SPE 112241

Drilling Better Wells Cheaper and Faster

Dr. Robin Brooks and Dr. John Wilson, Curvaceous Software Limited

This paper was prepared for presentation at the 2008 SPE Intelligent Energy Conference and Exhibition held in Amsterdam, The Netherlands, 25–27 February 2008.

Abstract

The control of a drill in realtime is demanding on the skills and experience of the drill operator and is variable across operating shifts because different operators have different levels of skill and experience. A mathematical model that could be shared by operators would eliminate this variability but few, if any, exist because of the mathematical difficulty and considerable expense of creating such a model in the first place and then of updating it as geology and hole depth and the type of drilling changes.

This paper describes and demonstrates a radically different approach and a solution to the problem by modelling the operating envelope of the drill operation as a multi-dimensional solid object so that the operating problem becomes a geometric problem of operating always as an interior point of the envelope. The beauty of this approach is that the model developers and maintainers do not need any mathematical knowledge or the ability to describe problems with algebraic or differential equations. The method is able to create models of high dimensionality using the original process variables only so is easily understood and accepted. It is well-placed for realtime exploitation of the increasing number of down-hole measurements. The geometric basis of the model makes the operating advice that it generates intrinsically safe. A realtime operator guidance model will be developed and shown during the presentation to show the concepts, mechanics and possibilities of the method.

The method is part of the overall technology known as Geometric Process Control (GPC) which is becoming well-established in downstream process industries and has already achieved success in problem-solving and offshore process improvement applications with several major North Sea operators. It has won awards for Innovation from EPSC, IChemE, IET and the CIA (Chemical Industries Association).

Introduction

Drilling depends to a large extent on the skill and experience of the individual operator. In many fields where this is the case, efforts have been made to capture the performance of the best operators so that all may achieve the same results. A large effort was put into Rule-Based systems which attempted to formulate skill and knowledge. The approach described here is completely different; the records of good drilling operations on a well are used to automatically build a model that generates advice to the operator.
The operator cannot see 'the edge of acceptability' today but must sense it in some indescribable way commonly labelled as 'skill and experience'. With the new model and its graphic display he is able to see it in realtime and use it to improve his current operation and Rate of Progress. This reduces the 'skill and experience' requirement and simultaneously guides him to perform as well as the experienced operator whose skill and experience form the 'Best Practice' foundation of the model.

The Operating Envelope in Geometric Process Control

Geometric Process Control (GPC) is based upon the use of envelopes of good process operation modelled as n-dimensional solids where the dimensions are the ranges of the variables that constitute the model. An envelope is found by identifying a set of historical operating points in the n-dimensional process space that all represent good operation. This is quite different from the traditional practice of setting fixed ranges for the operating variables.

Viewed geometrically, a set of ranges defines a multi-dimensional rectangular Box. It is rectangular because simple ranges on individual variables imply independence of variables so that for the simple two-variable example in Figure 1 the range AD on variable V1 and DC on variable V2 imply that we can operate anywhere inside the rectangle ABCD and get good product.

But the variables are not independent so it will be found that good product is actually obtained only when operating in the sub-ranges EH and HG. The two rectangles ABCD and EFGH are obviously connected by the shaded oval shape shown along one of the diagonals of ABCD.

The oval shape is a ‘contour’ within which operation is “good” (by some criteria separate from V1 and V2). ABCD is the enclosing rectangle and EFGH is one of many possible enclosed rectangles that has been found by the process operators by trial-and-error to produce best results. Different operators may have different working Boxes.

This geometrical view is easy to understand in the two dimensions needed to consider a two-variable problem or even in the three dimensions needed to understand a three-variable problem. It gets difficult in a real process when one may have to consider dozens or even hundreds of variables because we have not previously been able to view two or three-hundred dimensional objects. Obviously though the same principles apply to the enclosing Box, , to the operators preferred operating Box that must be one of the many hypercube equivalents of EFGH, and to the multi-dimensional envelope that represents the ‘contour’ within which good product is made.

The algorithmic part of GPC consists of methods for calculating the envelope (or “sausage”) from historical data and for calculating the control actions necessary to keep the operating point within the envelope.

