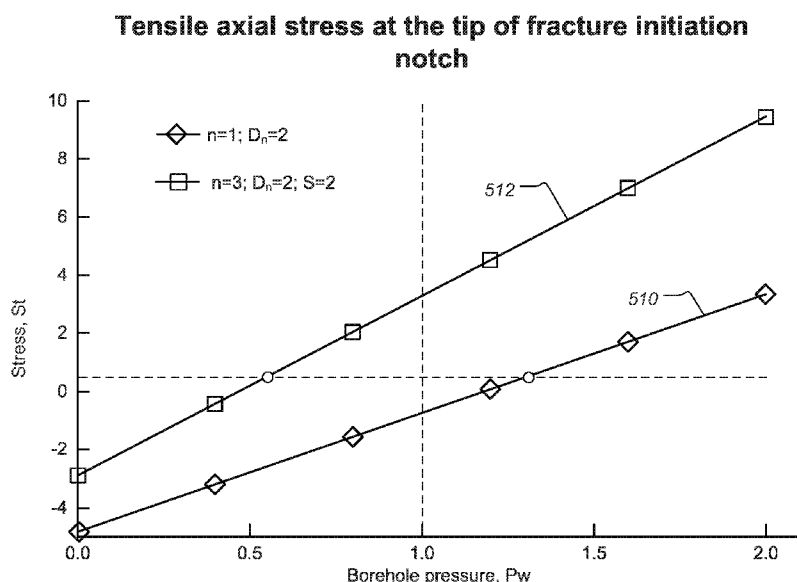




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(54) **Title:** FRACTURE INITIATION WITH AUXILIARY NOTCHES**FIG. 5**

(57) **Abstract:** Improved notching techniques are described for transverse fracture initiation from the wellbore (cased or open). One or more auxiliary notches are formed that are sealed from borehole pressure increase, yet still deformable under the fracturing pressure in the wellbore. Through the use of the auxiliary notches, lower fracturing pressure and/or shallower notches can be used when compared to known notching techniques without auxiliary notching. The described approaches can also provide greater control over the initial direction of the fracture.



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FRACTURE INITIATION WITH AUXILIARY NOTCHESCross-Reference To Related Application

[0001] The present application claims the benefit of, and priority to, U.S. Non Provisional Patent Application No. 14/595,983, filed January 13, 2015, which is hereby incorporated by reference in its entirety.

Field

[0002] The subject disclosure generally relates to hydraulic fracturing subterranean rock formations. More particularly, the disclosure relates to hydraulic fracture initiation in a main notch facilitated by one or more auxiliary notches.

Background

[0003] When a borehole is drilled in the direction of minimal far-field stress, the preferred hydraulic fracture propagation direction is in a plane perpendicular (or transverse) to the borehole axis. This assumes a rock where fracture propagation is driven by stresses, whereas effects of rock fabric are negligible. In this case, techniques to induce transverse hydraulic fracturing from the borehole are well-known in petroleum and environmental industries. One known technique includes cutting a circumferential notch (or slot) in a wellbore wall into the formation. For both cased and open holes, when wellbore pressure is increasing during fracturing operation, the tip of the notch concentrates axial tensile stress longitudinal to the wellbore axis at the predetermined location along the wellbore. A transverse fracture is thus created, extending from an extremity of the notch. In addition to controlling the position and orientation of induced fracture, tensile stress concentration developed at the notch tip also results in much lower wellbore pressure used

to initiate the fracture compared to the case of an un-notched wellbore. Note that a non-intervened, i.e., un-notched and un-perforated, open hole with an ideal wellbore surface free of natural flaws would fracture longitudinally regardless of the orientation of the wellbore with respect to far-field stress direction.

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] According to some embodiments, a method is described for fracturing a subterranean rock formation from a borehole penetrating the formation. The method includes: creating a fracture initiation notch extending from a wall of the borehole into the formation; creating at least one auxiliary notch extending from the borehole wall into the formation positioned and configured to facilitate fracture initiation from the fracture initiation notch; protecting the auxiliary notch(es) from direct fluid communication with the borehole; and increasing fluid pressure within the borehole thereby initiating a fracture from the fracture initiation notch. The auxiliary notch(es) are protected from the fluid pressure increase and are deformable such that the fracture initiation occurs at a lower pressure than if the auxiliary notch(es) did not exist.

[0006] According to some embodiments, borehole can be an open hole borehole or a cased hole borehole in the location of the fracturing. The notches can be formed using various notch cutting tools (e.g. jet cutting tool) and can have various cross section shapes such as V-shaped, or round-

ended. According to some embodiments, the auxiliary notch(es) are protected from direct fluid communication with the borehole by sealing their openings with a sleeve made of elastomer material, by sealing their openings using a polymer resin material, or by sealing their openings with an expandable metallic sleeve which may contain a swelling elastomer external coating which serves to seal against the wellbore wall. According to some embodiments, the auxiliary notch(es) are spaced from the fracture initiation notch by less than six times the radius of the borehole.

[0007] According to some embodiments, the fracture initiation notch is created having a depth that is less than would have been needed for fracture initiation at an equivalent pressure if the auxiliary notch(es) did not exist. The notches can be planar and approximately perpendicular to a central borehole axis. In cases where there are two auxiliary notches, they can be positioned with the fracture initiation notch between the two auxiliary notches. The two auxiliary notches can be spaced away from the fracture initiation notch by less than about 3 times the radius of the borehole. According to some embodiments, the two auxiliary notches are spaced away from the fracture initiation notch by less than about 2 times the radius of the borehole. In some cases more than two auxiliary notches are formed to aid in the fracture initiation.

[0008] According to some embodiments, creating of the fracture initiation notch and creating and protecting of the auxiliary notch(es) is repeated in multiple locations within a target region of the borehole such that fracturing can be sequentially or simultaneously initiated from a plurality of fracturing initiation notches. According to some embodiments, fractures are not initiated from any of the auxiliary notches.

[0009] According to some embodiments, a system is described for fracturing a subterranean rock formation from a borehole penetrating the formation. The system includes: a notch forming tool configured to form a fracture initiation notch extending from a wall of the borehole into the formation, and at least one auxiliary notch extending from the borehole wall into the formation. The at least one auxiliary notch is positioned and configured to facilitate fracture initiation from the fracture initiation notch. The system further includes a notch sealing system configured to seal and protect the at least one auxiliary notch from direct fluid communication with the borehole; a fluid pressurizing system configured to increase pressure in the borehole; and a control system programmed and configured to cause the pressurizing system to increase the pressure in the borehole to a fracture initiation pressure, which is calculated to initiate a fracture from the fracture initiation notch, and wherein the fracture initiation pressure is lower than a pressure that would be needed to initiate fracturing if the auxiliary notch(es) did not exist.

[0010] Further features and advantages of the subject disclosure will become more readily apparent from the following detailed description when taken in conjunction with the accompanying drawings.

Brief description of the drawings

[0011] To further clarify the above and other advantages and features of the subject matter of this patent specification, specific examples of embodiments thereof are illustrated in the appended drawings. It should be appreciated that these drawings depict only illustrative embodiments, and are therefore not to be considered limiting of the scope of this patent specification or the

appended claims. The subject matter hereof will be described and explained with additional specificity and detail through the use of the accompanying drawings in which:

[0012] FIG. 1 illustrates a borehole having a circumferential notch formed therein, according to known techniques;

[0013] FIG. 2 is a diagram illustrating a borehole having a fracture initiation notch and multiple auxiliary notches formed therein, according to some embodiments;

[0014] FIG. 3A is a cross section illustrating results of a simulated deformation of a fracture initiation notch formed according to known techniques;

[0015] FIG. 3B is a cross section illustrating results of a simulated deformation of a fracture initiation notch aided by two auxiliary notches, according to some embodiments;

[0016] FIG. 4A is a cross section illustrating the simulated case of a single fracture initiation notch, as is known in the art;

[0017] FIG. 4B is a cross section illustrating the simulated case of a fracture initiation notch with two auxiliary notches, according to some embodiments;

[0018] FIG. 5 is a graph comparing tensile axial stress calculated at the tip of the fracture initiation notch for a single notch and three-notch cases, as a function of borehole pressure, according to some embodiments;

[0019] FIG. 6 is a graph showing tensile axial stress calculated at the tip of the fracture initiation notch as a function of distance between notches in three-notch configuration, according to some embodiments;

[0020] FIG. 7 is a graph comparing tensile axial stress calculated as a function of wellbore pressure for single and three-notch configurations at different depths and spacings, according to some embodiments;

[0021] FIG. 8 through FIG. 17 are cross section diagrams illustrating techniques in forming fracture initiation notch and auxiliary notches for facilitating hydraulic fracturing, according to some embodiments;

[0022] FIG. 18 is a cross section diagram illustrating hydraulic fracturing using a fracture initiation notch and a single auxiliary notch, according to some embodiments;

[0023] FIG. 19 is a cross section diagram illustrating hydraulic fracturing using a fracture initiation notch and un-equally sized auxiliary notches, according to some embodiments;

[0024] FIG. 20 is a cross section diagram illustrating facilitating hydraulic fracturing using a fracture initiation notch and un-equally spaced auxiliary notches, according to some embodiments; and

[0025] FIG. 21 illustrates a system for facilitating hydraulic fracturing using a fracture initiation notch and auxiliary notches, according to some embodiments.

Detailed Description

[0026] The particulars shown herein are by way of example and for purposes of illustrative discussion of the examples of the subject disclosure only, and are presented in the cause of providing what is believed to be the most useful and readily understood description of the principles and conceptual aspects of the subject disclosure. In this regard, no attempt is made to show structural details in more detail than is necessary; the description taken with the drawings,

making apparent to those skilled in the art how the several forms of the subject disclosure may be embodied in practice. Furthermore, like reference numbers and designations in the various drawings indicate like elements.

[0027] When using a circumferential notch formed in a wellbore wall, axial tensile stress concentrates at the location of the notch tip to create transverse fracture extending from the notch tip. See, e.g. U.S. Patent No. 3,313,348; U.S. Patent No. 4,974,675 and U.S. Pat. Appl. Publ. No. US 2014/0069653. FIG. 1 illustrates a borehole having a circumferential notch formed therein, according to known techniques. The surface 114 of borehole 110 is shown having central axis 112. The borehole 110 has a radius R_w and is formed in a surrounding reservoir rock 100. A circumferential notch 120 is shown formed in borehole 110 protruding at the depth D_n in the plane orthogonal to the wellbore axis 112 into formation 100. The notch also is shown having a width W_n . A positive effect of a single notch over notch-less applications is in initiating transverse hydraulic fracture from its proximity at lower wellbore pressure. Tensile stress concentrated at the tip of notch 120 is illustrated with dotted arrows. According to some embodiments, cased or open hole wellbore in the lab or in the field can be notched by a variety of ways. See, e.g. U.S. Patent No. 3,313,348, which discusses a “mechanical” method, i.e., by using casing milling tools. U.S. Patent No. 3,211,221 and Lhomme, T., “*Initiation of hydraulic fractures in natural sandstones*”, PhD dissertation, Delft University of Technology, Delft, 2005, p. 117 (herein after “Lhomme, 2005”) discuss mechanical scribing techniques. A specific arrangement of shaped charges or explosives, or an abrasive jet from the rotating nozzle, can also be used. According to some embodiments, in order to achieve more reliable control on fracture initiation, plane direction notches should be formed with certain shape and dimension

constraints. For example, depth of a V-shaped notch should be at least 1.3 times the width of the notch at the face of the borehole, see, e.g. U.S. Patent No. 3,211,221. F. Chang, K. Bartko, S. Dyer, G. Aidagulov, R. Suarez-Rivera, J. Lund, “*Multiple Fracture Initiation in Openhole without Mechanical Isolation: First Step to Fulfill an Ambition*”, SPE 168638, 2014, includes lab experimental evidence showing that notch depth D_n should be at least one wellbore diameter ($2R_w$) to initiate a transverse fracture. In cases of shallower notches, a longitudinal fracture was initiated first. While making notches of almost any depth should not be a problem for abrasive jetting techniques, typical mechanical scribing methods are basically limited with one wellbore diameter depth or less, see, e.g., Lhomme, 2005, under condition of maintaining good depth-to-width ratio (D_n to W_n). At the same time, mechanical techniques can provide better control over geometry of the notch and depth to width ratio.

[0028] According to some embodiments, an improved notching approach to transverse fracture initiation from the wellbore (cased or open) is described. The described techniques, which use one or more auxiliary notches, can use lower fracturing pressure and/or use shallower notches compared to known notching techniques without auxiliary notching. The described approaches also allow greater control over the initial direction of the fracture.

[0029] FIG. 2 is a diagram illustrating a borehole having a fracture initiation notch and multiple auxiliary notches formed therein, according to some embodiments. The borehole 110 has a radius R_w drilled along an axis 112 in the direction of, or close to, minimal far-field stress of formation 100. A circumferential fracture initiation notch 120 is cut in the wellbore wall 114 to the depth D_n in the plane orthogonal to the wellbore axis 112. The angle the notch may be cut is dependent on the far-field stress state orientation with respect to the borehole direction and can

be achieved by inclining the notching tool at a pre-described angle. Notch 120 is assumed to have some non-zero width W_n . Placing the notch of certain depth D_n ensures higher concentration of axial tensile stress at the tip of the notch 120 (illustrated with dotted arrows), rather than tensile hoop stress at the wellbore wall 114 (illustrated with dashed arrows) that would undesirably promote initiation of longitudinal fracture. According to some embodiments, the tensile stress is concentrated to a greater extent at the tip of notch 120 by forming two additional notches 124 and 126 in a vicinity of the notch 120. According to some embodiments, auxiliary notches 124 and 126 are isolated (sealed) from the borehole 110, such that the auxiliary notches 124 and 126 are not directly exposed to the elevated borehole pressure caused during the fracturing treatment. According to some embodiments, the additional notches 124 and 126 are spaced apart from the notch 120 by a distance S which is equal to or less than about 6 times the borehole radius R_w . According to some embodiments, the spacing S is equal to or less than 2 or 3 times R_w . In some known techniques, for example U.S. Pat. Appl. Publ. No. US 2014/0069653, multiple notches are formed within a borehole, which are then either simultaneously or sequentially fractured. In such cases fractures are eventually initiated from each notch. Each notch is positioned in a location along the borehole at which it is desirable to initiate transverse fracturing. Such positioning depends on factors such as “sweet spot” location, reservoir quality, stress-shadow prevention, etc. As a result, the spacing S in such cases would not be close enough for one notch to provide advantages provided by close isolated auxiliary notches as described herein. These advantages include (1) initiating fractures at the tip of the notch at lower borehole pressures; and/or (2) allowing for shallower notches while still facilitating transverse fracture initiation.

