



A Real-Time Implementation of MSE

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Abstract

Mechanical Specific Energy (MSE) has been implemented in a drilling information system, providing MSE in real time on the rig and at remote monitoring locations. This paper covers how this was done, what has been learned to date about introducing and using this new technology and provides examples of its use.

Introduction

For drilling engineers interested in maximizing drill rates and minimizing cost per drilled interval, there exists a need for a quantitative and qualitative measure of the efficiency of the bit and, more generally, for the efficiency of the drilling process as a whole. Comparing drill rate performance to offset wells and bit records provides a relative comparison to past performance, but does not indicate what the maximum potential performance may be. Nor does it provide any guidance as to how to get improvements in performance. Various types of drill rate tests, such as the drilloff test¹, provide insight into optimum operating parameters for the given formation, bit, bottomhole assembly, hydraulics, etc. However, drilloff tests require time and analysis, and the results are specific to the interval in which the test was run.

The MSE value is a measure of the energy required to drill a fixed volume of rock or, equivalently, the ratio of rate of energy usage to rate of penetration. By itself, MSE provides a relative measure of the efficiency of the drilling process. Combined with knowledge of the rock compressive strength, MSE provides an absolute measure of the efficiency of the drilling process. Further, MSE provides these efficiency measures in a continuous manner and without any action by the rig crew, other than the routine maintenance of rig configuration data.

MSE was proposed in 1965 by Teale². It has been used by bit vendors for determining the drilling efficiency of drill bit designs and has been used in specialized field applications^{3,4}. In 2004, a real-time implementation of MSE was added to a commercial drilling instrumentation system, to assist an operator's investigation into use of MSE as a real-time tool for rig personnel to maximize rate of penetration⁵. This included developing the supporting technology so that MSE could be provided on the full array of rig and drillstring configurations. Since then, the system has been used on over 20 rigs in 6

areas of the US, by 5 operators. To the author's knowledge, this is the first real-time, comprehensive implementation of MSE to be provided by a drilling instrumentation vendor for "mass market" use by the industry.

In addition to the technical aspects of providing MSE, this project also focused on issues of use and acceptance by rig personnel.

Definition of MSE

The definition of MSE as used in this work is:

$$MSE = E_m \times \left(\frac{4 \times WOB}{\pi \times D^2 \times 1000} + \frac{480 \times N_b \times T}{D^2 \times ROP \times 1000} \right)$$

where:

- MSE = Mechanical Specific Energy, Kpsi
- E_m = Mechanical efficiency, ratio
- WOB = Weight on bit, lbs
- D = Bit diameter, inches
- N_b = Bit rotational speed, rpm
- T = Drillstring rotational torque, ft-lb
- ROP = Rate of penetration, ft/hr

Note that this definition of MSE includes the mechanical efficiency. As such, it deviates from Teale's definition¹ and is equivalent to Dupriest's MSE_{adj} definition⁵.

Functional Understanding of MSE Behavior

Experience has shown that the best way to get a functional understanding of how MSE behaves is to conduct MSE tests by independently varying weight on bit, bit rotational speed and hydraulics, and observe the response in MSE.

Prior to introducing the weight on bit test, Figure 1 (from Dupriest⁵) is referenced to highlight the three regions of bit efficiency. In Region II, the bit is efficient; increases in weight on bit produce linear increases in rate of penetration. In Region I, the bit is inefficient due to inadequate depth of cut. In Region III, the bit is inefficient due to founder. Examples of causes of founder are shown on the plot. Addressing the cause of the founder will extend the founder point to a higher weight on bit, and extend the range of Region II.

Figure 2 is an MSE test with WOB starting at 40 Klbs and then being varied in 20, 30, 40 and 50 Klb steps. The MSE value is constant over the entire WOB range

up to 50 Klbs, except for two intervals. Interval A at 20 Klbs shows higher MSE due to insufficient depth of cut; this is equivalent to Region I on Figure 1. Interval B indicates bit balling and is equivalent to Region III of Figure 1. Other than intervals A and B, all of the WOB's are in Region II. This is confirmed by the ROP increasing with WOB. Successive WOB tests were run with WOB's up to 60 Klbs. These tests showed that balling occurred continually at 55 Klbs.

Based on these WOB tests, the following conclusions were drawn for this situation:

- Drilling at up to 50 Klbs WOB can be efficiently done in most, but not all formations.
- A WOB of 40 Klbs was to be used for the rest of this bit run.
- The mill-tooth bit was to be replaced with a PDC on next bit run.
- Heavy-wall drillpipe was to be added to the drillstring on next bit run.

