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(54) **COUPLING SYSTEM FOR ARTICULATING PIPE JOINT**

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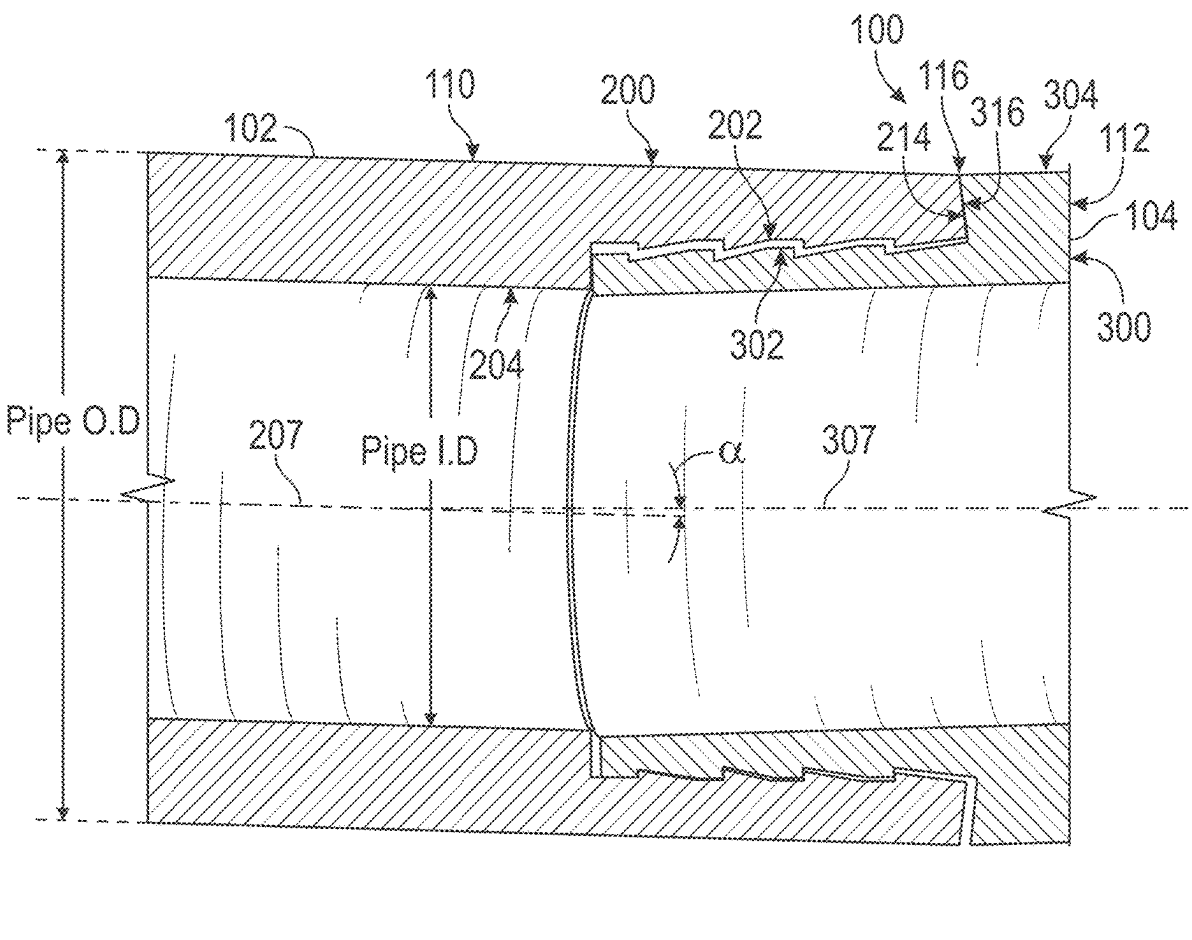
(52) **U.S. Cl.**
CPC ............. ***F16L 37/091*** (2013.01); ***F16L 1/036*** (2013.01); ***F16L 37/50*** (2013.01)

(57) **ABSTRACT**

Coupling systems for pipes that are press fit together in trenchless tunneling operations and which provide for the construction of curved pipelines can include a pipe with a pipe axis, a first end portion and a second end portion. The second end portion includes a female coupler having an inner wall surface and a set of coupler features formed on the inner wall surface, the coupler features including a plurality of teeth and a plurality of ramp surfaces between the teeth. The second end portion of the pipe includes a radially-extending distal end surface. The female coupler further includes a radially-extending shelf formed in the inner wall surface on an opposite side of the coupler features from the distal end surface. The distal end surface and the shelf are angled relative to a radially-extending reference line that is perpendicular to the pipe axis.



