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AADE 2009NTCE-10-02: PRACTICAL PERFORMANCE MEASURES FOR AUTOMATED MPD

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Abstract

Automation is fast becoming a standard feature of Managed Pressure Drilling (MPD) systems for constant bottom hole pressure (BHP) control. However, there are no standards for automation that an operator can use to distinguish one system's capability from another. Comparison of different MPD service companies is further complicated by the lack of a standard method for determining reliability. Even if a standard methodology existed, because MPD automation is still very much an emerging technology there is still insufficient data to establish reliability benchmarks in different applications.

In this paper we will discuss various practical measures that may be used to evaluate the level of performance for automated MPD services and quantify its value to the drilling operation. Actual data from automated MPD jobs will be used to illustrate and explain these measures.

Introduction

Managing bottom hole pressure is an especially crucial task in a depleted mature field where a narrow margin can increase cost to unprofitable levels and elevate risk to unacceptable levels. If sufficiently narrow it can block further development completely.

In the five years since it was first introduced, automated MPD has established itself as a practical method to reduce the cost and risk associated with narrow margin drilling. Indeed, in depleted fields literally impossible to drill with so-called conventional methods it proved to be not only a practical solution but the only one. It's no surprise that after such dramatic results it has became something of a standard in those fields for subsequent projects. Elsewhere, operators have used it for its ability to improve drilling efficiency. Taken together, these represent a pattern of acceptance for automated MPD as a well defined drilling process with well defined expectations.

Specifically, one such expectation is to eliminate or at the very least mitigate the conditions that can lead to the occurrence of a well control incident in a field where such incidents are common. Another is the successful drilling of a well into a planned target that was previously unreachable due to an unmanageable pressure regime. Yet another is drilling optimization through the reduction of instability, wellbore damage, drill time, non-productive time, mud weight, etc. All of these represent expected efficiency improvements. But in a field that can only be drilled with some form of proactive, automated pressure control operators expect more – recovery improvement.

However, an expectation achieved is not in and of itself a measure of performance. It is a measure of success that can only be achieved because of a system's fundamental and measurable capabilities which for automated managed pressure drilling have yet to be defined.

Potential users of automated MPD systems and services would benefit from well defined performance measures because they would provide a basis to evaluate a system's capability and ultimately its quantitative applicability for a particular project.

This paper represents an initial attempt to define a set of four performance measures that can be used to characterize the capabilities of an MPD system for such a purpose. They are:

- Steady state pressure window
- Dynamic pressure window
- Response time
- Connection time

These measures were derived from actual performance data acquired with the Dynamic Annular Pressure Control system during commercial MPD jobs.

It should be noted that not of all of these performance measures are applicable to every type of drilling operation. In particular, connection time is not applicable to a coiled tubing drilling system for obvious reasons though the rest are.

For the purposes of characterizing the first two measures in the above list, it will be necessary to define two specific phases of the drilling operation as they relate to the pressure conditions on the surface and downhole. One phase will be referred to as a Dynamic Transition Phase and the other as a Steady State Phase

This paper is by no means a compete treatment of the topic of MPD performance measures. It is meant to raise awareness among users and providers alike of the need for agreed upon definitions to eliminate misunderstandings between requirements and capabilities.

Actual job data will be used to explain and illustrate the MPD performance measures defined above. Only general well information will be provided as it relates to the geographic location of the well and application. If published information exits about any job referred to in this paper it will be reference in the bibliography.

It is not the intention of this paper to address failure modes or definitions for MPD. That is a task that should be taken up by an industry sponsored group comprising operating and service companies alike.

The DAPC System

All of the data presented in this paper came from jobs in which pressure was managed by the Dynamic Annular Pressure Control* (DAPC*) system. That system and its application have been well described in other previously published papers so only a brief description will be provided.

The DAPC system is an automated MPD system designed to perform the actions necessary to maintain, among other things, constant BHP. There are two simple concepts in the previous sentence that must be clarified: one is automated and the other is constant BHP. We'll start with the latter first.

Constant BHP

As it applies to MPD in general and to the BHP in particular the word constant is not used in its strictest sense. It does not mean fixed and immutable. Instead it refers to a prescribed and programmed pressure value and at least two limits, one above and one below the value, which together define the range or window within which the pressure must stay.

Ideally, we would like the pressure to be fixed and immutable but that is beyond the ability of existing technology. However, reference to constant BHP grew out of an effort to distinguish the different levels of control. At one level the margins are narrow and control is proactive at another the margins are broad and control is reactive. Both have upper and lower limits, but with automated MPD the proximity of those limits is quite small compared to what is achievable with conventional drilling.

Automation

That brings us to the concept of "automated" which like the word performance is meaningless without a clear definition. In MPD it has been used somewhat cavalierly but for our purposes, an automated pressure control system is one that in its entirety acts or operates in a manner independent of external human influence or control and which is self-regulating.

The key concept in that definition is "…in its entirety…" which is to say, in and of itself an automated choke manifold does not constitute an automated MPD system. More should be required.

