Title: DRILLING VIBRATION SCORING SYSTEM

Abstract: A method of evaluating drilling performance for a drill bit penetrating subterranean formation comprising: receiving data regarding drilling parameters characterizing ongoing wellbore drilling operations; wherein the drilling data at least includes mechanical specific energy (MSE); selecting a normalization MSE value, MSE$_n$, normalizing MSE with the MSE$_n$ value; and calculating a drilling vibration score, MSER.

FIG. 1
— as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))

— Published.

— with international search report (Art. 21(3))
DRILLING VIBRATION SCORING SYSTEM

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional No. 61/531,918, filed September 7, 2011 and U.S. Provisional No. 61/680,902 filed August 8, 2012.

FIELD

[0002] The present disclosure relates generally to systems and methods for evaluating drilling efficiency and performance. More particularly, the present disclosure relates to systems and methods that may be implemented in cooperation with hydrocarbon-related drilling operations to evaluate and quantify or score drilling efficiency and performance.

BACKGROUND

[0003] This section is intended to introduce the reader to various aspects of art, which may be associated with embodiments of the present invention. This discussion is believed to be helpful in providing the reader with information to facilitate a better understanding of particular techniques of the present invention. Accordingly, it should be understood that these statements are to be read in this light, and not necessarily as admissions of prior art.

[0004] The production of hydrocarbons, such as oil and gas, has been performed for many years. To produce these hydrocarbons, one or more wells in a field are typically drilled to a subsurface formation location. Producing hydrocarbons from the subsurface location typically involves various development phases including exploration phase, concept selection phase, wellbore development phase, drilling phase, completion phase, production phase, and reservoir management phase, etc. One of the development phases involves the drilling operations that form a wellbore or conduit from the subsurface location to the surface. The drilling operation involves using a variety of interrelated equipment and systems, such as drill string control systems, power systems, hydraulic circulation systems, drill strings, drilling bits, downhole-motors, measurement systems, etc.

[0005] Drilling operations are generally expensive and time-consuming. Evaluation of drilling performance or efficiency is a key to controlling costs, improving drill bit penetration, drilling operations, and identifying the potential root causes for NPT (Non-Production Time). Typically, Rate-of-Penetration (ROP) has been used for comparing performance between wells drilled in the same field or related set of geologic formations. However, even amongst wells within the same field or geologic proximity, the ROP comparison approach is limited in its ability to assess whether the wells were drilled in an
efficient manner because ROP may not reflect drilling dysfunctions experienced within various individual or combinations of wells, such as drilling vibrations, bit balling, etc.

The presence of undesirable downhole vibrations and other energy consuming effects are often detrimental to overall drilling performance. Vibrations and other detrimental effects are symptoms of inefficiencies in the drilling process and wastefully consume energy intended for use at the drill bit. As technology and research have progressed, tools (both physical and digital) with the ability to detect such vibrations and other inefficiencies have become commercially available. For example, Measurement-While-Drilling (MWD) tools have been developed that have the capability to measure and store vibration data in memory for later analysis, as well as transmit such data in real time to the rig crews and engineers at the surface. A multitude of vibrations data can be obtained for many drilling operations, should the operator decide to purchase and utilize such tools and services. However, such tools and services can be quite expensive and even prohibitively expensive for drilling economically marginal or long-payout wells, such as drilling shale-gas or other unconventional wellbores.

Although a great deal of technology has been developed in this area, the output of such technology is most often unprocessed, raw data, the interpretation of which requires a specialized skill set. Drilling engineers regularly process and analyze vibration data and in some cases, compare individual well datasets to assess the relative success (or failure) of attempts to reduce vibrations. This process is not trivial and conclusions are often subjective and in some cases, disputable.

Mechanical Specific Energy (MSE) has become a popular metric to evaluate drilling performance (U.S. Patents 7857047 and 7896105). The concept of MSE has been used effectively in lab environments to evaluate the drilling efficiency of bits (Teale, R. “The Concept of Specific Energy in Rock Drilling” Intl. J. Rock Mech. Mining Sci. 1965, 2: 57-73). MSE is roughly the ratio of input mechanical energy to the volume of rock removed by the bit. It reflects a number of effects related to the rock strength, drill-string dynamics, and drilling dysfunctions. If there is no downhole dysfunction, MSE correlates generally with the rock strength. Generally, when drilling efficiently through a homogenous formation, the lower the MSE, the lower the undesirable drilling dysfunctions, thus yielding a more efficient and predictable drilling process.

