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Hassig Fonseca et al.

(54) **COILED TUBING STRING MISSION PROFILE, DESIGN, AND OPTIMIZATION TOOL**

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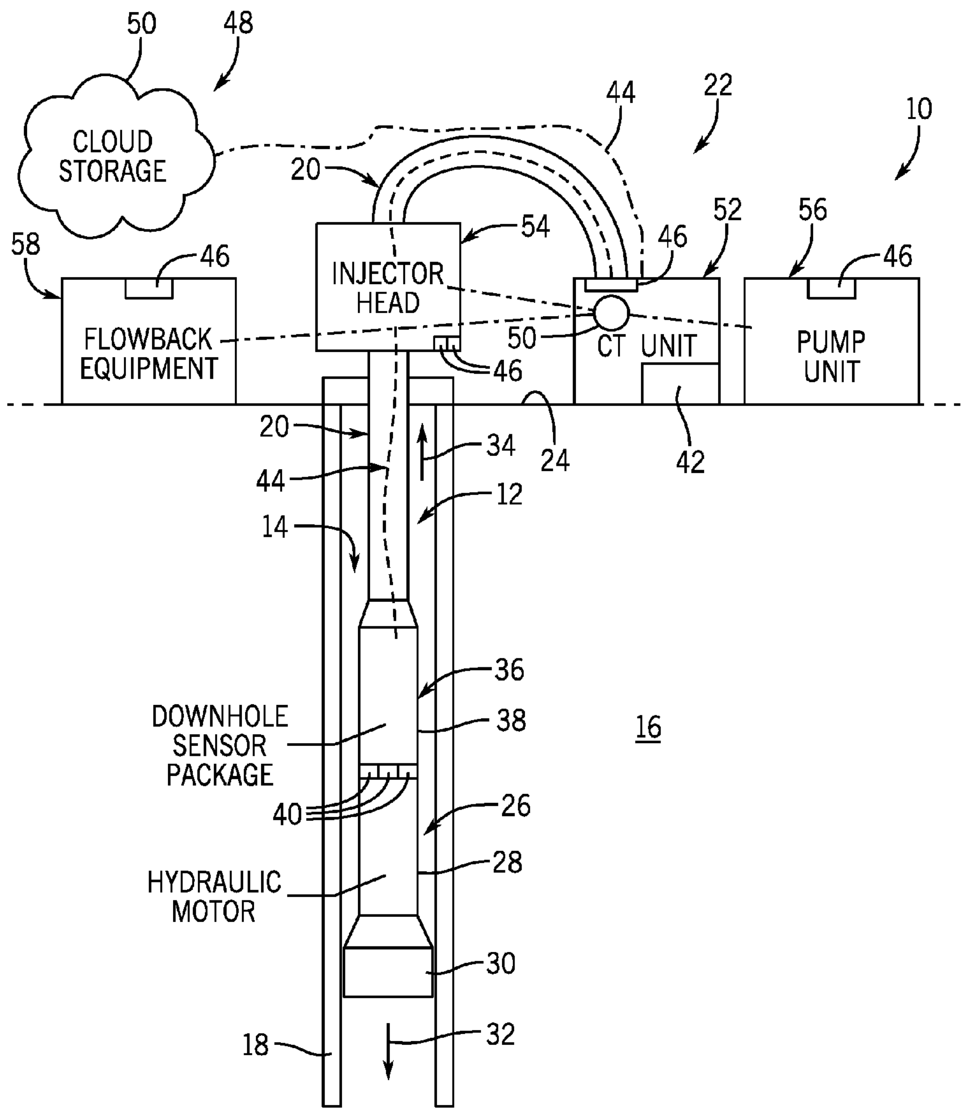
(57) **ABSTRACT**

Systems and methods presented herein are configured to optimize the design and validation of coiled tubing strings. For example, a processing workflow may include generating a mission profile for a coiled tubing (CT) string for deployment in a well based on CT analytics. The processing workflow may also include creating a CT string design for the CT string based at least in part on a plurality of operational parameters of the well. The CT string design of the CT string defines a plurality a physical characteristics of the CT string. The processing workflow may further include adjusting one or more of the plurality of physical characteristics of the CT string design of the CT string based at least in part on the generated mission profile for the CT string and a predicted life cycle of the CT string.



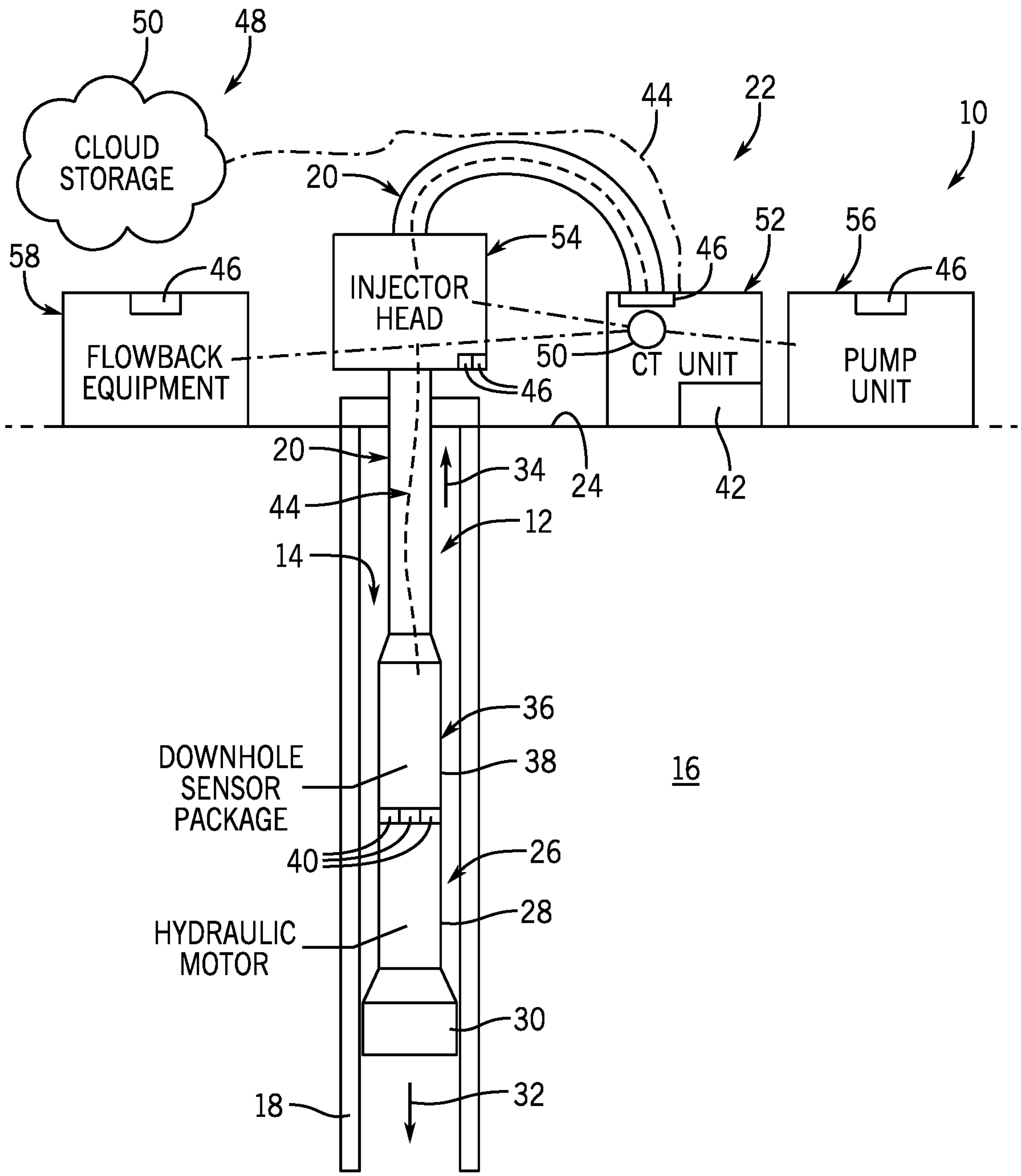

50
48
CLOUD STORAGE
44
22
10
20
54
52
56
58
46
INJECTOR HEAD
46
46
FLOWBACK EQUIPMENT
50
CT UNIT
PUMP UNIT
46
20
34
24
42
44
12
14
36
DOWNHOLE SENSOR PACKAGE
38
16
40
26
HYDRAULIC MOTOR
28
30
18
32

FIG. 1

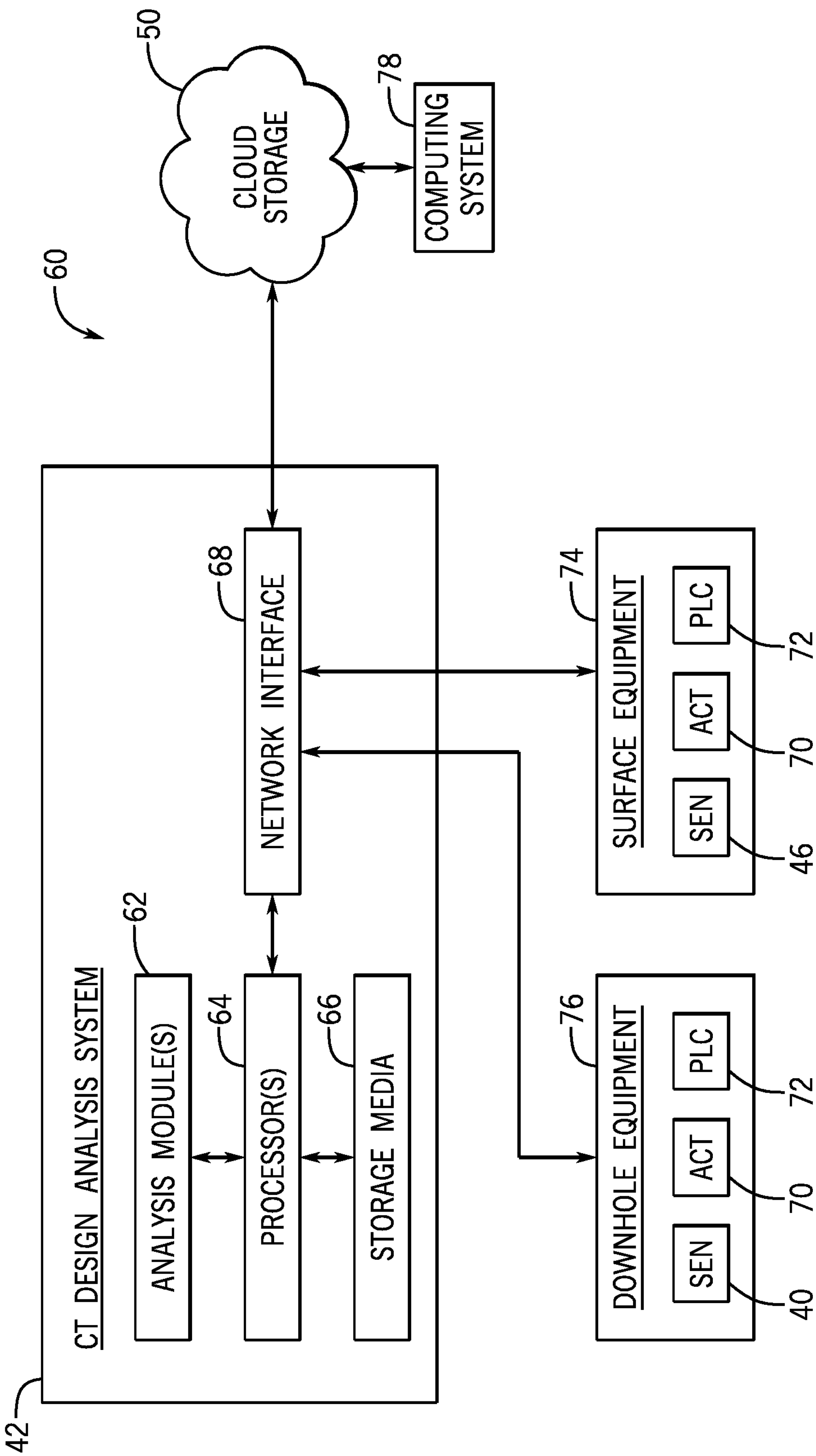

60
50
CLOUD STORAGE
78
COMPUTING SYSTEM
42
CT DESIGN ANALYSIS SYSTEM
62
ANALYSIS MODULE(S)
64
PROCESSOR(S)
66
STORAGE MEDIA
68
NETWORK INTERFACE
74
SURFACE EQUIPMENT
SEN
ACT
PLC
46
70
72
76
DOWNHOLE EQUIPMENT
SEN
ACT
PLC
40
70
72

FIG. 2

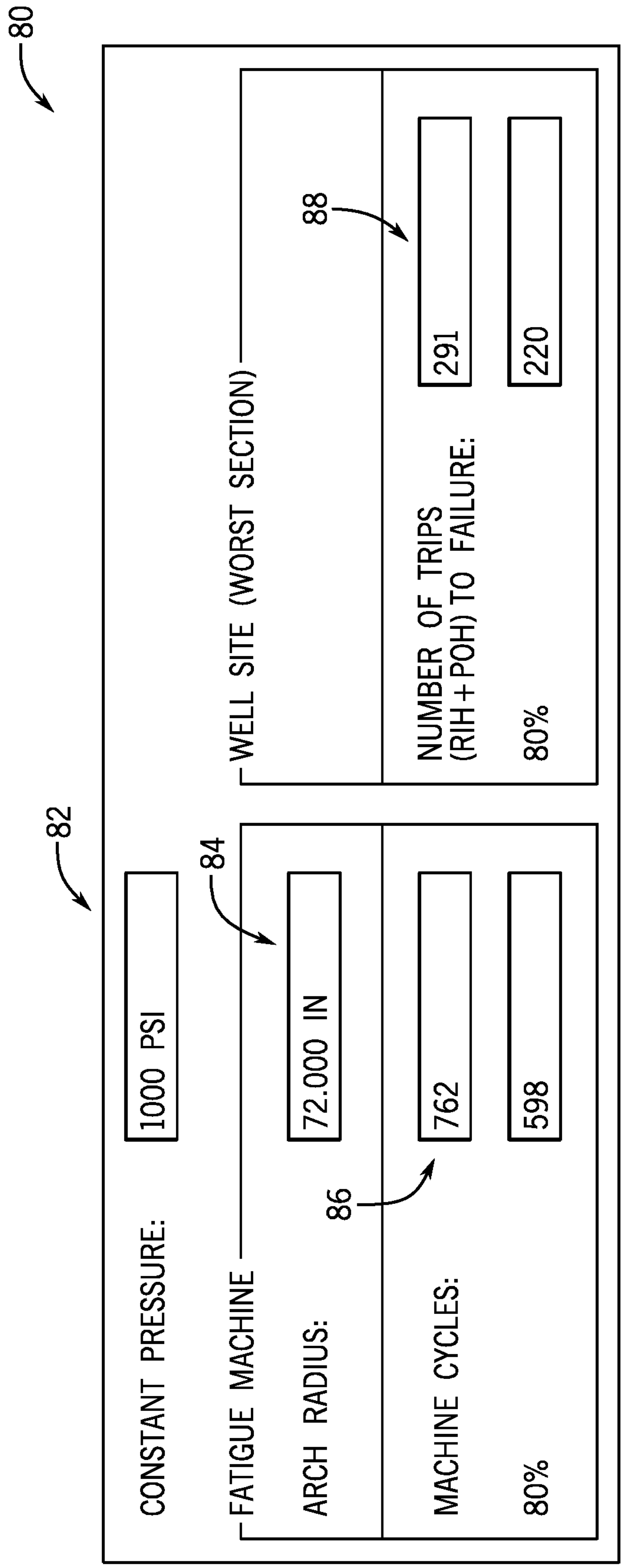

80
82
CONSTANT PRESSURE:
1000 PSI
FATIGUE MACHINE
84
ARCH RADIUS:
72.000 IN
86
MACHINE CYCLES:
762
80%
598
WELL SITE (WORST SECTION)
88
NUMBER OF TRIPS
(RIH + POH) TO FAILURE:
291
80%
220