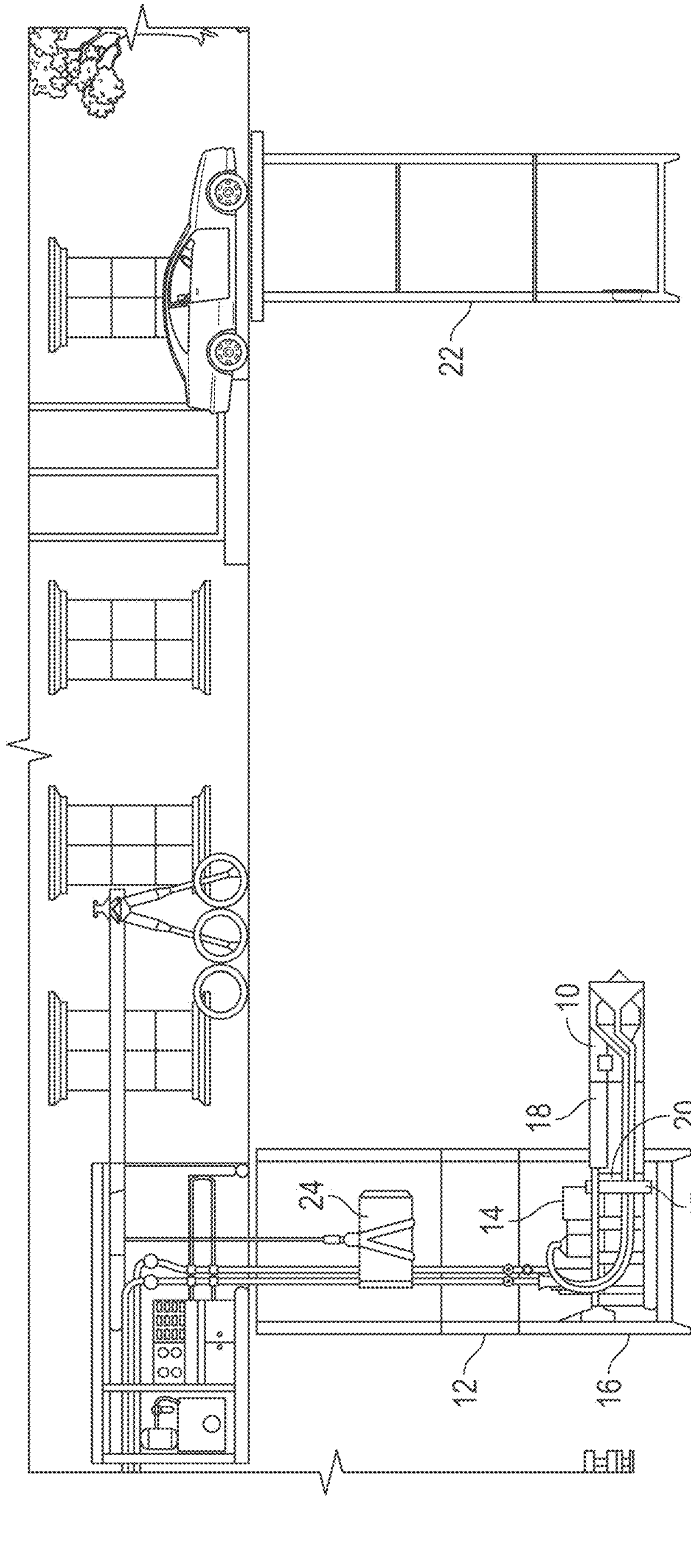



FIG. 1

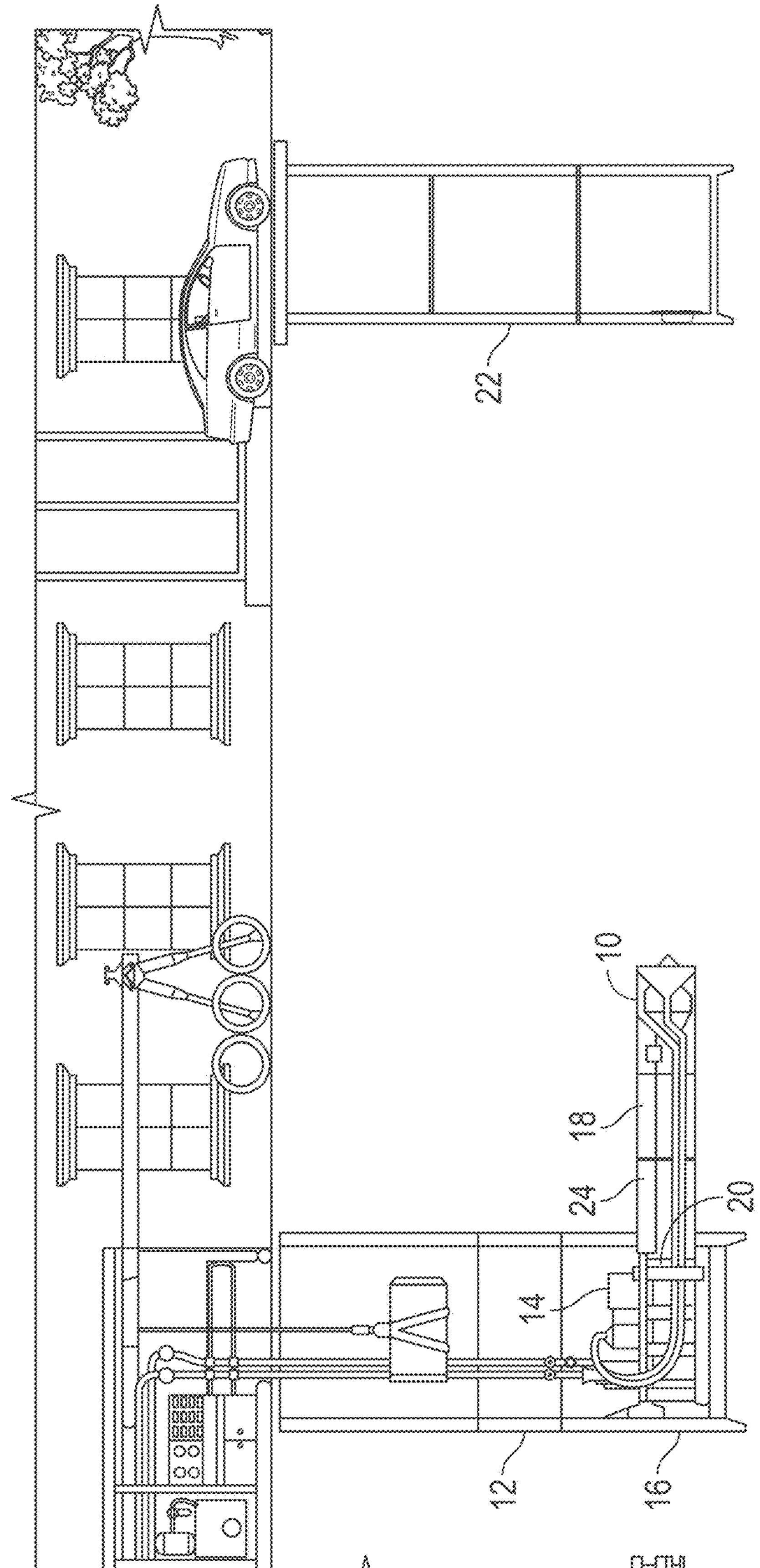



FIG. 2

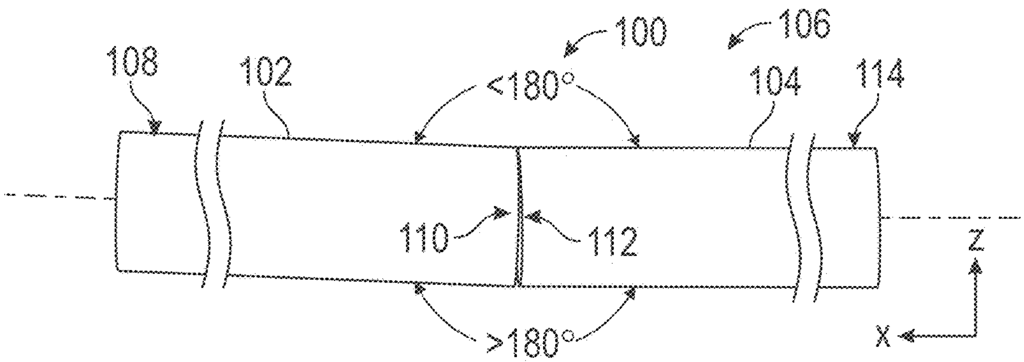

100
106
108
102
<180°
104
114
110
112
z
x
>180°

FIG. 3

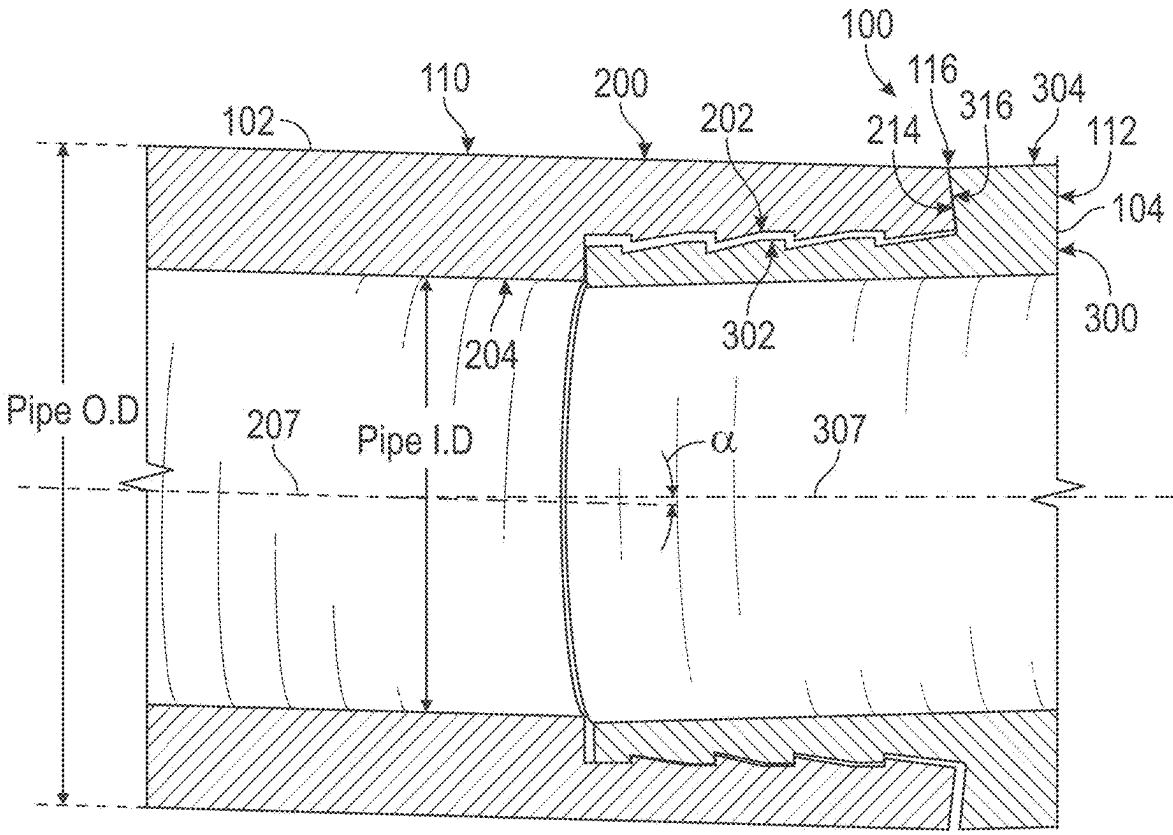
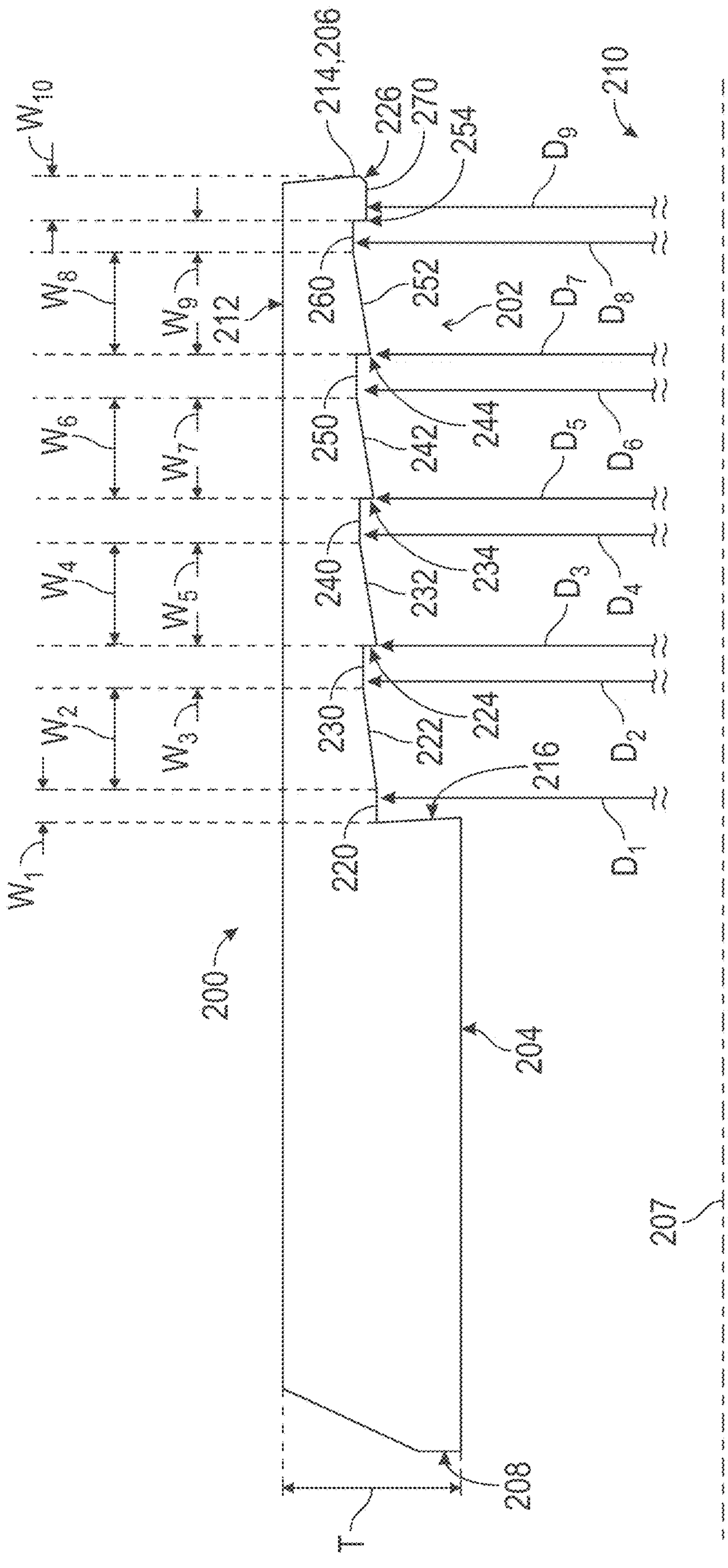

100
116
304
110
200
202
316
102
214
112
104
300
204
302
Pipe O.D
207
Pipe I.D
α
307

FIG. 4



200
202
204
207
208
210
212
214,206
216
220
222
224
226
230
232
234
240
242
244
250
252
254
260
270
T
$W_1$
$W_2$
$W_3$
$W_4$
$W_5$
$W_6$
$W_7$
$W_8$
$W_9$
$W_{10}$
$D_1$
$D_2$
$D_3$
$D_4$
$D_5$
$D_6$
$D_7$
$D_8$
$D_9$


FIG. 5

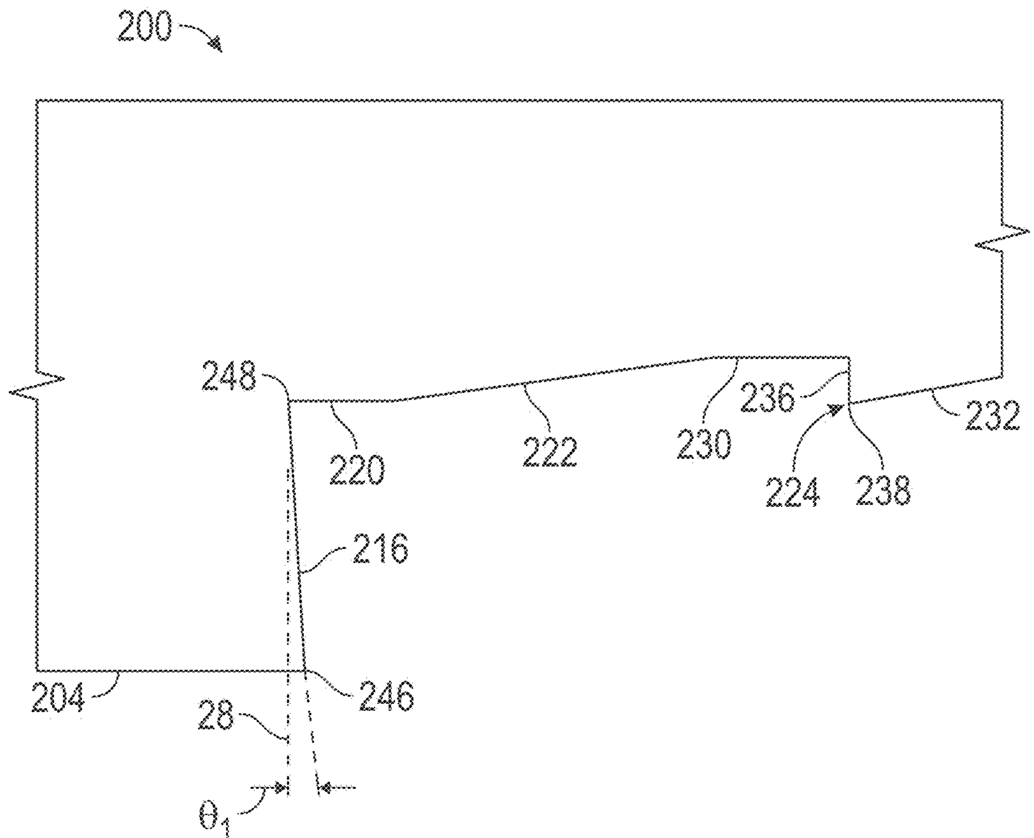

200
248
236
232
230
220
222
224
238
216
204
246
28
$\theta_1$

FIG. 6

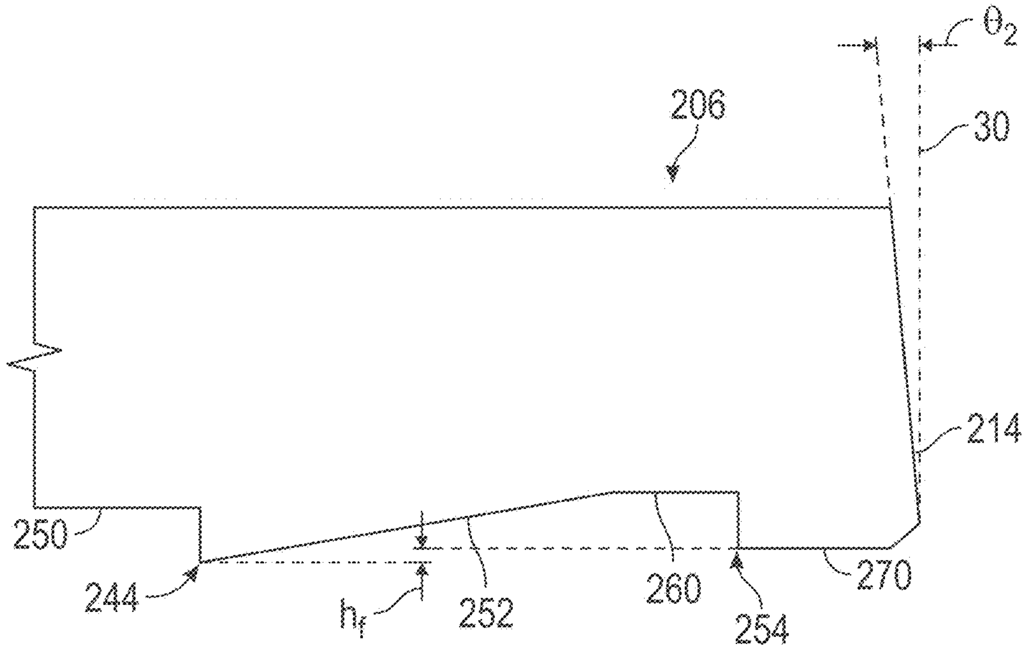

$\theta_2$
206
30
214
250
244
$h_f$
252
260
254
270

FIG. 7

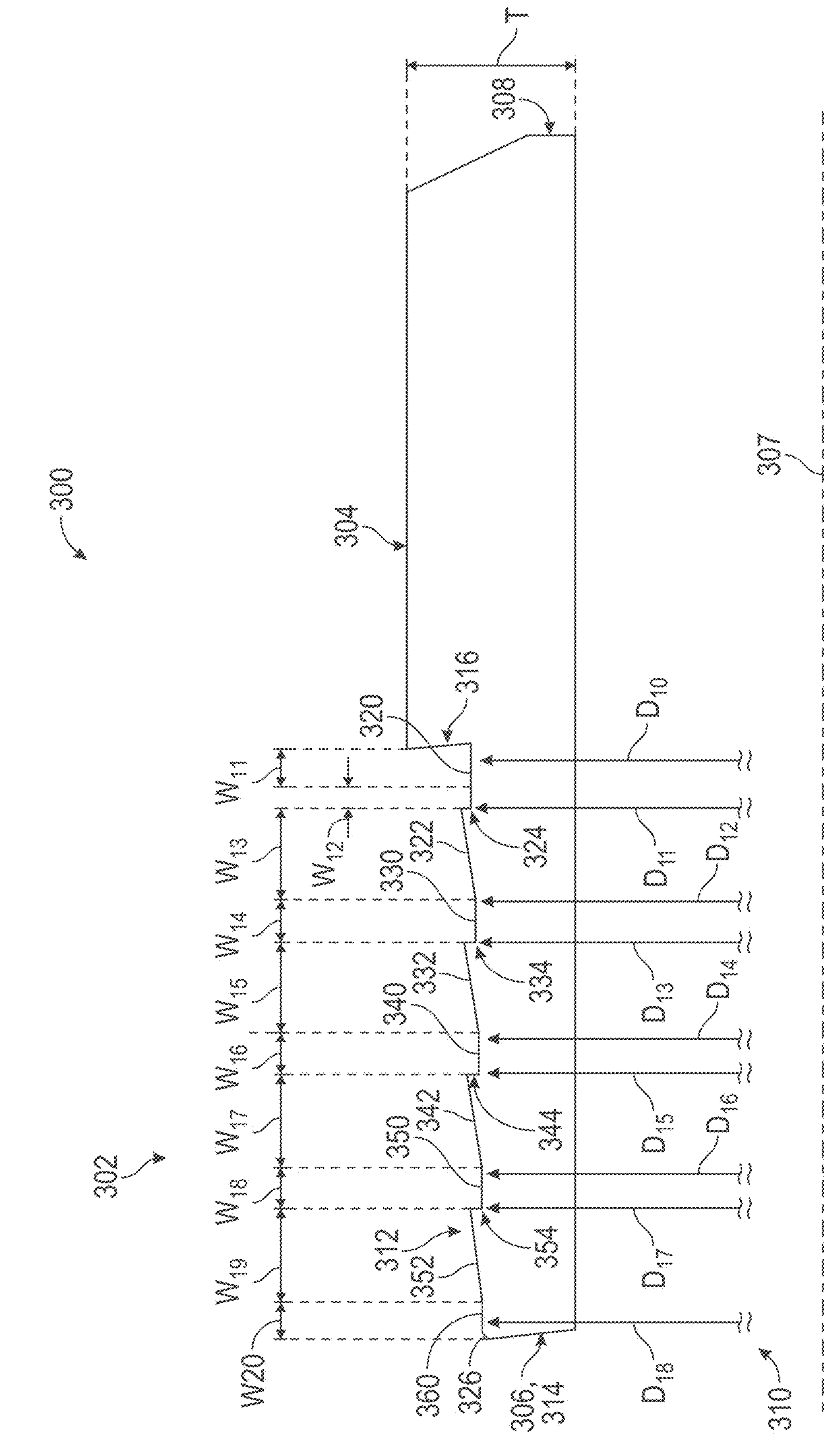

300
302
304
306, 314
307
308
310
312
316
320
322
324
326
330
332
334
340
342
344
350
352
354
360
T
W11
W12
W13
W14
W15
W16
W17
W18
W19
W20
D10
D11
D12
D13
D14
D15
D16
D17
D18

