mechanics by Frank M. White extensively to perform this analysis. Equations from this resource can be found in Appendix D.

For the analysis, the team was provided a table that showed the correlation between pressure and flow allowable for the nozzle specified for the high pressure system application. The data for a 0.070 in nozzle can be found in Appendix E. These data were plotted against each other in two charts and a trend line was fit to each graph (Appendix E). The equations of the trend lines were later used to verify loss calculations and check correlations in pressure and flow at the nozzle.

Ditch Witch informed the team in the beginning that the system would be required to produce at least 1500 PSI at the nozzle. Setting this as a minimum requirement, the team determined the pressure requirement of the high pressure pumping system. Using the equations of Appendix D and coefficients from the Fluid Mechanics textbook, the team was able to characterize the drill pipe and high pressure hose. This allowed the team to determine the pressure drop through the drill string.

Knowing that 7 GPM pumps were readily available and they could typically produce 2500 PSI, the team determined the pressure drop through the system to provide the required pressure at the pump. Pumps producing 7 GPM were also chosen because they typically require 11 to 12 HP (at 2500 PSI) for operation. This is a very common size for small gasoline engines, which would make finding an engine suitable for the team's application much easier and future manufacturing more economical. Given the conditions entered by the team, the required pressure at the pump was found to be 2470 PSI. The complete analysis can be found in Appendix F. Knowing this required pressure allowed the team to design systems that would provide suitable pressures for the application.

HM5x20z

The first alternative analyzed by the team was the hydraulic cylinder system. This design involves using two hydraulic cylinders, one filled with water and one filled with hydraulic fluid, to pump high pressure water through the system. Knowing the system requirements, the team compiled components that would operate well together to achieve the high pressure pumping goal. Table 1 lists the components of the system and Table 2 shows the operating conditions of the system.

HM5x20z Component List	
Engine	Honda 2.5 HP, 7800 RPM, CCW Rotation (Honda, 2006)
Pump	Sherwood Rubber Impellor Pump, 8 GPM, +3500 RPM (Surplus Center, 2006)
Hose	5/8" X 100' Soft Garden Hose (Lowes, 2006)
Cylinder	2- 5" X 20" w/ 1.5" Rod
Control Valve	4 Way, 3 Position, Tandem Centered
RC	TeleChief TM2000 (Control Chief, 2003)
Tank	Ditch Witch 50 gal

Table 1: HM5x20z Components

HM5x20z Operating Conditions	
Power	**U.S.**
Engine	Honda
Fuel	Gasoline
Flywheel Power	2.5
Maximum Governed Speed	7800 RPM
Pumping System	**U.S.**
Operating Flow Rate	7 GPM
Operating Fluid Pressure	2500 PSI
Supply Power Hose Length	100 ft
Supply Power Hose Rating	60 PSI
Supply Flow Rate	8 GPM
Supply Fluid Pressure	40 PSI
Fluid Capacities	**U.S.**
Water Reservoir	50 gal
Fuel Tank	1.2 qt
Control System	
Solenoid Valve	12 V DC
Wireless Remote	
Hardwired	

Table 2: HM5x20z Operating Conditions

The two hydraulic cylinders would be mounted on the machine and would require fluid power input from the ground drive of the JT520. One cylinder would be supplied water from an impellor pump (Appendix G), supply tank, and engine (Appendix G) on the trailer. A hydraulic schematic of the system is located in Appendix G.

While it is innovative and removes the rotational power supply requirement for the high pressure portion of the system, the design has its significant downfalls. There currently is not sufficient space to place the cylinders on the machine without changing the specifications of the unit. The team feels that not changing the product specifications of the unit should be kept at a very high priority for the sponsor's benefit. It is estimated that adding the cylinders to the unit will add approximately 125 lbs to the overall weight of the unit. It will be up to Ditch Witch to determine if this is significant.

Also held at a top priority was the desire to make the design a kit assembly. The team wanted a customer asking for this product to be able to call a dealer, run by the dealership, within an hour have the kit, and go back to work. This design does not allow that to be possible. A customer desiring this package would have to take their unit to the dealer, leave it, and come back to pick it up in approximately a day. Implementation of this system requires that some of the hydraulic system of the current unit be modified, as well as adding components to the trailer. It would require a substantial amount of time for the dealer to change the hydraulic components of the current unit before they could return the complete package to the customer.