However, MSE cannot be used for reliably comparing drilling performance across different fields because MSE data is influenced by numerous geologic factors such as pore pressure and formation rock strength. Although some researchers have recently attempted to extend MSE to include hydraulic as well as mechanical energy (SPE1 16667), such calculations still include the rock strength effect.
SUMMARY

[0010] The presently claimed technology provides methods and tools to remove or obviate various formation correlative factors, such as pore pressure and rock strength effects from MSE values and thereby enable cross-field drilling operation comparison. One aspect of this improved technology is to develop a normalized MSE that is reflected as a single value or "score" such as may be useful for cross-well, cross-formation, or cross-field correlation of MSE values. In addition to enabling such cross comparisons, in other aspects of the improved technology, the tools may also permit real-time quantitative and/or qualitative evaluation of drilling performance, and various other uses, such as post-drill comparison of different projects, and/or development of more precise and tighter standards for overall drilling performance.

[0011] The disclosed and claimed technology is directed to methods and systems for use in drilling a wellbore through geologic formations, such as a wellbore used in hydrocarbon production related operations. Some exemplary methods for application or use of the technology may include:

[0012] A drilling vibrations scoring systems that evaluates drilling vibration levels and related parameters, thereby enabling system analysis or direct comparison of vibrations levels between multiple drilling operations, either in real-time, at delayed time, and in the post-drill evaluation or pre-drill phase for subsequent wells.

[0013] The drilling vibrations scoring systems may be used to evaluate individual the performance of various drilling tools and assemblies, personnel performance such as driller performance, the overall performance of a crew or shift, or hour-by-hour drilling performance, or the performance of various drilling control systems, as desired (both in real-time or as a hind cast analysis).

[0014] The drilling vibrations scoring system may usefully provide a normalized, quantitative drilling vibrations score, adjusted for well architecture and/or geographic location.

[0015] The drilling vibrations scoring system may use an average or median MSER value to represent an overall drilling vibrations score over a given depth interval or time interval drilled.

[0016] The drilling vibrations scoring system may use an average or median MSER value to develop precise standards for drilling operations, such as within a project team, across teams, or on a global operations basis.

[0017] The present technology disclosure is further directed to computer-based tools or systems for use in association with drilling operations. Exemplary computer-based systems may include: 1) a processor adapted to execute instructions; 2) a storage medium
in communication with the processor; and 3) at least one instruction set accessible by the processor and saved in the storage medium. The at least one instruction set is adapted to perform methods related to or such as described herein. For example, the instruction set may be adapted to 1) receive data regarding drilling parameters characterizing ongoing wellbore drilling operations, wherein the drilling parameters include MSE and/or its components; 2) determine a normalized MSE value, MSE₀; 3) calculate a normalized drilling vibrations score from the observed MSE values and the determined MSE₀ normalizing values; and 4) provide means to display or output the normalized drilling vibrations score.

**BRIEF DESCRIPTION OF THE DRAWINGS**

[0018] So that the manner in which the present inventions can be better understood, certain illustrations, charts and/or flow charts are appended hereto. It is to be noted, however, that the drawings illustrate only selected embodiments of the inventions and are therefore not to be considered limiting of scope, for the inventions may admit to other equally effective embodiments and applications. The foregoing and other advantages of the present technique may become apparent upon reading the following detailed description and upon reference to the drawings in which:

Fig. 1 illustrates an exemplary plot of depth-based MSE data for a well.
Fig. 2 illustrates an exemplary chart of MSE data showing MSE₀ determined by the Combined Method.
Fig. 3 illustrates an exemplary chart of MSE data showing MSE₀ determined by Method [b].
Fig. 4 illustrates an exemplary plot of a vibrations score, MSER, calculated from the MSE data.

**DESCRIPTION OF THE INVENTION**

[0019] The inventions are described herein in connection with certain specific embodiments. However, to the extent that the following detailed description is specific to a particular embodiment or a particular use, such is intended to be illustrative only and is not to be construed as limiting the scope of the inventions.

[0020] Certain aspects of the inventions are also described in connection with various figures. In certain of the figures, the top of the drawing page is intended to be toward the surface, and the bottom of the drawing page toward the well bottom. While wells commonly are completed in substantially vertical orientation, it is understood that wells may also be inclined and or even horizontally completed. When the descriptive terms "up and down" or "upper" and "lower" or similar terms are used in reference to a drawing or in the claims, they are intended to indicate relative location on the drawing page or with respect to
claim terms, and not necessarily orientation in the ground, as the present inventions at least in some embodiments have utility no matter how the wellbore is orientated.