FIG. 3

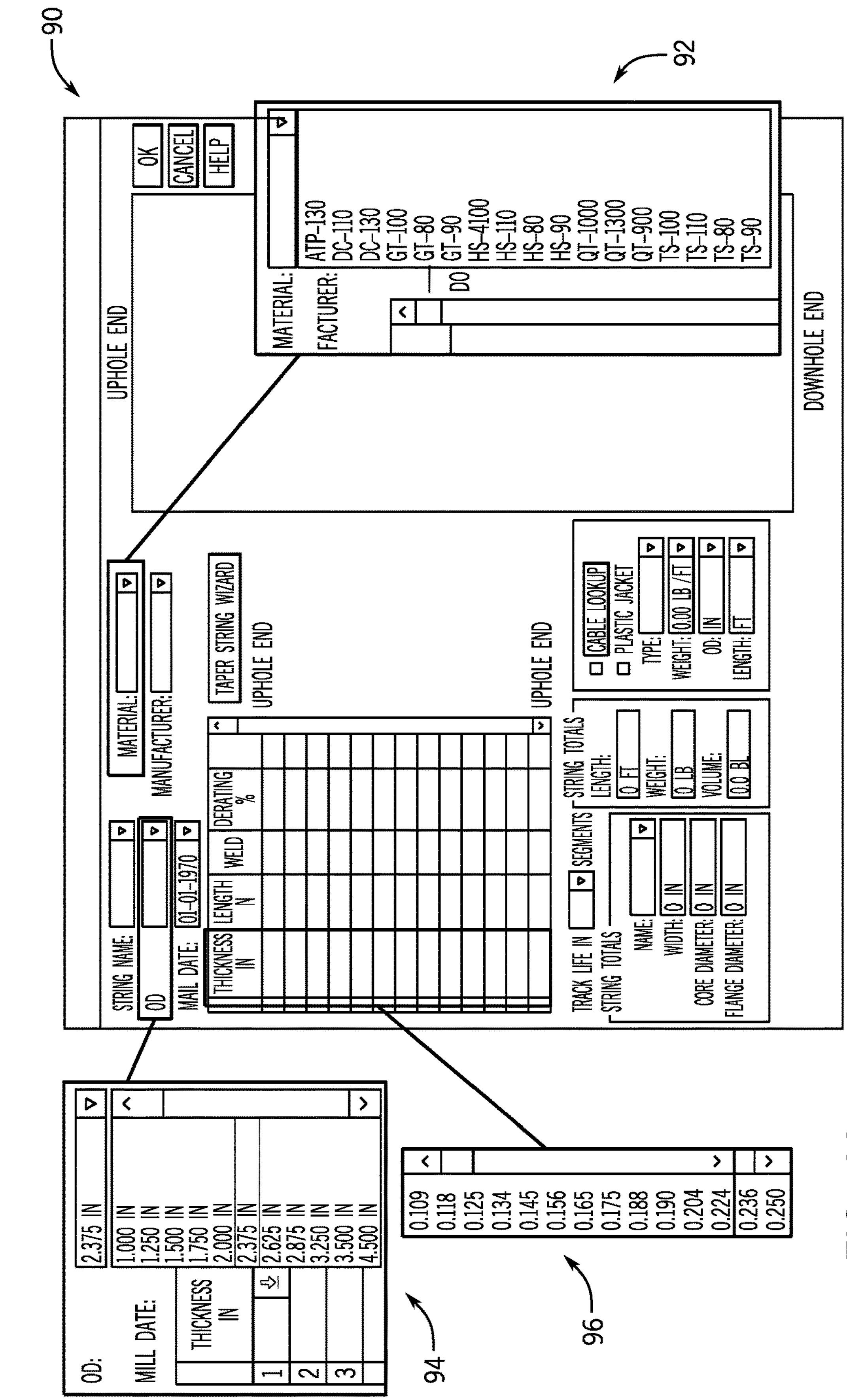

90
92
94
96
OK
CANCEL
HELP
UPHOLE END
DOWNHOLE END
MATERIAL:
FACTURER:
DO
ATP-130
DC-110
DC-130
GT-100
GT-80
GT-90
HS-4100
HS-110
HS-80
HS-90
QT-1000
QT-1300
QT-900
TS-100
TS-110
TS-80
TS-90
STRING NAME:
OD
MAIL DATE:
01-01-1970
MATERIAL:
MANUFACTURER:
TAPER STRING WIZARD
UPHOLE END
THICKNESS IN
LENGTH N
WELD
DERATING %
UPHOLE END
TRACK LIFE IN
SEGMENTS
STRING TOTALS
NAME:
WIDTH:
0 IN
CORE DIAMETER:
0 IN
FLANGE DIAMETER:
0 IN
STRING TOTALS
LENGTH:
0 FT
WEIGHT:
0 LB
VOLUME:
0.0 BL
CABLE LOOKUP
PLASTIC JACKET
TYPE:
WEIGHT:
0.00 LB/FT
OD:
IN
LENGTH:
FT
OD:
2.375 IN
MILL DATE:
THICKNESS IN
1
2
3
1.000 IN
1.250 IN
1.500 IN
1.750 IN
2.000 IN
2.375 IN
2.625 IN
2.875 IN
3.250 IN
3.500 IN
4.500 IN
0.109
0.118
0.125
0.134
0.145
0.156
0.165
0.175
0.188
0.190
0.204
0.224
0.236
0.250

FIG. 4A

98

HOLE SURVEY | WELL COMPLETEION TUBULAR | PERFORATION

TUBING / DRILL PIPE:

	MD FT	DEVIATION ANGLE DEG	AZIMUTH ANGLE DEG	TVD FT	DEVIATION BUILD RATE DEG /100FT	AZIMUTH BUID RATE DEG /100FT	DOGLEG SEVERITY DEF /100FT
1	0.0	0.0	333.7	0.0	0.0	0.0	0.0
2	98.4	0.0	333.7	98.4	0.0	0.0	0.0
3	196.9	0.0	333.7	196.9	0.0	0.0	0.0
4	295.3	0.0	333.7	295.3	0.0	0.0	0.0
5	393.7	0.0	333.7	393.7	0.0	0.0	0.0
6	492.1	0.0	333.7	492.1	0.0	0.0	0.0
7	590.6	0.0	333.7	590.6	0.0	0.0	0.0
8	689.0	0.0	333.7	689.0	0.0	0.0	0.0
9	787.4	0.0	333.7	787.4	0.0	0.0	0.0
10	885.8	2.6	301.0	885.8	2.6	-33.3	2.6
11	984.3	0.0	301.0	984.2	-2.6	0.0	2.6
12	1082.7	0.0	301.0	1082.6	0.0	0.0	0.0
13	1181.1	0.0	301.0	1181.0	0.0	0.0	0.0
14	1279.5	0.0	301.0	1279.5	0.0	0.0	0.0
15	1378.0	0.0	301.0	1377.9	0.0	0.0	0.0
16	1476.4	0.0	301.0	1476.3	0.0	0.0	0.0
17	1548.6	0.0	301.0	1548.5	0.0	0.0	0.0
18	1851.4	1.5	259.7	1851.3	0.5	-13.6	0.5
19	2027.9	0.0	259.7	2027.7	-0.8	0.0	0.8
20	2204.2	0.0	259.7	2204.1	0.0	0.0	0.0
21	2383.1	3.0	26.7	2382.9	1.7	71.0	1.7
22	2559.6	3.7	22.8	2559.2	0.4	-2.2	0.4
23	2736.1	2.6	15.3	2735.3	-0.6	-4.2	0.7
24	2871.9	4.5	34.6	2870.8	1.4	14.2	1.6

HOLE SURVEY | WELL COMPLETEION TUBULAR | PERFORATION

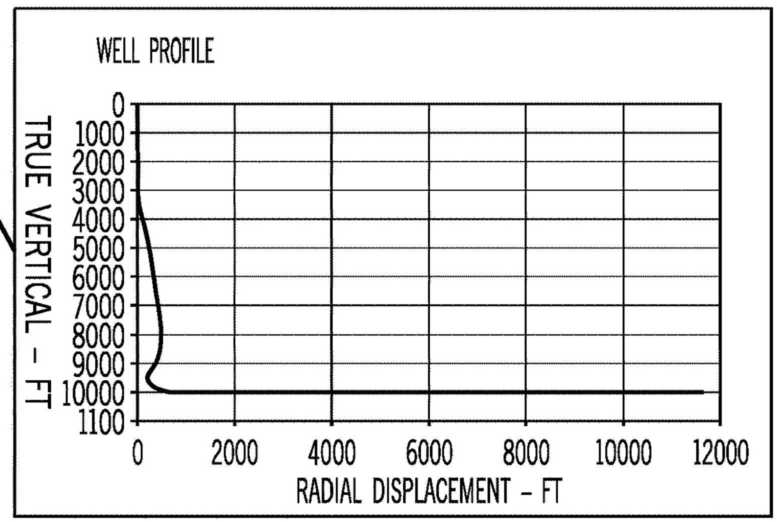
TUBING / DRILL PIPE:

	MD FT	OD IN	ID IN	WEIGHT IB / FT	GRADE	COLLAPSE PRESSURE PSI	BURST PRESSURE PSI
1	4700.0	4.500	3.500	23.5	N/A	0	0

TUBING / DRILL PIPE:

	MD FT	OD IN	ID IN	WEIGHT IB / FT	GRADE	COLLAPSE PRESSURE PSI	BURST PRESSURE PSI
1	21456.7	5.500	4.7500	24.4	P110	16490	15710

102



100

FIG. 4B

104

COILED TUBING | BHA INPUT |

COILED TUBING

	OD IN	THICKNESS IN	ID IN	SECTION LENGTH FT	WEIGHT LB / FT	SECTINO WEIGHT LB	SECTION VOLUME BBL
1	2.375	0.175	2.025	5713.2	4.115	23512	22.8
2	2.375	0.178	2.019	149.0	4.178	623	0.6
3	2.375	0.184	2.008	149.0	4.303	641	0.6
4	2.375	0.190	1.996	149.0	4.427	660	0.6
5	2.375	0.195	1.984	149.0	4.550	678	0.6
6	2.375	0.201	1.973	149.0	4.673	696	0.6
7	2.375	0.212	1.952	136.7	4.895	669	0.5
8	2.375	0.227	1.921	136.7	5.212	712	0.5
9	2.375	0.242	1.890	136.7	5.525	755	0.5
10	2.375	0.250	1.875	8160.0	5.679	46339	27.9
11	2.375	0.248	1.879	133.8	5.644	755	0.5
12	2.375	0.245	1.885	133.8	5.573	745	0.5
13	2.375	0.241	1.892	133.8	5.503	736	0.5
14	2.375	0.238	1.900	133.8	5.432	726	0.5
15	2.375	0.235	1.906	142.5	5.366	765	0.5
16	2.375	0.232	1.912	142.5	5.304	756	0.5
17	2.375	0.228	1.918	142.5	5.243	747	0.5

