HydroPulseä System Test (Chehalis-I)

Field Test Report Prepared for
U.S. Department of Energy, Federal Energy Technology Center
By Tempress Technologies Inc.
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Introduction

The first full-flow tests of the HydroPulse™ system were carried out on December 1, 1999 at Taylor Drilling near Chehalis Washington. The objective of full-flow testing is to evaluate tool reliability in a realistic environment. The tests were carried out at full flow inside a pressurized length of tubing. Specific test objectives, test setup, instrumentation and test results are discussed below.

Objectives

In order of priority, the objectives were as follows:

1. Demonstrate valve cycling at 400 gpm flow with a roller cone bit operating at 500 psi differential pressure.
2. Demonstrate generation of 700 psi pressure pulses around the bit.
3. Evaluate effects of nozzle configuration on performance.
4. Demonstrate 1 hour of valve operation at 400 gpm on Bentonite mud.

Test Setup

The test setup is shown in Figure 1. Taylor Drilling provided the mud pumps and fabricated the test setup including piping, choke valve and mud tanks. The HydroPulse™ tool was placed inside a pressure vessel designed to simulate a borehole. An 8-3/4” roller cone insert bit was attached to the valve discharge to simulate a complete bottomhole assembly. Mud was provided by a 400 gpm, 2000 psi triplex mud pump. Initial tests were carried out using water at flow rates ranging from 150 to 400 gpm.

At 400 gpm, the valve requires approximately 200 psi pressure drop for actuation at a cycle frequency of 30 Hz. The mud discharges through nozzles on the bit into the test chamber. A choke valve on the test chamber discharge allows control of pressure around the bit and HydroPulse™ valve housing. The choke valve outlet was connected to a 25 foot long length of 2” ID piping for return to the mud tank.

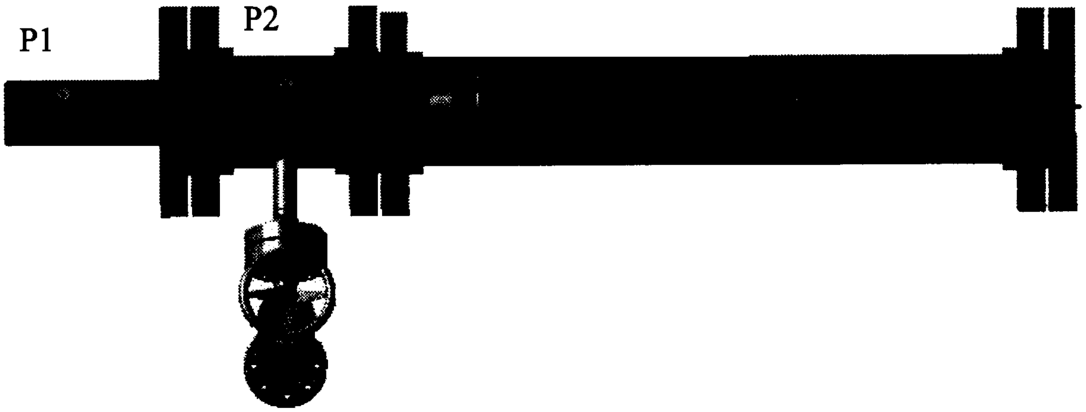

Figure 1. Test Setup.

Instrumentation

Pressure upstream and down stream of the valve were recorded during testing. Data was acquired on a laptop computer equipped with a DAQ PC card capable of 100 kHz acquisition rate. Transducer specifications are listed in Table 1. Pressure sensor locations are shown in Figure 1. One pressure transducer (PI) monitors pressure upstream of the valve. The second transducer (P2) will monitor pressure downstream of the tool, just before the choke. A third, dynamic transducer (P3) was used to record pressure pulses beneath the bit.

Table 1. Pressure transducer specifications.