[0021] There is currently no known product capable of inputting or receiving raw drilling vibration data and outputting an objective drilling vibrations value or score that is meaningful with respect to system performance that is independent from rock properties. The art is in need of a valuation or scoring system that produces a value or score that can usefully compare data from one wellbore environment against data from another wellbore environment. The presently disclosed "Drilling Vibrations Scoring System" (DVSS) enables direct comparison of drill system performance within, between, or across various geographic drilling operations. The DVSS may also provide a means to gauge relative drilling performance in real-time. The technology can be used to evaluate numerous drilling-related variables, such as individual driller performance, drilling system performance, overall performance of a crew or shift, hour-by-hour or depth interval drilling performance, bit performance, etc., as desired (both in real-time or as hindcast analysis).

[0022] One key element of practicality in the DVSS is its ability to provide a meaningful normalized quantitative score or metric, that is independent of variations in well architecture, rock properties, depositional environment, and/or geographic location. This capability to normalize drilling performance and develop quantitative metrics will foster improved performance and motivation for attaining various drilling goals and, in automated or analytical systems provide enhanced control and evaluation tools such as to enable evaluation of different programming techniques and models. The performance benefits of quantitative metrics have proven immensely valuable to date in the operator's performance drilling efforts and the methods related to the technology disclosed herein will provide added benefits to this program. Until this this disclosure, it is believed by the inventors hereto that there are no such previous performance normalization system available for the wellbore drilling industry.

[0023] To assist development of this technology, actual field data was collected while drilling and inputted into various DVSS algorithms in the post-drill phase. The algorithms were also developed through research and development application efforts. As illustrated in the attached Figures, an exemplary overall vibrations score (average or median MSER) was determined over the depth interval illustrated in the Figures. The drilling performance of the exemplary drilling interval can now be meaningfully and objectively compared to any other operation on which such vibrations score is assessed and calculated. The discussion below further explains the developed processes and technology.

[0024] The concept of "Mechanical Specific Energy" or "MSE" is at the core of the DVSS logic system. Generally, MSE is an indicator of drilling vibrations/dysfunction. MSE is a calculated number which can be regarded as a method of expressing "drilling efficiency".
Generally, the lower the MSE value, the lower the undesirable drilling vibrations and thus the more efficient the drilling process. A visual example of depth-based MSE data obtained or determined while drilling a depth interval is represented in Figure 1, with a plot of MSE illustrated by plot 11.

[0025] MSE is defined as (Teale, R. "The Concept of Specific Energy in Rock Drilling" Int. J. Rock Mech. Mining Sci. 1965, 2: 57-73). In the case where a downhole motor is used, RPM represents the bit rotational speed, which is the sum of the surface rotary speed and the downhole motor rotational speed.

\[
MSE = \frac{Input\ Mechanical\ Energy}{Cutting\ Volume} = \frac{(ROP \cdot WOB + Torque \cdot RPM)}{Hole\ Area \cdot ROP}
\]

[0026] From the above equation, it can be seen that MSE is not a dimensionless parameter and is essentially the ratio of input mechanical energy to volume of rock drilled over a given time interval. It is typically calculated in pounds per square inch (psi) or thousand pounds per square inch (kpsi) units. It is important to note that typically in the above formulation of MSE, the required torque value is obtained by a torque sensor at or near the surface. Therefore the torque value at the surface is the sum of the torque generated at the drill bit plus the torque imposed on the drillpipe due to wellbore friction. When MSE is calculated in this way it is referred to as "surface" MSE and represents one embodiment of the invention.

[0027] It may also be useful to replace determining the above mentioned surface torque value with determining or analyzing the torque available or applied directly at the drill bit. The drill bit torque value can be obtained in two ways. The first method involves using a downhole torque sensor. The second method involves separately measuring the torque value at the surface with the bit drilling the formation and with the bit rotating "off bottom" of the well (in a non-drilling condition). These two values are then subtracting to obtain the difference, representing the downhole torque. When MSE is calculated in this way it may be referred to as "downhole" MSE. If downhole MSE is used in the disclosed methods and systems, the effects of wellbore friction are eliminated or corrected for.

[0028] Different well types or wells drilled in different geographic locations may exhibit minor differences in MSE as compared to each other, given that wellbore friction (if using surface MSE) and rock strength often vary and therefore influence the MSE calculation. However, the influence of vibrations on MSE is typically orders of magnitude greater than variation influences due to wellbore differences in friction or due to differences in rock strength. In order to account for variations in well type (friction effects when using surface MSE) and rock strength (and thus isolate the major effect of vibrations), a new
parameter, MSE Ratio (MSER) is created in this improved technology, and is used as a feature of some embodiments of the DVSS taught and disclosed herein. MSER is a normalized, dimensionless parameter and in many embodiments is substantially independent of rock strength, well type, and well architecture. Additional improvements and further refinements of course may use the MSER concept with additional corrections made for well type, well architecture, and rock strength if desired. MSER can be calculated as a definitive, single performance indicator for a selected time period, over a selected depth range, and/or for an overall well section (final MSER). MSER can be expressed mathematically as:

\[
\text{MSER} = \frac{(\text{MSE}/\text{MSE}_0)}{1}
\]

where MSE\(_0\) represents a normalizing MSE value at a depth of interest. More generally, MSER may be calculated such as by an algebraic relationship between MSE and MSE\(_0\).