[0030] The two auxiliary notches 124 and 126 are in fluid isolation from the wellbore 110, and are thus kept under lower pressure during fracturing treatment. This allows a larger opening of the fracture initiation notch 120 and thus higher tensile stress concentration developed at its tip compared to the single notch setup at the same borehole pressure. The mechanism is demonstrated in FIGs. 3A and 3B. FIG. 3A is a cross section illustrating results of a simulated deformation of a fracture initiation notch formed according to known techniques. Borehole 310 is drilled in formation 300 with central axis 312 which is aligned or close to the direction of minimal far-field stress. A single notch 320 is formed as shown orthogonally or approximately orthogonally to the direction of minimal far-field stress and thus orthogonal or inclined to the wellbore axis. The dashed lines 322 show the shape of the surface of the borehole 310 and notch 320 prior to elevation of borehole pressure. The solid line 330 shows the deformation (or strain) of notch 320 under an elevated pressure. The deformation of shape shown in FIGs. 3A and 3B are exaggerated by 10 times for purposes of clarity. FIG. 3B is a cross section illustrating results of a simulated deformation of a fracture initiation notch aided by two auxiliary notches, according to some embodiments. As in FIG. 3A, borehole 310 is shown in formation 300 along central axis 312. A notch 320 is also formed with the same dimensions as in FIG. 3A. Two auxiliary notches 324 and 326 are formed as shown on either side of notch 320. The auxiliary notches 324 and 326 are in fluid isolation from the borehole 310, while the fracture initiation notch 320 is in open fluid communication with the borehole 310. The dashed lines 322 show the shape of the surface of the borehole 310 and notches 320, 324 and 326 prior to elevation of pressure. The dotted lines 330 show the surface of the borehole and notch 320 pressurized to the same level as shown in FIG. 3A, for comparison, in this case notch 320 is formed without

auxiliary notches 324 and 326. The solid lines 342 show the simulated deformation when the borehole 310 is pressurized to the same level as shown in FIG. 3A. In FIG. 3B it is apparent that under the applied wellbore pressure in borehole 310, the auxiliary notches 324 and 326 are deformed and allow for greater opening of the fracture initiation notch 320.

[0031] By forming the sealed auxiliary notches a number of benefits can be gained, for example: (1) the fracture initiation pressure can be decreased while keeping the same dimensions for the fracture initiation notch; (2) shallower dimensions can be used for the fracture initiation notch(es) while using the same pressure; or (3) a combination of lower pressure and shallower dimensions for the fracture initiation notch can be used. Both lower pressure and shallow notch dimension have positive impacts in cases such as (1) hard rock formations under high stress where building up sufficient breakdown pressure is a challenge; and (2) situations when it is impractical or impossible to cut a fracture initiation notch sufficiently deep so as to ensure desired transverse fracture initiation. According to some embodiments, isolation of the auxiliary notches from the wellbore can be attained by sealing means, such as rubber or metallic sleeves. According to some embodiments, by varying the depth of the auxiliary notches (e.g. forming un-equally, so as to be asymmetrical) it is possible to adjust the initial direction of the fracture.

[0032] Further details are now provided for numerical simulations of stress concentration at the tip of a fracture initiation notch facilitated by auxiliary sealed notches, according to some embodiments. For simplicity, results presented are of simulations for open hole boreholes. FIGs. 4A and 4B show the geometries considered in the simulations. FIG. 4A is a cross section illustrating the simulated case of a single fracture initiation notch, as is known in the art. FIG. 4B is a cross section illustrating the simulated case of a fracture initiation notch with two auxiliary

notches, according to some embodiments. The simulations assume an open hole borehole 410 of radius R_w drilled in the direction of the far-field principal stress σ_z^∞ with one (notch 420 in FIG. 4A) or three circular notches (notches 420, 424 and 426 in FIG. 4B) cut into the borehole wall to the depth D_n . It is also assumed that each notch has width W_n , which would typically be dependent on the notching tool used (e.g., mechanical cutter or abrasive jetting). It is also assumed the notches are round-ended. In the case of three notches of FIG. 4B, S is the distance between notches. In FIG. 4B, rubber sleeves 450 and 452 are shown as one possible way to isolate the auxiliary notches 424 and 426 from wellbore fluid so as to keep them non-pressurized during the fracturing treatment. The rock 400 is assumed to be homogeneous isotropic linear elastic media, defined by Young's modulus E and Poisson ratio ν . To keep this numerical demonstration simple and focused on the main mechanism behind the proposed technique, we also treat the rock as non-porous and impermeable, and thus omit the effects related to pore pressure. The process of fracturing treatment is simulated by solving numerically the elastic equilibrium equation for the rock mass subjected to the far-field stresses and elevated uniform borehole pressure P_w . Hydraulic fracture initiates at some point within the rock mass where the resulting maximum tensile principal stress reaches the tensile strength of the rock T_0 . In the case of three-notch configuration having a central fracture initiation notch 420 exposed to the wellbore pressure and two auxiliary notches 424 and 426 that are not exposed to the wellbore pressure, and thus these auxiliary notches are simulated as free surfaces. Note that in practice auxiliary notches sealed from the borehole may have some exposure to wellbore pressure due to permeability of the formation medium. However, any pressure increase in the auxiliary notches will be lower than the pressure increase in the unsealed fracture initiation notch. To simplify the

solution it is assumed that two other far-field principal stresses acting orthogonal to the borehole are equal to σ_r^∞ . This allows considering the problem as axisymmetric while still being illustrative.

[0033] In what follows, the distances were normalized with respect to wellbore radius R_w . The stresses, pressures, Young's modulus, and tensile strength of rock were normalized with respect to absolute value of the far-field stress acting along the wellbore $|\sigma_z^\infty|$. This is convenient scaling to study the fracture that opens against σ_z^∞ . The base configuration of dimensionless parameters is shown in Table 1. Note that hereinafter, the sign convention of compressive stresses as negative, and tensile as positive, is used.

Far-field stress orthogonal to wellbore, σ_r^∞	-1.333
Far-field stress along the wellbore axis, σ_z^∞	-1.0
Young's modulus, E	2000.0
Poisson ratio, ν	0.2
Wellbore radius, R_w	1.0
Tensile strength, T_0	0.5
Depth of notch, D_n	2.0
Width of notch, W_n	0.375
Distance to side notches, S	2.0

Table 1

[0034] Thus, for typical in-situ stress magnitude of 2000 psi, one gets Young's modulus $E=4$ Mpsi and tensile strength $T_0=1000$ psi which, with Poisson ratio $\nu = 0.2$, correspond to Indiana limestone.

[0035] For the rock that behaves linear elastically, which is assumed in our simulations, tensile fracture is expected to initiate at the surface of the borehole or notch. Thus, in the case of un-notched borehole, when longitudinal fracture initiates along the borehole, it is controlled by the maximum hoop stress value at the wellbore wall which gives the well-known Hubert-Willis estimation for fracture initiation pressure: $P_{init}^{HW} = T_0 - 2\sigma_r^\infty$ (see, e.g., E. Detournay,

R. Carbonell, “*Fracture-Mechanics Analysis of the Breakdown Process in Minifracture or Leakoff Test*”, SPE Production & Facilities, 1997). In case of notched wellbore, initiation of transverse fracture is controlled by the axial tensile stress, which reaches its maximum at the tip of the notch: $\sigma_z|_{tip}$. Note that for the linear problem statement, this value depends linearly on borehole pressure and far-field stresses with coefficients which can be found numerically with any precision required. For the base set of problem parameters shown in Table 1, tensile axial stress at the tip of fracture initiation notch, $\sigma_z|_{tip}$, will depend solely on the borehole pressure P_w as expressed in Table 2 and shown in FIG. 5 for a single notch and three-notch cases.

1 notch, $D_n = 2$	3 notches, $D_n = 2; S = 2$
$\sigma_z _{tip} = 4.09P_w - 4.84$	$\sigma_z _{tip} = 6.17P_w - 2.89$

Table 2

[0036] FIG. 5 is a graph comparing tensile axial stress calculated at the tip of the fracture initiation notch for a single notch and three-notch cases, as a function of borehole pressure, according to some embodiments. The lines 510 and 512 show the single notch and three-notch cases, respectively. It is apparent from FIG. 5 that for a relevant range of borehole pressures the axial stress at the tip of notch 420 for the three-notch configuration exceeds considerably the corresponding value for one-notch configuration. In particular, the axial stress for the three-notch configuration becomes tensile (i.e., positive) at lower borehole pressures than the one-notch configuration does. For example for the borehole pressure P_w equal 2.0 (which corresponds to 4000 psi) tension for the three-notch configuration (18900 psi) exceeds the one-notch configuration (6680 psi) by 180%. In reality tensile stresses will not go that high, as tensile fracture initiates in the rock before that (at lower tensions). From Table 2 and condition $\sigma_z|_{tip} =$

T_0 the hydraulic fracturing initiation pressure for both notched configurations can be estimated as shown in Table 3:

1 notch, $D_n = 2$	3 notches, $D_n = 2; S = 2$
$P_{i,1} = 0.24T_0 + 1.18$	$P_{i,3} = 0.16T_0 + 0.47$

Table 3

[0037] From Table 3 it is apparent that hydraulic fracturing initiation pressure in three-notch configurations is lower than in one-notch configurations, i.e.: $P_{i,3} < P_{i,1}$ and particularly for $T_0 = 0.5$ (which corresponds to 1000 psi) we have $P_{i,1} = 1.3$ (2600 psi) and $P_{i,3} = 0.55$ (1100 psi). In FIG. 5 fracture initiation pressures are marked as points of intersection of particular stress line with horizontal dashed line representing the tensile strength threshold ($\sigma_z|_{tip} = T_0 = 0.5$). It is apparent that the value $P_{i,3}$ is located to the left side from the vertical dashed line $P_w = |\sigma_z^\infty| = 1$ which corresponds to the zero “net pressure” inside the fracture initiation notch, while the value $P_{i,1}$ is to the right. This becomes possible solely due to the effect of auxiliary notches that “screened” the far-field stress acting in the borehole direction and reduced the effective compliance of the rock in this direction. In the three-notch configuration the rock would be broken at much lower borehole pressure compared to single-notch one (although, the further propagation of hydraulic fracture will require the borehole pressure higher than $|\sigma_z^\infty|$ to keep the net pressure positive).

[0038] FIG. 6 is a graph showing tensile axial stress calculated at the tip of the fracture initiation notch 420 loaded with borehole pressure $P_w=1.5$, as a function of distance between notches in three-notch configuration while depth of notches is fixed as per the base configuration $D_n=2$, according to some embodiments. The data, shown in Table 4 (column “n=3”), is plotted on curve 612, while the stress for the single notch case is plotted on line 610.

	$\sigma_z _{tip}$		
S	n=1	n=3	n3/n1
2	1.2950	6.3650	4.92
3		4.1611	3.21
4		3.1302	2.42
5		2.5444	1.96
6		2.1783	1.68

Table 4 (data for FIG. 6)

[0039] It is apparent that the difference between single-notch and three-notch configurations diminishes quickly with increasing distances between notches S . Thus in order to benefit from the effect, according to some embodiments, the auxiliary notches should not be further than 3-4 wellbore radii from the central fracture initiation notch. In practice, the distance S should be balanced with other considerations, such as the technology used for forming the notches, etc.

[0040] Further, a comparison is made between (1) a three-notch configuration where notches are formed at half of the depth (1 wellbore radius deep); and (2) a one-notch configuration with a notch that is 2 wellbore radii deep. FIG. 7 is a graph comparing tensile axial stress calculated as a function of wellbore pressure for single and three-notch configurations at different depths and spacings, according to some embodiments. Line 710 shows calculated stress for a single notch configuration with the notch depth equal to 2 wellbore radii. Line 712 shows calculated stress for a three-notch configuration with notches 1 wellbore radius deep and spaced 2 wellbore radii away from each other. Line 714 shows calculated stress for a three-notch configuration with notches 1 wellbore radius deep and spaced 3 wellbore radii away from each other.

[0041] Tensile stress at the tip of central notch 420 and the hydraulic fracturing initiation pressure for three-notch configuration is calculated as shown in Table 5.

3 notches, depth $D_n = 1$, distance $S=2$	3 notches, depth $D_n = 1$, distance $S=3$
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$\sigma_z _{tip} = 3.39P_w - 2.69$	$\sigma_z _{tip} = 3.06P_w - 3.05$
$P_{i,3} = 0.29T_0 + 0.79$	$P_{i,3} = 0.33T_0 + 1.00$

Table 5

[0042] It is apparent from the simulations that, for the same borehole pressures, a higher tension will be developed at the notch tip in a three-notch configuration with notches of one bore hole radius deep than in a single notch configuration with notch of two bore hole radii deep. Thus, the hydraulic fracturing initiation pressures will also be smaller in a three-notch configuration. In particular, $T_0 = 0.5$, $P_{i,3}(D_n = 1, S = 2) = 0.94$ and $P_{i,3}(D_n = 1, S = 3) = 1.17$ which both are less than $P_{i,1}(D_n = 2) = 1.3$.

