IMPROVING THE RELIABILITY OF A DECOKING JET PUMP TRAIN WITH A HYDRODYNAMIC VARIABLE SPEED DRIVE

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ABSTRACT

Delayed coking is a refining process that consists of the upgrading of petroleum residues into lighter and more valuable hydrocarbon fractions by promoting thermal cracking on the residue stream. Petroleum coke is a by-product of this process and depending on its morphology it can be used as fuel for steam generation, cement calcination or as feed stock for the manufacturing of aluminum and steel. Delayed cokers are very complex systems and require a considerable amount of hardware such as fired heaters, coke drums, a main fractionator and a hydraulic decoking system. In a typical delayed coker petroleum residues are passed through fired heaters before they are charged, in an alternating fashion, into large drums as boiling product. In the drums some of this effluent thermally cracks into lighter fractions (vapors) and these are removed from the drum overhead and returned to the coker fractionator before they are sent to a gas plant for further refining. The heavier product that stays behind slowly forms into coke and it is allowed to fill the drum over time. The time it takes to do this is usually referred to as the coking cycle. Once the drum is full and the feed is switched to start filling an empty drum, a series of activities such as sludging, quenching and steam-outs are performed on the full drum prior to removing the coke. Very high pressure water is used to cut this solid coke out and after some preparations this drum is empty and ready for a new coking cycle to begin again. As stated above, delayed coking is thus a combination of a continuous process through the fractionation tower and furnace and a batch process in the drums. As a result of this configuration the high pressure decoking pump only needs to operate a portion of the total cycle time.

Regardless of its “part-time” operation the water jet coke cutting pump is still a very important component of the hydraulic decoking system because it not only provides the required cutting pressure necessary to cut the coke but also contributes to the quality of coke removed and the duration of the decoking cycle. Recent history shows that the majority of new hydraulic decoking installations use electric motor drives with fixed speed operation. The pump generally requires one operating speed to produce the necessary pressure to cut the coke and its flow, pressurization, and depressurization duties are controlled by a decoking control valve. During noncutting cycles operators typically shut off the motor to minimize power consumption of the system or they keep the motor running (rarely done), depressurize the line and operate this valve on bypass to recirculate the water through a holding tank until the coke cutting is resumed. Both operating alternatives have their disadvantages with regards to reliability (the first) and energy consumption (the second).

This paper explores the use of a hydrodynamic variable speed drive (HVSD) with an electric motor-driven pump as a way to increase the flexibility and reliability of the hydraulic decoking system. The HVSD or variable speed coupling (VSC) is able to seamlessly vary the speed of the pump and accomplish the following:

- Keep the motor running and operate the pump at minimum idle speed during noncutting cycles, avoiding periodic motor shutdowns and start ups
- Eliminate the need for soft starter or special motor design considerations to handle periodic start ups
- Reduce work and extend life of the decoking control valve by helping with depressurization duties during noncutting cycles and cutting tool mode shifting
- Efficiently adjust cutting pressures depending on feed stock quality to avoid coke pulverization.

This paper also describes the function of the variable speed coupling and how its unique design features are suited for the start up and intermittent operation of the water jet coke cutting pump. Field data and operator experience from two existing installations are collected and evaluated and the advantages of variable speed operation over fixed speed operation of the decoking pump are highlighted.

INTRODUCTION

Since hydraulic decoking was first introduced to the industry in the late 1930s many process innovations and design modifications have been implemented to the system components to improve liquid yields, safety, cycle times, coke handling, reliability and efficiency of the overall operation. Among the most important advances is the evolution from manual cutting operations to an automated process that allows for all cutting activities and mode shifting to be performed by a combination tool that is rotary actuated and remotely shifted by water pressure changes. The shift to automation in the early 2000s has resulted in a higher level of safety for operators and shorter cycle times. Also advances in pump rotordynamics, metallurgy, and drive technology have been implemented to the decoking pump with the ultimate goal of increasing pump performance and decreasing the downtime of this critical piece of equipment.

The high pressure water jet decoking pump is at the heart of the hydraulic decoking system. This is a barrel type multistage centrifugal pump designed according to API 610. This pump provides the necessary pressure and flows at the cutting nozzles to remove the coke so its efficient operation and selection are essential to the reliability of the hydraulic decoking system. The decoking procedure starts with drilling or boring a pilot hole gradually from the top to the bottom of a drum. After the hole is completed the tool is switched to cutting mode and various passes are made up and down the drum to cut the coke horizontally. Cutting time will vary with the hardness of the coke, the condition of the hydraulic cutting nozzles, and the available cutting water pressure (Lieberman, 1983). One important characteristic about coking processes and especially hydraulic decoking is that the high pressure water pump only needs to operate a portion of the total cycle time.