STRING NAME: 11638_alt

CABLE LOOKUP

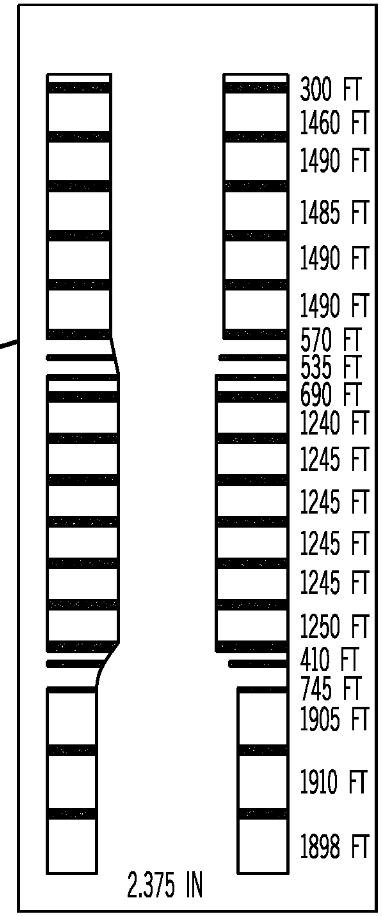
NOTE: SECTION 1 REPRESENTS THE TOOL END OF THE COILED TUBING

CT TOTAL LENGTH 23848.2 FT
CT TOTAL VOLUME 86.7 BBL
YOUNG'S MODULUS 3.000E+07 PSI
CABLE DIAMETER 0.000 IN

CT TOTAL WEIGHT 23848.2 FT
DT DENSITY 86.7 BBL
YIELD STRENGHT 3.000E+07 PSI
CABLE WEIGHT 0.000 IN

CT MATERIAL DC-130

CABLE LOOKUP



106

FIG. 4C

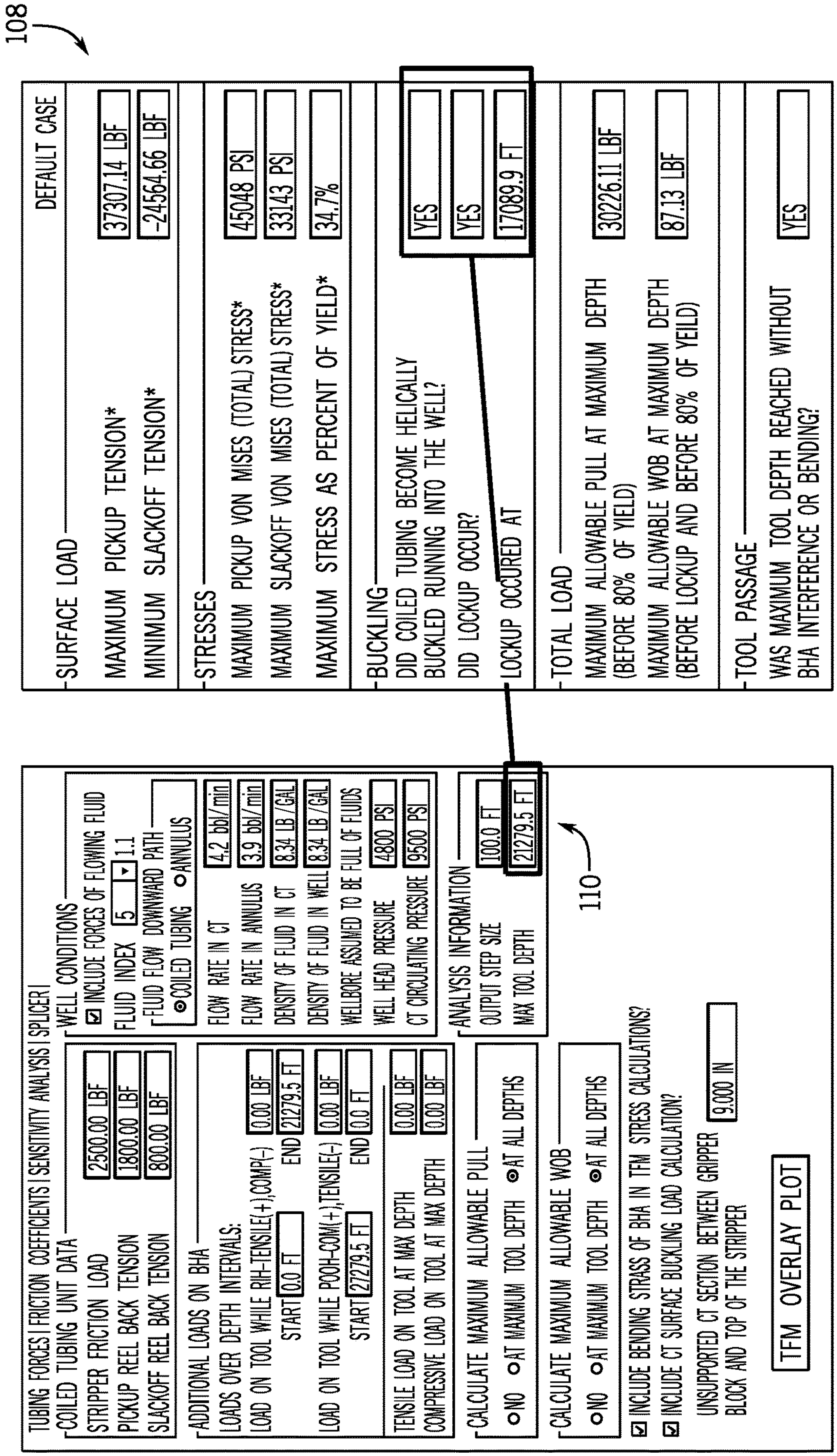

108
TUBING FORCES | FRICTION COEFFICIENTS | SENSITIVITY ANALYSIS | SPLICER |
COILED TUBING UNIT DATA
STRIPPER FRICTION LOAD
2500.00 LBF
PICKUP REEL BACK TENSION
1800.00 LBF
SLACKOFF REEL BACK TENSION
800.00 LBF
ADDITIONAL LOADS ON BHA
LOADS OVER DEPTH INTERVALS:
LOAD ON TOOL WHILE RIH-TENSILE(+),COMP(-)
0.00 LBF
START
0.0 FT
END
21279.5 FT
LOAD ON TOOL WHILE POOH-COM(+),TENSILE(-)
0.00 LBF
START
21279.5 FT
END
0.0 FT
TENSILE LOAD ON TOOL AT MAX DEPTH
0.00 LBF
COMPRESSIVE LOAD ON TOOL AT MAX DEPTH
0.00 LBF
CALCULATE MAXIMUM ALLOWABLE PULL
NO
AT MAXIMUM TOOL DEPTH
AT ALL DEPTHS
CALCULATE MAXIMUM ALLOWABLE WOB
NO
AT MAXIMUM TOOL DEPTH
AT ALL DEPTHS
INCLUDE BENDING STRASS OF BHA IN TFM STRESS CALCULATIONS?
INCLUDE CT SURFACE BUCKLING LOAD CALCULATION?
UNSUPPORTED CT SECTION BETWEEN GRIPPER BLOCK AND TOP OF THE STRIPPER
9.000 IN
TFM OVERLAY PLOT
WELL CONDITIONS
INCLUDE FORCES OF FLOWING FLUID
FLUID INDEX
5
1.1
FLUID FLOW DOWNWARD PATH
COILED TUBING
ANNULUS
FLOW RATE IN CT
4.2 bbl/min
FLOW RATE IN ANNULUS
3.9 bbl/min
DENSITY OF FLUID IN CT
8.34 LB/GAL
DENSITY OF FLUID IN WELL
8.34 LB/GAL
WELLBORE ASSUMED TO BE FULL OF FLUIDS
WELL HEAD PRESSURE
4800 PSI
CT CIRCULATING PRESSURE
9500 PSI
ANALYSIS INFORMATION
OUTPUT STEP SIZE
100.0 FT
MAX TOOL DEPTH
21279.5 FT
110
DEFAULT CASE
SURFACE LOAD
MAXIMUM PICKUP TENSION*
37307.14 LBF
MINIMUM SLACKOFF TENSION*
-24564.66 LBF
STRESSES
MAXIMUM PICKUP VON MISES (TOTAL) STRESS*
45048 PSI
MAXIMUM SLACKOFF VON MISES (TOTAL) STRESS*
33143 PSI
MAXIMUM STRESS AS PERCENT OF YIELD*
34.7%
BUCKLING
DID COILED TUBING BECOME HELICALLY BUCKLED RUNNING INTO THE WELL?
YES
DID LOCKUP OCCUR?
YES
LOCKUP OCCURED AT
17089.9 FT
TOTAL LOAD
MAXIMUM ALLOWABLE PULL AT MAXIMUM DEPTH (BEFORE 80% OF YIELD)
30226.11 LBF
MAXIMUM ALLOWABLE WOB AT MAXIMUM DEPTH (BEFORE LOCKUP AND BEFORE 80% OF YEILD)
87.13 LBF
TOOL PASSAGE
WAS MAXIMUM TOOL DEPTH REACHED WITHOUT BHA INTERFERENCE OR BENDING?
YES

FIG. 4D

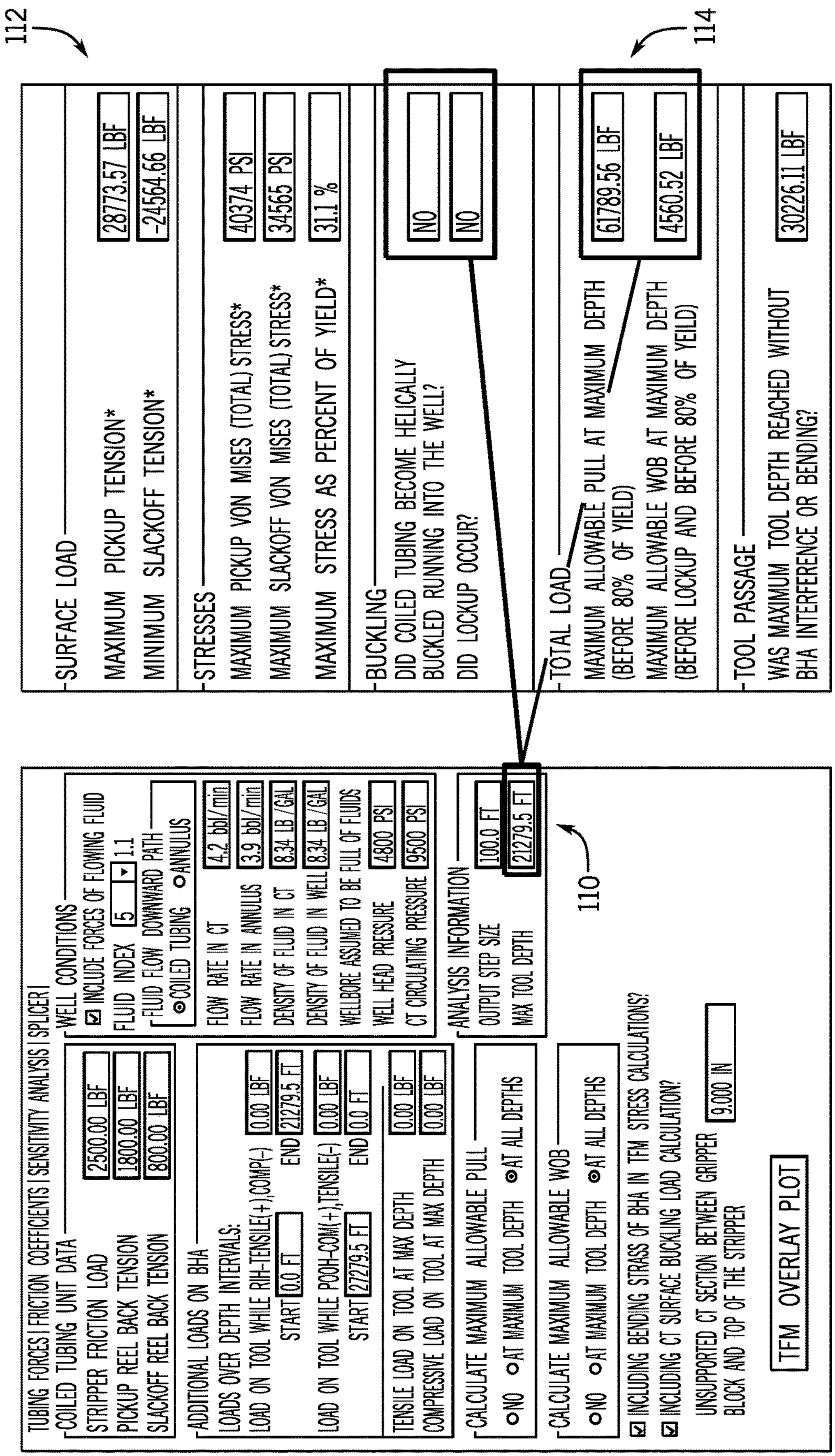

TUBING FORCES | FRICTION COEFFICIENTS | SENSITIVITY ANALYSIS | SPLICER |
COILED TUBING UNIT DATA
STRIPPER FRICTION LOAD 2500.00 LBF
PICKUP REEL BACK TENSION 1800.00 LBF
SLACKOFF REEL BACK TENSION 800.00 LBF
ADDITIONAL LOADS ON BHA
LOADS OVER DEPTH INTERVALS:
LOAD ON TOOL WHILE RIH-TENSILE(+),COMP(-) 0.00 LBF
START 0.0 FT END 21279.5 FT
LOAD ON TOOL WHILE POOH-COM(+),TENSILE(-) 0.00 LBF
START 27279.5 FT END 0.0 FT
TENSILE LOAD ON TOOL AT MAX DEPTH 0.00 LBF
COMPRESSIVE LOAD ON TOOL AT MAX DEPTH 0.00 LBF
CALCULATE MAXIMUM ALLOWABLE PULL
NO AT MAXIMUM TOOL DEPTH AT ALL DEPTHS
CALCULATE MAXIMUM ALLOWABLE WOB
NO AT MAXIMUM TOOL DEPTH AT ALL DEPTHS
INCLUDING BENDING STRASS OF BHA IN TFM STRESS CALCULATIONS?
INCLUDING CT SURFACE BUCKLING LOAD CALCULATION?
UNSUPPORTED CT SECTION BETWEEN GRIPPER BLOCK AND TOP OF THE STRIPPER 9.000 IN
TFM OVERLAY PLOT
WELL CONDITIONS
INCLUDE FORCES OF FLOWING FLUID
FLUID INDEX 5 1.1
FLUID FLOW DOWNWARD PATH
COILED TUBING ANNULUS
FLOW RATE IN CT 4.2 bbl/min
FLOW RATE IN ANNULUS 3.9 bbl/min
DENSITY OF FLUID IN CT 8.34 LB/GAL
DENSITY OF FLUID IN WELL 8.34 LB/GAL
WELLBORE ASSUMED TO BE FULL OF FLUIDS
WELL HEAD PRESSURE 4800 PSI
CT CIRCULATING PRESSURE 9500 PSI
ANALYSIS INFORMATION
OUTPUT STEP SIZE 100.0 FT
MAX TOOL DEPTH 21279.5 FT
110
112
SURFACE LOAD
MAXIMUM PICKUP TENSION* 28773.57 LBF
MINIMUM SLACKOFF TENSION* -24564.66 LBF
STRESSES
MAXIMUM PICKUP VON MISES (TOTAL) STRESS* 40374 PSI
MAXIMUM SLACKOFF VON MISES (TOTAL) STRESS* 34565 PSI
MAXIMUM STRESS AS PERCENT OF YIELD* 31.1 %
BUCKLING
DID COILED TUBING BECOME HELICALLY BUCKLED RUNNING INTO THE WELL? NO
DID LOCKUP OCCUR? NO
TOTAL LOAD
MAXIMUM ALLOWABLE PULL AT MAXIMUM DEPTH (BEFORE 80% OF YIELD) 61789.56 LBF
MAXIMUM ALLOWABLE WOB AT MAXIMUM DEPTH (BEFORE LOCKUP AND BEFORE 80% OF YEILD) 4560.52 LBF
TOOL PASSAGE
WAS MAXIMUM TOOL DEPTH REACHED WITHOUT BHA INTERFERENCE OR BENDING? 30226.11 LBF
114

FIG. 4E

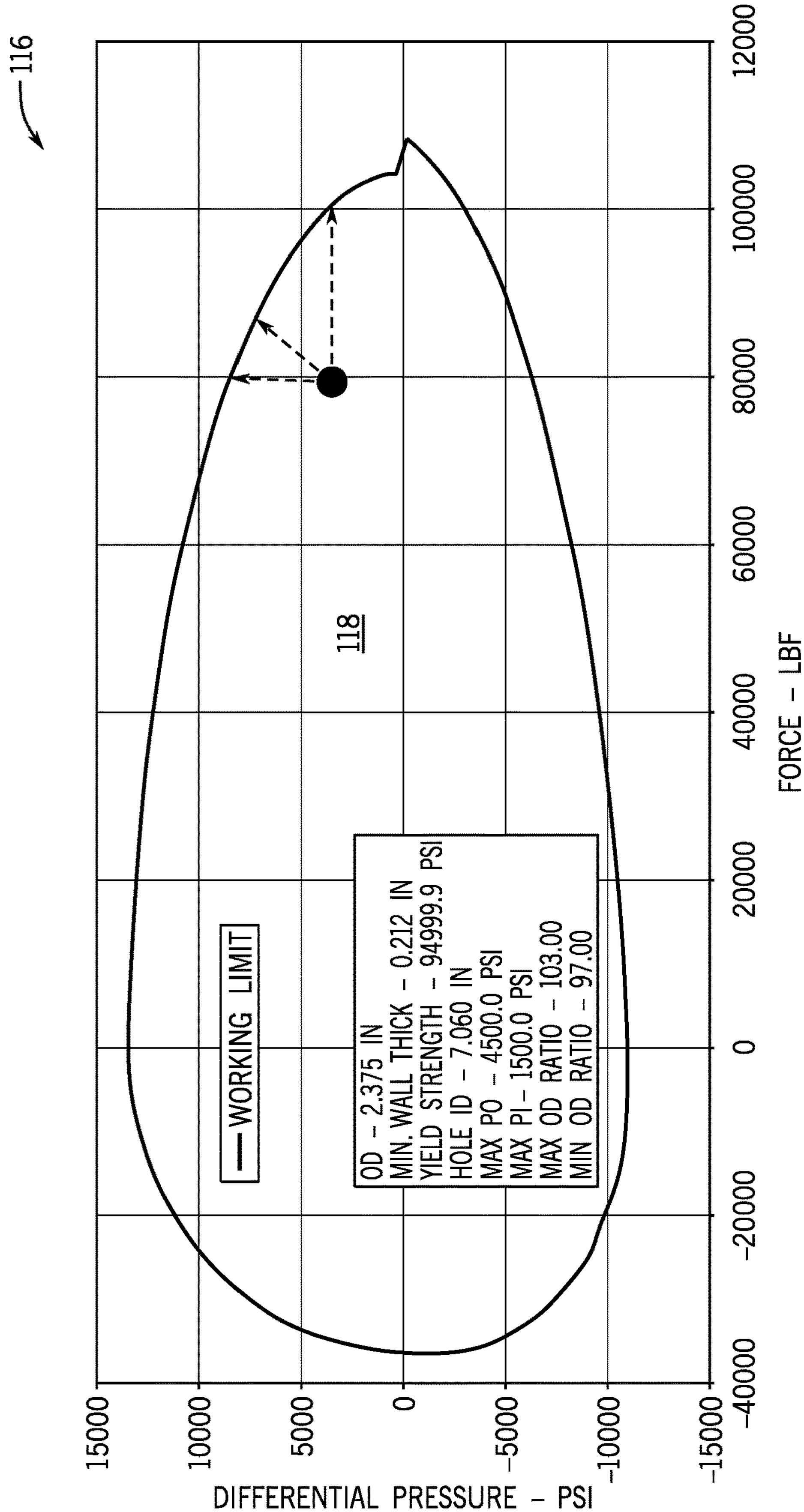

116
118
WORKING LIMIT
OD – 2.375 IN
MIN. WALL THICK – 0.212 IN
YIELD STRENGTH – 94999.9 PSI
HOLE ID – 7.060 IN
MAX PO – 4500.0 PSI
MAX PI – 1500.0 PSI
MAX OD RATIO – 103.00
MIN OD RATIO – 97.00
DIFFERENTIAL PRESSURE – PSI
15000
10000
5000
0
–5000
–10000
–15000
FORCE – LBF
–40000
–20000
0
20000
40000
60000
80000
100000
120000