FIG. 8

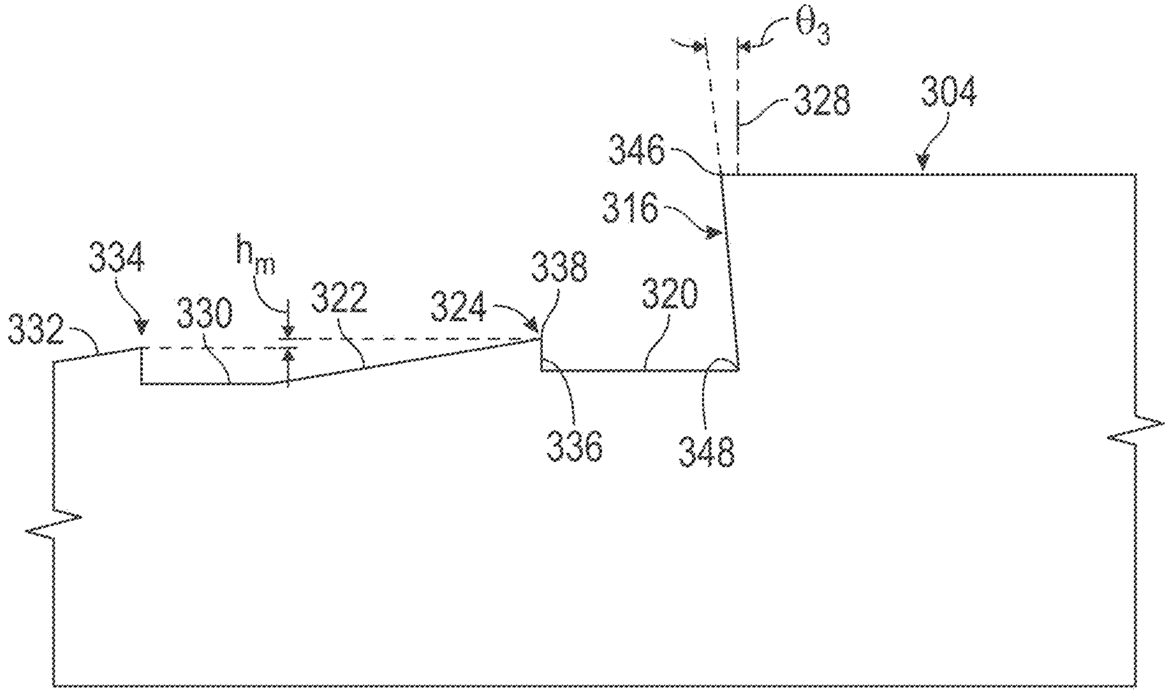

θ3
328
304
346
316
334
hm
322
338
324
320
332
330
336
348

FIG. 9

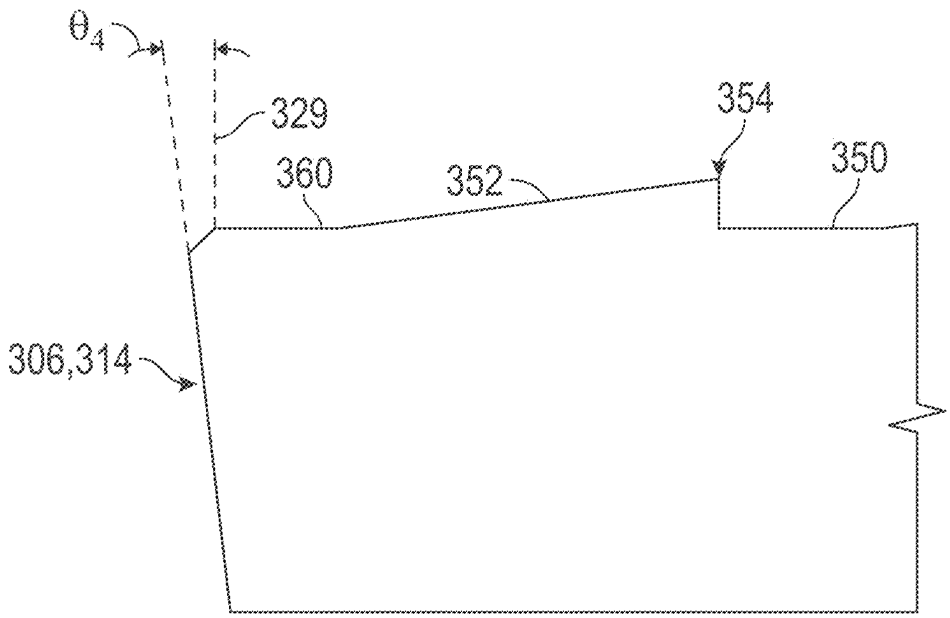

θ4
329
354
360
352
350
306,314

FIG. 10

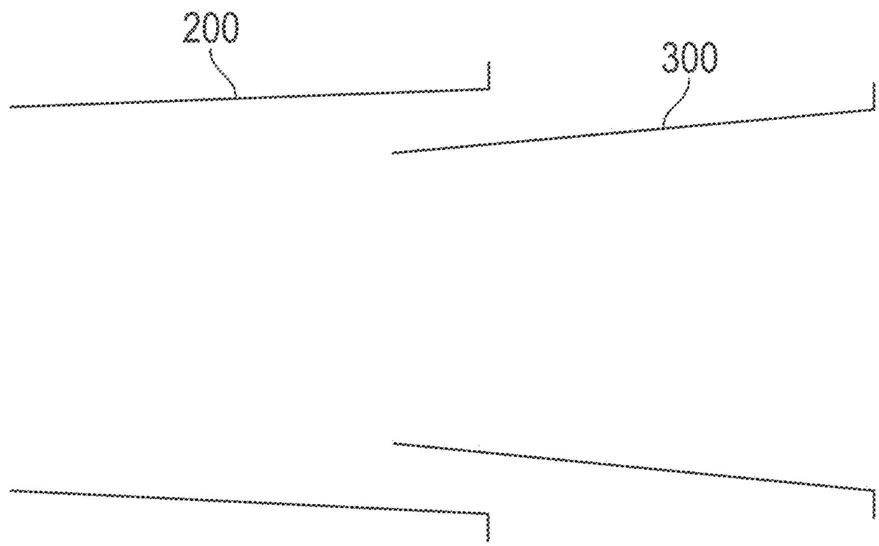



FIG. 11

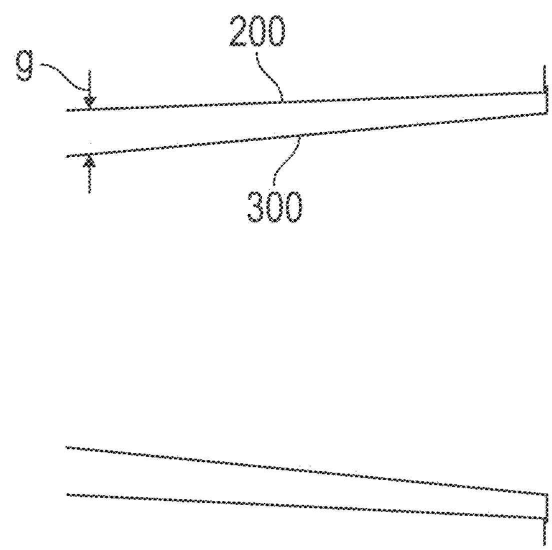



FIG. 12

# COUPLING SYSTEM FOR ARTICULATING PIPE JOINT

## CROSS REFERENCE TO RELATED APPLICATIONS

**[0001]** This application is a continuation of International Application No. PCT/US2023/078717, filed Nov. 3, 2023, which claims the benefit of U.S. Provisional Application No. 63/423,386, filed Nov. 7, 2022. Each of the above applications is incorporated herein by reference in its entirety.

## FIELD

**[0002]** The present disclosure relates to coupling systems for pipes that are press fit together in tunneling operations and that facilitate the construction of curved pipelines.

## BACKGROUND

**[0003]** Tunneling and microtunneling are trenchless tunnel construction techniques in which a shaft or tunnel is bored and sections of pipe are inserted into the shaft as boring progresses. Tunnel boring machines may have an operator onboard as the machine cuts through the ground. In microtunneling the diameter of the shaft may be too small to permit a human operator to ride along on the machine, and the machine may instead be controlled remotely from outside the shaft. The pipe sections placed in the tunnel form a protective casing for the tunnel, which can then accommodate other conduits, such as for utilities including water, sewer, electrical lines, fiber optic cables, etc. Tunneling and microtunneling can be advantageous when it is desirable to minimize ground subsidence and/or upheaval, such as when tunneling beneath buildings, roads, railroad tracks, etc. However, the pipes traditionally used in tunneling applications can curve only slightly, if at all, making the construction of curved tunnels difficult or impossible. Accordingly, there exists a need for improved coupling systems for pipes in tunneling applications.

## SUMMARY

**[0004]** Certain examples of the present disclosure pertain to coupling systems for pipes that are press fit together in trenchless tunneling operations and which provide for the construction of curved pipelines. In a representative example, a pipe comprises a pipe axis; a first end portion and a second end portion, the second end portion comprising a female coupler, the female coupler comprising an inner wall surface and a set of coupler features formed on the inner wall surface, the coupler features comprising a plurality of teeth and a plurality of ramp surfaces between the teeth, the first end portion of the pipe defining a pipe opening; the second end portion of the pipe comprising a radially-extending distal end surface; the female coupler further comprising a radially-extending shelf formed in the inner wall surface on an opposite side of the coupler features from the distal end surface; wherein the distal end surface and the shelf are angled relative to a radially-extending reference line that is perpendicular to the pipe axis.

**[0005]** In another representative example, a pipe comprises a pipe axis; a first end portion and a second end portion, the first end portion comprising a male coupler, the male coupler comprising an outer wall surface and a set of coupler features formed on the outer wall surface, the coupler features comprising a plurality of ramp surfaces and teeth, the first end portion of the pipe defining a pipe opening; the first end portion of the pipe comprising a radially-extending distal end surface; the male coupler further comprising a radially-extending shelf formed in the outer wall surface on an opposite side of the coupler features from the distal end surface; wherein the distal end surface and the shelf are angled relative to a radially-extending reference line that is perpendicular to the pipe axis.

**[0006]** In another representative example, a pipe system comprises a first pipe, comprising: a first pipe axis; a first end portion and a second end portion, the second end portion comprising a female coupler, the female coupler comprising an inner wall surface and a set of first coupler features formed on the inner wall surface, the first coupler features comprising a plurality of teeth and a plurality of ramp surfaces between the teeth, the first end portion of the first pipe defining a first pipe opening; the second end portion of the first pipe comprising a radially-extending distal end surface; the female coupler further comprising a radially-extending shelf formed in the inner wall surface on an opposite side of the first coupler features from the distal end surface; wherein the distal end surface and the shelf are angled relative to a radially-extending reference line that is perpendicular to the first pipe axis; and a second pipe comprises a second pipe axis; a first end portion and a second end portion, the first end portion comprising a male coupler, the male coupler comprising an outer wall surface and a set of coupler features formed on the outer wall surface, the coupler features comprising a plurality of ramp surfaces and teeth, the first end portion of the second pipe defining a pipe opening; the first end portion of the second pipe comprising a radially-extending distal end surface; the male coupler further comprising a radially-extending shelf formed in the outer wall surface on an opposite side of the coupler features from the distal end surface; wherein the distal end surface and the shelf of the male coupler are angled relative to a radially-extending reference line that is perpendicular to the second pipe axis; wherein the male coupler of the second pipe is received within the female coupler of the first pipe such that the male coupler features engage the female coupler features to form a pipe joint.

