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(54) **A BLANK FOR A FLOW FORMING METHOD**

(57) There is disclosed a tubular blank (31) for attaching to a stepped mandrel (41) of a flow forming assembly, wherein the tubular blank (31) has a stepped inner profile that may be tailored to the shape of the mandrel (41) before any flow forming is carried out on the

blank (31). Also disclosed is a corresponding method of flow forming a shaped article by plastically deforming the tubular blank (31) over the stepped mandrel (41), where the forming of the shaped article may be carried out in one operation.

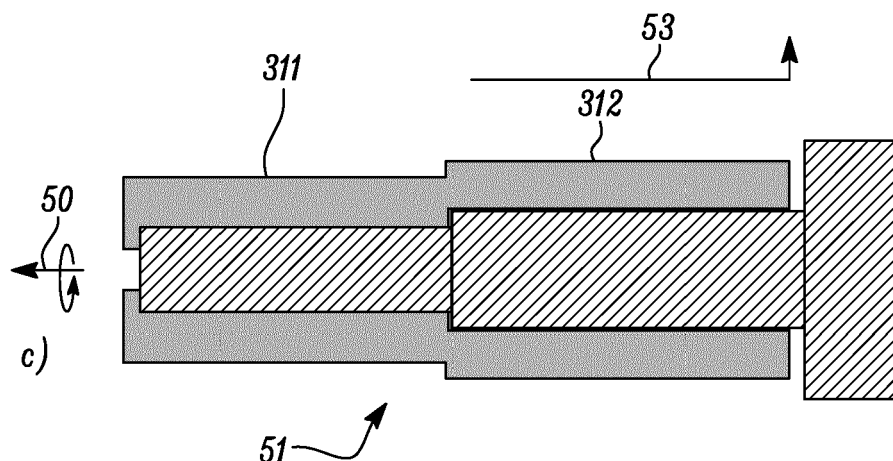


FIG. 5

Description

[0001] The present disclosure concerns a blank to be used in a flow forming method to produce a shaped article. The present disclosure also concerns a method of flow forming a shaped article using the blank.

[0002] Flow forming is a known metal forming process (sometimes known as a "chip-less machining method") for producing a shaped article from a blank using a cold rolling process. The shaped articles to be produced are typically in the form of rotationally symmetric, cylindrical components for aerospace applications, including undercarriage components, hydraulic cylinders and drive shafts for gas turbine engines.

[0003] Figure 1 shows a typical flow forming assembly 1. The assembly 1 comprises forming rollers 2 configured to plastically deform a blank in the form of an initial machined generally tubular pre-form 3 over a mandrel 4 to create a shaped article. The blank 3 is fitted tightly to the mandrel 4 such that when the mandrel 4 rotates, so does the blank 3. The rollers 2 move over the blank 3 along a mandrel axis X and rotate when in contact with the blank 3. As the mandrel 4 and rollers 2 rotate, and the rollers 2 are moved against the blank 3 towards a tailstock 5 of the mandrel 4, the blank is plastically deformed, such that the blank 3 is elongated and the walls of the tubular blank 3 are thinned, to produce a shaped article.

[0004] Typically, the wall thickness of the flow formed sections of the tubular blank 3 is reduced between a minimum of 20% and a maximum of 80% during a flow forming pass, which enables modest changes to the outer diameter to provide contour changes on the outer profile that cannot be achieved by alternative processes such as extrusion or drawing. Reducing the wall thickness consequently elongates the pre-form along the longitudinal axis X of the mandrel 4, such that the shaped article will have an inner diameter that matches the diameter of the mandrel 4. Typical elongations range between 100 and 400% of the original length of the blank.

[0005] Although flow forming is typically used to manufacture a shaped article having a single inner diameter, there are some applications where it is necessary or desired for the shaped article to have two inner diameters. Accordingly, it is known to provide a stepped mandrel having two outer diameters, to be used during the flow forming process. A tubular blank with a single inner diameter corresponding to the largest mandrel diameter is then fixed over the largest diameter region of the mandrel. The rollers then move over the blank along the mandrel axis to plastically deform the blank such that it forms a shaped article having two inner diameters that should match the shape of the mandrel along its axis.

[0006] Flow forming an oversized blank across the stepped region of a mandrel from the larger diameter region and the smaller diameter region is known as "necking in" the blank. However, it is often difficult to "neck-in" blanks to accurately match the outer profile of the mandrel. This is particularly true for higher strength

materials that are suitable for aerospace applications. Indeed, necking in has limitations in terms of the material type (strength) and thickness to be used for the blank, as well as the resulting length of the shaped article and the extent of variation between the inner diameters that is able to be achieved for the shaped article.

[0007] Accordingly, it is desired to provide an improved blank and corresponding flow forming method.

[0008] According to a first aspect of the disclosure there is provided a tubular blank for attaching to a stepped mandrel of a flow forming assembly, wherein the tubular blank has a stepped inner profile.