FIG. 4F

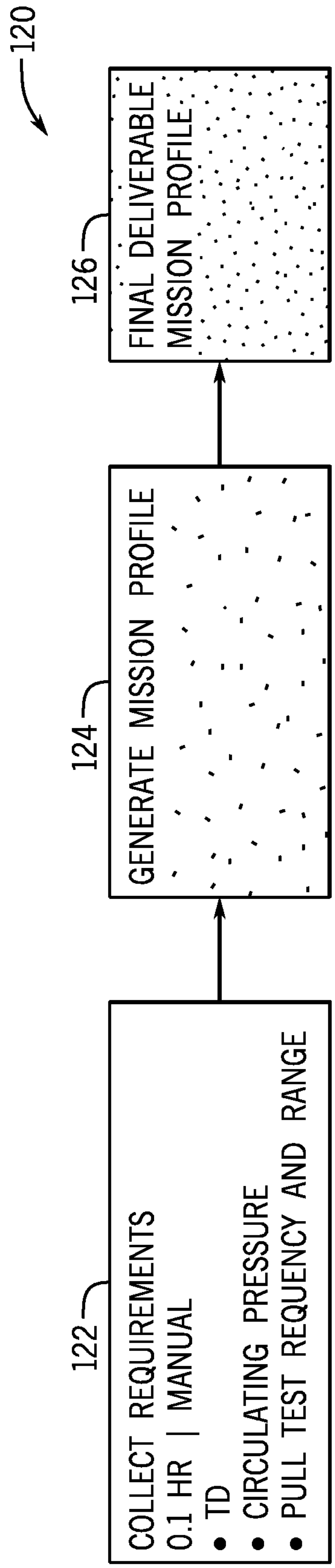

120
122
COLLECT REQUIREMENTS
0.1 HR | MANUAL
• TD
• CIRCULATING PRESSURE
• PULL TEST REQUENCY AND RANGE
124
GENERATE MISSION PROFILE
126
FINAL DELIVERABLE
MISSION PROFILE

FIG. 5

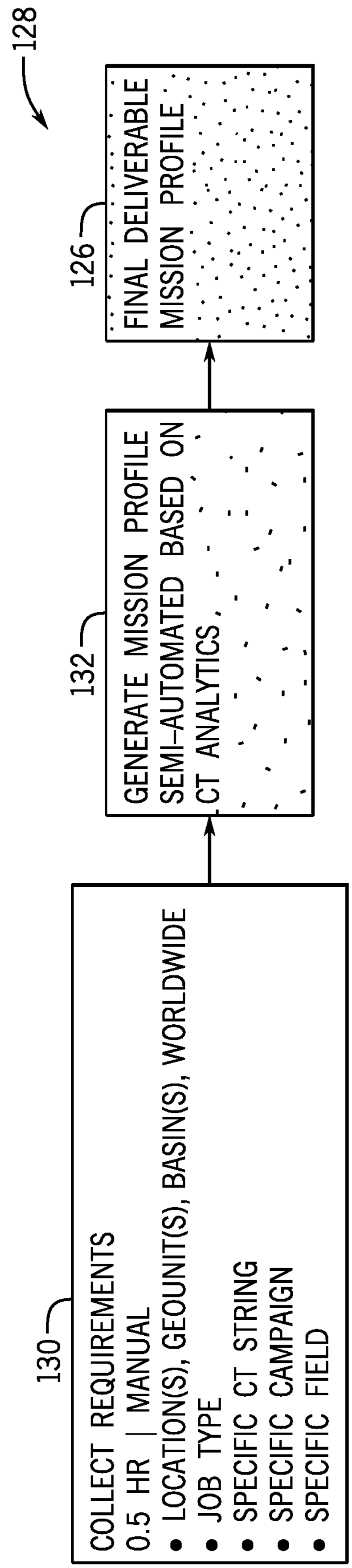

128
130
COLLECT REQUIREMENTS
0.5 HR | MANUAL
• LOCATION(S), GEOUNIT(S), BASIN(S), WORLDWIDE
• JOB TYPE
• SPECIFIC CT STRING
• SPECIFIC CAMPAIGN
• SPECIFIC FIELD
132
GENERATE MISSION PROFILE
SEMI-AUTOMATED BASED ON
CT ANALYTICS
126
FINAL DELIVERABLE
MISSION PROFILE

FIG. 6

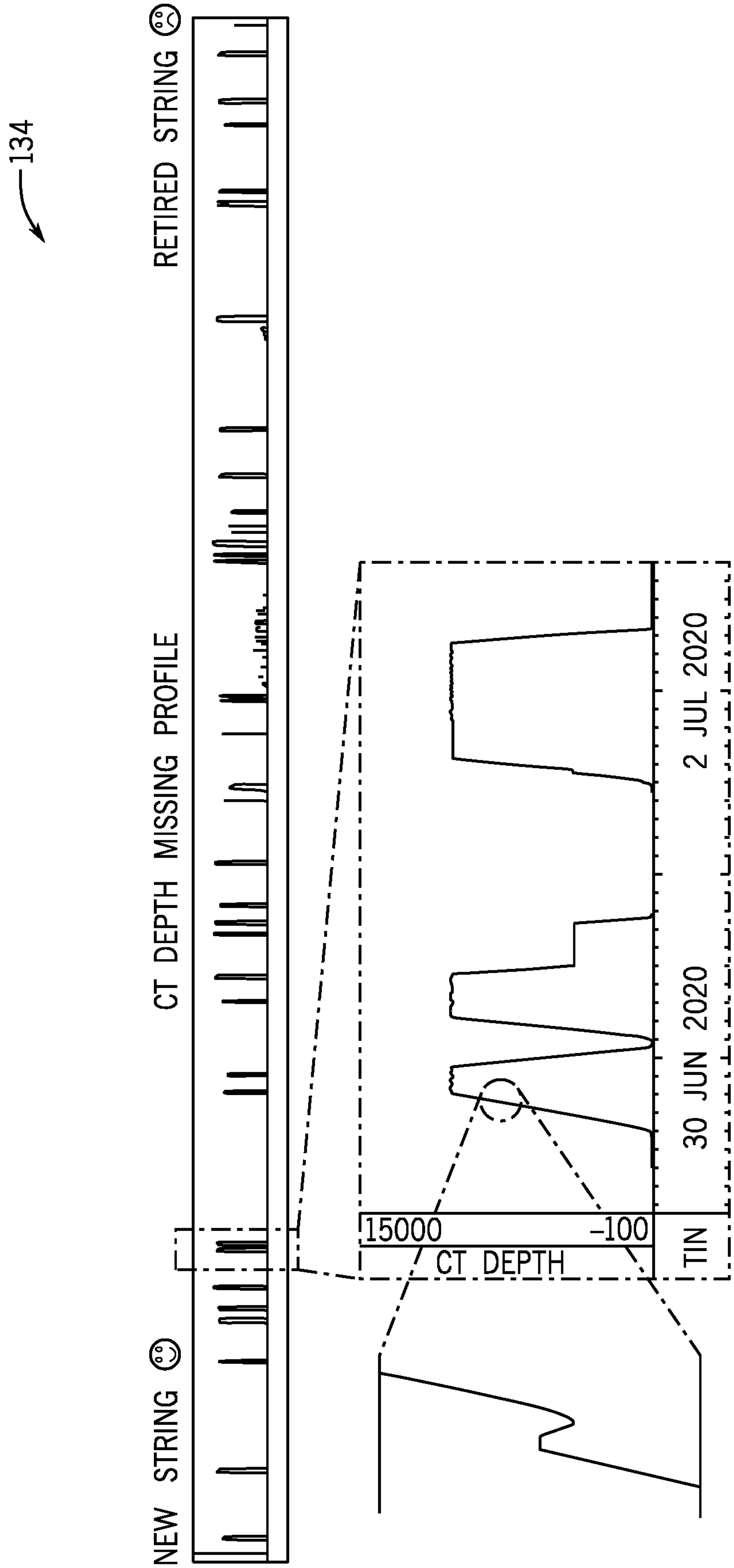

134
NEW STRING
CT DEPTH MISSING PROFILE
RETIRED STRING
15000
–100
CT DEPTH
TIN
30 JUN 2020
2 JUL 2020

FIG. 7

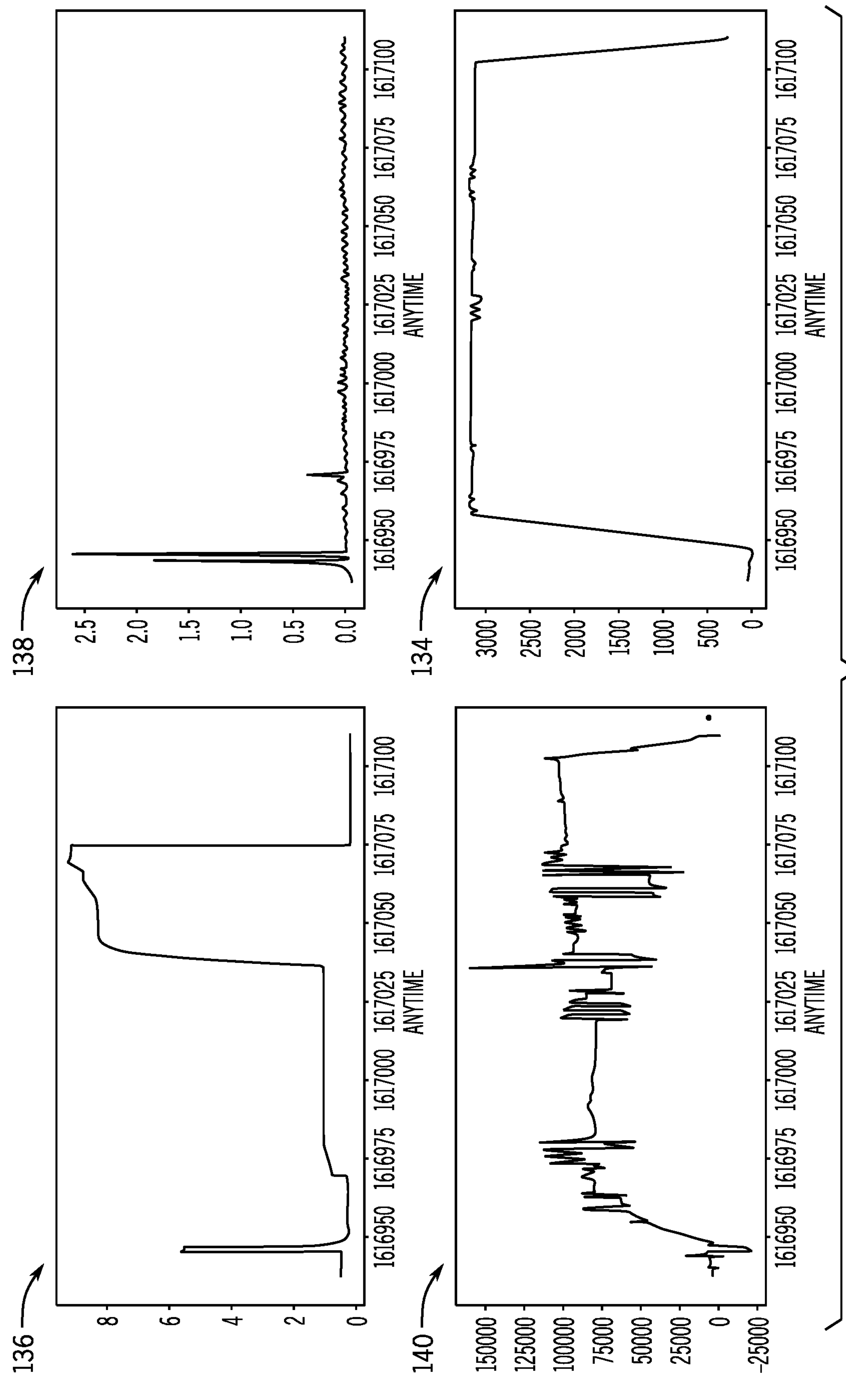


FIG. 8

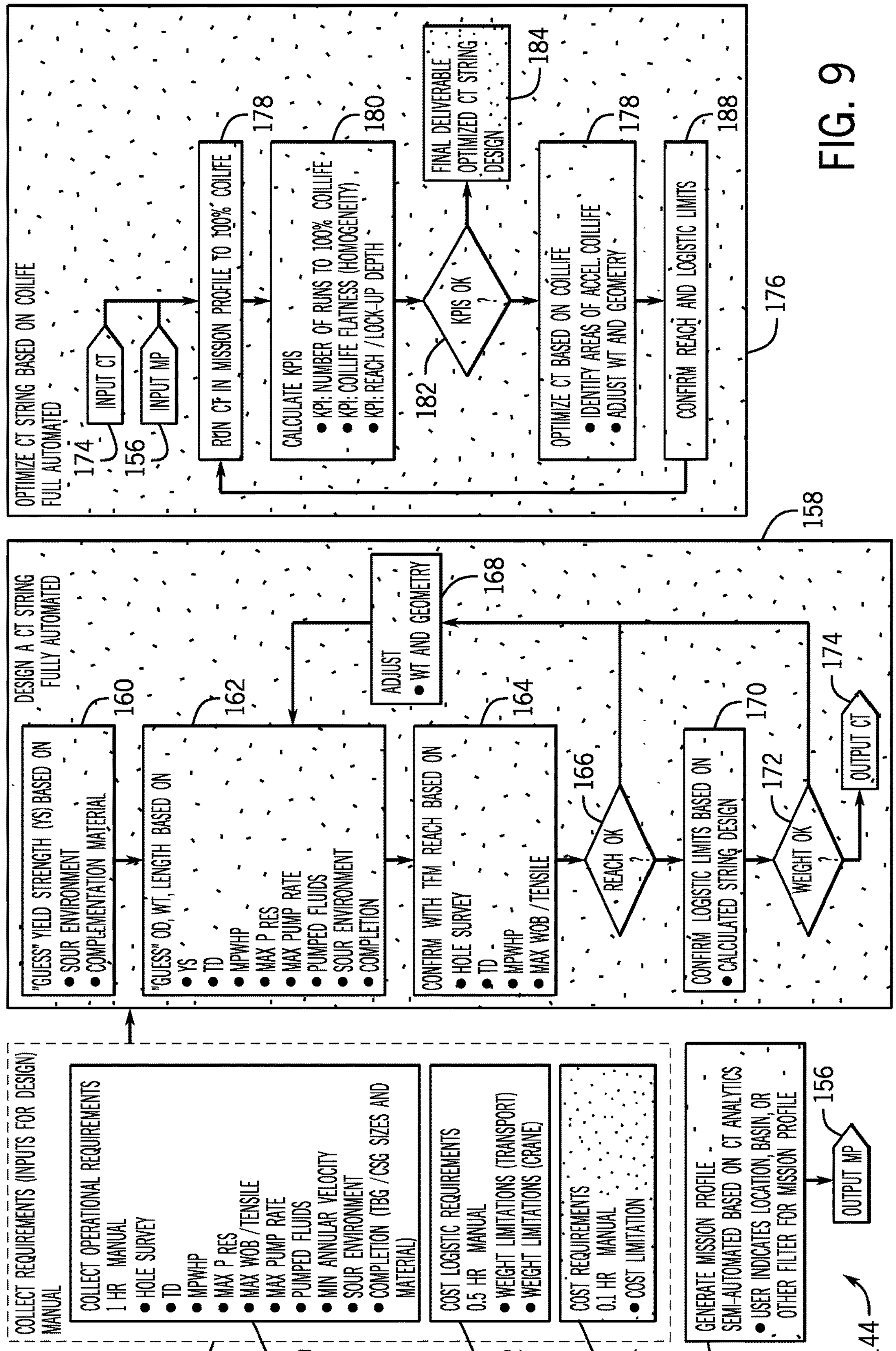

142
COLLECT REQUIREMENTS (INPUTS FOR DESIGN) MANUAL
146
COLLECT OPERATIONAL REQUIREMENTS
1 HR MANUAL
• HOLE SURVEY
• TD
• MPWHP
• MAX P RES
• MAX WOB / TENSILE
• MAX PUMP RATE
• PUMPED FLUIDS
• MIN ANNULAR VELOCITY
• SOUR ENVIRONMENT
• COMPLETION (TBG / CSG SIZES AND MATERIAL)
150
COST LOGISTIC REQUIREMENTS
0.5 HR MANUAL
• WEIGHT LIMITATIONS (TRANSPORT)
• WEIGHT LIMITATIONS (CRANE)
152
COST REQUIREMENTS
0.1 HR MANUAL
• COST LIMITATION
154
GENERATE MISSION PROFILE
SEMI-AUTOMATED BASED ON CT ANALYTICS
• USER INDICATES LOCATION, BASIN, OR OTHER FILTER FOR MISSION PROFILE
148
OUTPUT MP
156
144
DESIGN A CT STRING FULLY AUTOMATED
158
"GUESS" YIELD STRENGTH (YS) BASED ON
• SOUR ENVIRONMENT
• COMPLEMENTATION MATERIAL
160
"GUESS" OD, WT, LENGTH BASED ON
• YS
• TD
• MPWHP
• MAX P RES
• MAX PUMP RATE
• PUMPED FLUIDS
• SOUR ENVIRONMENT
• COMPLETION
162
ADJUST
• WT AND GEOMETRY
168
CONFIRM WITH TFM REACH BASED ON
• HOLE SURVEY
• TD
• MPWHP
• MAX WOB / TENSILE
164
REACH OK ?
166
CONFIRM LOGISTIC LIMITS BASED ON
• CALCULATED STRING DESIGN
170
WEIGHT OK ?
172
OUTPUT CT
174
OPTIMIZE CT STRING BASED ON COILIFE FULL AUTOMATED
INPUT CT
174
INPUT MP
156
RUN CT IN MISSION PROFILE TO 100% COILIFE
178
CALCULATE KPIS
• KPI: NUMBER OF RUNS TO 100% COILLIFE
• KPI: COILLIFE FLATNESS (HOMOGENEITY)
• KPI: REACH / LOCK-UP DEPTH
180
KPIS OK ?
182
FINAL DELIVERABLE OPTIMIZED CT STRING DESIGN
184
OPTIMIZE CT BASED ON COILIFE
• IDENTIFY AREAS OF ACCEL COILLIFE
• ADJUST WT AND GEOMETRY
178
CONFIRM REACH AND LOGISTIC LIMITS
188
176