P1 & P2	Sensotec TJE 743-06, 5000 psig	1.38 MPa/V	200 psi/V
P3	Kistler 5118-A2, 10,000 psi	12.63 MPa/V	1832 psi/V

Flow rate observations were based on counting pump strokes. The flow rate is 2.39 gallons per stroke. Flow rates were increased in nominal increments of 50 gpm and system pressures were recorded for 0.2 s. The tool configuration and operating parameters for the tests is summarized in Table 2. The flow course volume is calculated from the annular clearance and tool length. The bit volume was measured directly.

Table 2. Tool Configuration

Bit	8.75” J44 Insert Roller Cone
HydroPulse housing diameter	8.105”
Radial clearance	.325”
Flow course sectional area	8.54 in^2
Flow course volume	364 in^3
Bit volume	313 in^3

Test Results

The tool was first connected to the pumps and cycled in the open to verify cycling operation. Figure 2 shows mud pulses from the tool at a flow rate of around 300 gpm. The tool was then placed inside the pressure vessel as shown in Figure 3.

Figure 2. Open cycling of HydroPulse® tool.

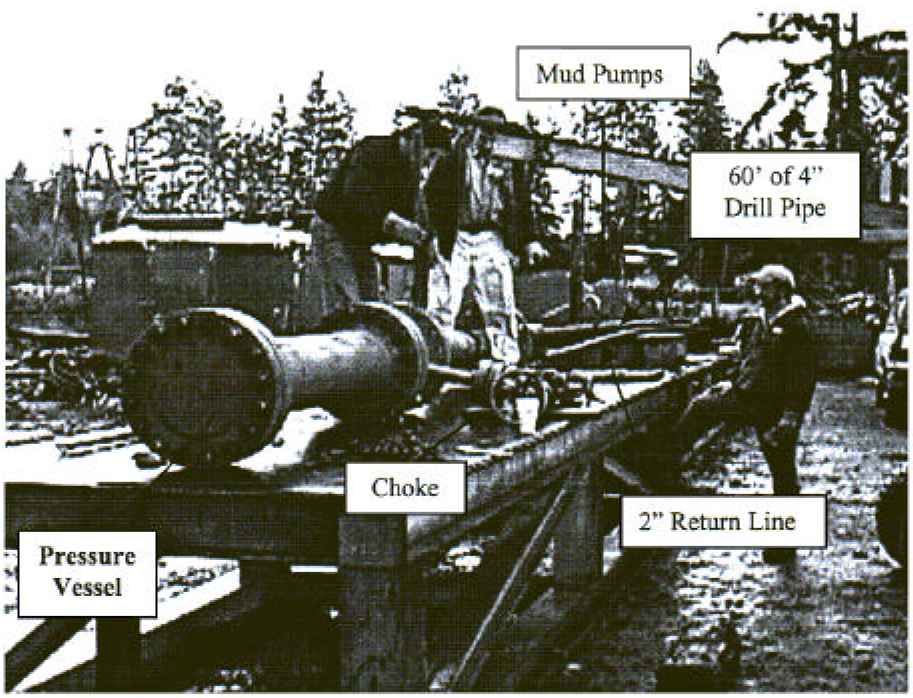

Figure 3. Installation of HydroPulse® Tool in Pressure Vessel.

Test Results

Two HydroPulse™ tool configurations were tested. In both tests the bit nozzles were sized for 500 psi pressure drop at 400 gpm (3 x 15/32" nozzles). In the first test, the valve discharge was equipped with a single 11/32" nozzle. In the second test the valve discharge had three larger nozzles. A summary of test variables, mean observed pressures and cycle rate is provided in Table 3.