The chart in Figure 1 shows a typical 16 hour coking cycle for a six-drum coker. It can be seen that for the 32 hour total cycle the pump will cut for approximately 18 hours in three hour periods. Assuming good conditions for the jet pump, the cutting tools and a coke that is neither too soft nor too hard, the pump will idle for approximately 14 hours of the total 32 hour cycle time. Even for shorter 12 hour coking cycles (in a six-drum coker) where decoking periods are approximately two hours, the idle time will be 12 hours of the total 24 hour cycle time. This significant idle time is primarily the reason why delayed coker operators with electric motor driven decoking pumps have tended to favor turning off the motors during idle periods rather than keeping the motor running and throttling back capacity. This method is certainly in line with energy consumption and emission reduction initiatives that are being implemented by many refineries today. However, this off and on operation has brought about other challenges related to the design of motors that can handle multiple starts and electrical systems that can minimize inrush current during across the line start ups. Because of their variable speed capability, variable frequency drives (VFD) and steam turbines have certainly been considered as methods to drive the pump that could reduce power consumption at periods of lower or no demand but they are usually not the preferred options. In the case of VFDs, there is a lack of experience in the particular application and they require sometimes up to 40 percent higher capital cost investment than the conventional fixed speed systems, deterring end users from selecting this option. Steam turbines as mechanical drives for water jet pumps are more commonly used but their implementation depends on the steam balance and high pressure steam availability of the particular refinery. Although steam turbines are proven to be very reliable as mechanical drivers and can provide seamless speed variation to the jet pump to adapt to their intermittent operation, they are less efficient than electric motor drives in transmitting power. Also, their utilization usually results in higher emissions and higher capital costs (and cost of ownership) than fixed speed electric motor systems. Therefore, the use of steam turbines as drivers for jet pumps depends on the careful economic evaluation of engineers in charge of designing the coker, high pressure steam availability, and the overall refinery's processing philosophy. Nevertheless, with regards to drivers for these pumps, the current trend points to the selection of electric motor driven jet pumps on almost all recent hydraulic decoking projects.

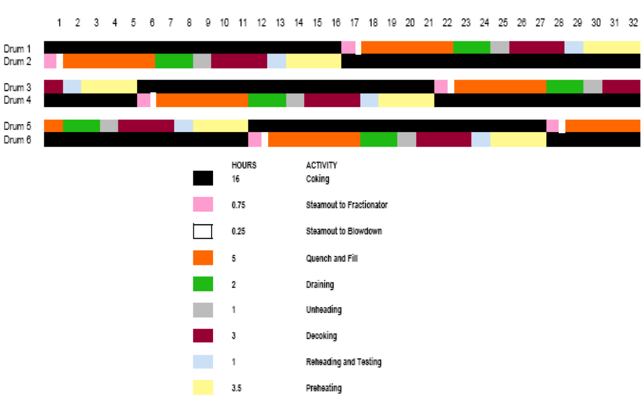


Figure 1. Six Coke Drum Cycle—Sixteen Hours Coking Cycle. (Courtesy Foster Wheeler USA Corporation)

It could be argued that most decoking pumps do not require a broad range of operating points that would make them suitable for the utilization of adjustable speed drives (ASD) to generate savings in energy consumption. Instead, these pumps usually require one operating speed or set pressure to cut the coke. Additionally, since most operators shut off the pump during noncutting cycles rather than throttling and recirculating the water to the source tank, the benefit of implementing an ASD, electrical or hydrodynamic, may not be quite evident. Simply put, the power savings that could be realized by operating the pump at minimum idle speed instead of throttling when the cutting is not required will not be greater than the power consumption savings achieved by turning off the motor.

However, the application of adjustable speed drives in decoking pumps deserves another look. Particularly hydrodynamic variable speed drives should be examined closely as there are a number of benefits they offer to the operation of a decoking pump. For example, during noncutting periods an HVSD allows the operator to seamlessly reduce speed of pump to minimum idle speed and recirculate water at a lower pressure to the source tank thus eliminating the need for periodic motor shutdowns. Although at reduced speed the power consumption is more than when the motor is off, this consumption is deemed insignificant by the end user because the resulting benefits in the long run contribute to a more reliable system and the extension of the maintenance cycle on the equipment. Since the pump and motor are no longer subject to repeated starts, the destructive forces that are usually present during across the line starts, known to contribute to bearing wear, water hammer on piping and pump, rotor fatigue and train stresses, can be significantly reduced. Also, since there is no need to start the motor multiple times during the day and the fact that an HVSD allows for a reduced load startup, a complex soft starter may no longer be required.

This paper first examines the conventional fixed speed electric motor-driven pump and presents the special considerations that operators have to make to operate the motor-pump train intermittently. Afterwards, the function of hydrodynamic variable speed drives is explained in detail. Variable speed couplings (VSC) and variable speed geared couplings (VSGC) are described with focus on the selection criteria used for the application of water jet decoking pumps. Supporting field experiences for two installations are examined with the goal of offering evidence that hydrodynamic variable speed drives can add flexibility and reliability to the hydraulic decoking system.

BACKGROUND—CONVENTIONAL OPERATION OF WATER JET PUMP DRIVEN BY ELECTRIC MOTOR

Although steam turbines have been used as mechanical drivers for water jet decoking pumps, especially for high speed requirements, most commonly these pumps are driven by electric motors. In order to understand the benefits that an HVSD offers to an electric motor driven coke cutting pump, the operation of the pump under fixed speed configuration should be studied first. Figure 2 shows a simple schematic of a hydraulic decoking system. One can see the decoking pump trains with motor, gear and pump arrangement, lube oil console, coke drums, decoking control valve and water tank. Depending on the size and number of coke drums, targeted coking cycle times and required cutting pressures, a decoking pump and appropriate driver are selected. The water pressure required typically ranges from 2500 psi for smaller systems to 5000 psi for larger ones. Cokers processing large amounts of heavy crude usually require high cutting pressures as the size of the coke drums become very large in diameter. The pump trains for these systems typically incorporate a four-pole motor and step up parallel shaft gear to achieve the high pump speeds required to produce the necessary pressures at the cutting nozzles. Smaller cokers typically have smaller diameter coke drums therefore the pressures required are less. For these systems two-pole motors are normally used to direct-drive the pumps as their design speed does not exceed that of the motor.