FIG. 9

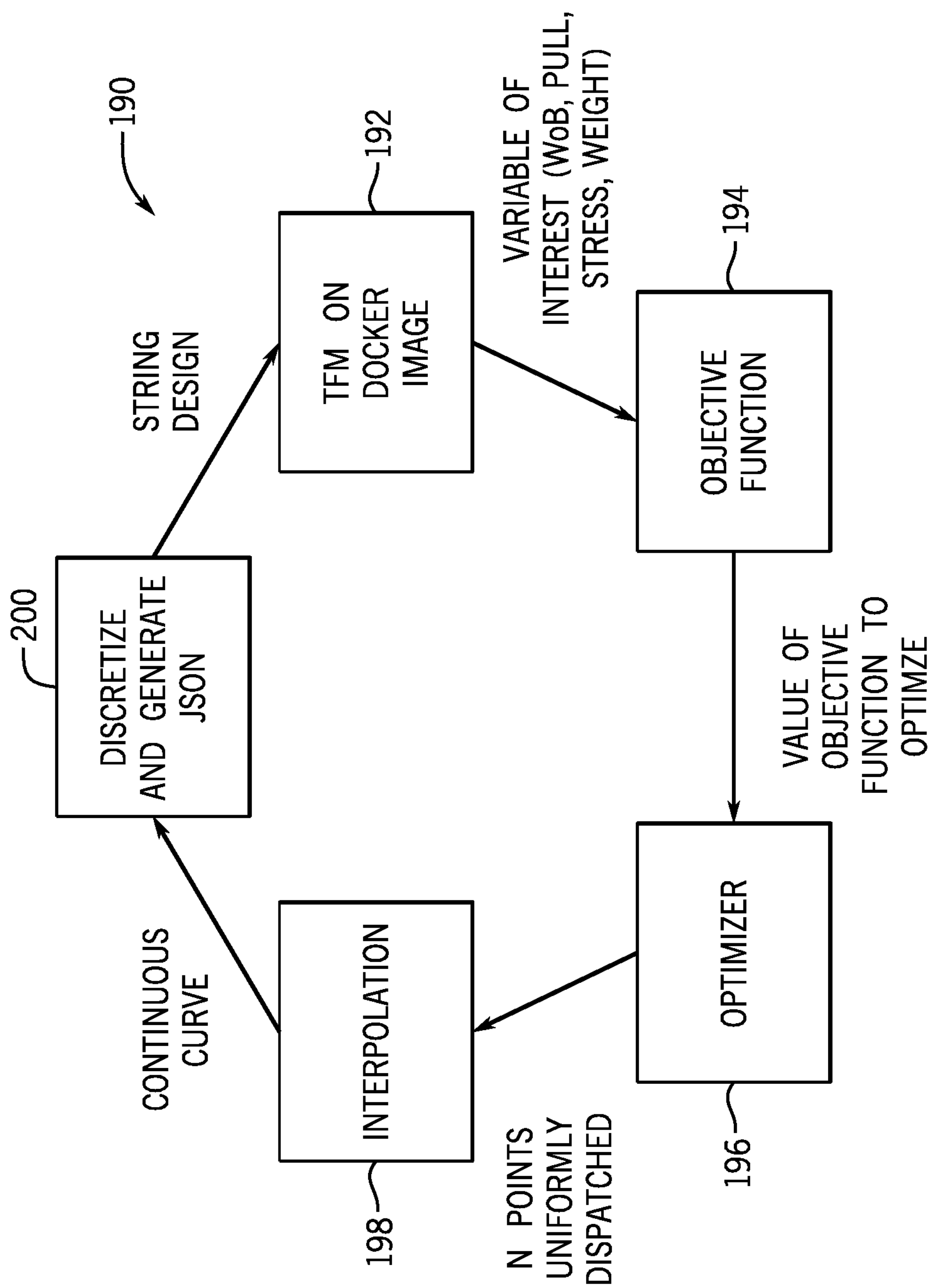

190
192
TFM ON DOCKER IMAGE
VARIABLE OF INTEREST (WoB, PULL, STRESS, WEIGHT)
194
OBJECTIVE FUNCTION
VALUE OF OBJECTIVE FUNCTION TO OPTIMZE
196
OPTIMIZER
N POINTS UNIFORMLY DISPATCHED
198
INTERPOLATION
CONTINUOUS CURVE
200
DISCRETIZE AND GENERATE JSON
STRING DESIGN

FIG. 10

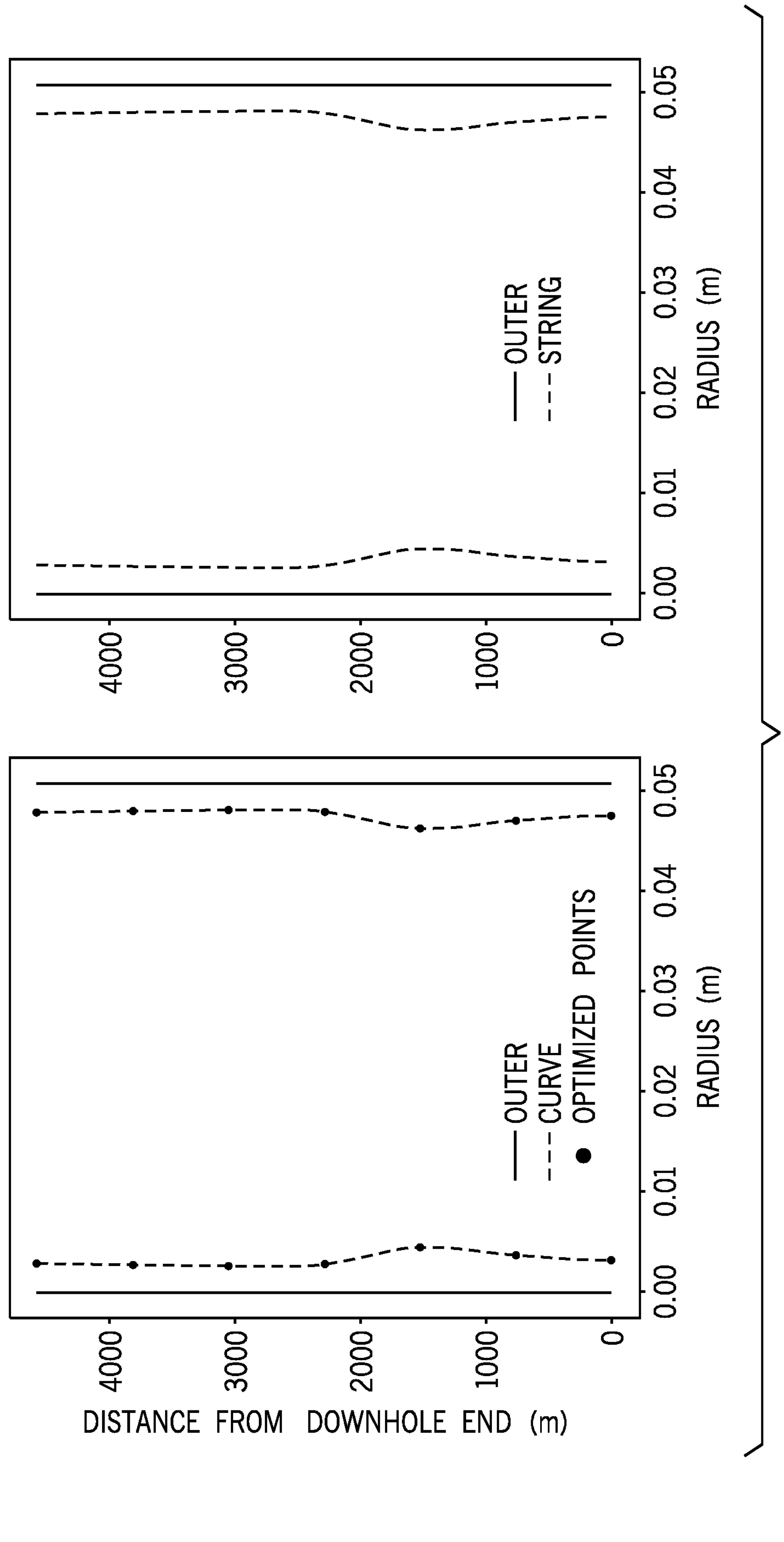

DISTANCE FROM DOWNHOLE END (m)
4000
3000
2000
1000
0
0.00
0.01
0.02
0.03
0.04
0.05
RADIUS (m)
OUTER
CURVE
OPTIMIZED POINTS
OUTER
STRING

FIG. 11

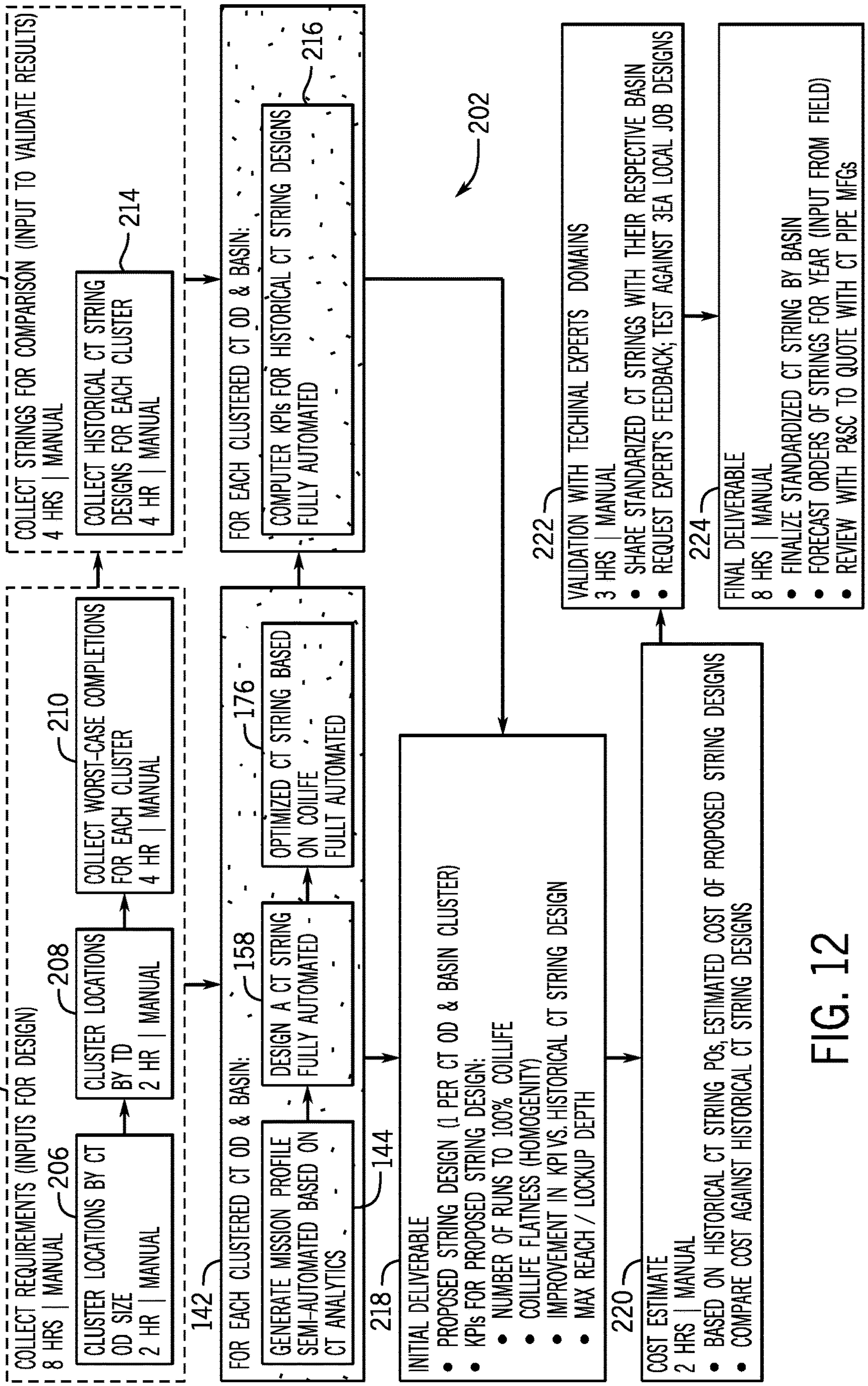

202
204
COLLECT REQUIREMENTS (INPUTS FOR DESIGN)
8 HRS | MANUAL
206
CLUSTER LOCATIONS BY CT OD SIZE
2 HR | MANUAL
208
CLUSTER LOCATIONS BY TD
2 HR | MANUAL
210
COLLECT WORST-CASE COMPLETIONS FOR EACH CLUSTER
4 HR | MANUAL
212
COLLECT STRINGS FOR COMPARISON (INPUT TO VALIDATE RESULTS)
4 HRS | MANUAL
214
COLLECT HISTORICAL CT STRING DESIGNS FOR EACH CLUSTER
4 HR | MANUAL
142
FOR EACH CLUSTERED CT OD & BASIN:
144
GENERATE MISSION PROFILE SEMI-AUTOMATED BASED ON CT ANALYTICS
158
DESIGN A CT STRING FULLY AUTOMATED -
176
OPTIMIZED CT STRING BASED ON COILIFE FULLT AUTOMATED
FOR EACH CLUSTERED CT OD & BASIN:
216
COMPUTER KPIs FOR HISTORICAL CT STRING DESIGNS FULLY AUTOMATED
218
INITIAL DELIVERABLE
• PROPOSED STRING DESIGN (1 PER CT OD & BASIN CLUSTER)
• KPIs FOR PROPOSED STRING DESIGN:
• NUMBER OF RUNS TO 100% COILLIFE
• COILLIFE FLATNESS (HOMOGENITY)
• IMPROVEMENT IN KPI VS. HISTORICAL CT STRING DESIGN
• MAX REACH / LOCKUP DEPTH
220
COST ESTIMATE
2 HRS | MANUAL
• BASED ON HISTORICAL CT STRING POs, ESTIMATED COST OF PROPOSED STRING DESIGNS
• COMPARE COST AGAINST HISTORICAL CT STRING DESIGNS
222
VALIDATION WITH TECHINAL EXPERTS DOMAINS
3 HRS | MANUAL
• SHARE STANDARIZED CT STRINGS WITH THEIR RESPECTIVE BASIN
• REQUEST EXPERT'S FEEDBACK; TEST AGAINST 3EA LOCAL JOB DESIGNS
224
FINAL DELIVERABLE
8 HRS | MANUAL
• FINALIZE STANDARDIZED CT STRING BY BASIN
• FORECAST ORDERS OF STRINGS FOR YEAR (INPUT FROM FIELD)
• REVIEW WITH P&SC TO QUOTE WITH CT PIPE MFGs

FIG. 12

COILED TUBING STRING MISSION PROFILE, DESIGN, AND OPTIMIZATION TOOL

BACKGROUND

[0001] The present disclosure generally relates to systems and methods for optimizing the design and validation of coiled tubing strings, also referred to as coiled tubing pipes.

