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DOE/GRI Development and Testing of a Downhole Pump for Jet-Assist Drilling

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CONTRACT INFORMATION

Contract Number DE-AC21-94MC31198

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Period of Performance Sept. 30, 1994 to Nov. 30, 1996

Schedule and Milestone

FY95 Program Schedule

	O	N	D	J	F	M	A	M	J	J	A	S
Market Evaluation	—	—	—	—								
Design				—	—	—	—	—				
Fabrication								—	—	—		
Laboratory Testing											—	—

OBJECTIVES

The objective of this project is to accelerate development and commercialization of a high pressure downhole pump (DHP™) to be used for ultra-high pressure, jet-assisted drilling. The purpose of jet-assisted drilling is to increase the rate of penetration (ROP) in the drilling of deeper gas and oil wells where the rocks become harder and more difficult to drill. As a means to accomplishing this objective, a second generation commercial prototype of a DHP™ is to be designed, fabricated, tested in the laboratory, and eventually tested in the field.

BACKGROUND INFORMATION

During the late 1980s and early 1990s, FlowDril developed the FlowDril System®, a surface based high pressure pumping system with a dual conduit drill string for ultra-high pressure, 234 MPa (34,000 psi), jet-assisted drilling of gas and oil wells. The FlowDril System® has been described in part by Butler et al. (1990), Cure and

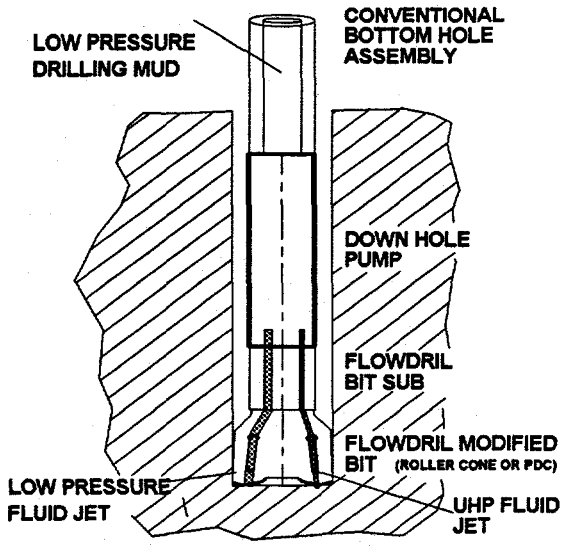

Figure 1. Jet-Assisted Drilling with a Downhole Pump

Fontana (1991), O'Connor and Scott (1991), and Veenhuizen et al. (1993). During field trials, this system was able to achieve reliable operation with ROP enhancements between 1.5 and 2.5 times conventional rates. However, due to the cost of the system, it had a limited market.

In late 1993, FlowDril and the Gas Research Institute (GRI), based on the technology developed in pumping and sealing high pressure drilling mud with the FlowDril System®, began development of a downhole high pressure pump (DHP™) for jet-assisted drilling. This approach is illustrated in Figure 1. The DHP™ is located in the conventional drill string just above the jet-assisted drill bit. The power to drive the DHP™ is provided from the mud stream pumped downhole through the drill string. Conventional flow rates are used but pressure at the rig pump is increased up to about 13.8 MPa (2,000 psi) above typical surface pressures. The size of the DHP™ is about the same as a conventional drill collar and is handled by the rig similar to a drill collar. An experimental field prototype DHP™ has been designed, fabricated, and has undergone testing in the laboratory. A market analysis indicated that the DHP™ should be sized for either 200 mm (7-7/8 inch) or 216 mm to 222 mm (8-1/2 inch to 8-3/4 inch) hole size. A 222 mm (8-3/4 inch) hole size was selected for the experimental prototype at the beginning of the design phase as it was thought that the technology would be easier to develop and demonstrate in the larger hole size and while still responding to a significant market segment.