As it relates to the DAPC system, automation refers to the self-regulated operation of five essential modules that work together without human intervention to maintain a constant BHP.

Those five essential modules are:

- Programmable logic control
- Real-time hydraulics model
- Human machine interface
- Choke manifold
- Back pressure pump

The above list is not exhaustive. It does not include the other components that make up the complete DAPC system, such as the rotating control device, the Coriolis flow meter and its bypass manifold, pressure relief choke, HCR, remote operating link, or any of the required flow piping and miscellaneous components that may be added as the application requires.

At a minimum therefore, as it relates to constant BHP and the topic presented in this paper an automated shall mean the automated and interconnected operation of the five modules in the above list.

Integrated Control

Central to the automated operation of any MPD system and its performance capability is the control technology and the degree to which the hydraulics model and human machine interface (HMI), among other things, are integrated into it.

In the DAPC system the hydraulics model and HMI are an integral part of system control. A supervisory program directs and manages command signals and the flow of internal and external control data between the three components via an Ethernet link. Among other functions, the model is programmed to calculate the BHP once a second and calibrate itself to pressure while drilling (PWD) data, if available. It is through frequent and accurate updates that enable the controller to respond to pressure changes as fast as possible and contain the minimum and maximum BHP fluctuations within the operating window.

As the title implies, the HMI is the interface between the Control System Technician and the controller. It enables the Technician to enter configuration data, issue commands to the PLC in an easy and understandable manner, monitor system functions, and track drilling operations. Under normal conditions the Technician never interferes in any process unless the system itself issues an alarm.

The links between the controller, model, HMI, and system equipment are shown in figure 1.

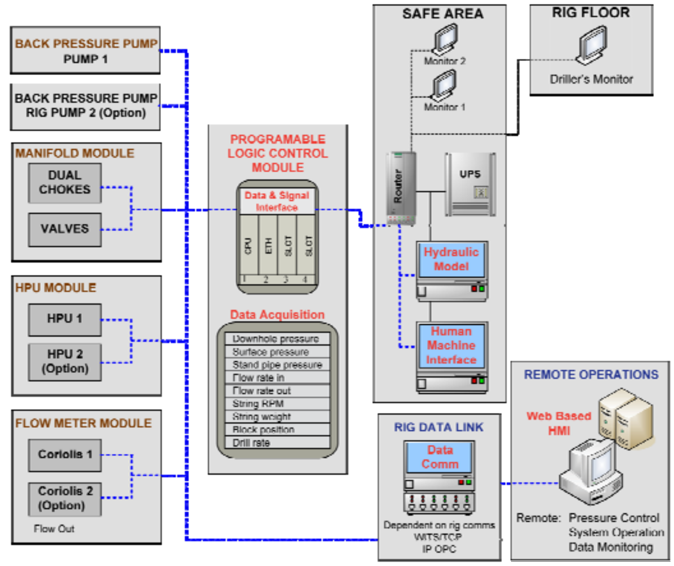

Figure 1 - schematic of DAPC integrated control system.

Figure 1 illustrates the manner in which the programmable control, hydraulics model, and human machine interface are integrated into an interconnected, self-regulated pressure management network. As a whole, it acts as an integrated pressure manager (IPM) to monitor and operate every DAPC system component, independent of external human control.

Response time is a function of a number of characteristics two of which are control system design and operating logic. As a system the IPM utilizes a control loop feedback mechanism that corrects the error observed between a measured pressure variable (e.g. BHP or back pressure) and a desired pressure setpoint by calculating and commanding corrective actions to the pressure control process. It utilizes proprietary algorithms to apply these corrective actions the objective of which is accurate and rapid process adjustment via choke position.

During system setup and installation, these corrective actions are tuned so that the controller applies the most accurate control action designed specifically to maintain constant BHP. In summary, the response of the system is a function of the controller's responsiveness to change, the magnitude of its initial response to maintain the pressure at the setpoint, and the degree to which the system can dampen the subsequent iterative responses.

Choke Manifold

Ultimately, control process actions under taken by the IPM result in automatic adjustments to the choke which is the tail end component of the response function. There are a number of different types of chokes each with different response characteristics. The types of chokes most commonly used for MPD applications are those with elements driven mechanically or by pressure balance.

It is by no means the intention of this paper to evaluate or differentiate these chokes. It is sufficient and maybe counter-intuitive to say that the most appropriate choke is not necessarily the one that can respond the fastest. More important is the compatibility between the choke (with a given response characteristic) and the controller. Greater still is the resultant stability of the system's response to pressure changes of a specific rate and magnitude. Therein lays the importance of having a performance measure that a customer can use to assess the ability of a system to respond to sudden changes in pressure or flow.

The pressure data presented in this paper come from jobs during which the pressure was managed by two different types of automated DAPC systems. One type includes a self-contained manifold which utilizes mechanical position chokes. The other type includes a modular manifold which utilizes pressure balance chokes.

The self-contained manifold, shown in figure 2 is built on a transportable skid which includes the chokes, hydraulic power unit

(HPU), and programmable logic control (PLC) panel. The modular manifold, shown in figure 3 comprises three separate but interconnected modules: the choke manifold, the HPU, and the PLC.