The other necessary part of GPC is a way of visualising multi-dimensional data. This is now described

Parallel Dimensions

To visualise points in multi-dimensional space we use a new type of graph, due to A. Inselberg of IBM, in which the axes are drawn vertically and parallel to each other, thus allowing many axes, and a related set of variable values (a multi-dimensional Point) is represented by a polygonal line connecting the values of each variable plotted on its own axis. Figure 2 shows an example from a chemical process, where all the process values of variables P1 through P14 at a particular time point have been associated with their resulting lab qualities (q4 through q8) and shown as one polygonal line.

The graph is more useful when many points are shown and in Figure 3 1244 data points are present. This data comes from well drilling. A selection has been made of some of the data by means of ranges on some variables, indicated by red triangles. The selected data points are coloured yellow.

There are two parallel-coordinate displays involved in GPC. The one shown in figures 2 and 3 is used in selecting good operating points. The other is used in the Operator Display, and is described below.

The Best Operating Zone

The multi-dimensional envelope we referred to above as the “sausage” is in fact the Best Operating Zone (BOZ). The BOZ is defined by good operating points selected by queries on the multi-dimensional display of historical operating data.

The resulting BOZ model is shown in Figure 4 is the Operator’s Display. It includes only variables already known to the operator – no artificial variables are used.

The black dots represent the instantaneous values of the process variables read from the real-time control system. The requirement to remain within the BOZ means that each variable must remain between upper and lower limits. These limits are due to the current values of the other variables and will change when a new set of values is received. These limits are joined by the green lines between the variable axes, and also shown in the panels at the bottoms of the axes.

In this case the value of the 8th variable, Gas_Flow, is below its current lower limit, and an alarm has been raised. The grey background to this variable’s name label indicates that it is a non-manipulated variable, not under the operator’s control. Therefore in order to clear the alarm the GPC algorithm has to move one or more manipulated variables so that the lower limit on Gas_Flow will be changed to be below the actual value of that variable. The first variable, RPM, and the third, Mud_Flow have been moved to the values indicated by the blue spots on their axes. The new limits due to the new values are joined by blue lines, and the new lower limit on Gas_Flow can be seen to be below its value. The advice to the operator, shown in the blue panels, is to decrease RPM to 165.54 and Mud-Flow to 422.83. The advice generated by GPC models is always to move into the BOZ envelope, never outwards, and is therefore intrinsically safe.

The operator could also notice that the 11th variable, M/min, is close to its current lower limit, and should be watched.

The Well-Drilling Model

The variables included in a GPC model for well drilling are likely to include the following; the use of other variables if available is not excluded.

Variables measured in real time and controllable by the drilling operator: rotation speed of drill (rpm); mud flow rate; Hook Load (used to adjust the weight on the drill bit). These are the Manipulated Variables.

Variables measured in real time but not controllable directly: torque on drill string; weight on drill bit; back pressure on the mud pump; mud exit temperature; well depth; drill bit height; rate of progress. These are the Non-Manipulated Variables.

Variables determined after the event: mud circulating density; mud solids content. These are the Quality Variables.

For the purpose of selecting normal drilling data, the values of the variables determined after the event are combined with the values of the on-line variables for each measurement time. To build the model, a sufficiently large amount of data representing 'good' or 'normal' drilling in the well being drilled is collected. This data may be the data gathered in drilling a preceding portion of the well. “Sufficiently large” means the number of data points be several orders of magnitude more than the number of variables, and should cover the full range of conditions to be encountered in operation.

The selection of the good data involves the drilling engineer’s process knowledge. Figure 5 shows a step in this selection for a particular well. The qeuries (conditions) used in this example are quite complex, consisting of combinations of predicates (requirements) involving torque and depth.

The model is regularly updated with new data to ensure that it represents normal drilling in the geological conditions obtaining at the bottom of the hole. As the model uses the best results obtained in the current hole and geological conditions, it assists all operators to achieve the results obtained by the most skilful operator working on the rig, as well as assisting all operators to achieve the best possible rate of progress all the time.

