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(54) **Title:** METHODS OF REDUCING STRESS IN DOWNHOLE TOOLS

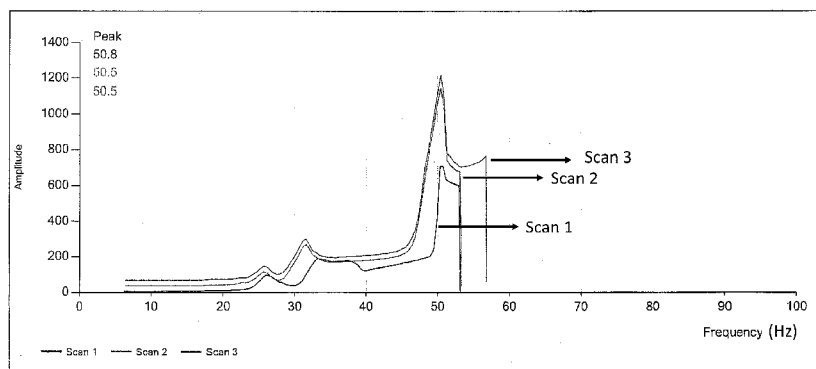


FIG. 6

(57) **Abstract:** A method for reducing stress in a downhole tool. The method includes varying a temperature of the downhole tool by at least 5°C. Vibrational energy may be transferred to the downhole tool with a vibration device coupled to the downhole tool. The vibrational energy may cause the downhole tool to move with a frequency from about 10 Hz to about 5 kHz.

METHODS OF REDUCING STRESS IN DOWNHOLE TOOLS

BACKGROUND

[0001] Embodiments described herein generally relate to downhole tools. More particularly, one or more such embodiments relate to systems and methods for preventing or reducing the likelihood or severity of crack formation in a downhole tool.

[0002] Downhole tools, such as drill bits, oftentimes include pockets formed in an outer surface thereof (*i.e.*, the bit face). Cutting elements may be inserted into the pockets and coupled thereto via a brazing process. The brazing process involves heating a filler metal above its melting point and using the liquefied filler metal to couple or join the cutting elements to the bit face. After the brazing process is complete, the drill bit, the cutting elements and the filler metal are allowed to cool.

[0003] The drill bit may also undergo a hardfacing process where a harder or tougher material is applied to the bit face via welding. Similar to the brazing process, the hardfacing process also subjects the drill bit to an increase in temperature. Thermal stresses may form in the bit when the drill bit cools from the brazing process or the hardfacing process, and cracks may form in the drill bit proximate the bit face or the bit may crack when being used in a downhole operation. The formation of cracks is more prevalent in larger drill bits. For example, the formation of cracks is more prevalent in drill bits having a diameter greater than about 25 cm.

SUMMARY

[0004] This summary is provided to introduce a selection of concepts that are further described below in the detailed description. This summary is not intended to identify key or essential features of the claimed subject matter, nor is it intended to be used as an aid in limiting the scope of the claimed subject matter.

[0005] A method for reducing stress in a downhole tool is disclosed. The method may be applied to a downhole tool where the temperature of the downhole tool is varying by at least 5°C. Vibrational energy may be transferred to the downhole tool with a vibration device

coupled to the downhole tool. The vibrational energy may cause the downhole tool to move with a frequency from about 10 Hz to about 5 kHz.

[0006] In another embodiment, the method for reducing stress in a downhole tool may include placing the downhole tool on a plate. A plurality of legs may be coupled to the plate, and a deformable material may be disposed between a first one of the plurality of legs and the plate. A temperature of the downhole tool may be decreased from between about 500°C and about 1250°C to between about 0°C and about 50°C. Vibrational energy may be transferred to the downhole tool with a vibration device coupled to the plate. The vibrational energy may cause the downhole tool to move with a peak-to-peak amplitude between about 1 μm and about 1000 μm and a frequency from about 10 Hz to about 5 kHz.

[0007] A system for reducing stress in a downhole tool is also disclosed. The system includes a vibration device that transfers vibrational energy to a downhole tool. The vibrational energy may cause the downhole tool to move with a frequency from about 10 Hz to about 5 kHz.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] So that the recited features may be understood in detail, a more particular description, briefly summarized above, may be had by reference to one or more embodiments, some of which are illustrated in the appended drawings. It is to be noted, however, that the appended drawings are illustrative embodiments, and are, therefore, not to be considered limiting of its scope.

[0009] Figure 1 depicts an exploded perspective view of an illustrative system for reducing stress in a downhole tool, according to one or more embodiments disclosed.

[0010] Figure 2 depicts a perspective view of the upper plate of the vibration table having an illustrative collet coupled thereto, according to one or more embodiments disclosed.

[0011] Figure 3 depicts a partial cross-sectional view of the collet shown in Figure 2 in an inactive state, according to one or more embodiments disclosed.

[0012] Figure 4 depicts a partial cross-sectional view of the collet shown in Figure 2 in an active state, according to one or more embodiments disclosed.

[0013] Figure 5 depicts a partial cross-sectional view of the vibration table having the collet disposed at least partially within an illustrative downhole tool, according to one or more embodiments disclosed.

[0014] Figure 6 shows a plot of the response, in amplitude versus frequency, to a vibratory process on a downhole tool as it cools after a thermal process.

[0015] Figure 7 shows a plot of the response, in amplitude versus frequency, to a vibratory process on a downhole tool at ambient temperature.

DETAILED DESCRIPTION

[0016] In one aspect, embodiments disclosed herein generally relate to methods of transferring vibrational energy to a downhole tool to prevent or reduce the likelihood or severity of crack formation and other damage to the downhole tool during the downhole tool's production and while it is in use downhole. Examples of types of downhole tools which may be subjected to vibrational energy include drill bits (particularly drill bits having cutting elements brazed thereon or which are hardfaced), reamers, stabilizers, pad clamps, or even cutting elements. However, other tools or components which may have thermal stresses therein from thermal processing may also be beneficially treated in accordance with the present embodiments. Such stresses may particularly result from different materials that may be subjected to differential heating and/or cooling particularly when joined with a dissimilar material or when it has a differing geometry (thickness) that may cause differing expansion and shrinkage upon heating and cooling.

[0017] In a particular embodiment, the vibrational energy may be transferred to a downhole tool by coupling a vibration device to the downhole tool. The coupling may be a direct coupling of the vibration device to the downhole tool or may be an indirect coupling of the vibration device. For example, in an indirect coupling of the vibration device to the downhole tool, the downhole tool may be placed in contact with a table or rack that is directly coupled to the vibration device, thereby allowing the transference of the vibrations from the device to the downhole tool via the table or rack. In order to ensure contact with the table or rack during the vibrational energy transfer the downhole tool may be clamped or otherwise secured to the table or rack. In yet another embodiment, multiple downhole tools may have vibrational energy transferred thereto via the indirect coupling provided by placing the

downhole tools in contact with a table or rack that is directly coupled to a vibration device. The transference of vibrational energy may be used to relax thermal stresses which may build up in a downhole tool during thermal processing of the tool, such as brazing, hardfacing, cladding, infiltration, or even formation of the tool or component. That is, by transferring sub-harmonic vibrations to the downhole tool (or component) formed with thermal processing, the thermal stresses in the tool (or component) may be relaxed.

[0018] In one or more embodiments, the vibration device may transfer vibrational energy to the downhole tool for a duration of time from a low of about 1 min, about 2 min, about 5 min, about 10 min, or about 15 min to a high of about 30 min, about 45 min, about 1 hr, about 2 hr, about 5 hr, about 10 hr, or more. In more specific embodiments, the vibration device may transfer vibrational energy to the downhole tool from between about 5 min and about 15 min, between about 10 min and about 30 min, or between about 30 min and 60 min. The time that the downhole tool is subjected to the vibrational energy may depend, at least in part, on the material(s) of the downhole tool and/or the weight of the downhole tool.

[0019] Further, the downhole tool may be subjected to at least two distinct intervals of vibrational energy transference by cycling between periods with vibrational energy on and the vibrational energy off. For example in a first interval, vibrational energy may be transferred to the downhole tool for a particular duration of time, after which the transference of vibrational energy may be stopped for a duration of time. The duration of time that the transference of vibrational energy is stopped may be a duration of time from a low of about 1 min, about 2 min, about 5 min, about 10 min, or about 15 min to a high of about 30 min, about 45 min, about 1 hr, about 2 hr, about 5 hr, about 10 hr, or more. Once the desired amount of non-transference time has occurred, vibrational energy may then again be transferred to the downhole tool for a second interval of time. The aforementioned on-off-on cycle may be repeated as many times as deemed necessary. Further, the first and second intervals of time may be substantially equal or substantially different amounts of time. In some embodiments, the first interval of time may be 45 minutes or more, while the second interval may be 30 minutes or less. It is also within the scope of the present disclosure that a single cycle may be used. The length of the interval (as well as the use of multiple intervals) may be based for example on the achievement of a reduction or relaxation in the stresses built up within the downhole tool (or component). In one or more embodiments, the vibrational

energy may be transferred until an approximate 10% minimum relaxation is achieved, as measured by the change in frequency of the maximum amplitude harmonic.