[0002] This section is intended to introduce the reader to various aspects of art that may be related to various aspects of the present techniques, which are described and/or claimed below. This discussion is believed to be helpful in providing the reader with background information to facilitate a better understanding of the various aspects of the present disclosure. Accordingly, it should be understood that these statements are to be read in this light, and not as an admission of any kind.

[0003] In many well applications, coiled tubing is employed to facilitate performance of many types of downhole operations. Coiled tubing offers versatile technology due in part to its ability to pass through completion tubulars while conveying a wide array of tools downhole. A coiled tubing system may comprise many systems and components, including a coiled tubing reel, a coiled tubing pipe, an injector head, a gooseneck, lifting equipment (e.g., a mast or a crane), and other supporting equipment such as pumps, treating irons, or other components. Coiled tubing has been utilized for performing well treatment and/or well intervention operations in existing wellbores such as hydraulic fracturing operations, matrix acidizing operations, milling operations, perforating operations, coiled tubing drilling operations, and various other types of operations.

SUMMARY

[0004] A summary of certain embodiments described herein is set forth below. It should be understood that these aspects are presented merely to provide the reader with a brief summary of these certain embodiments and that these aspects are not intended to limit the scope of this disclosure.

[0005] Certain embodiments of the present disclosure include systems and methods for optimizing the design and validation of coiled tubing strings. For example, a processing workflow may include generating a mission profile for a coiled tubing (CT) string for deployment in a well based on CT analytics. The processing workflow may also include creating a CT string design for the CT string based at least in part on a plurality of operational parameters of the well. The CT string design of the CT string defines a plurality a physical characteristics of the CT string. The processing workflow may further include adjusting one or more of the plurality of physical characteristics of the CT string design of the CT string based at least in part on the generated mission profile for the CT string and a predicted life cycle of the CT string.

[0006] The mission profile describes the downhole and surface conditions that the CT string will see each time it is conveyed into and out of a well. The mission profile can include geometry and sizing of the surface equipment such as the CT reel and injector head gooseneck; fluids pumped from the surface through the CT string flowpath or through the CT string/tubing annular space; surface conditions such as the CT weight; downhole application; downhole conditions such as temperatures, pressures, annular velocities, tensile and compressive forces at the downhole end of the CT string; downhole fluids and environment such as H_2S, fluids produced by the reservoir, and fluids already present in the well; wellbore geometry described by the hole survey; and wellbore geometry described by the completion tubulars.

[0007] Various refinements of the features noted above may be undertaken in relation to various aspects of the present disclosure. Further features may also be incorporated in these various aspects as well. These refinements and additional features may exist individually or in any combination. For instance, various features discussed below in relation to one or more of the illustrated embodiments may be incorporated into any of the above-described aspects of the present disclosure alone or in any combination. The brief summary presented above is intended to familiarize the reader with certain aspects and contexts of embodiments of the present disclosure without limitation to the claimed subject matter.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] Various aspects of this disclosure may be better understood upon reading the following detailed description and upon reference to the drawings, in which:

[0009] FIG. **1** illustrates a schematic diagram of an example coiled tubing (CT) system, in accordance with embodiments of the present disclosure;

[0010] FIG. **2** illustrates a well analysis system including a CT design analysis system, in accordance with embodiments of the present disclosure;

[0011] FIG. **3** illustrates a user interface showing functionality of a fatigue estimation engine of the CT design analysis system, in accordance with embodiments of the present disclosure;

[0012] FIGS. **4**A through **4**F illustrate various user interfaces of the CT design analysis system, in accordance with embodiments of the present disclosure;

[0013] FIG. **5** illustrates an example of a mission profile engine workflow based on manual inputs of total depth (TD) and circulating pressures, in accordance with embodiments of the present disclosure;

[0014] FIG. **6** illustrates an example of a mission profile engine workflow based on historical CT acquisitions (e.g., using CT analytics), in accordance with embodiments of the present disclosure;

[0015] FIG. **7** illustrates an example of a specific depth mission profile of a CT string based on historical CT acquisitions (e.g., using CT Analytics), in accordance with embodiments of the present disclosure;

[0016] FIG. **8** illustrates an example of a specific a mission profile for a single run based on historical CT acquisitions (e.g., using CT Analytics), where the mission profile can include wellhead pressure, circulating pressure, CT weight, and CT depth, in accordance with embodiments of the present disclosure;

[0017] FIG. **9** illustrates an example of a workflow for a CT String Design and Optimization Tool, in accordance with embodiments of the present disclosure;

[0018] FIG. **10** illustrates an optimization workflow utilizing the Mission Profile Generator and the CT String Design and Optimization Tool, in accordance with embodiments of the present disclosure;

[0019] FIG. **11** illustrates a process of a continuous solution to a discretized design, in accordance with embodiments of the present disclosure; and

[0020] FIG. **12** illustrates an example of a workflow for developing standardized CT string designs at a geographic level (e.g., with basin geography selected for the example), in accordance with embodiments of the present disclosure.

DETAILED DESCRIPTION

[0021] One or more specific embodiments of the present disclosure will be described below. These described embodiments are only examples of the presently disclosed techniques. Additionally, in an effort to provide a concise description of these embodiments, all features of an actual implementation may not be described in the specification. It should be appreciated that in the development of any such actual implementation, as in any engineering or design project, numerous implementation-specific decisions must be made to achieve the developers' specific goals, such as compliance with system-related and business-related constraints, which may vary from one implementation to another. Moreover, it should be appreciated that such a development effort might be complex and time consuming, but would nevertheless be a routine undertaking of design, fabrication, and manufacture for those of ordinary skill having the benefit of this disclosure.

[0022] When introducing elements of various embodiments of the present disclosure, the articles "a," "an," and "the" are intended to mean that there are one or more of the elements. The terms "comprising," "including," and "having" are intended to be inclusive and mean that there may be additional elements other than the listed elements. Additionally, it should be understood that references to "one embodiment" or "an embodiment" of the present disclosure are not intended to be interpreted as excluding the existence of additional embodiments that also incorporate the recited features.

[0023] As used herein, the terms "connect," "connection," "connected," "in connection with," and "connecting" are used to mean "in direct connection with" or "in connection with via one or more elements"; and the term "set" is used to mean "one element" or "more than one element." Further, the terms "couple," "coupling," "coupled," "coupled together," and "coupled with" are used to mean "directly coupled together" or "coupled together via one or more elements." As used herein, the terms "up" and "down," "uphole" and "downhole", "upper" and "lower," "top" and "bottom," and other like terms indicating relative positions to a given point or element are utilized to more clearly describe some elements. Commonly, these terms relate to a reference point as the surface from which drilling operations are initiated as being the top (e.g., uphole or upper) point and the total depth along the drilling axis being the lowest (e.g., downhole or lower) point, whether the well (e.g., wellbore, borehole) is vertical, horizontal or slanted relative to the surface.

[0024] In addition, as used herein, the terms "real time", "real-time", or "substantially real time" may be used interchangeably and are intended to described operations (e.g., computing operations) that are performed without any human-perceivable interruption between operations. For example, as used herein, data relating to the systems described herein may be collected, transmitted, and/or used in control computations in "substantially real time" such that data readings, data transfers, and/or data processing steps occur once every second, once every 0.1 second, once every 0.01 second, or even more frequent, during operations of the systems (e.g., while the systems are operating). In addition, as used herein, the terms "automatic" and "automated" are intended to describe operations that are performed or caused to be performed, for example, by a processing system (i.e., solely by the processing system, without human intervention). In addition, as used herein, the term "approximately equal to" may be used to mean values that are relatively close to each other (e.g., within 5%, within 2%, within 1%, within 0.5%, or even closer, of each other).

[0025] Coiled tubing (CT) is used in the intervention of wells and is often selected as an intervention method for its capacity to pump fluids, its rigidity which delivers extended reach in deviated wells, its pulling and pushing capacity, and the ability to intervene in live wells, to name a few advantages. Design considerations for a CT string include yield strength (YS) of the metal, outer diameter (OD) of the CT, and wall thickness(es) (WT) of the CT. The CT may be manufactured with segments that are welded together, where each segment may have different lengths and WT. A CT string with a single WT is known as "continuous"; whereas one with variations in WT is known as "tapered". Operational requirements, wellbore and completion design, the mission profile, CT handling and logistics, and cost are all relevant inputs to the design of a CT string. As used herein, a "CT string" is intended to refer to the both a string of CT as well as the pipe used as part of the CT string.

[0026] In general, the fluid to be pumped in the CT and the required pump rates will determine circulating pressures. In addition, in general, the maximum anticipated circulating pressure will dictate the strength of the CT so as to avoid burst conditions. In addition, in general, reservoir pressures and the fluids in the well will determine the maximum anticipated wellhead pressure (MPWHP), which will also dictate the strength of the CT so as to avoid collapse conditions. In addition, if the CT will be used to carry solids to the surface (e.g., cuttings, sand cleanouts, and so forth), annular velocities of fluids in the CT/tubing and CT/casing annuli must be considered. These annular velocities are a function of the permissible flowrates inside the CT, and the radial clearance between the CT and the CT/tubing and CT/casing annuli. This radial clearance is a function of the CT OD. The chemistry of the downhole environment can also play an important role in the design of a CT string. For instance, softer metals are less susceptible to embrittlement than harder metals when exposed to sour environments (e.g., exposure to H_2S, CO_2, and so forth). Taking into account a degree of exposure to such sour environments will have an impact on YS selection.

[0027] The wellbore and completion is defined by the hole geometry and completion design. In turn, the hole geometry is defined by a hole survey, which provides a three-dimensional portrait of the well from the surface to its terminal or total depth (TD). A simple hole survey might be a perfectly vertical well, whereas more complicated hole surveys may introduce deviations, extended horizontal sections, doglegs, and tortuosity. These compounding hole survey features affect CT reach in the well. The completion design may be defined by the materials of the tubulars, the size of the tubulars, and the open hole region. The materials can have an impact on erosion between the tubular and the CT. The type of fluid produced from or pumped into the reservoir **16**

can also have an impact on abrasion of tubular and pipes. For instance, operations in a dry gas well would see higher levels of abrasion. The CT string design may be adjusted to minimize the amount of abrasion generated during an operation (or a campaign of operations in wells if similar properties/environment).

[0028] As such, CT YS and WT sometimes selected to address erosion and abrasion risks for a given mission profile. The size of the tubulars may also impact the radial clearance between the CT and the internal diameter (ID) of the completions, and the radial clearance impacts CT reach. Materials and open hole regions also have an impact on expected frictions, which also impact CT reach. There are other design considerations such as net weight of the CT string as well as the size of the CT reel and/or whether it is on a vessel or on a platform. For example, certain locations have more restrictive weight requirements for transporting loads on highways. In addition, offshore platforms and vessels will have limited crane capacities. Furthermore, remote operations in the jungle may require the CT string to be hauled via helicopter with payload limitations. These weight limitations will have a direct impact on the design of the CT string. Finally, there is the consideration of cost. Cost can correlate with volume of raw material (e.g., longer or bigger WT), complexity of string geometry (e.g., tapered or additional telescoping sections), and manufacturing material and process (e.g., harder YS, quenching technologies).

[0029] There are several challenges associated with CT string design including, but not limited to, those described herein. First, conventional optimization techniques for CT string design are, at best, an educated guess with limited validation. For example, the CT string designer attempts to maximize reach, minimize risk of burst/collapse, maximize annular velocities for cleanouts, optimize weights for lifts/transport, maximize useful life, minimize manufacturing cost, and so forth). However, the CT string designer often does so in a toilsome manner that requires making an initial guess, manually running that design through different engines and simulators, and making adjustments based on outcomes. The embodiments described herein provide an automated, consistent optimization, based on both computation capabilities and leveraging experience of former CT string designs.

[0030] Second, wells are drilled in increasingly challenging environments (e.g., due to depth, tortuosity, HPHT conditions, sour conditions, and so forth). The conventional optimization techniques for CT string design do not include a formal approach or process, and are lagging with respect to the evolution of well and intervention complexity. The embodiments described herein provide a baseline for optimizations that can be improved to address new challenges.

[0031] Third, the large variety of operational and wellbore considerations leads to a large variety in CT string designs. For example, in a single calendar year, an oil and gas operator may order several hundreds of unique varieties of CT strings. There has heretofore been no attempt to standardize CT string designs across different locations, geographical areas, basins, or CT application or job types. Such an exercise of standardizing strings could produce fewer varieties of CT strings that could still meet the operational requirements worldwide. The embodiments described herein leverage CT acquisition data from around the world to generate mission profiles that can be used to generate standardized (or default) CT string designs for specific downhole and operating conditions.

[0032] With the foregoing in mind, FIG. **1** illustrates a schematic diagram of an example CT system **10**. As illustrated, in certain embodiments, a CT string **12** may be run into a wellbore **14** that traverses a hydrocarbon-bearing formation **16** (i.e., reservoir). While certain elements of the CT system **10** are illustrated in FIG. **1**, other elements of the CT system **10** (e.g., blow-out preventers, wellhead "tree", etc.) may be omitted for clarity of illustration. In certain embodiments, the CT system **10** includes an interconnection of pipes, including vertical and/or horizontal casings **18**, CT **20**, and so forth, that connect to a surface facility **22** at the surface **24** of the CT system **10**. In certain embodiments, the CT **20** extends inside the casing **18** and terminates at a tubing head (not shown) at or near the surface **24**. In addition, in certain embodiments, the casing **18** contacts the wellbore **14** and terminates at a casing head (not shown) at or near the surface **24**. It should be appreciated that the embodiments described herein may be applicable to oil and gas wells as well as other types of wells including, but not limited to, geothermal or carbon capture, utilization, and storage (CCUS) wells, for example.

[0033] In certain embodiments, a bottom hole assembly ("BHA") **26** may be run inside the casing **18** by the CT **20**. As illustrated in FIG. **1**, in certain embodiments, the BHA **26** may include a downhole motor **28** that operates to rotate a drill or mill bit **30** (e.g., during drilling or milling operations) or other downhole tools. In certain embodiments, the downhole motor **28** may be driven by hydraulic forces carried in fluid supplied from the surface **24** of the CT system **10**. In certain embodiments, the BHA **26** may be connected to the CT **20**, which is used to run the BHA **26** to a desired location within the wellbore **14**. It is also contemplated that, in certain embodiments, the rotary motion of the drill bit **30** may be driven by rotation of the CT **20** effectuated by a rotary table or other surface-located rotary actuator. In such embodiments, the downhole motor **28** may be omitted.

[0034] In certain embodiments, the CT **20** may also be used to deliver fluid **32** to the drill bit **30** through an interior of the CT **20** to aid in the drilling process and carry cuttings and possibly other fluid or solid components in return fluid **34** that flows up the annulus between the CT **20** and the casing **18** (or via a return flow path provided by the CT **20**, in certain embodiments) for return to the surface facility **22**. It is also contemplated that the return fluid **34** may include remnant proppant (e.g., sand) or possibly rock fragments that result from a hydraulic fracturing application, and flow within the CT system **10**. Under certain conditions, fracturing fluid and possibly hydrocarbons (oil and/or gas), proppants and possibly rock fragments may flow from the fractured formation **16** through perforations in a newly opened interval and back to the surface **24** of the CT system **10** as part of the return fluid **34**. In certain embodiments, the BHA **26** may be supplemented behind the rotary drill by an isolation device such as, for example, an inflatable packer that may be activated to isolate the zone below or above it and enable local pressure tests. In addition, in certain embodiments, the BHA **26** may include a tractor system that is capable of improving reach and WOB of the BHA **26** during CT operations.