[0029] MSE\(_0\) can be obtained using various methods, such as the two exemplary independent methods (methods [a] and [b]) disclosed below. MSE\(_0\) can also be selected based on field experience or the expected formation rock strength, typically as a function of depth. Alternatively, MSE\(_0\) may simply be represented by a constant threshold value that may be chosen for different fields or geologic formations. Two non-limiting, non-exclusive exemplary embodiments are Methods [a] and [b]:

[0030] Method [a]: A statistical method that obtains MSE\(_0\) by processing actual MSE data and identifying the lowest values or "valley points" within a depth range which corresponds to each lithological unit which is drilled. These statistically rare data points represent a data sample of the lowest theoretically attainable MSE values within their respective depth ranges, where the influence of vibrations are negligible in the MSE calculation. This approach may be well-suited for use in repetitive drilling applications, such as for development wells, with numerous wells drilled through substantially similar formations, but it may also be useful in exploration or "one-off" applications where data trends allow one to quantify the lowest theoretically attainable MSE value in a depth range.

[0031] If Method [a] is used to calculate MSE\(_0\), it should be considered carefully when used in isolation (such as for exploratory wells), as it may reflect the effect of falsely reducing the MSER if drill bit damage has occurred while drilling. Rather, in exploratory or isolated well applications, Method [a] preferably should be used in conjunction with Method [b] to affirm the reliability of the MSE\(_0\) value. Thereby, the minimum MSE\(_0\) calculated using both methods can stands as the dominant value when calculating MSER. This may be
referred to as the Combined Method. An example of MSE₀ calculated using the Combined Method and plotted alongside measured MSE data is shown in exemplary Figure 2. Plot 21 illustrates the data from plot 11 of Figure 1, while plot 22 illustrates a plot of calculated MSE₀ values.

[0032] Method [b]: An initial actual minimum MSE value (MSEᵢ) may be obtained from drilling data while drilling the first several hundred feet of the evaluated hole section. Using the MSE, value, a final theoretical minimum MSE value (MSEᵢ) can be calculated using critical inputs, such as demonstrated below. Note that a plurality of off-bottom torque measurements and adjustments can enable comparison of wells with different wellbore angles, architectures, and consider associated frictional components. Similarly, a plurality of rock strength measurements adjustments can allow for comparison of wells with substantively different rock compressive strengths due to variable lithology.

\[ \text{MSE}ᵢ = \text{MSE}_x \times \frac{Tᵢ}{Tᵢ} \times (\text{RSM} - \text{RSi}) \]

Where  
\( Tᵢ = \) initial off-bottom torque at start of hole section (calculated or actual)  
\( Tᵢ = \) final off-bottom torque at end of hole section (calculated or actual)  
\( \text{RSi} = \) initial compressive rock strength at start of hole section  
\( \text{RSM} = \) maximum compressive rock strength seen throughout hole section

It is important to note that if downhole MSE is used to obtain MSE, and MSEᵢ, the wellbore friction effects have already been accounted for, therefore the \( Tᵢ \) and \( T \) terms may be omitted from the MSEᵢ formula.

[0033] In one embodiment, a linear relationship may be formulated using the initial and final minimum MSE values and this relationship may be used to calculate MSE₀ at any given depth, such as:

\[ \text{MSE}_0 = \text{MSE}_x + \left( (\text{MSE}_ᵢ - \text{MSE}_x) \times \frac{(D - Dᵢ)}{(Dᵢ - D)} \right) \]

Where  
\( D \) = current drilling depth  
\( Dᵢ \) = depth at start of hole section  
\( D \) = final depth of hole section

[0034] Note that off-bottom torques \( Tᵢ \) and \( Tᵢ \) also may be computed from a drillstring model that calculates real-time MSER. On the other hand, such as for post-drill analysis \( Tᵢ \) and \( Tᵢ \) may be estimated from field-wide drilling data.

[0035] An example of MSE₀ calculated using Method [b] and plotted alongside an MSE plot is illustrated in Figure 3. Plot 31 illustrates the data from plot 11, while plot 32 illustrates a plot of calculated MSE₀ values using method [b]. Although generally the
measured depth (MD) would be used in these calculations, in some applications it may be
appropriate to base the MSE₀ adjustments on true vertical depth (TVD).