[0009] In other words, the inner profile of the blank is tailored to the shape of the mandrel (and accordingly the desired inner profile of the shaped article) before any flow forming is carried out on the blank. Accordingly, radial flow to conform to the stepped profile of a mandrel is reduced as compared with radial flow when using an unstepped tubular blank. That is, the radial extent by which the inner surface(s) of the blank must deform to conform to the mandrel is reduced. In examples, the radial extent by which the inner surface(s) of the blank must deform to conform to the mandrel is less than the radial extent of a step in the inner profile of the blank.

[0010] In this way, the blank will conform to the shape of the stepped mandrel more closely during flow forming, such that the resultant shaped article will have an inner profile that more accurately matches the outer profile of the mandrel, as compared to, e.g., conventional arrangements in which an oversized blank is "necked-in".

[0011] The stepped inner profile may comprise a first inner surface extending circumferentially about a central longitudinal axis to define a first inner volume having a first inner diameter. The stepped inner profile may comprise a second inner surface axially adjacent the first inner surface and extending circumferentially about the central longitudinal axis to define a second inner volume having a second inner diameter that is larger than the first inner diameter. The stepped inner profile may comprise an inner shoulder between the first inner surface and the second inner surface.

[0012] The first inner surface and the second inner surface may be parallel to a central longitudinal axis of the blank to define a substantially cylindrical first inner volume and a substantially cylindrical second inner volume, respectively. The first inner surface and the second inner surface may, however, be angled with respect to the central longitudinal axis, such that the first inner volume and the second inner volume are tapered in the longitudinal direction. In that case, the first inner diameter may correspond to an inner diameter of the first inner volume, and the second inner diameter may correspond to an inner diameter of the second inner volume.

[0013] The tubular blank may comprise an end wall extending radially inwardly from the second inner surface to at least partly close the first inner volume. The end wall may be a flange.

[0014] The tubular blank may be made of a material

comprising at least one of a wrought steel, a nickel alloy and a titanium alloy.

[0015] According to a second aspect of the disclosure there is provided a flow forming kit comprising a stepped mandrel and a tubular blank according to any one or more of the statements above.

[0016] The stepped mandrel may comprise a first mandrel region having a first outer mandrel diameter and a second mandrel region having a larger second outer mandrel diameter. The tubular blank may be configured to cooperate with the stepped mandrel in that the first inner diameter corresponds to, e.g. matches, the first outer mandrel diameter such that the first inner volume is suitable for, e.g. snugly, receiving the first mandrel region. The tubular blank may be configured to cooperate with the stepped mandrel in that the second inner diameter corresponds to, e.g. matches, the second outer mandrel diameter such that the second inner volume is suitable for, e.g. snugly, receiving the second mandrel region.

[0017] The first inner volume and the first mandrel region may have an engineering fit, preferably a location or transition fit. The second inner volume and the second mandrel region may have an engineering fit, preferably a location or transition fit.

[0018] The first inner surface may have an axial extent such that, when the first inner volume receives the first mandrel region, an inner shoulder of the blank longitudinally opposes an outer mandrel shoulder between the first mandrel region and the second mandrel region.

[0019] The first inner surface may have an axial extent such that, when the first inner volume is fully occupied by the first mandrel region, some but not all of the second mandrel region is received by the second inner volume of the blank, to support the blank on the second mandrel region.

[0020] A step of the inner profile may have a shape that conforms to the shape of a step in the mandrel. The inner shoulder of the blank may be parallel with the outer mandrel shoulder, when the first inner volume receives the first mandrel region.

[0021] The present disclosure extends to a method of flow forming a shaped article using a stepped mandrel and a tubular blank as described above in accordance with any one of the statements included herein.

[0022] Thus, according to a third aspect of the disclosure, there is provided a method of flow forming a shaped article, comprising: providing a stepped mandrel that comprises a first mandrel region having a first outer mandrel diameter and a second mandrel region having a second outer mandrel diameter that is larger than the first outer mandrel diameter; providing a tubular blank having a stepped inner profile; locating the tubular blank on the mandrel; and plastically deforming the tubular blank over the mandrel to create the shaped article.

[0023] The tubular blank may comprise a first inner volume having a first inner diameter and a second inner volume having a second inner diameter that is larger than

the first inner diameter. Locating the tubular blank on the mandrel may comprise the tubular blank snugly receiving the first mandrel region in the first inner volume of the tubular blank.

[0024] The method may comprise locating the tubular blank on the mandrel such that an inner shoulder of the blank longitudinally opposes an outer shoulder of the mandrel. The method may also comprise plastically deforming the tubular blank over the mandrel such that the inner shoulder of the blank translates longitudinally along the first mandrel region towards the outer shoulder of the mandrel.