Table 3. Summary Test Results

Nozzles	**Test 1**				**Test 2**	
Bit Nozzles, 1/32"	15, 15, 15				15, 15, 15	
Valve Nozzle, 1/32"	11, 0, 0				12, 13, 13	
Observations						
Test ID	1-1	1-2	1-3	1-4	2-1	2-2
Flow Rate, gpm	136	?	227	323	143	310
Flow Velocity, in/s	61		102	146	64	140
Upstream Pressure (P1)	780	1300	907	1231	1151	-
Choke Pressure (P2), psi	700	1130	600	883	1133	-
Bit Pressure Drop (P1-P2), psi	80	170	307	349	17	-
Pulse Amplitude (ΔP3), psi	470	590	385	900	500	-
Upstream Pulse (ΔP1)I	290	300	1100	800	200	-
Cycle Rate, Hz	7	9	13	18	8	-
Operating Times, minutes	5	5	10	5	60	5

Pulse Amplitude

Figure 4 shows the pressure traces from test 1-4. This data was taken at 323 gpm and shows the highest frequency and pulse amplitude achieved. Both upstream and downstream pulses were larger than anticipated. The downstream pressure goes to zero at the bit and the choke. This pulse amplitude is due to water hammer pressure in the 2" choke discharge line. At 323 gpm this line would generate a 2000 psi pressure spike with a duration of 10 milliseconds, which corresponds with the observed signal. A larger choke discharge line will eliminate this pressure spike.

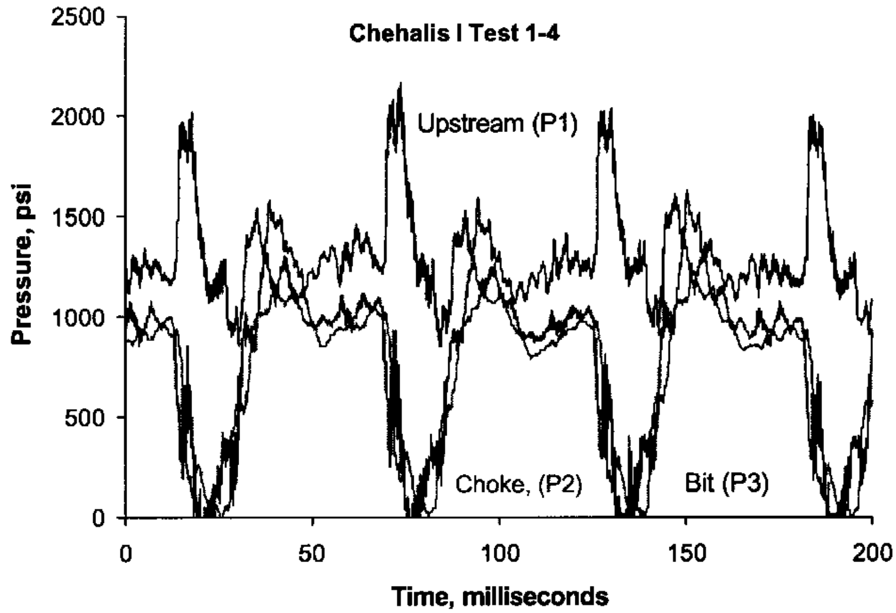

Figure 4. Pressure records from Test 1-4, 323 gpm.

The difference between the choke and bit pressure is the suction pulse associated with flow around the HydroPulse™ tool housing. This pressure difference is shown in Figure 5 for one valve cycle. This is the pulse magnitude that would be expected in a borehole. The pulse has a duration of around 2 milliseconds and an amplitude of about 550 psi (3.8 NTa). It is followed by ringing at a period of 5 ms corresponding to the two-way travel time of a pulse through the length of the pressure vessel. The theoretical pulse amplitude is given by

$$\Delta P = v \sqrt{\boldsymbol{r}_w K_w \frac{V_H}{V_H + V_B}} \ ,$$

where ν is the flow velocity in m/s, ρ_w is the density of the mud, K_w is the bulk modulus, V_H is the volume of fluid in the high speed flow course and V_B is the internal and external volume of the fluid around the bit. The flow rate in test 1-4 was 146 in/s (3.7 m/s). The bit used for these tests has an internal volume of 115 in^3 and an external volume of 198 in^3. The additional volume reduces the pulse magnitude to 73% of the maximum value or 589 psi (4.1 MPa), which is very close to the observed value.