**[0036]** Calculation of MSE₀ using both the Combined Method [a] and Method [b]
often yield near identical results. Calculation of MSE₀ using Method [b] to calculate MSER
may represents a preferred embodiment of the invention as it is the simpler of the two
methods.

**[0037]** MSER as described above can be calculated for every depth-based (or time-
based) data point and averaged to yield an overall Drilling Vibrations Score (average
MSER). An example of such result is illustrated in Figure 4, with each result 41 indicated by
data points and plot 42 illustrating an averaged MSER plot. This method of averaging
MSER values represents a short-hand method of calculating the ratio of the discrete integral
of the MSE curve to the discrete integral of the MSE₀ curve.

**[0038]** Another alternative is to calculate the median MSER over an interval of
interest for assessing a Drilling Vibrations Score thereto, as the median of a series is less
sensitive to outlier data points. Such a method provides still another assessment or
measurement method within the scope of the invention. More generally, other commonly
known statistical approaches may be used to determine a drilling vibration score for an
interval from the individual normalized MSER data, and these alternative approaches are to
be considered to be within the scope of the present invention.

**[0039]** The MSER score provides a quantitative indication of the overall level of
drilling dysfunction within the analyzed interval. Vibrations, such as lateral, axial, torsional
stick-slip, bit whirl, etc. thereby may be comparatively observed during on-bottom drilling
operations, such that the observed values are independent of well architecture and rock
strength. As mentioned previously, this method can be applied both as a real-time indicator
of the level of drilling dysfunction or as a hind-casting technique to judge overall drilling
performance. In both cases, a drill team may use the overall MSER value as a key metric in
judging the success or failure of efforts to reduce drilling dysfunction on a well-to-well basis.
An overall MSER value of zero represents a drilling operation completely free of undesirable
vibration. Furthermore, although preferentially the calculations would be depth-based, it is
within the scope of the invention for the MSER to be a time-based calculation. Ultimately,
the operator can implement efforts to reduce the drilling vibrations score as low as possible,
for example, until three vibrations score (overall MSER value) approaches zero (or goes to
substantially zero or near zero). Such low score may indicate improved drilling efficiency,
such as near the economic limit of a respective drilling system design or improved system
redesign.

**[0040]** Thereby, some of the benefits or improvements of the presently disclosed
methods and systems may include providing a drilling vibrations scoring system evaluates
drilling vibration levels and enables the direct comparison of vibrations levels between drilling operations both in real-time and in the post-drill phase. The drilling vibrations scoring system may be used to evaluate individual driller performance, the overall performance of a crew or shift, or hour-by-hour drilling performance, as desired (both in real-time or as a hindcast analysis). A drilling vibration scoring system provides a tool that determines a normalized quantitative drilling vibrations score that is independent of well architecture and geographic location. The disclosed drilling vibrations scoring system can use the average or median MSER value to represent an overall drilling vibrations score over a selected drilled depth interval. The drilling vibrations scoring system uses the average or median MSER value to develop precise standards or practices for drilling operations, such as within a project or on a wider operations basis. A simple, preferred expression for the MSER value is:

\[
\text{MSER} = \left( \frac{\text{MSE}}{\text{MSE}_0} \right) - 1
\]

[0041] Method [a]: A statistical method that obtains \( \text{MSE}_0 \) by processing actual MSE data and identifying the lowest values or "valley points" within a depth range which corresponds to each lithological unit which is drilled. These statistically rare data points represent a data sample of the lowest theoretically attainable MSE values within their respective depth ranges, where the influence of vibrations are negligible in the MSE calculation.

[0042] Method [b]: An initial actual minimum MSE value (\( \text{MSE}_i \)) is obtained from drilling data while drilling the first several hundred feet of the hole section. Using the MSE, value, a final theoretical minimum MSE value (\( \text{MSE}_f \)) is calculated using critical inputs as shown below. It is noted that off-bottom torque adjustments enable comparison of wells with different architecture and associated frictional components. Similarly, rock strength adjustments allow for comparison of wells with substantively different rock compressive strengths due to variable lithology.

\[
\text{MSE}_i = (\text{MSE}_i \times T_i / T_i) + (R_S - R_S_i)
\]

\[
\text{MSE}_0 = \text{MSE}_i + [(MSE_i - MSE_f) \times (D - D_0) / (D_i - D_0)]
\]

\( R_Si \) is a measurement or estimate of the rock strength at the beginning of the drilling interval and where \( R_Sm \) is a measurement or estimate of the rock strength at the end of the drilling interval. Off-bottom torques \( T_i \) and \( T_f \) may be computed from a drillstring model for real-time MSER. For post-drill analysis \( T_i \) and \( T_f \) may be estimated from field data. In some applications it may be appropriate to base the \( \text{MSE}_0 \) adjustments on true vertical depth (TVD).
[0043] Calculation of $\text{MSE}_0$ using both the Combined Method and Method [b] often yield near identical results. Calculation of $\text{MSE}_0$ using Method [b] to calculate MSER represents a primary embodiment of the invention as it is the simpler of the two methods.