By the next tour, the drillers themselves had developed a technique whereby they could identify the occurrence of balling using the MSE trend and then run the WOB (40 or 50 Klbs) appropriate for the specific formation.

Figure 3 is an MSE test with bit RPM starting at 160 rpm and then being varied in 100, 125, 150 and 175 rpm steps. A common baseline across test steps does not exist in this test. Instead, MSE is steadily increasing with each step up in bit rpm. While there are increases in ROP, they are not commensurate with the increases in torque. It was presumed that the energy increases from higher rpm were lost in vibrations and drillstring friction, and did not result in increased energy at the bit. This was confirmed by drillstring vibrations at the surface which were noticeable at 150 rpm and severe at 175 rpm. While drilling at the higher rpm's would have produced higher ROP's, the MSE test showed that this would have not been optimum for bit life and rig wear-and-tear. This conclusion was already obvious to the rig personnel. However, MSE provided an understanding of the drilling mechanics and an independent confirmation that the higher rpm's and ROP's were not the optimum choice in this case.

Figure 4 is an MSE test varying hydraulics, with the pump rate starting at 130 spm, dropping in 15 spm steps and then returning to 130 spm. Each time the pump rate was lowered, there was a short delay and then MSE would start rising, as shown by slopes A and B. At the end of the 115 spm section, it was clear that MSE was dropping, and the decision was made to reduce spm again. At the end of the 100 spm section, it did not appear that MSE was going to drop, so the pump rate was quickly raised. This test shows the impact of hydraulics on drilling efficiency. This is interesting, as an inspection of the MSE equation shows it does not

directly contain any hydraulics-related parameters. However, the hydraulics do impact how efficiently the cuttings are being removed from under the bit as they are generated. It was presumed that each flow rate change required some time to travel downhole and then cause a disruption in flow pattern and cuttings removal. During this period, drilling efficiency was reduced due to excess cuttings accumulating below the bit. This effect is also seen in the torque and ROP curves. While it is common practice to use the maximum flowrate (for the given nozzles and pressure limitations), this test illustrates that hydraulics do impact drilling efficiency and this impact is reflected in MSE.

While the previously shown hydraulics test was done for educational purposes, hydraulics does need to be considered when evaluating the WOB and Bit RPM MSE tests. In the WOB test example in Figure 2, simply increasing hydraulic horsepower by reducing nozzle sizes may eliminate the MSE rise in interval B, along with the corresponding drop in ROP.

Real-Time Implementation

The decision was made to implement MSE and the required supporting technology on the M/D Totco RigSense system. The primary driving forces for this were to have instrumentation support for all rig environments and configurations, and to have the MSE data available anywhere on the rig and at remote locations. The architecture of the RigSense system is shown in Figure 5. The NTTracer provides a touch-screen display for the driller, and is suitable for use in other hazardous areas as well. The RigSense Clients can be placed in all safe area locations, such as the offices of the Toolpusher and Company Man. Remote users with internet access can view the MSE data historically (via WellData) and in real-time (via WellData/RT).

The MSE logic and supporting technology were originally implemented in the data acquisition system (DAQ) and were later relocated to the RigSense AppServer, for reasons of maintenance, performance and portability. The current version of the software is written in C++ and communicates with RigSense once per second.

Two common screen layouts are shown in Figures 6 and 7. Figure 6 is focused specifically on MSE and drilling performance, while Figure 7 adds MSE to the typical EDR-style display.

In order to be able to provide MSE for all possible rig and drilling configurations, following are some of the issues and the supporting technology that was developed on the RigSense system.

The rig may have a top drive, rotary table or both. Each may have torque already available in ft-lbs, or torque in relative units (such as amps or psi). The solution was to add torque conversion options and to identify which device (top drive or rotary table) is rotating

the drillstring. Additional benefits of this are that drillstring RPM and torque are readily available on rig and remotely (for any well) without knowledge of rig configuration, and torque is consistently in ft-lbs.

If a mud motor is present in the string, it generates additional torque and rotational speed near the bit. Since surface-measured torque is used, no change is required there, as the surface torque is the sum of all reactive torques from bit to surface. Computation of mud motor RPM was added to the system, using mud motor specifications and flow in. When a mud motor is present, mud motor RPM is added to drillstring RPM to produce bit RPM, which is then used in the MSE equation. When a mud motor is not present, bit RPM is equal to drillstring RPM.

When slide drilling with a mud motor, surface torque measurement is typically not available, which prevents calculation of MSE. For this case, computation of mud motor torque was added to the system, using mud motor specifications and differential pressure. The mud motor torque is then used in the MSE equation.