The first field experiment with the DHP™ was conducted in January of this year at AMOCO's Catoosa Drilling Test Facility in Oklahoma. Photographs of it being picked up by the rig at Catoosa are shown in Figure 2 and Figure 3. The ultra-high pressure, jet-assisted drill bit used is shown in the photograph in Figure 4. The objective of this first experiment was to evaluate the dynamic wear and loading on various components within the DHP™ in a downhole environment. Particular interest was with centralizers in the pump and accumulator sections, and with the high pressure plungers under combined pressure and g-loads. Additional interest was in whether or not the pump operated normally when stressed

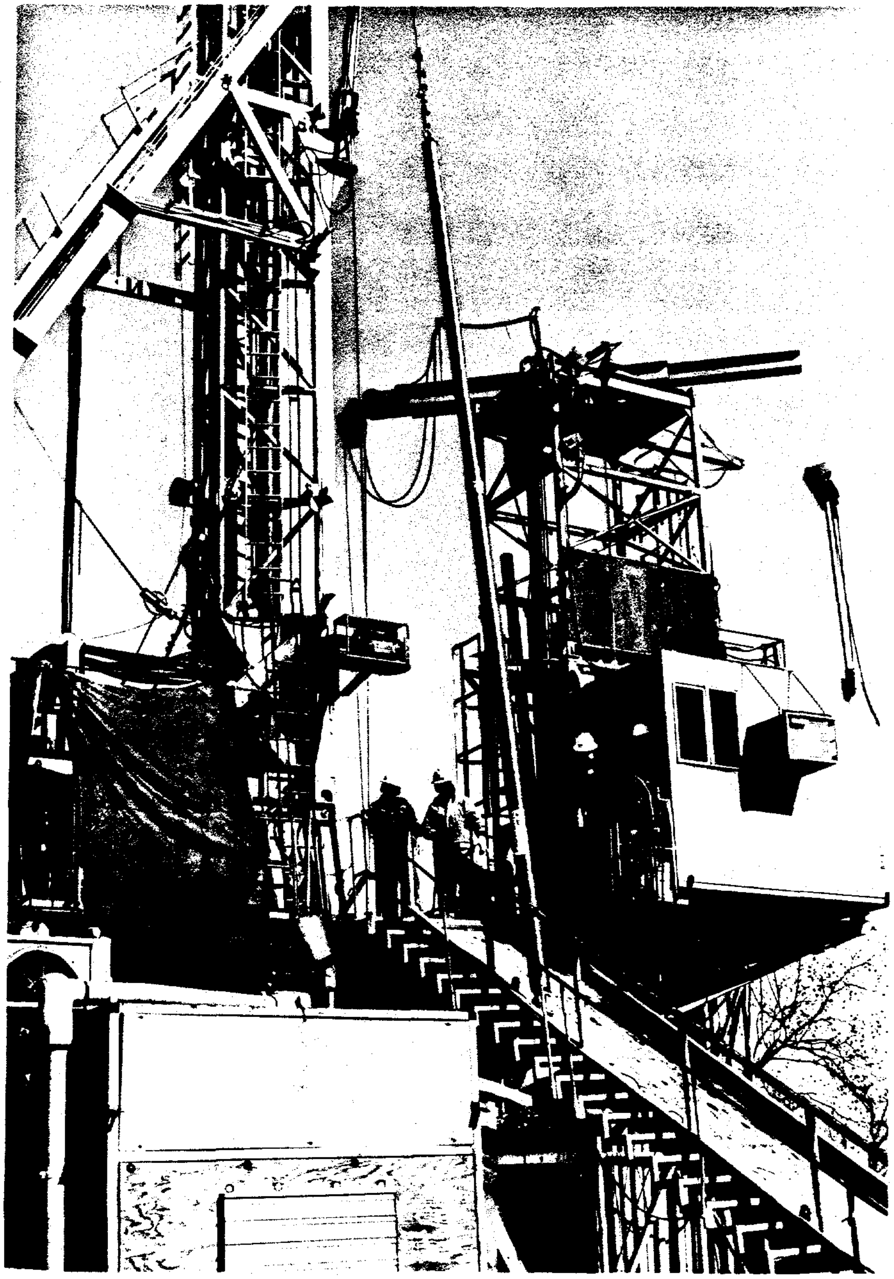

Figure 2. The FlowDril DHP™ Being Picked Up by the Rig During First Field Experiment, Catoosa, OK