[0025] The method may comprise one or more rollers engaging a first outer surface of the blank, which is radially outwards of a first inner surface defining the first inner volume, thereby elongating the first inner surface such that the inner shoulder translates longitudinally along the first mandrel region towards the outer shoulder of the mandrel. The method may comprise the one or more rollers disengaging the first outer surface in response to determining that the inner shoulder of the blank is abutting the outer mandrel shoulder. The method may comprise the one or more rollers engaging a second outer surface of the blank, which is radially outwards of a second inner surface defining the second inner volume, thereby elongating the second inner surface along the second mandrel region while keeping the inner shoulder of the blank in an abutting arrangement with the outer mandrel shoulder.

[0026] Longitudinal translation of the inner shoulder along the first mandrel region may cause the second inner volume of the blank to translate in the same longitudinal direction such that it snugly receives the second mandrel region.

[0027] Plastically deforming the tubular blank over the mandrel to create the shaped article may comprise elongating the tubular blank without, e.g. substantially, changing the inner diameters of the tubular blank during the flow forming method. However, it will be appreciated that there may be a slight diametric change of the inner diameters of the blank during flow forming as a result of slight tangential flow of material.

[0028] The forming of the shaped article may be carried out in one operation.

[0029] The skilled person will appreciate that except where mutually exclusive, a feature described in relation to any one of the above aspects may be applied *mutatis mutandis* to any other aspect. Furthermore except where mutually exclusive any feature described herein may be applied to any aspect and/or combined with any other feature described herein.

[0030] Embodiments will now be described by way of example only, with reference to the Figures, in which:

Figure 1 is a schematic illustration of a known flow forming method;

Figure 2 is a sectional side view of a gas turbine

engine;

Figure 3 schematically illustrates a blank and corresponding mandrel to be used in a flow forming method according to the present disclosure;

Figure 4 schematically illustrates the blank of **Figure 3** in detail; and

Figure 5 schematically illustrates a method of producing a shaped article by flow forming the blank of **Figures 3 and 4**, in accordance with the present disclosure.

[0031] With reference to **Figure 2**, a gas turbine engine is generally indicated at 10, having a principal and rotational axis 11. The engine 10 comprises, in axial flow series, an air intake 12, a propulsive fan 13, an intermediate pressure compressor 14, a high-pressure compressor 15, combustion equipment 16, a high-pressure turbine 17, an intermediate pressure turbine 18, a low-pressure turbine 19 and an exhaust nozzle 20. A nacelle 21 generally surrounds the engine 10 and defines both the intake 12 and the exhaust nozzle 20.

[0032] The gas turbine engine 10 works in the conventional manner so that air entering the intake 12 is accelerated by the fan 13 to produce two air flows: a first air flow into the intermediate pressure compressor 14 and a second air flow which passes through a bypass duct 22 to provide propulsive thrust. The intermediate pressure compressor 14 compresses the airflow directed into it before delivering that air to the high pressure compressor 15 where further compression takes place.

[0033] The compressed air exhausted from the high-pressure compressor 15 is directed into the combustion equipment 16 where it is mixed with fuel and the mixture combusted. The resultant hot combustion products then expand through, and thereby drive the high, intermediate and low-pressure turbines 17, 18, 19 before being exhausted through the nozzle 20 to provide additional propulsive thrust. The high 17, intermediate 18 and low 19 pressure turbines drive respectively the high pressure compressor 15, intermediate pressure compressor 14 and fan 13, each by suitable interconnecting shaft.

[0034] Other gas turbine engines to which the present disclosure may be applied may have alternative configurations. By way of example such engines may have an alternative number of interconnecting shafts (e.g. two) and/or an alternative number of compressors and/or turbines. Further the engine may comprise a gearbox provided in the drive train from a turbine to a compressor and/or fan.

[0035] The shafts used in gas turbine engines, such as the interconnecting shafts of **Figure 2**, are rotationally symmetric, cylindrical components that transfer torque between different parts of the engine. The shafts often traverse large sections of the engine and in regions where space may be limited, e.g. due to the presence of other

components. It is therefore necessary, on occasions, for a shaft to be manufactured with varying inner diameters, e.g. to reduce the overall size of one or more regions of the shaft or to connect the shaft to correspondingly sized components of the engine. Furthermore, the shaft is often tapered to facilitate or ease assembly when feeding the shaft into the core of the engine. The tapered nature also contributes to the stiffness of the component.

[0036] With reference to **Figures 3 and 4**, there is described a flow forming kit comprising a blank 31 and corresponding stepped mandrel 41, which are to be used during a flow forming method to manufacture a shaped article having two different inner diameters. **Figure 3** shows a longitudinal cross-section of both the blank 31 and the mandrel 41 when disposed concentrically about a common central longitudinal axis 50. **Figure 4**, meanwhile, shows a more detailed view of the blank 31 of **Figure 3**. Although not shown, the blank 31 and the mandrel 41 are each rotationally symmetric about the longitudinal axis 50, such that the blank 31 and mandrel 41 have generally the same profile as that shown in **Figures 3 and 4** for any longitudinal cross-section taken along through axis 50.