[0044] The calculation of $\text{MSE}_0$ using the combined method to calculate MSER represents another embodiment of the invention and may, in some cases yield a somewhat more accurate result.

[0045] MSER as described above can be calculated for every depth-based (or time-based, whereby data is accumulated according to a specified time increment as opposed to a specified depth increment) data point and averaged to yield an overall Drilling Vibrations Score (average MSER). (This method of averaging MSER values represents a short-hand method of calculating the ratio of the discrete integral of the MSE curve to the discrete integral of the MSE0 curve.) An alternative method is to calculate the median MSER over the interval of interest as the Drilling Vibrations Score, as the median of a series is less sensitive to outlier data points this provides an alternative measure method, still within the scope of invention.

[0046] The overall MSER score will provide a quantitative indication of the overall level of drilling dysfunction (vibrations - axial and/or torsional, stick-slip, fluctuations in MSE at the bit, etc.) seen during on-bottom drilling operations for a given drilling operation, independent of well architecture and rock strength. As mentioned previously, this method can be applied both as a real-time indicator of the level of drilling dysfunction or as a hind-casting technique to judge overall drilling performance. In both cases, a drill team may use the overall MSER value as a key metric in judging the success or failure of efforts to reduce drilling dysfunction on a well-to-well basis. An overall MSER value of zero represents a drilling operation completely free of undesirable vibration. Furthermore, although preferentially the calculations would be depth-based, it is within the scope of the invention for the MSER to be a time-based calculation.

[0047] In other embodiments, the methods and systems disclosed herein may be used in conjunction with drilling a wellbore or preparing a wellbore for use in hydrocarbon recovery operations, drilling operations, producing hydrocarbons, injection of fluids, or related wellbore boring, use or preparation operations.

[0048] Illustrative embodiments of the invention may be expressed such as set forth in the following paragraphs:

A. A method of evaluating drilling performance for a drill bit penetrating subterranean formation to create a wellbore, the method comprising:
   - determining mechanical specific energy (MSE) from drilling performance data;
   - selecting a normalization MSE value, $\text{MSE}_0$;
normalizing MSE with the MSE₀ value;
calculating a drilling vibration score, MSER.

B. The method of Paragraph A, wherein the drilling parameters data further comprises bit depth data.

C. The method of Paragraph A, wherein the drilling parameters data further comprises drilling time data.

D. The method of Paragraph A, wherein the MSE is calculated using a torque value representative of the torque generated at a surface of the wellbore.

E. The method of Paragraph A, wherein the MSE is calculated using a torque value representative of the torque generated at the drill bit.

F. The method of Paragraph A, wherein the MSE₀ value is obtained by identifying a minimum MSE data set during the drilling of a first interval and extrapolating at least one of a depth-based relationship or a time-based relationship to a second interval based on friction and rock strength effects.

G. The method of Paragraph A, wherein the MSE₀ is obtained by repetitively identifying a minimum MSE data set and interpolating to obtain at least one of a depth- or time-based relationship.

H. A method of evaluating drilling performance for a drill bit penetrating subterranean formation, the method comprising:
   receiving data regarding drilling parameters characterizing wellbore drilling operations; wherein the drilling data at least includes mechanical specific energy (MSE);
   selecting a normalization MSE value, MSE₀;
   normalizing MSE with the MSE₀ value;
   calculating a drilling vibration score, MSER;
   determining an overall drilling vibration score from the individual MSER values.

I. The method of Paragraph H, wherein the data regarding drilling parameters include bit depth in addition to MSE.

J. The method of Paragraph H, wherein the data regarding drilling parameters include time in addition to MSE.
K. The method of Paragraph H, wherein the MSE is calculated using a torque value representative of the torque generated at the surface of the well.

L. The method of Paragraph H, wherein the MSE is calculated using a torque value representative of the torque generated at the drill bit.

M. The method of Paragraph H, wherein the MSE₀ is obtained by identifying minimum MSE data during the drilling of a first interval and extrapolating a depth or time-based relationship to a second interval based on friction and rock strength effects.

N. The method of Paragraph H, wherein the MSE₀ is obtained by continuously identifying minimum MSE data, and interpolating a depth or time-based relationship.