Field Acceptance

As with any new technology, the question of acceptance by the rig and office personnel is an issue to be considered. In general, the acceptance of MSE has been good, for the following reasons:

- MSE provides useful information and an interesting insight into drilling mechanics.
- MSE data is available continuously in real-time, providing a trend that is easy to monitor.
- Once basic configuration is done, no additional effort is required to generate the MSE data.

The third reason is particularly appealing to those interested in drilling performance. Similar information can be derived from conducting drill-off tests. However, drill-off tests require interpretation and only provide data in the intervals where tests are conducted.

In the field testing, specific attention was paid to working with the drillers as to their motivation to monitor and use MSE. This was done at the request of some operators and contractors, who saw the driller as the closest to the drilling operation and the one who could provide big benefits by their use of MSE. The drillers in general seemed to like using MSE. They found it to be a useful combination of several parameters that they were already monitoring, especially torque and ROP. The fact that MSE provided one trace made it easier to monitor when their attention was also required in other areas. As they got used to how MSE behaved, they developed their own techniques. Most of these techniques involved adjusting parameters to reduce/maintain MSE at a lower level, and using MSE to identify when a change in parameters was warranted.

The other aspect that seemed to interest the drillers was that the MSE value responded quickly to any changes they made in drilling parameters. Of the drillers who were provided a range of WOB and rotary speeds within which they had the authority to work, their acceptance of MSE was high and it quickly became an integral part of how they drilled. Conversely, it was also noticed that of the drillers who were provided a fixed WOB and rotary speed to maintain, their interest was low and was motivated more by curiosity than by a desire to drill faster or better.

Having both types of screen layouts, as shown in Figures 6 and 7, also helped with acceptance. When all was going well and the driller was focused on drilling performance, the MSE-focused display (Figure 6) was used. When the driller had to focus more on other efforts, such as monitoring pit volumes, pump rates and flow out, then the EDR-style display (Figure 7) was used. Since the driller can easily change between the two screens with a single touch and can also modify or create screens using his touch screen, there were no concerns raised by the drillers over the addition of MSE to the existing data.

MSE Application Strategies

It was noticed in the field testing that how MSE was used varied among operators, among different wells and also often over the duration of a given well. At the highest level, three strategies for applying MSE became apparent. These are named and described as follows:

“Enhance the Status Quo”: This strategy starts with the assumption that no major changes will be made to the current drilling practices. MSE is used as a trend that the crew monitors and gets used to its behavior. “Normal” MSE behavior later in the well and on succeeding wells provides confirmation of consistent performance and warnings of deviations from expected performance, up to and including earlier detection of drilling problems.

“Optimize within Current Constraints”: This strategy includes adjusting drilling parameters to increase ROP where feasible and to minimize problems where ROP is limited for reasons other than drill rate performance, such as controlled drilling. It also includes using MSE learnings to improve performance on the next bit run, next well, etc. However, it does not include radical changes in drilling procedures or well design.

“Maximize ROP, Re-Engineer Drilling Practices”: This strategy consists of continually using MSE to find what factors are limiting ROP, operating at the limits during the bit run, and continually re-engineering drilling procedures to get the maximum ROP on the next bit run, next well, etc. Examples of using this technique and results achieved are found in Dupriest⁵.

A comparison of the trade-offs made between potential benefits, potential risk and level of engineering effort required is provided in Table 1. There are also

trade-offs that can be made within the table; for example, risk can be reduced by more engineering, and vice versa. This is not meant to imply that any one strategy is superior to the others, other than there is probably an optimum selection for each situation.

An interesting observation during the field testing was how different decision makers viewed what the potential benefits (such as maximum achievable ROP) could be – some saw it as the best performance from previous bit records, others saw it as an unknown waiting to be found.

Another interesting observation was that, regardless of which strategy was used, as a general rule anything done to reduce MSE led to positive results. For example, in most cases the maximum ROP occurred at the conditions where MSE was minimum value. When maximum ROP did not occur at minimum MSE, the consensus was that minimum MSE did produce the maximum “good ROP”; i.e. higher ROP’s were possible, but not without deleterious side-effects.

Conclusions

The use of Mechanical Specific Energy in real-time is a useful tool for both drillers and drilling engineers.

A real-time implementation of MSE has been developed by a drilling instrumentation vendor which is applicable to all rig and drillstring configurations.

Field acceptance of new technology was a major issue which was considered during this development.

Conducting MSE tests in real-time is an effective way to develop an understanding of MSE behavior and contributes to acceptance by rig personnel.

A variety of strategies are available to apply MSE to actual operational situations.

The general practice of adjusting drilling parameters to minimize the value of MSE is a good rule of thumb.