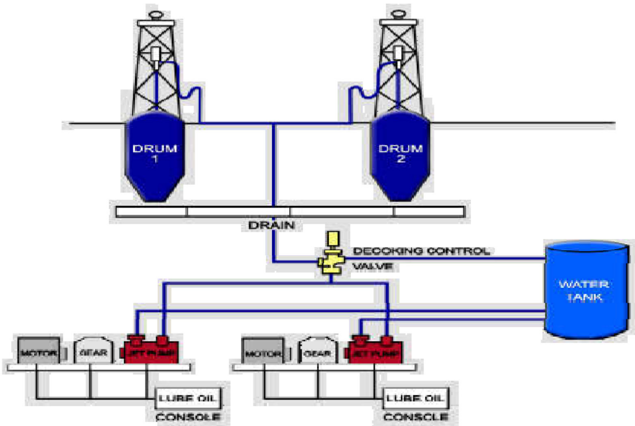


Figure 2. Hydraulic Decoking System.

As stated earlier, due to the intermittent requirement of cutting, most operators make the decision to shut the motor off during noncutting cycles to save energy that would be consumed in the operation of the pump under discharge throttle. Depending on the coking cycle, number of drums, size of drums and system design, the pump may operate as often as four times per day for two to three hour periods. Because of this off and on configuration, special considerations have to be made in the selection of drivers. Coker duty motors, which are typically selected, are designed to meet special starting and load characteristics present during across the line starting. Motor data indicates that coker duty motors are designed to consider heat storage and dissipation from rotor elements, heat generation rates, distribution duty cycle analysis and fatigue stress analysis of the rotor elements. The same data also states that attention must be given to the heat generation rates and temperature distribution within the rotor elements, particularly as a result of the repeated starts and stops associated with this application. This analysis is necessary to determine the allowable locked rotor and stall time limits (Reliance, 1981). In some cases even special motor design considerations to handle multiple across the line starts are not sufficient to prevent motor failures. Therefore, some refineries also implement a form of reduced voltage starter to limit inrush current such as an electronic controlled starter or conventional autotransformer. For example, an electronic controlled starter can prevent the creation of mechanical stresses and excessive heating within the motor by controlling the acceleration and deceleration ramp time and current levels. Gray, et al. (1997), wrote a short paper about the application of an electronic starter for a delayed coker process water jet decoking pump. Described in it is a job site where an electronic starter was installed to address many motor and pump reliability problems due to severe starting conditions related to the large number of across the line starts. This particular installation had as many as 1400 motor starts per year and as many as four starts per day. As a result of this intermittent operation, engineers concluded that the numerous motor problems, which resulted in maintenance costs, equipment costs and operational upsets, provided them with an economic incentive to implement alternative means for controlling the motor.

The main issue with coker duty motors and soft starters is that although they can effectively alleviate motor stresses and protect integrity of the pump train, they do not completely eliminate all the problems associated with the periodic motor starts. These components are also expensive and the complexity they add to the system may result in a less reliable decoking pump train. Some operators also believe that when a decoking pump is idle for a long period of time the fine coke particles present in the water have enough time to settle and become entrained in the pump, valves, and piping, and this is believed to contribute to the accelerated wear of these components over time. When liquids containing solids with a high settling rate are pumped, excessive solids accumulation can occur in the pump, causing wear. Therefore, it is paramount that when the speed of the pump is reduced the liquid velocity be maintained high enough in the pump and in the pumping system to avoid settling out of the solids (Hydraulic Institute, et al., 2004).

What if operators could find a way to keep the motor running all the time, keep the water flowing and simultaneously reduce throttling duties and power consumption during noncutting cycles? One way to accomplish this is to implement a variable frequency drive that controls the rotational speed of an AC motor by controlling the frequency of the electrical power supply to it. During noncutting cycles the VFD could reduce speed of the pump to reduce system water pressure and the decoking control valve could be put on bypass to recirculate water to the source tank. The VFD would keep the motor running continuously and minimize motor, pump and piping stresses associated with multiple motor starts. However, for the typical power rating of a decoking pump and the fact that the pump only operates at a set maximum and minimum speed, the investment for a VFD would be hard to justify. These drives are efficient but they are also expensive. VFDs require significant footprint due to the large number of components needed such as a frequency converter, a rectifier, a VFD motor, air-conditioning system, fire prevention system, and in some cases harmonic filters and isolation transformers. Additionally, the pump train with a VFD will still require a lube system, and for high speed applications, a speed increasing gear. Many experts tend to estimate that the lifetime of power electronic equipment such as a VFD is rather short since it may suffer from chemical aging of semiconductor elements and is susceptible to damage by electric shocks (Janknecht, 2008). Because of limited lifetime, number of components, hazardous and dusty environments, high capital cost investment, and space required a VFD could be considered impractical for this application.

Another solution that is compact, economic and simple is to install a variable speed coupling between a standard induction or synchronous motor and the jet pump. Like a VFD, the VSC allows operators to keep the motor running and reduce speed of pump to minimum idle speed during noncutting cycles. The following section describes the function of hydrodynamic variable speed drives, variable speed turbo couplings and variable speed geared couplings and their application to decoking pumps.

VARIABLE SPEED OPERATION IN DECOKING PUMPS

Function

A variable speed coupling is a hydrodynamic transmission designed according to the Fottinger converter to provide seamless speed control to a driven machine (Figure 3). It consists of a fluid circuit that is filled with an operating fluid, typically turbine oil, a pump impeller (primary bladed wheel) connected to a driver and a turbine (secondary bladed wheel) connected to the driven machine, all in a closed working chamber where the oil circulates in very small space inside a toroidal housing. The small space permits a direct exchange of energy between pump and turbine and reduces transformation and flow losses that would occur in the individual operation of these components. In a variable speed coupling the mechanical energy introduced by the motor is transformed into kinetic energy in the pump and then converted back to mechanical energy in the turbine. Since the energy carrier of a variable speed coupling is oil or fluid, power and torque can be transmitted without wear. Figure 4 (A and B) shows the internal components of a hydrodynamic variable speed coupling.