O. The method of Paragraph H, wherein MSER is calculated using the relationship

\[
MSER = \left(\frac{MSE}{MSE_0}\right) - 1.
\]

P. The method of Paragraph H, wherein MSER is calculated by an algebraic relationship between MSE and MSE₀.

Q. The method of Paragraph H, wherein the overall drilling vibration score is calculated as the average MSER over a discrete portion of a well.

R. The method of Paragraph H, wherein the overall drilling vibration score is calculated as the median MSER over a discrete portion of a well.

S. The method of Paragraph H, wherein the overall drilling vibration score is calculated as the standard deviation or another statistical parameter of the MSER over a discrete portion of a well.

T. A method of evaluating drilling performance for a drill bit penetrating subterranean formation, the method comprising:

- receiving data regarding drilling parameters characterizing wellbore drilling operations; wherein the drilling data at least includes mechanical specific energy (MSE);
- selecting a normalization MSE value, MSE₀;
- normalizing MSE with the MSE₀ value;
- calculating a drilling vibration score, MSER;
- determining an overall drilling vibration score from the individual MSER values; and
comparing the overall drilling vibration score between at least two datasets to quantify relative drilling performance.

U. The method of Paragraph T, wherein the data regarding drilling parameters include bit depth in addition to MSE.

V. The method of Paragraph T, wherein the data regarding drilling parameters include time in addition to MSE.

W. The method of Paragraph T, wherein the MSE is calculated using a torque value representative of the torque generated at the surface of the well.

X. The method of Paragraph T, wherein the MSE is calculated using a torque value representative of the torque generated at the drill bit.

Y. The method of Paragraph T, wherein the $\text{MSE}_0$ is obtained by identifying minimum MSE data during the drilling of a first interval and extrapolating a depth or time-based relationship to a second interval based on friction and rock strength effects.

Z. The method of Paragraph T, wherein the $\text{MSE}_0$ is obtained by continuously identifying minimum MSE data, and interpolating a depth or time-based relationship.

AA. The method of Paragraph T, wherein the drilling vibration score, MSER is calculated by $\text{MSER} = \frac{(\text{MSE}/\text{MSE}_0) - 1}{\text{MSE}/\text{MSE}_0}$.

BB. The method of Paragraph T, wherein the drilling vibration score, MSER is calculated by an algebraic relationship between MSE and $\text{MSE}_0$.

CC. The method of Paragraph T, wherein the overall drilling vibration score is calculated as the average MSER over a discrete portion of a well.

DD. The method of Paragraph T, wherein the overall drilling vibration score is calculated as the median MSER over a discrete portion of a well.

EE. The method of Paragraph T, wherein the overall drilling vibration score is calculated as the standard deviation or another statistical parameter of the MSER over a discrete portion of a well.

[0049] It is believed that the following claims particularly point out certain combinations and sub-combinations that are directed to one of the disclosed inventions and are novel and non-obvious. Inventions embodied in other combinations and sub-
combinations of features, functions, elements and/or properties may be claimed through amendment of the present claims or presentation of new claims in this or a related application. Such amended or new claims, whether they are directed to a different invention or directed to the same invention, whether different, broader, narrower, or equal in scope to the original claims, are also regarded as included within the subject matter of the inventions of the present disclosure.
What is claimed is:

1. A method of evaluating drilling performance for a drill bit penetrating subterranean formation to create a wellbore, the method comprising:
   a. determining mechanical specific energy (MSE) from drilling performance data;
   b. selecting a normalization MSE value, MSE₀;
   c. normalizing MSE with the MSE₀ value;
   d. calculating a drilling vibration score, MSER.

2. The method of Claim 1, wherein the drilling parameters data further comprises bit depth data.

3. The method of Claim 1, wherein the drilling parameters data further comprises drilling time data.

4. The method of Claim 1, wherein the MSE is calculated using a torque value representative of the torque generated at a surface of the wellbore.

5. The method of Claim 1, wherein the MSE is calculated using a torque value representative of the torque generated at the drill bit.

6. The method of Claim 1, wherein the MSE₀ value is obtained by identifying a minimum MSE data set during the drilling of a first interval and extrapolating at least one of a depth-based relationship or a time-based relationship to a second interval based on friction and rock strength effects.

7. The method of Claim 1, wherein the MSE₀ is obtained by repetitively identifying a minimum MSE data set and interpolating to obtain at least one of a depth- or time-based relationship.