[0020] In some embodiments, the vibrational energy is transferred to the downhole tool while the temperature of the downhole tool is either increasing as a result of a thermal operation or decreasing after the cessation of a thermal operation. A thermal operation may include one of brazing, cladding, welding, friction welding, hardfacing, infiltration, or even sintering or formation of the tool (or component thereof). Further, in some embodiments, the vibrational energy may be transferred to the downhole tool during a thermal operation, wherein at any point during the thermal operation the temperature of the downhole tool may be increasing, decreasing, or substantially isothermal. In yet other embodiments, the vibrational energy may be transferred to the downhole tool when the tool is completely cooled and at ambient temperatures.

[0021] During a brazing process the downhole tool may be heated to between about 450°C and 550°C at which point it may then be heated via a torch to about 800°C to facilitate the brazing process. Before a welding process the downhole tool may be heated to between about 300°C and 500°C prior to the welding process depending on the specific steels used. During the welding process the downhole tool may be heated to temperatures above about 1100°C. During a hardfacing process the downhole tool may be preheated to about 350°C or higher before elevating the temperature to about 800°C or higher during the hardfacing process. During an infiltration process the temperature may increase to about 1400°C.

[0022] In some embodiments, the transferred vibrational energy induces a motion in the table or rack surface contacting the downhole tool and/or the downhole tool, which may have a peak-to-peak amplitude ranging from about 1 μm , about 2.5 μm , about 5 μm , about 10 μm , or about 25 μm to about 50 μm , about 75 μm , about 100 μm , about 250 μm , about 500 μm , about 1000 μm , or more. For example, the amplitude may be between about 1 μm and about 1000 μm , between about 5 μm and about 25 μm , or between about 10 μm and about 20 μm .

[0023] In some embodiments, the transferred vibrational energy induces a motion in the table or rack surface contacting the downhole tool and/or the downhole tool, which may have a frequency ranging from about 5 Hz, about 10 Hz, about 20 Hz, about 30 Hz, or about 40 Hz to about 60 Hz, about 80 Hz, about 100 Hz, about 150 Hz, about 200 Hz, or more. For

example, the frequency may be between about 10 Hz and about 40 Hz, between about 30 Hz and about 60 Hz, between about 50 Hz and about 80 Hz, between about 70 Hz and about 100 Hz, between about 100 Hz and about 150 Hz, between about 150 Hz and about 200 Hz, between about 35 Hz and about 85 Hz, or between about 10 Hz and about 100 Hz. In another embodiment, the frequency may range from about 10 Hz, about 100 Hz, or about 500 Hz to about 1 kHz, about 3 kHz or about 5 kHz. For example, the frequency may be between about 10 Hz and about 500 Hz, between about 10 Hz and about 1 kHz, or between about 10 Hz and about 5 kHz.

[0024] Figure 1 depicts an exploded perspective view of an illustrative system for reducing stress in a downhole tool, according to one or more embodiments. The system includes a vibration table 100 having a plurality of legs 110 (four are shown). A first or "lower" end portion of each leg 110 may have a base plate 112 coupled thereto or integral therewith. The base plate 112 may have one or more openings 114 (two are shown) formed therethrough. In at least one embodiment, fastening devices, such as screws or bolts, may be inserted through the openings 114 to secure the base plates 112 and, thus, the vibration table 100 to another structure or the floor 116. In another embodiment, the base plates 112 may be secured to another structure or the floor 116 via clamps, a friction fit, adhesive or the like.

[0025] One or more cross-beams 120, 122 (two are shown) may be disposed between two adjacent legs 110. As shown, a first or "lower" cross-beam 120 is disposed below a second or "upper" cross-beam 122. The cross-beams 120, 122 may be substantially perpendicular to the legs 110. The cross-beams 120, 122 may provide structural support to the legs 110 when the vibration table 100 vibrates, as discussed in greater detail below.

[0026] The legs 110 and/or the cross-beams 120, 122 may be made of wood, metal or the like. For example, the legs 110 and the cross-beams 120, 122 may be made of steel, such as low carbon alloy steel. In at least one embodiment, the legs 110 and/or the cross-beams 120, 122 may be at least partially hollow. The table 100 may be designed to support the total operational weight (*e.g.*, the table 100, the products/tools, the couplings and the vibration device 140, as discussed below).

[0027] An upper plate 130 may be coupled to a second or "upper" end portion of the legs 110. As shown, the upper plate 130 is rectangular or square; however, as may be appreciated,

the upper plate 130 may be any shape. The upper plate 130 may have a thickness 132 ranging from about 0.5 cm, about 1 cm, about 2 cm, about 3 cm, or about 4 cm to about 5 cm, about 6 cm, about 8 cm, about 10 cm, or more. For example, the thickness 132 of the upper plate 130 may be between about 2 cm and about 6 cm, between about 4 cm and about 8 cm, or between about 6 cm and about 10 cm. The upper plate 130 may be made of metal. For example, the upper plate 130 may be made of steel, such as low carbon alloy steel. The upper plate 130 may be annealed to reduce or prevent internal stress.

[0028] The upper plate 130 may have one or more openings 134 (nine are shown) formed therethrough. As shown, the openings 134 are formed in three rows with three openings in each row. However, as may be appreciated, the upper plate 130 may include any number of openings 134, and the openings 134 may be distributed in any pattern or orientation. The openings 134 may have a cross-sectional shape that is circular, ovular, rectangular, square, or the like. The cross-sectional length (*e.g.*, diameter) of the openings 134 may range from about 0.25 cm, about 0.5 cm, about 0.75 cm, or about 1 cm to about 2 cm, about 3 cm, about 4 cm, about 5 cm, or more. For example, the cross-sectional length of the openings 134 may be between about 0.5 cm and about 1.5 cm, between about 1 cm and about 2 cm, or between about 1.5 cm and about 3 cm.

[0029] A vibration device 140 may be coupled to the upper plate 130, as shown. The vibration device 140 may be coupled to the upper plate 130 by screws, bolts, clamps, or the like. The vibration device 140 is adapted to impart or transfer sub-harmonic vibrational energy to the upper plate 130 and/or a downhole tool 300 coupled to the upper plate 130 (see Figure 5) causing the upper plate 130 and/or downhole tool 300 to vibrate or oscillate in one dimension, two dimensions and/or three dimensions. In at least one embodiment, the vibration device 140 may be coupled directly to the downhole tool 300.

[0030] The motion of the upper plate 130 and/or the downhole tool 300 may have a peak-to-peak amplitude ranging from about 1 μm , about 2.5 μm , about 5 μm , about 10 μm , or about 25 μm to about 50 μm , about 75 μm , about 100 μm , about 250 μm , about 500 μm , about 1000 μm , or more. For example, the amplitude may be between about 1 μm and about 1000 μm , between about 5 μm and about 25 μm , or between about 10 μm and about 20 μm .

[0031] The motion of the upper plate 130 and/or the downhole tool 300 may have a frequency ranging from about 5 Hz, about 10 Hz, about 20 Hz, about 30 Hz, or about 40 Hz to about 60 Hz, about 80 Hz, about 100 Hz, about 150 Hz, about 200 Hz, or more. For example, the frequency may be between about 10 Hz and about 40 Hz, between about 30 Hz and about 60 Hz, between about 50 Hz and about 80 Hz, between about 70 Hz and about 100 Hz, between about 100 Hz and about 150 Hz, between about 150 Hz and about 200 Hz, between about 35 Hz and about 85 Hz, or between about 10 Hz and about 100 Hz. In another embodiment, the frequency may range from about 10 Hz, about 100 Hz, or about 500 Hz to about 1 kHz, about 3 kHz or about 5 kHz. For example, the frequency may be between about 10 Hz and about 500 Hz, between about 10 Hz and about 1 kHz, or between about 10 Hz and about 5 kHz.

[0032] A deformable material 150 may be disposed between the upper end portion of the legs 110 and the upper plate 130. The deformable material 150 may be or include an elastomer, rubber, or the like. The hardness of the deformable material 150 may range from about 20 durometers to about 80 durometers, as measured by the ASTM D2240 type A and/or type D scales. For example, the hardness of the deformable material may be between about 20 durometers and about 60 durometers, between about 40 durometers and about 80 durometers, or between about 50 durometers and about 70 durometers.