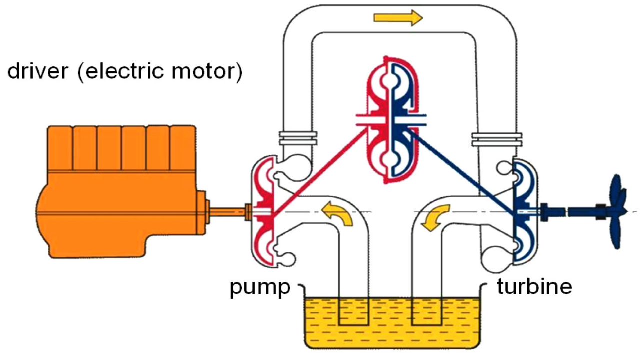
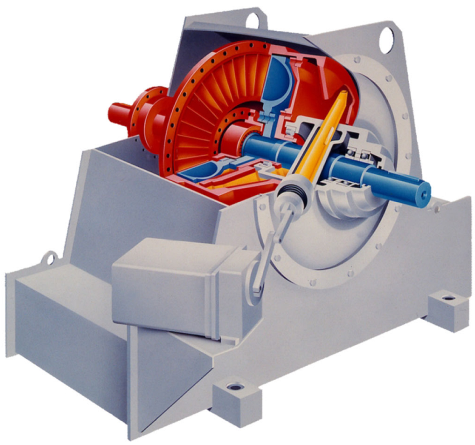
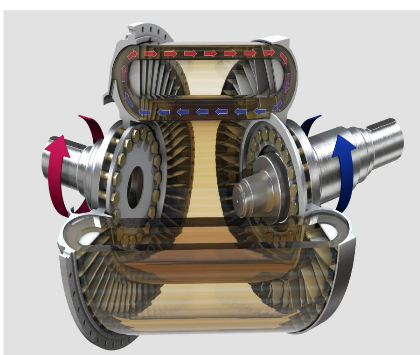


Figure 3. Schematic Representation of Fottinger Principle.



A)



B)

Figure 4. Internal Components of a Hydrodynamic Variable Speed Coupling.

It should be noted that a variable speed turbo coupling does not convert or multiply torque like a hydrodynamic torque converter, instead it permits input and output shafts to rotate at different speeds due to *slip*. The transmittable torque depends on the deflection of fluid flow in the turbine wheel and thus on the speed ratio *v. Slip* is expressed in percent in accordance to Equation (1). Torque can only be transmitted with a difference in speed between pump impeller and turbine wheel, although this difference might be a small one.

$$100\ (1-v) = 100\ (np-nt)/np = s \tag{1}$$

where:

np = Input or pump impeller speed
nt = Output or turbine speed
v = nt/np = Speed ratio
s = Slip

Figure 5 shows a simplified longitudinal section of a variable speed turbo coupling with standard components. Essentially, the torque and speed a coupling can transmit can be changed by varying the degree of filling in the working chamber. A scoop tube actuated by a 4 to 20 mA signal is used to vary the fill level of turbo couplings and in most cases its operation is integrated into a process control circuit of the driven machine. The position of scoop tube ranges from 0 percent (close to zero output speed) to 100 percent of travel (maximum output speed.) The scoop tube is especially designed to remove more oil from the working chamber than can be injected by the shaft driven circulation pump so its position controls the amount of oil flow that is transferred from primary or pump wheel to turbine wheel. Therefore, the higher the quantity of oil in the chamber, the higher the speeds and torque transmitted to turbine wheel and to output shaft. A working or transmission oil cooler is also needed because in the work of power transmission between pump wheel and turbine wheel there are friction losses that result in the heating of the oil. The scoop tube removes the working oil from the shell, drains into a sump and this oil is transferred by the shaft driven circulation pump into a heat exchanger or cooler to return the oil to its operating temperature. Larger hydrodynamic turbo couplings may require separate oil circuits to handle higher power ratings and oil flows. The fill level of the operating fluid can be varied during operation between full and drained, thus enabling exact dynamic speed control of the driven machine across a wide range when the coupling operates against different load characteristics. This operating range depends on the load characteristics (torque relative to speed) and the control accuracy required.

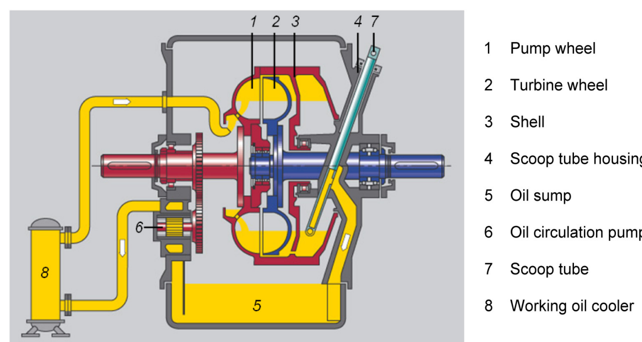
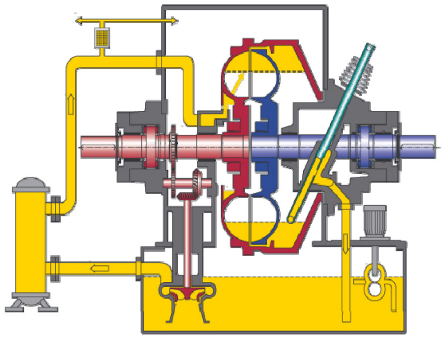


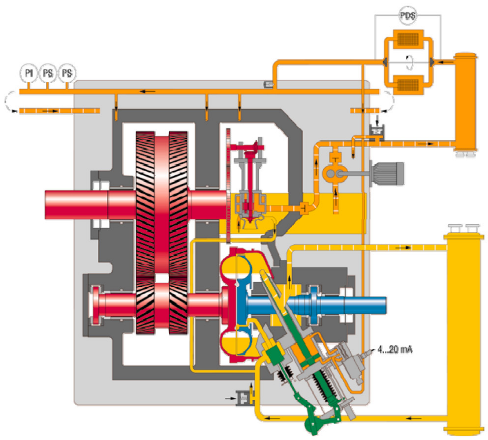
Figure 5. Simplified Longitudinal Section of a Variable Speed Turbo Coupling.