The data required to build the model is already gathered by the well logging system. The selection of the good drilling data from all the available data is all the work of building the model. This makes the GPC method particularly suitable for use by engineers concerned with well drilling rather than with mathematical modelling.

Abnormal Events

As well as optimising normal drilling, an advisory display should warn of the onset of Pack Off to enable the operator to take corrective action. Pack Off s are collapses of the sides of the hole. They are not specifically related to cutting.

Figure 6 shows four steps in a possible Pack-Off event. The sequence in time is yellow, dark blue, turquoise and pink. Between yellow and blue is a sharp rise in torque (atrq) which is the first indication of a significant Pack-Off event. One minute later (turquoise) the back pressure at the pump (pumpp) rises significantly as the mud is pushed through and lifts the debris of the pack-off. In the final step (pink) the operator has intervened to raise both rpm and mudflow to fully clear the packoff.

To advise the operator in a Pack Off situation, it is necessary to build a separate Pack Off BOZ. This involves selecting data referring to Pack Offs that were successfully dealt with. A “sharp” increase in Torque is detected by the control system which switches the model to the Pack Off BOZ. Resumption of normal cutting is similarly detected and the control system switches back to the cutting BOZ.

Example – Comparison with Operator Action

Historical drilling log data was replayed in the Drilling model. Figure 7 shows advice generated by the model, and figure 8 shows the model display with data taken 30 seconds later. The Operator when the data was recorded was not using the GPC system, so the operator’s action based on experience is being compared with GPC advice. The model advised reducing RPM from 266.67 to 241.91 and Mud_Flow from 498.62 to 486.19. 30 seconds later the actual values were 262.89 and 490.60. It appears that this operator decided on smaller moves than the GPC model in the same direction.

Conclusions

Geometric Process Control is an easy-to-use method for building advisory systems for drilling operators using the best results so far achieved on the well. The model can be kept in line with current well conditions by selecting more data at when the drilling engineer considers it appropriate. The model can be put on-line to the drilling log system using an OPC interface or other appropriate technology, and provides an easily-understood multi-dimensional visual indication of where the current operating point is in relation to the Best Operating Zone, and advice on how to remain it.