Figure 3. The FlowDril DHP™ Being Brought onto the Rig Floor

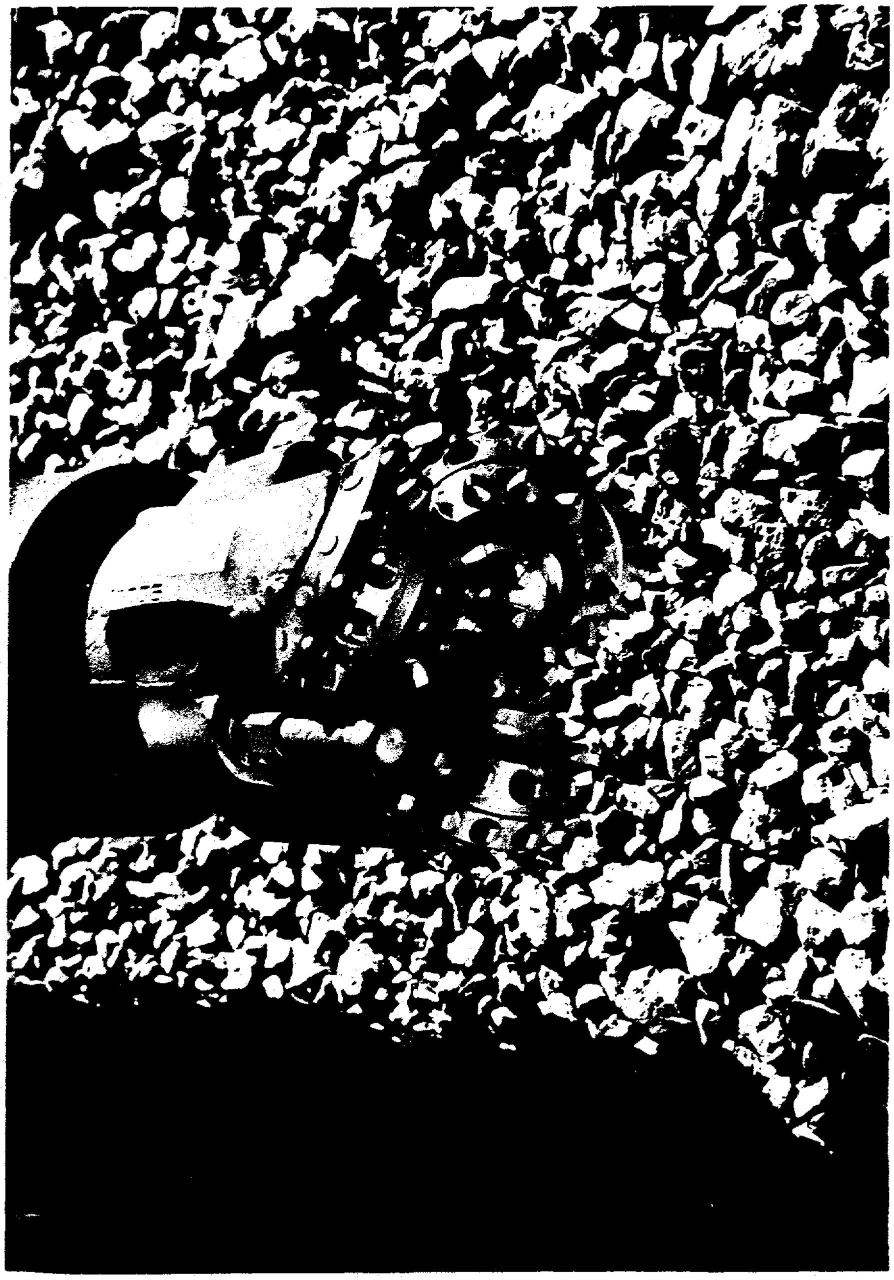

Figure 4. The FlowDril DHP™ Ultra-High Pressure Nozzle on Drill Bit

downhole with weight on the bit, and whether the by-pass valve would operate consistently and was compatible with rig and drilling operations.

Results of a thorough examination of the DHP™ in the laboratory after the experiment at Catoosa revealed that there was very little wear or vibration effect, and no apparent erosion on any of the pump components, with exception of those associated with a low pressure seal failure. The low pressure static seal that failed prevented operation of the pump at full output pressure after the first 45 meters (150 feet) of drilling. It was believed to have been damaged during assembly before being sent to the field. This problem had been experienced previously during laboratory testing and the design had been changed, but not implemented before the field experiment.

