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Drilling Tests of an Active Vibration Damper

Martin E. Cobern SPE, Carl A. Perry, Jason A. Barbely & Daniel E. Burgess, APS Technology, Inc.
and Mark E. Wassell SPE, APS Oilfield Services, Ltd.

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Abstract

Drillstring vibration is a serious problem, particularly in deep and hard rock drilling; it can reduce the rate of penetration (ROP), shorten bit life, and damage expensive downhole components. Testing of an active drilling vibration damper (AVD) system at TerraTek Laboratory, under conditions designed to induce vibration, demonstrated that the use of the AVD reduced vibration, maintained more consistent weight-on-bit (WOB) and increased ROP.

The AVD has a structure similar to that of a shock sub with the shock absorber filled with magnetorheological fluid (MRF), rather than hydraulic oil. Under the influence of a magnetic field, MRF instantaneously increases its viscosity. Using a series of coils to induce intense electromagnetic fields across the fluid gap, the damping coefficient can be changed in milliseconds by a factor of 7-10. A linear motion detector provides feedback to control the AVD in response to bit motion.[1]

In these tests, the AVD was used behind a tricone bit to drill through blocks of hard concrete, each of which had a 12" granite slab mounted within it at a 10º angle. By inducing an asymmetric load on the bit, the interfaces produced severe vibration during drilling the control holes. A total of 28 holes were drilled, including 11 control holes, at varying WOB and rotation rates.

Analysis of the data confirmed the anecdotal observations made during drilling. The vibrations at the bit were reduced significantly; the variation of the measured WOB was significantly curtailed, and the ROP was increased. These tests demonstrated that the AVD is likely to provide significant time and cost savings, particularly in deep wells. These will arise, not only from the increased instantaneous ROP, but also from fewer trips for bit or equipment changes, and lower costs for replacing damaged MWD tools, motors or other expensive components.

Introduction

In deep drilling, ROP is a major determinant of the ultimate cost of the well, and vibration is the enemy of ROP. When the bit vibrates, it is not drilling at maximum efficiency, and sometimes not at all. Bit bounce can reduce bit life and the resultant drillstring vibration can increase the number of trips required as a result of premature failure of MWD tools, motors and other components. Reduced instantaneous ROP and more frequent trips can harm the financial viability of deep drilling projects, even at today's oil prices. While shock sub can help reduce these problems, on occasion, they can resonate and make them worse[2].

A typical, massive drillstring (See **Figure 1**) has a relatively low resonance frequency. At rotation rates below those that would excite it, the bit maintains contact with the well bottom, but may not be drilling optimally Above the resonance, vibration is reduced because the drillstring cannot react to irregularities in the well bottom, and essentially skips over them, drilling only some of the time. These effects limit the range of WOB/RPM combinations that can be run, and frequently exclude the most desirable from a bit performance point of view.

The addition of the AVD has two effects on the drillstring response, as shown in :**Figure 2**

- First, be decoupling the lower BHA from the rest of the drillstring, it significantly raises the resonant frequency, the black dashed curve. This is true of any shock sub.
- Second, by continually optimizing the damping coefficient, it can almost completely remove the resonant condition, as shown in the red curve.

This combination allows the choice of WOB and RPM to be optimized for the bit and formation, without consideration of drillstring resonance effects.

Principles of Operation

The operating principle of this tool is identical to that of the suspension of the Ferrari 599 GTB Fiorano (**Figure 3**), which *Motor Trend*[3] described as follows:

> Each wheel on the so-called "SCM" suspension is controlled by a damper filled with a special fluid; the viscosity of the fluid can be modified almost instantaneously via an electronically generated magnetic field, A sensor at each wheel constantly monitors wheel and body movements; the computer reacts to changing road conditions (altering shock damping accordingly) in as little

as one millisecond. Ferrari claims that SCM reduces vertical excursions on bumps by 30 percent compared with the 575M.

If one changes the word “wheel” to “bit” and “body” to “drillstring,” this paragraph describes the operation of the AVD.

The key to the operation of the AVD is the magneto-rheological fluid (MRF). MRF is a suspension of fine iron particles in a fluid, generally oil. Under normal conditions, the particles have essentially no effect on the viscosity or the oil. In a magnetic field, however, the particles form long strings along the field lines, greatly increasing the viscosity. APS has formulated its own MR fluid to survive higher temperatures without settling.

As illustrated in **Figure 4**, the yield stress of the MRF varies from 0 to over 50 kPa under the application of a magnetic field. In other words, the MR fluid transforms itself from a fluid into a semi-solid colloid with the application of a magnetic field. It is important to note that this transformation is ***repeatable***, ***reversible*** and ***takes place in milliseconds*** By using MRF in the place of standard hydraulic fluid, it is possible to instantaneously vary the damping coefficient of the damper over a wide range of values.

Tool Design

The AVD design is show in **Figure 5**:

- The downhole end looks very much like a part of a conventional shock sub. It has a torsional bearing and a Belleville spring stack.
- The upper portion contains the APS high temperature (200º C) turbine-alternator to supply power, and a sonde-to borehole connector.
- The heart of the system is in the middle portion:
  - An LVDT sensor monitors the relative motion of the bit and drillstring;
  - A hydraulic compensation system keeps the pressures balanced; and
  - A magnetorheological fluid (MRF) valve continually adjusts the damping coefficient of the system

Details of the MRF damper are shown in **Figure 6** . The MRF is located in the volume between the mandrel and the housing. A series of coils in grooves in the housing create bucking fields, which are strongest in the gaps between the coils. The MRF in these areas will become more viscous as a function of the field strength, thereby varying the damping of the motion of the mandrel relative to the housing.

Testing

Laboratory Tests

Earlier laboratory tests[4] on a prototype damper showed that the dynamic stiffness could be changes by about an order of magnitude with the application of sufficient current. The results are shown in **Figure 7**. The effect is somewhat dependent upon the drive frequency, as a result of the nonlinear properties of the fluid. Note also that the property change of the MR fluid follows a typical “S-curve” and saturates at high fields.