[0033] The deformable material 150 may be adapted to absorb at least a portion of the vibrational energy from the vibration device 140 and the upper plate 130, thereby reducing the amount of vibrational energy transferred to the remainder of the vibration table 100 (*i.e.*, the legs 110, the cross-beams 120, 122, and the base plates 112). The deformable material 150 may have a thickness 152 ranging from a low of about 1 cm, about 2 cm, about 3 cm, or about 4 cm to a high of about 5 cm, about 6 cm, about 8 cm, about 10 cm, or more. For example, the deformable material 150 may have a thickness 152 between about 2 cm and about 6 cm, between about 4 cm and about 8 cm, or between about 6 cm and about 10 cm.

[0034] Figure 2 depicts a perspective view of the upper plate 130 of the vibration table 100 having an illustrative collet 200 coupled thereto, and Figure 3 depicts a partial cross-sectional view of the collet 200 in an inactive state, according to one or more embodiments. The collet 200 may include a rod 210 that is adapted to extend through one of the openings 134 in the upper plate 130. A conical element 220 may be coupled to a first or "upper" end portion 212

of the rod 210. The conical element 220 may be conical or frustoconical such that a first or upper end portion 222 of the conical element 220 has a greater cross-sectional length (*e.g.*, diameter) than a second or lower end portion 224 of the conical element 220.

[0035] An expandable device 230 may be coupled to the rod 210 and/or the conical element 220 and disposed radially-outward therefrom. The expandable device 230 may be a substantially cylindrical sleeve having a bore 238 formed axially therethrough. The rod 210 and the conical element 220 may be at least partially disposed within the bore 238. The outer surface 226 of the conical element 220 proximate the first end portion 222 of the conical element 220 may be in contact with the inner surface 236 of the expandable device 230.

[0036] A plurality of slits or grooves 242 (Figure 2) may be formed axially within the expandable device 230, thereby forming a plurality of circumferentially-offset fingers 240. The grooves 242 may allow the fingers 240 to expand radially-outward when a force is exerted on the inner surface 236 of the expandable device 230. In at least one embodiment, the second or lower end portion 234 of the expandable device 230 may have a substantially fixed cross-sectional length (*e.g.*, diameter).

[0037] The collet 200 shown in Figures 2 and 3 is in the inactive state. In the inactive state, the conical element 220 is disposed proximate a first or "upper" end portion 232 of the expandable device 230, and the expandable device 230 has a first cross-sectional length (*e.g.*, diameter) 250. When in the inactive state, a line extending axially through a finger 240 of the expandable device 230 may be oriented at an angle (not shown) with respect to a longitudinal centerline through the rod 210. The angle may range from a low of about 0°, about 0.5°, about 1°, or about 2° to a high of about 4°, about 6°, about 8°, about 10°, or more. For example, the angle may be between about 0° and about 2°, between about 1° and about 4°, or between about 2° and about 8°.

[0038] Figure 4 depicts a partial cross-sectional view of the collet 200 in an active state, according to one or more embodiments. To actuate the expandable device 230 from the inactive state to the active state, a downward force is exerted on the rod 210, as shown by arrow 211, thereby pulling the conical element 220 in the downward direction with respect to the expandable device 230. When the rod 210 pulls the conical element 220 in the downward direction 211, the outer surface 226 of the conical element 220 proximate the first end portion

222 of the conical element 220 exerts a force on the inner surface 236 of the expandable device 230 in the radially-outward direction. As the second end portion 234 of the expandable device 230 has a substantially fixed cross-sectional length, this force causes the first end portion 232 of the expandable device 230 to move radially-outward, thereby forming a truncated or frustoconical shape, as shown in Figure 4.

[0039] Thus, when in the active state, the expandable device 230 has a second cross-sectional length (*e.g.*, diameter) 252 that is greater than the first cross-sectional length (*e.g.*, diameter) 250. Further, when in the active state, the line extending axially through a finger 240 of the expandable device 230 may be oriented at an angle 254 with respect to the longitudinal centerline through the rod 210. The angle 254 may range from a low of about 2°, about 4°, about 6°, or about 8° to a high of about 10°, about 15°, about 20°, about 30°, or more. For example, the angle may be between about 2° and about 5°, between about 5° and about 10°, or between about 10° and about 30°.

[0040] Figure 5 depicts a partial cross-sectional view of the vibration table 100 having the collet 200 disposed at least partially within an illustrative downhole tool 300, according to one or more embodiments. The collet 200 may be used to secure a downhole tool 300 in place on the vibration table 100. The downhole tool 300 may be or include any tool that is designed to be run into a wellbore. Although the downhole tool 300 shown in Figure 5 is a drill bit and will be described as such going forward for purposes of simplicity, it may be appreciated that other downhole tools are also contemplated. For example, illustrative downhole tools 300 include, but are not limited to, drill bits (including roller cone bits, mill tooth bits, fixed cutter bits), bore enlargement tools, underreamers, downhole mills, stabilizers and the like.

[0041] The downhole tool 300 may include a body 310 have a bore 312 formed at least partially therethrough. The body 310 may include one or more components. As shown, the body 310 includes two components coupled together via a threaded connection 314. The body 310 may also include one or more threads 316 disposed on an outer radial surface thereof. The threads 316 may be adapted to couple the body 310 to another tool, such as a drill string (not shown). In a particular embodiment, the cutting element may be a cutter (having a substrate and a diamond table thereon) that is brazed to a cutter pocket on a fixed

cutter drill bit (having a plurality of blades extending from a bit body in which the cutting elements are brazed in cutter pockets).

[0042] One or more pockets 320 may be formed in a first or "outer" axial surface (*i.e.*, the bit face) 318 of the body 310. The pockets 320 may be adapted to receive inserts or cutting elements 330. The cutting elements 330 may be coupled to the inner surface of the downhole tool 300 defining the pockets 320 by friction fit (also known as interference fit), welding, brazing, or the like. The cutting elements 330 may be semi-round top (known as "SRT") cutting elements, frustoconical cutting elements (known as "stingers"), or the like.

[0043] The outer axial surface 318 of the body 310 may have a cross-sectional length (*e.g.*, diameter) 350 ranging from about 5 cm, about 10 cm, about 15 cm, about 20 cm, about 25 cm, or about 30 cm to about 40 cm, about 50 cm, about 60 cm, about 70 cm, about 80 cm, about 90 cm, or more. For example, the cross-sectional length may be between about 10 cm and about 20 cm, between about 20 cm and about 30 cm, between about 30 cm and about 40 cm, between about 40 cm and about 50 cm, between about 50 cm and about 60 cm, between about 60 cm and about 70 cm, between about 70 cm and about 80 cm, between about 80 cm and about 90 cm, or between about 25 cm and about 90 cm.

[0044] In operation, the vibration device 140 may be coupled directly to the downhole tool 300 or indirectly to the downhole tool 300 via the vibration table 100. For example, the downhole tool 300 may be placed on the upper plate 130 of the vibration table 100 such that the collet 200 is disposed within the bore 312 of the downhole tool 300. A second or "inner" axial surface 319 of the downhole tool 300 may be in contact with the upper surface of the upper plate 130. The collet 200 may be in the inactive state (Figures 2 and 3) when inserted into the bore 312 of the downhole tool 300. Once the collet 200 is disposed within the bore 312 of the downhole tool 300, the rod 210 may be grasped from below the upper plate 130 and pulled in the downward direction 211, thereby actuating the collet 200 from the inactive state (Figure 3) to the active state (Figures 4 and 5).

[0045] When in the active state, the second cross-sectional length (*e.g.*, diameter) 252 of the expandable device 230 is such that the outer surface 237 of the expandable device 230 contacts the inner surface 313 of the downhole tool 300 defining the bore 312. This contact

may provide a force sufficient to secure the downhole tool 300 to the upper plate 130 of the vibration table 100.

[0046] The collet 200 may be locked in the active state to secure the downhole tool 300 to the upper plate 130. As shown, the second or lower end portion 214 of the rod 210 includes one or more threads 216 disposed on an outer surface thereof. A nut 218 may be threadably engaged with the threads 216. Once the rod 210 is pulled in the downward direction 211 and the collet 200 is in the active state, the nut 218 may be rotated until it contacts the lower surface of the upper plate 130. The contact between the nut 218 and the upper plate 130 prevents the rod 210 from moving back in the upward direction, which would actuate the collet 200 back into the inactive state. Thus, the nut 218 may be used to lock the collet 200 in the active state.

