DOWNHOLE VIBRATION MONITORING & CONTROL SYSTEM

QUARTERLY TECHNICAL REPORT #1

Starting date:	October 1, 2002
Ending Date:	December 31, 2002
Principal Author:	Martin E. Cobern
Date Issued:	February, 2003
DOE Award Number:	DE-FC26-02NT41664
Submitting Organization	APS Technology, Inc. 800 Corporate Row Cromwell, CT 06416

TABLE OF CONTENTS

TABLE OF FIGURES

ABSTRACT

The purpose of this program is to develop the Drilling Vibration Monitoring & Control System (DVMCS) to both record and reduce drilling vibrations in a 'smart' drill string. It is composed of two main elements. The first is a multi-axis active vibration damper to minimize harmful axial, lateral and torsional vibrations, and thereby increase both rate of penetration (ROP) and bit life, as well that the life of other drillstring components. The hydraulic impedance (hardness) of this damper will be continuously adjusted using unique technology that is robust, fast-acting and reliable. The second component is a real-time system to monitor 3-axis drillstring vibration, and related parameters including weight- and torque-on-bit (TOB) and temperature. This monitor will determine the current vibration environment and adjust the damper accordingly. In some configurations, it may also send diagnostic information to the surface *via* real-time telemetry.

Phase I of this program addresses an evaluation of the environment in which the DVMCS will operate; modeling of a drillstring response including the active damper; a top-level design of the mechanical and electronic systems; analyzing the anticipated performance of the damper by modeling and laboratory testing of small prototypes; and doing preliminary economic, market, environmental and financing analyses. This phase is scheduled to last fourteen months, until November 30, 2003.

During this first quarter, significant progress was achieved on the first two objectives, and work was begun on several others. Initial designs of the DVMCS are underway.

NOTE: The Project Officer has requested monthly reports on this program. This report consists of the first two such reports. The first covers October and November, and the second the month of December. They were not prepared in the recommended format, but subsequent quarterly reports will be.

REPORT FOR THE PERIOD OCTOBER-NOVEMBER 2002

Overview

The project is advancing per the original (12-month) schedule. Work on some tasks has begun in advance of the plan. Details of specific tasks, as described in Volume 2 of the application, are summarized below.

Individual Tasks

Analyze requirements for DVMCS using WellDrill[SM]

Review Sources of Vibration

COMPLETE. We have reviewed the major sources of vibration that are likely to influence the bottom hole assembly (BHA) in general and the bit in particular. These were characterized, as described below, by their anticipated frequency range and amplitude. The results for these properties are illustrated below in **Figure 1** and **Figure 2**, respectively.

There are a number of drill vibration sources that could potentially reduce ROP and cause vibration damage to sensors and collars. These are:

Bit excitations from the cones and blades on the bit.

There are multiple cones or blades on the bit. As these travel over discontinuities at the base of the borehole, they produce excitation forces on the drillstring. The excitation is a multiple of the bit speed. For example, a tricone bit has three cones that each strike the discontinuity every revolution of the bit. Therefore a bit rotating at 100 rpm is excited 3 times per revolution, or 300 cycles/min (5 Hz). PDC bits usually have 3 to 8 blades resulting in 3 to 8 excitations per bit revolution.

Tricone bits also have hardened teeth that strike the borehole base as the cones rotate. These also setup drill string excitations based on the number of teeth.

Forward Whirl

Forward whirl is a lateral vibration excited by imbalances within the drillstring. The imbalance may come from machining features of the collar such as hatch pockets, or they may be due to bent collars. The imbalance causes a 1x excitation that may excite lateral vibrations along the drillstring.

Backward Whirl

Backward whirl is cause by the friction between the drillstring and the borehole. If there is sufficient contact force and rotary speed then the collars begin to whirl around the borehole in a counter clockwise direction. The frequency of the whirl depends on the OD of the collars and the ID of the borehole.

Excitation = Collar OD / (Borehole ID – Collar OD)

Mud Motors

Mud motors have an internal rotor that has an eccentric orbit within the stator. This creates an imbalance force on the drillstring. The excitation is a multiple of the motor speed times the number of lobes on the rotor.