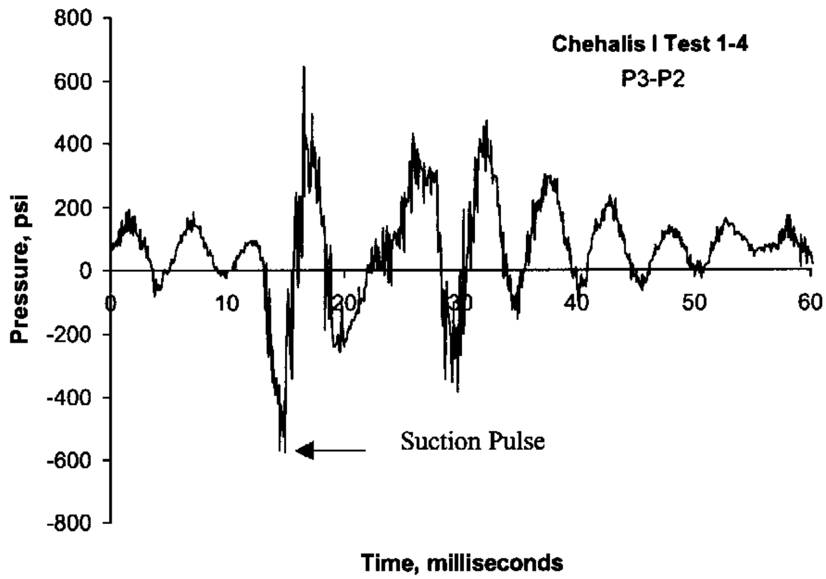

Figure 5. Net suction pulse associated with HydroPulse ã tool from test 1-4. The Interval shown here is equal to one cycle of the valve.

Valve Operation

The valve was operated for a total of around two hours during the field testing, this time includes about 10 minutes at full flow rate. All operation was on water, however the tool did pass a significant quantity of scale and debris from the piping, pumps and open mud tank during testing. During the final test, 2-2, the cycle frequency was observed to change abruptly and the test was stopped. No data was obtained from this test.

When the tool was removed from the pressure vessel, one of the carbide cross-port plugs was found outside of the tool. These are ½" diameter by .125"-thick carbide parts that were used to close off ports in the tool during final assembly. The tool was disassembled and several of the plugs were found to be broken or missing. Loss of the plugs would cause the tool to cycle erratically. At least one of these plugs passed through the tool. The valve spools were inspected and found to have minor chipping damage, which was presumably caused by the passage of carbide fragments through the valve.

The test tool incorporates two elastomeric bumpers and a metal spring bumper to reduce impact loads during cycling. One of the elastomeric bumpers exhibited some damage after testing.

Design Changes for the Next Test

The first full-flow test of the HydroPulse™ tool successfully demonstrated high rate cycling at 323 gpm. A 550 psi suction pulse was generated by interrupting the flow around the tool housing. This pulse magnitude was predicted by theoretical considerations. This test also uncovered design problems with the test setup and the tool that will be corrected before the next test.

1. The flow line from the choke should be at least 6” in diameter rather than the 2” used during the test. This will more closely simulate the flow area and velocities above the tool. A 6” flow line corresponds in area to the annulus between an 8-3/4” bit and a 6” drill collar. The choke will be placed at the end of this flow line. This step should eliminate the high pulse magnitudes observed in the first test, which tend to obscure the pulse generated around the tool housing.
2. The carbide cross port plugs will be replaced with steel plugs and a more secure retaining mechanism.
3. The upstream pressure pulse was significant - over 1000 psi in one test. This pulse could cause fatigue in the drill pipe if not addressed. These high pulse magnitudes are predicted by our model of valve actuation but were not observed on the small-scale tool. A pressure relief valve will be integrated into the upper end of the valve to reduce this pulse amplitude and smooth upstream flow prior to the next test.
4. An alternative elastomer material will be tested for the valve spool bumper. The spring bumper appears to be effective and could be incorporated into this location, however this would involve lengthening the tool housing. We will continue with testing with elastomeric materials although a metal spring bumper appears to be the long-term solution. We will also consider a lighter spool and poppet material to reduce the impact loading and reduce bumper energy absorption requirements.