[0047] In another embodiment (not shown), the second end portion 214 of the rod 210 may have one or more openings formed therethrough and axially offset from one another. Once the rod 210 is pulled in the downward direction 211 and the collet 200 is in active state, a pin may be inserted into one of the openings (*e.g.*, the opening closest to the lower surface of the upper plate 130) to prevent the rod 210 from moving back in the upward direction, thereby locking the collet 200 in the active state. However, in other embodiments the downhole tool may be otherwise clamped to the table. Such as, for example, utilizing bit breaker slots or similar geometrical regions of the tool that aid in making up the connection of the tool with a drill string for securing a clamp to the tool and that table or rack.

[0048] Once the downhole tool 300 is secured to vibration device 140 and/or the vibration table 100, the cutting elements 330 may be coupled or joined to the inner surface of the downhole tool 300 defining the pockets 320 via a brazing process. During the brazing process, the downhole tool 300 (or the outer axial surface 318 thereof) is heated to a first temperature by, for example, induction, radio frequency (*e.g.*, microwave) heating, convective heating, or the like. In at least one embodiment, the first temperature may range from about 200°C, about 300°C, about 400°C, or about 500°C to about 600°C, about 800°C, about 1000°C, about 1200°C, about 1400°C, or more. For example, the first temperature may be between about 400°C and about 650°C, between about 650°C and about 900°C, or between about 900°C and about 1150°C. A silver brazing operation occurs between about

660°C and about 750°C using a preheat temperature of about 500°C. During a hardfacing operation, temperatures of the hardfacing material may exceed about 1200°C.

[0049] A torch may then increase the temperature of the outer axial surface 318 of the downhole tool 300 proximate the pockets 320 (*i.e.*, localized heat) from the first temperature to a second temperature for a brief period of time (*e.g.*, 3 seconds – 10 seconds). The second temperature may be greater than the first temperature by between about 50°C and about 300°C or between about 100°C and about 200°C. The second temperature may range from about 300°C, about 400°C, about 500°C, or about 600°C to about 800°C, about 1000°C, about 1200°C, about 1400°C, about 1600°C, or more. For example, the second temperature may be between about 500°C and about 750°C, between about 750°C and about 1000°C, or between about 1000°C and about 1250°C.

[0050] The cutting elements 330 may be disposed within the pockets 320 when the downhole tool 300 is at ambient temperature, the first temperature, the second temperature or any temperature therebetween. At the second temperature, a filler metal 340 melts and flows into the space or gap between the inner surface defining the pockets 320 and the cutting elements 330. Suitable filler metals 340 include, but are not limited to, aluminum-silicon, copper, copper-silver, copper-zinc (*i.e.*, brass), gold-silver, nickel alloy, silver alloy, or the like.

[0051] In at least one embodiment, the vibration device 140 may be turned on during the joining process (*e.g.*, cladding, brazing, or hardfacing) to transfer sub-harmonic vibrational energy to the downhole tool 300 either directly or indirectly (*e.g.*, through the upper plate 130 and/or the collet 200). The vibrational energy may impart a surface compression to the downhole tool 300, which may increase the stress required to cause cracking.

[0052] The vibrational energy may cause the downhole tool 300 to have a peak-to-peak amplitude ranging from about 1 µm, about 2.5 µm, about 5 µm, about 10 µm, or about 25 µm to about 50 µm, about 75 µm, about 100 µm, about 250 µm, about 500 µm, about 1000 µm, or more. For example, the amplitude may be between about 1 µm and about 1000 µm, between about 5 µm and about 25 µm, or between about 10 µm and about 20 µm.

[0053] The vibrational energy may cause the downhole tool 300 to have a frequency ranging from about 5 Hz, about 10 Hz, about 20 Hz, about 30 Hz, or about 40 Hz to about 60 Hz, about 80 Hz, about 100 Hz, about 150 Hz, about 200 Hz, or more. For example, the

frequency may be between about 10 Hz and about 40 Hz, between about 30 Hz and about 60 Hz, between about 50 Hz and about 80 Hz, between about 70 Hz and about 100 Hz, between about 100 Hz and about 150 Hz, between about 150 Hz and about 200 Hz, between about 35 Hz and about 85 Hz, or between about 10 Hz and about 100 Hz. In another embodiment, the frequency may range from about 10 Hz, about 100 Hz, about 500 Hz, about 1 kHz, about 10 kHz, or about 100 kHz to about 500 kHz, about 1 MHz, or about 10 MHz. For example, the frequency may be between about 10 Hz and about 500 Hz, between about 10 Hz and about 1 kHz, or between about 10 Hz and about 5 kHz. The frequency may be less than a frequency that would cause the downhole tool 300 or any part or component thereof to liquefy and flow due to heat generated by the vibrational movement.

[0054] The vibrational energy may be transferred to the downhole tool 300 as the downhole tool 300 is heated from an ambient temperature (*e.g.*, between about 0° and about 50°C) to the first temperature and/or as the downhole tool 300 is heated from the first temperature to the second temperature. For example, the vibrational energy may be transferred to the downhole tool 300 as the temperature of the downhole tool 300 increases by at least 5°C, at least 10°C, at least 50°C, at least 100°C, at least 250°C, at least 500°C, at least 750°C, at least 1000°C or at least 1250°C. The vibrational energy may prevent cracks from forming, or reduce the likelihood or severity of cracks forming or propagating, in the downhole tool 300 (*e.g.*, proximate the outer axial surface 318) as the temperature of the downhole tool 300 increases. In one or more other embodiments, the vibrational energy may be transferred to a downhole tool that has previously been subjected to such increases in temperature.

[0055] In at least one embodiment, the cutting elements 330 may be coupled to the downhole tool 300 via the brazing process at another location (*i.e.*, not while the downhole tool 100 is coupled to the vibration device 140 and/or the vibration table 100), and the downhole tool 300 may be transferred and secured to the vibration table 100 after the brazing process is complete. After the brazing process is complete (whether it takes place on the vibration table 100 or at another location), the downhole tool 300, the cutting elements 330, and the filler metal 340 may cool. As the filler metal 340 cools below its melting point, the filler metal undergoes a phase change from liquid to solid. Once solidified, the filler metal 340 joins or secures the cutting elements 330 to the inner surface of the downhole tool 300 defining the pockets 320, as shown in Figure 5.

[0056] As the downhole tool 300, the cutting elements 330, and the filler metal 340 cool, the vibration device 140 may be turned on to transfer sub-harmonic vibrational energy to the downhole tool 300 either directly or indirectly (*e.g.*, through the upper plate 130 and/or the collet 200). The vibrational energy may be transferred to the downhole tool 300 as the downhole tool 300 cools from the first and/or second temperature down to an ambient temperature (*e.g.*, between about 0° and about 50°C). For example, the vibrational energy may be transferred to the downhole tool 300 as the temperature of the downhole tool 300 decreases by at least 5°C, at least 10°C, at least 50°C, at least 100°C, at least 250°C, at least 500°C, at least 750°C, at least 1000°C or at least 1250°C. The vibrational energy may prevent cracks from forming, or reduce the likelihood or severity of cracks forming or propagating, in the downhole tool 300 (*e.g.*, the outer axial surface 318) as the temperature of the downhole tool 300 decreases due to thermal stresses induced by joining materials and component geometry. In one or more other embodiments, the vibrational energy may be transferred to a downhole tool that has previously been cooled with such temperatures decreases.

[0057] The vibration device 140 may transfer vibrational energy to the downhole tool 300 (as the temperature of the downhole tool 300 increases and/or decreases) from a low of about 1 min, about 2 min, about 5 min, about 10 min, or about 15 min to a high of about 30 min, about 45 min, about 1 hr, about 2 hr, about 5 hr, about 10 hr, or more. For example, the vibration device 140 may transfer vibrational energy to the downhole tool 300 from between about 5 min and about 15 min, between about 10 min and about 30 min, or between about 30 min and 60 min. The time that the downhole tool 300 is subjected to the vibrational energy may depend, at least in part, on the material(s) of the downhole tool 300 and/or the weight of the downhole tool 300. Process times without vibrational energy "protection" may exceed past 6 hours for large downhole tools 300 (*e.g.*, drill bits).

[0058] Once the downhole tool 300 reaches ambient temperature, the collet 200 may be actuated from the active state (Figures 4 and 5) to the inactive state (Figure 3). The downhole tool 300 may then be removed from the vibration table 100.