Drilling Tests

To get a more realistic evaluation of the performance of the AVD under drilling conditions, the tool was tested at the TerraTek drilling laboratory in Salt Lake City. The objectives of this test were to:

- Create conditions which will be likely to induce vibration, and, under these conditions
- Compare drilling performance with and without the AVD, concentrating on:
  - WOB consistency
  - Bit & drillstring vibration
  - ROP

To create a drilling environment prone to inducing vibrations, the block design in

Figure 8 was chosen. Four blocks of high-strength concrete (4’ x 4’ x 3’) each had a 1’ slab of granite mounted within it at a 10º angle. Each block had a template of 8 holes laid out on its top, as shown in the Figure. The intention was that the bit’s encountering the tilted formation boundary would cause it to vibrate more. In practice, this design excited only marginal vibration increases.

Twenty-eight holes were drilled in the four formation blocks. A vibration monitoring sub was mounted below the AVD to monitor the motion of the bit. The AVD is equipped with an accelerometer to measure the vibration of the BHA. In addition, external sensors measured the WOB and BHA vibrations.

Eleven holes were drilled without the AVD under different conditions to provide control data. In general, the testing showed that with the AVD there was less bit motion, more consistent WOB and improved ROP. The tests were not fully successful in that the formations did not induce anything close to “worst case” drilling vibrations. This may have been partly attributable to the short, stiff BHA and the low WOB values possible in the drilling laboratory. Also, the LVDT signal was too low to be distinguished from the noise, so no closed-loop feedback algorithms were tested. Rather the AVD was set to a number of fixed damping values.

Results

WOB consistency

Early in the project, one of us (MEW) modeled the effect of the AVD on different drilling parameters. In **Figure 9,** one can see that when the damping is held in the optimum range (2-4 klb.-sec./in.), the WOB remains very close to the 30,000 lbs. that was nominally being applied, with only slight variation (±2,000 lbs.) Outside this range, below 1,000 or above 4,500, the variation increases rapidly until the minimum WOB goes to 0 and the bit begins to bounce.

A sample of the experimental results is shown in **Figure 10**[*]**.** In this figure, the variation in WOB using the AVD is compared to that observed when drilling with a straight drill collar replacing it. As can be seen, the drilling in concrete was quite sensitive to the damping, and with the lowest damping coefficient, the WOB variation was reduced by 60%. While

[*] The coding for all of the experimental figures is **M-R-W**, where **M** is the material (**G** = granite, **C** = concrete), **R** is the rotary speed (in RPM) and **W** is the WOB (in kilopounds.)

the variation was not as dramatic for the drilling through granite, the optimum damping reduced the variation by 40-60%, which would have a significant impact on both ROP and bit life.

Bit motion & vibration

Figure 11 shows the effect of the AVD on bit motion, as measured by the relative motion of the damper mandrel and housing. Once again, the effect in the concrete is most dramatic. The motion is reduced by 40% (2.5”→ 1.5”) as the damping is increased. The relatively minor changes seen in the granite drilling is a reflection of the fact that the damping is in the proper range for these relatively benign conditions and changing its value within this range has little effect.

Rate of penetration

The modeled change in the rate of penetration as a function of damping is shown in **Figure 12**.. The figure shows that when the damping is kept in a broad optimum range, the ROP is at its maximum. The uptick at very high damping represents the onset of bit impact, which can increase the instantaneous ROP. bit at the expense of bit life.

Experimental data from the drilling test are shown in **Figure 13.** As in the previous cases, the most pronounced effect is seen in the concrete drilling. Here, the ROP changes from 15% below the control rate to 15% above, indicating that the damper is having a significant effect. Again because the WOB is fairly light and the drilling mechanism is quite rigid, the effects in the granite are not as pronounced. Nevertheless, in two of the three cases shown, optimum damping resulted in improvements of 5-10% of the ROP. (We do not have a good explanation for the results in granite at 120 rpm and 15,000 lbs. WOB. It may be that the damping required for this case was not within the test range.

Conclusions

The results of these drilling tests show that by varying the damping coefficient in a drillstring damper, key drilling parameters can be improved. Vibration and variations of WOB can be reduced, which leads to improved ROP. The conditions during this test proved to be more benign than was hoped. It is anticipated that the AVD will have a more pronounced effect under more rigorous drilling conditions that induce greater vibration.

Future Plans

The AVD has been redesigned and is being rebuilt. Among the changes are:

- The MR valve has been redesigned for greater efficiency.
- A new LVDT sensor has been implemented to give a stronger
- All active components have been moved out of the lower sub

The latest design, shown in **Figure 5**, has the important feature that the lower third of the tool may be constructed of standard oilfield components (bearings, Belleville springs, *etc*.) All of the active elements (the AVD valve itself, the control and compensation systems, the turbine-alternator, *etc*.) are located in the two upper subs. This will greatly facilitate assembly and maintenance.

Precommercial prototypes were being assembled at the time of submission of this paper, and a drilling test at the Rocky Mountain Oilfield Test Facility (RMOTC) is currently scheduled for January, 2007.

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The authors also thank Dr. Alan Black and the staff of TerraTek Drilling Laboratories for their assistance during testing.

References

[1] M.E. Wassell, “Magnetorheological fluid apparatus, especially adapted for use in a steerable drill string, and a method of using same,” **US Patent #6,257,356 B1**, issued July 10, 2001.

[2] T.M. Warren, J.H. Oster, L.A. Sinor, and D.C.K. Chen, “Shock Sub Performance Tests,” **IADC/SPE 39323**, presented at the 1998 IADC/SPE Drilling Conference, Dallas, March 3-6, 1998.