[0043] FIG. 8 through FIG. 17 are cross-section diagrams illustrating techniques in forming fracture initiation notches and auxiliary notches for facilitating hydraulic fracturing, according to some embodiments. In FIG. 8 a borehole 810 is shown penetrating subterranean rock formation 800. In this example, the section of borehole 810 shown is an open hole section that has been formed in the direction of minimal far-field stress of formation 800. Also shown in FIG. 8 is a tool 860 used to cut notches in the borehole wall 822. According to some embodiments, the notching tool 860 is a coiled-tubing deployed jet cutting tool with a rotating jet cutting head 864 and coiled tubing 862. In FIG. 9, a jetting fluid 870 is being pumped through the coiled tubing 862 and jet cutting head 864 so as to cut or form an auxiliary notch 826 from borehole 810 into formation 800. In FIG. 10, the coiled tubing deployed jet cutting tool 860 is moved to another location as shown and activated so as to form a second auxiliary notch 824 from borehole 810 into formation 800. In FIG. 11, the coiled tubing 862 is used to circulate a degradable plugging material 872 through tubing 862 and into the borehole 810, including notches 824 and 826. Several methods are available for controlling where the plugging material 872 is placed.

According to some embodiments, an inflatable packer 873 is placed "below" the coiled tubing notching tool, and another inflatable packer (not shown) is positioned "above" (i.e. to the "left" side of in FIG. 11) notch 824. According to some other embodiments, the coiled tubing 862 can be moved to "displace" the plugging material 872 along the wellbore as a gel. The displacement of the fluid from the annular side of the coiled tubing could also be controlled by pumping a fluid down the annulus to force the plugging material 872 into the zone of interest. According to some embodiments, a gel-like material 872 is used which can be thermally set, for example. In FIG. 12, the degradable plugging material is shown over-displaced into the auxiliary notches 824 and 826. In FIG. 13, a polymer resin fluid 874 is circulated through coiled tubing 862 and into the borehole in the vicinity of notches 824 and 826. Note that the degradable plugging material still resides in the notches 824 and 826. According to some embodiments an inflatable packer 875 is placed "below" the coiled tubing notching tool, and another inflatable packer (not shown) is positioned "above" (i.e. to the "left" side of in FIG. 13) notch 824. In FIG. 14, the polymer resin 874 is over-displaced as shown and allowed to cure, thus forming sealing material 876 in the vicinity of notches 824 and 826, thereby effectively sealing the notches from the borehole 810. In FIG. 15, the jet cutting tool 860 is moved to a location between the notches 824 and 826 as shown, and jetting fluid 870 is used to cut fracture initiation notch 820. Note that in this example, the jetting tool 860 first cuts through the sealing material before cutting into the formation rock 800. In FIG. 16, the plugging material 872 has been degraded in auxiliary notches 824 and 826 so that the notches 824 and 826 are compressible while being sealed from fluid in borehole 810 by sealing material 876. In FIG. 17, fracturing fluid 878 is injected at elevated pressures so as to initiate fracture 890 from the tip of fracture initiation notch 820 as

shown. As described herein, through the use of the auxiliary notches 824 and 826, the depth of notch 820 can be made shallower and/or a lower fracture initiation pressure can be used to initiate fracture 890 when compared to the case where the notches 824 and 826 were not present.

[0044] According to some embodiments, the described auxiliary-notch-assisted transverse fracturing technique is repeated multiple times within a given wellbore. The fracturing is carried out either sequentially over multiple fracturing stages or simultaneously from several auxiliary-notch assisted fracture initiations notches. According to some embodiments, the described pattern of fracture initiation notch surrounded by two auxiliary notches isolated from the borehole pressure is repeated for each "sweet spot" along a wellbore where transverse fracturing is desired.

[0045] FIG. 18 is a cross section diagram illustrating facilitating hydraulic fracturing using a fracture initiation notch and a single auxiliary notch, according to some embodiments. This example is similar or identical to those shown in FIGs. 8-17, except that the notch cutting tool 860 is used to make a single auxiliary notch 826 instead of two auxiliary notches. According to other embodiments, other numbers of auxiliary notches can be used in facilitating hydraulic fracturing.

[0046] FIG. 19 is a cross section diagram illustrating facilitating hydraulic fracturing using a fracture initiation notch and un-equally sized auxiliary notches, according to some embodiments. In this example, auxiliary notch 1924 is shallower than auxiliary notch 1926. In some cases, this technique can be used to slant or "steer" the resultant fracture 1990 towards the side with the larger auxiliary notch.

[0047] FIG. 20 is a cross section diagram illustrating facilitating hydraulic fracturing using a fracture initiation notch and un-equally spaced auxiliary notches, according to some embodiments. In this example, auxiliary notch 2024 is closer to fracture initiation notch 820 (i.e. the distance “S” is shorter) than auxiliary notch 2026. As in the case of FIG. 19, this technique can be used to slant or “steer” the resultant fracture 2090 towards the side with the closer auxiliary notch. According to some embodiments, a combination of auxiliary notch sizes, spacing and numbers can be used depending on the particular application.

[0048] FIG. 21 illustrates a system for facilitating hydraulic fracturing using a fracture initiation notch and auxiliary notches, according to some embodiments. The fracturing is desired in subterranean hydrocarbon-bearing formation 800. A notch cutting tool 860 is deployed via coiled tubing truck 2120 into wellbore 810 that extends from the well head 2112 on the surface to the formation 800 that is to be fractured. Equipment at the wellsite 2110 includes one or more other service vehicles, such as 2122, as well as mixing and pumping equipment 2124. Also shown in FIG. 21 is data processing unit 2150, which according to some embodiments, includes a central processing system 2144, a storage system 2142, communications and input/output modules 2140, a user display 2146 and a user input system 2148. The data processing unit 2150 may be located in or on either of trucks 2120 and 2122, and/or may be located in other facilities at wellsite 2110 or in some remote location. According to some embodiments, processing unit 2150 is used to monitor and control notch cutting tool 860 and pumping equipment that may be located in one or more of trucks 2120, 2122 and mixing and pumping equipment 2124. Further examples of tools and/or systems that may be used in hydraulic fracturing are provided in U.S.

Pat. No. 7,828,063 and U.S. Pat. Appl. Publ. No. US2014/0069653, both of which are incorporated herein by reference.

[0049] Although some embodiments have been described herein with respect to hydrocarbon-bearing formations, the techniques described are applicable to other types of subterranean formations. According to some embodiments, the hydraulic fracturing facilitation techniques are applied to other types of formations including: geothermal formations, CO₂ storage formations, and/or water-bearing formations.

[0050] The foregoing outlines features of several embodiments so that those skilled in the art may better understand the aspects of the present disclosure. Those skilled in the art should appreciate that they may readily use the present disclosure as a basis for designing or modifying other processes and structures for carrying out the same purposes and/or achieving the same advantages of the embodiments introduced herein. Those skilled in the art should also realize that such equivalent constructions do not depart from the spirit and scope of the present disclosure, and that they may make various changes, substitutions and alterations herein without departing from the spirit and scope of the present disclosure.

CLAIMS

WHAT IS CLAIMED IS:

1. A method of fracturing a subterranean formation from a borehole penetrating the formation, the method comprising:
creating a fracture initiation notch extending from a wall of the borehole into the formation;
creating at least one auxiliary notch extending from the borehole wall into the formation positioned and configured to facilitate fracture initiation from said fracture initiation notch;
protecting said at least one auxiliary notch from direct fluid communication with said borehole; and
increasing fluid pressure within the borehole and said fracture initiation notch thereby initiating a fracture from said fracture initiation notch, wherein said at least one auxiliary notch being protected from said fluid pressure increase and being deformable such that said fracture initiation occurs at a lower pressure than if the auxiliary notch did not exist.
2. The method according to claim 1 wherein said borehole is an open-hole borehole in the location of the fracture initiation notch and the at least one auxiliary notch.

3. The method according to claim 1 wherein said borehole is a cased borehole in the location of the fracture initiation notch and the at least one auxiliary notch.
4. The method according to claim 1 wherein said fracture initiation notch and said at least one auxiliary notch are V-shaped.
5. The method according to claim 1 wherein said fracture initiation notch and said at least one auxiliary notch are U-shaped.
6. The method according to claim 1 wherein protecting said at least one auxiliary notch from direct fluid communication with said borehole includes sealing an opening to said at least one auxiliary notch with a sleeve made of elastomer material.
7. The method according to claim 1 wherein protecting said at least one auxiliary notch from direct fluid communication with said borehole includes sealing an opening to said at least one auxiliary notch with a polymer resin material.
8. The method according to claim 1 wherein said at least one auxiliary notch is spaced from said fracture initiation notch by less than six times a radius of the borehole.

9. The method according to claim 1 wherein said fracture initiation notch is created having a depth that is less than would have been needed for fracture initiation at an equivalent pressure if said auxiliary notch did not exist.
10. The method according to claim 1 wherein said fracture initiation notch is planar and approximately perpendicular to a central borehole axis.
11. The method according to claim 1 wherein said fracture initiation notch is planar and non-perpendicular to a central borehole axis.
12. The method according to claim 1 where said at least one auxiliary notch includes two auxiliary notches positioned with the fracture initiation notch between the two auxiliary notches.
13. The method according to claim 12 wherein each of the two auxiliary notches is spaced away from the fracture initiation notch by less than about 3 times a radius of the borehole.
14. The method according to claim 12 wherein the two auxiliary notches are spaced away from the fracture initiation notch by non-equal distances.

15. The method according to claim 1 where said at least one auxiliary notch includes at least three auxiliary notches.
16. The method according to claim 1 wherein said fracture initiation notch and said at least one auxiliary notch are created using a jet cutting tool deployed via coiled tubing.
17. The method according to claim 1 wherein protecting said at least one auxiliary notch from direct fluid communication with said borehole includes at least partially filling said at least one auxiliary notch with a degradable plugging material.
18. The method according to claim 1 wherein the subterranean formation is a hydrocarbon-bearing formation.
19. The method according to claim 1 further comprising repeating said creating a fracture initiation notch, creating at least one auxiliary notch, and protecting, such that said increasing fluid pressure initiates a plurality of fractures from a plurality of fracturing initiation notches.
20. The method according to claim 1 further comprising repeating said creating a fracture initiation notch, creating at least one auxiliary notch, protecting, and increasing fluid pressure, thereby sequentially fracturing the formation from each of several fracturing initiating notches.

21. The method according to claim 1 wherein fractures are not initiated from said at least one auxiliary notch.
22. A system for fracturing a subterranean formation from a borehole penetrating the formation, the system comprising:
- a notch forming tool configured to form a fracture initiation notch extending from a wall of the borehole into the formation, and at least one auxiliary notch extending from the borehole wall into the formation, the at least one auxiliary notch being positioned and configured to facilitate fracture initiation from said fracture initiation notch;
 - a notch sealing system configured to sealingly protect said at least one auxiliary notch from direct fluid communication with said borehole;
 - a fluid pressurizing system configured to increase pressure in the borehole; and
 - a control system programmed and configured to cause the pressurizing system to increase the pressure in the borehole to a fracture initiation pressure which is calculated to initiate a fracture from said fracture initiation notch and wherein said fracture initiation pressure is lower than a pressure that would be needed to initiate fracturing if the at least one auxiliary notch did not exist.

23. The system according to claim 22 wherein said control system and said notch forming tool are configured to form the at least one auxiliary notch and the fracture initiation notch such they are spaced apart by no more than six times a radius of the borehole.
24. The system according to claim 22 wherein said control system and said notch forming tool are configured to form the at least one auxiliary notch and the fracture initiation notch such they are spaced apart by no more than three times a radius of the borehole.
25. The system according to claim 22 wherein said control system and said notch forming tool are configured to form the fracture initiation notch having a depth that is less than would have been needed for fracture initiation at an equivalent pressure if said at least one auxiliary notch did not exist.
26. The system according to claim 22 where said at least one auxiliary notch includes two auxiliary notches positioned with the fracture initiation notch between the two auxiliary notches.
27. The system according to claim 22 wherein said notch forming tool is a jet cutting tool deployable via coiled tubing.