[0059] In another embodiment, rather than undergoing a temperature variation during a brazing process, the downhole tool 300 may undergo a temperature variation during a cladding or hardfacing process. Cladding and hardfacing are metalworking processes where

a harder or tougher material is applied/joined to a dissimilar base metal (*e.g.*, the downhole tool 300). For example, the downhole tool 300 may be made of steel, and an illustrative hardfacing material includes crushed carbide and a binder, such as a nickel binder. The hardfacing material may also include stainless steel, tube rod and/or INCONEL®. The hardfacing material may increase the wear resistance and/or corrosion resistance of a new downhole tool 300 and/or restore a worn-down downhole tool 300. The hardfacing material may be applied to the downhole tool via shielded metal arc welding, gas metal arc welding, gas tungsten arc welding, oxyfuel welding, submerged arc welding, electrosag welding, plasma arc welding, electron beam welding, thermal spraying, high velocity oxygen fuel thermal spraying, oxy-acetylene hardfacing, and/or laser cladding. The vibration device 140 may be turned on to transfer sub-harmonic vibrational energy to the downhole tool 300 either directly or indirectly (*e.g.*, through the upper plate 130 and/or the collet 200 or another type of clamp) as the temperature varies during the hardfacing process.

[0060] In yet another embodiment, the downhole tool 300 may undergo a temperature variation when two or more components are joined to form the downhole tool 300, or when the downhole tool 300 is joined to another part or component made of a similar material. For example, the downhole tool 300 may include a steel or matrix drill bit, and the other part or component may be or include a steel pin connection. The downhole tool 300 and the other part or component may be joined via shielded metal arc welding, gas metal arc welding, gas tungsten arc welding, oxyfuel welding, submerged arc welding, electrosag welding, plasma arc welding, and/or electron beam welding or through an infiltration process. The vibration device 140 may be turned on to transfer sub-harmonic vibrational energy to the downhole tool 300 either directly or indirectly (*e.g.*, through the upper plate 130 and/or the collet 200) as the temperature varies during the joining process.

[0061] Examples

[0062] In the examples presented below the downhole tools are matrix PDC drill bits that have had cutters brazed into the cutter pockets. The matrix PDC drill bits have been clamped to a vibration proof table which is directly coupled to a vibration device. Vibrational energy is then transferred to the downhole tool by a META-LAX® instrument, a product of Bonal Technologies, Inc., scanning the frequency range shown while measuring the amplitude of the harmonic response. The highest amplitude harmonic is identified from the scan and a

sub-harmonic frequency is thereby selected as the appropriate frequency for the constant frequency vibrational energy to be transferred to the downhole tool. The constant frequency vibrational energy is then transferred to the downhole tool and after the desired duration of time for the first interval has passed the transfer of constant frequency vibrational energy is stopped. Then vibrational energy is transferred to the downhole tool by scanning the frequency range shown while measuring the amplitude of the harmonic response. Based on this scan, the change in frequency of the harmonic with highest amplitude is determined and used to select the next sub-harmonic frequency to be transferred at constant frequency to the downhole tool. The desired sub-harmonic frequency is then transferred to the downhole tool for a duration of time to complete a second interval. The frequency scanning process is then repeated along with the selection of a sub-harmonic frequency based on the frequency of the harmonic with highest amplitude in the scan. This sub-harmonic is then transferred at a constant frequency for a duration of time to complete a third interval of transference of vibrational energy.

[0063] Example 1

[0064] A matrix PDC drill bit that is cooling after having undergone brazing to attach cutters into the cutter pockets has vibrational energy transferred to it by scanning a frequency range, from which the frequency of 50.8 Hz is identified in the scan as the highest amplitude harmonic. A sub-harmonic frequency of 46.2 Hz is then selected and is transferred to the downhole tool via the vibration device for 60 minutes to complete the first interval. The downhole tool then has vibrational energy transferred to it by scanning a frequency range, from which the frequency of 50.5 Hz is identified in the scan as the highest amplitude harmonic. A sub-harmonic frequency of 47.1 Hz is then selected and is transferred to the downhole tool via the vibration device for 15 minutes to complete the second interval. The downhole tool then has vibrational energy transferred to it by scanning a frequency range, from which the frequency of 50.5 Hz is identified in the scan as the highest amplitude harmonic. A sub-harmonic frequency of 47.2 Hz is then selected and is transferred to the downhole tool via the vibration device for 15 minutes to complete the third interval.

[0065] The frequency scan results for the downhole tool of Example 1 are shown in FIG. 6. It can be seen that the frequency of the highest amplitude harmonic is substantially identical in scans 2 and 3 (50.5 Hz), and shifted to a lower frequency than scan 1 (50.8 Hz). This

result indicates that the constant frequency interval of transferred vibrational energy occurring between scans 1 and 2 produced substantial stress relief of the tool, while the constant frequency interval between scans 2 and 3 did not provide significant stress relief indicating that the stress relief capable of being provided by the transference of vibrational energy to the downhole tool was complete.

[0066] Example 2

[0067] A matrix PDC drill bit that has cooled completely (is at ambient temperature) after having undergone brazing to attach cutters into the cutter pockets has vibrational energy transferred to it by scanning a frequency range, from which the frequency of 44.6 Hz is identified in the scan as the highest amplitude harmonic. A sub-harmonic frequency of 42.1 Hz is then selected and is transferred to the downhole tool via the vibration device for 60 minutes to complete the first interval. The downhole tool then has vibrational energy transferred to it by scanning a frequency range, from which the frequency of 44.1 Hz is identified in the scan as the highest amplitude harmonic. A sub-harmonic frequency of 31.9 Hz is then selected and is transferred to the downhole tool via the vibration device for 15 minutes to complete the second interval. The downhole tool then has vibrational energy transferred to it by scanning a frequency range, from which the frequency of 44.0 Hz is identified in the scan as the highest amplitude harmonic. A sub-harmonic frequency of 31.6 Hz is then selected and is transferred to the downhole tool via the vibration device for 15 minutes to complete the third interval.

[0068] The frequency scan results for the downhole tool of Example 2 are shown in FIG. 7. It can be seen that the frequency of the highest amplitude harmonic differs by only a tenth of a Hz in scans 2 and 3, and is shifted to a lower frequency than scan 1 (44.6 Hz). This result indicates that the constant frequency interval of transferred vibrational energy occurring between scans 1 and 2 produced substantial stress relief of the tool, while the constant frequency interval between scans 2 and 3 did not provide significant stress relief indicating that the stress relief capable of being provided by the transference of vibrational energy to the downhole tool was complete.

[0069] As used herein, the terms "inner" and "outer;" "up" and "down;" "upper" and "lower;" "upward" and "downward;" "above" and "below;" "inward" and "outward;" and other like

terms as used herein refer to relative positions to one another and are not intended to denote a particular direction or spatial orientation. The terms "couple," "coupled," "connect," "connection," "connected," "in connection with," and "connecting" refer to "in direct connection with" or "in connection with via one or more intermediate elements or members." The terms "hot" and "cold" refer to relative temperatures to one another.

[0070] Although only a few embodiments have been described in detail above, those skilled in the art will readily appreciate that many modifications are possible in the example embodiments without materially departing from the disclosure. Accordingly, all such modifications are intended to be included within the scope of this disclosure. In the claims, means-plus-function clauses are intended to cover the structures described herein as performing the recited function and not only structural equivalents, but also equivalent structures. Thus, although a nail and a screw may not be structural equivalents in that a nail employs a cylindrical surface to secure wooden parts together, whereas a screw employs a helical surface, in the environment of fastening wooden parts, a nail and a screw may be equivalent structures. It is the express intention of the applicant not to invoke 35 U.S.C. § 120, paragraph 6 for any limitations of any of the claims herein, except for those in which the claim expressly uses the words 'means for' together with an associated function.

[0071] Certain embodiments and features have been described using a set of numerical upper limits and a set of numerical lower limits. It should be appreciated that ranges including the combination of any two values, *e.g.*, the combination of any lower value with any upper value, the combination of any two lower values, and/or the combination of any two upper values are contemplated unless otherwise indicated. Certain lower limits, upper limits and ranges appear in one or more claims below. All numerical values are "about" or "approximately" the indicated value, and take into account experimental error and variations that would be expected by a person having ordinary skill in the art.

[0072] Various terms have been defined above. To the extent a term used in a claim is not defined above, it should be given the broadest definition persons in the pertinent art have given that term as reflected in at least one printed publication or issued patent. Furthermore, all patents, test procedures, and other documents cited in this application are fully incorporated by reference to the extent such disclosure is not inconsistent with this application and for all jurisdictions in which such incorporation is permitted.

[0073] While the foregoing is directed to embodiments of the present disclosure, other and further embodiments of the disclosure may be devised without departing from the basic scope thereof.