The most significant design disadvantage of this system is the limited operation capabilities of the unit while the high pressure system is operating. While the cylinders are operating during a steering period, a large amount of horsepower is required of the JT520 unit. This leaves little power for other operations, such as thrusting or rotating the bit, during steering. Table 3 shows the team's analysis of the system's power requirements.

Power Evaluation for HM5x20z	Fluid Power (hp)
Available power from the JT520	14.6
Power required by high pressure system	10.2
Power remaining for other operations	4.4

Table 3: Limited Power Available with HM5x20z

HM2500z

The second alternative analyzed by the team involves the implementation of a high pressure water pump as part of a skid-mounted kit installed entirely on the T9B trailer. Table 4 lists the components of the system and Table 5 shows the operating conditions of the system. Figure 10 shows the HM2500z kit mounted on the T9B trailer and Figure 11 shows the kit by itself.

HM2500z Component List	
Engine	Honda 13 HP, 3900 RPM, CCW Rotation (Honda, 2006)
Pump	General Pump TSF2021as, Triplex, 7 GPM, 3600 PSI (Chappell Supply, 2006)
HD Hose	1/2" X 100' 5800 PSI
RC	TeleChief TM2000 (Control Chief, 2003)
Tank	Ditch Witch 50 gal

Table 4: HM2500z Components

HM2500z	
Power	**U.S.**
Engine	Honda
Fuel	Gasoline
Flywheel Power	13
Maximum Governed Speed	3900 RPM
Pumping System	**U.S.**
Operating Flow Rate	7 GPM
Operating Fluid Pressure	2500 PSI
Power Hose Length	100 ft
Power Hose Rating	5000 PSI
Fluid Capacities	**U.S.**
Water Reservoir	50 gal
Fuel Tank	7.4 qt
Control System	
Electrical Clutch	12 V DC
Wireless Remote	

