AN EVOLUTION IN THE DESIGNS OF SMALL SCALE CUTTER SUCTION DREDGES; ECONOMICAL BENEFITS OF MODERN EQUIPMENT

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ABSTRACT

Over the past 10+ years many new products have entered the market that also apply to the dredge manufacturing processes. Original Equipment Manufacturers (OEM's) are spending more money and time into Research & Development to explore increased efficiencies, longer life and more affordable components. As these new components find themselves available for sale in the marketplace, they offer benefits to end users in many industries. The dredge manufacturing industry is a market that can utilize the new components in their product designs when beneficial use and economics allow for these enhancements. This paper will address the trends in the dredging industry and the efficiencies offered from new product offerings particularly in the hydraulics, electrical, controls and automation fields. Electronics and powerful HMI's are not only becoming increasingly popular, but are quickly becoming the norm for even the smallest of dredges. Monitoring equipment is in an evolutionary stage where new products and upgrades seem to be offered overnight. Advances in coating systems, bio-friendly lubricants, GPS systems, data recording devices, communication systems, automation and operating systems will also be addressed in both their new offerings and their increased efficiencies to the overall dredging machine. Other major OEM suppliers, such as Caterpillar, are now offering increased available power in the same or smaller equipment packages that were seen 5-10 years ago. These advances help the dredge manufacturers allow for additional options and increased performance simply based on other OEM upgrades. New winch designs, noise abatement devices, design software and electrical power systems have also recently entered the marketplace – allowing dredge manufactures to use these products to advance the industry.

KEYWORDS: Dredge efficiency, hydraulic, electrical, automation, control

INTRODUCTION

Some of the most obvious dredge equipment enhancements have occurred in the hydraulics, electrical, controls and automation fields. Fluid power systems on mobile equipment have changed dramatically over the years. In applications with changing demand, high efficiency variable displacement pumps are becoming increasingly popular in open loop systems with load sense and pressure compensated control. In continuous duty high horsepower systems, closed loop or hydrostatic transmissions have become standard. Dredge electrical systems have also changed significantly in way of equipment. Newer model AC Variable Frequency Drives (VFD's) have moved to the forefront as DC drives and motors loose the cost, maintenance and reliability edge. When compared to constant speed motor control, VFD's offer improved starting characteristics and variable speed range capability. Both can result in significant cost savings. The control and automation aspect of all systems drastically enhance the performance and operation of dredging equipment and monitoring and aid in operator safety, a paramount objective in today's manufacturing facilities. Changes taking place in the controls arena are ones we can truly see, touch and hear.

Evolution of dredge equipment over the years is sometimes the result of extensive Research and Development. The scope of this paper is to expose some of the trends and to give examples of cost savings associated with operating more efficient equipment (individual component) as well as examples of the cost savings associated with running modern state-of-the-art systems.

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HYDRAULICS / FLUID POWER

Many dredges utilize hydraulic systems for mooring, spud lift and cutter functions. Generally speaking, these hydraulic systems consist of a reservoir, hydraulic pump, directional control valve, hydraulic motor or cylinder and gearbox(s). Older moderately priced and highly functional hydraulic systems utilized manual control valves and were designed and reused for years, so the evolution of the newer piston type machinery and electric over hydraulic controls into the dredge machine took time. Hydraulic systems on dredges in general were designed around high flow and low pressure components that were common, economical and less sensitive to contamination. Today the trend is shifting back towards high efficiency low flow, high pressure systems. The cost of the more efficient equipment decreases with size and becomes less expensive to operate and maintain. It is truly a savings that can be passed down. This will be obvious in Hydraulic Example 1. In Hydraulic Example 2, the author will illustrate cost savings by virtue of using a variable displacement hydraulic pump in a similar system.

Hydraulic motor overall efficiency is the product of volumetric and mechanical efficiency and is measured by its ability to develop speed (RPM) and torque. Similarly, hydraulic pump overall efficiency is the product of volumetric and mechanical efficiency and is measured by its ability to develop flow (GPM) and pressure.