What is claimed is:

1. A method for reducing stress in a downhole tool, comprising:
varying a temperature of the downhole tool by at least 5°C; and
transferring vibrational energy to the downhole tool with a vibration device coupled to the downhole tool, wherein the vibrational energy causes the downhole tool to move with a frequency from about 10 Hz to about 5 kHz.
2. The method of claim 1, wherein the vibrational energy causes the downhole tool to move with a frequency from about 10 Hz to about 200 Hz.
3. The method of claim 1, wherein vibrational energy is transferred to the downhole tool in at least two separate instances for a duration of time.
4. The method of claim 3, wherein the duration of time varies from about 5 minutes to more than 10 hours.
5. The method of claim 1, wherein the vibrational energy is transferred to the downhole tool while the temperature of the downhole tool is varying by at least 5°C.
6. The method of claim 5, wherein the varying temperature of the downhole tool by at least 5°C comprises at least one of increasing the temperature of the downhole tool from between about 0°C and about 50°C to between about 500°C and about 1250°C or decreasing the temperature of the downhole tool from between about 500°C and about 1250°C to between about 0°C and about 50°C.
7. The method of claim 6, wherein the downhole tool is a drill bit, and further comprising:
inserting a cutting element into a pocket formed in the drill bit; and
joining the cutting element to the drill bit via a brazing process.
8. The method of claim 1, wherein the vibrational energy causes the downhole tool to move with a peak-to-peak amplitude between about 1 µm and about 1000 µm.

9. The method of claim 1, wherein the downhole tool is selected from the group consisting of a drill bit, a borehole enlargement tool, an underreamer, a downhole mill, and a stabilizer.
10. The method of claim 1, further comprising joining two or more components together to make the downhole tool.
11. A method for reducing stress in a downhole tool, comprising:
placing the downhole tool on a plate, wherein a plurality of legs are coupled to the plate, and wherein a deformable material is disposed between a first one of the plurality of legs and the plate; and
transferring vibrational energy to the downhole tool with a vibration device coupled to the plate, wherein the vibrational energy causes the downhole tool to move with a peak-to-peak amplitude between about 1 μm and about 1000 μm and a frequency from about 10 Hz to about 5 kHz.
12. The method of claim 11, wherein the vibrational energy is transferred to the downhole tool while the temperature of the downhole tool is varying by at least 5°C.
13. The method of claim 12, wherein the varying temperature of the downhole tool by at least 5°C comprises at least one of increasing the temperature of the downhole tool from between about 0°C and about 50°C to between about 500°C and about 1250°C or decreasing the temperature of the downhole tool from between about 500°C and about 1250°C to between about 0°C and about 50°C.
14. The method of claim 11, wherein the downhole tool is a drill bit, and further comprising:
increasing the temperature of the drill bit from between about 0°C and about 50°C to between about 500°C and about 1250°C;
inserting a cutting element into a pocket formed in the drill bit when the temperature of the drill bit is between about 500°C and about 1250°C; and
joining the cutting element to the drill bit via a brazing process.
15. The method of claim 11, further comprising applying a cladding material to the downhole tool.

16. The method of claim 11, wherein the vibrational energy causes the downhole tool to move with a frequency from about 10 Hz to about 200 Hz.
17. A system for reducing stress in a downhole tool, comprising:
a vibration device that transfers vibrational energy to a downhole tool, and wherein the vibrational energy causes the downhole tool to move with a frequency from about 10 Hz to about 5 kHz.
18. The system of claim 17, further comprising:
a plurality of legs;
a plate coupled to the plurality of legs, wherein the plate has an opening formed therethrough; and
a deformable material disposed between a first one of the plurality of legs and the plate.
19. The system of claim 1, wherein the downhole tool comprises a drill bit.
20. The system of claim 1, wherein the drill bit has a plurality of cutting elements coupled thereto via a brazing process.

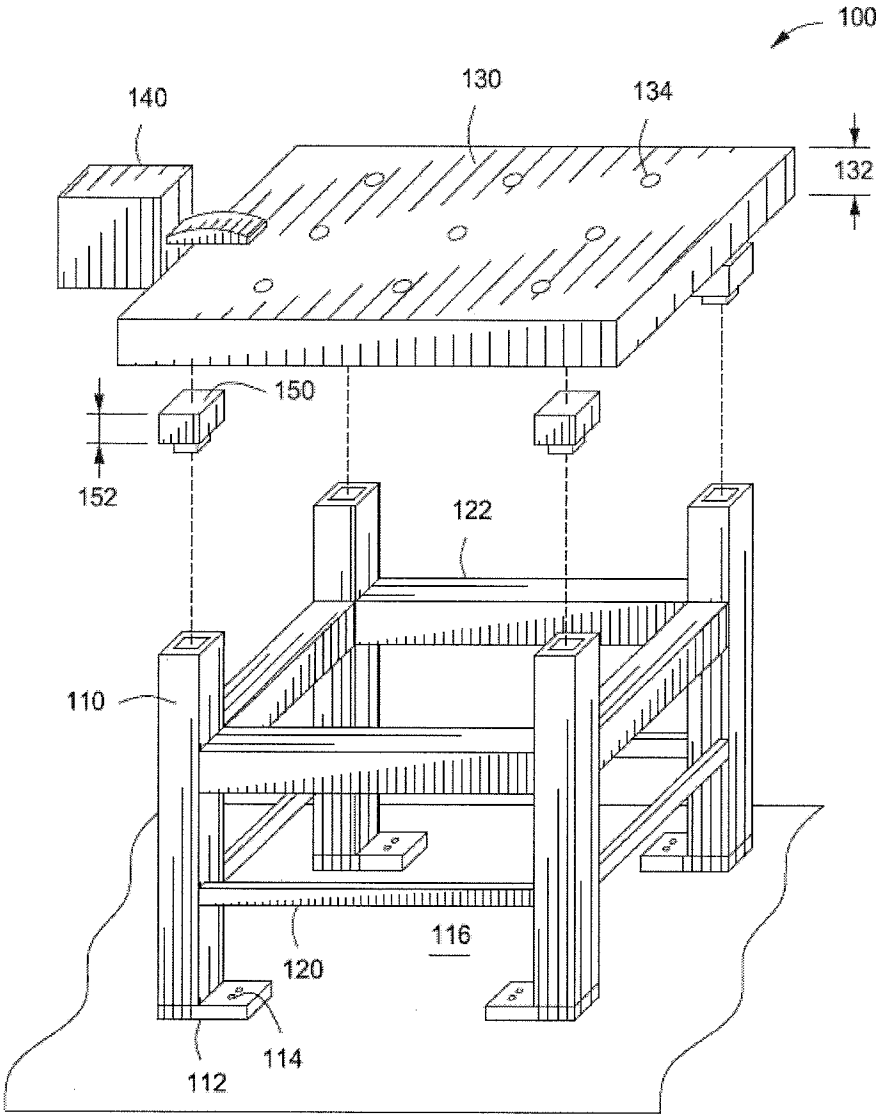


FIG. 1

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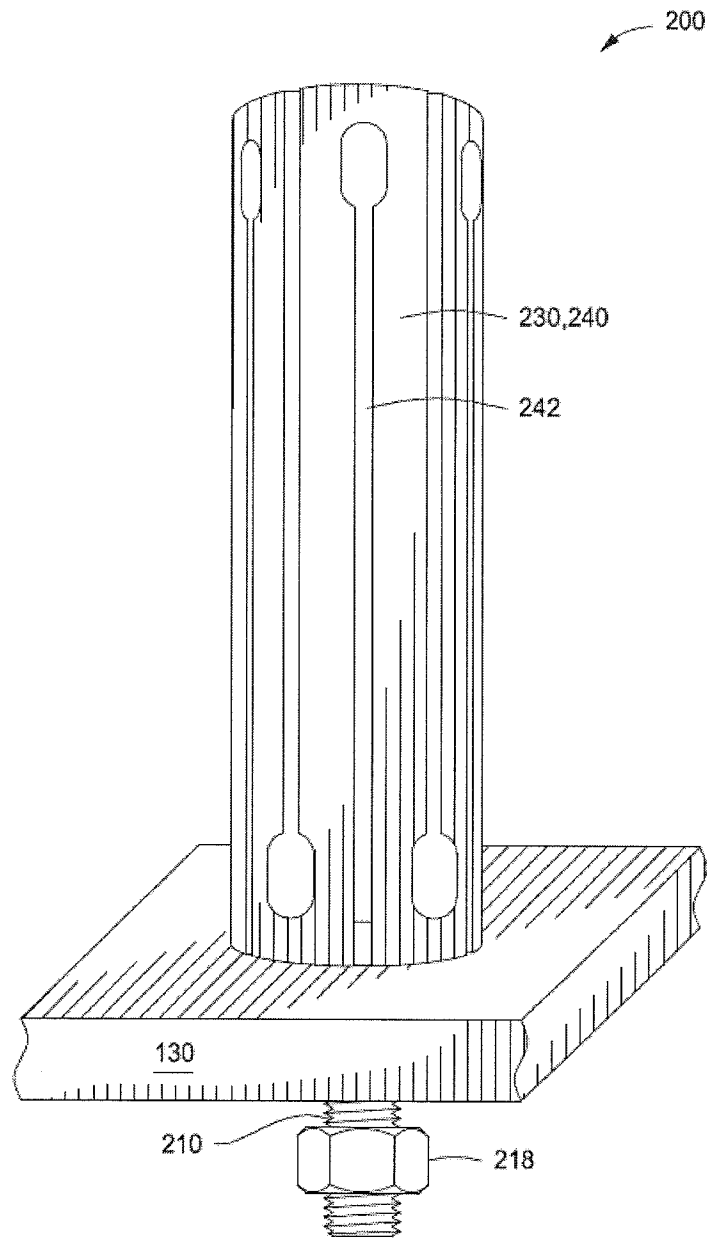