Table 5: HM2500z Operating Conditions

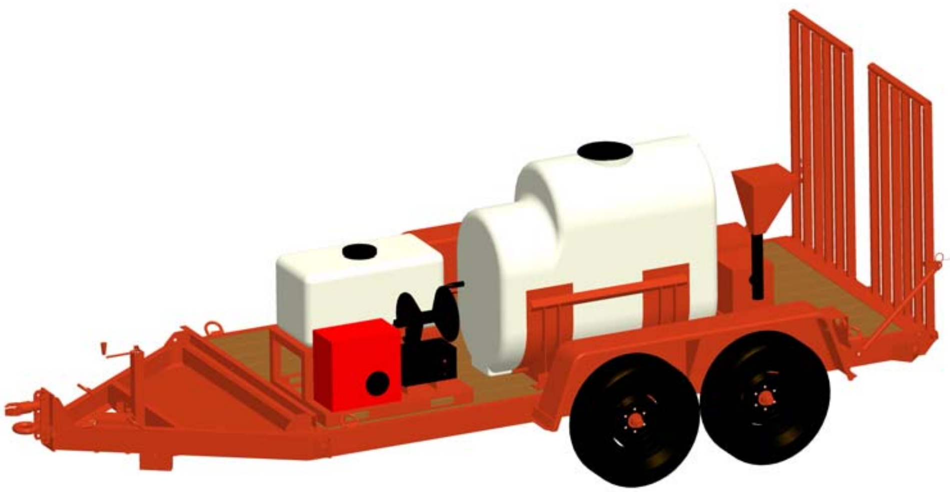

Figure 10: HM2500z and T9B

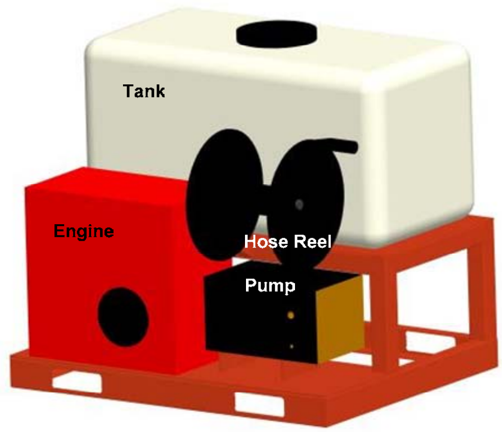

Figure 11: HM2500z

The high pressure Triplex pump, TSP2021as (Appendix H), powered by the Honda 13 HP engine (Appendix H), would draw water from the 50 gallon supply tank. It would pump the high pressure water through the hydraulic hose to the JT520 unit. A tee joint and two check valves will be installed to direct flow and insure that flow will not go back through the two pumps, but will only go to the drill string. When the high pressure pump is turned on with the remote control, it will pump water through the hydraulic hose and check valve and into the drill string.

This design has several significant advantages over the HM5x20z system. In no way will the design specifications of the current JT520 unit need to be changed by implementing the HM2500z. Other than implementing the tee and one of the check valves, the unit will experience no changes.

The HM2500z is also not only easy to implement, it is by far the best solution for installation for the dealer and customer. It is a package that can be sent to the dealer by Ditch Witch in essentially one box. A customer can come in with the trailer and unit; the dealer can load the skid on the trailer with a forklift or hoist and install the tee and check valve; and the customer can be out of the dealership in a matter of a couple of hours.

In contrast to the HM5x20z operation, the HM2500z requires no power from the JT520. Therefore, the unit will be capable of thrusting or turning the bit at the same time the high pressure system is operating. This could be very beneficial to steering the drill head, as the thrusting and turning portions are vital to steering capabilities.

Additional Design Considerations

The team decided to implement a remote control system that would allow the operator to activate either design. It would include a two or three-button remote and would be very simple to operate (Appendix I). The cost (described later in the project budget) would be small enough that if it were to fail, its replacement would not be a significant expense.

The team also had to be concerned about the weight limits available from the T9B trailer (Appendix J), which has a weight rating of 8650 lbs. Table 6 shows this analysis. With the current JT520 unit and filled FT5 there is approximately 5051 lbs of weight on the trailer, with 2980 lbs on the right side of the trailer and 2071 lbs on the left side of the trailer. Weight estimates of the high pressure kit totaled 717 lbs, and it was assumed this would be about the same for both kits. The current design intends for the kit to be mounted on the left side of the trailer, in front of the FT5 unit. It was concluded that not only was the trailer able to support the added weight, but would be better balanced from left to right sides.

Trailer Weight Capacity

Trailer Weight Rating (lbs)
8650

Current Weight (lbs)	
JT520 Weight	2980
FT5 Wet Weight	2071
TOTAL	5051

Total Load (lbs)
5768

Assumed Pumping Unit Weights (lbs)	
50 gal Tank, Wet Weight	440
Frame (Skid)	80
Engine	81
Pump	41
Hose	75
TOTAL	717

Table 6: Trailer Weight Analysis

Proposed Budget

In the beginning of the project, Ditch Witch did not specify that cost would be a significant item of consideration in the design process. The team was informed that customers who desired this type of system would not be overly concerned about the cost, unless it was unreasonable. An estimated budget was formed for both designs and the team will make its recommendation for manufacture based on both budget and overall design. The team will ask Ditch Witch to make the final decision if economic factors are significant enough for consideration.

Table 7 shows the estimated budgets for each design, including the cost of individual components. The cost estimates are based on a per unit basis, and would likely be cheaper if purchased in larger quantities. The HM5x20z unit is approximately $1500 cheaper than the HM2500z. The team will ask Ditch Witch to determine if this difference is significant for consideration along with physical design criteria and dealer/customer satisfaction.

KIT COSTS		
Component	HM2500z	HM5x20z
Engine	$674.99	$299.99
Pump	$2,091.00	$60.00
Tank	$119.99	$119.99
HD Hose	$584.00	N/A
Low Pressure Hose	N/A	$34.98
Cylinders	N/A	$900.00
Control Valves*	N/A	$650.00
Remote Control	$475.00	$475.00
Tank Skid*	$72.00	$72.00
TOTAL	$4,016.98	$2,611.96
* Cost estimate subject to change		

Table 7: Budget Estimates

Project Schedule

Project scheduling was initially divided into two major sections representing each semester of the design project. The fall semester included project definition, concept development, concept analysis, documentation, and design presentation, with tasks listed under each of these categories. The spring semester includes final design analysis, ordering components, manufacture, testing, documentation, and presentation, again with tasks listed under each. After the design presentation is given, the fall semester will be complete and the team will become more focused on producing the final concept product to fulfill the sponsor's needs. A detailed Gantt chart of the team's projected schedule is located in Appendix K.