[0035] As such, in certain embodiments, the CT system **10** may include a downhole well tool **36** that is moved along the wellbore **14** via the CT **20**. In certain embodiments, the downhole well tool **36** may include a variety of drilling/cutting tools coupled with the CT **20**. In the illustrated embodiment, the downhole well tool **36** includes the drill bit **30**, which may be powered by the downhole motor **28** (e.g., a positive displacement motor (PDM), or other hydraulic motor) of the BHA **26**. In certain embodiments, the wellbore **14** may be an openhole wellbore or a cased wellbore defined by the casing **18**. In addition, in certain embodiments, the wellbore **14** may be vertical or horizontal or inclined. It should be noted the downhole well tool **36** may be part of various types of BHAs **26** coupled to the CT **20**.

[0036] As also illustrated in FIG. **1**, in certain embodiments, the CT system **10** may include a downhole sensor package **38** having multiple downhole sensors **40**. In certain embodiments, the sensor package **38** may be mounted along the CT string **12**, although certain downhole sensors **40** may be positioned at other downhole locations in other embodiments. In addition, in certain embodiments, downhole sensors **40** disposed on the CT **20** may be configured to detect downhole flow rates, downhole temperatures, and downhole pressures, and so forth, in the wellbore **14**. In addition, in certain embodiments, downhole sensors **40** disposed on the casing **18** may be configured to detect downhole temperatures, downhole pressures, axial load (or "weight") and torque applied on the bit, casing collar locators (CCLs), resistivity, and so forth, in the wellbore **14**.

[0037] In certain embodiments, data from the downhole sensors **40** may be relayed uphole to a CT design analysis system **42** (e.g., a computer-based processing system) disposed at the surface **24** and/or other suitable location of the CT system **10**. In certain embodiments, the data may be relayed uphole in substantially real time (e.g., relayed while it is detected by the downhole sensors **40** during operation of the downhole well tool **36**) via a wired or wireless telemetric control line **44**, and this real-time data may be referred to as edge data. In certain embodiments, the telemetric control line **44** may be in the form of an electrical line, fiber-optic line, or other suitable control line for transmitting data signals. In certain embodiments, the telemetric control line **44** may be routed along an interior of the CT **20**, within a wall of the CT **20**, or along an exterior of the CT **20**. In addition, as described in greater detail herein, additional data (e.g., surface data) may be supplied by surface sensors **46** and/or stored in a memory location **48**. By way of example, historical data and other useful data may be stored in the memory location **48** such as a cloud storage **50**.

[0038] As illustrated, in certain embodiments, the CT **20** may be deployed by a CT unit **52** and delivered downhole via an injector head **54**. In certain embodiments, the injector head **54** may be controlled to slack off or pick up the CT **20** so as to control the tubing string weight and, thus, the weight-on-bit (WOB) acting on the drill bit **30** (or the downhole well tool **36**). In certain embodiments, the downhole well tool **36** may be moved along the wellbore **14** via the CT **20** under control of the injector head **54** so as to apply a desired tubing weight and, thus, to achieve a desired rate of penetration (ROP) as the drill bit **30** is operated. Depending on the specifics of a given application, various types of data may be collected downhole, and transmitted to the CT design analysis system **42** in substantially real time to facilitate improved operation of the downhole well tool **36**. For example, as described in greater detail herein, the data may be used to fully or partially automate downhole operations, to optimize the downhole operations, and/or to provide more accurate predictions regarding components or aspects of the downhole operations.

[0039] In certain embodiments, fluid **32** may be delivered downhole under pressure from a pump unit **56**. In certain embodiments, the fluid **32** may be delivered by the pump unit **56** through the downhole motor **28** to power the downhole motor **28** and, thus, the drill bit **30**. In certain embodiments, the return fluid **34** is returned uphole, and this flow back of the return fluid **34** is controlled by suitable flowback equipment **58**. In certain embodiments, the flowback equipment **58** may include chokes and other components/equipment used to control flow back of the return fluid **34** in a variety of applications, including well treatment applications.

[0040] As described in greater detail herein, the CT unit **52**, the injector head **54**, the pump unit **56**, and the flowback equipment **58** may include advanced surface sensors **46**, actuators, and local controllers, such as PLCs, which may cooperate together to provide sensor data to receive control signals from, and generate local control signals based on communications with, respectively, the CT design analysis system **42**. In certain embodiments, as described in greater detail herein, the surface sensors **46** may include flow rate, pressure, and fluid rheology sensors **46**, among other types of sensors. In addition, as described in greater detail herein, the actuators may include actuators for pump and choke control of the pump unit **56** and the flowback equipment **58**, respectively, among other types of actuators.

[0041] In certain embodiments, surface sensors **46** of the CT unit **52** may be configured to detect positions of the CT **20**, weights of the CT **20**, and so forth. In addition, in certain embodiments, surface sensors **46** of the injector head **54** may be configured to detect wellhead pressure, and so forth. In addition, in certain embodiments, surface sensors **46** of the pump unit **56** may be configured to detect pump pressures, pump flow rates, and so forth. In addition, in certain embodiments, surface sensors **46** of the flowback equipment **58** may be configured to detect fluids production rates, solids production rates, and so forth.

[0042] FIG. **2** illustrates a well analysis system **60** that may include the CT design analysis system **42** to facilitate the optimization of design of CT strings **12**, as described in greater detail herein. In certain embodiments, the CT design analysis system **42** may include one or more analysis modules **62** (e.g., a program of computer-executable instructions and associated data) that may be configured to perform various functions of the embodiments described herein. In certain embodiments, to perform these various functions, the one or more analysis modules **62** may execute on one or more processors **64** of the CT design analysis system **42**, which may be connected to one or more storage media **66** of the CT design analysis system **42**. Indeed, in certain embodiments, the one or more analysis modules **62** may be stored in the one or more storage media **66**.

[0043] In certain embodiments, the computer-executable instructions of the one or more analysis modules **62**, when executed by the one or more processors **64**, may cause the one or more processors **64** to generate one or more models, which may be used by the CT design analysis system **42** to optimize the design of CT strings **12**, as described in greater detail herein. In certain embodiments, the analysis modules **62** that enable the embodiments described herein may run locally (e.g., on a local computer), as a cloud-based solution, or as a plugin to existing software.

[0044] In certain embodiments, the one or more processors **64** may include a microprocessor, a microcontroller, a processor module or subsystem, a programmable integrated circuit, a programmable gate array, a digital signal processor (DSP), or another control or computing device. In certain embodiments, the one or more processors **64** may include machine learning and/or artificial intelligence (AI) based processors. In certain embodiments, the one or more storage media **66** may be implemented as one or more non-transitory computer-readable or machine-readable storage media. In certain embodiments, the one or more storage media **66** may include one or more different forms of memory including semiconductor memory devices such as dynamic or static random access memories (DRAMs or SRAMs), erasable and programmable read-only memories (EPROMs), electrically erasable and programmable read-only memories (EEPROMs) and flash memories; magnetic disks such as fixed, floppy and removable disks; other magnetic media including tape; optical media such as compact disks (CDs) or digital video disks (DVDs); or other types of storage devices. Note that the computer-executable instructions and associated data of the analysis module(s) **62** may be provided on one computer-readable or machine-readable storage medium of the storage media **66**, or alternatively, may be provided on multiple computer-readable or machine-readable storage media distributed in a large system having possibly plural nodes. Such computer-readable or machine-readable storage medium or media are considered to be part of an article (or article of manufacture), which may refer to any manufactured single component or multiple components. In certain embodiments, the one or more storage media **66** may be located either in the machine running the machine-readable instructions, or may be located at a remote site from which machine-readable instructions may be downloaded over a network for execution.

[0045] In certain embodiments, the processor(s) **64** may be connected to a network interface **68** of the CT design analysis system **42** to allow the CT design analysis system **42** to communicate with multiple downhole sensors **40** and surface sensors **46** described herein, as well as communicate with the actuators **70** and/or PLCs **72** of surface equipment **74** (e.g., CT units **52**, injector heads **54**, pump units **56**, flowback equipment **58**, and so forth) and of downhole equipment **76** (e.g., BHAs **26**, downhole motors **28**, drill bits **30**, downhole well tools **36**, and so forth) of various CT systems **10** for the purpose of optimizing the design process for CT strings **12** of CT systems **10**, as described in greater detail herein. In certain embodiments, the network interface **68** may also facilitate the CT design analysis system **42** to communicate data to the cloud storage **50** (or other wired and/or wireless communication network) to, for example, archive the data and/or to enable external computing systems **78** to access the data and/or to remotely interact with the CT design analysis system **42**.

[0046] It should be appreciated that the well analysis system **60** illustrated in FIG. **2** is only one example of a well analysis system, and that the well analysis system **60** may have more or fewer components than shown, may combine additional components not depicted in the embodiment of FIG. **2**, and/or the well analysis system **60** may have a different configuration or arrangement of the components depicted in FIG. **2**. In addition, the various components illustrated in FIG. **2** may be implemented in hardware, software, or a combination of both hardware and software, including one or more signal processing and/or application specific integrated circuits. Furthermore, the operations of the well analysis system **60** as described herein may be implemented by running one or more functional modules in an information processing apparatus such as application specific chips, such as application-specific integrated circuits (ASICs), field-programmable gate arrays (FPGAs), programmable logic devices (PLDs), systems on a chip (SOCs), or other appropriate devices. These modules, combinations of these modules, and/or their combination with hardware are all included within the scope of the embodiments described herein.

[0047] As described in greater detail herein, the embodiments described herein facilitate the design of CT strings **12**. For example, a variety of data (e.g., downhole data and surface data) may be collected to enable optimization of the design of the CT strings **12** illustrated in FIG. **1** by the CT design analysis system **42** illustrated in FIG. **2** (or other suitable processing systems). In particular, the embodiments described herein include two software engines that enable new workflows:

[0048] 1. Mission Profile Generator: Provides a CT intervention mission profile with which to evaluate the performance of a CT string design.

[0049] 2. CT String Design and Optimization Tool: Designs and optimizes a CT string design based on user-defined requirements and mission profile.

[0050] FIG. **3** illustrates a user interface **80** of the CT design analysis system **42** that partially fulfills the functionality of the Mission Profile Generator as a fatigue estimation engine. A user may provide a constant pressure **82** (e.g., circulating pressure inside a CT string **12**) and an arch radius **84** (e.g., radius of a gooseneck of an associated injector head **54**) and the fatigue estimation engine outputs machine cycles **86** and number of trips to failure **88**. Elements that are missing from the illustrated estimator are expected behaviors such as pull tests, the impact of the fatigue induced by the plastic deformation of spooling and unspooling the CT **20** from the work reel or drum of the CT unit **52**, and modifying factors.

[0051] FIGS. **4**A through **4**F illustrate various user interfaces **90**, **98**, **104**, **108**, **112**, **116** of the CT design analysis system **42** that partially fulfills the functionality of the CT String Design and Optimization Tool. However, it is noted that one or more engines, simulations, or models are used by an engineer to design a CT string **12** and validate that the designed CT string **12** will meet operational requirements. FIGS. **4**A through **4**F illustrate one example of how an engineer may design a CT string **12**, but it should be appreciated that there are many other approaches, order of operations, and considerations that are not captured by this example.

[0052] FIG. **4**A illustrates a first user interface **90** through which an engineer may choose CT string material **92**, OD **94**, thickness **96**, length, and geometry. FIG. **4**B illustrates a second user interface **98** (showing two different tabs being selected) through which an engineer may define hole survey data **100** and tubular data **102**. FIG. **4**C illustrates a third user interface **104** through which an engineer may load data for a CT design (e.g., as illustrated by element **106**). FIG. **4**D illustrates a fourth user interface **108** through which an engineer may verify reach **110** (e.g., maximum tool depth) of a CT string **12** with a tubing forces module (TFM). FIG. **4**E illustrates a fifth user interface **112** through which an engineer may modify the CT string design to get the required reach and desired WOB **114** and torque-on-bit (TOB) margins. FIG. **4**F illustrates a sixth user interface **116** illustrating a plot **118** from which an engineer may validate safety margins of effective forces and differential pressures based on the worst-case scenario and operating limit. After entering all of the data via the user interfaces **90**, **98**, **104**, **108**, **112**, **116**, an engineer may validate a number of runs or cycles to failure using the fatigue estimation engine that is used in conjunction with the user interface **80** illustrated in FIG. **3**.

[0053] The embodiments of the present disclosure extend the general workflows that are facilitated by the user interfaces **80**, **90**, **98**, **104**, **108**, **112**, **116** of the CT design analysis system **42** illustrated in FIGS. **3** through **4**F via additional functionality of the Mission Profile Generator and the CT String Design and Optimization Tool described in greater detail herein.

Mission Profile Generator

[0054] The Mission Profile Generator is an engine that generates a mission profile for a design of a CT string **12**. Much like a hypothetical racetrack or landscape against which a car's mileage and performance can be measured against, a CT string mission profile can be used to evaluate and validate the performance of a CT string **12**. FIG. **3** illustrates basic functionality of a CT performance engine that outputs cycles **86** to failure as a function of arch radius **84** and circulating pressure **82**. However, the user interface **80** illustrated in FIG. **3** does not accurately capture how CT **20** is cycled throughout its life. Rather, it assumes cycling the full length of the CT **20** and back. It also does not allow for a more nuanced circulating pressure profile, rather assuming a static pressure.

[0055] The embodiments of the present disclosure include a Mission Profile Generator engine that provides a time-gated mission profile for depth and pressure cycling, thereby more accurately capturing variations in these parameters. FIG. **5** illustrates a workflow **120** of this engine, where an engineer manually provides inputs **122** (e.g., design requirements) such as TD, circulating pressure range, and pull test frequency and range. By extension, the engineer could manually provide inputs such as CT depth and pump rate to automatically simulate the anticipated circulating pressure range and annular velocities, among other mission profile inputs. Likewise, the engineer could leverage TFM to simulate anticipated CT weights as an input for the mission profile. The engine **124** would then generate a time-gated mission profile of depth and pressures as a final deliverable **126**. It is noted that, in the figures described herein, certain shaded blocks (e.g., blocks **124**, **126**, **132**, **144**, **148**, **154**, **158**, **176**, and **216**) designate that the processing steps are at least partially performed automatically (e.g., without human intervention) by the analysis module(s) **62** (e.g., executed by a CT design analysis system **42**) described in greater detail herein.

[0056] If the engineer wants to leverage existing job acquisitions, they may use the Mission Profile Generator as per the workflow **128** illustrated in FIG. **6**. In this example, the Mission Profile Generator may be provided with inputs **130** such as one or more locations, geological locations (e.g., GeoUnits), basins, and/or job types. In certain embodiments, one or more historical CT strings **12** could be selected. Or the mission profile could be limited to a specific campaign or field. The engine **128** would then generate a mission profile based on CT analytics as a final deliverable **126**.

[0057] FIG. **7** illustrates an example of a specific CT depth mission profile **134** for a particular CT string **12**. This specific CT string **12** could be used to evaluate the performance of a new CT string design using actual RIH/POOH cycling, including pull tests, as well as circulating pressures during each job. In addition to CT depth, FIG. **8** provides examples of mission profiles of wellhead pressure **136**, circulating pressure **138**, and CT weight **140**.

[0058] In each of these examples, the Mission Profile Generator may directly use historical data, or it may derive a new mission profile that is the average or worst-case of mission profiles that are filtered using geography, field, job type, and so forth.

CT String Design and Optimization Tool

[0059] The CT String Design and Optimization Tool is an engine (or multiple engines that work jointly) that outputs a CT string design based on user inputs (e.g., operational requirements) and optimizes these based on requirements and key performance indicators (KPIs). FIG. **9** illustrates an example workflow **142** of the CT String Design and Optimization Tool. It is noted that the majority of the processing performed in the workflow **142** of FIG. **9** are at least partially performed automatically (e.g., without human intervention) by the analysis module(s) **62** (e.g., executed by a CT design analysis system **42**) described in greater detail herein.