Stabilizers

Stabilizers have blades that contact the borehole. The excitation is a multiple of the rotary speed times the number of blades. Straight blades cause more vibration than angled blades.

Stick slip

Stick slip is cause by the friction between the collars or stabilizers and the borehole resulting from the gravitational forces along the drillstring, which may cause the element to hang up. As the drillstring rotates, the drillstring begins to wind up until there is enough force to break free of the friction, then the drillstring spins at a high angular velocity.

Results

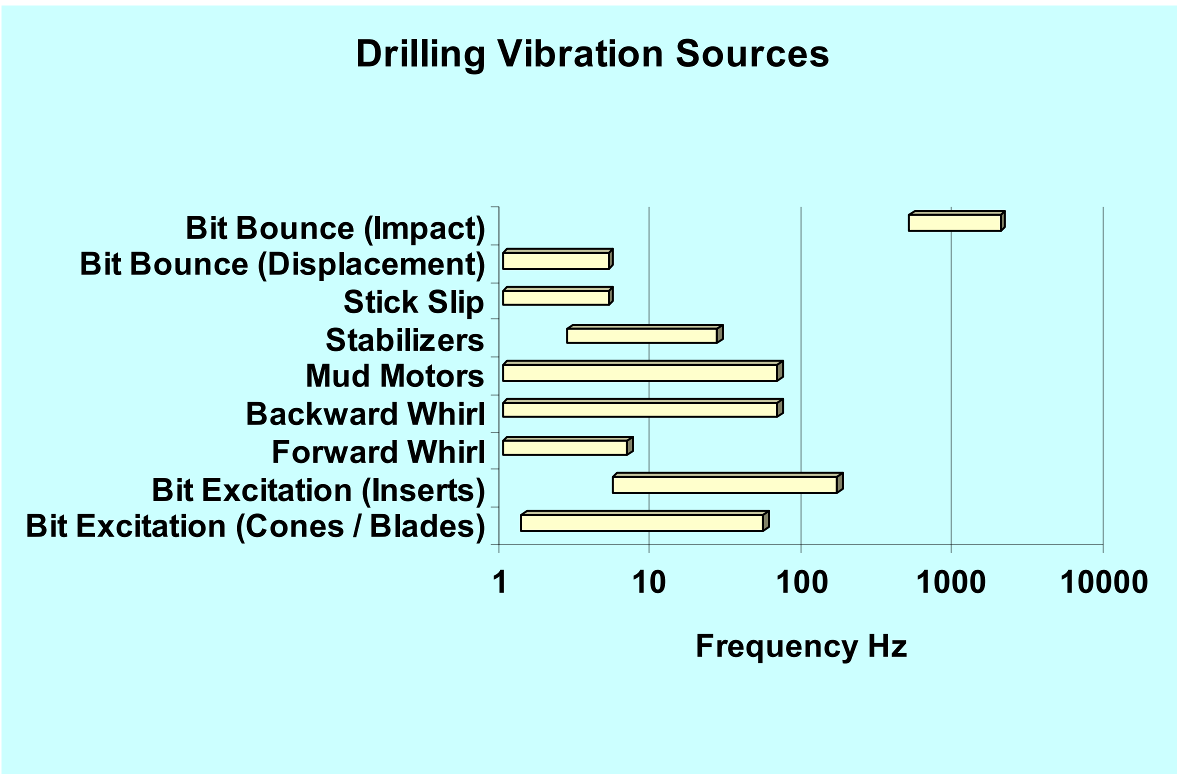

Figure 1: Frequency Distribution of Common Sources of Bit Vibration

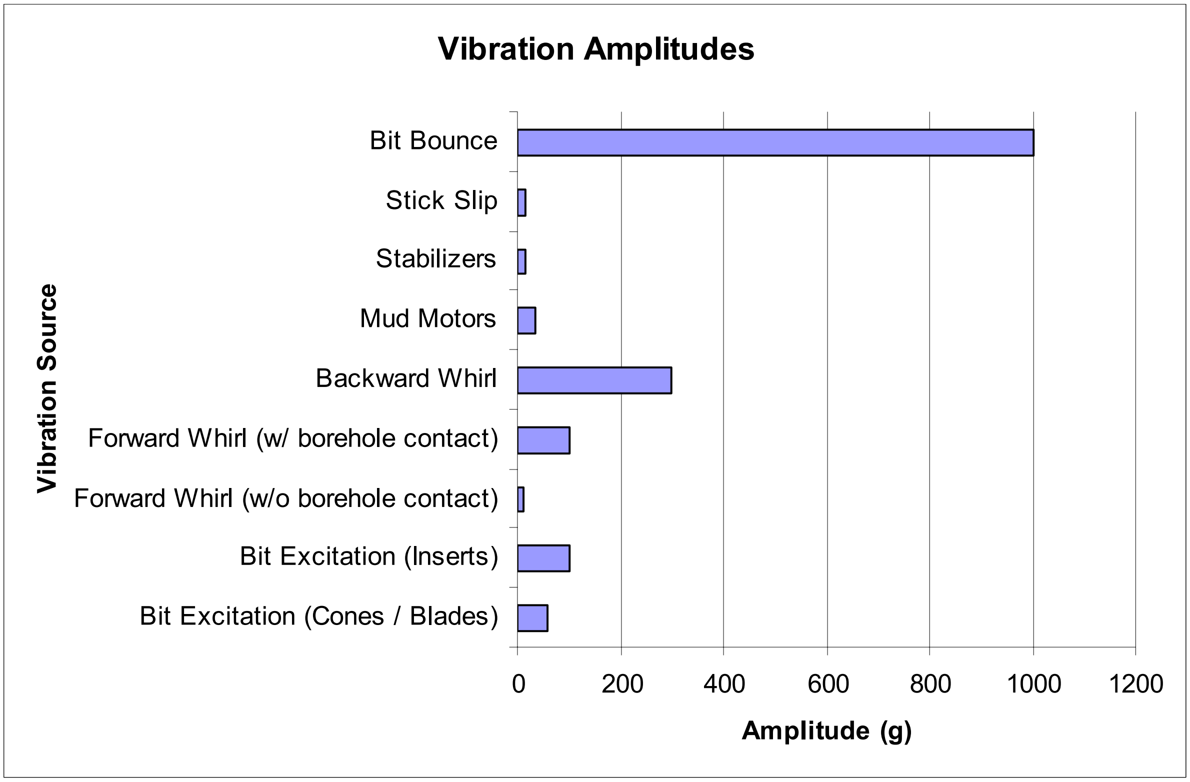

Figure 2: Range of Amplitudes of Common Sources of Bit Vibration

Modify WellDrill program to include MR damper

Work has begun on this task.

Develop specifications for the DVMCS

Preliminary work has begun including, for example, the vibration sources identified above. Completion of this task will require the analysis of the response of the drillstring to the excitations, and the corresponding damping parameters required, both to be derived from the WellDrill calculations above.

Prepare top-level design for the DVMCS

Mechanical

Preliminary sketches of possible MR valve designs and damper concepts have been prepared, in anticipation of the final specifications. We have also outlined a design for the three-axis vibration monitoring system.

Electrical

Preliminary concepts for the monitoring circuitry are being considered.

Analyze design using FEA to predict performance

Awaiting completion of final top-level design, above.

Characterize properties of damper via *testing*

Small-scale models of several valve concepts are being designed.

Complete preliminary economic analyses, etc.

Not yet begun.

Develop preliminary financing plan

Not yet begun.

Complete Phase II development and testing plan

Not yet begun.

Complete Phase I report

Not yet begun.

REPORT FOR DECEMBER 2002

Overview

The project continues to advance per the original (12-month) schedule. Work on some tasks has begun in advance of the plan. Details of specific tasks, as described in Volume 2 of the application, are summarized below.