- Volumetric Efficiency = Flow (Actual) / Flow (Theo) * 100
- Mechanical Efficiency = Torque (Theo) / Torque (Actual) * 100
- Overall Efficiency = Volumetric Efficiency * Mechanical Efficiency
- Gear Equipment Overall Efficiency 65% - 85%
- Vane Equipment Overall Efficiency 85% - 92%
- Piston Equipment Overall Efficiency 80% (Open Loop) - 93% (Hydrostatic Transmission)
- HP = Flow (GPM) * PSI / 1714 * Overall Efficiency
- where 1HP = 0.746 KW

Hydraulic Example 1 - Operating Cost Savings based on Equipment Selection-Open Loop vs. Closed Loop

Cutter drive application, fixed displacement gear pumps. and motors vs. hydrostatic transmission are shown in Figure 1 and Figure 2. These figures are typical and do not represent a particular manufacturer's piece of equipment. The 67 KW (90 HP), 30 RPM cutter drive with 3 stage planetary gear (Fixed Displacement Pumps and Motors (Open Loop) are

- Torque = HP*5252 / RPM = 15,756#-ft.
- Efficiency Data (Fixed Displacement Pump and Motor - Gear Type):
- Overall Efficiency of Pump = 0.80
- Overall Efficiency of Motor = 0.80
- Overall Efficiency of Planetary (98% per stage) = 0.94
- System Overall Efficiency = 0.60 (0.80*0.80*0.94)
- HP Input = HP Output/System Overall Efficiency = 90/0.6 = 149 HP or 111 KW

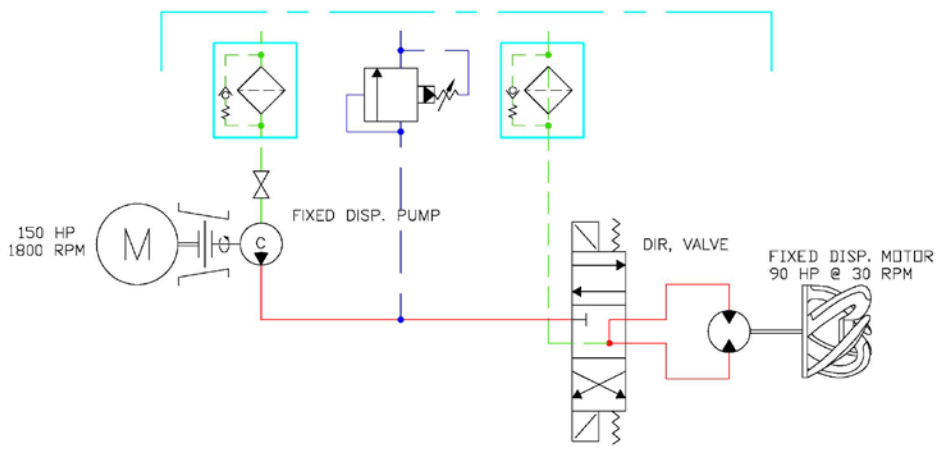

Figure 1. Open loop cCircuit - fixed displacement pump

The 67 KW (90 HP), 30 RPM Cutter Drive with 3 Stage Planetary Gear (Variable Displacement Piston Pump and Fixed Displacement Piston Motor) - Hydrostatic Transmission is characterized by

- Torque = HP*5252 / RPM = 15,756#-ft.
- Efficiency Data (Variable Displacement Pump and Fixed Displacement Motor-Piston Type):
- Overall Efficiency of Pump = 0.93
- Overall Efficiency of Motor = 0.93
- Overall Efficiency of Planetary (98% per stage) = 0.94
- System Overall Efficiency = 0.81 (0.93*0.93*0.94)
- HP Input = HP Output/System Overall Efficiency = 90/0.81 = 111 HP or 83 KW