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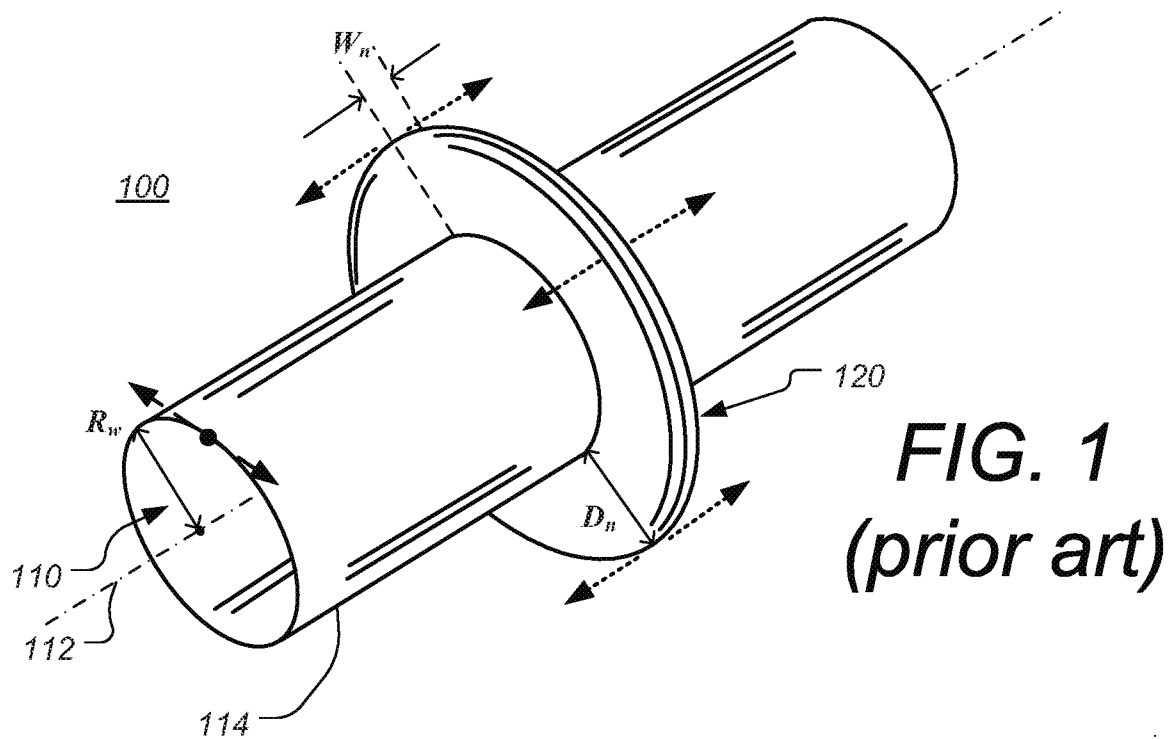


FIG. 1
(prior art)

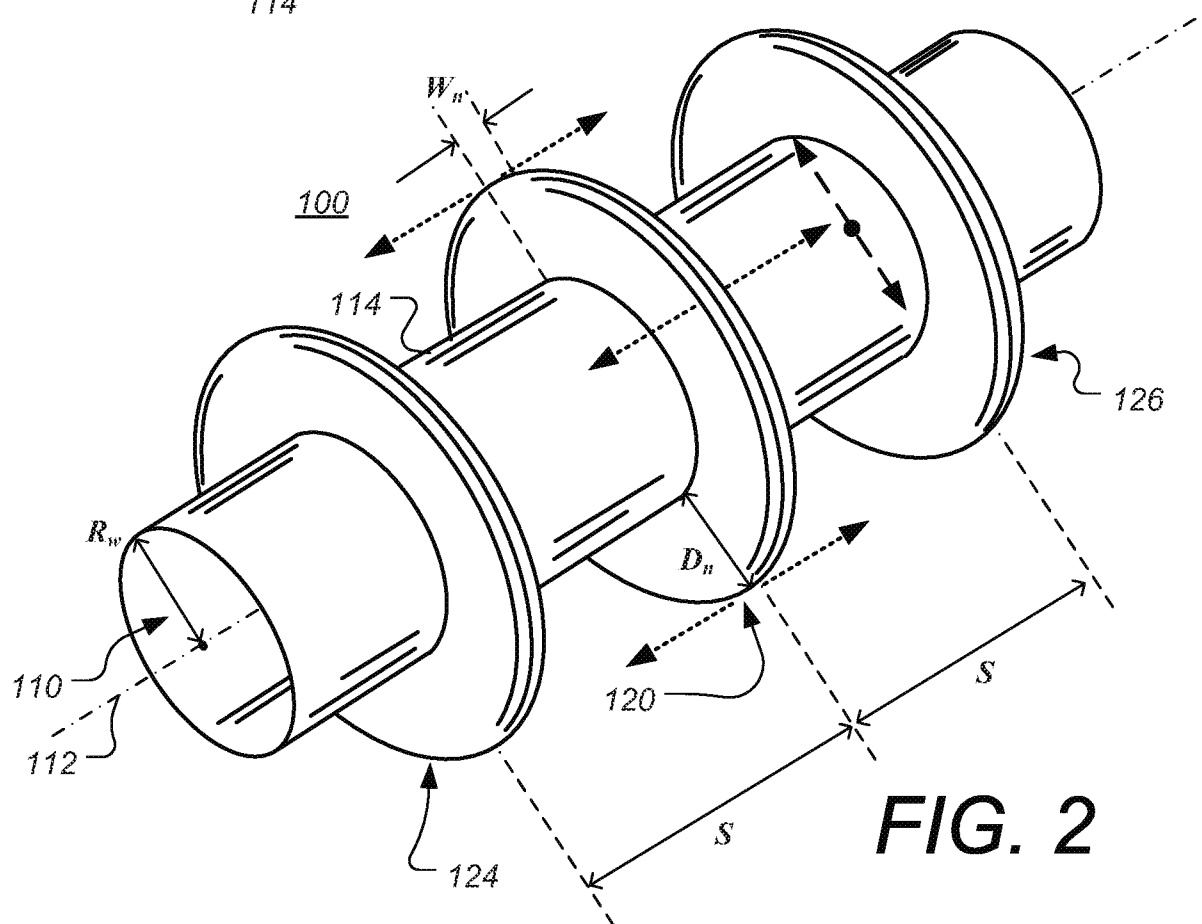


FIG. 2

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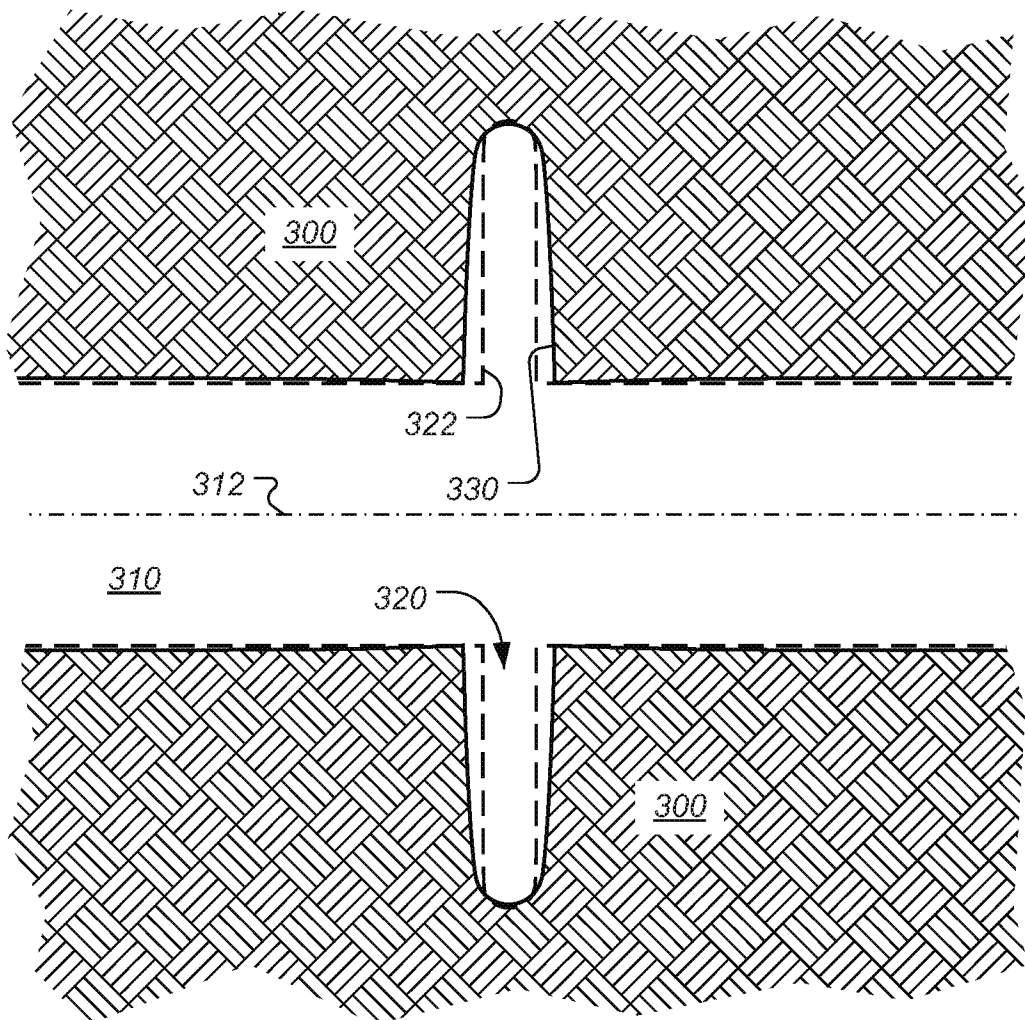


FIG. 3A
(prior art)

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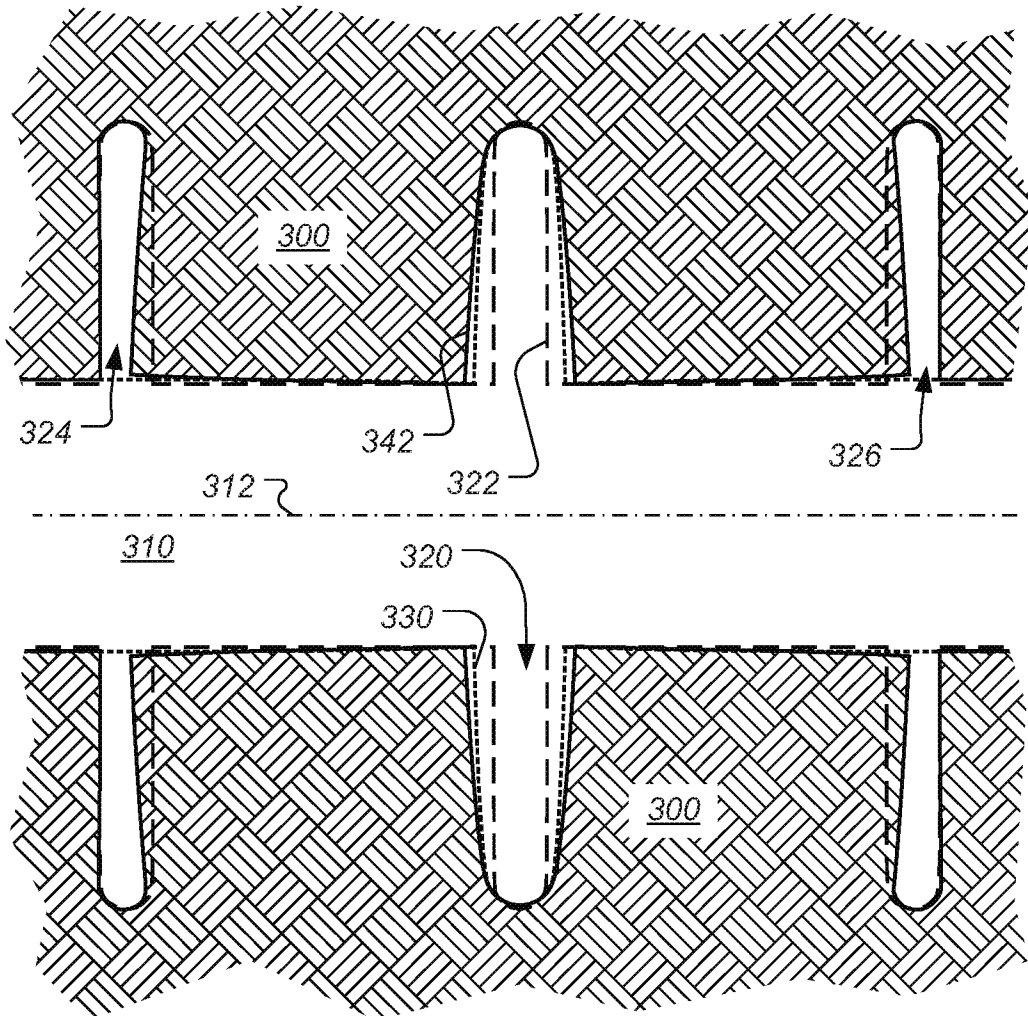


FIG. 3B

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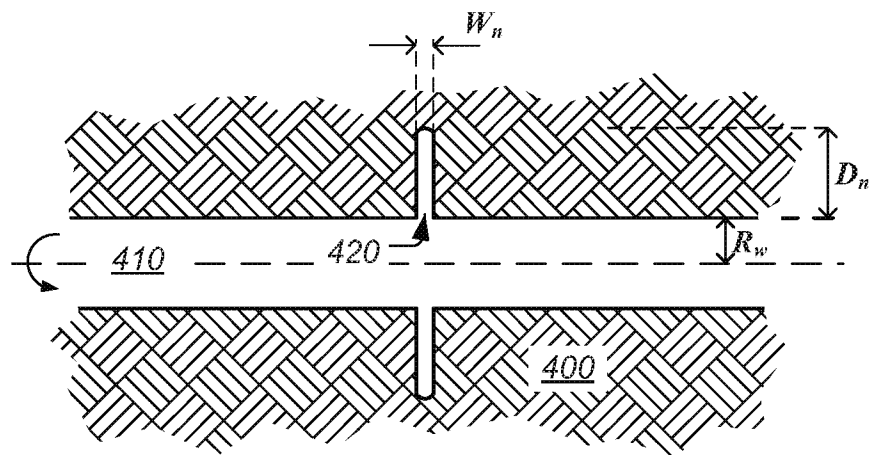


FIG. 4A (prior art)