**[0007]** In another representative example, a pipe comprises a first end portion comprising a female coupler, the female coupler comprising an inner wall surface and a set of coupler features formed on the inner wall surface, the first end portion of the pipe defining a pipe opening; the pipe comprising a radially-extending shelf formed in the inner wall surface on an opposite side of the coupler features from the pipe opening; wherein the coupler features comprise a repeating unit of, in a direction toward the pipe opening, a radially-extending tooth surface and a ramp surface that extends from the tooth surface to an annular surface, wherein a next radially-extending tooth surface extends from the annular surface.

**[0008]** In another representative example, a pipe comprises a pipe axis; a female coupler mounted to or formed in a first end of the pipe, the female coupler comprising an inner wall surface and a set of coupler features formed on the inner wall surface, the coupler features comprising a plurality of ramp surfaces and teeth, the first end of the pipe defining a pipe opening; the first end of the pipe comprising a distal end and a radially-extending shelf formed in the inner wall surface on an opposite side of the coupler features from the distal end; the coupler features comprising, in a

direction from the shelf toward the distal end, a first annular surface having a first annular surface diameter that is constant moving in the direction toward the distal end, a first ramp surface with a first ramp surface diameter that increases in the direction toward the distal end, a second annular surface having a second annular surface diameter that is constant moving in the direction toward the distal end, a first tooth comprising a first tooth surface extending radially from the second annular surface toward the pipe axis, and a second ramp surface extending from the first tooth surface to a third annular surface in the direction toward the distal end.

**[0009]** In another representative example, a pipe system comprises a first pipe comprising a female coupler having a distal end and a radially-extending shelf formed in an inner wall surface of the first pipe, the shelf being spaced apart from the distal end along a longitudinal axis of the first pipe; a second pipe comprising a male coupler received in the female coupler of the first pipe to form a joint; the female coupler of the first pipe comprising a plurality of tooth surfaces extending radially inwardly from annular surfaces formed in the inner wall surface of the first pipe; the male coupler of the second pipe comprising a plurality of radially-extending tooth surfaces formed in an outer wall surface of the second pipe, the tooth surfaces of the second pipe engaging the tooth surfaces of the first pipe, wherein the annular surfaces of the second pipe are axially aligned with annular surfaces of the first pipe, and wherein gaps measured in the radial direction between the annular surfaces of the second pipe and the axially aligned annular surfaces of the first pipe increase moving in a direction from the distal end of the first pipe toward the shelf of the first pipe.

**[0010]** In another representative example, a pipe system comprises a first pipe comprising a female coupler having a distal end and a radially-extending shelf formed in an inner wall surface of the first pipe, the shelf being spaced apart from the distal end along a longitudinal axis of the first pipe; a second pipe comprising a male coupler received in the female coupler of the first pipe to form a joint; the female coupler of the first pipe comprising a plurality of tooth surfaces extending radially inwardly from annular surfaces formed in the inner wall surface of the first pipe; the male coupler of the second pipe comprising a plurality of radially-extending tooth surfaces formed in an outer wall surface of the second pipe, the tooth surfaces of the second pipe engaging the tooth surfaces of the first pipe, wherein radial heights of the tooth surfaces of the first pipe are greater than radial heights of the tooth surfaces of the second pipe.

**[0011]** In another representative example, a pipe system comprising: a first pipe comprising a female coupler having a distal end and a radially-extending shelf formed in an inner wall surface of the first pipe, the shelf being spaced apart from the distal end along a longitudinal axis of the first pipe; a second pipe comprising a male coupler received in the female coupler of the first pipe to form a joint; the female coupler of the first pipe comprising a plurality of tooth surfaces extending radially inwardly from annular surfaces formed in the inner wall surface of the first pipe; the male coupler of the second pipe comprising a plurality of radially-extending tooth surfaces formed in an outer wall surface of the second pipe, the tooth surfaces of the second pipe engaging the tooth surfaces of the first pipe, wherein the male coupler comprises a first annular surface nearest an opening defined by the second pipe, the female coupler comprises a first annular surface nearest the shelf of the female coupler, and wherein a gap defined between the first annular surface of the male coupler and the first annular surface of the female coupler is 70% to 110% of a radial height of the tooth surfaces of the female coupler.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0012]** FIGS. **1** and **2** are schematic side elevation views of an exemplary microtunneling project.

**[0013]** FIG. **3** is a perspective view of an example of a pipe system with two pipes coupled together at a joint and angulated relative to each other.

**[0014]** FIG. **4** is a cross-sectional side elevation view through the joint between the pipes in FIG. **3**.

**[0015]** FIG. **5** is a partial cross-sectional view of an example of a female coupler.

**[0016]** FIG. **6** is a magnified cross-sectional view of a proximal portion of the female coupler of FIG. **5**.

**[0017]** FIG. **7** is a magnified cross-sectional view of a distal portion of the female coupler of FIG. **5**.

**[0018]** FIG. **8** is a partial cross-sectional view of an example of a male coupler.

**[0019]** FIG. **9** is a magnified cross-sectional view of a proximal portion of the male coupler of FIG. **8**.

**[0020]** FIG. **10** is a magnified cross-sectional view of a distal portion of the male coupler of FIG. **8**.

**[0021]** FIGS. **11** and **12** are schematic representations of the female coupler of FIG. **5** and the male coupler of FIG. **8** as cones.

## DETAILED DESCRIPTION

### Explanation of Terms

**[0022]** The following explanations of terms are provided to assist in understanding the present disclosure. For purposes of this description, certain aspects, advantages, and novel features of the embodiments of this disclosure are described herein. The disclosed methods, apparatus, and systems should not be construed as being limiting in any way. Instead, the present disclosure is directed toward all novel and nonobvious features and aspects of the various disclosed embodiments, alone and in various combinations and sub-combinations with one another. The methods, apparatus, and systems are not limited to any specific aspect or feature or combination thereof, nor do the disclosed embodiments require that any one or more specific advantages be present or problems be solved.

**[0023]** Although the operations of some of the disclosed embodiments are described in a particular, sequential order for convenient presentation, it should be understood that this manner of description encompasses rearrangement, unless a particular ordering is required by specific language set forth below. For example, operations described sequentially may in some cases be rearranged or performed concurrently. Moreover, for the sake of simplicity, the attached figures may not show the various ways in which the disclosed examples can be used in conjunction with other examples.

**[0024]** As used in this disclosure and in the claims, the singular forms “a,” “an,” and “the” include the plural forms unless the context clearly dictates otherwise. Additionally, the term “includes” means “comprises.” Further, the terms “coupled” and “associated” generally mean electrically, electromagnetically, and/or physically (e.g., mechanically or chemically) coupled or linked and does not exclude the presence of intermediate elements between the coupled or associated items absent specific contrary language.

**[0025]** In some examples, values, procedures, or apparatus may be referred to as "lowest," "best," "minimum," or the like. It will be appreciated that such descriptions are intended to indicate that a selection among many alternatives can be made, and such selections need not be better or otherwise preferable to other selections.

**[0026]** In the description, certain terms may be used such as "up," "down," "upper," "lower," "horizontal," "vertical," "left," "right," and the like. These terms are used, where applicable, to provide some clarity of description when dealing with relative relationships. But, these terms are not intended to imply absolute relationships, positions, and/or orientations. For example, with respect to an object, an "upper" surface can become a "lower" surface simply by turning the object over. Nevertheless, it is still the same object.

**[0027]** Unless otherwise indicated, all numbers expressing quantities of components, forces, moments, molecular weights, percentages, temperatures, times, and so forth, as used in the specification or claims are to be understood as being modified by the term "about." Accordingly, unless otherwise indicated, implicitly or explicitly, the numerical parameters set forth are approximations that can depend on the desired properties sought and/or limits of detection under test conditions/methods familiar to those of ordinary skill in the art. When directly and explicitly distinguishing embodiments from discussed prior art, the embodiment numbers are not approximates unless the word "about" is recited.

**[0028]** Although there may be alternatives for various components, parameters, ratios, dimensions, operating conditions, etc., set forth herein, that does not mean that those alternatives are necessarily equivalent and/or perform equally well. Nor does it mean that the alternatives are listed in a preferred order unless stated otherwise.

**[0029]** Where applicable, values and relationships modified by the term "substantially" mean±10% of the stated value or relationship. The term "substantially parallel" means an angle of +10° between an object and a reference. The term "substantially perpendicular" means an angle of 80° to 100° between an object and a reference.

## Overview of the Disclosed Technology

**[0030]** The present disclosure pertains to coupling systems for pipes that are press fit together, such as in tunneling applications, which permit articulation of the coupled pipes within a selected range of motion. The coupling systems can comprise male and female couplings including a plurality of coupler features that engage when the male coupling is inserted into the female coupling. The coupling features of the female coupler can be formed in an inner wall surface of the female coupling, and can include a plurality of teeth and a plurality of ramp surfaces between the teeth. The distal end portion of the female coupling can have a radially-extending distal end surface. The female coupling can further comprise a radially-extending shelf formed in the inner wall surface on the opposite side of the coupler features from the distal end surface. The distal end surface and the shelf can be angled relative to a radially-extending reference line that is perpendicular to the pipe axis.

**[0031]** The male coupling can comprise a plurality of coupling features formed in an outer wall surface of the male coupling. The coupling features of the male coupling can also include a plurality of teeth and a plurality of ramp surfaces between the teeth. The male coupling can also comprise a distal end surface and a shelf on the opposite side of the coupling features from the distal end surface. The distal end surface and the shelf of the male coupling can also be angled relative to a radially-extending reference line that is perpendicular to the pipe axis. In certain examples, the teeth of the male coupling can decrease in height or "step down" in a direction toward the male coupler pipe opening at a higher rate than the teeth of the female coupling "step up" in the direction toward the female coupler pipe opening. As a result, there can be a gap between the male coupling features and the female coupling features when the couplers are engaged. The gap can increase in a direction toward the proximal shelf of the female coupling. The gap between the features can permit the male coupling to articulate relative to the female coupling within a selected range of motion. The angled distal end surfaces and angled shelf surfaces of the male and female couplings can also facilitate contact between these surfaces when the pipe couplings are angled, permitting transmission of jacking force along sequential pipes of a pipe system in a curved tunnel.

## Example 1: Tunnel Boring and Microtunneling

**[0032]** Tunnels are typically bored under roads, buildings, and other structures in order to install utility conduits while minimizing ground subsidence and disturbance. Such tunnels typically have a tunnel casing comprising a string of pipes that are coupled together end to end and inserted into the tunnel as boring progresses. Typical pipe diameters range from 36 inches to 96 inches or greater. When the inner diameter of the tunnel is too small to permit an operator to ride along on the tunnel boring machine, such operations are typically referred to as "microtunneling" operations.

**[0033]** With reference to FIG. **1**, in microtunneling, a microtunneling machine **10** (also referred to as a pipe-jacking machine) is placed in a pit or shaft referred to as a "launch shaft" or a "drive shaft" **12**. The microtunneling machine **10** can have a cutting head selected for tunneling through the material (e.g., soil, clay, rock, etc.) along a selected path between the launch shaft **12** and a reception shaft **22**. A hydraulic jacking rig **14** is positioned in the launch shaft **12** between a reaction wall **16** and the microtunneling machine **10**. The jacking rig **14** can have one or a plurality of hydraulic jacks **15**. In certain examples, the jacking rig **14** can be on a track or other support and/or guide positioned in the launch shaft. A first pipe **18** (also referred to as a first casing pipe) having a specified length and diameter is attached to the microtunneling machine **10**. The jacking rig **14** can engage the first pipe **18** with a coupling ring **20**. The jacking rig **14** can thrust the first pipe **18** and the microtunneling machine **10** forward through the ground along a predetermined trajectory toward the reception shaft **22**. The microtunneling machine **10** can bore a tunnel of specified diameter as it is pushed through the ground.

**[0034]** After the microtunneling machine **10** has traveled a specified distance, the hydraulic jacks **15** of the jacking rig **14** can be retracted. The specified distance can be such that a trailing end of the first pipe **18** is accessible in the launch shaft **12**, and there is sufficient space between the jacking rig **14** and the first pipe **18** to lower a second pipe **24** into the launch shaft **12**. The second pipe **24** can have coupling features on its leading end that engage coupling features on the trailing end of the first pipe **18**. In certain examples, the trailing end of the first pipe **18** can comprise a male coupler comprising a plurality of teeth configured to engage teeth of a female coupler of the leading end of the second pipe as further described below.

**[0035]** Referring to FIG. **2**, after the second pipe **24** is placed in the launch shaft the jacking rig **14** can engage the second pipe **24** with the coupling ring **20**. The second pipe **24** can be coupled to the first pipe **18** by driving the female coupler of the second pipe **24** over the male coupler of the first pipe **18** with the jacking rig **14**. The jacking rig **14** can then be used to push the second pipe **24**, the first pipe **18**, and the microtunneling machine **10** forward toward the reception shaft **22**. Additional pipes can be inserted and coupled to the pipe string in the manner above until the microtunneling machine **10** reaches the reception shaft **22**. The microtunneling machine **10** can then be removed, and the string of coupled pipes can be left in place as a tunnel casing. The launch and reception shafts can then be finished as access shafts for servicing the tunnel and the utility conduits transiting the tunnel.

**[0036]** Tunnel boring for larger diameter tunnels can proceed in a similar manner as described above, except that an operator may ride along on the tunneling machine in the shaft to control the tunneling machine.

## Example 2: Coupling System for Articulating Pipe Joint

**[0037]** Certain examples of the disclosure pertain to coupling systems for pipes that are press fit together, and which permit the two coupled pipes to articulate within a specified range about the coupling. For example, FIG. **3** illustrates two pipes **102** and **104** coupled together at a joint **100** to form a pipe system **106** (also referred to as a pipeline or a pipe string). The first pipe **102** has a first end portion **108** and a second end portion **110**. The second pipe **104** has a first end portion **112** and a second end portion **114**. The first end portion **112** of the second pipe **104** is coupled to the second end portion **110** of the first pipe **102** at the joint **100**.