[3] *Motor Trend*, July, 2006, *pp.* 64 *ff.*

[4] M.E. Cobern, & M.E. Wassell, “Laboratory Testing of an Active Drilling Vibration Monitoring & Control System,” **AADE-05-NTCE-25**, presented at the AADE 2005 National Technical Conference and Exhibition, Houston, Texas, April 5-7, 2005

Figures

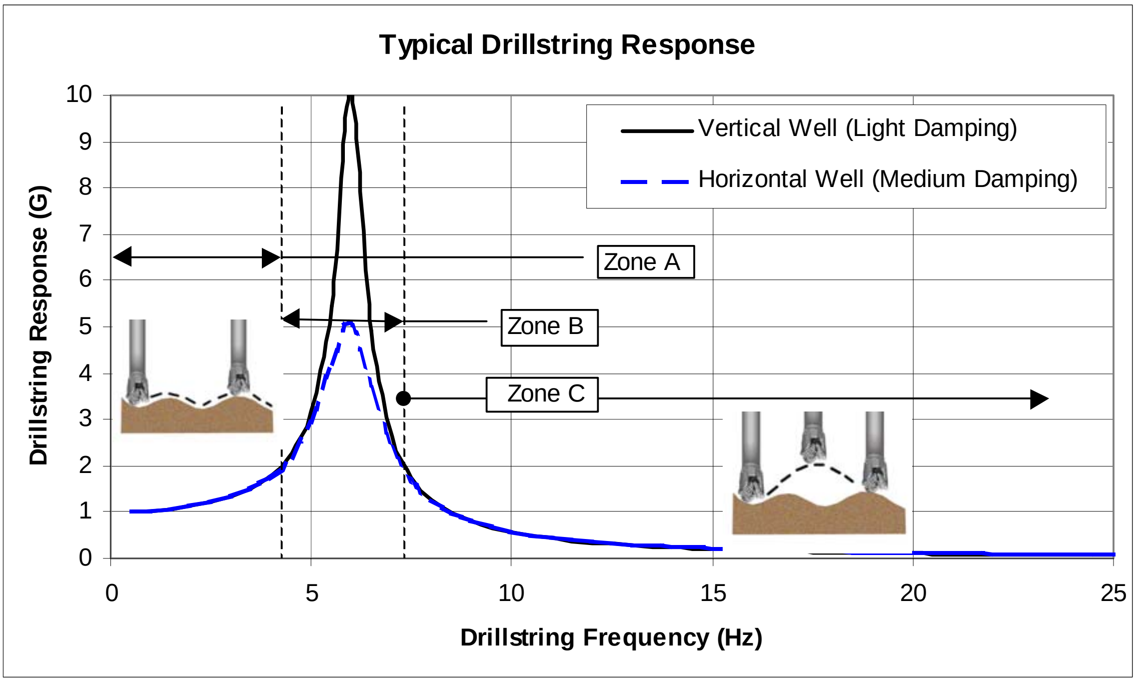

Figure 1: Typical Drillstring Response to Drilling Frequences

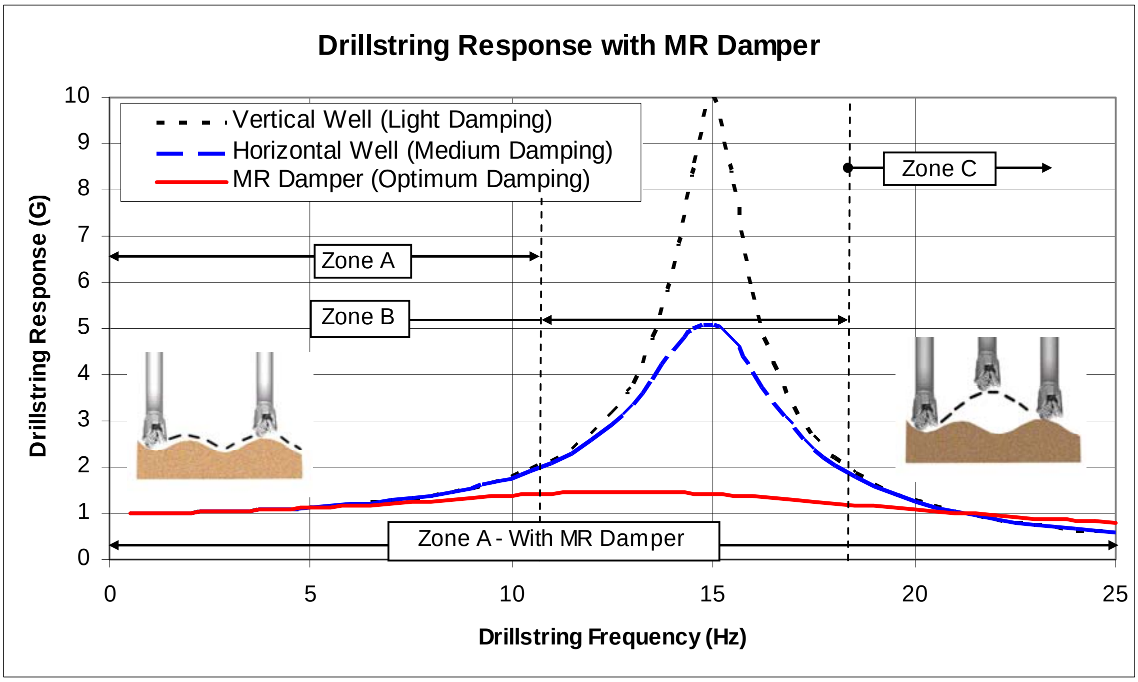

Figure 2: Effect of MR Damper on Drillstring Response