[0037] As best shown in **Figure 3**, the mandrel 41 is a shaped solid bar, e.g. of metal, which is to be placed inside a blank 31 to be flow formed. The mandrel 41 comprises a tailstock 46 which is connected to a lathe (not shown) that, during operation, rotates the mandrel 41 and blank 31 (when fitted) about the central longitudinal axis 50.

[0038] The mandrel 41 is shaped in that it has an outer profile that is pre-configured and machined to match the inner profile that is required for the shaped article to be flow formed. In the example of **Figure 3**, the mandrel 41 is shaped to define two concentric and axially adjacent cylinders of different diameters. In particular, the mandrel 41 comprises a first mandrel region 42 at a distal end from the tailstock 46 and a second mandrel region 43 proximal to the tailstock 46 (as compared to the first mandrel region 43). The first mandrel region 42 has a first radially outer surface 421 defining a first outer mandrel diameter 44 and the second mandrel region 43 has a second radially outer surface 431 defining a second outer mandrel diameter 45 that is larger than the first outer diameter 44.

[0039] Between the first radially outer surface 421 and the second radially outer surface 431 is a radially extending, outer mandrel shoulder 47. In this example, the outer mandrel shoulder 47 is annular, although in other examples it may be tapered in the longitudinal direction, i.e. at an angle relative to axis 50. Surfaces 421, 431, 47 together define a stepped profile around the circumference of the mandrel 41.

[0040] The values of the first outer diameter 44 and the second outer diameter 45, as well as the shape of the outer mandrel shoulder 47 is selected to define an outer profile that matches the inner profile that the shaped article to be flow formed should have. This may involve

reverse engineering a notional, predefined shaped article to be manufactured, or an existing shaped article that has been previously manufactured, e.g., using other manufacturing methods.

[0041] While it is known to provide a tubular blank having a single inner diameter that matches the largest diameter of a stepped mandrel, i.e. the second outer diameter of the mandrel 41 of Figure 3, it is difficult to flow form such a blank without having to compromise on the accuracy, strength and/or rigidity of the resulting shaped article. However, the present disclosure is concerned with a blank 31 that is tailored to the shape of the mandrel 41 (and accordingly the desired inner profile of the shaped article) before any flow forming is carried out on the blank 31. In particular, the blank of the present disclosure comprises a stepped inner profile. The features of the blank 31 of the present disclosure will now be described with particular reference to Figure 4.

[0042] The blank 31 is substantially tubular in structure in that it comprises a wall that extends circumferentially around the longitudinal central axis 50 to define a generally cylindrical shape having a hollow central passage extending there through in the longitudinal direction. The wall thicknesses are selected so that the corresponding reductions during flow forming will meet the required wall dimensions for the shaped article. The volume of material required is also calculated and selected accordingly.

[0043] The length of the blank 31 on its radially outer side is divided into two axially adjacent sections, a first section comprising a first outer surface 311 that extends along a first length of the blank 31 and a second section comprising a second outer surface 313 that extends along a second length of the blank 31. The first and second outer surfaces 311, 313 are parallel but separated in the radial direction by an outer shoulder 315 that extends radially therebetween.

[0044] At longitudinally opposite ends of the blank 31, there is a front end surface 313 and a rear end surface 314. The rear end surface 314 has a first opening 38 for receiving the mandrel 41 within the blank 31 and the front end surface 313 has a second opening 39 such that, when the mandrel 41 is received in the first opening 38, the second opening 39 allows air to escape the blank 31.

[0045] The inner profile of the blank 31 is defined by a first inner surface 32, a second inner surface 33, an inner shoulder 36 and an end wall surface 310. The first inner surface 32 and the second inner surface 33 are axially adjacent to one another and both extend parallel to the longitudinal axis 50 of the blank 31. The inner shoulder 36 and the end wall surface 310 extend radially to the central axis 50. In that way, the inner shoulder 36 and the end wall surface 310 are annular.

[0046] The end wall surface 310 extends radially inwardly from the first inner surface 32 to define, together with the front surface 313, an end wall or flange 37 that at least partly closes the first inner volume 316. The end wall surface 310 is configured to abut the distal end 48 of the mandrel 41 that is to be received in the blank 31,

in use. In this way, the flange 47 acts as a stopper to prevent the further passage of distal end 48 of the mandrel 41 through the blank 31. The end wall surface 310 extends from the first inner surface 32 by a length that ensures that the first opening 38 has a diameter that is smaller than the first outer diameter 44 of the mandrel 41 to be received in the blank 31.

[0047] The flange 37 also acts to prevent the mandrel 41 from being inserted in the blank 31 at the distal end opposite the first opening 38, thereby ensuring that the mandrel 41 can only be inserted into the blank 31 through the first opening 38 and therefore in the correct orientation for flow forming. The flange may be used to secure the blank 31 to a distal end 48 of the mandrel 41, e.g. using a clamp.