Figure 2 - photo of a self-contained DAPC choke manifold.

The choke manifold pictured in figure 2 is described as self-contained because the skid unit houses the manifold, the hydraulic power unit, and the programmable logic control panel. The manifold includes 2 redundant chokes for active pressure control and 1 for pressure relief. All three are automated and mechanically driven.

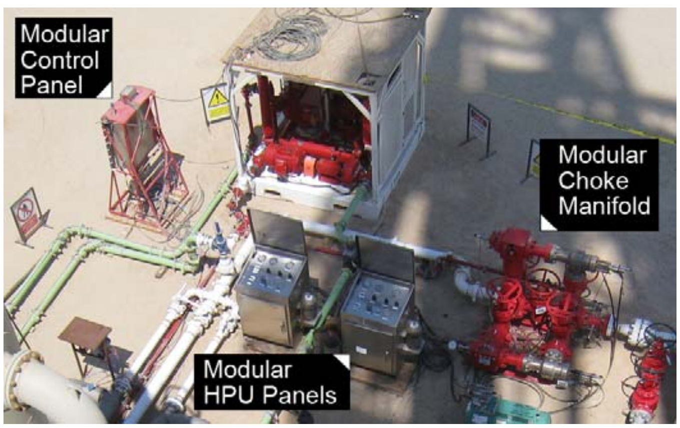

Figure 3 - photo of a modular DAPC choke manifold.

The system pictured in figure 3 is described as modular because the manifold, hydraulic power unit (HPU), and the programmable logic control (PLC) panel are each separate components. The manifold includes two 2 redundant pressure balance chokes for active pressure control.

<u>Back Pressure Pump</u>

In a closed circulation system any choke system, MPD or otherwise, can be closed to trap the pressure in the annulus when the mud stops circulating. The amount of pressure that can be trapped depends on the ability of the person or control system to close the choke before the mud stops flowing. In other words, it depends on how quickly they can respond.

If pressure is being managed to keep the BHP within a specific margin then the amount of pressure that has to be trapped is predetermined by the size of the margin. In a narrow margin, response time becomes particularly crucial because the fluctuations that can be tolerated in the BHP are much smaller.

No matter how quickly a person or system can respond, once the pump is stopped and the choke closed the BHP will remain fixed at the level trapped in the annulus provided the well isn't breathing or the seals leaking.

Therein lays the functional benefit of a back pressure pump. It supplies the hydraulic energy needed to continue managing the BHP actively when the flow rate slows or stops completely. Also, it provides the means to increase or decrease the back pressure with or without the rig pumps.

A back pressure pump (shown in figure 4) by itself does not add to a system's ability to respond any faster. But it does add to the system's ability to respond with more control.

The pressure data presented in this paper come from jobs during which the pressure was managed by DAPC systems that included an automated back pressure pump.

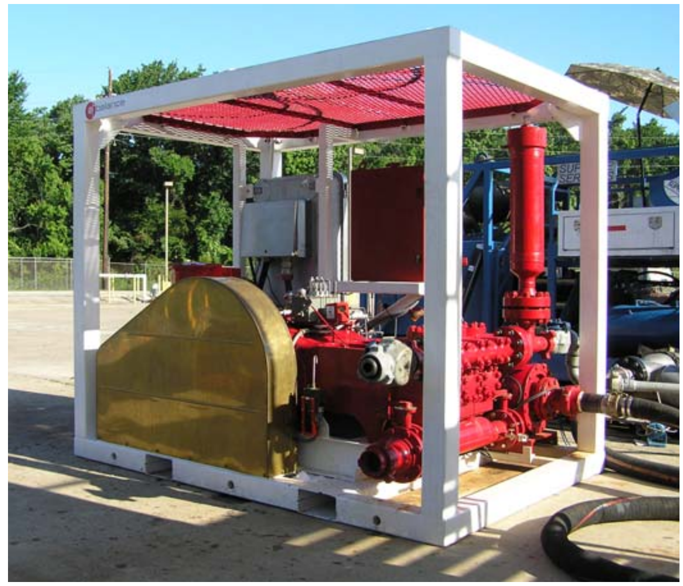

Figure 4 - photo of a DAPC back pressure pump.

The back pressure pump (figure 4) is automatically operated by the DAPC controller and used to provide an on-demand source of mud flow when return flow from the well has stopped or dropped below the level needed for constant BHP.

<u>Steady State Phase</u>

Steady state can be defined as a period of time during the drilling of a well when the rig pump rate is constant or zero and no transient pressure forces are present. Steady states can occur while making a connection, during trips in and out of a well when the rig pumps are off, and even while drilling when the rig pump rate is constant.

Automated managed pressure drilling involves the control of the bottom hole pressure during one or all of those planned operational phases, i.e. drilling, tripping, connections. At any time during those phases, the MPD system is also normally expected to control the BHP whenever conditions change in an unplanned way.

By example, the graph in figure 5 highlights steady state conditions during a connection.