FIG. 2

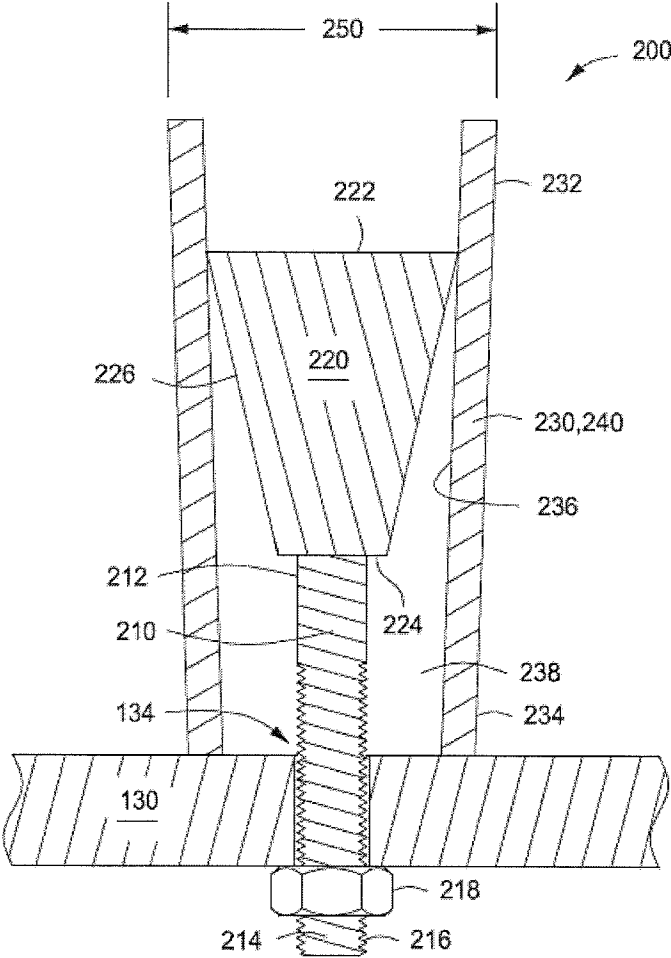


FIG. 3

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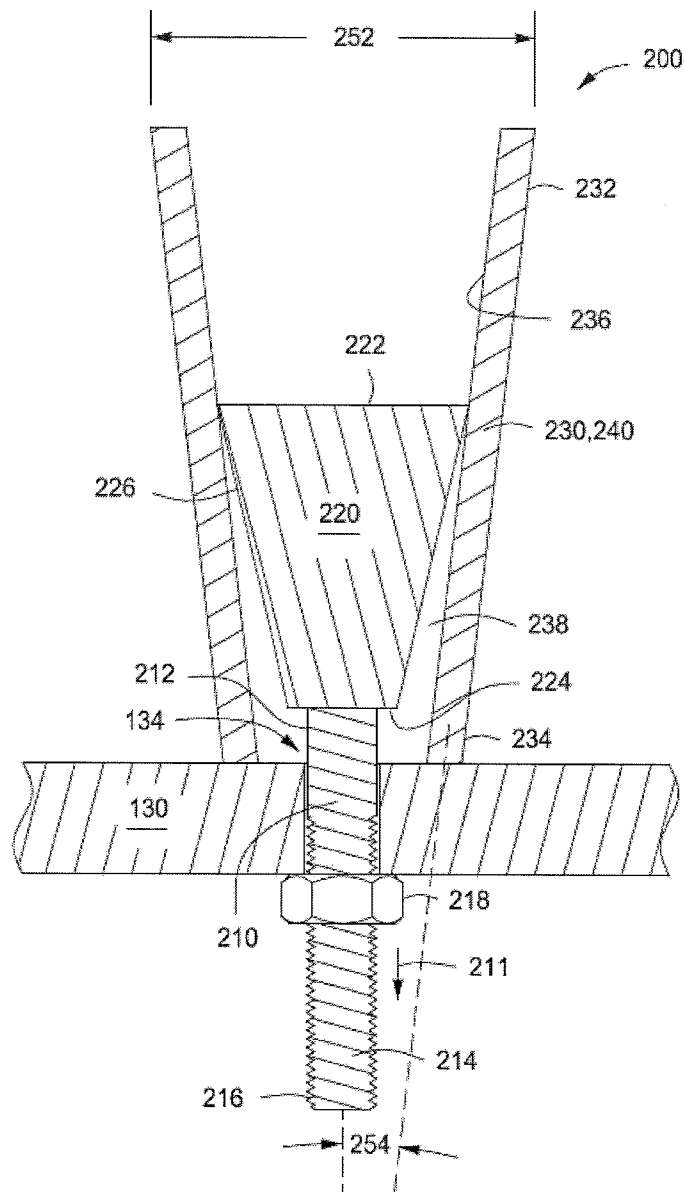