Selection Criteria for Water Jet Decoking Pumps

Depending on the pump and motor design speeds, a variable speed turbo coupling or variable speed geared coupling, as seen in Figure 6, can be chosen. To select the appropriate frame size for the hydrodynamic variable speed drive that can handle the power and speed to be transmitted to the decoking pump, the pump power consumption and operating speeds at design point (maximum) and idle point (minimum) are needed. If the maximum operating speed of the pump is lower than the motor speed then a VSC can be used to control speed from 100 percent down to about 20 percent and peak efficiency can be up to 97 percent. If the water jet pump speed is higher than motor speed then a VSGC, with up to 96 percent peak efficiency, is selected and this machine incorporates a parallel shaft gear arrangement, designed according to API 613, AGMA or DIN standards. Both types of variable speed couplings incorporate a shaft driven hydraulic oil pump to transmit the hot working oil from the oil sump through an oil cooler and back into the fluid coupling chamber. Both machines can also incorporate as an option an integrated lube oil system that consists of a shaft-driven pump, auxiliary oil pump for pre and post lubrication duties, and a larger reservoir. The shaft driven and electric motor driven auxiliary pumps are designed to provide lubrication to the motor, fluid drive, jet pump bearings and gears (if applicable), thus they eliminate the need for an external lube oil console. Both the shaft-driven pump and auxiliary oil pumps for this integrated lube system are of positive displacement design.



Variable Speed Coupling (VSC)



Variable Speed Geared Coupling (VSGC)

Figure 6. Variable Speed Coupling and Variable Speed Geared Coupling.

Even though an HVSD can provide seamless speed control from the maximum pump design speed percent down to about 20 percent of this speed, for a decoking pump application the maximum (cutting) and minimum (idle) speed would typically be the only operating points. Because of their design, variable speed couplings offer a number of advantages to the operation of the water jet pump when compared to the conventional fixed speed operation. For example, since driving and driven machines are separated when the coupling is drained, a load free start up can be realized. Even though the motor is usually kept running in jet pumps with a hydrodynamic variable speed drive, having a no load start up is still beneficial in the event the operator decides to shut down the motor periodically, like it will be seen in the case 1 installation described below. Other criteria that make HVSD suitable for decoking pump applications are:

- Reduced power and elimination of high wear throttle device.
- High control accuracy and fast reaction times.
- Wear free transmission of power through hydrodynamic energy of a fluid.
- Easy to operate, low maintenance components and easy maintenance.
- Seven to eight years time recommended between scheduled overhauls.
- Robust design with long service life and high availability.
- For large systems requiring water jet pumps with step up gears a VSGC with integrated lube oil system could actually result in a lower capital cost investment than a coker duty motor, soft starter, step up gear, and lube oil console
- Provide damping of torsional vibration and shock loads
- Possibility to use VSC integrated oil system to lubricate motor and pump bearings
- Suitable for the demanding environmental conditions of a delayed coker

Although VFDs are known to be more efficient than HVSDs, especially at lower speeds, HVSDs do offer some advantages over VFDs with regards to price, space savings, durability, and reliability. For example, for high speed jet pumps for large crude capacity systems, a variable speed geared coupling can result in a lower capital investment when compared to a VFD system with lube oil console and step up gear. This difference in price can be as large as 40 percent. A VSGC integrates speed control, lube oil console and speed increasing gear in one housing so it results in a more compact and often more economical solution. Also, as stated before, due to the aging of components and sensitivity to heat, electric shocks, harmonics and environmental conditions, a VFD practical lifetime can be between 12 to 15 years. In contrast, an HVSD, as long as preservation methods and maintenance cycles are followed, can last for decades. For example, there are many cases of hydrodynamic variable speed drives that have been in operation since the early 1960s and are still running today. With regards to reliability, the mean time between failure (MTBF) of a high power rating VFD is on the average much shorter than HVSDs. The published MTBF of one of the main manufacturers of hydrodynamic variable speed drives is more than 200,000 hours. The fact that a VFD requires a greater number of accessories than an HVSD and that each of its components has a reliability and efficiency factor associated with it may explain why the reliability over efficiency ratio of the hydrodynamic solution is higher than the VFD solution. If loss of production and capital costs are considered, HVSDs usually end up being more economical to their owners over the long run.

APPLICATION OF HYDRODYNAMIC VARIABLE SPEED DRIVES IN WATER JET DECOKING PUMPS

Hydrodynamic variable speed drives have been successfully employed to drive decoking pumps in recent years. Described below are two case installations that use VSDs at two delayed cokers with two different operating philosophies and equipment configurations. Selection criteria and performance data for a VSC and a VSGC are examined.