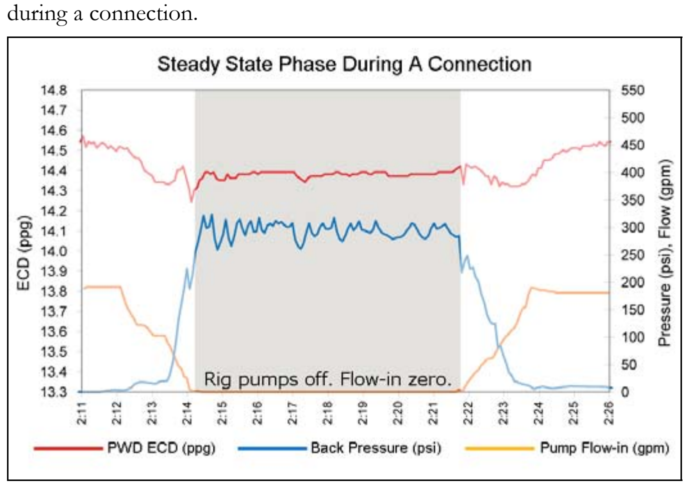

Figure 5 - plot of pressure and flow managed by the DAPC system during a connection showing the phase defined as steady state.

In figure 5, the start of the connection is indicated by the Pump Flow-in curve which shortly after 2:12 the driller starts to reduce from 200 gpm to zero at around 2:14. At the same time the DAPC system automatically increases the Back Pressure as indicated by the blue data curve. A steady state exists when the rig pumps are off but the DAPC system is on and actively controlling the pressure indicated by the area of the plot highlighted in grey.

During steady state conditions a system's accuracy can be measured by its ability to maintain the BHP at a programmed setpoint during static or steady flow conditions.

Steady State Pressure Window

The following examples of steady state fluctuations were recorded during MPD jobs using the DAPC system.

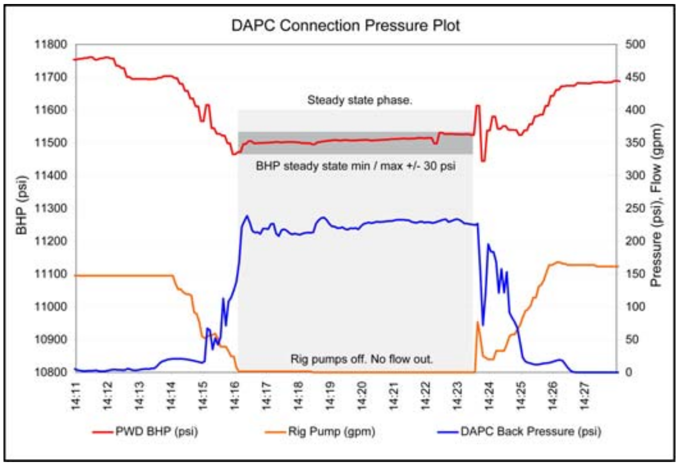

Figure 6 – pressure plot example showing steady state window during a connection.

In figure 6, steady state is highlighted in grey during which time the rig pumps are off and the BHP varied by +/- 30 psi. The slight increase in BHP correlates to the increase in back pressure. The reason for that is illustrated in figure 7.

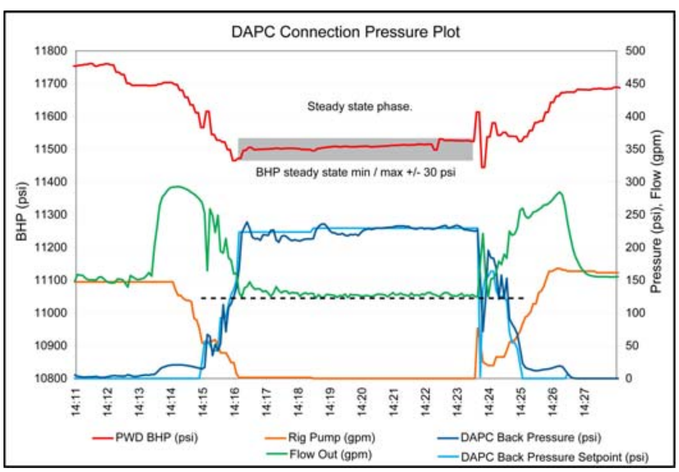

Figure 7 – the same pressure plot example as shown in figure 6 of a steady state during a connection showing a slight amount of flow-back as indicated by the flow-out curve just after the rig pump was turned off.

As can be seen in figure 7, after the rig pump was turned off just after 14:16 on the time scale, the well flowed slightly indicated by the difference between the Flow Out (green) curve and the black dashed line. As the flow back dissipated during the connection, the system maintained control of the BHP in a 60 psi window by actively managing the back pressure at the programmed setpoint.

Technically, by definition, there should be no transient pressure forces present during steady state. The connection in figure 7 was chosen because the flow back though small was enough to illustrate the small size of the adjustments and precise level of control that is often required during steady state.

As a performance measure then, the size of the window within which an automated MPD system can control pressure during a steady state phase would be an indication of how fine the control is which is an important consideration in very narrow margins.