**[0038]** The pipe axis of the first pipe **102** is angled relative to the pipe axis of the second pipe **104** such that the pipe system **106** is curved at the joint **100**. For purposes of illustration the pipes **102** and **104** are angled in the x-z plane such that an angle measured on the inside of the curve at the vertex is less than 180° and an angle measured on the outside of the curve at the vertex (e.g., on the opposite side of the pipe joint) is greater than 180°. This results in a relatively small curve or deviation in the axis of the pipe system **106**. By joining a plurality of pipes in this manner, it is possible to create a pipe system that defines a curved (e.g., non-straight) path between two end points, where the curvature is achieved in increments at each pipe joint.

**[0039]** FIG. **4** illustrates a cross section through the joint **100** of FIG. **3**. In FIG. **4** the second end portion **110** of the pipe **102** has a female coupler **200** comprising a plurality of coupling features generally indicated at **202** that are formed in an inner wall surface **204** of the female coupler. The first end portion **112** of the second pipe **104** has a male coupler **300** including a plurality of coupling features generally indicated at **302** that are formed in an outer wall surface **304** of the male coupler.

**[0040]** FIG. **5** illustrates a representative example of the female coupler **200** in greater detail. As noted with reference to FIG. **4** above, the female coupler **200** can comprise a plurality of coupling features generally indicated at **202** that are formed in an inner wall surface **204** of the coupler. In certain examples such as that shown in FIG. **5**, the female coupler **200** can be a ring configured for mounting to the end of a main length of pipe, such as the pipes **102** and **104**. Thus, in the illustrated example the female coupler **200** can have a first end **206** (also referred to as a distal end) and a second end **208** (also referred to as a proximal end). The second end **208** can be configured for attachment to the main length of pipe (e.g., by welding). Once attached to the pipe, the distal end **206** can define a pipe opening **210**.

**[0041]** The coupling features **202** can comprise a variety of teeth and/or ridges, sloped and/or ramped surfaces, and/or surfaces that have a constant or substantially constant diameter. The coupling features **202** can be formed in a distal end portion **212** of the female coupler. At the distal end **206** the female coupler can comprise an end surface **214** (also referred to as a distal end surface). The end surface **214** can extend radially relative to the longitudinal pipe axis **207**. Offset inwardly from the distal end **206** (to the left in FIG. **5**) the female coupler can comprise a radially-extending surface referred to hereinafter as a "shelf" or a "proximal shelf" **216**. From the shelf **216** onward in the proximal direction (e.g., toward the second end **208**) the female coupler can have a first thickness T corresponding a nominal thickness of the pipe to which the female coupler is attached. From the shelf **216** moving in a distal direction the female coupler can have a reduced thickness in the area where the coupling features are machined into the inner wall surface **204**.

**[0042]** Starting from the shelf **216** and moving in a direction toward the distal end surface **214** (e.g., in a direction toward the pipe opening), the coupler features of the female coupler can comprise a plurality of circumferentially-extending rings and/or surfaces **220**, **230**, **240**, **250**, **260**, and **270** that have a constant or substantially constant diameter, referred to hereinafter as "annular surfaces." The coupler features can also include a plurality of ramp surfaces **222**, **232**, **242**, **252**. The ramp surfaces **222**, **232**, **242**, and **252** can be sloped in the direction of the pipe opening. The slopes can be such that the diameters of the ramp surfaces increase from left to right in FIG. **5** (e.g., in a direction toward the pipe opening).

**[0043]** The coupler features can also include a plurality of teeth generally indicated at **224**, **234**, **244**, and **254**. Each tooth can comprise a radially-extending surface that is perpendicular or substantially perpendicular to the pipe axis **207**. Each tooth can also comprise an apex. In the illustrated example, the apices of the teeth can mark the transition from the radially-extending surface of the tooth to the adjacent ramp surface.

**[0044]** Thus, still referring to FIG. **5**, the female coupler can comprise, in a direction from the shelf **216** toward the distal end surface **214**, a first annular surface **220**, a first ramp surface **222**, a second annular surface **230**, a first tooth **224**, a second ramp surface **232**, a third annular surface **240**, a second tooth **234**, a third ramp surface **242**, a fourth annular surface **250**, a third tooth **244**, a fourth ramp surface **252**, a fifth annular surface **260**, a fourth tooth **254**, and a sixth annular surface **270**. In certain examples, a chamfer **226** can extend between the sixth annular surface **270** and the distal end surface **214**.

**[0045]** As noted above, each tooth can comprise a radially-extending surface and an apex. FIG. **6** illustrates the first tooth **224** by way of example. The first tooth **224** can include a radially-extending tooth surface **236** that is perpendicular or substantially perpendicular to the pipe axis **207**, and an apex **238**. The apex **238** can mark the transition between the radially-extending tooth surface **236** and the second ramp surface **232**. In the illustrated example, the first tooth **224** does not include an annular surface between the apex **238** and the second ramp surface **232**. This can facilitate angulation of the male coupler once received in the female coupler as further described below.

**[0046]** In certain examples, the distal end surface **214** and/or the shelf **216** can be angled relative to the pipe axis **207**. In certain examples, the distal end surface **214** and/or the shelf **216** can be non-perpendicular with the pipe axis **207**. In certain examples, one or both of the distal end surface **214** and the shelf **216** can be angled relative to a radially-extending reference line that is perpendicular to the pipe axis **207**. For example, FIG. **6** illustrates the shelf **216** in greater detail. The radially-extending surface of the shelf **216** can define an angle $\theta_1$ with a radially-extending reference line **28** that is perpendicular to the pipe axis. In certain examples, the angle $\theta_1$ can be 1° to 45°, such as 1° to 30°, 1° to 20°, 1° to 10°, 2° to 45°, 2° to 30°, 2° to 20°, 2° to 10°, 5° to 20°, 5° to 15°, 5° to 10°, etc. In one particular example, the angle $\theta_1$ can be 10°. In certain examples, the shelf **216** can be angled such that an apex **246** formed by the intersection of the radially-extending surface of the shelf **216** and the inner wall surface **204** of the coupler is closer to the first tooth **224** than an apex or corner **248** formed by the intersection of the first annular surface **220** and the radially-extending surface of the shelf **216**. Stated differently, the apex **246** is closer to the pipe opening than the corner **248**.

**[0047]** FIG. **7** illustrates the distal end surface **214** in greater detail. The radially-extending distal end surface **214** can define an angle $\theta_2$ with a radially-extending reference line **30** that is perpendicular to the pipe axis **207**. In certain examples, the angle $\theta_2$ can be 1° to 45°, such as 1° to 30°, 1° to 20°, 1° to 10°, 2° to 45°, 2° to 30°, 2° to 20°, 2° to 10°, 5° to 20°, 5° to 15°, 5° to 10°, etc. In one particular example, the angle $\theta_2$ can be 10°.

**[0048]** In certain examples, the angle $\theta_1$ can be greater than the angle $\theta_2$ or vice versa. In certain examples, the angles $\theta_1$ and 02 can be equal.

**[0049]** In certain examples, the annular surfaces, ramps, and teeth of the coupler features can be arranged in repeating units along the inner wall surface. For example, referring again to FIG. **5**, in the illustrated example the region of each tooth **224**, **234**, **244**, and **254** can comprise a repeating unit of a radially-extending tooth surface, a ramp surface, and an annular surface. One such repeating unit is illustrated in detail in FIGS. **5** and **6**. The repeating unit can comprise the radially-extending tooth surface **236** (FIG. **6**) of the tooth **224**, the ramp surface **232**, and the annular surface **240** (FIG. **5**). Moving in a direction toward the pipe opening, the annular surface **240** can lead directly to the next repeating unit, which is a second repeating unit comprising the radially-extending tooth surface of the tooth **234**, the ramp surface **242**, and the annular surface **250**. In the illustrated example, the female coupler can comprise a third repeating unit including the radially-extending tooth surface **244**, the ramp surface **252**, and the annular surface **260**. The illustrated female coupler can thus comprise three repeating units of coupler features as defined above in which each annular surface leads directly to the next radially-extending tooth surface, and each radially-extending tooth surface leads directly to the next ramp surface. Stated differently, the radially-extending surface of each tooth transitions immediately to the following ramp surface at the apex of the tooth without an annular surface between the radially-extending surface and the ramp surface. It should be understood that the female couplers described herein can have any number of repeating units of coupling features according to, for example, the specifications of a particular pipe system to be constructed.

**[0050]** Referring again to FIG. **5**, the various coupler features can have widths measured along the pipe axis **207**. For example, the first annular surface **220** can have a width $W_1$, the first ramp **222** can have a width $W_2$, the second annular surface **230** can have a width $W_3$, the second ramp surface **232** can have a width $W_4$, the third annular surface **240** can have a width $W_5$, the third ramp surface **242** can have a width $W_6$, the fourth annular surface **250** can have a width $W_7$, the fourth ramp surface **252** can have a width $W_8$, the fifth annular surface **260** can have a width $W_9$, and the sixth annular surface **270** can have a width $W_{10}$.

**[0051]** In certain examples, at least the widths $W_3$, $W_5$, $W_7$, and $W_9$ of the second, third, fourth, and fifth annular surfaces **230**, **240**, **250**, and **260** can be equal or substantially equal (e.g., within +10% of the specified dimension). In certain examples, the width $W_1$ of the annular surface **220** can be greater than the widths $W_3$, $W_5$, $W_7$, and $W_9$ (e.g., to facilitate receiving the corresponding annular surface **360** at the distal end of the male coupler). The width $W_{10}$ of the annular surface **270** can also be greater than the widths $W_3$, $W_5$, $W_7$, and $W_9$. In certain examples, the width $W_{10}$ of the annular surface **270** can be greater than the width $W_1$ of the annular surface **220**.

**[0052]** In certain examples, the widths $W_2$, $W_4$, $W_6$, and $W_8$ of the first, second, third, and fourth ramp surfaces **222**, **232**, **242**, and **252** can be equal or substantially equal (e.g., within ±10% of the specified dimension). In certain examples, certain of the ramp surfaces can also be longer or shorter than the other ramp surfaces depending on the particular characteristics sought. In certain examples, the ramp surfaces can have the same slope. In other examples, certain of the ramps can have a different slope than other ramps. For example, in certain examples the ramp surface **252** can have a slope that is less than the slopes of the ramp surfaces **242**, **232**, and/or **222** to facilitate insertion of the male coupler **300** into the female coupler **200**. Pipe couplers with ramp surfaces having different slopes are described in U.S. Pat. No. 10,823,320, which is incorporated herein by reference in its entirety.

**[0053]** Certain of the coupler features can also have diameters/radii measured perpendicular to the pipe axis **207**. For example, the first annular surface **220** can have a diameter $D_1$, the second annular surface **230** can have a diameter $D_2$, the first tooth **224** can have a diameter $D_3$ (e.g., measured between two diametrically opposed locations on the apex of the first tooth **224**), the third annular surface **240** can have a diameter $D_4$, the second tooth **234** can have a diameter $D_5$, the fourth annular surface **250** can have a diameter $D_6$, the third tooth **244** can have a diameter $D_7$, the fifth annular surface **260** can have a diameter $D_8$, and the sixth annular surface **270** can have a diameter $D_9$. The tooth **254** can have the same diameter Do as the sixth annular surface **270**. The diameter of the first ramp surface **222** can increase from the diameter $D_1$ to the diameter $D_2$. The diameter of the second ramp surface **232** can increase from the diameter $D_3$ to the diameter $D_4$. The diameter of the third ramp surface **242** can increase from the diameter $D_5$ to the diameter $D_6$, and the diameter of the fourth ramp surface **252** can increase from the diameter $D_7$ to the diameter $D_8$.

**[0054]** Thus, in certain examples the female coupler can comprise coupler features including, from the shelf **216** in a direction toward the distal end **206**, the first annular surface **220** having the diameter $D_1$ (the first annular surface diameter) that is constant moving in the direction toward the distal end, the first ramp surface **222** with a diameter (a first ramp surface diameter) that increases in the direction toward the distal end, the second annular surface **230** having the diameter $D_2$ (the second annular surface diameter) that is constant moving in the direction toward the distal end, the first tooth **224** comprising the first tooth surface **236** extending radially from the second annular surface **230** toward the pipe axis **207**, and the second ramp surface **232** extending from the first tooth surface **236** to the third annular surface **240** in the direction of the distal end. In this example, the first tooth **224** does not have a flat annular surface extending from its apex **238** but instead transitions immediately to the ramp surface **232**. This facilitates angulation of the male coupler relative to the female coupler as further explained below.

**[0055]** FIG. **8** illustrates the male coupler **300** in greater detail. As noted above with reference to FIG. **3**, the male coupler **300** can comprise a plurality of coupling features generally indicated at **302** that are formed in an outer wall surface **304** of the coupler. The male coupler **300** can be a ring configured for attachment to the end of a main length of pipe such as the pipes **102** and **104**, or the coupling features **302** can be machined directly into the main pipe as described above. The male coupler **300** can have a first end **306** (also referred to as a distal end) and a second end **308** (also referred to as a proximal end). In the illustrated configuration the male coupler is a ring, and the second end **308** can be configured for attachment to the main length of pipe (e.g., by welding). Once attached to the pipe, the distal end **306** can define a pipe opening **310**.