Case 1—Variable Speed Turbo Coupling

In 1985 a variable speed coupling with a wheel profile diameter measuring 562 mm was installed to drive a water jet pump at a two drum, 6600 barrel per day, delayed coker in a refinery in the Midwestern United States. There is not much information available with regards to the decision making behind the selection of the hydrodynamic variable speed drive but it can be assumed that it was chosen to add flexibility to the hydraulic decoking operation, especially during manual cutting tool switching. The VSC was supplied with an integrated lube oil system consisting of a shaft driven oil pump, oil sump, piping, and instrumentation to handle lubrication of the motor, VSC, and pump bearings. At this coker, the water jet pump runs for six hours a day and it is shutdown for 18 hours of the day to save on power. The hydraulic decoking system does not incorporate an automated cutting mode switching (combination) tool therefore the operators manually switch from boring to cutting and during this period they slow down the pump and divert water through a recirculation valve back to the cutting water tank. Due to the small size of this coker and the lower cutting pressures required a speed increaser was not necessary so a two-pole induction motor was chosen together with a hydrodynamic variable speed coupling. The VSC controls speed from 3580 rpm down to about 30 percent of this speed. For approximately four hours a day the pump operates at maximum speed during drum cuts. For about two hours a day the pump operates at minimum speed during manual cutting tool switching. For the remainder of time, approximately 18 hours, the operators shut down the motor to save on power consumption. Table 1 below indicates some general information obtained from this installation.

Table 1.

Motor	**AC Motor, 2 pole Induction.**
Pump	**Multistage Centrifugal Barrel Type.**
Variable Speed Coupling (VSC)	**562 mm wheel profile diameter, Split Housing Design.**
Rating	3499 HP, *3580 RPM/1074RPM.*
Start of Commercial Operation	*1985.*
Train Operation Time	*52,560 hours of operation. 4 hours at full speed and 2 hours minimum idle speed. 18 hours a day the motor, drive and pump are shutdown.*
Reported Problems	
VSC	None reported.
Motor	None reported.
Pump	Not available.
Decoking Control Valve	This installation does not have a decoking control valve.

Service reports and historical data on the decoking pump train indicate that the hydrodynamic variable speed drive has been operating very reliably over the last 24 years. The VSC was commissioned in 1985. In the year 2000 this coupling was inspected for the first time. During this first overhaul, 15 years after start up, the rotating element was removed and dismantled and the unit was found to be in an "as new" condition. Parts were cleaned and bearing clearances were found to be within tolerances. It should be noted that the VSC was not operated continuously for over 15 years. Instead, the pump train was operated intermittently so it is estimated that the VSC had about 33000 hours of operation and 40 percent of the time was operated at minimum idle speed. This may explain the good condition of the internals of the VSC; however, it is still remarkable to find a machine in such good condition after it was subjected to so many startups. Since the year 2000, the VSC continued to operate without problems. In 2005 the operators reported that the VSC was overheating during pump operation. When the service technician arrived on site he found the mechanism for the control valve actuator was grossly out of adjustment. This restricted the amount of oil going to the oil cooler. The service technician proceeded to loosen the clamping screw from the cam and adjusted the position on the shaft. No one at site had any idea how the cam came to this new position. No damaged parts were found. Further inspection found the fusible plugs were blown in the unit. The fusible plugs are installed on the primary wheel of these drives to protect the machine components and train in the event of excessively high oil temperatures. The plugs melt and drain the oil into the reservoir of the VSC. These plugs were replaced and the unit has operated continuously till present day.

At the time this installation was designed, the automated combination cutting tool was still not available in the market. This could explain the chosen operating philosophy for this hydraulic decoking system. The VSC is mainly used to aid in the water pressure reduction during manual switching of cutting tools and also during motor start ups. Because of the unloaded start capability and lower inertia requirements that the VSC provides, the motor can be started across the line without any inrush current problems and the pump can be smoothly accelerated. The operators believe that not only the VSC is a reliable piece of equipment but that it has contributed to the reliability of the train components by allowing for unloaded starts of motor, minimizing axial loads on bearings, and permitting the operation of the pump at minimum speed, which minimize the negative effect of high speeds on lube oil temperatures. Having a VSC also contributed to a faster switching time and cutting time and increased safety of the operators. By not turning off the motor during switching, the pump could be brought back to cutting mode speed much quicker than if it had to be started from the off position. Also, the water pressure of the system can be reduced to levels that are much safer for the operators doing the switching in the event of a failure of the safety mechanisms to bypass water to the source tank. This VSC also incorporates an integrated lube oil system so the external lube oil console is eliminated thus making this system more compact and with fewer number of components subject to maintenance and reliability considerations. For this installation, having a VSC also permitted the operators to eliminate a decoking control valve because water pressure changes are controlled by the drive with speed regulation. This is believed to have added reliability to the system because a decoking control valve typically requires significant maintenance due to potential water quality issues that affect its operation and the wear and tear caused by throttling duties due to high pressure differentials across the valve.

Case 2—Variable Speed Geared Coupling

On August 19, 2002, a variable speed geared coupling was put in operation to drive a 4500 hp water jet pump at a four drum, 75,000 barrel per day, delayed coker in a refinery in Mexico. Fixed speed, VFD and HVSD systems were considered in the evaluation of pump drivers. The engineers at the refinery had expressed concern with a grid capability that could handle multiple starts and the power factor of the existing electrical distribution system, therefore a fixed speed conventional configuration was quickly eliminated as an option. The engineers eventually selected the hydrodynamic solution because it addressed the grid limitations, improved power factor, and also provided reduced footprint and a lower capital cost investment than a VFD. The VSGC was supplied with an integrated lube system designed to supply lubrication to motor and pump bearings, therefore, an external lube oil console was also eliminated. This feature contributed to the further reduction of footprint and provided additional capital cost savings. During the selection of the hydrodynamic drive there was one concern about its efficiency at part load. The peak efficiency of a VSGC can be up to 96 percent so for the design operating point at the maximum power consumption this efficiency was acceptable.