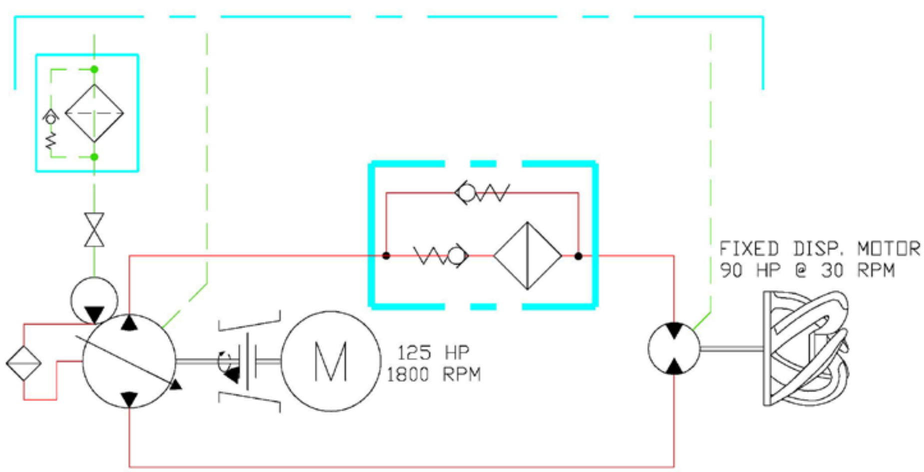

Figure 2. Closed loop or hydrostatic transmission - variable displacement pump

The example above only looks at the cost savings associated with the more efficient system. Now look at the savings over a 10 year life when the machine operates 2000 hours annually. Assume the industrial electrical rate equals $0.07/KWh

- HP Difference = 38 = 28.3 KW
- Rate equals 28.3KW * 2000 hours = 56,600 KW h
- $0.07 cents/KWh * 56,600 KWh = $3960/year or $39,620 savings over 10 year life

This savings can be viewed as that associated with the OEM making a decision to use more efficient components without sacrificing any customer desired performance. The capital cost difference from one system to the next was less that 20% of the number listed above. Equipment Life Duty Cycle is a very important consideration while selecting components. There is no real value in installing high efficiency components if the unit is at idle or on standby most of the day. However, if the machine is running at design capacity most of the time, the cost savings can be significant.

Hydraulic Example 2 - Operating Cost Savings based on Equipment Selection-Fixed Displacement Open Loop vs. Variable Displacement Open Loop

The 90 HP and 30 RPM winch drive application is shown in Figure 3.