**[0056]** The coupling features **302** can comprise a variety of teeth and/or ridges, sloped and/or ramped surfaces, and/or annular surfaces having a constant or substantially constant diameter similar to the coupling features of the female coupler. The male coupling features **302** can be formed in a distal end portion **312** of the male coupler. At the distal end **306** the male coupler can comprise an end surface **314** (also referred to as a distal end surface) extending radially relative to the longitudinal pipe axis **307**. Offset inwardly from the distal end **306** (to the right in FIG. **8**) the male coupler can comprise a radially-extending surface referred to hereinafter as a "shelf" or a "proximal shelf" **316**. From the shelf **316** onward in the proximal direction (e.g., toward the second end **308**) the male coupler can have a thickness T corresponding the nominal thickness of the pipe to which the male coupler is attached. From the shelf **316** moving in a distal direction the male coupler can have a reduced thickness in the area where the coupling features are machined into the outer wall surface **304**.

**[0057]** Starting from the shelf **316** and moving in a direction toward the distal end surface **314** (e.g., in a direction toward the pipe opening), the coupler features of the male coupler can comprise a plurality of annular surfaces **320**, **330**, **340**, **350**, and **360**, having a constant or substantially constant diameter. The coupler features can also include a plurality of ramp surfaces **322**, **332**, **342**, **352**, which can be sloped in the direction of the pipe opening. The slopes can be such that the diameters of the ramp surfaces decrease from right to left in FIG. **8** (e.g., in a direction toward the pipe opening).

**[0058]** The coupler features can also include a plurality of teeth generally indicated at **324**, **334**, **344**, and **354**. Each tooth can comprise a radially-extending surface that is perpendicular or substantially perpendicular (e.g., 80° to) 110° to the pipe axis, and an apex. As with the female coupler above, the apices of the teeth can mark the transition from the radially-extending surface of the tooth to the adjacent ramp surface.

**[0059]** Thus, the male coupler can comprise, in a direction from the shelf **316** toward the distal end surface **314**, a first annular surface **320**, a first tooth **324**, a first ramp surface **322**, a second annular surface **330**, a second tooth **334**, a second ramp surface **332**, a third annular surface **340**, a third tooth **344**, a third ramp surface **342**, a fourth annular surface **350**, a fourth tooth **354**, a fourth ramp surface **352**, and a fifth annular surface **360**. In the illustrated example, the fifth annular surface **360** can be an introductory annular surface that engages the annular surface **270** to guide the male and female couplers together when the couplers are engaged. In the illustrated example, the fifth annular surface **360** can be axially aligned with the first annular surface **220** of the female coupler when the male and female couplers are fully engaged. In the illustrated example, a chamfer **326** can extend between the fifth annular surface **360** and the distal end surface **314** to facilitate insertion of the male coupler into the female coupler.

**[0060]** As noted above, each tooth of the male coupler can comprise a radially-extending surface and an apex. FIG. **9** illustrates the first tooth **324** by way of example. The first tooth **324** can include a radially-extending surface **336** that is perpendicular or substantially perpendicular to the pipe axis **307**, and an apex **338**. The apex **338** can mark the transition between the radially-extending surface **336** and the first ramp surface **322**. In the illustrated example, the first tooth **324** does not include an annular surface between the apex **338** and the second ramp surface **332**, similar to the female coupler described above.

**[0061]** In certain examples, the distal end surface **314** and/or the shelf **316** can be angled relative to the pipe axis **307**. In certain examples, the distal end surface **314** and/or the shelf **316** can be non-perpendicular with the pipe axis **307**. In certain examples, one or both of the distal end surface **314** and the shelf **316** can be angled relative to a radially-extending reference line that is perpendicular to the pipe axis **307**. For example, FIG. **9** illustrates the shelf **316** in greater detail. The radially-extending surface of the shelf **316** can define an angle $\theta_3$ with a radially-extending reference line **328** that is perpendicular to the pipe axis. In certain examples, the angle $\theta_3$ can be 1° to 45°, such as 1° to 30°, 1° to 20°, 1° to 10°, 2° to 45°, 2° to 30°, 2° to 20°, 2° to 10°, 5° to 45°, 5° to 30°, 5° to 20°, 5° to 15°, 5° to 10°, etc. In one particular example, the angle $\theta_3$ can be 8°. In certain examples, the shelf **316** can be angled such that an apex **346** formed by the intersection of the radially-extending surface of the shelf **316** and the outer wall surface **304** of the coupler is closer to the first tooth **324** than a corner **348** formed by the intersection of the first annular surface **320** and the radially-extending surface of the shelf **316**. Stated differently, the apex **346** is closer to the pipe opening than the corner **348**.

**[0062]** FIG. **10** illustrates the distal end surface **314** in greater detail. The radially-extending distal end surface **314** can define an angle $\theta_4$ with a radially-extending reference line **329** that is perpendicular to the pipe axis **307**. In certain examples, the angle $\theta_4$ can be 1° to 45°, such as 1° to 30°, 1° to 20°, 1° to 10°, 2° to 45°, 2° to 30°, 2° to 20°, 2° to 10°, 5° to 45°, 5° to 30°, 5° to 20°, 5° to 15°, 5° to 10°, etc. In one particular example, the angle $\theta_4$ can be 10°.

**[0063]** In certain examples, the angle $\theta_4$ can be greater than the angle $\theta_3$ or vice versa. In certain examples, the angles $\theta_3$ and 04 can be equal. In certain examples, the angle $\theta_2$ of the distal end surface **214** of the female coupler can be greater than the angle $\theta_3$ of the shelf **316** of the male coupler, or vice versa. For example, in certain examples the angle $\theta_3$ of the shelf **316** of the male coupler can be 50% to 100%, 60% to 100%, 70% to 100%, 80% to 100%, 90% to 100%, 50% to 95%, 60% to 95%, 70% to 95%, 50% to 90%, 60% to 90%, 70% to 90%, etc., of the angle $\theta_2$ of the female coupler distal end surface **214**. In the particular example illustrated herein, the angle $\theta_3$ of the male coupler shelf **316** is 80% of the angle $\theta_2$ of the female coupler distal end surface **214**. By making the angle $\theta_3$ of the male coupler shelf **316** different from the angle $\theta_2$ of the female coupler distal end surface **214**, the male coupler shelf **316** can come into contact with the female coupler distal end surface **214** when the pipes are angulated as further described below.

**[0064]** In certain examples, the annular surfaces, ramps, and teeth of the male coupler features can be arranged in repeating units along the outer wall surface. For example, referring again to FIG. **8**, in the illustrated example the region of each tooth **324**, **334**, **344**, and **354** can comprise a repeating unit of, in a direction toward the distal end **306**, a radially-extending tooth surface, a ramp surface, and an annular surface. One such repeating unit is illustrated in detail in FIG. **9**. The repeating unit can comprise the radially-extending tooth surface **336** of the tooth **324**, the ramp surface **322**, and the annular surface **330**. Moving in a direction toward the pipe opening, the annular surface **330** can lead directly to the next repeating unit, which is a second repeating unit comprising the radially-extending tooth surface of the tooth **334**, the ramp surface **332**, and the annular surface **340**. In the illustrated example, the male coupler can comprise a third repeating unit including the radially-extending tooth surface **344**, the ramp **342**, and the annular surface **350**, and a fourth repeating unit including the radially-extending tooth surface **354**, the ramp surface **352**, and the annular surface **360**. The illustrated male coupler can thus comprise four repeating units of coupler features as defined above in which each annular surface (except for annular surface **360**) leads directly to the next radially-extending tooth surface, and each radially-extending tooth surface leads directly to the next ramp surface. Stated differently, the radially-extending surface of each tooth transitions immediately to the following ramp surface at the apex of the tooth without an annular surface between the radially-extending surface and the ramp surface. It should be understood that the male couplers described herein can have any number of repeating units of coupling features according to, for example, the specifications of a particular pipe system to be constructed.

**[0065]** Referring again to FIG. **8**, the various coupler features can have widths measured along the pipe axis. For example, the first annular surface **320** can have a total width that is a sum of a width $W_{11}$ and a width $W_{12}$. The first ramp **322** can have a width $W_{13}$, the second annular surface **330** can have a width $W_{14}$, the second ramp surface **332** can have a width $W_{15}$, the third annular surface **340** can have a width $W_{16}$, the third ramp surface **342** can have a width $W_{17}$, the fourth annular surface **350** can have a width $W_{18}$, the fourth ramp surface **352** can have a width $W_{19}$, and the fifth annular surface **360** can have a width $W_{20}$.

**[0066]** In certain examples, at least the widths $W_{12}$, $W_{14}$, $W_{16}$, and $W_{18}$ of the first, second, third, and fourth annular surfaces **320**, **330**, **340**, and **350** can be equal or substantially equal (e.g., within ±10% of the specified dimension). In certain examples, the total combined width $W_{11}+W_{12}$ of the annular surface **320** can be greater than the widths $W_{14}$, $W_{16}$, $W_{18}$, and $W_{20}$ (e.g., to facilitate receiving the corresponding annular surface **270** at the distal end of the female coupler). For example, the width $W_{11}$ represents the distance occupied by the annular surface **270** of the female coupler when the male and female couplers are joined together, and the width $W_{12}$ represents the axial distance along which the male and female couplers may move or slide relative to each other when the pipes are angulated. The width $W_{20}$ of the annular surface **360** can also be greater than the widths $W_{12}$, $W_{14}$, $W_{16}$, and $W_{18}$. In certain examples, the total combined width $W_{11}+W_{12}$ of the annular surface **320** can be greater than the width $W_{20}$ of the annular surface **360**.

**[0067]** In certain examples, the widths $W_{13}$, $W_{15}$, $W_{17}$, and $W_{19}$ of the first, second, third, and fourth ramp surfaces **322**, **332**, **342**, and **352** can be equal or substantially equal (e.g., within ±10% of the specified dimension). In certain examples, certain of the ramp surfaces can also be longer or shorter than the other ramp surfaces depending on the particular characteristics sought. In certain examples, the ramp surfaces can have the same slope. In other examples, certain of the ramps can have a different slope than other ramps. For example, in certain examples the ramp surface **352** can have a slope that is less than the slopes of the ramp surfaces **342**, **332**, and/or **322** to facilitate insertion of the male coupler **300** into the female coupler **200** as described with reference to U.S. Pat. No. 10,823,320 incorporated by reference above.

**[0068]** Certain of the coupler features can also have diameters/radii measured perpendicular to the pipe axis **307**. For example, the first annular surface **320** can have a diameter $D_{10}$, the first tooth **324** can have a diameter $D_{11}$ (e.g., measured between two diametrically opposed locations on the apex of the first tooth **324**), the second annular surface **330** can have a diameter $D_{12}$, the second tooth **334** can have a diameter $D_{13}$, the third annular surface **340** can have a diameter $D_{14}$, the third tooth **344** can have a diameter $D_{15}$, the fourth annular surface **350** can have a diameter $D_{16}$, the fourth tooth **354** can have a diameter $D_{17}$, and the fifth annular surface **360** can have a diameter $D_{18}$. Moving in a direction from the shelf **316** toward the distal end **306**, the diameter of the first ramp surface **322** can decrease from the diameter $D_{11}$ to the diameter $D_{12}$. The diameter of the second ramp surface **332** can decrease from the diameter $D_{13}$ to the diameter $D_{14}$. The diameter of the third ramp surface **342** can decrease from the diameter $D_{15}$ to the diameter $D_{16}$, and the diameter of the fourth ramp surface **352** can decrease from the diameter $D_{17}$ to the diameter $D_{18}$.

**[0069]** Thus, in certain examples the male coupler can comprise coupler features including, from the shelf **316** in a direction toward the distal end **306**, the first annular surface **320** having the diameter $D_{10}$ (the first annular surface diameter) that is constant moving in the direction toward the distal end, the first tooth **324** comprising the first tooth surface **336** extending radially from the first annular surface **320** away from the pipe axis, the first ramp surface **322** with a diameter (a first ramp surface diameter) that decreases in the direction toward the distal end, the second annular surface **330** having the diameter $D_{12}$ (the second annular surface diameter) that is constant moving in the direction toward the distal end, and the second tooth **334** including a second tooth surface extending radially from the second annular surface **330**. In this example, the first tooth **324** does not have a flat annular surface extending from its apex **338** but instead transitions immediately to the ramp surface **322**. This facilitates angulation of the male coupler relative to the female coupler as further explained below.

**[0070]** In certain examples, the diameter of the teeth of the female coupler can increase by a specified height increment moving in a direction toward the pipe opening. For example, referring again to FIG. **7** a female tooth height increase increment $h_f$ is shown measured between the tooth **244** and the tooth **254** in the radial direction. Stated differently, the tooth height increase $h_f$ from the tooth **244** to the tooth **254** can be expressed by the difference $D_9-D_7=h_f$. In certain examples, the height difference between each sequential tooth of the female coupler can be equal or substantially equal to the height increase increment $h_f$. Similarly, the teeth of the male coupler can have a tooth height decrease increment that is the difference between the diameter of a given tooth and the diameter of the subsequent tooth in a direction toward the pipe opening of the male coupler. Referring to FIG. **9** by way of example, male tooth height decrease increment $h_m$ is shown measured between the apex of the first tooth **324** and the apex of the subsequent tooth **334**, expressed as $D_{11}-D_{13}=h_m$. In certain examples, the height difference between each sequential tooth of the male coupler can be equal or substantially equal to the tooth height decrease increment $h_m$.

**[0071]** In certain examples, the height increase increment $h_f$ of the teeth of the female coupler can be different than the height decrease increment $h_m$ of the teeth of the male coupler. In certain examples, the height decrease increment $h_m$ of the male coupler teeth is greater than the height increase increment $h_f$ of the female coupler teeth. Thus, the apices of the male coupler teeth step down in the distal direction (e.g., a direction from the shelf **316** toward the distal end surface **314**) at a higher rate than the teeth of the female coupler step up in the distal direction (e.g., the direction from the shelf **216** toward the distal end surface **214**). FIGS. **11** and **12** schematically illustrate the female and male couplers as cones. The tapered lines of the cones are straight lines connecting the apices of the teeth in a cross-sectional view of the male and female couplers. Stated differently, the tapered lines of the cones are best fit lines connecting the apices of the teeth at locations 180° apart around the circumference of the male and female couplers. As shown in FIG. **11**, the cone of the male coupler **300** is more tapered (e.g., narrows at a higher rate from right to left) than the cone of the female coupler **200**. The greater slope of the male cone results because the tooth height decrease increment $h_m$ of the male coupler teeth is greater than the tooth height increase increment $h_f$ of the female coupler teeth (e.g., $h_m>h_f$).