Individual Tasks

Analyze requirements for DVMCS using WellDrill^{SM}

Review Sources of Vibration

COMPLETE.

Modify WellDrill program to include MR damper

A program has been written to evaluate bit bounce under a variety of drilling conditions. The program utilizes the following inputs:

- A given discontinuity shape and height
- RPM
- Spring rate
- WOB
- Formation dependent ROP
- Damping

It then calculates:

- Percent contact with the formation
- Static compression
- Upward and downward stroke
- Minimum and Maximum WOB for the drilling conditions
- Actual ROP
- Accelerations of bit and drillstring
- Plots of the following *vs*. time
  - Displacement
  - WOB
  - Acceleration
  - Damping

Based on the analysis of different combinations of spring rate and damping for a variety of drilling conditions, the following conclusions were drawn:

- The spring rate and damping determine the drilling performance. The spring rate is very important; it should be selected such that ***the natural frequency of the drill string below the damper is greater than the frequency of the discontinuities***. Under these conditions, the spring force is out of phase to the direction of motion and the damper exerts more force on the crest of the discontinuity and less in the root. This causes the drilling process to reduce the discontinuities and enhance bit contact. If the natural frequency is ***lower*** than the discontinuity frequency, then the force is in phase with the direction of motion. The damper then places more force at the root, less at the crest, which is opposite of what is desired.
- Without damping, the spring rate alters the lobe pattern over time to its own natural frequency. After the lobe pattern is changed, the system self excites.
- Hard formations require greater damping than softer formations

- There are two thresholds for damping. The lower threshold is that required to damp the vibration; the upper threshold defines when the system gets too stiff to be effective.

The follow curves show some of the results of this study

Comparing **Figure 3** and **Figure 4**, one can see that in the first case, the maximum WOB (and hence cutting) will occur when the bit encounters the crest, thereby reducing the size of the lobe. When the damper frequency is below that of the lobes, the phase is nearly reversed and drilling will tend to enforce the discontinuities, increasing bit bounce