[0060] In a first stage **144** of the workflow **142** (e.g., Collect Requirements **146** and Generate Mission Profile **148**), a user may provide operational requirements **150** that include, for example, environment (e.g., land, offshore platform, vessel, and so forth, whether fixed or moving), hole survey, TD, MPWHP, maximum reservoir pressure (as well as maximum temperature of the well), maximum WOB/TOB, and so forth. In addition, other types of operational parameters **150** that may impact the MP **156** may include, but are not limited to, the types of downhole well tools **36** that are used in the CT system **10** (e.g., the BHA selection including tractors, agitators, jars, fishing tools, hydraulically activated tools, perforating guns, and so forth). Other requirements at this stage **144** may include logistic requirements **152** (e.g., weight and size limitation for the purposes of transporting or carrying or installing the string) and cost limitations **154**. In certain embodiments, the Mission Profile Generator may also be used to guide or complete the operational requirements **150**; for instance, CT analytics may be used to find worst-case hole survey, TD, MPWHP, WOB/TOB for a given geography, environment, job type, and so forth. to output a mission profile (MP) **156**.

[0061] A second stage of the workflow **142** (e.g., Design a CT string **158**) designs an initial CT string **12** by fixing YS, OD, WT, and length of individual sections. It does so by pursuing an initial "guess" (e.g., of YS in block **160** and OD, WT, and length in block **162**) that can be based on historical designs, best practices, logic, randomized, and manual user-defined inputs. The initial "guess" is then subjected to the TFM **164** to confirm proper reach, WOB, and TOB, among other parameters, at TD. A determination of whether sufficient margins in terms of burst and collapse conditions are confirmed. In addition, a decision may be made as to whether the reach is acceptable (decision block **166**). If the reach is not acceptable, the WT and section lengths can be adjusted (e.g., block **168**) to change the string's geometry and achieve desired reach and pressure performance (e.g., by proceeding back to block **162**). YS and OD can be used to modify reach and pressure performance. These design choices impact net weight, which can impact compliance with logistic limits **170**. Material choice, WT(s), and geometry can also impact cost. In addition, a decision may be made as to whether the weight is acceptable (decision block **172**). If the weight is not acceptable, the WT and section lengths can be adjusted (e.g., block **168**) to change the string's geometry and achieve desired reach and pressure performance (e.g., by proceeding back to block **162**). However, if the weight is acceptable, the CT string design **174** may be output. The user can define desired objectives and weight of those objectives (e.g., prioritize maximizing WOB or prioritize minimizing the net weight). The adjustments of the second stage can be automated to repeatedly iterate on a CT string design **174** in an automatic fashion, delivering a CT string design **174** in seconds or a fraction of a second.

[0062] A third stage (e.g., the Optimize CT String based on a CT string fatigue engine and Cost block **176**) takes the CT string design **174** provided by the second stage **158** and subjects it to the MP **156** provided by the first stage **144** using a CT string fatigue simulation engine (e.g., indicated as CoilLIFE in the figures). The third stage **176** performs fine-tuning of the existing design to maximize fatigue life. The third stage **176** may also perform fine-tuning to minimize net weight and cost. In effect, the third stage **176** is an optimization stage that may, in certain embodiments, be incorporated into the second stage **158** depending on back-end implementation and optimization methodology.

[0063] As illustrated in FIG. **9**, in certain embodiments, the third stage **176** may include running the CT string design **174** in the MP **156** to 100% CT string fatigue profile (block **178**). Then, various KPIs may be calculated (block **180**) and a determination may be made as to whether the calculated KPIs are acceptable (decision block **182**). If the calculated KPIs are acceptable, the optimized CT string design **174** may be the final deliverable **184**. However, if the calculated KPIs are not acceptable, the CT string design **174** may be further optimized based on the CT string fatigue profile (block **186**) and a reconfirmation that reach and logistics limits are met may be made (**188**) before proceeding back to block **178**.

[0064] A solution was developed to fulfill the goal presented in block **158** of FIG. **9**. In particular, given a particular MP **156** (i.e., hole survey, completion, tubing forces), the proposed algorithm provides an optimized geometry of the CT string **12**. First, an initial CT string design of a given OD, length, and material is proposed. Then, the geometry (i.e., the wall thickness along the CT string **12**) will be changed iteratively to optimize on the following properties: maximum depth, maximum pull, maximum WOB, YS, total weight of the string. Other implementations may fix other parameters (e.g., wall thickness) and sensitize to optimize over the rest of the parameters (e.g., OD, material, length). Other implementations may also optimize for KPIs such as minimizing circulating pressure for an operating envelope of flow rates and fluids, annular velocity for a given completion geometry, and even cost.

[0065] FIG. **10** illustrates an optimization workflow **190** utilizing the Mission Profile Generator and the CT String Design and Optimization Tool, as described in greater detail herein. As illustrated in FIG. **10**, the optimization workflow **190** may include cyclic steps where a TFM **164** acts on a CT string design **174** (block **192**) to determine variables of interest, for which an objective function is defined (block **194**), the value of which is optimized by an Optimizer (block **196**) to generate data points that may be interpolated (block **198**) to create a continuous curve that may be discretized to create a JavaScript Object Notation (JSON) (block **200**), which may be used to update the CT string design **174**.

[0066] The embodiments described herein alter a continuous design of a CT string **12** before discretizing it into a specific CT string design **174** that can be manufactured. FIG. **11** illustrates a process of a continuous solution (e.g., the continuous curves on the left) to a discretized design (e.g., the discretized string design on the right). It is noted that the discretized values on the right are based on the existing wall thicknesses that CT pipe suppliers are capable of manufacturing. Therefore, this step is indispensable to producing an actually manufacturable CT pipe. The string design may be tested through the TFM **164** to compute the various KPIs mentioned earlier. These KPIs may then be combined into an objective function to obtain a score that evaluates the general performance of a CT string design **174** and helps comparing two different CT string designs **174**. In addition to TFM, other models can be used to calculate KPIs for the string design.

[0067] The CT String Design and Optimization Tool described herein may be used in a workflow, the purpose of which is to create one or more standardized CT string designs **174** that will meet the operational requirements of a constrained geography and/or job type. For example, consider the geography of a basin that includes several countries. These countries, historically, might be purchasing 20+ unique varieties of CT strings **12** each year. The workflow could design standardized CT strings **12** that meet the operational requirements of all the countries in that basin. Instead of 20+ unique varieties, the workflow may find that five standardized designs could meet all the operational requirements for the basin. In addition, the workflow may use the KPIs of the CT string Design and Optimization Tool to compare the standardized designs against the 20+ CT strings **12** that have been historically used in the basin; this would require using the basin's mission profile. The standardized designs could also be validated by input from the technical experts and domains in the basin. The standardized designs could also be used to secure better pricing in the procurement of future CT strings **12**.

[0068] FIG. **12** illustrates an example of a workflow **202** for developing standardized CT string designs at a geographic level (e.g., with basin geography selected for the example). For example, the workflow **202** may begin with Collect Requirements **204** (e.g., Cluster Locations by CT OD Size **206**, Cluster Locations by TD **208**, and Collect Worst-Case for each Cluster Location **210**), which may be used as inputs to Collect Strings for Comparison **212** (e.g., including to Collect historical CT string designs **174** for each cluster) and, for each clustered CT OD and basin, incorporating the processing steps **144**, **158**, **176** of the workflow **142** described above with reference to FIG. **9**. In addition, for each clustered CT OD and basin, the CT string data collected in block **212** may be used to Compute KPIs for historical CT string designs **174** (block **216**).

[0069] From there, an Initial Deliverable **218** may include a proposed CT string design **174** (e.g., per CT OD and basin cluster) from the workflow **142** and the computed KPIs for the proposed CT string design **174**. Then, a Cost Estimate **220** for the proposed CT string design **174** may be performed based on historical CT string designs **174**. In addition, the proposed CT string design **174** may be validated with technical experts and domains who may share standardized CT strings with their respective basin (block **222**), which may be requested based on local job designs. Then, a Final Deliverable **224** may include a finalized CT string by basin, a forecast of orders of CT strings per year, and a review of quotes from CT pipe manufacturers.

[0070] Although certain shaded blocks (e.g., blocks **124**, **126**, **132**, **144**, **148**, **154**, **158**, **176**, and **216**) in the figures illustrating the various workflows described herein are intended to designate processing steps that may be at least partially automated (e.g., by utilizing the analysis module(s) **62**, for example, executed by a CT design analysis system **42**, as described in greater detail herein), some of the other blocks may also be at least partially automated to further optimize the design of CT strings **12**. For example, in certain embodiments, the Cost Estimate **220** functionality may also be performed automatically.

[0071] The embodiments described here optimize CT string designs **174** that can outperform current CT string designs, thereby extending the useful life of a CT string **12** and reducing cost of service delivery (e.g., extending the CT string **12** life by, for example, 20%). In particular, CT string design domain expertise may be captured by the CT String Design and Optimization Tool by, for example, being programmed with algorithms that are capable of utilizing machine learning to automatically identify relationships between various types of CT-related data, as described in greater detail herein.

[0072] In general, the embodiments described herein eliminate a majority of the manual toil required by conventional techniques and reduce the process of designing, optimizing, and validating CT string designs **174**. For example, a CT string design currently takes approximately four hours to design and validate. Given that hundreds of varieties of CT strings may be purchased per year, potentially 1,000 (or more) man-hours (e.g., or more than 100 man-days) may be dedicated annually to such CT string designs and associated validations. The embodiments described herein may reduce the process to approximately one hour to design and validate, yielding time savings of approximately 75% or reducing the effort to only 25 man-days or so per year.

[0073] The embodiments described herein may also extract additional value from various discrete engines, simulators, and models through their integration in the CT string design engine and workflows described herein. Furthermore, standardizing CT string designs will reduce the variety of such designs. These standardized designs may then be leveraged by procurement and sourcing functions to secure lower pricing with CT pipe manufacturers.

[0074] The specific embodiments described above have been illustrated by way of example, and it should be understood that these embodiments may be susceptible to various modifications and alternative forms. It should be further understood that the claims are not intended to be limited to the particular forms disclosed, but rather to cover all modifications, equivalents, and alternatives falling within the spirit and scope of this disclosure.

[0075] The techniques presented and claimed herein are referenced and applied to material objects and concrete examples of a practical nature that demonstrably improve the present technical field and, as such, are not abstract, intangible or purely theoretical. Further, if any claims appended to the end of this specification contain one or more elements designated as "means for [perform]ing [a function] . . . " or "step for [perform]ing [a function] . . . ", it is intended that such elements are to be interpreted under 35 U.S.C. 112(f). However, for any claims containing elements designated in any other manner, it is intended that such elements are not to be interpreted under 35 U.S.C. 112(f).

1. A method, comprising:

(a) generating a mission profile for a coiled tubing (CT) string for deployment in a well based on CT analytics;

(b) creating a CT string design for the CT string based at least in part on a plurality of operational parameters of the well, wherein the CT string design of the CT string defines a plurality a physical characteristics of the CT string; and

(c) adjusting one or more of the plurality of physical characteristics of the CT string design of the CT string based at least in part on the generated mission profile for the CT string and a predicted life cycle of the CT string.

2. The method of claim **1**, wherein the mission profile for the CT string is generated based at least in part on a location and environment of the well, a basin of the well, or some combination thereof.

3. The method of claim **1**, wherein the plurality of operational parameters of the well comprise a hole survey for the well, a total depth of the well, a maximum anticipated wellhead pressure of the well, a maximum reservoir pressure of the well, a maximum temperature of the well, a maximum weight-on-bit of the well, a maximum torque-on-bit of the well, a maximum pump rate of the well, a type of one or more fluids pumped into the well, a minimum annular velocity of the well, a degree to which the well operates in a sour environment, physical characteristics of casings of the well, whether the well is an offshore well or an onshore well, whether the CT is deployed from a fixed platform or a moving vessel, a type of one or more downhole well tools used, or some combination thereof.

4. The method of claim **1**, wherein the plurality a physical characteristics of the CT string comprise a yield strength of metal of the CT string, an outer diameter of the CT string, a wall thickness of the CT string, a length of the CT string, or some combination thereof.

5. The method of claim **1**, wherein (b) creating a CT string design for the CT string comprises confirming that the CT string design will be capable of a minimum desired reach.

6. The method of claim **1**, wherein (b) creating a CT string design for the CT string comprises confirming logistical limits associated with the CT string design.

7. The method of claim **1**, wherein (b) creating a CT string design for the CT string comprises confirming that a weight of the CT string design is acceptable.

8. The method of claim **1**, wherein the one or more of the plurality of physical characteristics of the CT string design of the CT string are adjusted based at least in part on confirmation that one or more key performance indicators for the CT string design are acceptable.

9. The method of claim **1**, comprising performing steps (a)-(c) for each of a plurality of combinations of cluster locations, basin identifications, and CT outer diameter size of other CT string designs having similar cluster locations and basin identifications as the well, and having a similar CT outer diameter as the CT string design.

10. A coiled tubing (CT) design analysis system, comprising:

one or more processors configured to execute processor-executable instructions stored in memory of the CT design analysis system, wherein the processor-executable instructions, when executed by the one or more processors, cause the CT design analysis system to:

(a) generate a mission profile for a coiled tubing (CT) string for deployment in a well based on CT analytics;

(b) create a CT string design for the CT string based at least in part on a plurality of operational parameters of the well, wherein the CT string design of the CT string defines a plurality a physical characteristics of the CT string; and

(c) adjust one or more of the plurality of physical characteristics of the CT string design of the CT string based at least in part on the generated mission profile for the CT string and a predicted life cycle of the CT string.

11. The CT design analysis system of claim **10**, wherein the mission profile for the CT string is generated based at least in part on a location and environment of the well, a basin of the well, or some combination thereof.

12. The CT design analysis system of claim **10**, wherein the plurality of operational parameters of the well comprise a hole survey for the well, a total depth of the well, a maximum anticipated wellhead pressure of the well, a maximum reservoir pressure of the well, a maximum temperature of the well, a maximum weight-on-bit of the well, a maximum torque-on-bit of the well, a maximum pump rate of the well, a type of one or more fluids pumped into the well, a minimum annular velocity of the well, a degree to which the well operates in a sour environment, physical characteristics of casings of the well, whether the well is an offshore well or an onshore well, whether the CT is deployed from a fixed platform or a moving vessel, a type of one or more downhole well tools used, or some combination thereof.

13. The CT design analysis system of claim **10**, wherein the plurality a physical characteristics of the CT string comprise a yield strength of metal of the CT string, an outer diameter of the CT string, a wall thickness of the CT string, a length of the CT string, or some combination thereof.

14. The CT design analysis system of claim **10**, wherein (b) creating a CT string design for the CT string comprises confirming that the CT string design will be capable of a minimum desired reach.

15. The CT design analysis system of claim **10**, wherein (b) creating a CT string design for the CT string comprises confirming logistical limits associated with the CT string design.

16. The CT design analysis system of claim **10**, wherein (b) creating a CT string design for the CT string comprises confirming that a weight of the CT string design is acceptable.

17. The CT design analysis system of claim **10**, wherein the one or more of the plurality of physical characteristics of the CT string design of the CT string are adjusted based at least in part on confirmation that one or more key performance indicators for the CT string design are acceptable.

18. The CT design analysis system of claim **10**, wherein the processor-executable instructions, when executed by the one or more processors, cause the CT design analysis system to perform steps (a)-(c) for each of a plurality of combinations of cluster locations, basin identifications, and CT outer diameter size of other CT string designs having similar cluster locations and basin identifications as the well, and having a similar CT outer diameter as the CT string design.

19. A method, comprising:

(a) generating a mission profile for a coiled tubing (CT) string for deployment in a well based on CT analytics, wherein the mission profile for the CT string is generated based at least in part on a location and environment of the well, a basin of the well, or some combination thereof;

(b) creating a CT string design for the CT string based at least in part on a plurality of operational parameters of the well, wherein the CT string design of the CT string defines a plurality a physical characteristics of the CT string; and

(c) adjusting one or more of the plurality of physical characteristics of the CT string design of the CT string based at least in part on the generated mission profile for the CT string, a predicted life cycle of the CT string, and confirmation that one or more key performance indicators for the CT string design are acceptable.

20. The method of claim **19**, comprising performing steps (a)-(c) for each of a plurality of combinations of cluster locations, basin identifications, and CT outer diameter size of other CT string designs having similar cluster locations and basin identifications as the well, and having a similar CT outer diameter as the CT string design.

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