Conclusion

Based on the above analysis, The West Central Pump Works would like to recommend the HM2500z for manufacture in the spring. This recommendation is based on its design advantages over the HM5x20z, especially in the area of customer satisfaction. Based on the above analysis, budget, and recommendation, the team is asking Ditch Witch to select the design that would be suitable for their company's interests. When this decision is complete, the team will continue on as stated in the project schedule.

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Appendix A

Patents

Appendix B

FX60 Pump Specification Sheet

Appendix C

Concept Generation and Evaluation

Kit assembly with water pump on the trailer:

This concept would primarily consist of a high pressure water pump, high pressure hose and reel, supply tank, and engine, skid mounted on the T9B trailer.

Kit assembly with water pump on the trailer and beside the unit:

This concept would primarily consist of a supply tank, a high pressure water pump, a booster pump, two power sources, a hose and reel, and a cart. A booster pump located on the trailer would provide water to a high pressure water pump located on a cart that sat beside the JT520 unit.

Enhance the current mud pump on the JT520 unit:

This alternative involves increasing the performance of the mud pump that is currently on the JT520. Current operation of the unit does not require the pump to operate at its maximum capacity. By increasing the power to the pump, a higher flow rate and pressure could be produced through the drill string.

Replace the current mud pump on the JT520 unit:

This alternative calls for replacing the current mud pump on the unit with a higher performance mud pump.

High pressure water pump installed on the JT520 unit:

This alternative involves installing a high pressure water pump on the JT520.

Pressure intensifier or crank drive pump:

Pressure intensifiers and crank drive pumps were suggested as a means of providing substantial pressure to the drill string. Before the team determined approximately how much pressure would be required, this was seen as a possible alternative.

Accumulator:

An accumulator can be used to store energy in the fluid. Examples of accumulator applications are pumpkin launchers and combine headers. Accumulators have the capability of producing the high pressures and flow rates that would be required at the end of the drill string for this application.

Hydraulic cylinder application:

This alternative calls for two hydraulic cylinders mounted on the JT520 unit. One hydraulic cylinder, supplied with hydraulic oil, would force fluid through another hydraulic cylinder, supplied with water. A rough schematic is shown in Figure C1.

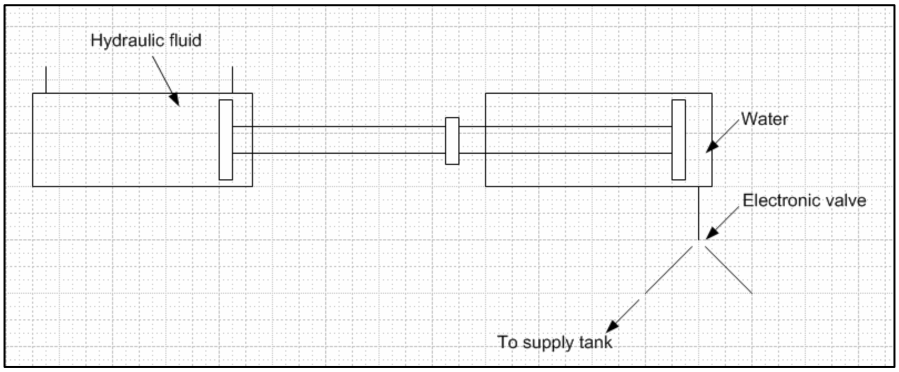

Figure C1: Hydraulic Cylinder Schematic

Table C1 shows an analysis and comparison of advantages and disadvantages of each alternative.