Figures

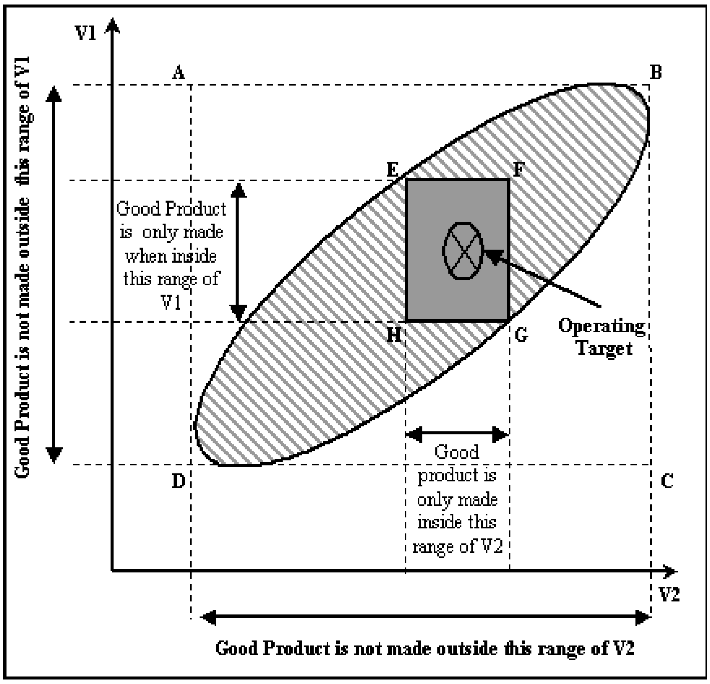

Figure 1 The Operating Zone in 2 dimensions

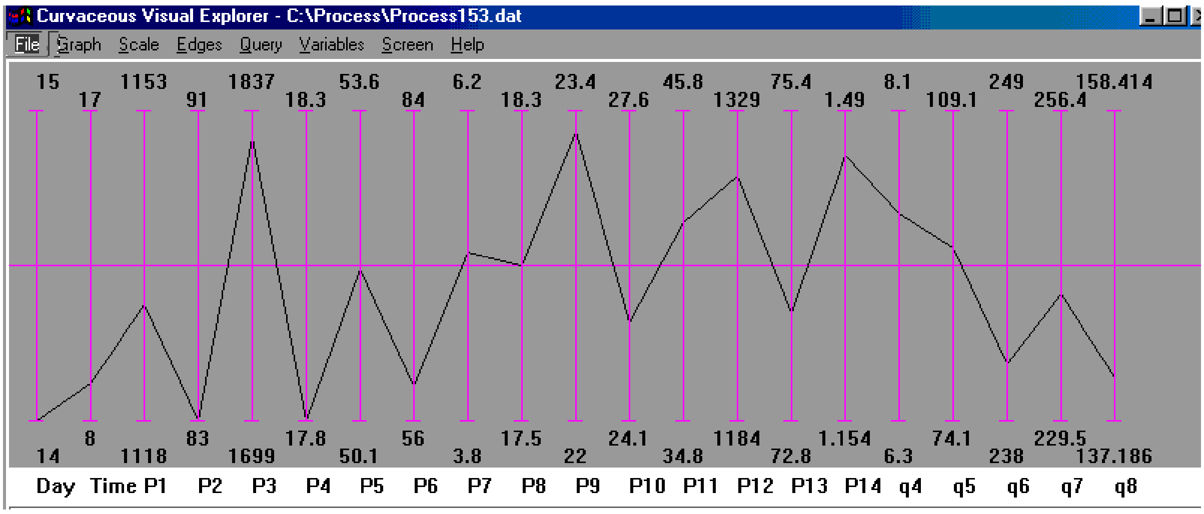

Figure 2 A point in 21 dimensions in parallel co-ordinates