[0048] The first inner surface 32 extends circumferentially about the central longitudinal axis 50 to define a cylindrical first inner volume 316 of the blank 31 and the second inner surface 33 extends circumferentially about axis 50 to define a cylindrical second inner volume 317 of the blank 31.

[0049] As mentioned above, the inner profile of the blank 31 is tailored to the shape, i.e. the outer profile, of the mandrel 41 and accordingly, the inner profile that the shaped article is to have after flow forming the blank 31. More specifically, the blank 31 is configured with a stepped inner profile. In this way, the blank 31 will conform to the shape of the mandrel more closely during the flow forming method, such that the resultant shaped article will have an inner profile that more accurately matches the outer profile of the mandrel 41, as compared to, e.g., conventional arrangements in which an oversized blank is "necked-in".

[0050] With particular reference to Figure 4, the first inner volume 316 has a first inner diameter 34 and the second inner volume 317 has a second inner diameter 35 which is larger than the first inner diameter 34. Further, the blank 31 is precision engineered such that the first inner diameter 34 and the second inner diameter 35 are the same as the first outer diameter 44 and the second outer mandrel diameter 45 of the mandrel 41, respectively. That is, the first inner diameter 34 matches (e.g. equals) the first outer mandrel diameter 44 to provide a snug fit between the first inner surface 32 and the first radially outer surface 421 of the mandrel 41, when the first mandrel region 42 is received in the first inner volume 316. The second inner diameter 35 matches (e.g. equals) the second outer mandrel diameter 45 to provide a snug fit between the second inner surface 33 and the second radially outer surface 431 of the mandrel 41, when the second mandrel region 43 is received in the second inner volume 317 (e.g. due to elongation of the blank 31 during flow forming).

[0051] Precision engineering the first inner diameter 34 and the second inner diameter 35 to match the diameters of the mandrel, before the flow forming process, ensures that the inner diameters of the shaped article will be closer to the nominal inner diameter values pre-

defined for the shaped article. It will also ensure that regions of the shaped article that have different diameters will be concentric, which in turn increases the integrity of the shaped articles compared to hypothetical arrangements where concentricity will depend on how accurately the rollers can deform the blank to fit the mandrel.

[0052] The inner profile of the blank 31 is also tailored to the shape of the mandrel 41 in that the stepped profile itself corresponds to, e.g. closely matches or conforms to, the shape of the stepped profile of the mandrel. In particular, the inner shoulder 36 of the blank 31 is parallel with the outer mandrel shoulder 47, when the blank 31 is located on the mandrel 41.

[0053] It will be appreciated that, although the mandrel 41 and corresponding blank 31 are shown in the Figures to have only two regions or volumes having different diameters, the mandrel 41 and corresponding blank 31 may be machined to include any number of inner volumes having different respective diameters, as desired.

[0054] It is also not necessary for the inner shoulder 36 to be annular, i.e. perpendicular to the first inner surface 32 and the second inner surface 33 of the blank 31. The inner shoulder 36 can be of any desired shape, and be disposed with any orientation relative to the first inner surface 32 and the second inner surface 33 of the blank 31. For example, the inner shoulder 36 may be a curved surface, or may be a planar surface that is angled relative to the first inner surface 32 and the second inner surface 33 of the blank 31. The configuration of the inner shoulder 36 will depend, in embodiments, on the shape and orientation of the outer shoulder 47 machined into the mandrel 41.

[0055] The blank 31 can be manufactured from e.g. a bar, a forging, a tube, welded wrapper or by extrusion. Furthermore, the blank 31 may comprise materials typically considered to be too hard or rigid to be flow formed onto a stepped mandrel with sufficient accuracy. Such materials include, for example, wrought steels, nickel (super-)alloys and titanium alloys or generally medium alloy steels. In particular, the tubular blank may be made of any one of IN718, C263, CMV, 17/4PH, and A286 alloys, etc.

[0056] In use a flow forming method is carried out on the blank 31, where rollers are configured to plastically deform the blank 31 over the mandrel 41, to create a shaped article. The flow forming method of the present disclosure will now be described in detail with respect to **Figures 5a-5c.**

[0057] The method begins as shown in Figure 5a by locating the tubular blank 31 to the mandrel 41. The mandrel 41 is inserted into the blank 31 via first opening 38 such that the inner shoulder 36 of the blank 31 longitudinally opposes the outer mandrel shoulder 47. The distal end 48 of the mandrel 41 is received in the blank 31 and abuts the end wall surface 310. The blank 31 is then secured to the mandrel 41 such that the blank 31 will rotate together with the mandrel 41 during the flow forming method.