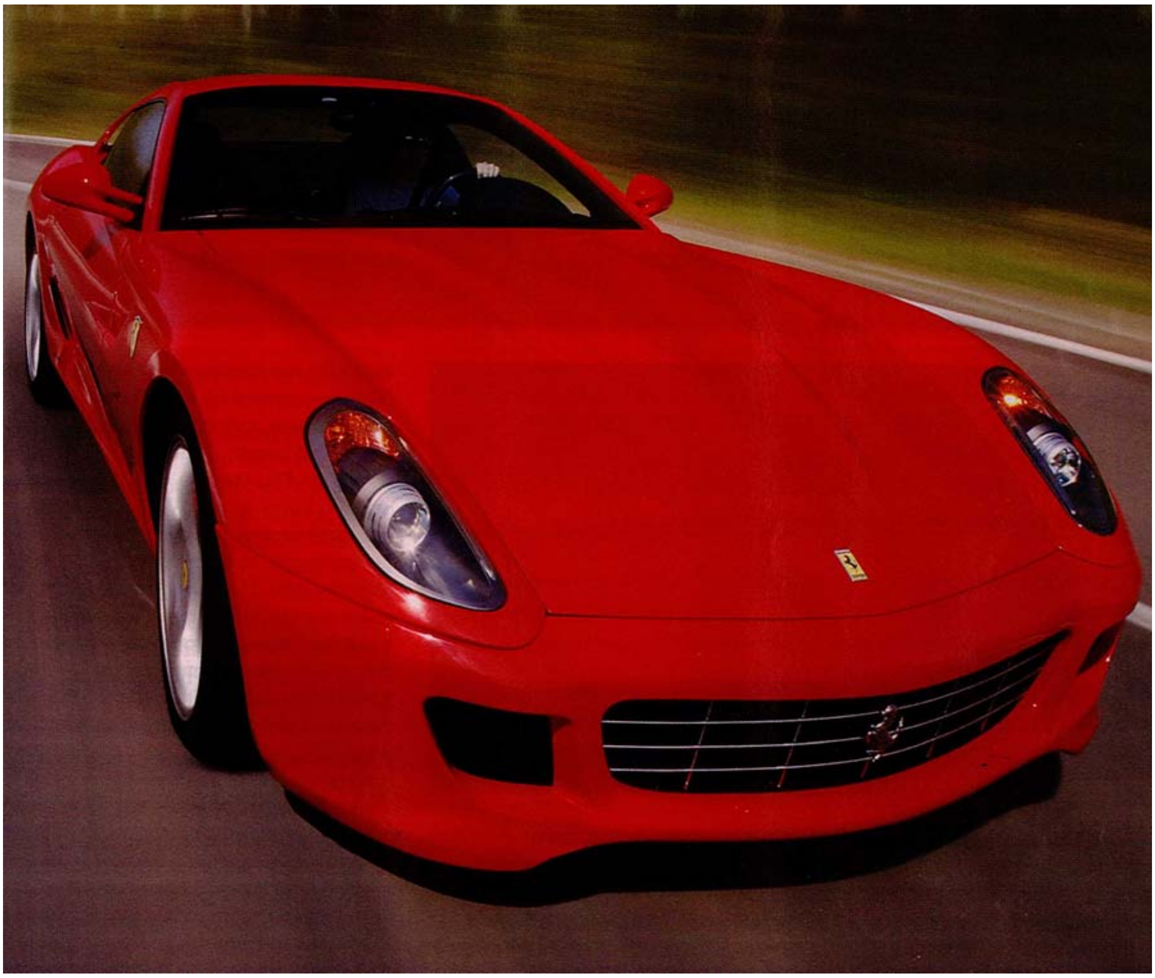

Figure 3: Ferrari 599 GTB Fiorano

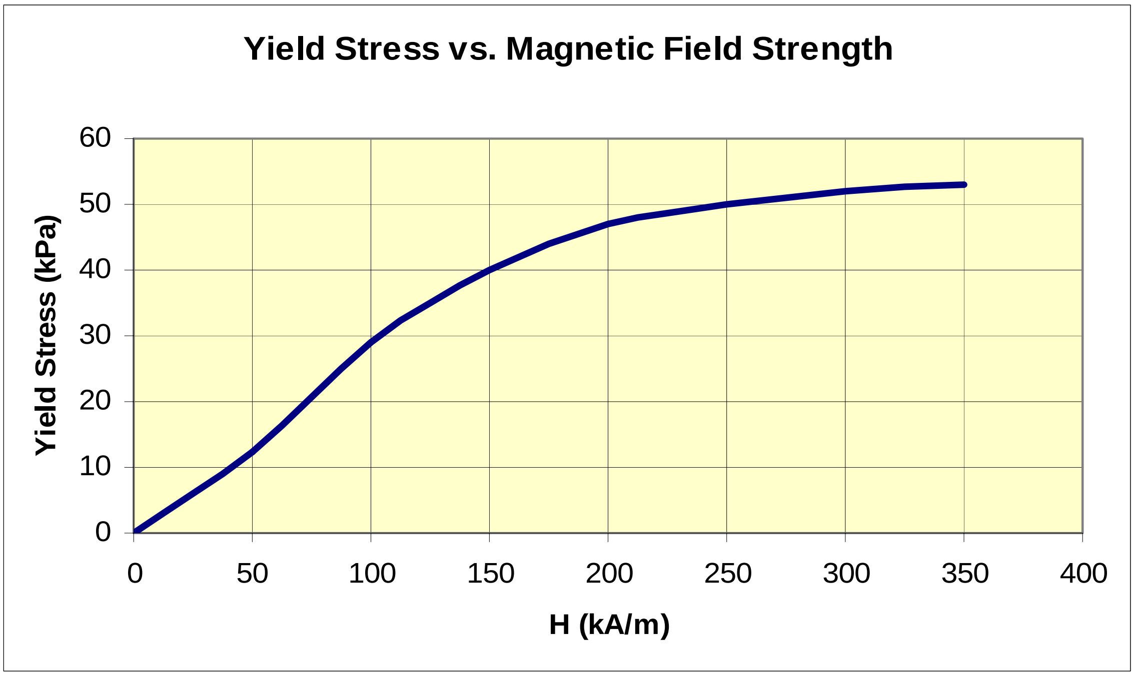

Figure 4: Response of Magnetorheological Fluid to a Magnetic Field

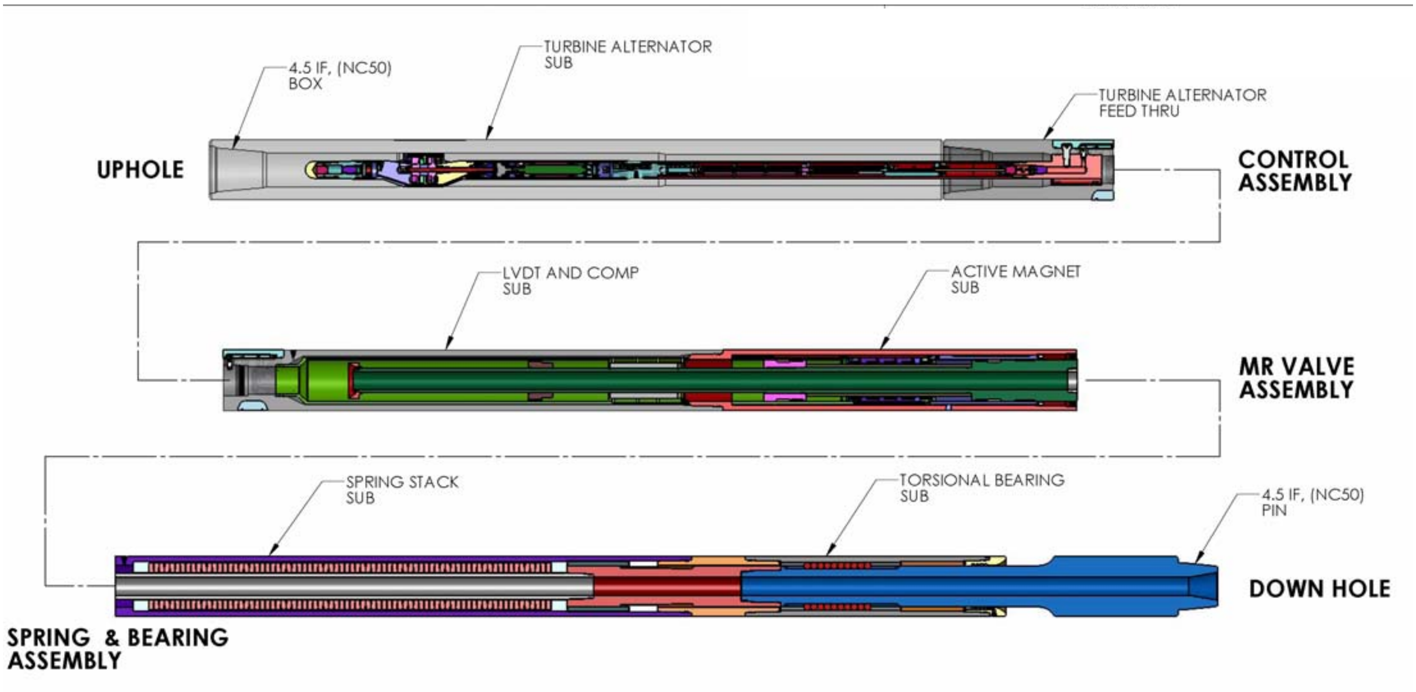

Figure 5: Schematic of the AVD Tool