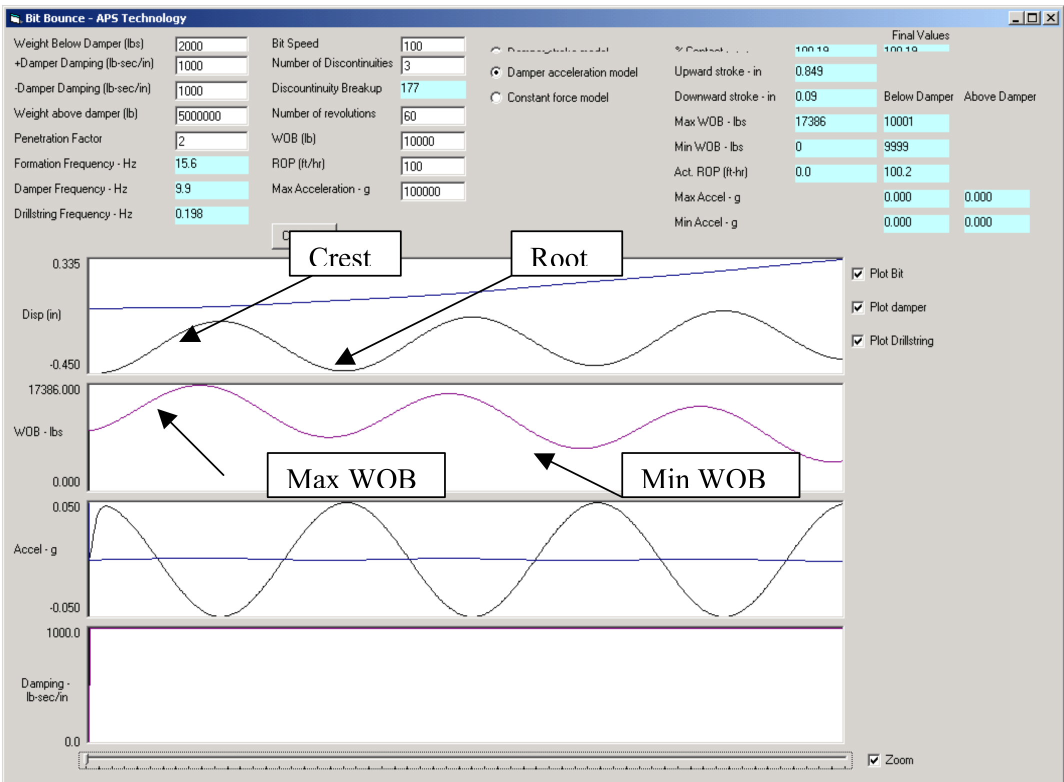

Figure 3: Damper frequency above the natural frequency of discontinuities

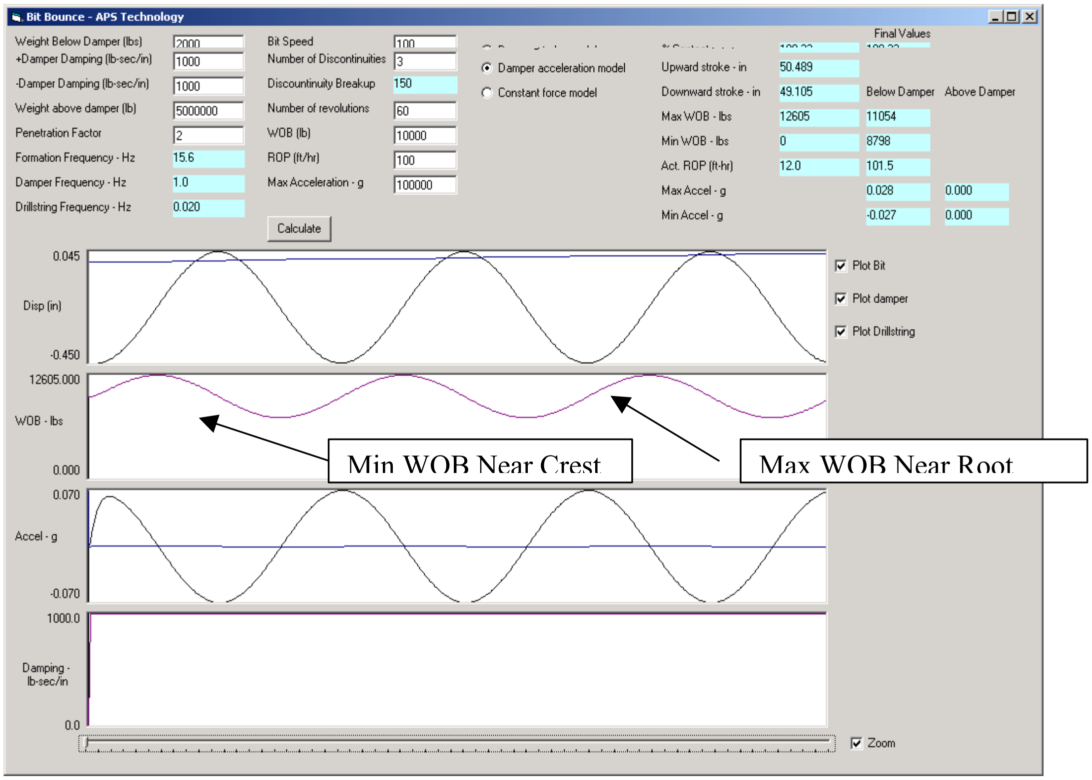

Figure 4: Damper frequency below the natural frequency of discontinuities

Once an appropriate spring rate is chosen, it is necessary to optimize the damping. The effect of damping can be seen in the following illustrations, which show that when the drillstring is underdamped, significant bit bounce causes tremendous swings in WOB and acceleration, with greatly reduced bit contact and ROP. Within the optimum range, there is almost constant WOB and contact, with negligible acceleration and improved ROP. In the overdamped condition, ROP remains high, but the bit is subject to severe damage from bouncing.