However, at part load or minimum idle speed, the efficiency of the VSGC power transmission drops significantly. Since the horsepower of the pump varies according to the cube of the speed, based on Affinity Laws, it was determined that at the lower speed range although the efficiency of the power transmission was lower, the power consumed was also much lower (<300 hp) so the losses through the drive in transmitting this power were only about 500 hp or 10 percent of the rated bhp power consumption of pump. The VSGC also incorporated a disk brake on its high speed output shaft to allow the pump to be slowed down to a complete halt. Since this installation was originally supplied without an automated cutting tool system, the idea was to use the brake to reduce pressure to zero during manual cutting tool switching operations without having to turn off the motor. A disk brake, which was mounted at the flange of the coupling hub, incorporated an actuator, disk, shoe, and console. Its installation resulted in about 10 percent additional reduction of power consumption because at 0 rpm, only windage of the coupling needs to be considered to calculate power at the motor shaft. In the end the EPC and end user felt that losses at minimum idle speed (no load condition) were sufficiently low and not significant over the life of the equipment when compared to the added capital costs of a soft starter, coker duty motor, external lube oil console and the potential reliability issues related to the intermittent operation of the motor and pump.

Figure 7. Water Jet Pump Train with Variable Speed Geared Coupling.

It is important to mention that the hydraulic decoking system at this refinery was upgraded two to three years after its first commissioning to include an automated switching tool. As a result of this upgrade the brake was no longer used for the tooling change. The decoking control valve was instead used to drop system pressure to allow for the change to automatically occur and permit recirculation to the water tank until cutting was resumed. However, the brake is still used during idling operations (noncutting periods) and it is also part of the logic as a permissive to start the water jet pump.

Table 2 shows the operation of the variable speed geared coupling at this installation based on available service and maintenance data. The plant operators feel that the HVSD has contributed to the reliability of the train because this site has not experienced any problems related to the motor or any start up and inrush current issues existing at other sister refineries. Due to the fact that a synchronous motor was selected to drive the pump, this provided for a power factor correction when the water jet pump motor was not connected to a load. Also, during these idle periods this motor could supply reactive power required by induction motors in the refinery. One problem reported on the VSGC actuator was addressed during the noncutting cycle of the pump resulting in no down time for the system. At press time, operators were trying to find out causes for slightly higher levels of lube temperature and vibration on the VSGC. Although these levels are not considered serious and are within the allowable limits, they may be an indication that lube oil coolers may require inspection and cleaning and that after almost 10 years from shipment and eight years of continuous operation the bearings may need to be inspected. The operators at the plant indicated that the pump and decoking valve problems were associated with water quality and issues with changes in the process. There was a report of change in the feedstock quality and quantity to this refinery that it is believed to have affected the operation of the system and some of the reported problems. At the time this plant was visited by the author the pump was operating at about 85 percent of design speed. Having HVSD allowed the plant to operate more efficiently at part load than if throttling would have been implemented. The possibility of changing the logic and operating philosophy was discussed with operators with the aim of extending the life of the decoking control valve by reducing the pressure differential during mode switching. Because there were reported problems with the decoking control valve but very little data available at the refinery on the cause of those problems, the thinking of operators is that by reducing the speed of the pump to reduce the system’s water pressure immediately before switching from boring to cutting could result in a lower pressure drop across the valve. The expectation is that this would alleviate the work performed by the valve and as a result extends its life.

Table 2.

Motor	**Synchronous 4 pole Motor, V: 13200; 5000 HP; SF:1.0.**
Decoker Jet Pump	**Multistage Centrifugal , Severe Service , Double Case Barrel Type.**
Geared Variable Speed Coupling (VSGC)	**510 mm wheel profile diameter for fluid coupling and parallel shaft gear with 450mm axle distance for spur gear stage.**
Rating	4120 HP , 1800/4281 RPM.
Start of Commercial Operation	August 19, 2002.
Operation Time	Approximately 61,300 hours operating at full speed around 6 hours per day (2 to 3) intervals and 18 hours per day at idle speed.
Reported Problems since Start of Commercial Operation	
VSGC	Actuator malfunction and high lube oil temperature.
Motor	No problems reported.
Pump	No data provided.
Decoking Control Valve	4 problems reported. In all 4 instances the valve was replaced.

APPROACHES AND FUTURE CONSIDERATIONS

These two cases showed two different operating configurations and philosophies. The smaller plant with the VSC turns off motor during noncutting periods and only uses the fluid drive to reduce the speed of the pump (to reduce nozzle pressure) during manual cutting tool mode switching operations and also as a soft starter. The smaller plant also does not incorporate a decoking control valve. The larger plant incorporates a decoking control valve and uses the VSGC to reduce speed of pump during noncutting periods (idle time) and for startup purposes. A new delayed coker project, currently in construction, which is larger in size than the one described in case 2, is incorporating a VSGC coupling to drive the coke cutting pump. The drive will be used to reduce speed of a 5700 hp pump during noncutting cycles (Figure 8). The argument to select it was to avoid intermittent operation of a 6000 hp motor-pump train and the reliability issues related to turning off and on a motor of this size in a periodic fashion. Engineers involved with the project felt that keeping the motor and pump in hot running conditions all the time was more favorable because, for such a large system, subjecting the pump and motor to periodic starts could contribute to accelerated wear of components and create a potential for particle settling if the pump speed was brought to zero. For this reason a brake was not included with this system. Additionally, engineers indicated that other alternatives were evaluated such as coker duty motors, soft starters, and VFDs but these represented a larger capital cost investment than the chosen HVSD and standard motor configuration.