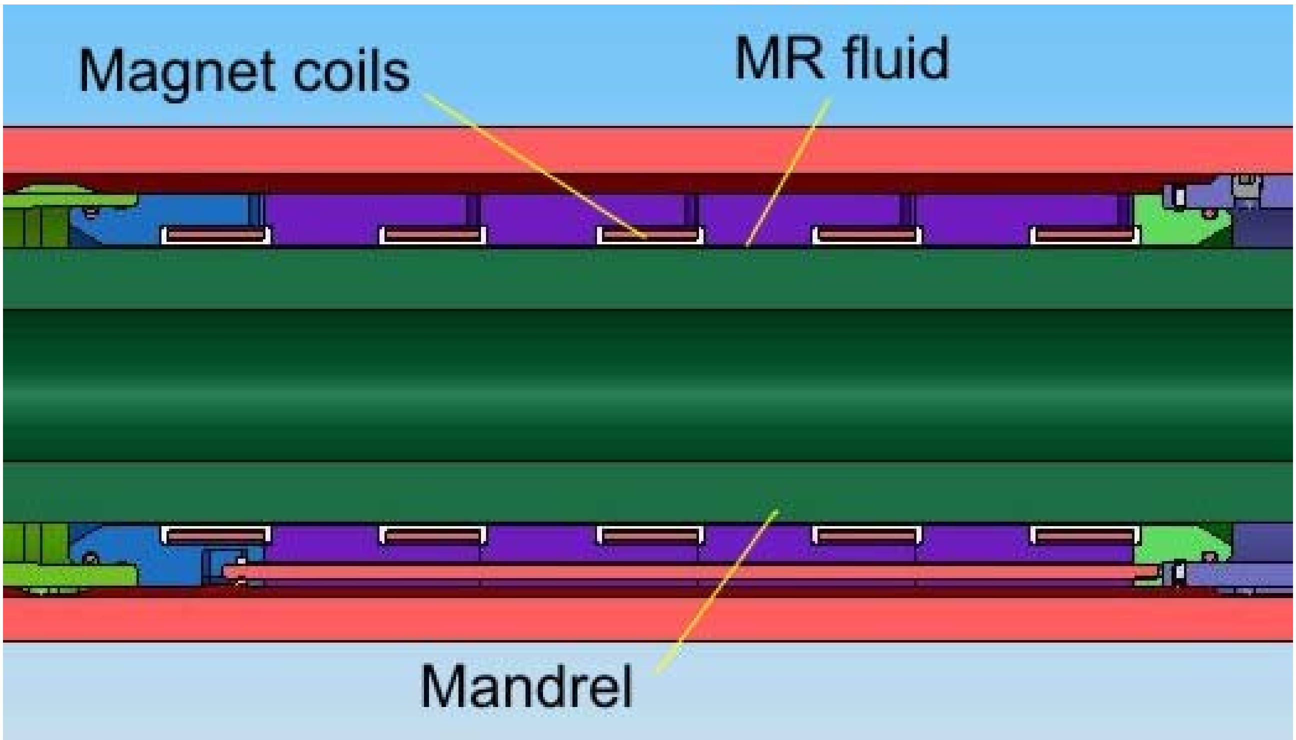

Figure 6: Detailed view of the MRF damper

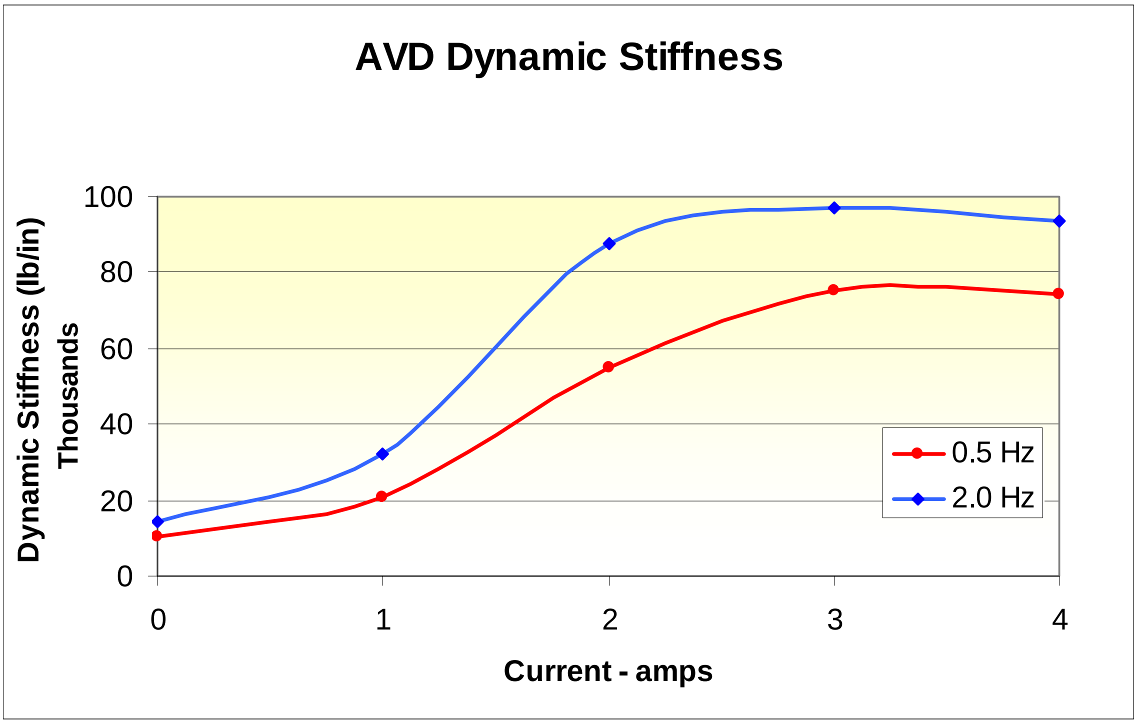

Figure 7: Effect of applied current to prototype damper dynamic stiffness

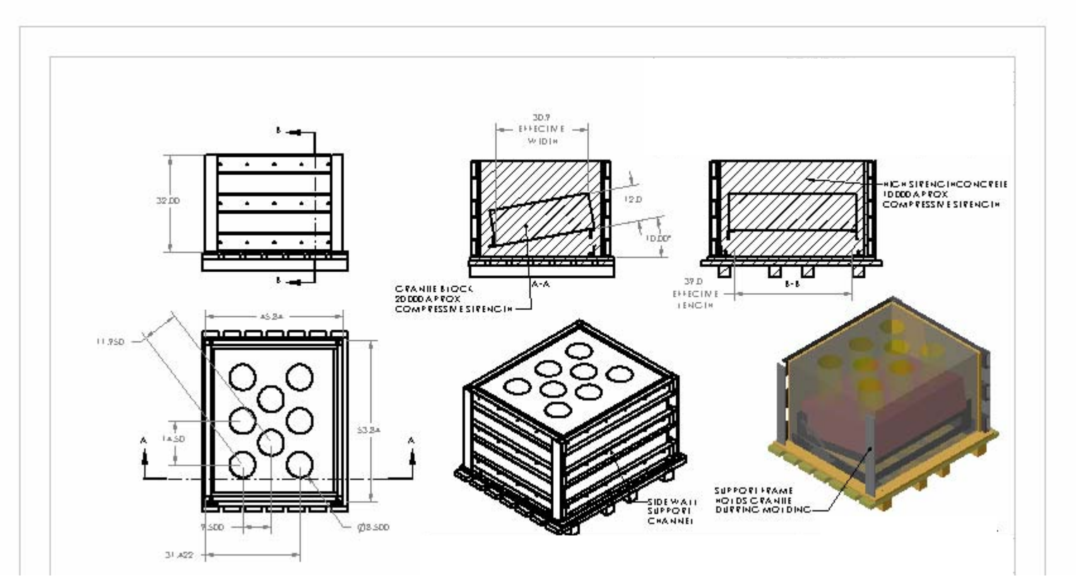