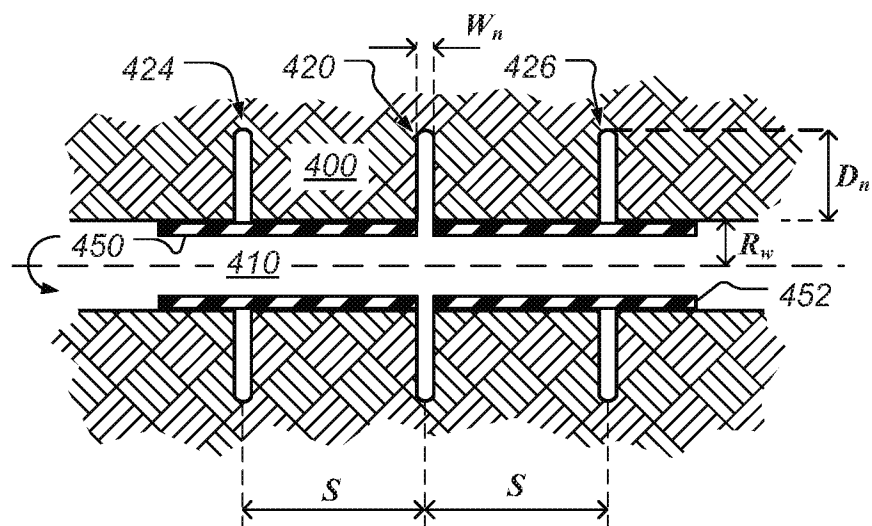


FIG. 4B

Tensile axial stress at the tip of fracture initiation notch

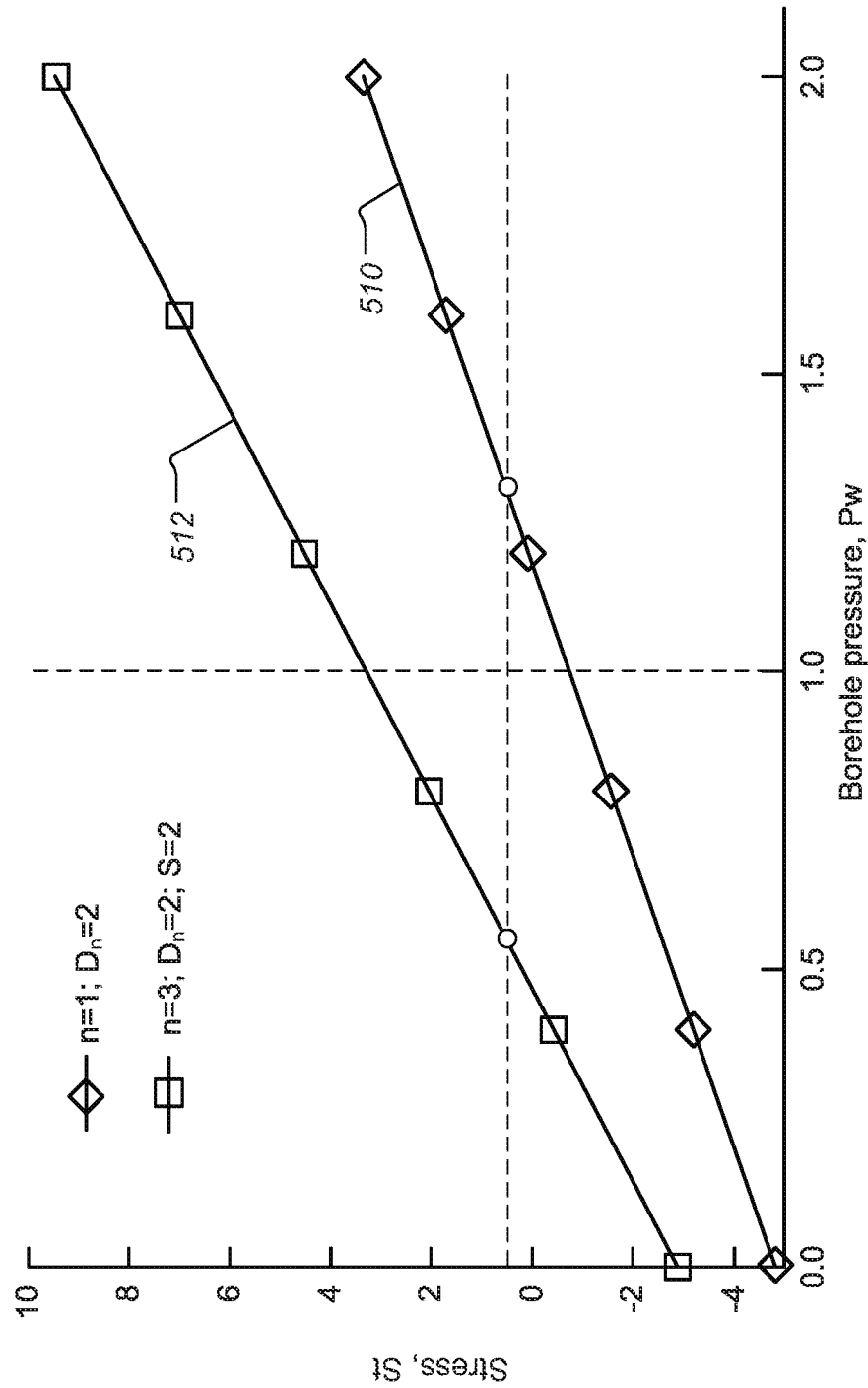


FIG. 5

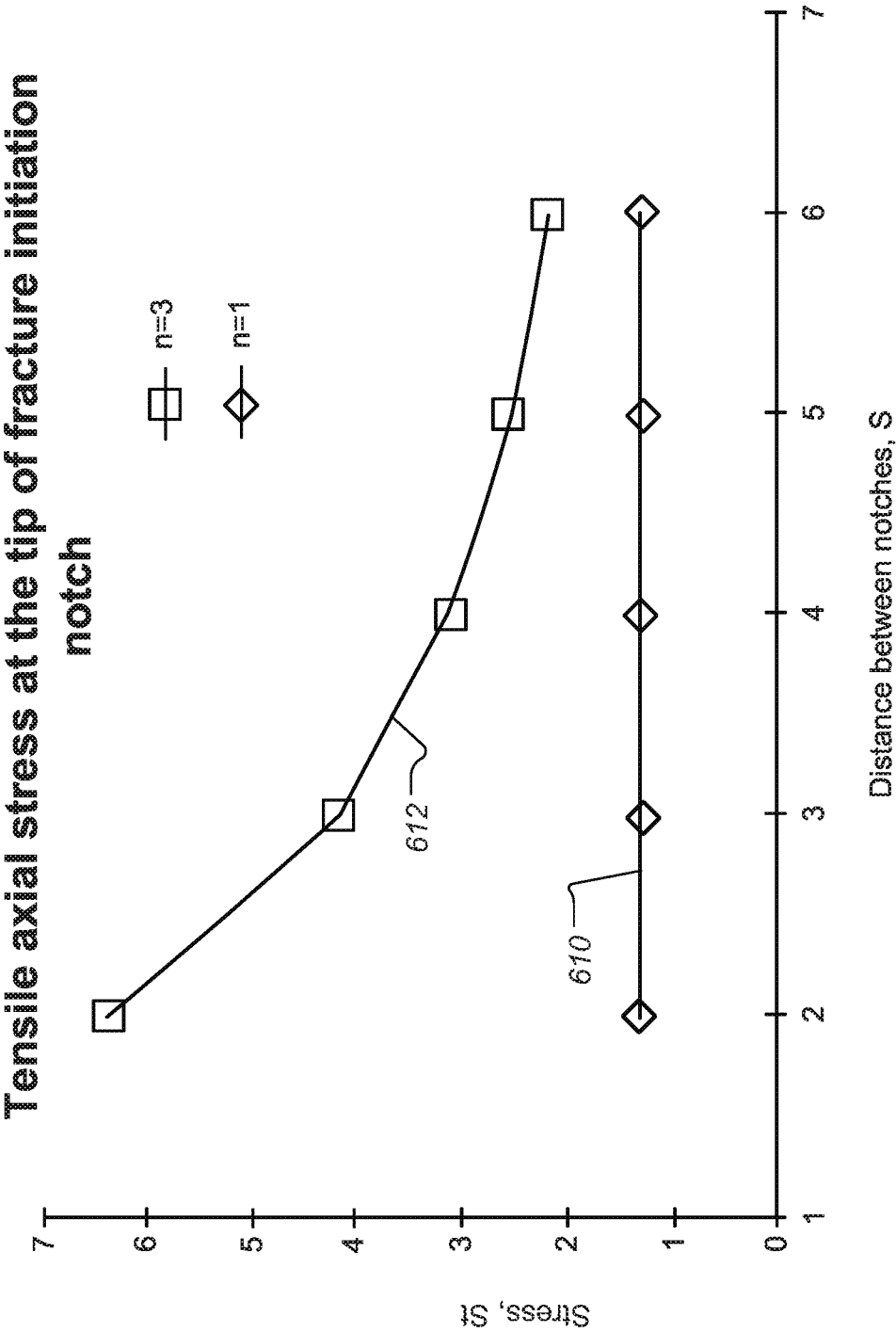


FIG. 6

Tensile axial stress at the tip of fracture initiation notch

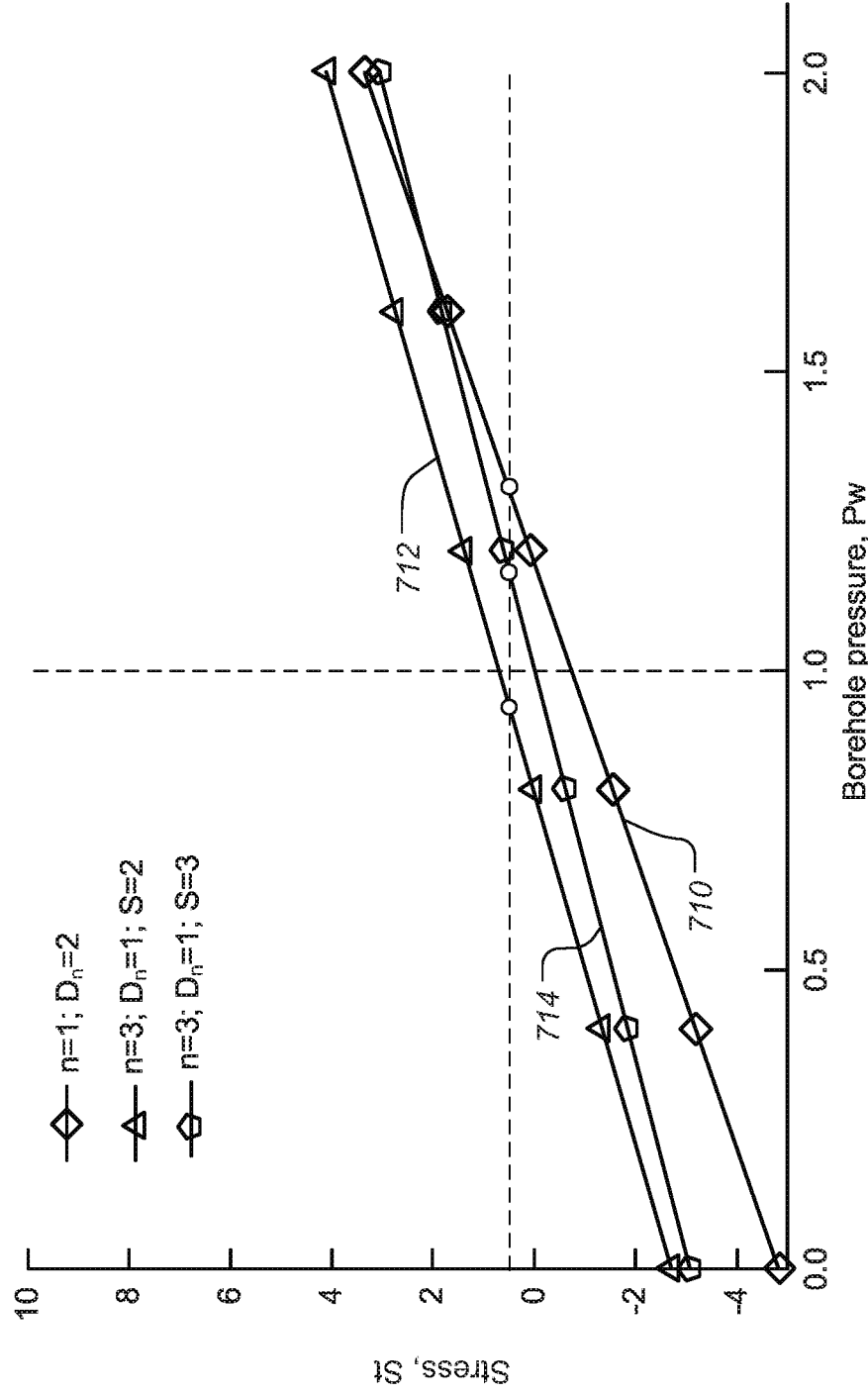


FIG. 7

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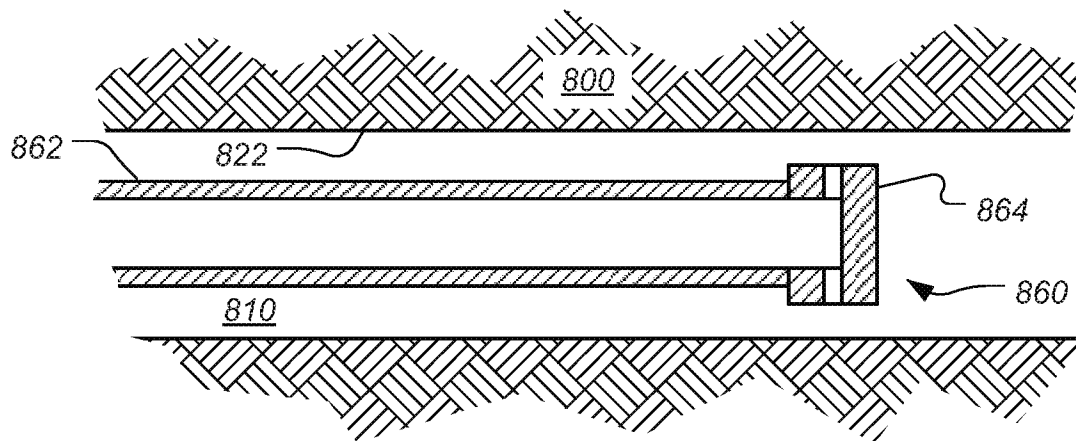