Today, no standards exist to communicate expectations for or govern the control of BHP during a steady state phase and distinguish it from a dynamic phase. Too often pressure limits more appropriate for a steady state phase are used to specify expectations for MPD even during a dynamic phase, without considering the degree of control required versus the depth at or conditions under which it is to be provided.

Steady states can also exist while drilling and tripping even though during both of those operational phases large and damaging on and off bottom pressure transients can occur. An example of an MPD steady state phase during tripping is shown in figure 8.

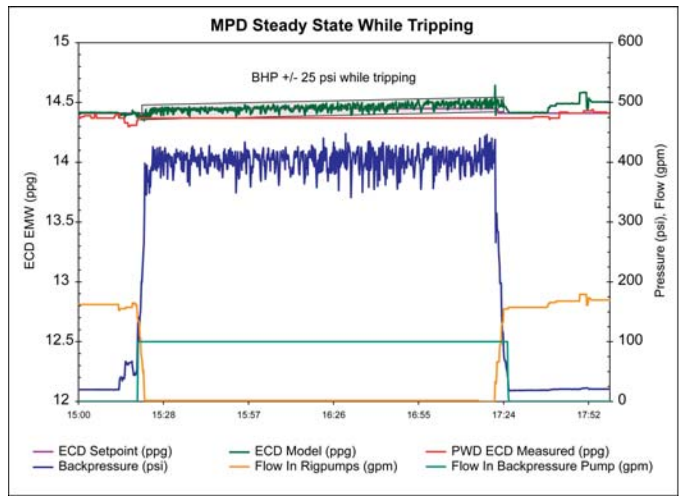

Figure 8 – pressure plot example showing a steady state phase and pressure window while tripping out of a well.

However, swab and surge can cause the BHP to fluctuate by 1 ppg or more. Even though automated MPD control can help reduce the magnitude of swab and surge it can not eliminate them entirely. In terms of psi swab and surge can be very large compared to steady state.

For those reasons, transient fluctuations and the pressure conditions under which they can occur should be categorized separately from steady state as should the limits that govern MPD control expectations.

Dynamic Transition Phase

A dynamic transition phase can be defined as a drilling phase during which the flow rate is actively changing either by the planned actions of the driller as he adjusts the rig pump rate or by the unplanned actions of the well itself or those caused by equipment faults.

For the sake of illustration, we will focus on the dynamic transitions that occur prior to every connection, when the driller is ramping down the pump rate and afterwards when he is ramping it up. If severe enough, a sudden change in flow rate during a connection can cause the BHP to fluctuate well beyond the allowable margin and create a potential well control condition. It is the professed role of an automated MPD system is to prevent that.

The pressure plot in figure 9 illustrates the dynamic transitions that occur before and after a connection.

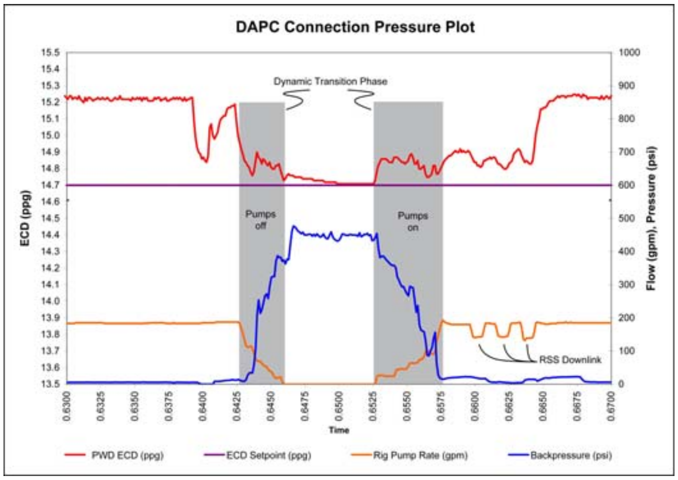

Figure 9 – plot of pressure managed by the DAPC system during a connection showing the dynamic transition phase during which the rig pump is being turned off and on.

Figure 9 highlights the pump-off phase prior to the connection being made and the pump-on phase after the connection has been made. A dynamic state exists when the rig pumps are being turned on and off and during which time the DAPC system is on and actively controlling the pressure indicated by the blue back pressure curve.

Dynamic Pressure Window

During the pumps-off transition phase an automated MPD system will take control of the BHP to make it equal to the programmed setpoint and during the pumps-on phase it will give up control as the pumps are turned on and ECD increases to the operating level. Another measure of a system's performance is its ability to achieve the programmed BHP setpoint while managing the fluctuations within specific dynamic limits.