**[0072]** In FIG. **11** the cones of the male coupler **200** and the female coupler **300** only partially overlap, representing initial, partial engagement between the male and female couplers. FIG. **12** illustrates the cones of the male coupler **300** and the female coupler **200** fully engaged, and with the pipe axes aligned (e.g., the male and female couplers are not angulated). As shown in FIG. **12**, there can be a relatively larger gap measured in the radial direction between the male coupler and the female coupler at the proximal end of the female coupler (e.g., adjacent the shelf **216**) than at the distal end of the female coupler adjacent the end surface **214**. The gap between the male and female coupler features increases moving from the pipe opening of the female coupler toward the back (e.g., toward the proximal end) of the female coupler. The gap g defined between the male and female coupler features at the distal end of the male coupler when they are fully engaged can determine the range of angulation of the two couplers, and thus of the two pipes at the joint. The male and female couplers can thus permit a selected degree of angulation of the two pipes that is related to the gap g. In certain examples, the gap g can be measured between the annular surface **360** of the male coupler and the annular surface **220** of the female coupler when the couplers are fully engaged and axially aligned, and with the longitudinal pipe axes parallel to each other. In certain examples, the gap g can be calculated as the difference $D_1-D_{18}=g$. The gap between the annular surfaces of the male and female couplers can increase moving in a direction from the pipe opening of the female coupler toward the shelf **216**.

**[0073]** In certain examples, the gap g defined between the annular surface **360** of the male coupler and the annular surface **220** of the female coupler can be 50% to 150% of the radial height dimension of the tooth surfaces of the female coupler (e.g., the radial distance that the teeth extend above the adjacent annular surface), such as 60% to 110%, 60% to 100%, 70% to 110%, 70% to 100%, etc., of the radial height dimension of the tooth surfaces of the female coupler. The gap g can fall within similar ranges relative to the radial height dimension of the tooth surfaces of the male coupler.

**[0074]** As noted above, the gap g between the male and female couplers can determine the extent of angulation between the couplers when joined together. This is illustrated in FIG. **4**. Referring to FIG. **4**, when the male and female pipe couplers **300** and **200** are fully engaged and angulated, the joint **100** forms a curve. The coupling features of the proximal end of the male coupler and the coupling features of the distal end of the female coupler can be in contact and/or most closely spaced at the vertex on the inside of the curve formed by the two pipes (e.g., at the top of the cross-section in FIG. **4**). The coupling features of the proximal end of the male coupler and the coupling features of the distal end of the female coupler can be spaced apart by a greater amount at the vertex on the outside of the curve (e.g., at the bottom of the cross-section in FIG. **4**). In particular examples, the vertex on the inside of the curve can correspond to a distal end surface-shelf contact region **116** in which the distal end surface **214** of the female coupler and the shelf **316** of the male coupler are in contact. Conversely, the coupling features can be spaced apart by the greatest amount, but still engaged, on the opposite side of the curve, for example at the vertex on the outside of the curve. The vertex on the outside of the curve can be circumferentially offset from the distal end surface-shelf contact region **116** by 180° around the circumference of the couplers. When the couplers are angulated to the maximum extent, there may be little if any contact between the distal end surface **214** of the female coupler and the shelf **316** of the male coupler at the vertex on the outside of the curve.

**[0075]** In other examples, the dimension $h_f$ of the teeth of the female coupler can be greater than the dimension $h_m$ of the teeth of the male coupler.

**[0076]** In certain examples, the radial dimension (also referred to as the radial height) of the tooth surfaces of the female coupler can be greater than the radial height of the tooth surfaces of the male coupler. For example, in certain examples the radial dimensions of the tooth surfaces of the female coupler can be 101% to 130% of the radial dimensions of the tooth surfaces of the male coupler, such as 105% to 125%, 105% to 120%, etc. In a particular example, the radial dimensions of the tooth surfaces of the female coupler can be 115% of the radial dimensions of the tooth surfaces of the male coupler.

**[0077]** In certain examples, the angle $\theta_3$ (FIG. **9**) of the male coupler shelf **316** and/or the angle $\theta_4$ of the male coupler distal end surface **314** can be larger than the angle formed between the axes of the male and female coupler when they are angulated. For example, in FIG. **4** the axis **207** of the female coupler **200** forms an angle $\alpha$ relative to the axis **307** of the male coupler **300**. The male coupler shelf **316** can be sized and shaped such that when the male and female couplers are joined together and angulated as shown in FIGS. **3** and **4**, the angle $\theta_3$ of the male coupler shelf **316** can be $1.5\alpha$ to $12\alpha$ (e.g., 1.5 times to 12 times the angle $\alpha$), such as $1.5\alpha$ to $10\alpha$, $1.5\alpha$ to $8\alpha$, $1.5\alpha$ to $6\alpha$, $1.5\alpha$ to $5\alpha$, $1.5\alpha$ to $4\alpha$, $1.5\alpha$ to $3\alpha$, $1.5\alpha$ to $2\alpha$, $2\alpha$ to $12\alpha$, $2\alpha$ to $10\alpha$, $2\alpha$ to $8\alpha$, $2\alpha$ to $6\alpha$, $2\alpha$ to $5\alpha$, $2\alpha$ to $4\alpha$, $2\alpha$ to $3\alpha$, $3\alpha$ to $10\alpha$, $4\alpha$ to $10\alpha$, $5\alpha$ to $10\alpha$, etc. The angle $\theta_4$ of the male coupler distal end surface **314** can have any of the angle ranges given above with reference to $\theta_3$. By angling the male coupler shelf **316** and/or the male coupler distal end surface **314** in this way, the force of the pipe jack on the couplers can drive the couplings together and avoid one coupler slipping over the other.

**[0078]** Any or all of the pipe coupling examples described herein can provide a number of significant advantages over existing pipe couplings. For example, the pipe couplings described herein can provide the ability to angulate or articulate the pipes at a joint relative to each other within a selected range of motion that is surprisingly large, and without compromising the structural integrity of the joint. The vertex and the distal end surface-shelf contact region **116** of the resulting curved joint can be located at any location around the circumference of the pipe couplings. By coupling multiple pipes together using the couplings described herein, a pipe system with a curved path of specified curvature can be constructed between two end points. The angle between pipes achievable with the couplings described herein can vary according to the diameter of the pipes, but can be 2° or more in some examples.

**[0079]** Moreover, the configuration of the male and female pipe couplings described herein can provide significant advantages in the context of tunneling and microtunneling applications where sequential casing pipes are driven into a curved tunnel shaft (for example, by jacking). For example, the angled distal end surfaces and the angled shelf surfaces of the male and female couplings can facilitate contact between these surfaces when the couplings are joined together at an angle as shown in FIG. **4**. The angle ranges of these surfaces described herein can ensure that a relatively larger surface area of the distal end surfaces and the shelf surfaces are in contact at the vertex of the curve than if the surfaces were perpendicular to the respective axes of the couplers. Because the force of the pipe jack is transmitted between pipe sections at the area where the pipe couplings are in contact, a greater contact area at the interface between the distal end surface of the female coupler and the shelf of the male coupler in particular can improve force transmission, especially along a pipe system with multiple pipes coupled at multiple angled joints. Angling the distal end surface of the female coupler and the shelf of the male coupler as described herein can also urge the surfaces together in abutting contact. Stated differently, the angled distal end surface of the female coupler and the angled shelf of the male coupler serve to force the joint together as the pipes are jacked forward in the shaft, and can reduce or prevent "ramping" in which the female coupler slides over the outer diameter surface of the male coupler. The angled surfaces of the female coupler shelf **216** and the male coupler distal end surface **314** can also improve contact between these surfaces at the vertex when the pipes are angulated, further contributing to force transmission along the pipe system.

## Additional Examples of the Disclosed Technology

**[0080]** In view of the above-described implementations of the disclosed subject matter, this application discloses the additional examples enumerated below. It should be noted that one feature of an example in isolation or more than one feature of the example taken in combination and, optionally, in combination with one or more features of one or more further examples are further examples also falling within the disclosure of this application.

**[0081]** Example 1. A pipe, comprising: a pipe axis; a first end portion and a second end portion, the second end portion comprising a female coupler, the female coupler comprising an inner wall surface and a set of coupler features formed on the inner wall surface, the coupler features comprising a plurality of teeth and a plurality of ramp surfaces between the teeth, the first end portion of the pipe defining a pipe opening; the second end portion of the pipe comprising a radially-extending distal end surface; the female coupler further comprising a radially-extending shelf formed in the inner wall surface on an opposite side of the coupler features from the distal end surface; wherein the distal end surface and the shelf are angled relative to a radially-extending reference line that is perpendicular to the pipe axis.

**[0082]** Example 2. The pipe of any example herein, particularly example 1, wherein the distal end surface forms an angle with the radially-extending reference line of 2° to 20°.

**[0083]** Example 3. The pipe any example herein, particularly example 1 or example 2, wherein the shelf forms an angle with the radially-extending reference line of 2° to 20°.

**[0084]** Example 4. The pipe of any example herein, particularly examples 1-3, wherein the angle formed by the distal end surface with the radially-extending reference line and the angle formed by the shelf with the radially-extending reference line are different.

**[0085]** Example 5. The pipe of any example herein, particularly examples 1-3, wherein the angle formed by the distal end surface with the radially-extending reference line and the angle formed by the shelf with the radially-extending reference line are equal.

[0086] Example 6. The any example herein, particularly examples 1-4, wherein the angle formed by the distal end surface with the radially-extending reference line is greater than the angle formed by the shelf with the radially-extending reference line.

[0087] Example 7. The pipe of any example herein, particularly examples 1-4, wherein the angle formed by the distal end surface with the radially-extending reference line is less than the angle formed by the shelf with the radially-extending reference line.

[0088] Example 8. The pipe of any example herein, particularly examples 1-7, wherein the coupler features comprise a repeating unit of, in a direction toward the pipe opening, a radially-extending tooth surface and a ramp surface that extends from the tooth surface to an annular surface, wherein a next radially-extending tooth surface extends from the annular surface.

[0089] Example 9. The pipe of any example herein, particularly examples 1-8, wherein the coupler features comprise, in a direction from the shelf toward the distal end, a first annular surface having a first annular surface diameter that is constant moving in the direction toward the distal end, a first ramp surface with a first ramp surface diameter that increases in the direction toward the distal end, a second annular surface having a second annular surface diameter that is constant moving in the direction toward the distal end, a first tooth comprising a first tooth surface extending radially from the second annular surface toward the pipe axis, and a second ramp surface extending from the first tooth surface to a third annular surface in the direction toward the distal end.

[0090] Example 10. The pipe of any example herein, particularly examples 1-9, wherein the first end portion of the pipe comprises a male coupler comprising a plurality of coupler features formed on an outer wall surface of the male coupler.

[0091] Example 11. A pipe system, comprising: the pipe of example 1, wherein the pipe is a first pipe; and a second pipe comprising a male coupler that is coupled to the female coupler of the first pipe, the male coupler comprising: an outer wall surface and a set of male coupler features formed on the outer wall surface, the male coupler features comprising a plurality of ramp surfaces and teeth; the male coupler of the second pipe comprising a radially-extending distal end surface; the male coupler further comprising a radially-extending shelf formed in the outer wall surface on an opposite side of the coupler features from the male coupler distal end surface; wherein the distal end surface and the shelf of the male coupler are angled relative to a radially-extending reference line that is perpendicular to an axis of the second pipe.

[0092] Example 12. A pipe, comprising: a pipe axis; a first end portion and a second end portion, the first end portion comprising a male coupler, the male coupler comprising an outer wall surface and a set of coupler features formed on the outer wall surface, the coupler features comprising a plurality of ramp surfaces and teeth, the first end portion of the pipe defining a pipe opening; the first end portion of the pipe comprising a radially-extending distal end surface; the male coupler further comprising a radially-extending shelf formed in the outer wall surface on an opposite side of the coupler features from the distal end surface; wherein the distal end surface and the shelf are angled relative to a radially-extending reference line that is perpendicular to the pipe axis.

[0093] Example 13. The pipe of any example herein, particularly example 12, wherein the distal end surface forms an angle with the radially-extending reference line of 5° to 20°.

[0094] Example 14. The pipe of any example herein, particularly example 12 or example 13, wherein the shelf forms an angle with the radially-extending reference line of 5° to 20°.

[0095] Example 15. The pipe of any example herein, particularly examples 12-14, wherein the angle formed by the distal end surface with the radially-extending reference line and the angle formed by the shelf with the radially-extending reference line are different.

[0096] Example 16. The pipe of any example herein, particularly examples 12-14, wherein the angle formed by the distal end surface with the radially-extending reference line and the angle formed by the shelf with the radially-extending reference line are equal.

[0097] Example 17. The pipe of any example herein, particularly examples 12-15, wherein the angle formed by the distal end surface with the radially-extending reference line is greater than the angle formed by the shelf with the radially-extending reference line.

[0098] Example 18. The pipe of any example herein, particularly examples 12-15, wherein the angle formed by the distal end surface with the radially-extending reference line is less than the angle formed by the shelf with the radially-extending reference line.

[0099] Example 19. The pipe of any example herein, particularly examples 12-18, wherein the second end portion of the pipe comprises a female coupler comprising a plurality of coupler features formed on an inner wall surface of the female coupler.