FIG. 8

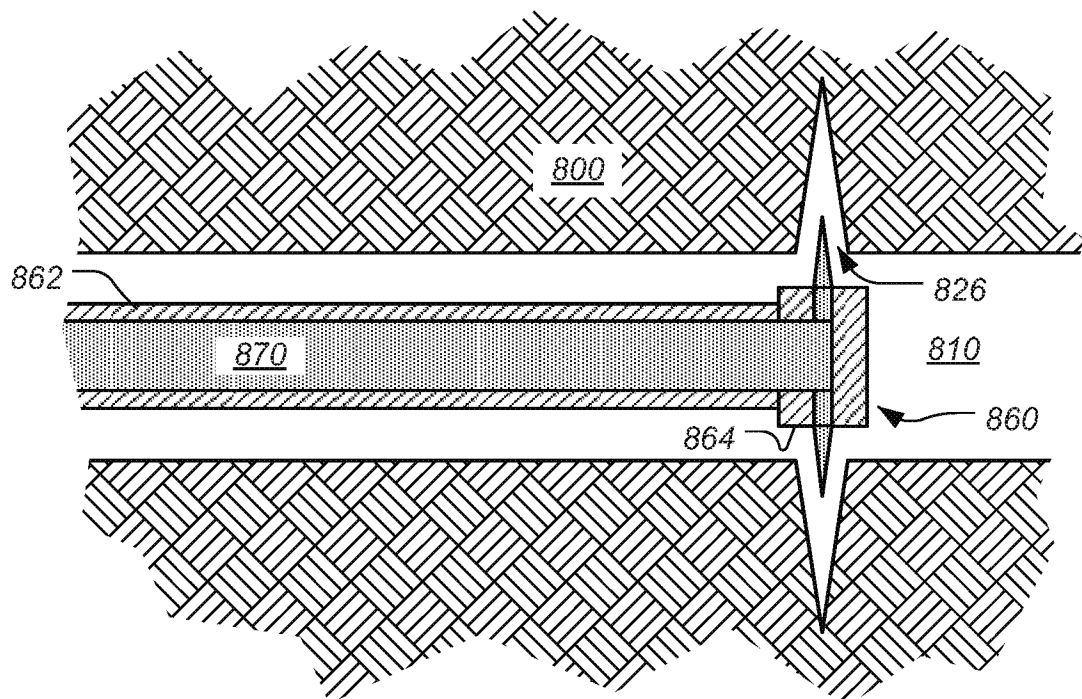


FIG. 9

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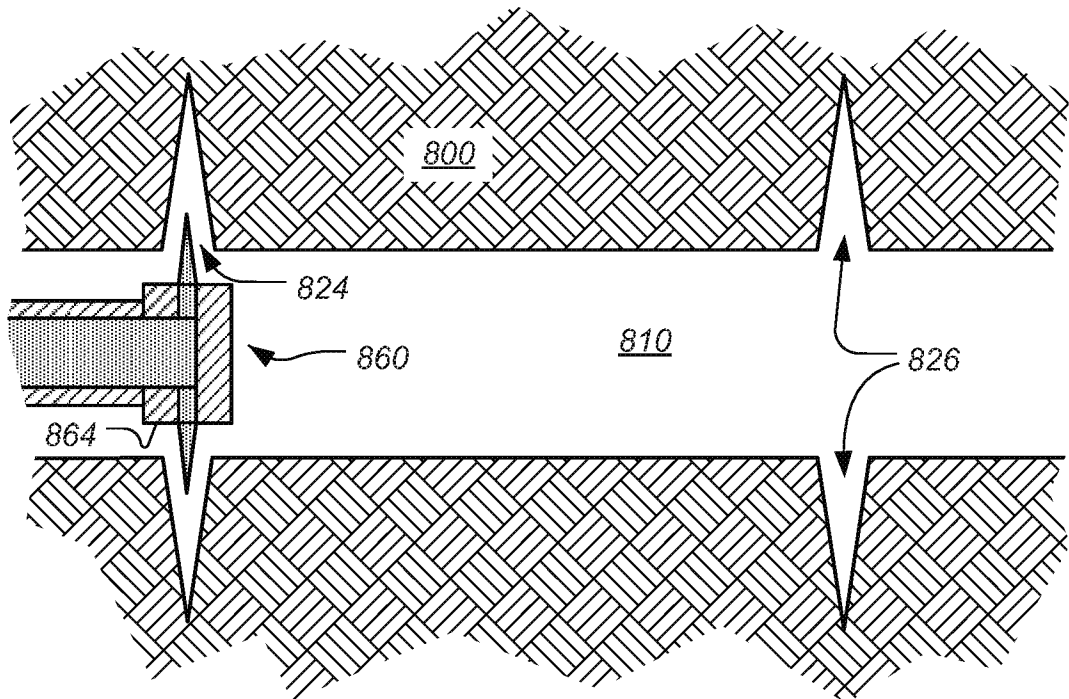


FIG. 10

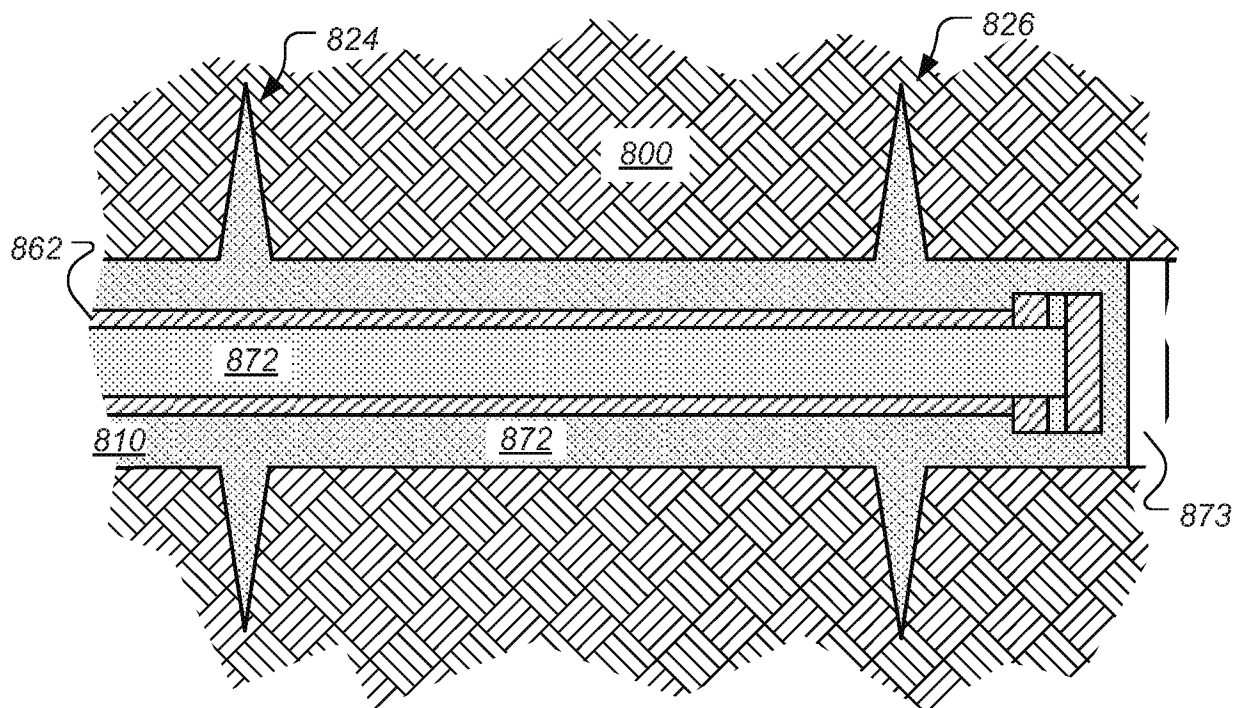


FIG. 11

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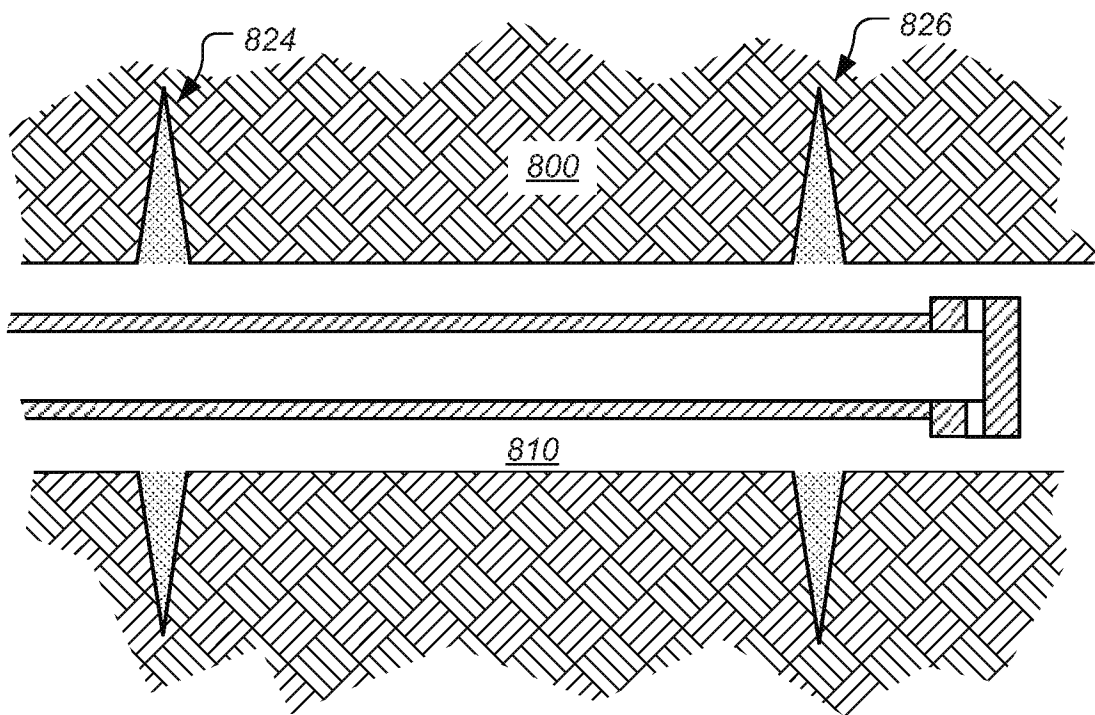