These curves indicate that the active damper may not require rapid adjustment in order to optimize drilling. Merely by ensuring that the resonant frequency remains above the excitation frequency and that the damping is within the desired range should yield the desired benefits.

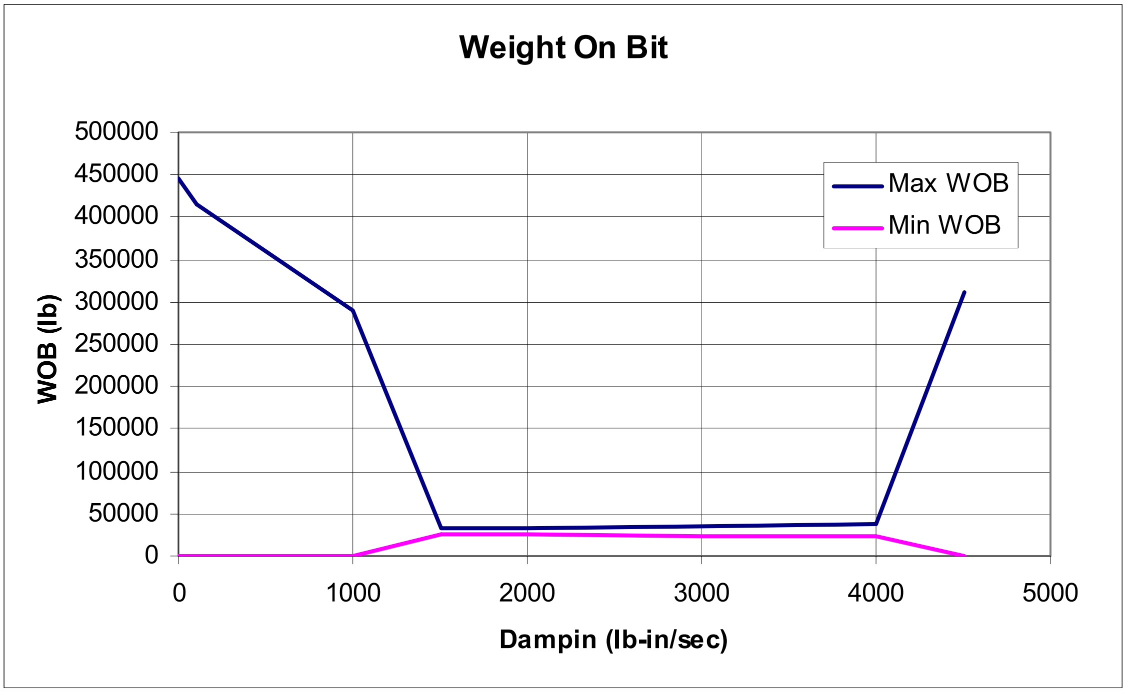

Figure 5: Effect of damping on WOB, 30 klb. nominal WOB

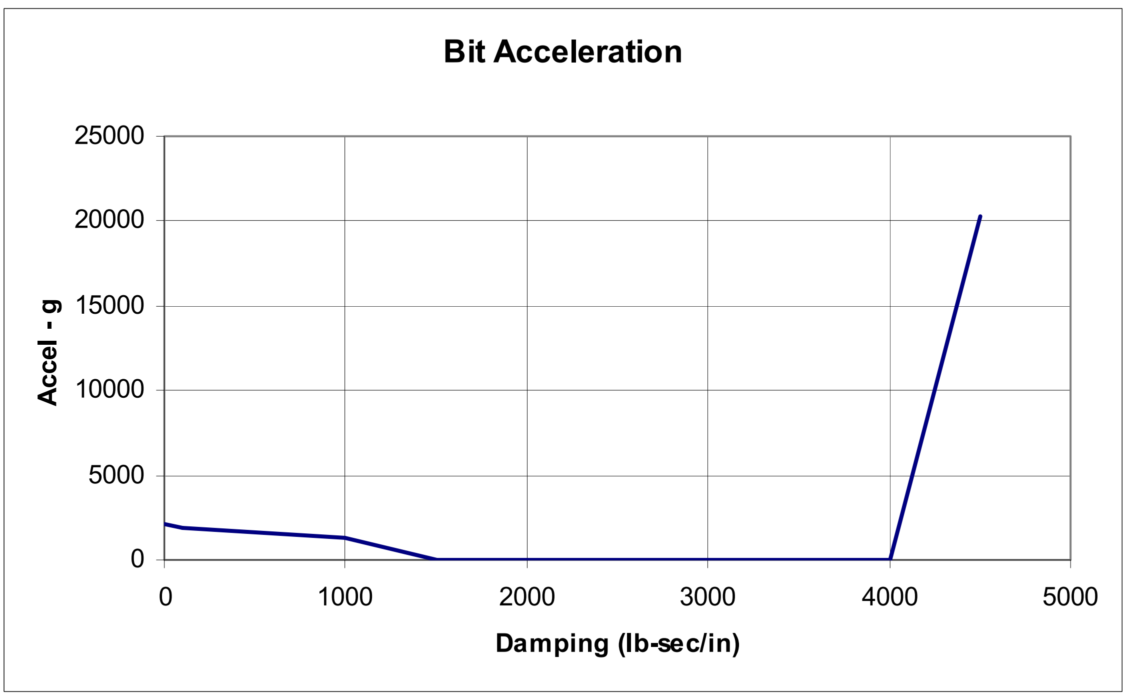

Figure 6: Effect of damping on bit acceleration, 30 klb. WOB

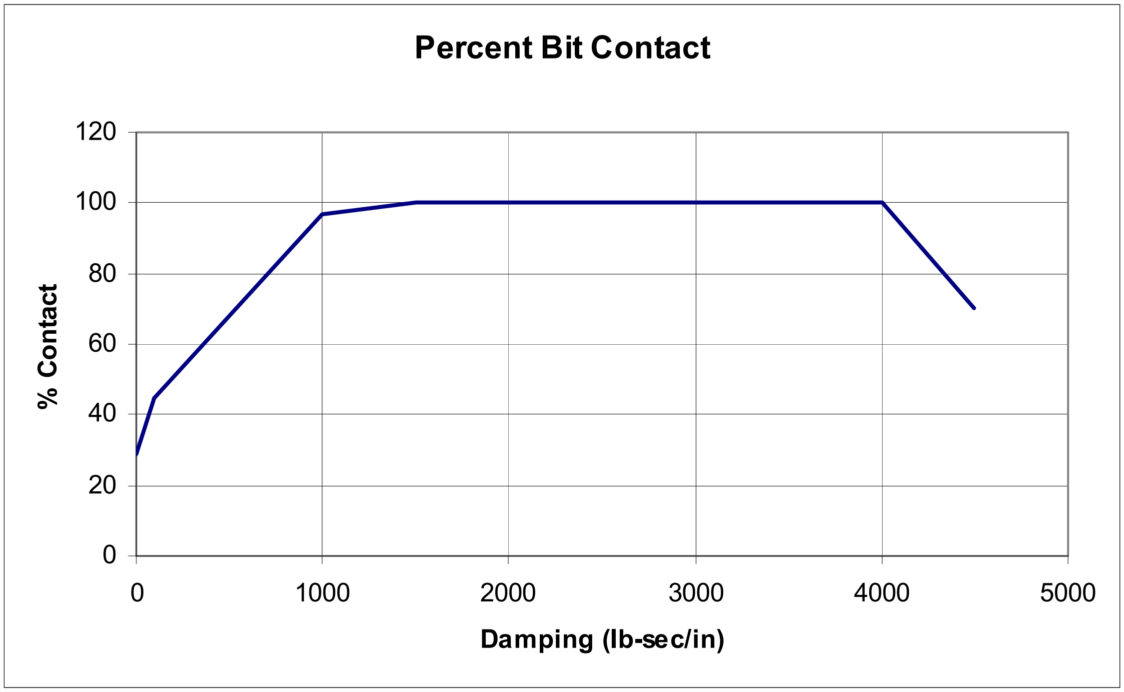

Figure 7: Effect of damping on bit contact, 30 klb. WOB

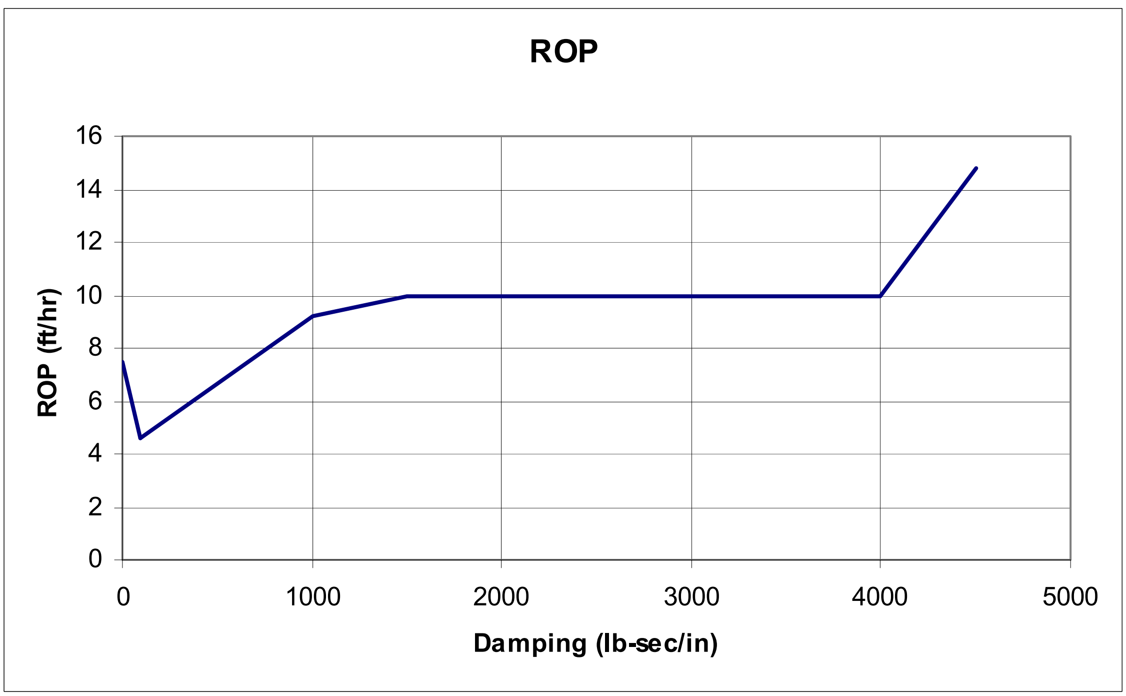

Figure 8: Effect of damping on ROP, 30 klb. WOB

Develop specifications for the DVMCS

Preliminary work has begun including, for example, the vibration sources identified above. Completion of this task will require the analysis of the response of the drillstring to the excitations, and the corresponding damping parameters required, both to be derived from the WellDrill calculations above.

Prepare top-level design for the DVMCS

Mechanical

Preliminary sketches of possible MR valve designs and damper concepts have been prepared, in anticipation of the final specifications. We have also outlined a design for the three-axis vibration monitoring system.

Electrical

The circuit concept is complete; required electrical components are being investigated.

Analyze design using FEA to predict performance

Awaiting completion of final top-level design, above.

Characterize properties of damper via *testing*

Small-scale models of several valve concepts are being designed. A preliminary design for a horizontal test fixture is underway.

Complete preliminary economic analyses, etc*.*

Not yet begun.

Develop preliminary financing plan

Not yet begun.

Complete Phase II development and testing plan

Not yet begun.

Complete Phase I report

Not yet begun.

UNITS

To be consistent with standard oilfield practice, English units have been used in this report. The conversion factors into SI units are given below.

1 ft.	=	0.30480 m
1 g	=	9.82 m/s
1 in.	=	0.02540 m
1 klb.	=	4448.2 N
1 lb.	=	4.4482 N
1 rpm	=	0.01667 Hz