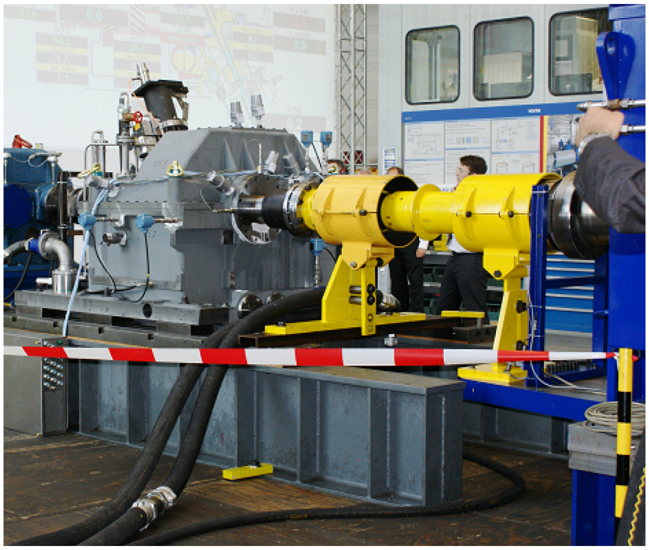


Figure 8. 5700 HP Variable Speed Geared Coupling at Test Stand.

The fact that hydrodynamic variable speed drives were utilized for different reasons at these plants can provide proof that these drives give the operators more flexibility to operate the hydraulic decoking equipment in many different ways. The HVSD can be adapted according to the needs of the operators depending on the configuration of the system, coking cycle times, and size of water jet decoking pump. Since new hydraulic systems will most likely incorporate automated combination cutting tools and the trend is to build large capacity systems that require high pressures pumps with high power consumption, the next step in the application of HVSD to water jet decoking pumps is to optimize their implementation. One area that deserves more investigation is the implementation of synchronous motors in combination with these drives to improve the power factor of the whole distribution system at a refinery. Since these motors are at times connected to no loads (especially when brakes are used) they could be used for power factor correction. Also, more thought needs to be given to using these drives to extend the life of the decoking control valve by reducing speed of the pump during tool switching thus reducing pressure differential across the valve or possibly altogether eliminating the decoking control valve as it was shown in case 1. The drive could be used to control water pressure reduction required for tool switching and a simpler bypass valve used to recirculate to the cutting water tank.

One subject that has not been mentioned but that also deserves future investigation is the use of HVSD to seamlessly adjust cutting pressures to prevent coke pulverization. An HVSD can control speed of a pump with 1/10 percent degree of accuracy so pressures could be adjusted precisely according to the type of coke being produced. One condition that operators like to avoid is pulverizing coke because of the problems this can create with regards to maintenance and coke handling. Delayed cokers with varying types of feedstock could benefit from having an HVSD because it allows the pump to more efficiently adapt to cutting requirements and the plant to have more operating flexibility to handle different conditions. Plant operators and engineers designing these plants would have to devise a procedure to detect the grade and softness of coke being produced to automatically set the ideal cutting pressure to produce a product that is of optimum quality.

HVSDs are typically chosen for reliability and flexibility advantages they offer operators of hydraulic decoking systems. However, regardless of the manner in which an operator decides to run the jet pump, speed regulation, as a general rule, can also be beneficial to the performance and service life of the motor and pump. It is a well-known fact that high speeds can result in potential pump seal wear because of excessive heat generation between seal faces through rubbing contact. So the ability to lower the speed of a pump can extend the life of the pump and its components. Operating at high speeds can also result in excessive heating of the lube oil that can reduce its viscosity over time and lower the lubrication of the pump bearings. Also, as it was demonstrated in case 2, in an unpredictable situation where the capacity of the pump needed to be reduced, variable speed operation offered the job site power savings by not having to throttle this capacity with a decoking control valve.

CONCLUSION

Although electric motor-driven water jet coke cutting pumps are not commonly known to require or implement speed regulation, the examples given show that for large systems hydrodynamic variable speed drives can provide a reliable alternative to the operation of these pumps under intermittent off and on configuration. For example, in case 2, it could be seen that although some of the jet pump and decoking valve problems could be attributed to water quality and process changes at this refinery, the motor and VSGC exhibited no downtime. For the smaller system under intermittent operation described in case 1, a hydrodynamic variable speed drive can also be adapted to help with unloaded start-ups and water pressure control. For neither case 1 nor case 2, the refineries were able to provide respective jet pump bearing life or pump MTBF data to see if the variable speed drives directly contributed to improvement in those areas. However, operators believe that by avoiding repeated axial loading on pump bearings and water hammer conditions that happen during start ups, accelerated wear of these components is being prevented with these drives. An HVSD can help to eliminate the reliability issues associated with operating these pumps intermittently and also provide the operator with the already enumerated functional advantages like the flexibility to efficiently operate the pump at different speeds according to the system's pressure requirements.

The capacity and type of coker, the number of drums, size of drum, and coking cycle times will certainly influence the overall design of the hydraulic decoking systems and the selection of a water jet pump train. It is recommended that the designer of such a system takes into consideration the jet pump horsepower requirements, cutting pressures, and idle times, to determine if an HVSD can be technically and financially justified. A life cycle cost analysis that considers such factors as initial equipment cost, energy cost, operating cost, downtime, maintenance costs, and installation and commissioning time, can be used to compare the various drive alternatives to determine the best solution for the particular system.

Finally, more investigation is needed to look at the implementation of an HVSD to extend the life of the decoking control valve or possibly substitute it for a simpler bypass valve. The nozzle pressure changes can be controlled by varying the speed of the pump so cutting pressures can be adjusted to adapt to the type of coke being cut to prevent pulverization.

NOMENCLATURE

ASD	= Adjustable speed drive
HVSD	= Hydrodynamic variable speed drive
MTBF	= Mean time between failure
VFD	= Variable frequency drive
VSC	= Variable speed turbo coupling
VSGC	= Geared variable speed turbo coupling

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