Acknowledgments

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Nomenclature

Define symbols used in the text here unless they are explained in the body of the text. Use units where appropriate.

EDR = electronic drilling recorder
MSE = Mechanical Specific Energy
ROP = drilling rate of penetration
rpm = revolutions per minute
RPM = rotational speed
spm = strokes per minute
WOB = weight on bit

References

1. Lubinski, A.: “Proposal for Future Tests”, The Petroleum Engineer (Jan 1958)
2. Teale, R.: “The Concept of Specific Energy in Rock Drilling”, Intl. J. Rock Mech. Mining Sci. (1965) 2, 57-73
3. Pessier, R.C. and Fear, M.J., “Quantifying Common Drilling Problems with Mechanical Specific Energy and Bit-Specific Coefficient of Sliding Friction”, IADC/SPE paper No. 24584 presented at 67th Annual Conference and Exhibition, Washington, D.C., 4-7 October, 1992
4. Waughman, R.J., Kenner, J.V., Moore, R.A., “Real-Time Specific Energy Monitoring Reveals Drilling Inefficiency and Enhances the Understanding of When to Pull Worn PDC Bits”, IADC/SPE paper No. 74520 presented at Annual Conference, Dallas, Texas, 26-28 February, 2002
5. Dupriest, F.E., Koederitz, W.L., “Maximizing Drill Rates with Real-Time Surveillance of Mechanical Specific Energy”, IADC/SPE paper No. 92194 presented at SPE/IADC Drilling Conference, Amsterdam, The Netherlands, 23-25 February, 2005

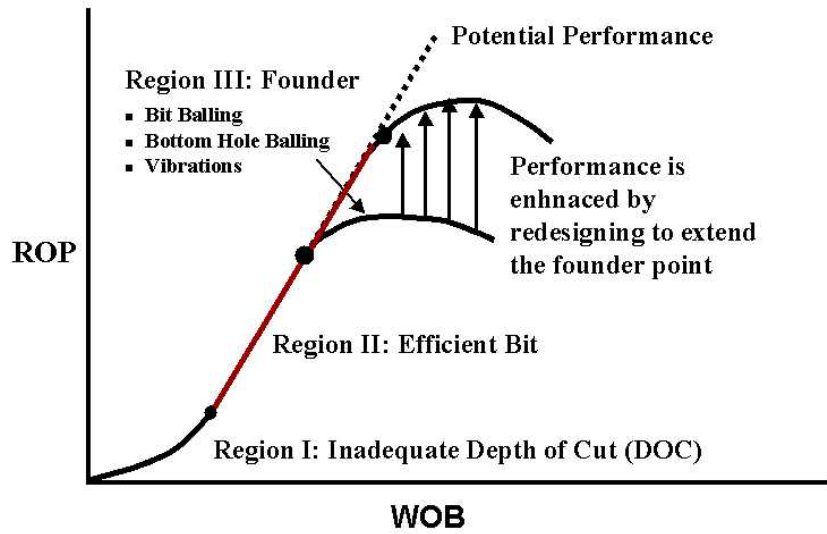


Fig. 1 - Relationship between ROP and WOB (from Dupriest⁵)