Figure 8: Concrete & granite blocks used for drilling tests

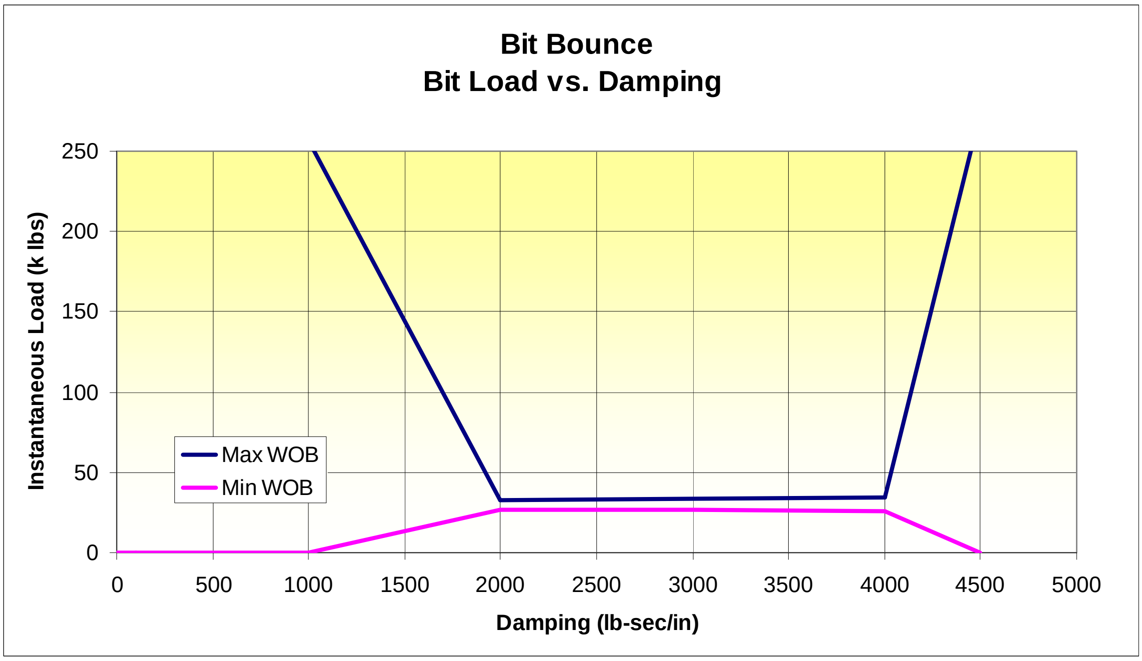

Figure 9: Effect of damping on bit bounce – model

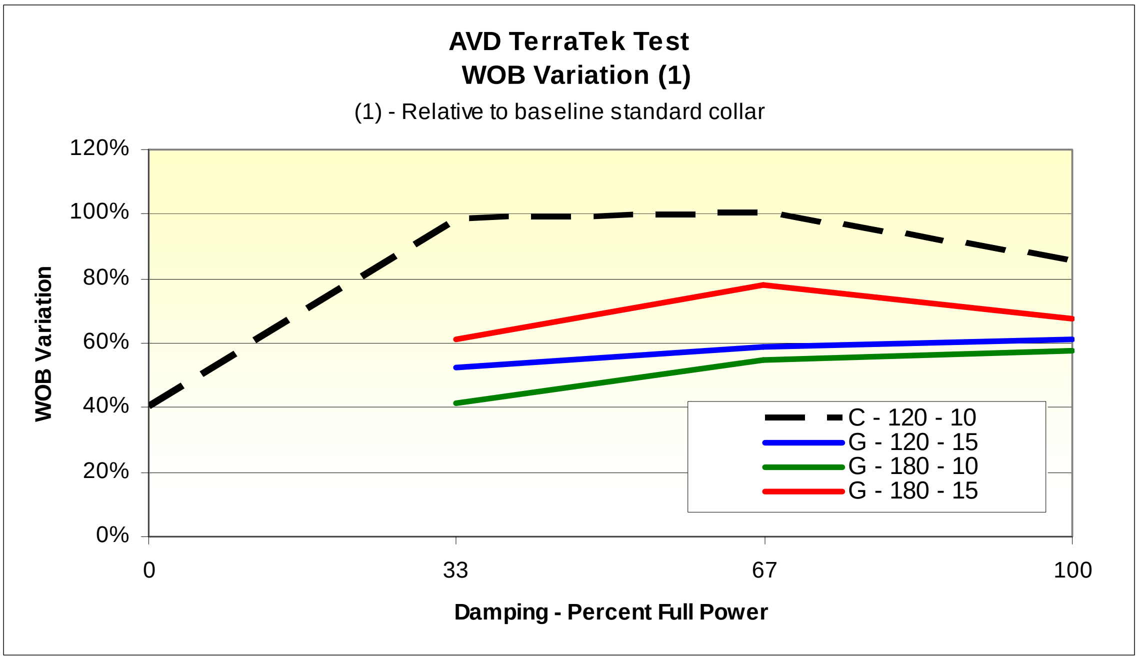

Figure 10: Effect of AVD on WOB variation

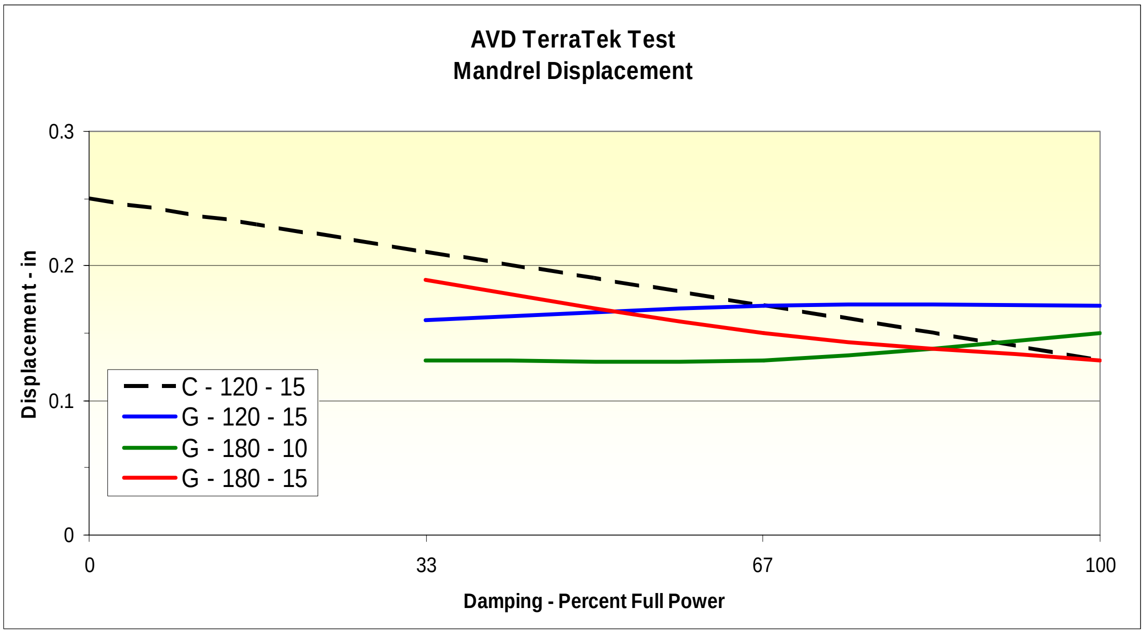