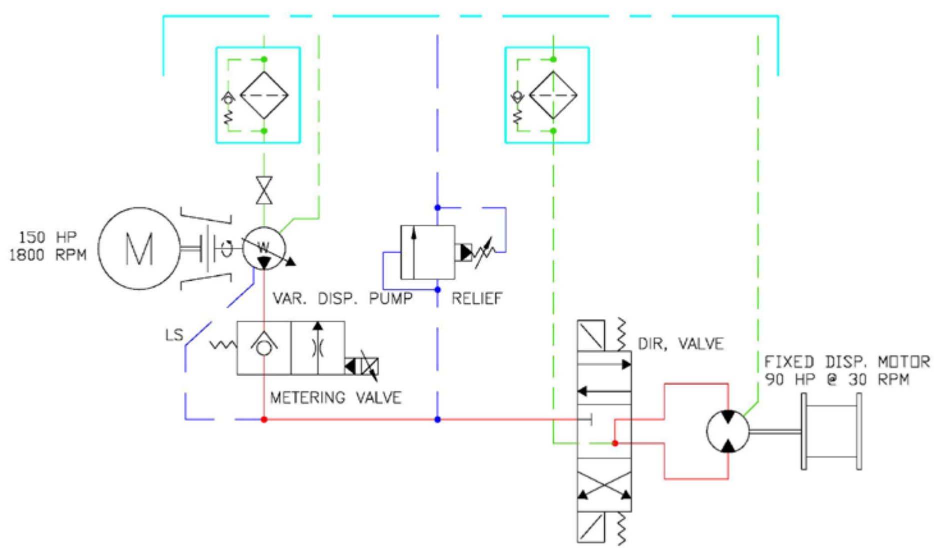

Figure 3. Open loop circuit - variable displacement pump

It is becoming more common to see load sense or pressure compensated control hydraulic circuits on dredging equipment today. This type of control makes the pump "smart" from the standpoint that it will automatically de-stroke or change displacement (swash plate angle) on demand. If the demand exists, the pump will stroke and provide oil flow and pressure to the winch function. When the demand goes away, the pump shifts to standby mode and utilizes significantly less energy while not being used. The savings add up quickly.

From Hydraulic Example 1, a fixed displacement hydraulic gear pump is driving a fixed displacement hydraulic gear motor. Since the pump is fixed displacement, its output flow is a function of speed. Regardless of whether the oil is being used to operate a function, it is being circulated at some flow rate corresponding with speed and displacement and pressure. In this example, the pump was sized to deliver 265 liters/min (70 GPM). The system pressure in this condition is the sum of the losses in the system. With the hydraulic valve in neutral, there is 1103 kPa (160 psi) pressure drop through the valve and return filter.

- Fixed Displacement Gear Pump Load while winch hydraulics are idle (ladder winch)
- 70 GPM, 160 PSI (Valve Pressure Drop), 100% Overall Efficiency (Function not running)
- HP = Flow (GPM) * PSI / 1714 * Overall Efficiency = 70 * 160 / 1714 *1 = 7 HP or 5 KW
- Variable Displacement Piston Pump Load while winch hydraulics are idle (ladder winch)
- <1 GPM, 290 PSI (Valve Pressure Drop or Load Sense Setting), 100% Overall Efficiency (Function not running)
- HP = Flow (GPM) * PSI / 1714 * Overall Efficiency = 1 * 290 / 1714 *1 = 1 HP or 0.746 KW

Purpose of this example is to illustrate that although a machine may be running at idle, it can be using a significant quantity of energy. In this case, the standby energy usage ratio in the ladder winch circuit is 7 to 1. This is one circuit only as the machine has at least two other circuits that should be considered.

- HP Difference = 6 = 4.5 KW (Ladder circuit)
- Rate equals 4.5 * 2000 hours = 9,000 KW h
- $0.07 cents/KWh * 9,000 KWh = $630/year or $6,300 savings over 10 year life

ELECTRICAL - ADJUSTABLE SPEED VS. CONSTANT SPEED DRIVES

Over the years, dredge electrical system components have not changed much in way of form and fit. Electric motors are increasingly being used on new equipment, particularly because of environmental restrictions, emissions control, reduced maintenance and competitive cost over diesel driven equipment. Because dredging conditions are variable due to pipeline length, discharge elevation and virgin materials so is the need for variable speed control on the dredge pump, hence AC or DC Drive. DC motors and drives have been the choice amongst design engineers primarily because of cost. But over the last few years AC Drive cost have come down and have since become more competitively priced and reliable. New power devices such as IGBT's (Insulated Gate Bi Polar Transistors) and digital microprocessor control have also advanced AC Drive technology to what it is today.

There are many dredges designed around DC electrical equipment because it was available as surplus after the wars. Overflow from the drilling and transportation industries contributed to the surplus as well. GE 752 traction motor was renowned for being one of the most durable models used on dredges all over the world. As equipment service life diminished, and surplus motors were sold off, used DC motor availability rapidly decreased. Not long after, new DC motor price surpassed new AC motor price. But AC drives were still much more expensive. Up until a few years ago, AC drive price dropped to the point where the motor/drive set, DC or AC, is comparable in the 745.7 KW (1000 HP) range. And so many OEM's find themselves wanting to stay on the technology edge and switch to the AC motor and drive.