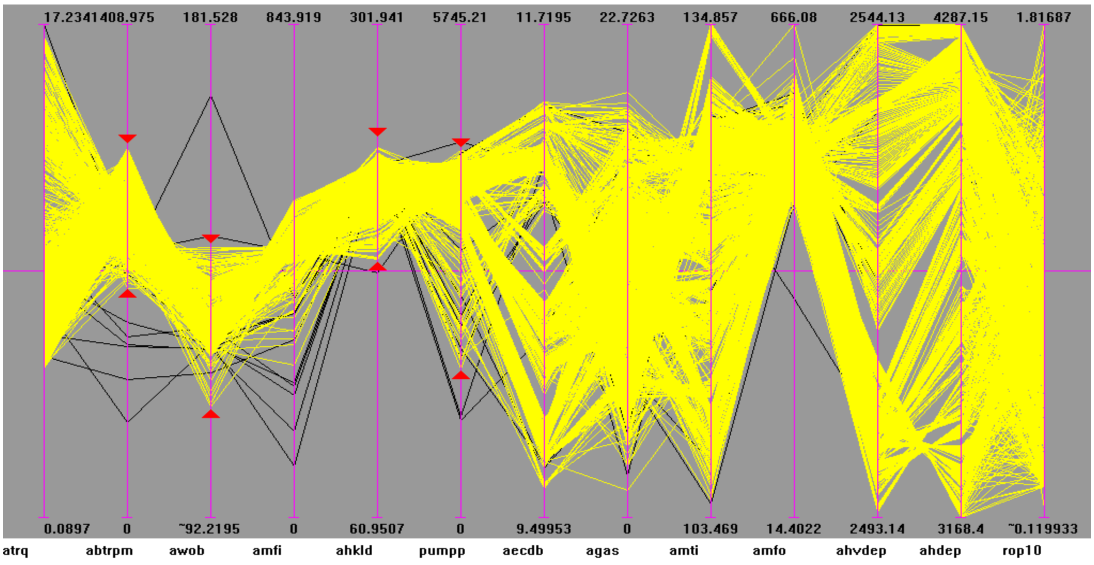

Figure 3 Many data points in 13-D with selection

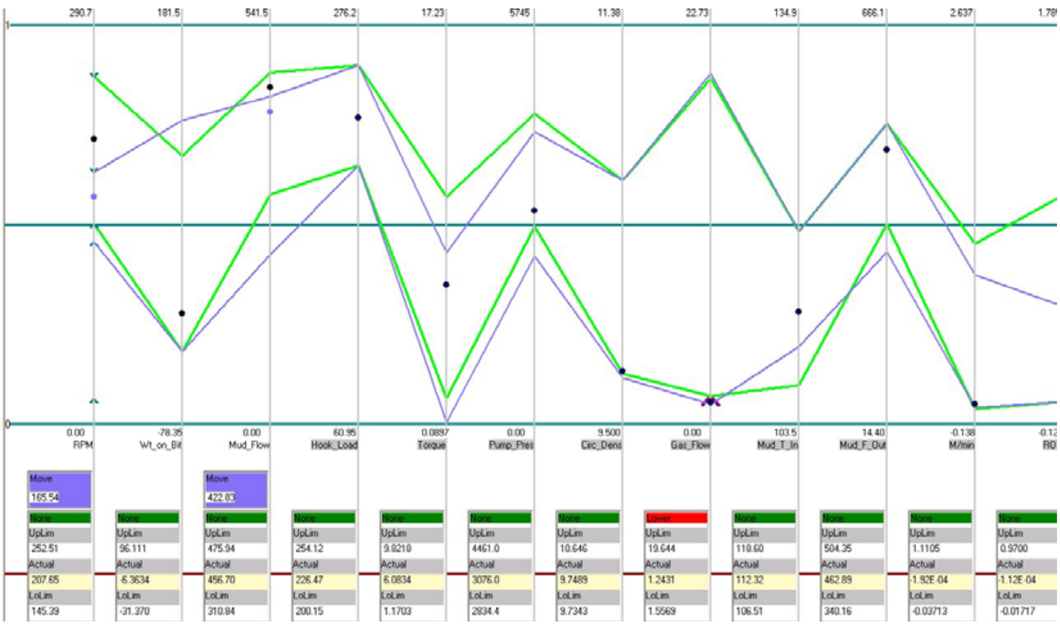

Figure 4 The Operator Display with Advice