[0058] The tubular blank 31 snugly receives the first mandrel region 42 in the first inner volume 316, such that the first inner surface 32 sheathes some but not all of the length of the first mandrel region 42 of the mandrel 41. This is in contrast to conventional flow forming methods where the entire blank is located about the outside of the largest diameter region of the mandrel, i.e. corresponding to the second mandrel region 43 of Figure 3.

[0059] The blank 31 is also configured, e.g. in length, such that when it is secured to the mandrel 41, a portion (some, but not all) of the second inner surface 33 is in contact with and sheathes some, but not all of the length of the second mandrel region 43. That is, an axial extent of the first inner volume 316 and an axial extent of the second inner volume 317 are configured such that, when the first inner volume 316 is fully occupied by the first mandrel region 42, some but not all of the second mandrel region 43 is received by the second inner volume 317 of the blank 31. In this way, the blank 31 is supported on the second mandrel region 43 during the flow forming method. This increases the stability of the blank 31 and acts to guide the blank along the mandrel 41 as the blank 31 is elongated.

[0060] As shown in Figure 5b, the rollers engage the first outer surface 311 of the blank 31 while it is under rotation and translate in a longitudinal direction towards the tailstock 46, such that the outer wall of the blank 31 thins and elongates along the radially outer surface 421. That is, the rollers first engage the blank 31 in a region corresponding to the smallest mandrel diameter and translate along the blank 31 in the longitudinal direction towards a region corresponding to the largest mandrel diameter. This is in contrast to hypothetical flow forming methods where the rollers translate in a direction beginning at the largest mandrel diameter and towards the smallest mandrel diameter.

[0061] The inner shoulder 36 of the blank 31 is caused to translate longitudinally along the first mandrel region 42 towards the outer shoulder 47 of the mandrel 41. The longitudinal translation of the inner shoulder 36 along the first mandrel region 42 causes the second inner volume 317 of the blank 31 to translate in the same longitudinal direction such that it snugly receives the second mandrel region 43. This will continue until it is determined that the inner shoulder 36 of the blank 31 abuts or contacts the outer mandrel shoulder 47 machined into the mandrel 41, in response to which the rollers radially retract and disengage the blank 31 as denoted by arrow 52 in Figure 5b, to prevent further thinning.

[0062] The flow forming method proceeds as shown in Figure 5c, where the rollers relocate and re-engage the blank 31 on the second outer surface 312 and translate in a longitudinal direction towards the tailstock 46, until the second inner surface 33 is elongated to a desired length, while keeping the inner shoulder 36 of the blank 31 in an abutting arrangement with the outer mandrel shoulder 47. The resulting shaped article 51 is then detached from the mandrel and the flange 37 may be re-

moved if desired.

[0063] The shaped article 51 is in the form of a shaft having an inner profile that comprises two inner diameters that are equal to the first and second outer diameters of the mandrel 41. However, it will be appreciated that the inner diameters will substantially correspond to the first inner diameter and the second inner diameter of the original blank, such that the inner diameters of the blank remain unchanged during the flow forming method. The outer profile of the shaped article may vary from that shown in Figure 5 to include provide contour changes, as desired.

[0064] The blank 31 is flow formed to produce the completed shaped article 51 in a single operation in which the blank 31 remains secured to the mandrel 41, i.e. the blank 31 is not removed from the mandrel 41 until after completion of the flow forming method. This reduces the complexity (the number of additional operations, set up and cost) of the flow forming method as compared to hypothetical methods in which flow forming is paused so that a blank can be removed from the mandrel, e.g. to machine a second inner diameter into the blank, before resuming the flow forming operation.

[0065] From the above, it is clear that the technology described herein facilitates the production of a more accurate shaped article in that the final inner diameters will be closer to the nominal predefined values for the shaped article, thereby improving general tolerances of the shaped article due to the inherent stability associated with forming a closely matched article against a mandrel. It also enables materials of higher strength, and blanks of greater thicknesses, to be used to flow form a shaped article, thereby increasing the versatility of the flow forming method.

[0066] It will be understood that the invention is not limited to the embodiments above-described and various modifications and improvements can be made without departing from the concepts described herein. Except where mutually exclusive, any of the features may be employed separately or in combination with any other features and the disclosure extends to and includes all combinations and subcombinations of one or more features described herein.

Claims

1. A tubular blank (31) for attaching to a stepped mandrel (41) of a flow forming assembly, wherein the tubular blank (31) has a stepped inner profile.
2. The tubular blank (31) as claimed in Claim 1, wherein the tubular blank (31) has a stepped inner profile comprising:

a first inner surface (32) extending circumferentially about a central longitudinal axis (50) to define a first inner volume (316) having a first inner

diameter (34);

a second inner surface (33) axially adjacent the first inner surface (32) and extending circumferentially about the central longitudinal axis (50) to define a second inner volume (317) having a second inner diameter (35) that is larger than the first inner diameter (34); and
an inner shoulder (36) between the first inner surface (32) and the second inner surface (33).