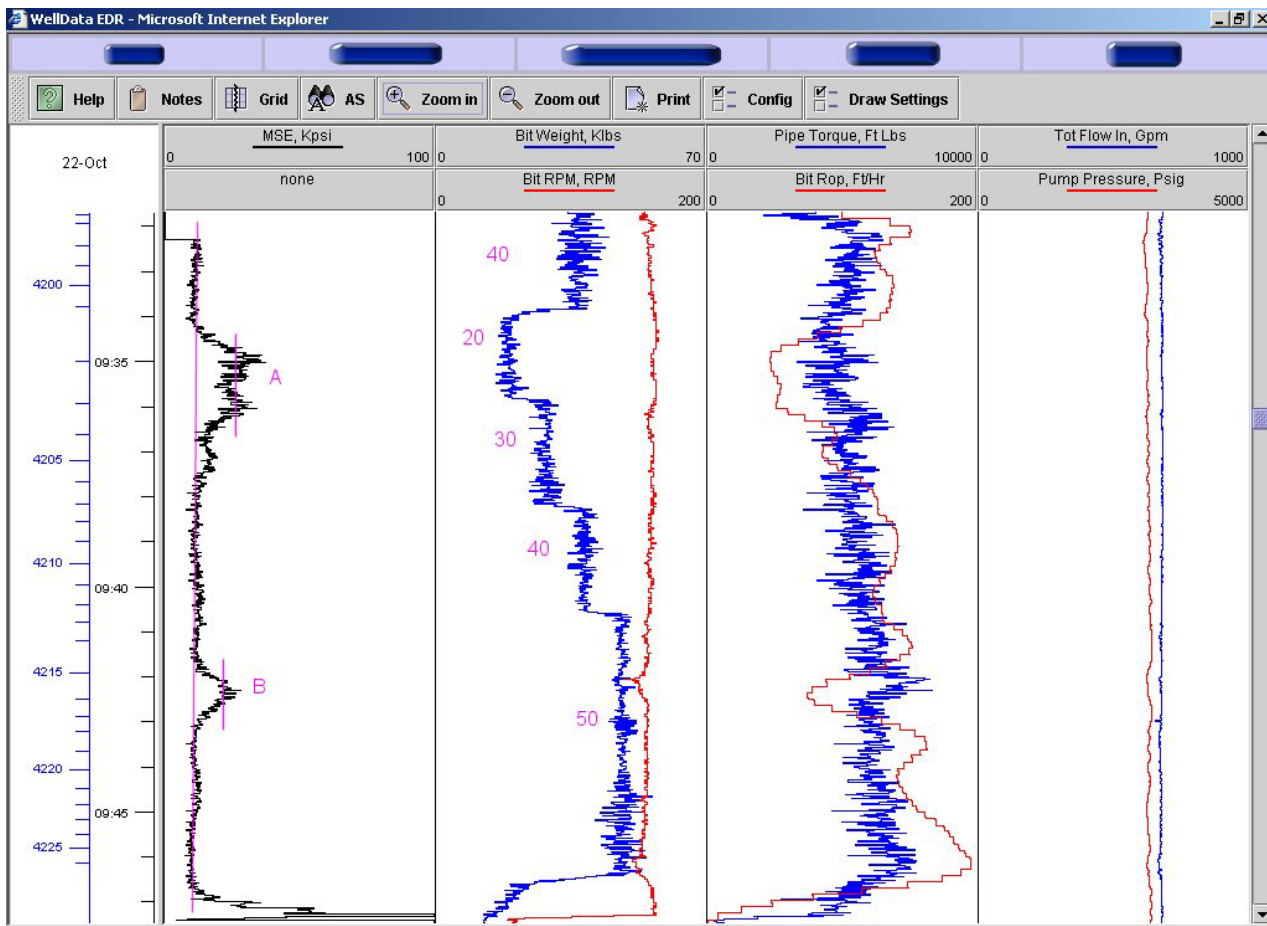


Fig. 2 - Weight on Bit MSE Test

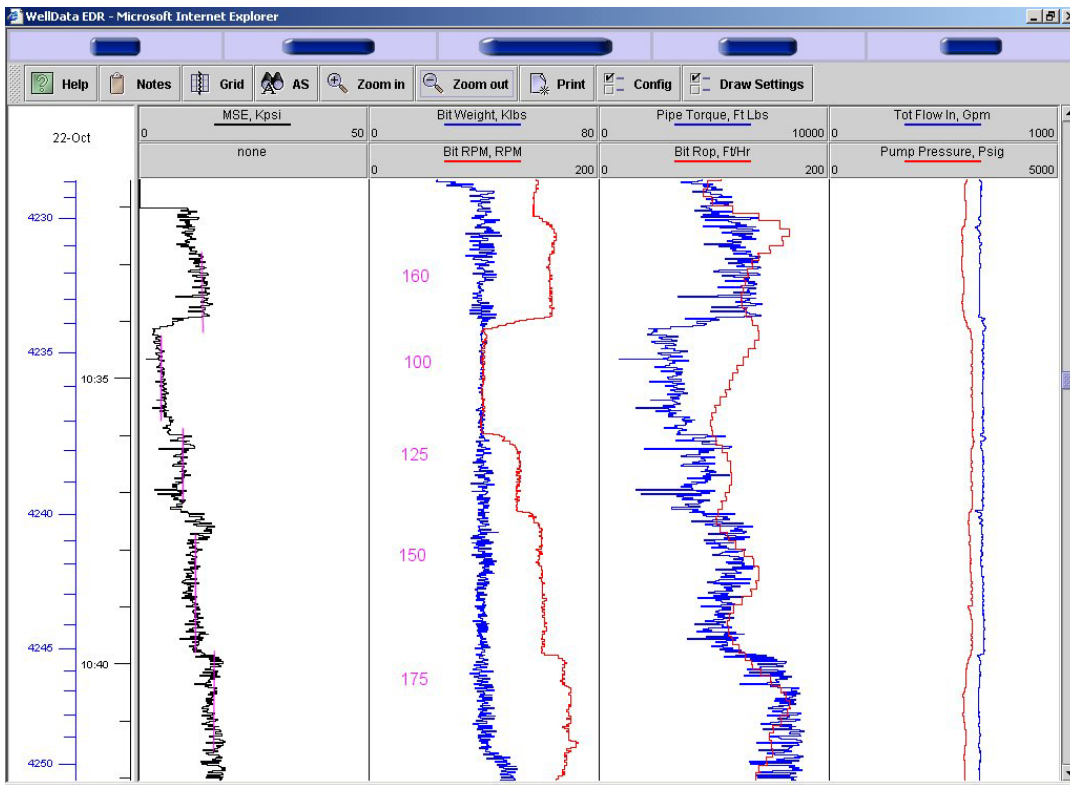


Fig. 3 – Bit RPM MSE Test

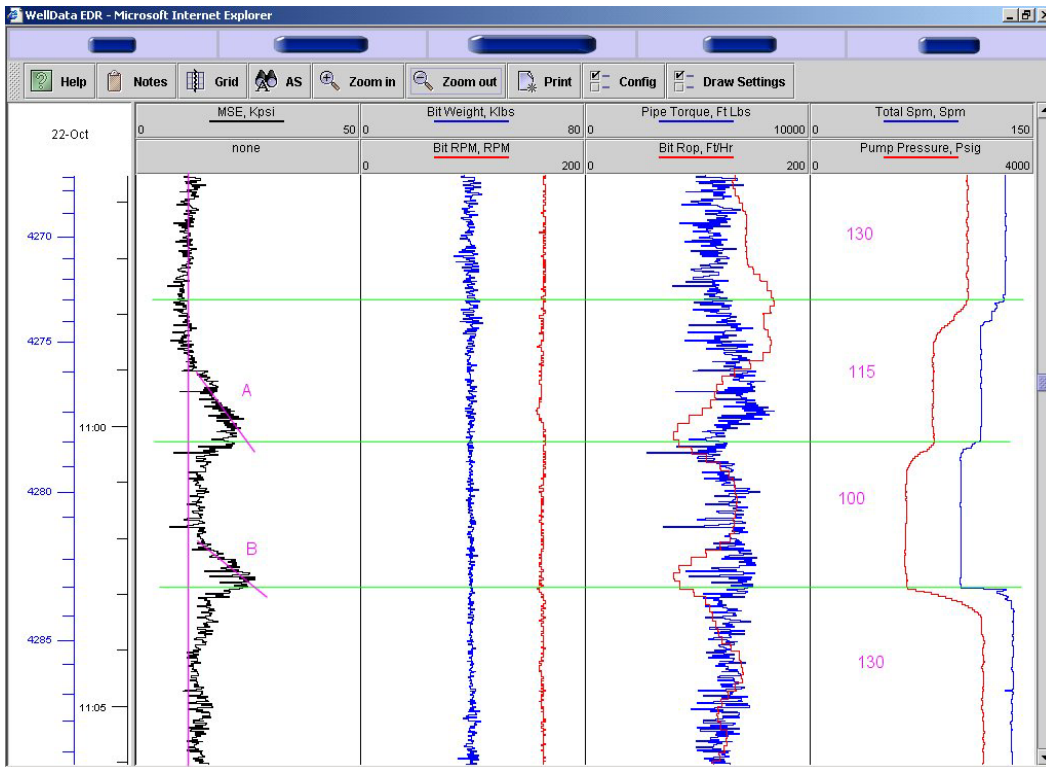