Appendix D

Analysis Equations

Variables:

HP = Horsepower
GPM = Gallons per Minute
PSI = Pounds per Square Inch
F = Force
P = Pressure
A = Area
h_L = Pipe Head Loss
f = Darcy (Moody Chart) Friction Factor
L = Length of Pipe
D = Diameter of Pipe
V = Velocity of Flow
g = Gravity Constant
K_L = Loss Coefficient
A_1 = Area 1
A_2 = Area 2
Q = Flow Rate
Re = Reynolds Number
ρ = Density
μ = viscosity
C_d = Discharge Coefficient
β = d/D = (obstruction diameter)/(pipe diameter)

Equations:

Horsepower: $HP = \frac{GPM * PSI}{1714}$

Force: $F = \frac{P}{A}$

Pipe Head Loss: $h_L = f \frac{L}{D} \frac{V^2}{2g}$

Loss Coefficient: $K_L = \left[1 - \frac{A_1}{A_2}\right]^2$

Pipe Head Loss: $h_L = K_L \frac{V^2}{2g}$

Flow Rate: $Q = VA$

Reynolds Number: $\text{Re} = \frac{\rho V D}{\mu}$

Nozzle Flow Rate: $Q = C_d A \left[\frac{2\Delta P}{\rho(1-\beta)^4}\right]^{\frac{1}{2}}$

(White, 2003)

Appendix E

Nozzle Data and Graphs

Orifice Data	
GPM	**PSI**
4.10	800
4.55	1000
5.70	1500
6.48	2000
7.20	2500
7.90	3000
8.53	3500