The by-pass valve, used to by-pass the pump section during circulating periods, operated consistently and satisfactorily throughout the experiment. Large drill cuttings were found inside the pump housing above the pump section, and inside the drive section of the pump. These are believed to have entered through the conventional bit nozzles during connections or during tripping, and can be prevented by using a conventional float valve in the drill string.

Although not part of the objectives of field experiments with the DHP™, ROP as well as drilling parameters were measured. A plot of these data for most of the period during which the DHP™ was capable of a full 200 MPa (29,000 psi) output pressure is shown in Figure 5. With ultra-high pressure jet-assist and the softer formation, the bit drilled the first 6 meters (20 feet) in 4 minutes, or an ROP of 91 m/h (300 fph). This is an ROP 2.6 times that of the offset hole, DM-2, drilled conventionally with a comparable bit with more than twice the bit weight. If adjustments for weight on bit and rpm are made, the jet-assist ROP was about four to five times the conventional ROP. This kind of ROP enhancement, it must be noted, is indicative of an ultra-high pressure jet that is cavitating because of the shallow depth and is therefore much more effective than would be expected at deeper well depths where cavitation does not occur. At deeper well depths where the DHP™ would normally operate, an ROP increase of 1.5 to 2.5 times conventional is to be expected. During the experiment, the fast ROP caused concern that the hole annulus was being over-loaded with drill cuttings and might cause sticking problems, and that the bit was being over-drilled and might cause hole deviation problems. As a consequence of these concerns, ROP was limited to about 46 m/h (150 fph) by controlling weight on bit for the remainder of the experiment.

Plans for the experimental field prototype DHP™ are for continued laboratory testing and additional field experimentation. A second field experiment is planned for March of this year. It will be in a 250 mm (9-7/8 inch) hole. It will be at a depth of about 1900 meters (6,200 feet) in an East Texas commercial gas well to be drilled for Union Pacific Resources. The objective of this field experiment will be to establish the strengths and weaknesses of the experimental field prototype DHP™ design as a basis for continued design improvements.

PROJECT DESCRIPTION

To accelerate development and commercialization of the DHP™ technology for ultra-high pressure, jet-assisted drilling, FlowDril has contracted with DOE to develop and test a commercial prototype DHP™. The DOE project is outlined by the following:

- Market Evaluation
- Design
- Fabrication
- Laboratory Testing
- Field Prototype Design and Fabrication
- Field Prototype Testing