Fig. 4 – Hydraulics MSE Test

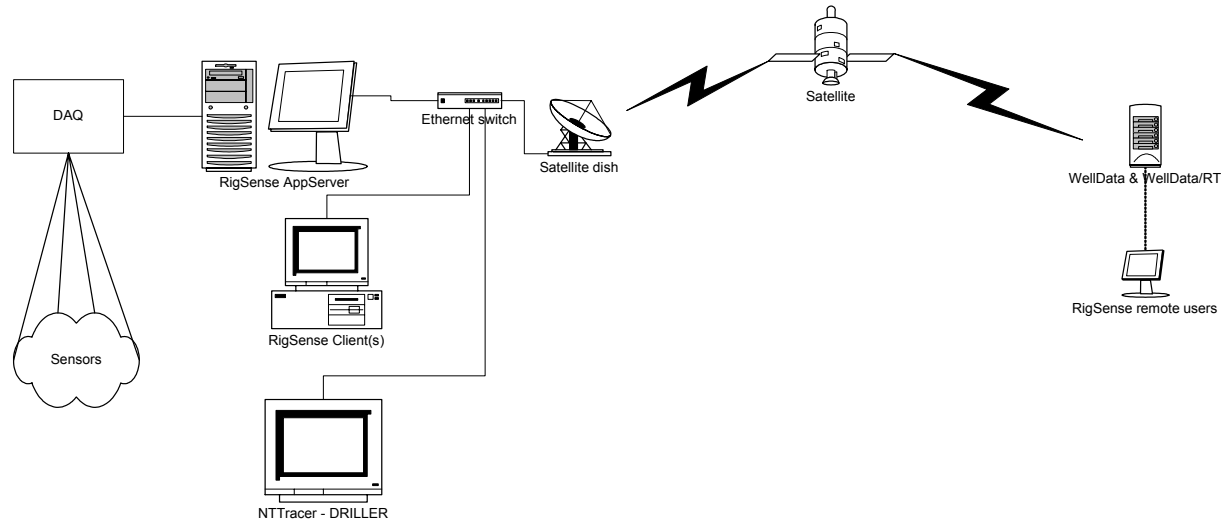


Fig. 5 – Architecture of RigSense System

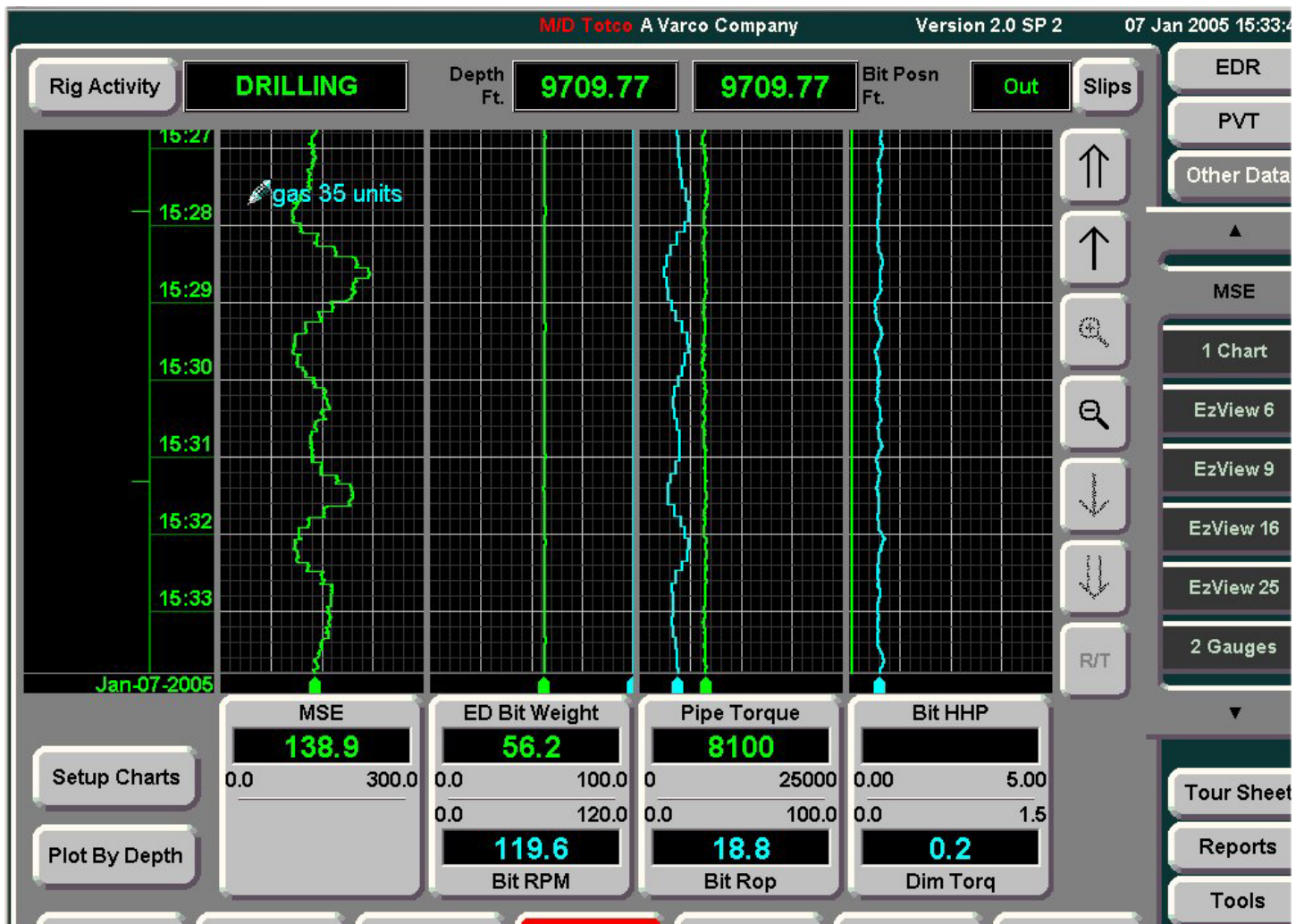


Fig. 6 – Example Screen Layout – MSE-focused