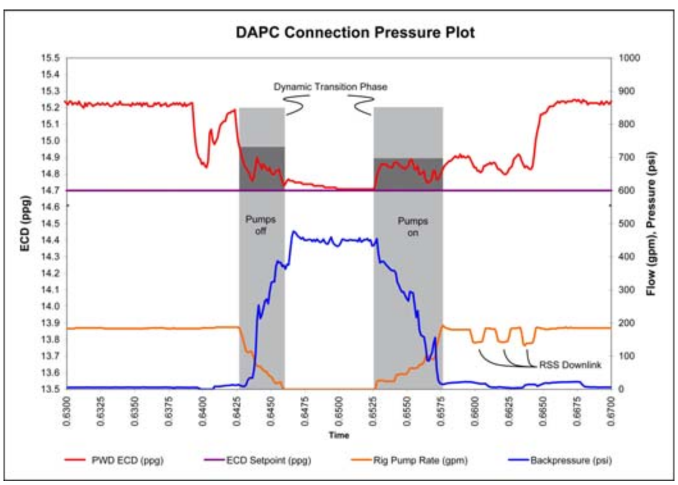

Figure 10 – the same pressure plot as shown in figure 8 highlighting the BHP fluctuations that occur as recorded by the PWD tool during the dynamic transition.

As shown in figure 10, the BHP will fluctuate during the dynamic transition especially when, as highlighted by this example, the plan involves maintaining the BHP during connections at a level below the ECD but above wellbore stability. Regardless of the actual objective value of the BHP to be maintained during a connection it is relatively standard practice to specify the setpoint and window limits in terms of mud density as is commonly done with pore pressure, fracture pressure, and ECD.

Fluctuations that occur during a dynamic phase are normally much larger than those that occur during a steady state phase and if unmanaged can exceed the narrow margins typically found in a depleted field. It is for that reason that the most crucial control limits placed on an automated MPD system are ones that dictate the limits within which the pressure must be maintained to stay within narrow downhole pressure margins during dynamic phases.

During any dynamic transition, planned or otherwise, it can be said that the job of an automated MPD system through which drilling fluid is actively circulating is to manage dynamic fluctuations within the prescribed window.

A performance measure that reflects the size of the dynamic pressure window within which an automated system can and has managed BHP can only help apply different MPD technology more efficiently and cost effectively.

In the case presented in figure 10 the actual specified control limit was +/- 0.3 ppg relative to the ECD setpoint of 14.7 ppg. As can be seen from the plot the BHP was maintained within that limit during the pump-off and pump-on transition.

Another way report this performance measure is at the end of a job with a summary plot of all connections during which an automated system managed the transition from dynamic to static BHP. An example of such a summary plot is presented in figure 11. It shows a summary of actual pressure limits achieved by the DAPC system during 115 connections made over the course of a 3 well project.

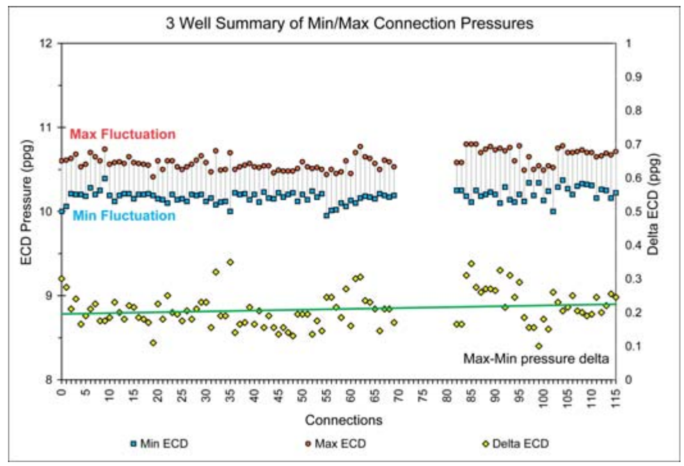

Figure 11 – summary of minimum and maximum pressures managed by the DAPC system during 115 connections, 109 of which (95%) of which were within a +/- 0.3 ppg window relative to a 10.5 ppg setpoint. The green line represents the average trend of min/max pressure delta over the 3 wells.

Response Time

Response time is a measure of an MPD system's ability to respond quickly to sudden changes in flow and pressure while maintaining the BHP within the prescribed windows under dynamic conditions. Like the dynamic pressure window response time is also tied to the size of the downhole pressure margin. A short response time enables a system to minimize the impact of a sudden fluctuation in BHP. In general, a very narrow margin would require a much shorter response time than a very wide margin.

To better understand response time one has to look for the devil in the details of a system's response during a dynamic transition.

Figure 12 is a connection pressure plot that highlights a fairly typical pump operation by the driller. After the connection is made and the driller is ready to go back to drilling he will kick on the pump quickly to start the MWD tool.

This is a good example to use to examine automated response time.

Figure 12 highlights an action typically taken by most drillers when they are ready to go back to drilling after a connection. They will quickly bring up the pumps in an effort to start the MWD downhole tool. However, if such an action is repeated on every connection and not managed it can lead to large fluctuations in the BHP and ultimately contribute to wellbore instability.