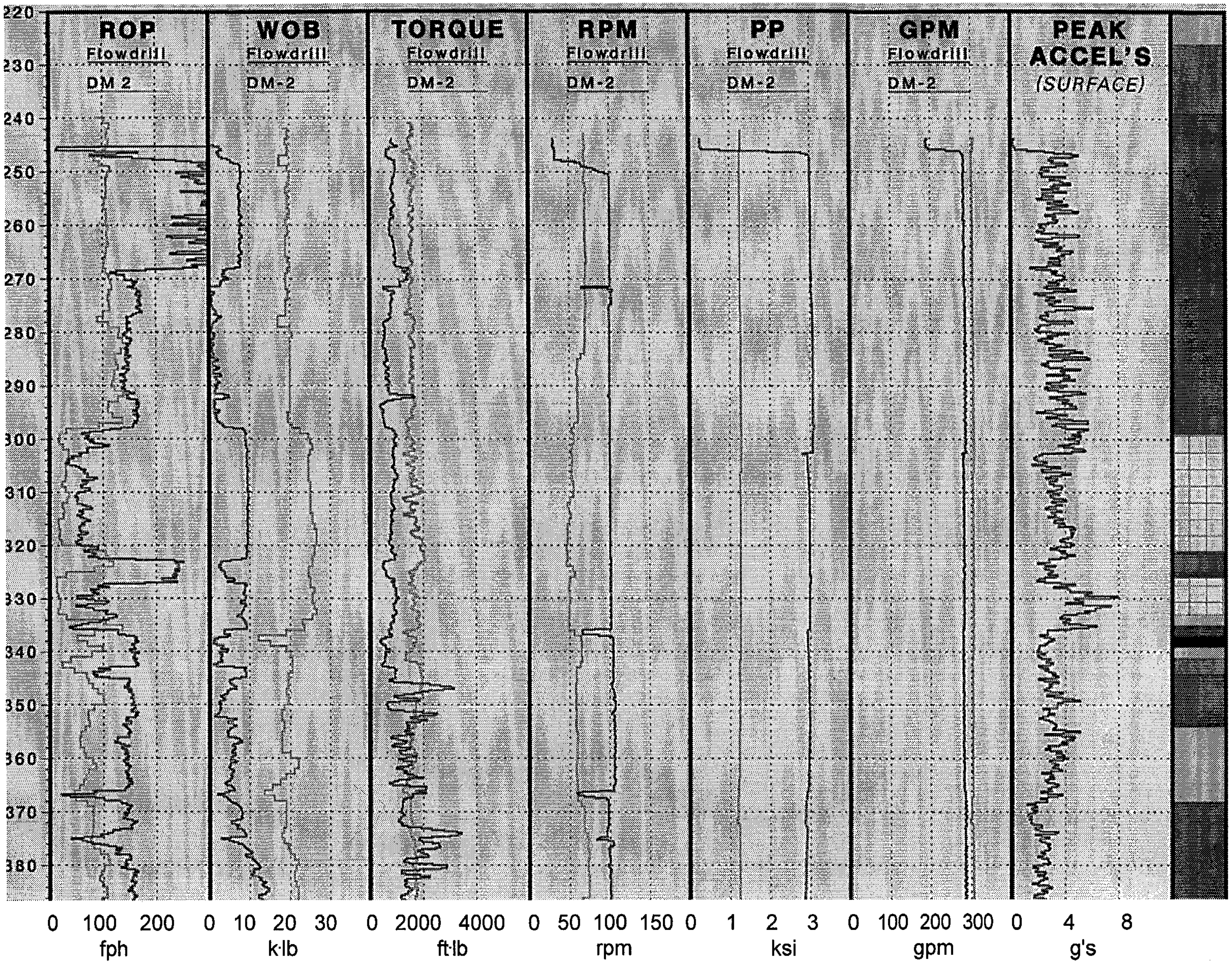

Figure 5. Drilling Parameters, First Field Experiment FlowDril DHP™, Catoosa, OK

Table 1.
U.S. DHP Market Size

Hole Size	DHP™ Annual Market Size(Revenue)
311 mm (12-1/4")	$12.4 million/yr.
240 - 250 mm (9-1/2" - 9-7/8")	$47.6 million/yr.
216 - 222 mm (8-1/2" - 8-3/4")	$58.0 million/yr.
200 mm (7-7/8")	$76.6 million/yr.
152 - 170 mm (6" - 6-3/4")	$11.4 million/yr.
120 mm (4-3/4")	$ 4.0 million/yr.

The purpose of the market evaluation is to define the hole size for the DOE commercial prototype DHP™ that best responds to the market place for domestic gas and oil well drilling. Hole sizes from 4-3/4 inch slim-hole size up through conventional surface hole sizes are considered. The detailed design is to be a commercial prototype design that is an improvement over the experimental prototype design. The DHP™ components designed and fabricated for testing in the laboratory will be field grade commercial prototype components, but only the actual pump section will be completed for laboratory testing. The remainder of the complete commercial prototype DHP™ to enable field testing is to be completed under field prototype design and fabrication which remains at the discretion of DOE pending results from laboratory testing.

RESULTS

A market analysis by Veenhuizen and O'Connor (1993) using 1992 data indicated that about a $200 million annual market exists for jet-assisted drilling using the DHP™ in the drilling of deeper gas, oil and dry wells in the US. For only gas wells, there is about a $74 million annual market. Estimated savings to the drilling industry, assuming a two times conventional rate of penetration, were $173 million and $42 million annually for all drilling and for only gas drilling, respectively. The hole size for which the largest DHP™ market was identified was 200 mm (7-7/8 inch), with 216 mm to 222 mm (8-1/2 inch to 8-3/4 inch) being the second largest.

The market analysis was revisited to re-assess market size by hole size. An emphasis was an examination of potential market for DHP™ jet-assist drilling at slim-hole sizes up to 6-1/8 inch sizes. Drilling smaller size holes with coiled tubing was included as a subset of slim-hole drilling. Results by hole size from the updated market analysis are tabulated in Table 1. The 6 inch to 6-3/4 inch hole size range consists primarily of 6-1/8 inch and 6-1/2 inch. The market size shown for 4-3/4 inch is all slim-hole drilling and is the estimated maximum market size for 1995. It is expected to grow to $8 million - $10 million by the year 2000, but still remain less than for other hole sizes.