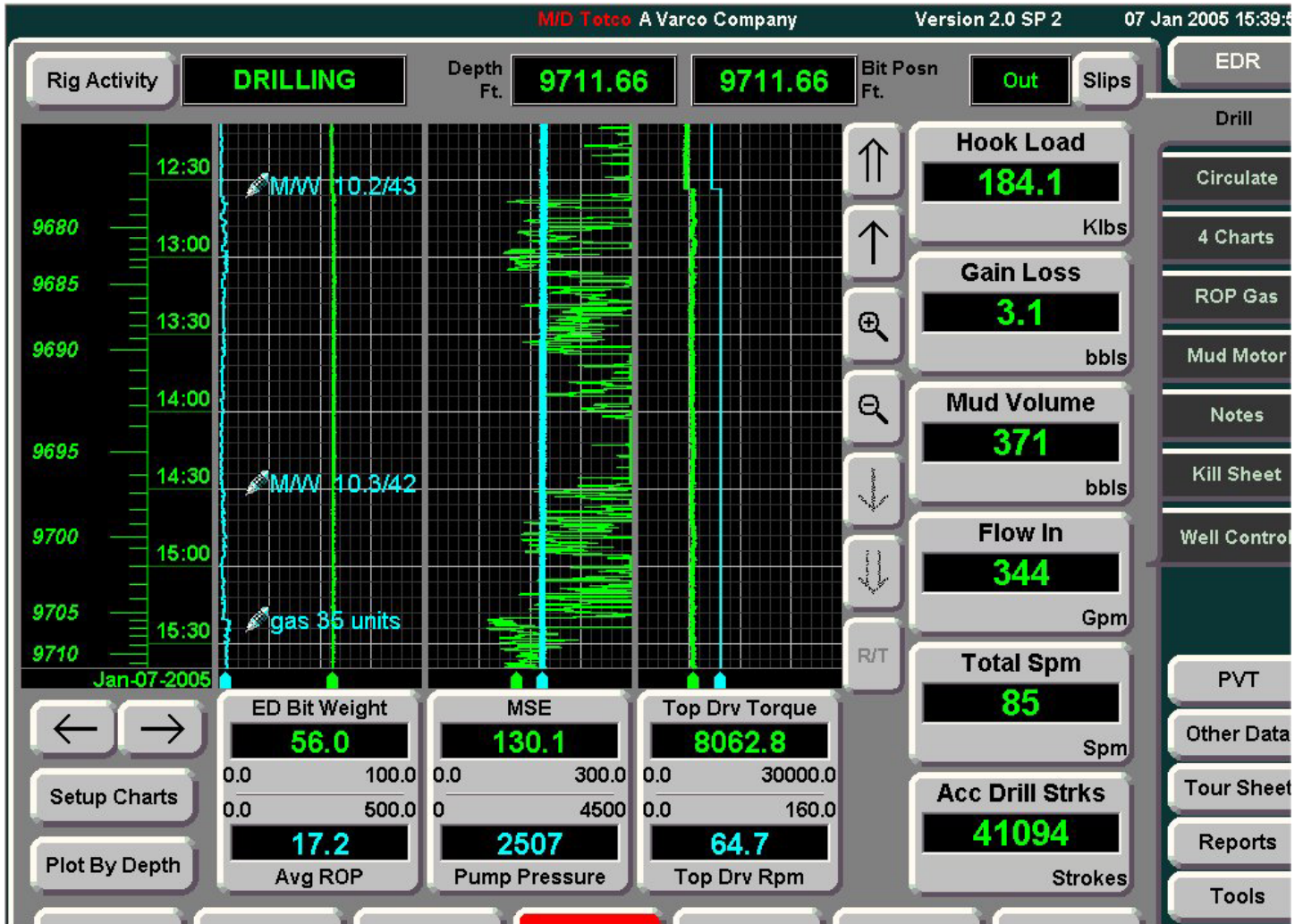


Fig. 7 – Example Screen Layout – EDR-style

Strategy	Potential Benefits	Potential Risk	Level of Engineering Required
Enhance Status Quo	Low	Low	Low
Optimize within Current Constraints	Medium	Medium	Medium
Maximize ROP, Re-Engineer Drilling Practices	High	High	High

Table 1 – Comparison of MSE Application Strategies