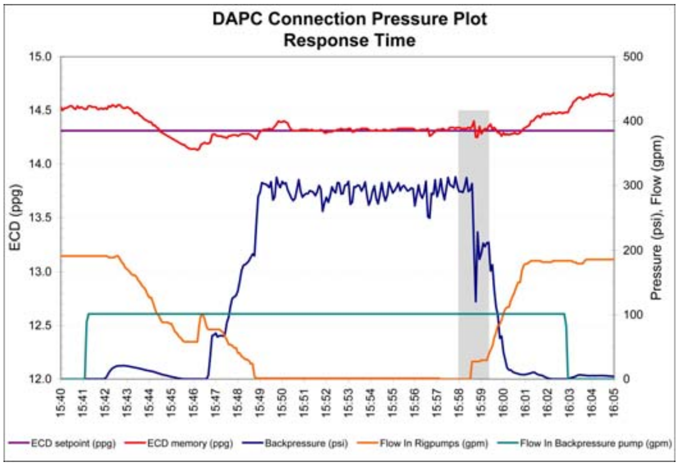

Figure 12 – pressure plot highlighting a transient pressure event caused by sudden increase in the flow rate immediately after the connection.

In response to the sudden change the DAPC system will automatically act to minimize the effect of the pressure increase by reducing the back pressure (blue curve).

In the plot in figure 13 the time scale of the plot in figure 12 was expanded to study the details of transient event.

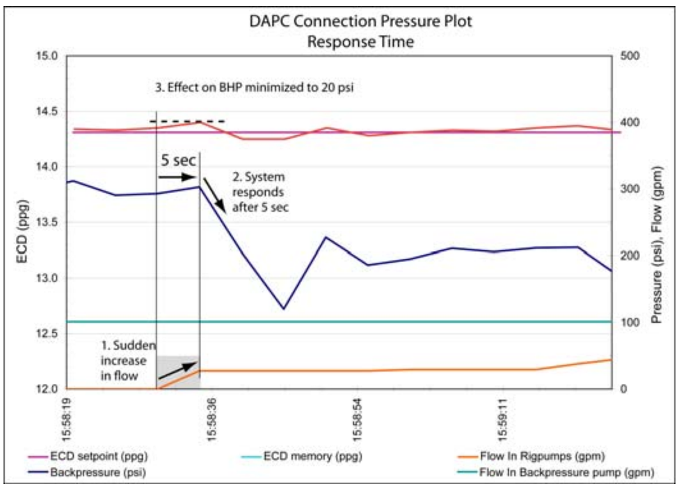

Figure 13 – same pressure plot as in figure 12 with expanded time scale to show the details of the transient event.

Figure 13 shows how the DAPC system responded. Within 5 seconds it detected the change in flow and opened the choke to reduce the back pressure and minimize the effect on the BHP. That response action minimized the effect of the sudden flow rate change to only 20 psi.

Using response time and dynamic control to measure and characterize an automated MPD system's performance can help operators better assess the level of technology that a narrow margin field would require.

Connection Time

Connection time as it applies to a choke based, automated MPD system is the time it takes to complete the transition from pumps-on to pumps off prior to a connection and from pumps-off to pumps-on after the connection. It can be viewed as a measure that largely depends on a system's response time and dynamic control as well as procedural efficiency. In this section we will not discuss procedural efficiency.

At a basic level every automated MPD system must have the ability to track pump rate changes prior to and after each connection and make choke adjustments to maintain a constant BHP. But, not every system is the same. One way in which they will differ is by the design features that govern the speed at which the rig pumps can be turned off without causing BHP fluctuations outside the prescribed downhole margin.

But in spite of those differences, by design, procedure, or both it is a fundamental objective of MPD to shorten the connection time while maintaining a constant BHP.

As a performance measure connection time can be used not only to estimate how long a connection will take with MPD but it can also be used as a measure of operational improvement.

A recommended practice for a multi-well MPD project involving a rig crew unfamiliar with MPD procedures is to benchmark not only the connection transition times but every rig maintenance task that involves dynamic transitions in the rig pump flow rate. This type of practice has led not only to process improvements but also to product improvements.

The pressure plot in figure 14 will help put this into perspective.

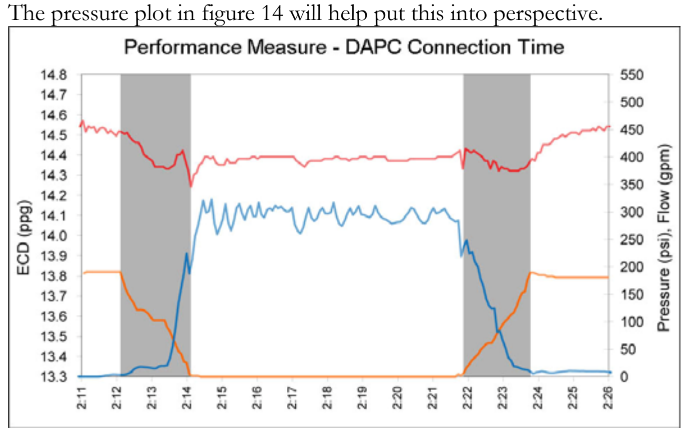

Figure 14 – pressure plot highlighting the MPD connection time which coincides with the transient periods prior to and after a connection.