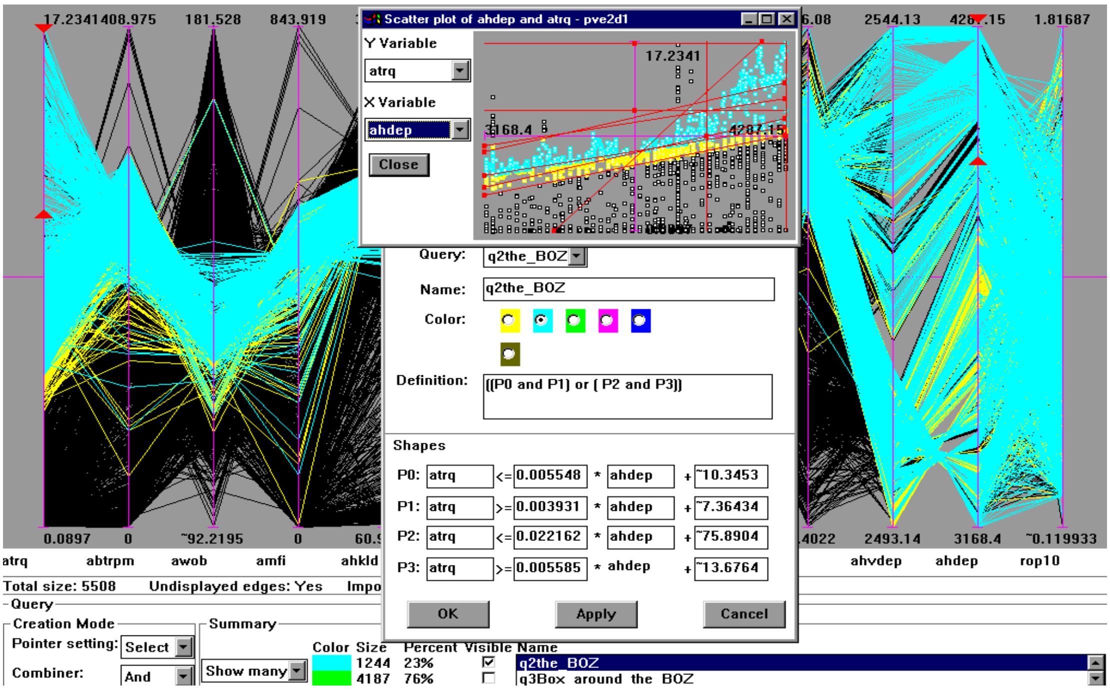

Figure 5 Selecting the Best Operating dataset

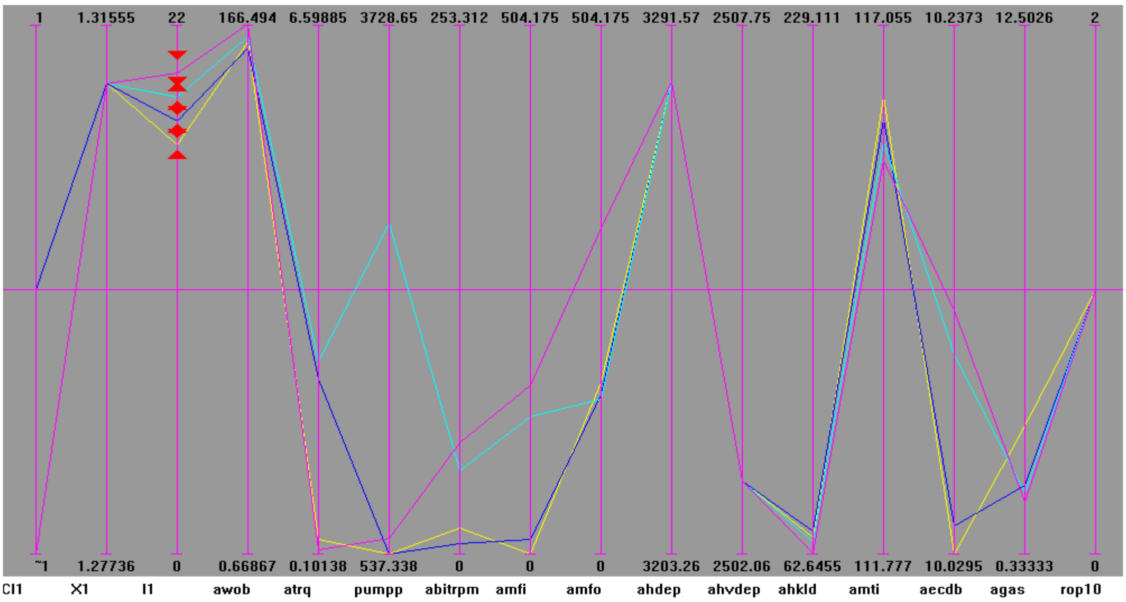

Figure 6 Four steps in a Pack Off event