[0100] Example 20. A pipe system, comprising: a first pipe, comprising: a first pipe axis; a first end portion and a second end portion, the second end portion comprising a female coupler, the female coupler comprising an inner wall surface and a set of first coupler features formed on the inner wall surface, the first coupler features comprising a plurality of teeth and a plurality of ramp surfaces between the teeth, the first end portion of the first pipe defining a first pipe opening; the second end portion of the first pipe comprising a radially-extending distal end surface; the female coupler further comprising a radially-extending shelf formed in the inner wall surface on an opposite side of the first coupler features from the distal end surface; wherein the distal end surface and the shelf are angled relative to a radially-extending reference line that is perpendicular to the first pipe axis; a second pipe, comprising: a second pipe axis; a first end portion and a second end portion, the first end portion comprising a male coupler, the male coupler comprising an outer wall surface and a set of coupler features formed on the outer wall surface, the coupler features comprising a plurality of ramp surfaces and teeth, the first end portion of the second pipe defining a pipe opening; the first end portion of the second pipe comprising a radially-extending distal end surface; the male coupler further comprising a radially-extending shelf formed in the outer wall surface on an opposite side of the coupler features from the distal end surface; wherein the distal end surface and the shelf of the male coupler are angled relative to a radially-extending reference line that is perpendicular to the second pipe axis; wherein the male coupler of the second pipe is received within the female coupler of the first pipe such that the male coupler features engage the female coupler features to form a pipe joint.

**[0101]** Example 21. The pipe system of any example herein, particularly example 20, wherein the first pipe is angulated relative to the second pipe.

**[0102]** Example 22. The pipe system of any example herein, particularly example 20 or example 21, wherein: the first pipe axis and the second pipe axis define an angle $\alpha$ between them; and an angle defined between the shelf of the male coupler and the radially-extending reference line that is perpendicular to the second pipe axis is $1.5\alpha$ to $10\alpha$.

**[0103]** Example 23. The pipe system of any example herein, particularly examples 20-22, wherein: the first pipe axis and the second pipe axis define an angle $\alpha$ between them; and an angle defined between the distal end surface of the male coupler and the radially-extending reference line that is perpendicular to the second pipe axis is $1.5\alpha$ to $10\alpha$.

**[0104]** Example 24. A pipe, comprising: a first end portion comprising a female coupler, the female coupler comprising an inner wall surface and a set of coupler features formed on the inner wall surface, the first end portion of the pipe defining a pipe opening; the pipe comprising a radially-extending shelf formed in the inner wall surface on an opposite side of the coupler features from the pipe opening; wherein the coupler features comprise a repeating unit of, in a direction toward the pipe opening, a radially-extending tooth surface and a ramp surface that extends from the tooth surface to an annular surface, wherein a next radially-extending tooth surface extends from the annular surface.

**[0105]** Example 25. A pipe, comprising: a pipe axis; a female coupler mounted to or formed in a first end of the pipe, the female coupler comprising an inner wall surface and a set of coupler features formed on the inner wall surface, the coupler features comprising a plurality of ramp surfaces and teeth, the first end of the pipe defining a pipe opening; the first end of the pipe comprising a distal end and a radially-extending shelf formed in the inner wall surface on an opposite side of the coupler features from the distal end; the coupler features comprising, in a direction from the shelf toward the distal end, a first annular surface having a first annular surface diameter that is constant moving in the direction toward the distal end, a first ramp surface with a first ramp surface diameter that increases in the direction toward the distal end, a second annular surface having a second annular surface diameter that is constant moving in the direction toward the distal end, a first tooth comprising a first tooth surface extending radially from the second annular surface toward the pipe axis, and a second ramp surface extending from the first tooth surface to a third annular surface in the direction toward the distal end.

**[0106]** Example 26. A pipe system, comprising: a first pipe comprising a female coupler having a distal end and a radially-extending shelf formed in an inner wall surface of the first pipe, the shelf being spaced apart from the distal end along a longitudinal axis of the first pipe; a second pipe comprising a male coupler received in the female coupler of the first pipe to form a joint; the female coupler of the first pipe comprising a plurality of tooth surfaces extending radially inwardly from annular surfaces formed in the inner wall surface of the first pipe; the male coupler of the second pipe comprising a plurality of radially-extending tooth surfaces formed in an outer wall surface of the second pipe, the tooth surfaces of the second pipe engaging the tooth surfaces of the first pipe, wherein the annular surfaces of the second pipe are axially aligned with annular surfaces of the first pipe, and wherein gaps measured in the radial direction between the annular surfaces of the second pipe and the axially aligned annular surfaces of the first pipe increase moving in a direction from the distal end of the first pipe toward the shelf of the first pipe.

**[0107]** Example 27. A pipe system, comprising: a first pipe comprising a female coupler having a distal end and a radially-extending shelf formed in an inner wall surface of the first pipe, the shelf being spaced apart from the distal end along a longitudinal axis of the first pipe; a second pipe comprising a male coupler received in the female coupler of the first pipe to form a joint; the female coupler of the first pipe comprising a plurality of tooth surfaces extending radially inwardly from annular surfaces formed in the inner wall surface of the first pipe; the male coupler of the second pipe comprising a plurality of radially-extending tooth surfaces formed in an outer wall surface of the second pipe, the tooth surfaces of the second pipe engaging the tooth surfaces of the first pipe, wherein radial heights of the tooth surfaces of the first pipe are greater than radial heights of the tooth surfaces of the second pipe.

**[0108]** Example 28. A pipe system, comprising: a first pipe comprising a female coupler having a distal end and a radially-extending shelf formed in an inner wall surface of the first pipe, the shelf being spaced apart from the distal end along a longitudinal axis of the first pipe; a second pipe comprising a male coupler received in the female coupler of the first pipe to form a joint; the female coupler of the first pipe comprising a plurality of tooth surfaces extending radially inwardly from annular surfaces formed in the inner wall surface of the first pipe; the male coupler of the second pipe comprising a plurality of radially-extending tooth surfaces formed in an outer wall surface of the second pipe, the tooth surfaces of the second pipe engaging the tooth surfaces of the first pipe, wherein the male coupler comprises a first annular surface nearest an opening defined by the second pipe, the female coupler comprises a first annular surface nearest the shelf of the female coupler, and wherein a gap defined between the first annular surface of the male coupler and the first annular surface of the female coupler is 70% to 110% of a radial height of the tooth surfaces of the female coupler.

**[0109]** The features described herein with regard to any example can be combined with other features described in any one or more of the other examples, unless otherwise stated. For example, any one or more of the features of one pipe coupler example can be combined with any one or more features of another pipe coupler example.

**[0110]** In view of the many possible embodiments to which the principles of the disclosed technology may be applied, it should be recognized that the illustrated embodiments are only examples and should not be taken as limiting the scope of the disclosure. Rather, the scope of the disclosure is at least as broad as the following claims and equivalents of the features recited therein. We therefore claim all that comes within the scope and spirit of these claims.

**1**. A pipe, comprising:

a pipe axis;

a first end portion and a second end portion, the second end portion comprising a female coupler, the female coupler comprising an inner wall surface and a set of coupler features formed on the inner wall surface, the coupler features comprising a plurality of teeth and a plurality of ramp surfaces between the teeth, the first end portion of the pipe defining a pipe opening;

the second end portion of the pipe comprising a radially-extending distal end surface;

the female coupler further comprising a radially-extending shelf formed in the inner wall surface on an opposite side of the coupler features from the distal end surface;

wherein the distal end surface and the shelf are angled relative to a radially-extending reference line that is perpendicular to the pipe axis.

**2**. The pipe of claim **1**, wherein the distal end surface forms an angle with the radially-extending reference line of 2° to 20°.

**3**. The pipe of claim **2**, wherein the shelf forms an angle with the radially-extending reference line of 2° to 20°.

**4**. The pipe of claim **3**, wherein the angle formed by the distal end surface with the radially-extending reference line and the angle formed by the shelf with the radially-extending reference line are different.

**5**. The pipe of claim **3**, wherein the angle formed by the distal end surface with the radially-extending reference line and the angle formed by the shelf with the radially-extending reference line are equal.

**6**. The pipe of claim **3**, wherein the angle formed by the distal end surface with the radially-extending reference line is greater than the angle formed by the shelf with the radially-extending reference line.

**7**. The pipe of claim **3**, wherein the angle formed by the distal end surface with the radially-extending reference line is less than the angle formed by the shelf with the radially-extending reference line.

**8**. The pipe of claim **1**, wherein the coupler features comprise a repeating unit of, in a direction toward the pipe opening, a radially-extending tooth surface and a ramp surface that extends from the tooth surface to an annular surface, wherein a next radially-extending tooth surface extends from the annular surface.

**9**. The pipe of claim **1**, wherein the coupler features comprise, in a direction from the shelf toward the distal end, a first annular surface having a first annular surface diameter that is constant moving in the direction toward the distal end, a first ramp surface with a first ramp surface diameter that increases in the direction toward the distal end, a second annular surface having a second annular surface diameter that is constant moving in the direction toward the distal end, a first tooth comprising a first tooth surface extending radially from the second annular surface toward the pipe axis, and a second ramp surface extending from the first tooth surface to a third annular surface in the direction toward the distal end.

**10**. The pipe of claim **1**, wherein the first end portion of the pipe comprises a male coupler comprising a plurality of coupler features formed on an outer wall surface of the male coupler.

**11**. A pipe system, comprising:

the pipe of claim **1**, wherein the pipe is a first pipe; and

a second pipe comprising a male coupler that is coupled to the female coupler of the first pipe, the male coupler comprising:

an outer wall surface and a set of male coupler features formed on the outer wall surface, the male coupler features comprising a plurality of ramp surfaces and teeth;

the male coupler of the second pipe comprising a radially-extending distal end surface;

the male coupler further comprising a radially-extending shelf formed in the outer wall surface on an opposite side of the coupler features from the male coupler distal end surface;

wherein the distal end surface and the shelf of the male coupler are angled relative to a radially-extending reference line that is perpendicular to an axis of the second pipe.

**12**. A pipe, comprising:

a pipe axis;

a first end portion and a second end portion, the first end portion comprising a male coupler, the male coupler comprising an outer wall surface and a set of coupler features formed on the outer wall surface, the coupler features comprising a plurality of ramp surfaces and teeth, the first end portion of the pipe defining a pipe opening;

the first end portion of the pipe comprising a radially-extending distal end surface;

the male coupler further comprising a radially-extending shelf formed in the outer wall surface on an opposite side of the coupler features from the distal end surface;

wherein the distal end surface and the shelf are angled relative to a radially-extending reference line that is perpendicular to the pipe axis.

**13**. The pipe of claim **12**, wherein the distal end surface forms an angle with the radially-extending reference line of 5° to 20°.

**14**. The pipe of claim **13**, wherein the shelf forms an angle with the radially-extending reference line of 5° to 20°.

**15**. The pipe of claim **14**, wherein the angle formed by the distal end surface with the radially-extending reference line and the angle formed by the shelf with the radially-extending reference line are different.

**16**. The pipe of claim **14**, wherein the angle formed by the distal end surface with the radially-extending reference line and the angle formed by the shelf with the radially-extending reference line are equal.

**17**. The pipe of claim **14**, wherein the angle formed by the distal end surface with the radially-extending reference line is greater than the angle formed by the shelf with the radially-extending reference line.

**18**. The pipe of claim **14**, wherein the angle formed by the distal end surface with the radially-extending reference line is less than the angle formed by the shelf with the radially-extending reference line.

**19**. The pipe of claim **12**, wherein the second end portion of the pipe comprises a female coupler comprising a plurality of coupler features formed on an inner wall surface of the female coupler.

**20**. A pipe system, comprising:

a first pipe, comprising:

a first pipe axis;

a first end portion and a second end portion, the second end portion comprising a female coupler, the female coupler comprising an inner wall surface and a set of first coupler features formed on the inner wall surface, the first coupler features comprising a plurality of teeth and a plurality of ramp surfaces between the teeth, the first end portion of the first pipe defining a first pipe opening;

the second end portion of the first pipe comprising a radially-extending distal end surface;

the female coupler further comprising a radially-extending shelf formed in the inner wall surface on an opposite side of the first coupler features from the distal end surface;

wherein the distal end surface and the shelf are angled relative to a radially-extending reference line that is perpendicular to the first pipe axis;

a second pipe, comprising:

a second pipe axis;

a first end portion and a second end portion, the first end portion comprising a male coupler, the male coupler comprising an outer wall surface and a set of coupler features formed on the outer wall surface, the coupler features comprising a plurality of ramp surfaces and teeth, the first end portion of the second pipe defining a pipe opening;

the first end portion of the second pipe comprising a radially-extending distal end surface;

the male coupler further comprising a radially-extending shelf formed in the outer wall surface on an opposite side of the coupler features from the distal end surface;

wherein the distal end surface and the shelf of the male coupler are angled relative to a radially-extending reference line that is perpendicular to the second pipe axis;

wherein the male coupler of the second pipe is received within the female coupler of the first pipe such that the male coupler features engage the female coupler features to form a pipe joint.

**21**. The pipe system of claim **20**, wherein the first pipe is angulated relative to the second pipe.

**22**. The pipe system of claim **21**, wherein:

the first pipe axis and the second pipe axis define an angle $\alpha$ between them; and

an angle defined between the shelf of the male coupler and the radially-extending reference line that is perpendicular to the second pipe axis is $1.5\alpha$ to $10\alpha$.

**23**. The pipe system of claim **21**, wherein:

the first pipe axis and the second pipe axis define an angle $\alpha$ between them; and

an angle defined between the distal end surface of the male coupler and the radially-extending reference line that is perpendicular to the second pipe axis is $1.5\alpha$ to $10\alpha$.

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