Figure 14 highlights the transition phases before and after a connection. The length of time it takes to make the transition is in part a function of the MPD system's ability and the procedural efficiency of MPD operations. After the rig pumps have been turned off the connection proceeds independent of MPD operations. Other actions and task can occur during these transitions which will add to their duration, e.g. MWD operations, RSS down-linking, routine rig maintenance, etc.

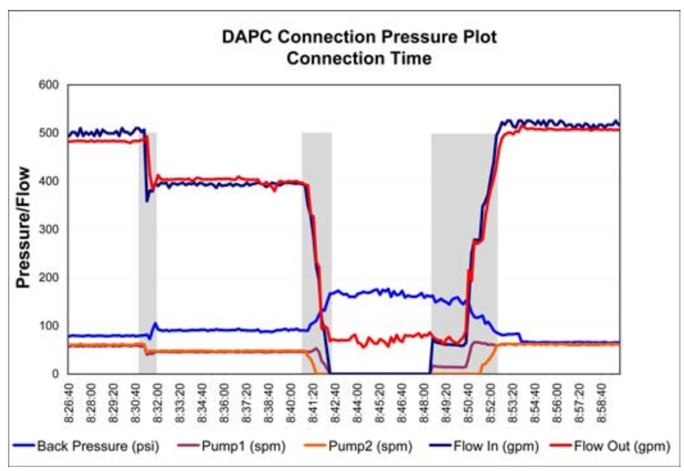

Figure 15 – pressure plot highlighting several dynamic transient periods including a sudden drop in flow and the pump transitions before and after the connection.

The plot in figure 15 is a specific example that will be used to illustrate several aspects of MPD operations including connection time. That data came from a job in which the DAPC system managed pressure continuously while drilling and during connections.

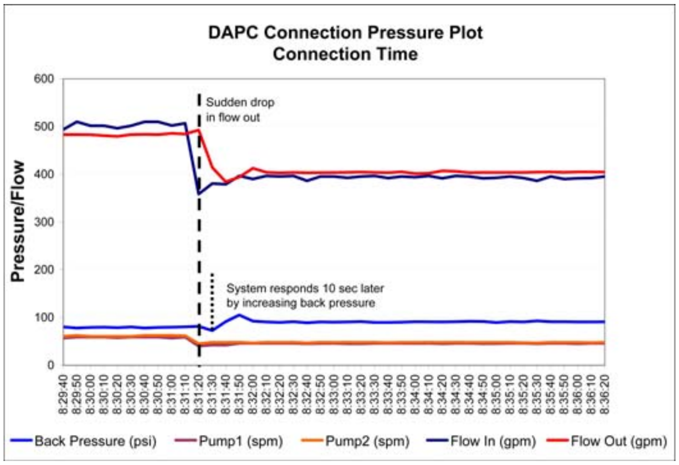

Figure 16 – a detail look at the sudden drop in flow just prior to the connection.

Up to about 8:31:10 as marked on the time line in figure 16, the system was maintaining 80 psi of back pressure while drilling. At that point the pump rate was decreased very quickly prior to picking up off bottom and setting the pipe in slips. Ten seconds after detecting the change in the pump rate the system increased the back pressure to about 100 psi and held it until around 8:41:00 as recorded on the time line in figure 17 at which point the pump transition was started to make the connection.

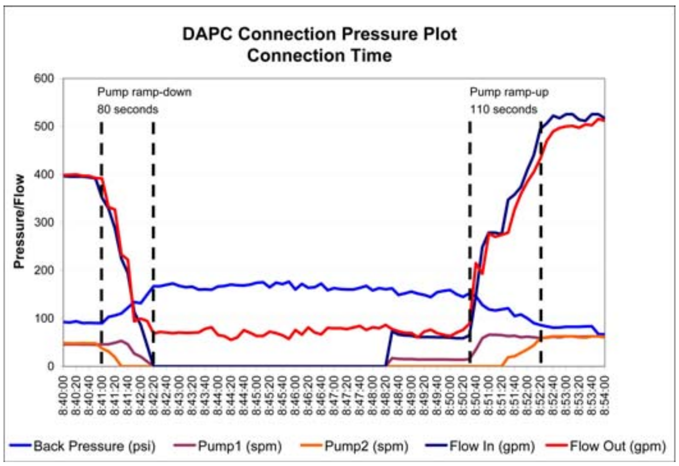

Figure 17 – a detail look at the pump transitions before and after the connection and their duration.

The plot in figure 17 highlights the time it took to ramp the pumps down and up before and after the connection, respectively. Together the pre- and post-connection transitions took only 190 seconds.

It is that time, 190 seconds which represents the level of performance that can be achieved with that particular automated system during a connection.

This is connection represents a performance snapshot and it is for that reason that we recommend plotting the trend in connection time over the life of a long well or multi-well project to track operations improvements.

Summary

This paper proposed, defined, and presented examples of four performance measures for use with automated MPD systems:

- Steady state pressure window
- Dynamic pressure window
- Response time
- Connection time

In addition, static and dynamic operational phases were defined to help explain how and when those performance measures apply.

It is our hope that this discussion will continue in an industry sponsored forum for the eventual development of standard measures that would be adopted by MPD service companies and MPD users.

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