As shown in Table 1, the largest market and corresponding savings to the drilling industry is expected to be for 200 mm (7-7/8 inch) hole size. Accordingly, with the experience from the experimental design, and to accelerate commercialization of the DHP™ technology, the DOE second generation commercial prototype DHP™ is sized for a 200 mm (7-7/8 inch) hole.

The DOE commercial prototype DHP™ will be based on the same concept as the

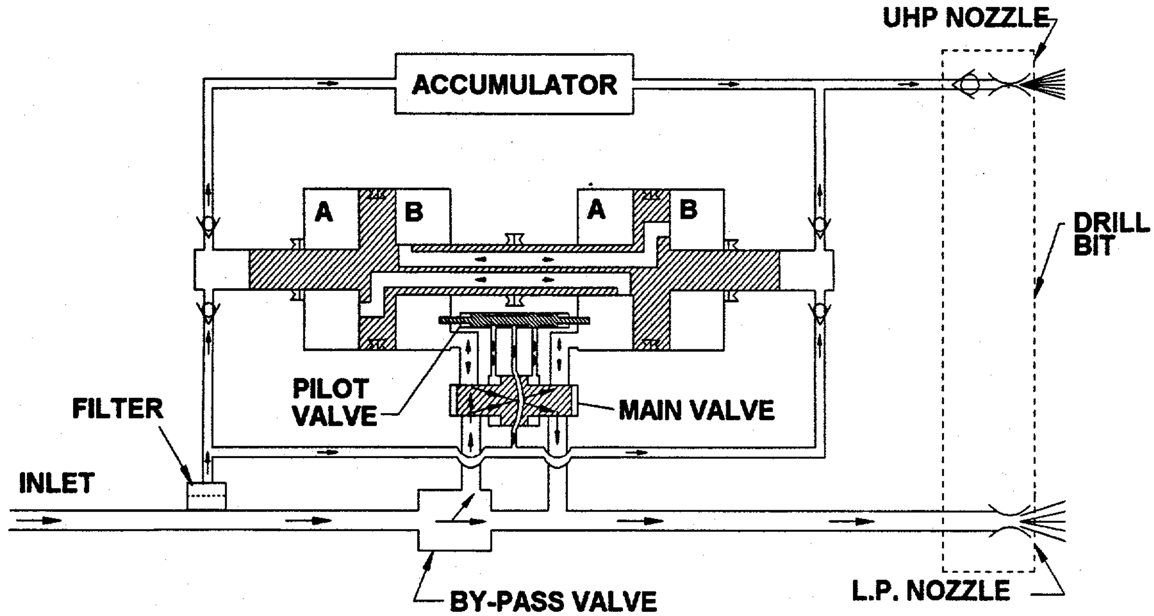

Figure 6. FlowDril Downhole Pump Concept

experimental prototype. The concept, illustrated in Figure 6, utilizes a reciprocating intensifier style high pressure pump. With the by-pass valve closed, the drive fluid passes through the main four-way directional control valve and is directed to either the "A" side or the "B" side of the low pressure drive pistons. The larger diameter drive pistons and the smaller diameter high pressure plungers are connected and form the main assembly that reciprocates back and forth in the pump. When the drive piston/plunger assembly reaches the end of its travel, a trigger mechanically activates the pilot valve, which in turn shifts the main valve, re-directing the drive fluid from "A" to "B", or "B" to "A", driving the drive piston/plunger assembly in the opposite direction. When the by-pass is closed, all of the fluid is directed into the drive section of the DHP™, except that which is drawn off through the self-cleaning filter to become the high pressure fluid output of the pump. The output pressure of the DHP™ is determined by the drive fluid pressure and the ratio of the area of the larger diameter drive pistons to the smaller diameter plungers.

During periods of circulating downhole, the by-pass is open and the pumping section does not generate high pressure. The purpose of the accumulator is to maintain flow of high pressure fluid through the ultra-high pressure (UHP) nozzle during the change in stroke direction when the drive piston/plunger assembly momentarily stops.