The few benefits of using AC drive and motor are:

- 1000 HP TEFC sealed inverter duty motor very common
- Drive maintains Power Factor close to unity

- Controlled starting and stopping, reduced power demand and lower line voltage sag at startup
- Adjustable speed range
- Energy savings, increased equipment life

Gear Reduction

Significant cost savings can be achieved by simply using a gearbox and a smaller 4 pole electric motor (Synchronous speed = 1800 RPM). A twelve pole motor has three times the copper as a four pole motor and is sizably larger than the smaller motor and gearbox combination. Gearboxs designed for industrial service are fairly efficient and very reliable; They add little work to equipment maintenance program.

Savings

Savings associated with using adjustable speed drives is largely dependent on the application. In the dredging industry, they basically pay for themselves in short order if replacing a fixed speed pump, particularly one that is running at an elevated speed perhaps due to a short pipeline which forces the operator to run right of BEP.

There are various models available to compute energy saving by switching to a VFD. Some use drive power ratios, which take into consideration how the pump is loaded at time of startup. In a primed water system, the pump is fully loaded.

Example 1 - 1000 HP Electric motor started with AC Drive vs. Constant Speed

- AC Motor rating - 1000HP or 746 KW
- Proposed Drive Power ratio = 0.41 (VFD)
- Drive Power Ratio = 1.0 (No control)
- AC Drive Demand = 746KW * 0.41 = 306KW
- Constant Speed Drive Demand = 746KW * 1.0 = 746 KW

Assuming annual operating hours equals 2000 and $0.07/KWh consumption rate, the annual savings can be calculated as follows:

Annual Savings ($) = (746-306) * 2000*0.07 = $61,600

It is important to note that in a typical constant speed drive, electric motor winding life is also reduced because of the stress induced in it at time of starting. The startup current can be as high as 7-8 times full load current. Another way to view savings associated with using VFD's is to analyze the pump affinity laws. Flow is proportional to speed; Pressure is proportional to speed squared; HP is proportional to speed cubed

Example 2 - Pump speed reduction

Pump speed in a system is reduced to 80%.

Flow is Proportional to speed, which is reduced 20%. Since HP is proportional to the speed cubed, a 20% decrease in speed equals approximately a 50% decrease in HP demand. Savings gained from DC to AC Drive are not as significant as the fixed speed example. However, there may be possible demand charges associated with poor power factor as DC Drive decreases PF linearly with decreasing speed (1.0 at full gate, 0.5 at 1/2 gate, etc.). AC Drives target PF close to unity (0.98). Additionally reduced DC motor brush maintenance cost may prove to be significant, particularly if the motor is exposed to harsh operating environment.

Variable frequency drives are typically setup to communicate with a PLC or other controllers. PLC's can be setup with control loops that vary the motor or pump speed to achieve optimum flow rather than throttle a discharge valve to accomplish the same. Throttling a valve does work, but it cost!

CONTROLS

Operator controls have made significant advancements over the past 20 years with the advent of HMI's (Human Machine Interface) and increase use of PLC's and PC's. PLC's (Programmable Logic Controllers) have been used in the Canning Industry since the 1960's. Noisy switches, manual hydraulic controls and massive console's are not as common in modern equipment operator's cabs as they use to be. Noisy pilot operated hydraulic control valves are being replaced by electric over hydraulic controls. Inefficient across the line motor starters are being replaced by soft starts or variable frequency drives (VFD's) where practical.

It is not uncommon to see an operator control cab outfitted with a "Control Chair", an ergonomic and comfortable seat with built-in control arms outfitted with necessary control switches. The appearance of operating the equipment has taken on similar meaning to playing a video game in a climate controlled room.

HMIs or touch screens often complement the "Control Chair" concept and is moving to the forefront of the controls industry. HMI's not only replace or free space by eliminating switches and consoles, they are also easily programmable/customizable and update with sufficient speed to replace old manual glycerin-filled gauges. They can be setup to automatically scroll, or simply display. They provide a means of entering set point data for use by the equipment alarm or warning system. HMI's come is a variety of sizes. They can be specified for indoor (200-400 NITS) or outdoor use (1000 NITS) depending on brightness and sealing requirements. Newer models are setup for improved communication with support equipment.