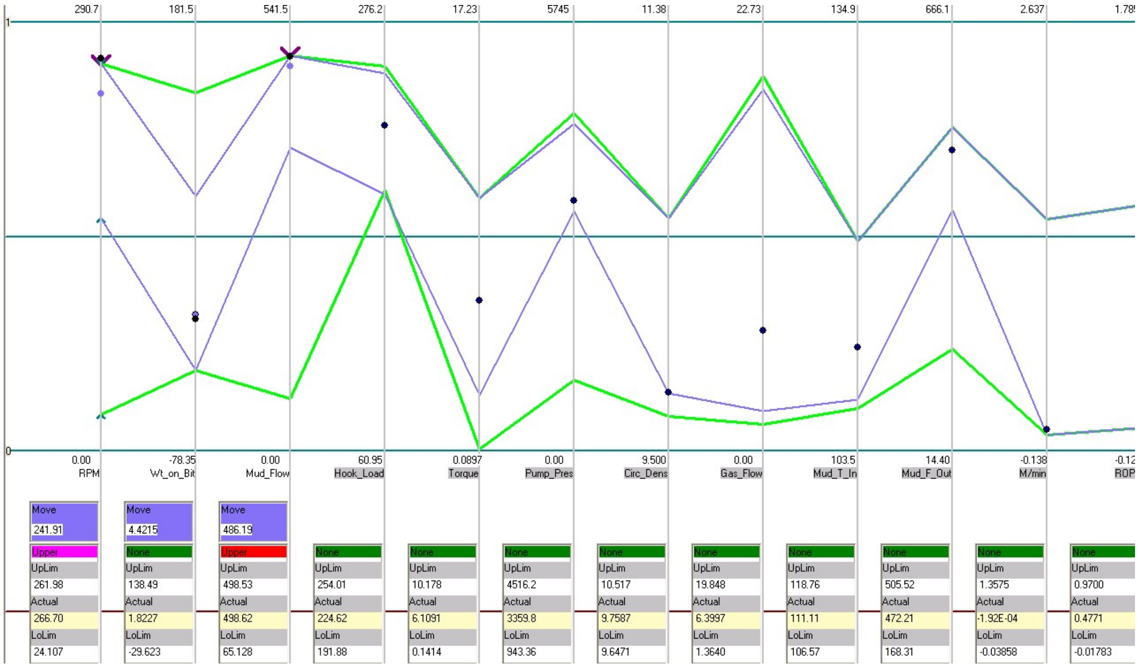

Figure 7 Data from drilling log with GPC advice

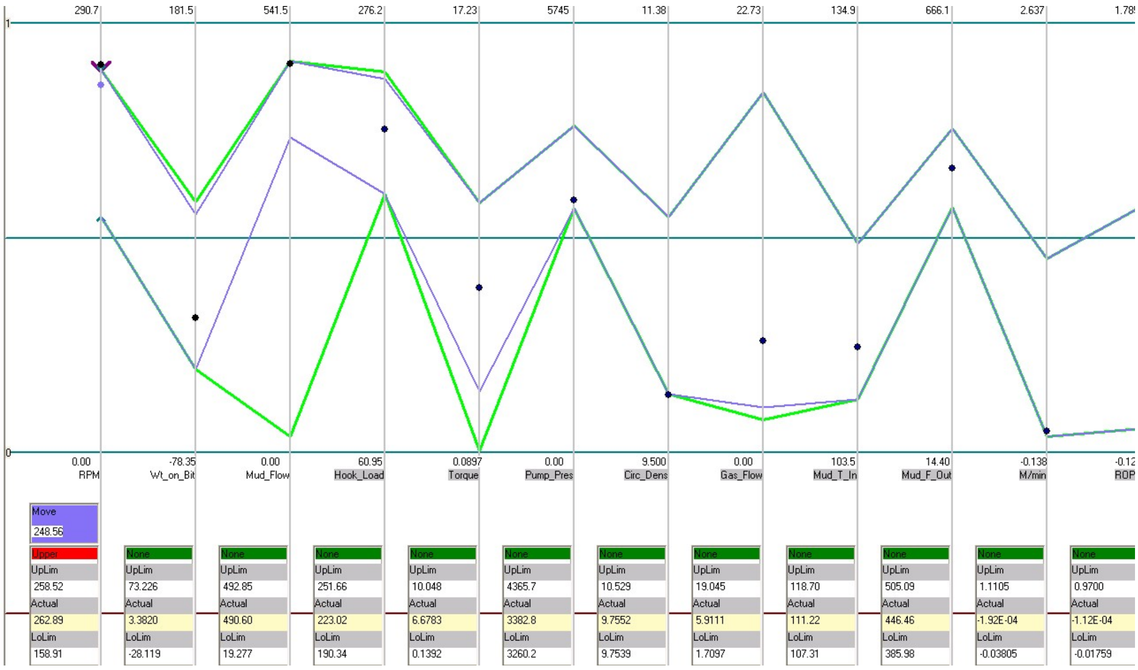

Figure 8 Data from drilling log 30 seconds after figure 7