8. A method of evaluating drilling performance for a drill bit penetrating subterranean formation to prepare a wellbore, the method comprising:
   a. receiving data regarding drilling parameters characterizing wellbore drilling operations; wherein the drilling data at least includes mechanical specific energy (MSE);
   b. selecting a normalization MSE value, MSE₀;
   c. normalizing MSE with the MSE₀ value;
   d. calculating a drilling vibration score, MSER;
e. determining an overall drilling vibration score from the individual MSER values.

9. The method of Claim 8, wherein the data regarding drilling parameters include bit depth in addition to MSE.

10. The method of Claim 8, wherein the data regarding drilling parameters include time in addition to MSE.

11. The method of Claim 8, wherein the MSE is calculated using a torque value representative of the torque generated at the surface of the wellbore.

12. The method of Claim 8, wherein the MSE is calculated using a torque value representative of the torque generated at the drill bit.

13. The method of Claim 8, wherein the MSE is obtained by identifying minimum MSE data during the drilling of a first interval and extrapolating a depth or time-based relationship to a second interval based on friction and rock strength effects.

14. The method of Claim 8, wherein the MSE is obtained by continuously identifying minimum MSE data, and interpolating a depth or time-based relationship.

15. The method of Claim 8, wherein MSER is calculated by $\text{MSER} = \frac{\text{MSE}}{\text{MSE}_0} - 1$.

16. The method of Claim 8, wherein MSER is calculated by an algebraic relationship between MSE and $\text{MSE}_0$.

17. The method of Claim 8, wherein the overall drilling vibration score is calculated as the average MSER over a discrete portion of the wellbore.

18. The method of Claim 8, wherein the overall drilling vibration score is calculated as the median MSER over a discrete portion of the wellbore.

19. The method of Claim 8, wherein the overall drilling vibration score is calculated as the standard deviation or another statistical parameter of the MSER over a discrete portion of the wellbore.

20. A method of evaluating drilling performance for a drill bit penetrating subterranean formation to prepare a wellbore therein, the method comprising:
a. receiving data regarding drilling parameters characterizing wellbore drilling operations; wherein the drilling data at least includes mechanical specific energy (MSE);
b. selecting a normalization MSE value, MSE₀;
c. normalizing MSE with the MSE₀ value;
d. calculating a drilling vibration score, MSER;
e. determining an overall drilling vibration score from the individual MSER values; and
f. comparing the overall drilling vibration score between at least two datasets to quantify relative drilling performance.

21. The method of Claim 20, wherein the data regarding drilling parameters include bit depth in addition to MSE.

22. The method of Claim 20, wherein the data regarding drilling parameters include time in addition to MSE.

23. The method of Claim 20, wherein the MSE is calculated using a torque value representative of the torque generated at the surface of the wellbore.

24. The method of Claim 20, wherein the MSE is calculated using a torque value representative of the torque generated at the drill bit.

25. The method of Claim 20, wherein the MSE₀ is obtained by identifying minimum MSE data during the drilling of a first interval and extrapolating a depth or time-based relationship to a second interval based on friction and rock strength effects.

26. The method of Claim 20, wherein the MSE₀ is obtained by continuously identifying minimum MSE data, and interpolating a depth or time-based relationship.

27. The method of Claim 20, wherein the drilling vibration score, MSER is calculated by

\[ \text{MSER} = \frac{\text{MSE}}{\text{MSE}_0} \cdot \text{MSER}_0 \]

28. The method of Claim 20, wherein the drilling vibration score, MSER is calculated by an algebraic relationship between MSE and MSE₀.

29. The method of Claim 20, wherein the overall drilling vibration score is calculated as the average MSER over a discrete portion of the wellbore.
30. The method of Claim 20, wherein the overall drilling vibration score is calculated as the median MSER over a discrete portion of the wellbore.

31. The method of Claim 20, wherein the overall drilling vibration score is calculated as the standard deviation or another statistical parameter of the MSER over a discrete portion of the wellbore.
FIG. 1

FIG. 2
INTERNATIONAL SEARCH REPORT

PCT/US2012/05061

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - E21 B 45/00 (2012.01)
USPC - 702/9

According to International Patent Classification (IPC) or to both national classification and IPC.

B. FIELDS SEARCHED:

Minimum documentation searched (classification system followed by classification symbols)

IPC(8) - E21B 7/00, 44/00, 45/00 (2012.01)
USPC - 175/40, 50; 702/9

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched:

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

PatBase, Google Patents, Google Scholar

C. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
<thead>
<tr>
<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
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<td>Y</td>
<td>US 2009/0250264 A1 (DUPRIEST) 08 October 2009 (08.10.2009) entire document</td>
<td>1-31</td>
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</table>

Further documents are listed in the continuation of Box C.

Date of the actual completion of the international search
19 October 2012

Date of mailing of the international search report
02 NOV 2012

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