PLC's serve many purposes: eliminate mechanical devices such as relay's, simplify wiring, equipped with the necessary modules to facilitate discrete and analog inputs and outputs and drive equipment communication. On the more advanced side, they are capable of operating multiple PID (Proportional, Integral and Derivative) control loops. These control loops are commonly setup within the operating code to facilitate constant velocity or other control loops aimed at maximizing production and facilitating the operator.

Data recording is a long awaited feature that can be used for maintenance interval purposes as well as production monitoring. Data can be exported to a flash drive, where it can be uploaded into spreadsheet format so that it can be analyzed and manipulated at a later date.

Cost on HMI's, PLC's, VFD's, etc. have slowly declined over the years. Generally speaking, HMI's, PLC's and VFD's costs often associated with modern control systems are offset by savings in wiring, improved reliability and operator comfort.

Figure 4 . HMI and adjustable control chair and arms

AUTOMATION

The automation field is ever growing as OEM's seek out more efficient ways to operate and boost productivity. On dredges today, there are many functions that can be automated, but the most common is pump flow or speed control which are directly proportional. The operator predefines a velocity set point and selects a operation mode, automatic or manual. The control or PID loop will automatically ramp the pump speed to achieve the desire set point. The savings associated with this feature can be huge as HP is a function of flow.

- HP = Flow (GPM) * PSI / 1714 * Overall Efficiency
- where 1 HP = 0.746 KW.

Suppose an operator is running a cutter suction dredge in manual mode. The operator is continuously observing the vacuum and discharge readings and adjusting the pump speed accordingly. This process can be tedious, and any delay in reaction to high vacuum or low flow could result in a discharge pipeline plug. In an effort to avoid this scenario, he runs the dredge almost full speed and pays for it in wear and energy cost.

Automated suction relief valves are economical particularly on dredges that are capable of high solids concentration. This valve can also be automated to actuate on high vacuum, low flow, high discharge pressure or high density conditions. Fresh water can be introduced into the pumping system to dampen out the spikes in the pumping system, and provide a more consistent slurry concentration to the plant. These valves are also very useful in aiding the operator in ladder removal should a cave-in exist.

Another facet of dredge automation is operational. This part of the machine is driven by a winch and or spud functions can be sequenced to operate automatically and save time and eliminate operator error. There is growing interest in streamlining personnel and processes.

Booster automation popularity is becoming increasing popular for many reasons:

- Operate unmanned
- Telemetry allows the dredge operator to see booster operating conditions and make changes remotely
- Operate automatically or manually

Remote access is a new system that is being offered on high end equipment today. Dredges can be accessed via cellular network. The manufacturer can access dredge data to assist with operator technique, troubleshooting problems, etc. Additionally, dredges are being offered with data recording systems that give managers new tools that can be used better estimate downtime and production.

CONCLUSION

In today's completive market place, OEM's strive to improve equipment cost, performance and company bottom line. The end result is improved selection and competition for the ever growing customer base. OEM's are always looking for ways to improve their profitability. Some key considerations when it comes to engineering a dredge are performance, capital cost, operating cost and maintenance. The scope of the search can range from an individual component in a system up to a complete retrofit or redesign of the entire system. Field request for individual component modifications usually stem from successive failures. System redesign generally carries a higher up-front cost because of engineering at all levels, plus higher capital cost associated with equipment improvements. However operating cost savings can be significant over the long haul, particularly in electrical and diesel drive systems like hydraulics or dredge pumps.

Economic downturns are an excellent time to review long term product goals. Not only do engineering teams have more time to dedicate to product development, but suppliers also have additional time to dedicate to their sales leads and contacts. Extra attention directed towards corporate visions enhances momentum, and improves success. In short time, new features and enhancements from a variety of industries, such as fluid power, automation and electrical, begin to make their way into standard product offerings, and the evolution in equipment design continues.