FIG. 12

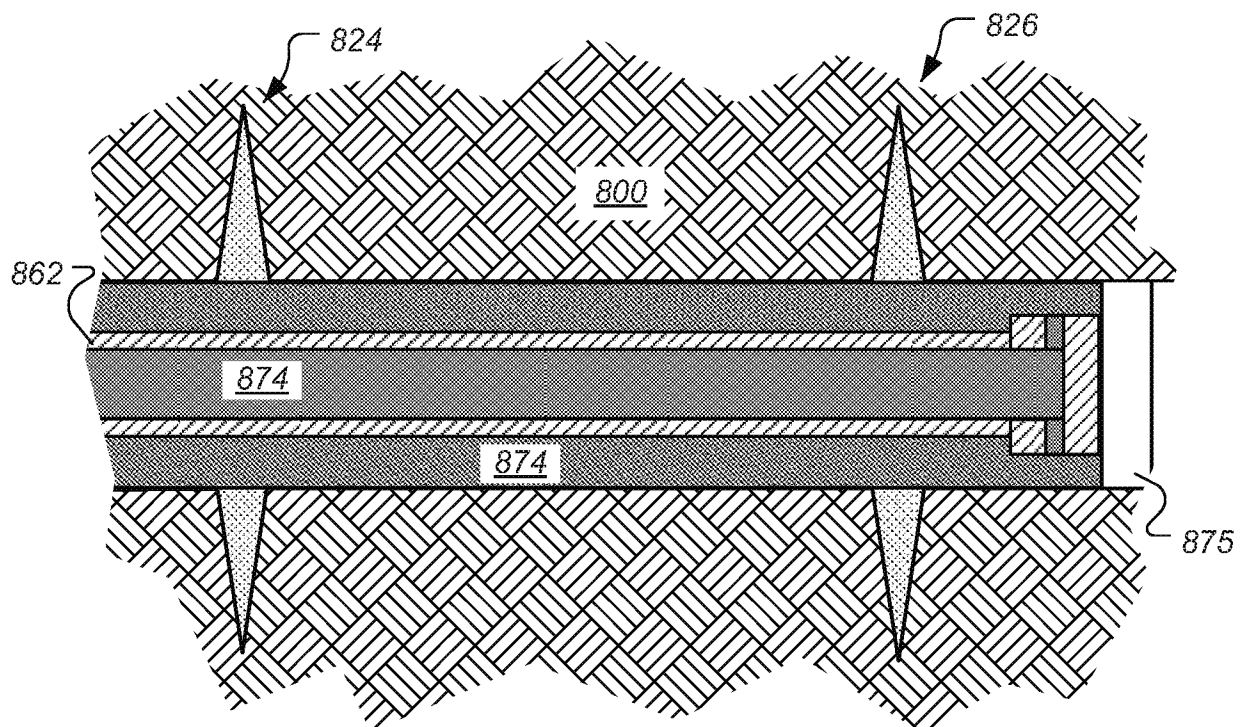


FIG. 13

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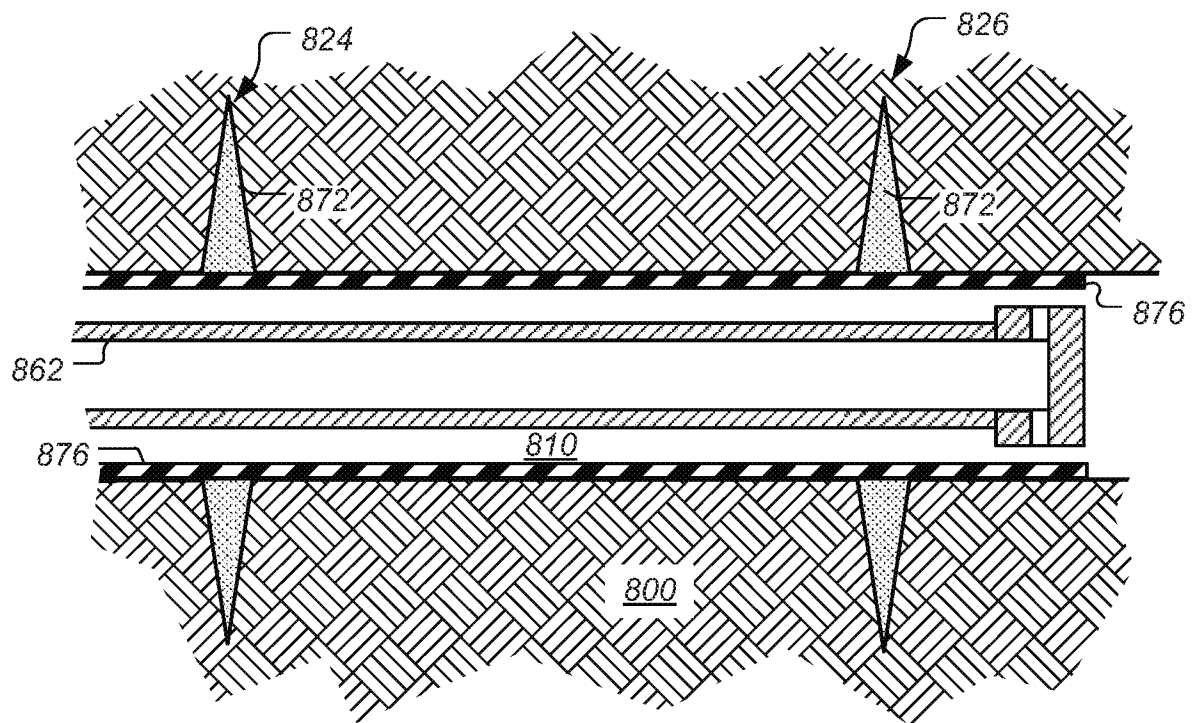


FIG. 14

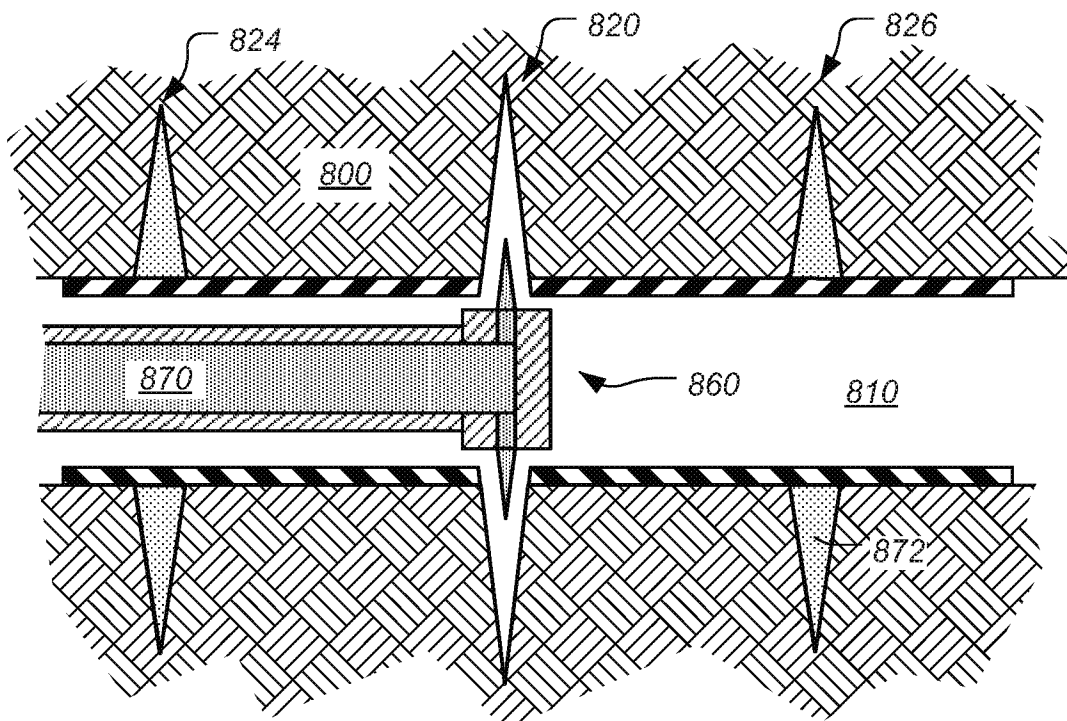


FIG. 15

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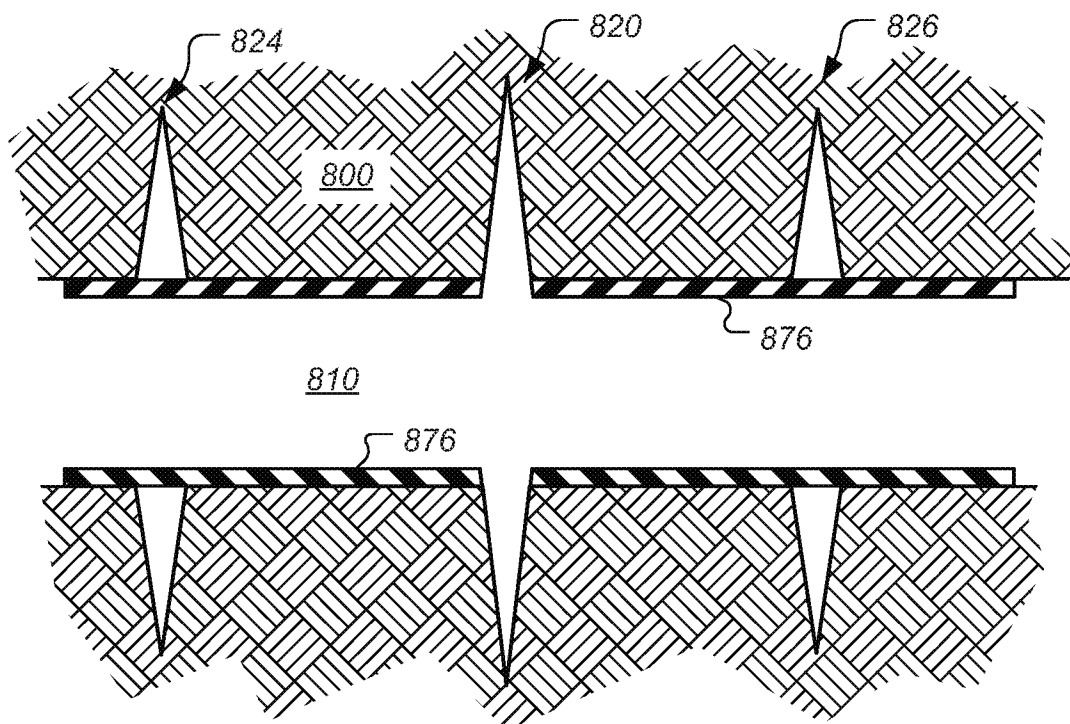


FIG. 16

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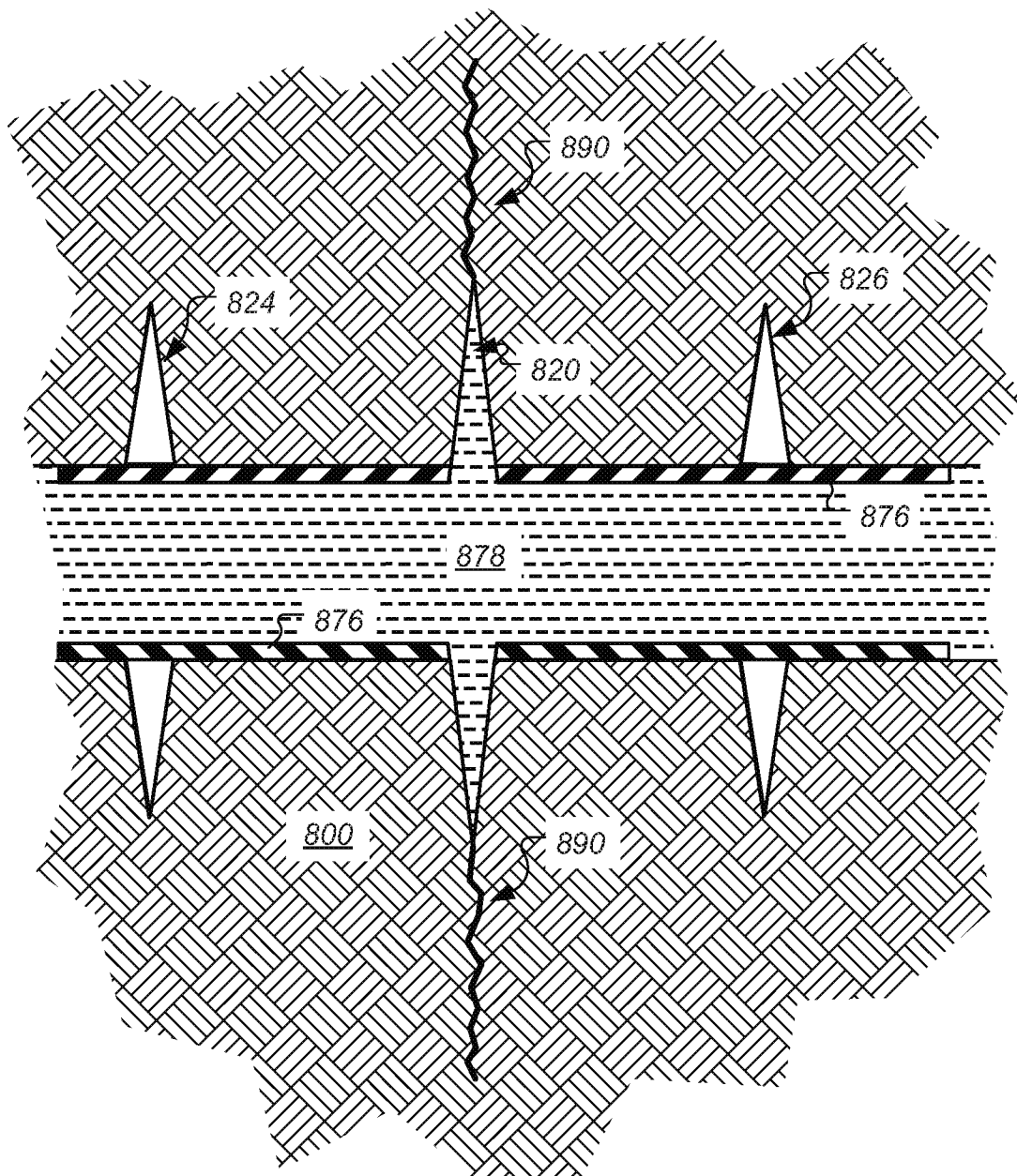


FIG. 17

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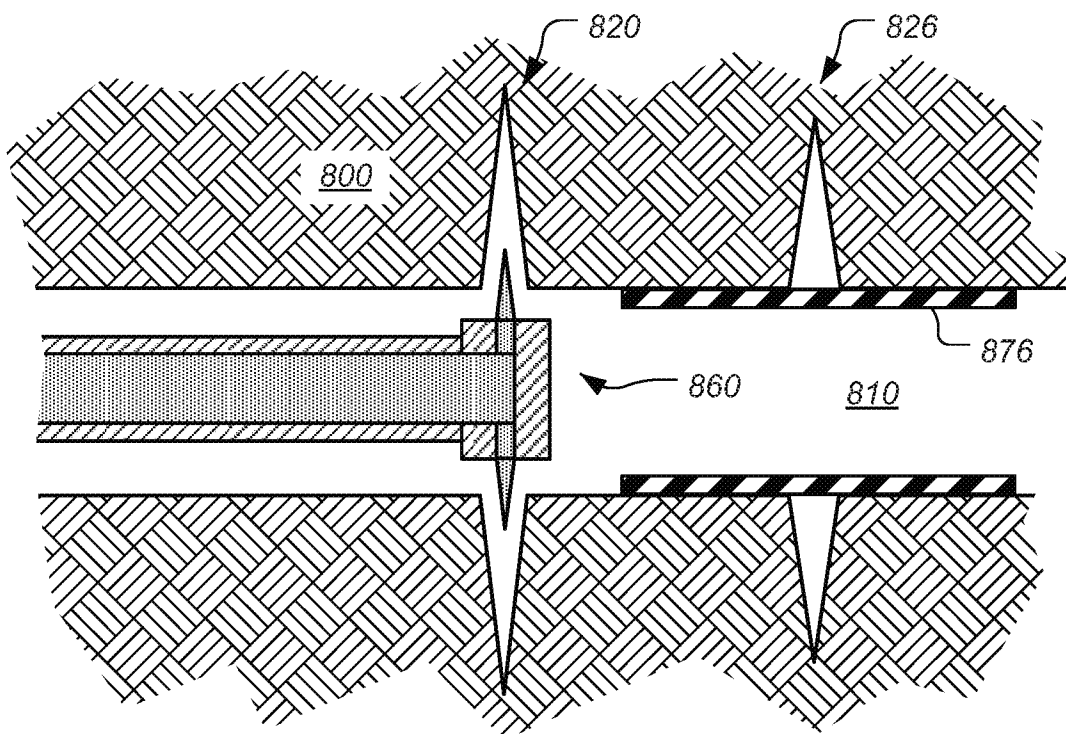