The arrangement of the basic components within the DOE commercial prototype design with four drive pistons is shown in Figure 7. To reduce the outer diameter to 171 mm (6-3/4 inch) for the smaller diameter hole requires increasing the number of low pressure drive pistons from three to four. The DOE design of the DHP™ will use the same internal fluid porting scheme, but the main valve will be an alternative design that reduces internal pressure losses through the pump. This will lead to a better overall pump efficiency. The pilot valve will be of a more compact design, allowing more flexibility in space utilization within the control valve manifold. The housing will be a single piece that includes the accumulator and pump instead of the three piece design of the experimental design. Incorporating the accumulator into the upper end of the housing will allow the overall length to be shortened from 10 meters (33 feet) to about 7.6 meters (25 feet). The most notable differences will be a smaller outside diameter, shorter overall length, and the addition of a fourth drive piston in the low pressure drive section. The main features of the DOE design are summarized below.

- Outer Diameter 171 mm (6-3/4") for 200mm (7-7/8) Hole
- Drive Pistons 4 instead of 3
- 1-Piece Housing with Integral Accumlator instead of 3-Piece
- Overall length of 7.6 meters (25 feet) instead of 10 meters (33 feet)
- More Compact Pilot Valve
- Alternate Main Valve Design
- Fewer Parts, Fewer Seals
- Better Efficiency

The general specifications for the DOE and for the larger experimental design are shown in Table 2. Both are designed to produce an output pressure of 207 MPa (30,000 psi). Because a smaller hole size requires less flow of drilling fluid, the DOE design will produce less output flow than the pump for the larger hole size. The higher average efficiency for the DOE design is primarily the result of the fourth drive piston and a more hydraulically efficient main valve.

FUTURE WORK

The design of the DOE commercial prototype DHP™ is currently in progress. The layout of the complete DHP™ is expected to be completed by mid-April. Fabrication and laboratory experimentation is expected to be completed in September. Pending successful completion of the laboratory testing phase, the DOE commercial DHP™ should be ready for testing in the field by the end of the calendar year.

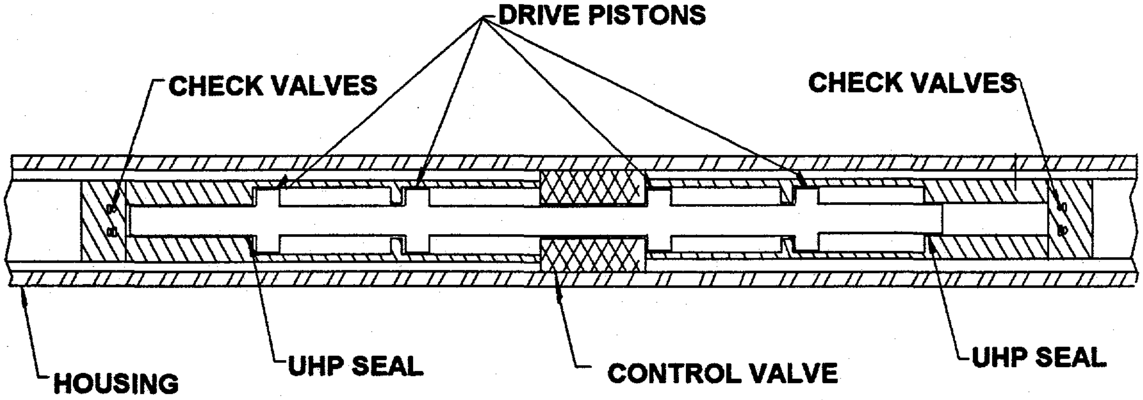

Figure 7. Arrangement of Basic Components within the DOE/FlowDril DHP™ Showing Four Drive Pistons

Table 2.
DOE/ FlowDril DHP™ Specifications

	DOE Tool	Experimental Tool
Bit Diameter	7-7/8"	8-3/4"
Length	25' 1-Piece	33' 3-Piece
DHP Outside Diameter	6-3/4"	7-5/8"
Area Ratio	14:1	14:1
Maximum Output Pressure*	30,000 psi	30,000 psi
Maximum Output Flow*	19.7 gpm	23.6 gpm
Average Efficiency*	72 %	69 %

* 10,000 feet, 45,000 lb WOB, 9.5 ppg mud

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