3. The tubular blank (31) as claimed in Claim 2, further comprising an end wall (37) extending radially inwardly from the second inner surface (33) to at least partly close the first inner volume (316).
4. The tubular blank (31) as claimed in any one of Claims 1, 2 or 3, wherein the tubular blank (31) is made of a material comprising at least one of a wrought steel, a nickel alloy and a titanium alloy.

5. A flow forming kit comprising:

a stepped mandrel (41) comprising a first mandrel region (42) having a first outer mandrel diameter (44) and a second mandrel region (43) having a larger second outer mandrel diameter (45); and

a tubular blank (31) as claimed in claim 2; wherein the tubular blank (31) is configured to cooperate with the stepped mandrel in that:

the first inner diameter (34) corresponds to the first outer mandrel diameter (44) such that the first inner volume (316) is suitable for receiving the first mandrel region (42); and

the second inner diameter (35) corresponds to the second outer mandrel diameter (45) such that the second inner volume (317) is suitable for receiving the second mandrel region (43).

6. The flow forming kit as claimed in Claim 5, wherein: the first inner surface (32) has an axial extent such that, when the first inner volume (316) receives the first mandrel region (42), an inner shoulder (36) of the blank (31) longitudinally opposes an outer mandrel shoulder (47) between the first mandrel region (42) and the second mandrel region (43).
7. The flow forming kit as claimed in Claim 5 or Claim 6, wherein: the first inner surface (32) has an axial extent such that, when the first inner volume (316) is fully occupied by the first mandrel region (42), some but not all of the second mandrel region (43) is received by the second inner volume (317) of the blank (31), to support the blank (31) on the second mandrel region

(43).

8. The flow forming kit as claimed in any one of Claims 5, 6 or 7, wherein a step of the inner profile has a shape that conforms to the shape of a step in the mandrel (41). 5
9. A method of flow forming a shaped article (51), comprising: 10
 - providing a stepped mandrel (41) that comprises a first mandrel region (42) having a first outer mandrel diameter (44) and a second mandrel region (43) having a second outer mandrel diameter (45) that is larger than the first outer mandrel diameter (44); 15
 - providing a tubular blank (31) having a stepped inner profile;
 - locating the tubular blank (31) on the mandrel (41); and 20
 - plastically deforming the tubular blank (31) over the mandrel (41) to create the shaped article (51).
10. The method of flow forming a shaped article (51) as claimed in Claim 9, wherein: 25
 - the tubular blank (31) comprises a first inner volume (316) having a first inner diameter (34) and a second inner volume (317) having a second inner diameter (35) that is larger than the first inner diameter (34); and 30
 - locating the tubular blank (31) on the mandrel (41) comprises the tubular blank (31) snugly receiving the first mandrel region (42) in the first inner volume (316) of the tubular blank (31). 35
11. The method of flow forming a shaped article (51) as claimed in Claim 10, comprising: 40
 - locating the tubular blank (31) on the mandrel (41) such that an inner shoulder (36) of the blank (31) longitudinally opposes an outer shoulder (47) of the mandrel (41); and 45
 - plastically deforming the tubular blank (31) over the mandrel (41) such that the inner shoulder (36) of the blank (31) translates longitudinally along the first mandrel region (42) towards the outer shoulder (47) of the mandrel (41). 50
12. The method of flow forming a shaped article (51) as claimed in Claim 11, further comprising: 55
 - one or more rollers engaging a first outer surface (311) of the blank (31), which is radially outwards of a first inner surface (32) defining the first inner volume (316), thereby elongating the first inner surface (32) such that the inner shoulder (36)

translates longitudinally along the first mandrel region (42) towards the outer shoulder (47) of the mandrel (41);

the one or more rollers disengaging the first outer surface (311) in response to determining that the inner shoulder (36) of the blank (31) is abutting the outer mandrel shoulder (47); and the one or more rollers engaging a second outer surface (312) of the blank (31), which is radially outwards of a second inner surface (33) defining the second inner volume (317), thereby elongating the second inner surface (33) along the second mandrel region (43) while keeping the inner shoulder (36) of the blank (31) in an abutting arrangement with the outer mandrel shoulder (47).

13. The method of flow forming a shaped article (51) as claimed in Claim 11 or Claim 12, wherein longitudinal translation of the inner shoulder (36) along the first mandrel region (42) causes the second inner volume (317) of the blank (31) to translate in the same longitudinal direction such that it snugly receives the second mandrel region (43).

14. The method of flow forming a shaped article (51) as claimed in any one of Claims 9 to 13, wherein plastically deforming the tubular blank (31) over the mandrel (41) to create the shaped article (51) comprises elongating the tubular blank (31) without changing the inner diameters of the tubular blank (31) during the flow forming method.