FIG. 4

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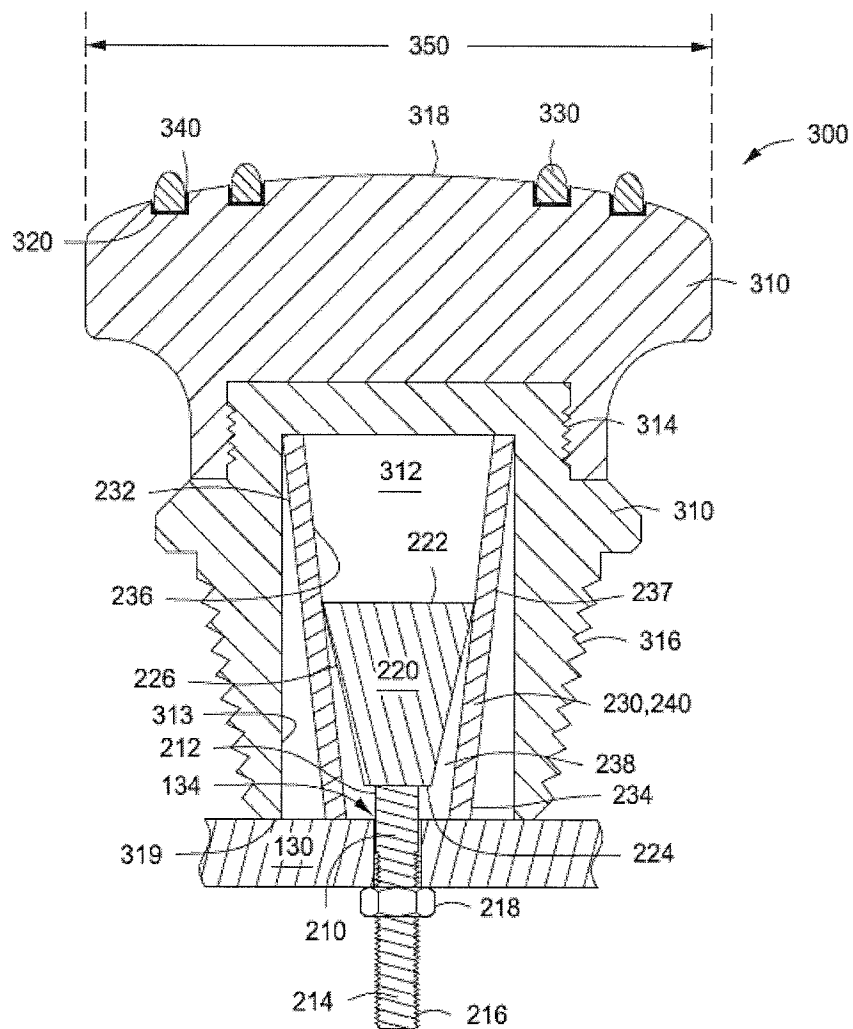
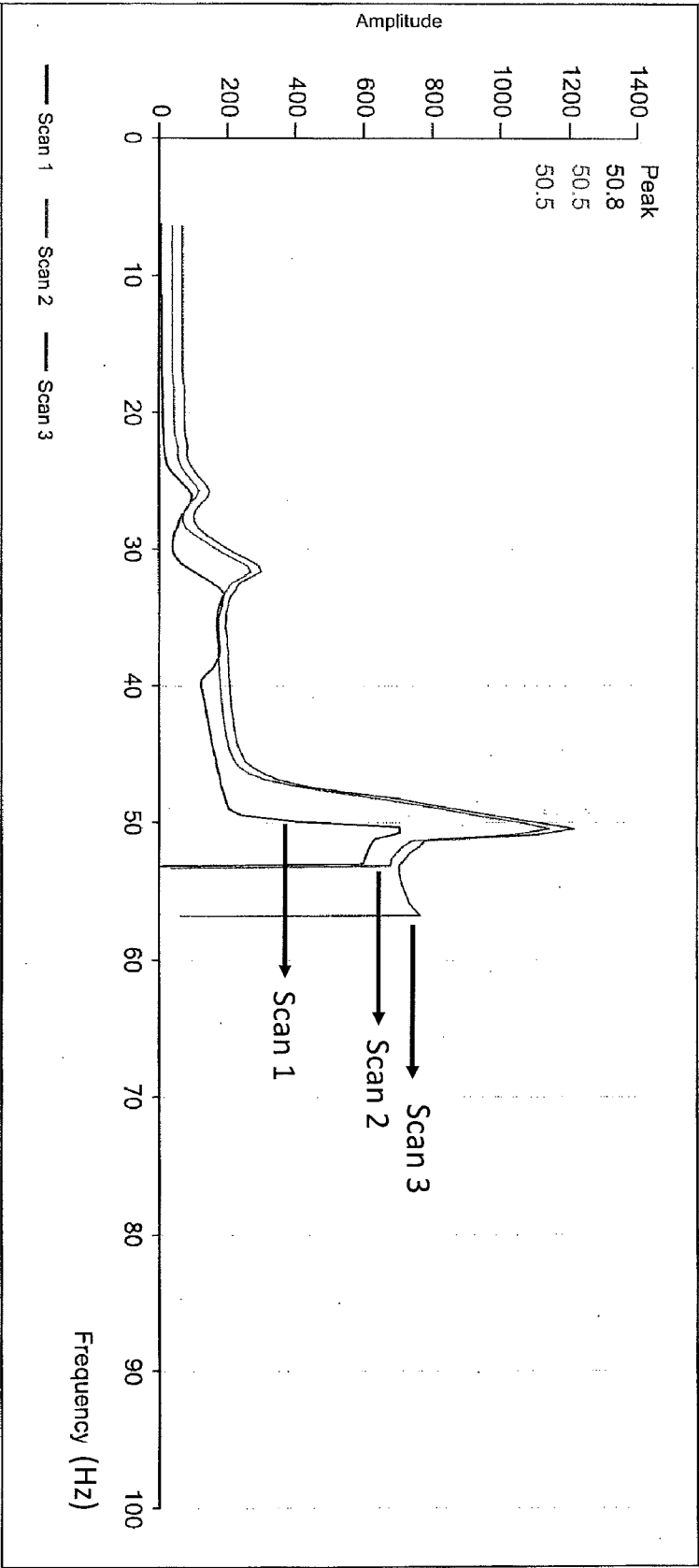


FIG. 5



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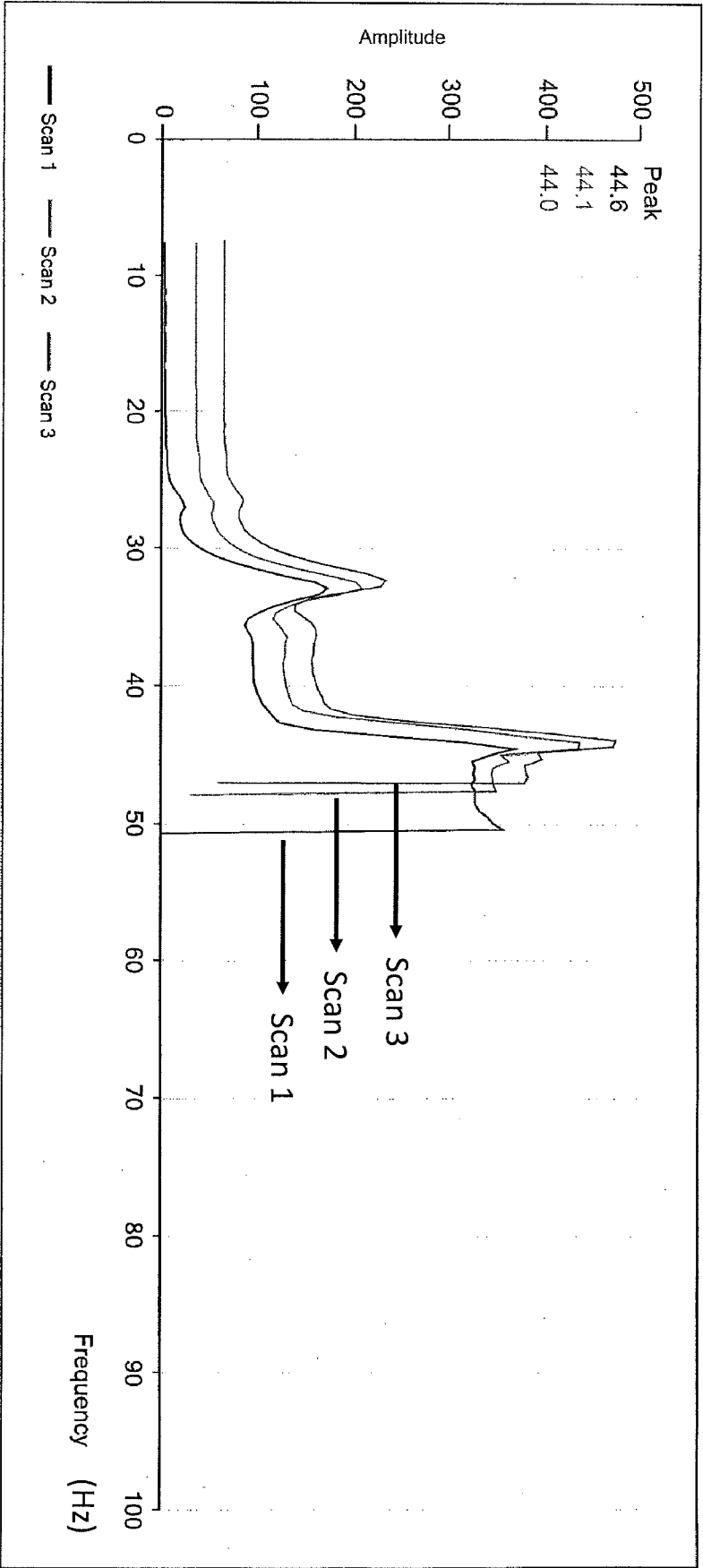


FIG. 7

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2014/043240**A. CLASSIFICATION OF SUBJECT MATTER****C21D 10/00(2006.01)i, E21B 10/00(2006.01)i**

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)

C21D 10/00; B23K 28/00; B23B 47/34; E02B 3/06; B23B 37/00; F16F 15/08; H01L 41/083; E04H 9/02; E21B 10/00

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

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

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

eKOMPASS(KIPO internal) & Keywords: stress, crack, reduction, vibration, variation, frequency, and downhole tool

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4386727 A (UNDE, MADHAV A.) 07 June 1983 See abstract; column 4, line 31 - column 5, line 29; claims 1,5,9; and figures 1,2B.	1-10, 17, 19, 20
A		11-16, 18
A	US 2007-0216258 A1 (SUGAHARA et al.) 20 September 2007 See abstract; paragraphs [0086]-[0088], [0092]-[0094]; and figures 8A, 8B.	1-20
A	JP 10-077618 A (KAJIMA CORP.) 24 March 1998 See abstract; paragraphs [0010]-[0015]; and figure 1.	1-20
A	US 2012-0107062 A1 (MORARU et al.) 03 May 2012 See abstract; paragraphs [0025]-[0028]; claim 1; and figure 1.	1-20
A	JP 09-177886 A (TECH RES. & DEV. INST. OF JAPAN DEF. AGENCY et al.) 11 July 1997 See abstract; and paragraphs [0015]-[0017].	1-20

☐ Further documents are listed in the continuation of Box C.☒ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

24 October 2014 (24.10.2014)

Date of mailing of the international search report

27 October 2014 (27.10.2014)

Name and mailing address of the ISA/KR

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2014/043240

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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