Table E1: 0.070 in Nozzle Values

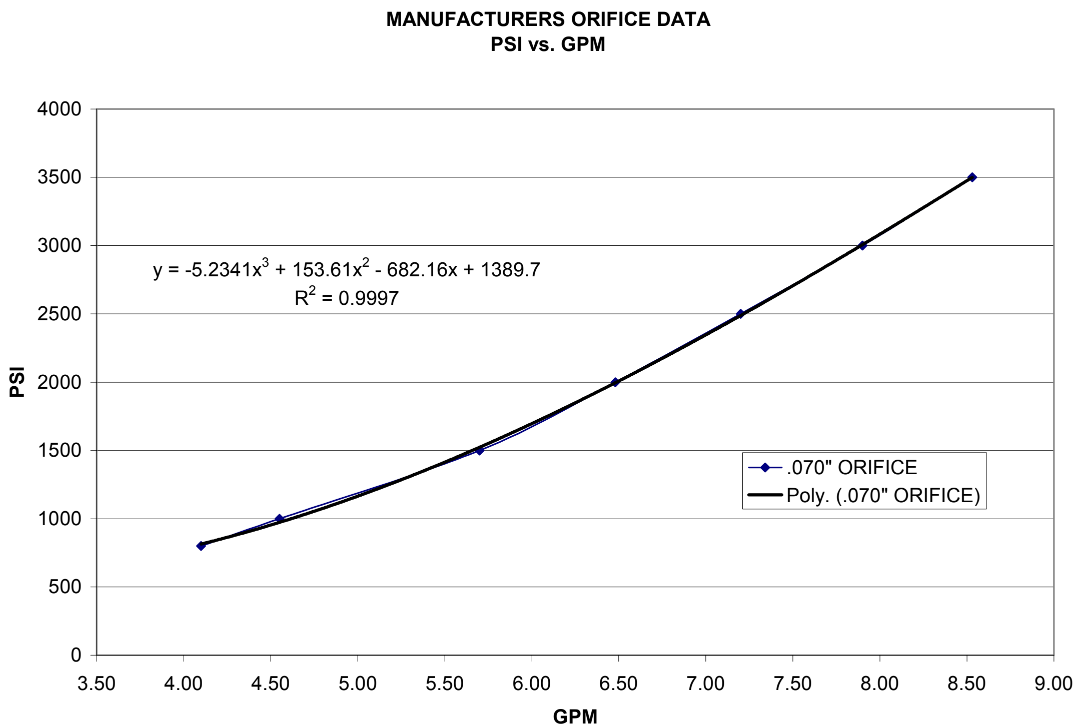

Figure E1: Nozzle Pressure vs. Flow Rate

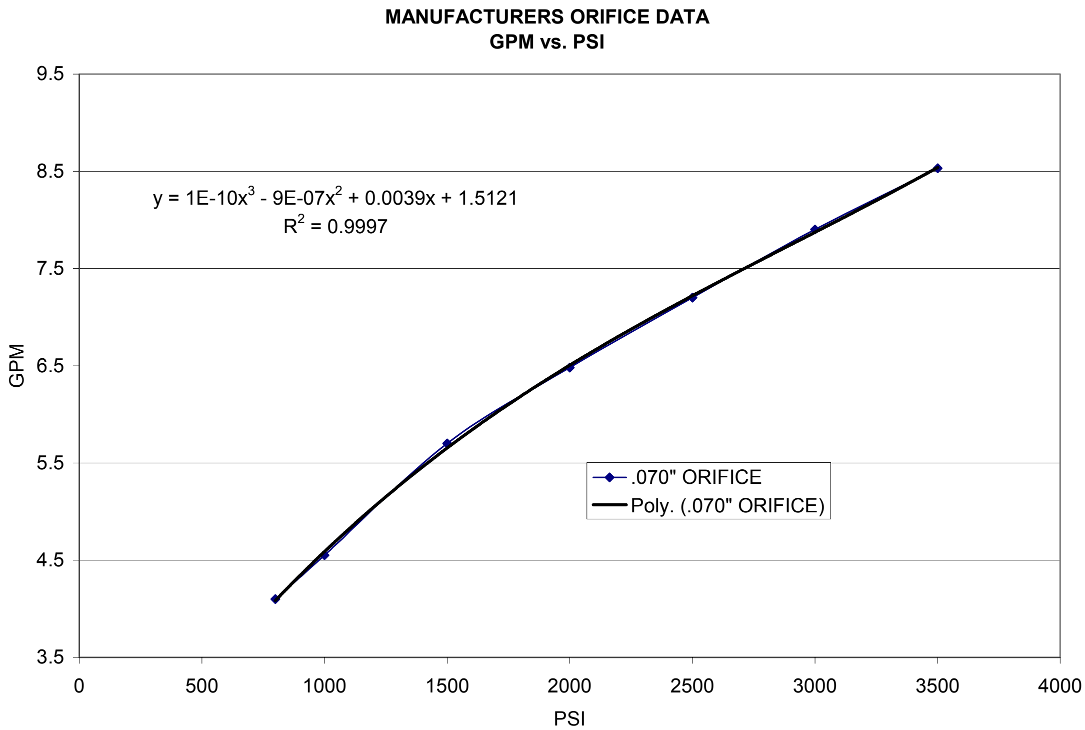

Figure E2: Nozzle Flow Rate vs. Pressure

Appendix F

Design Requirement Analysis

JT520: HEAD LOSS & ORIFICE PSI

ASSUMED PARAMETERS	
Pressure at Orifice	2400
Flow Rate Q (GPM)	7
Down Hole PSI	50
f (moody friction factor) #7	0.045
f (moody friction factor) hose	0.025
Number of Pipes	15
Orifice Size (in)	0.07
Large Diameter Orifice	0.375
C_d	0.595

PSI From Chart
2346.17

GPM From Chart
7.07

Pressure at Pump (PSI)
2471.5

PIPE SECTIONS	d (in)	AREA (ft^2)	d/D	L (in)	K	V (ft/s)	Re	H_L psi
1	0.56	0.00171	0.77	N/A	0.18	9.12	39498	0.10
2	0.73	0.00292	0.67	N/A	0.30	5.34	30217	0.06
3	1.10	0.00660	0.67	N/A	0.26	2.36	20108	0.01
4	0.73	0.00292	0.77	N/A	0.18	5.34	30217	0.03
5	0.56	0.00171	0.55	N/A	0.30	9.12	39498	0.17
6	0.31	0.00052	0.55	N/A	0.43	29.76	71351	2.56
7	0.62	0.00210	N/A	59.05	N/A	7.44	35676	1.60
hose	0.50	0.00136	N/A	1200		11.44	44238	52.83

TOTAL PSI DROP PER PIPE	57.4
TOTAL PSI DROP	125.3

Table F1: Design Requirement Analysis

Appendix G

HM5x20z Design Information

Appendix H

HM2500z Design Information

Appendix I

Wireless Controller Specifications

Appendix J

T9B Trailer

Figure J1: T9B

Appendix K

Gantt Chart