Figure 11: Effect of AVD on bit motion

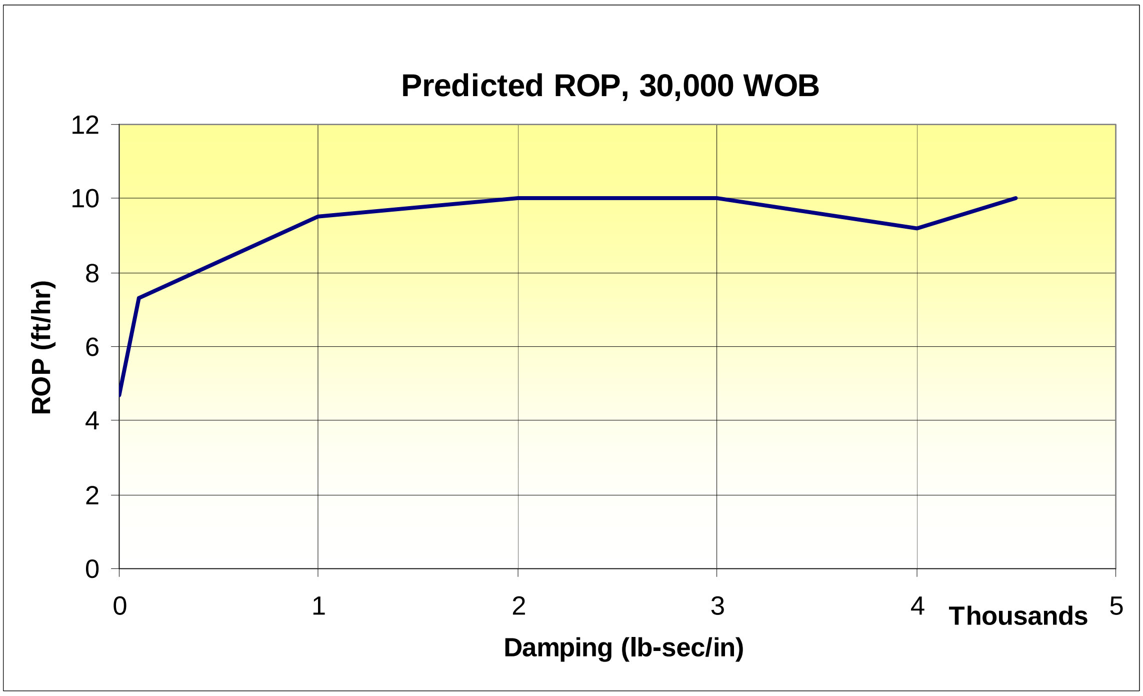

Figure 12: Effect of damping on rate of penetration - Model

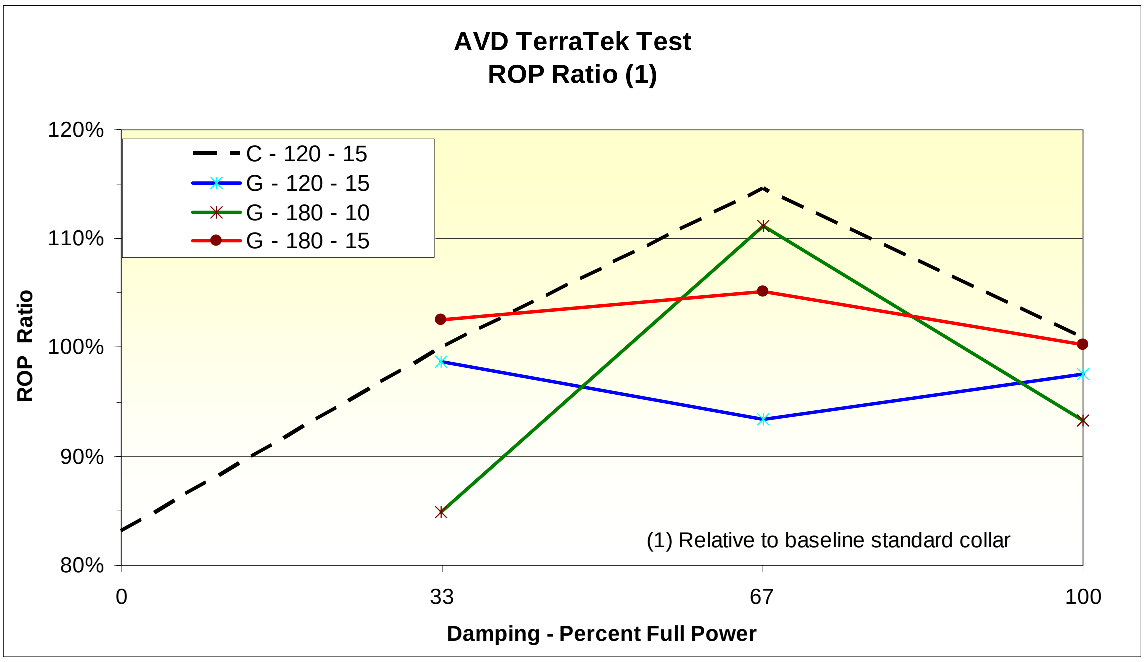

Figure 13: Drilling speed as a function of damping