FIG. 18

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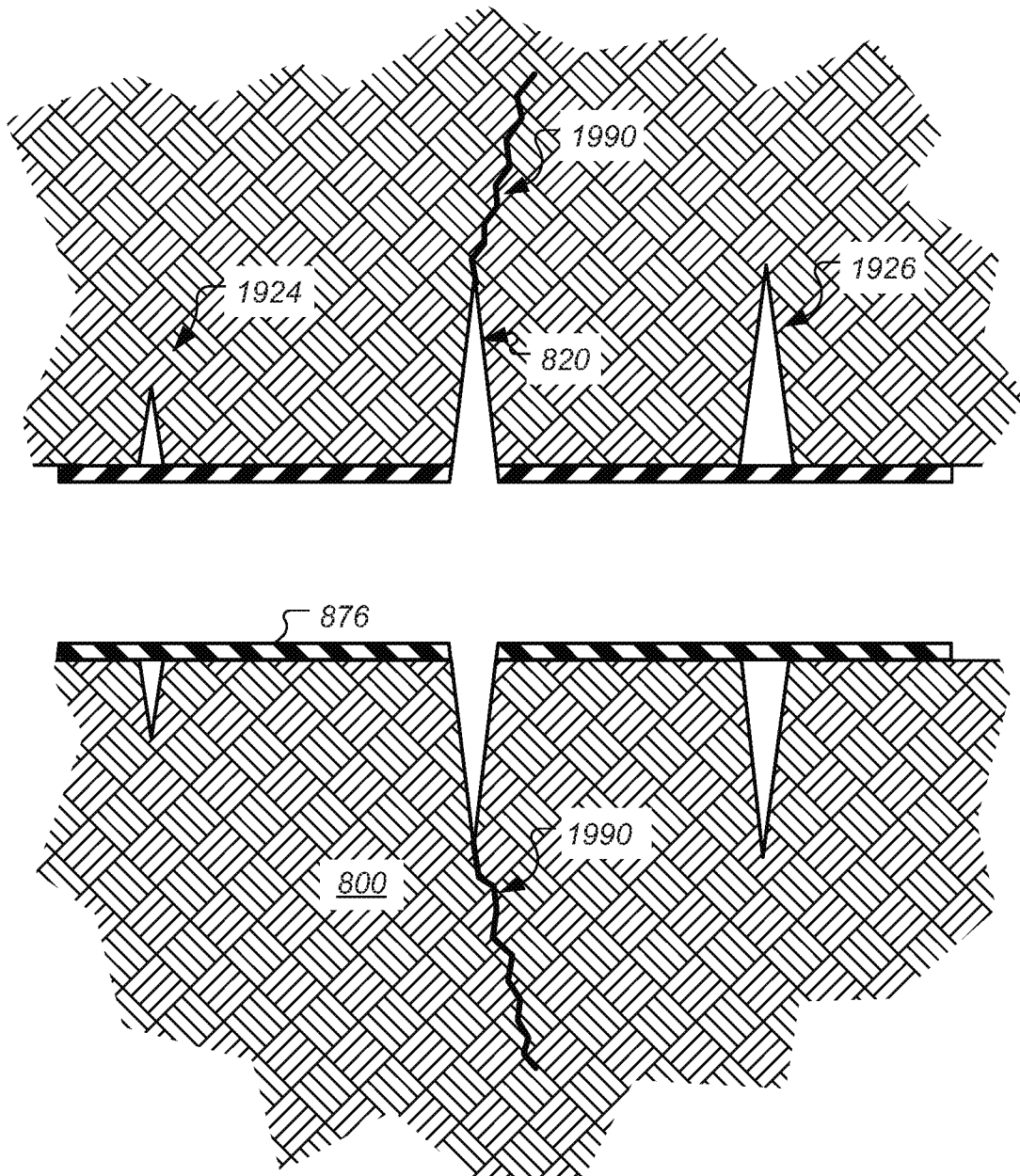


FIG. 19

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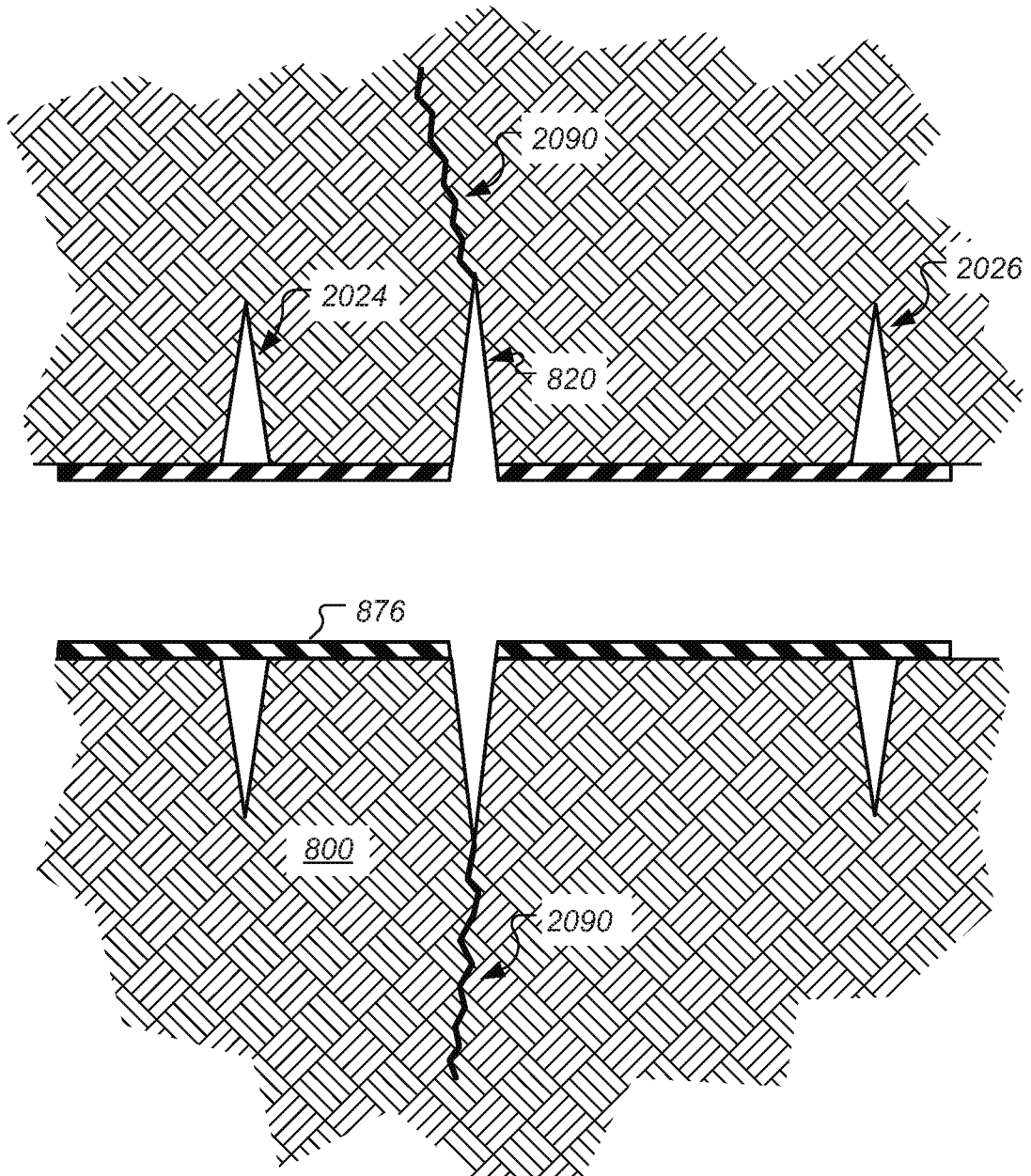


FIG. 20

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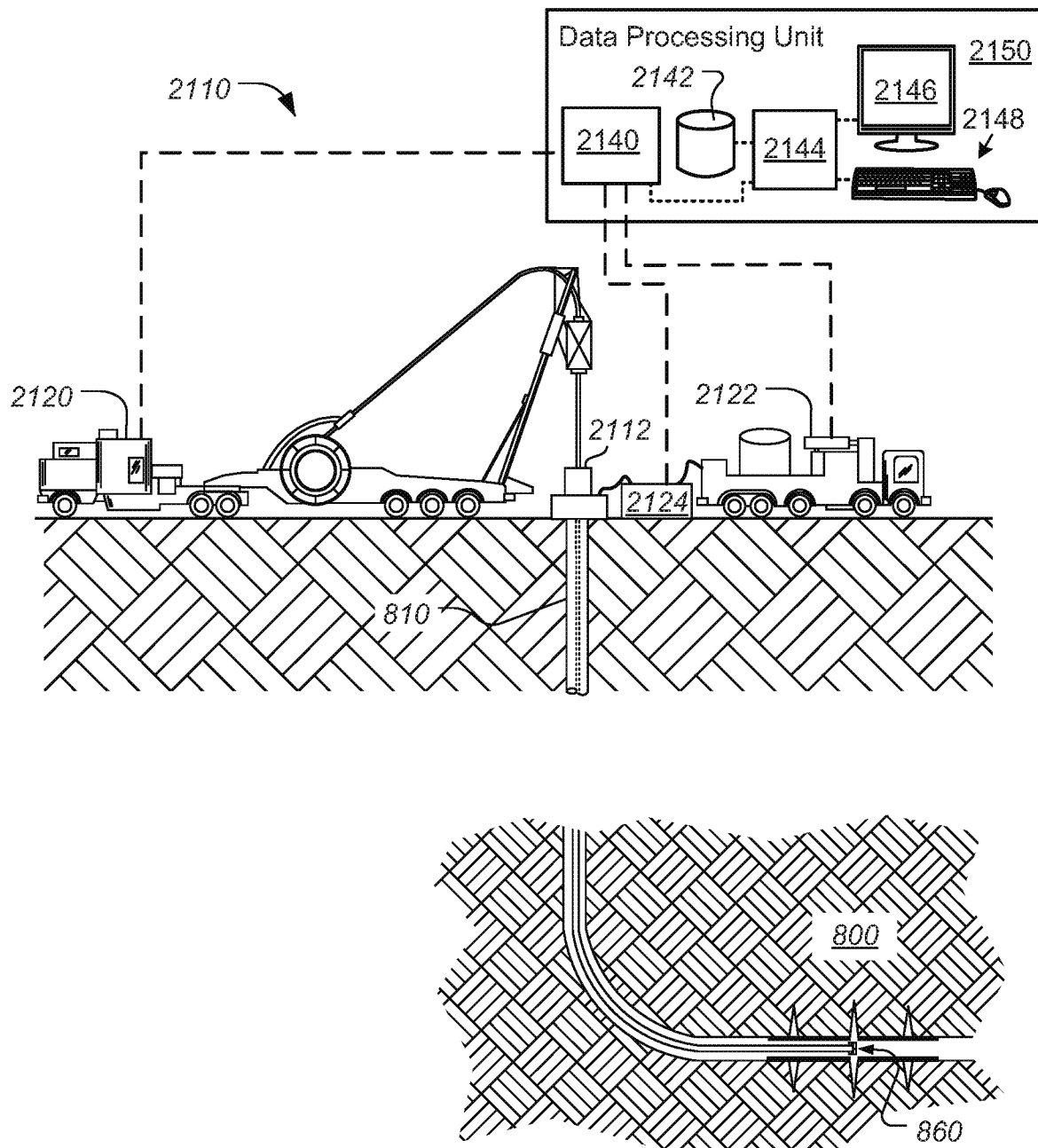


FIG. 21

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2016/013159**A. CLASSIFICATION OF SUBJECT MATTER****E21B 43/17(2006.01)i, E21B 43/26(2006.01)i, E21B 41/00(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)

E21B 43/17; E21B 47/00; E21B 49/00; E21B 43/26; E21B 34/10; E21B 41/00

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: fracturing, borehole, fracture initiation notch, auxiliary notch, protect, seal and pressure

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2014-0069653 A1 (LIU et al.) 13 March 2014 See paragraphs [0020]-[0066] and figures 1.1-8.	1-27
A	US 2011-0209868 A1 (DUSTERHOFT et al.) 01 September 2011 See paragraphs [0016]-[0060] and figures 1-5.	1-27
A	US 2009-0218094 A1 (MCLEOD et al.) 03 September 2009 See paragraphs [0022]-[0038] and figures 1-6.	1-27
A	US 2009-0151938 A1 (CONKLE et al.) 18 June 2009 See paragraphs [0013]-[0088] and figures 1-4.	1-27
A	US 5482116 A (EL-RABAA et al.) 09 January 1996 See column 3, line 60 - column 10, line 12 and figures 1-10.	1-27



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

30 March 2016 (30.03.2016)

Date of mailing of the international search report

31 March 2016 (31.03.2016)

Name and mailing address of the ISA/KR

International Application Division

Korean Intellectual Property Office

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Authorized officer

LEE, Hun Gil

Telephone No. +82-42-481-8525



INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2016/013159

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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		WO 2011-107732 A2	09/09/2011
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		EP 2235321 B1	18/04/2012
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		WO 2009-077715 A3	15/10/2009
US 5482116 A	09/01/1996	None	