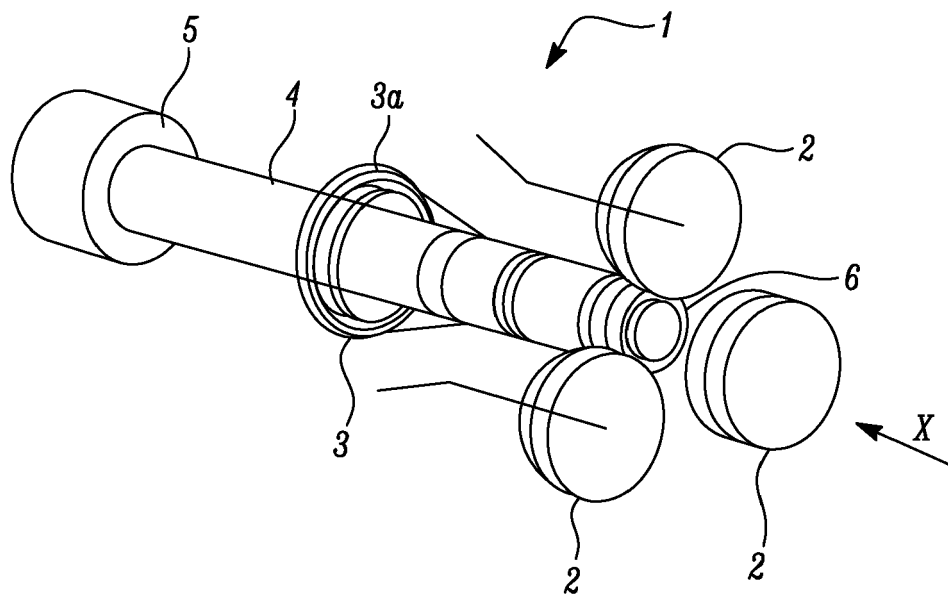


FIG. 1

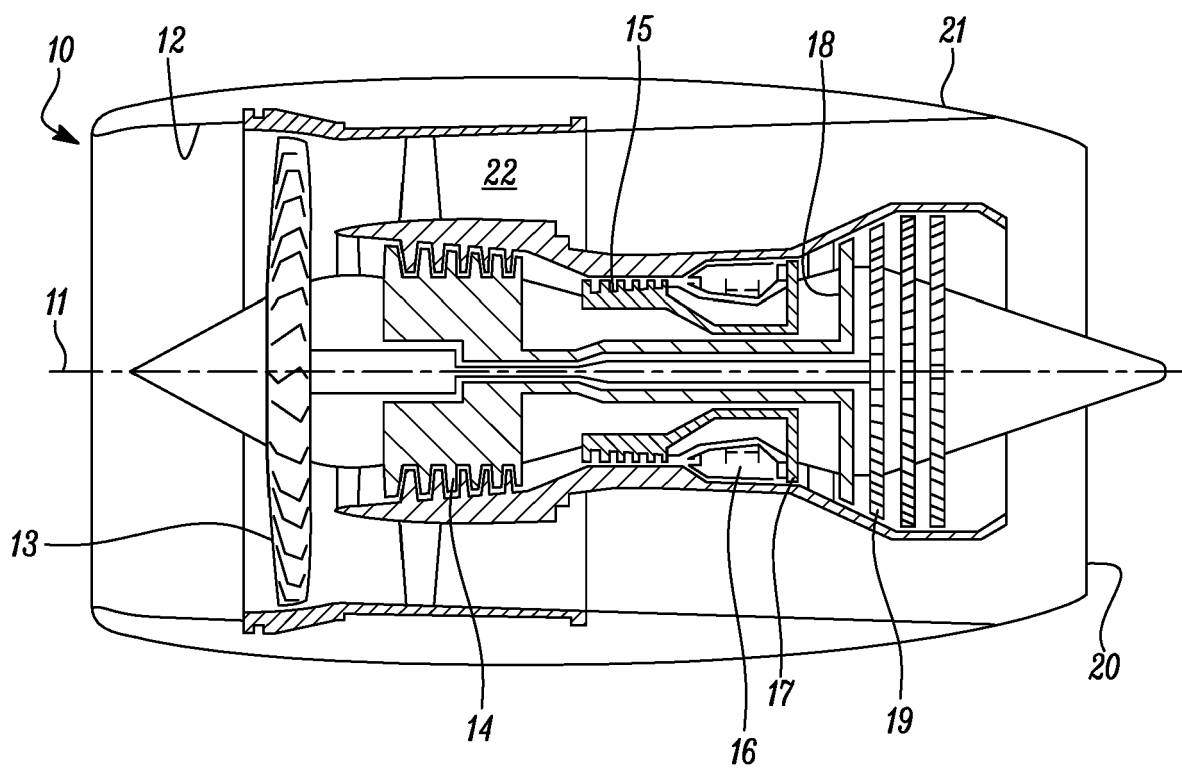


FIG. 2

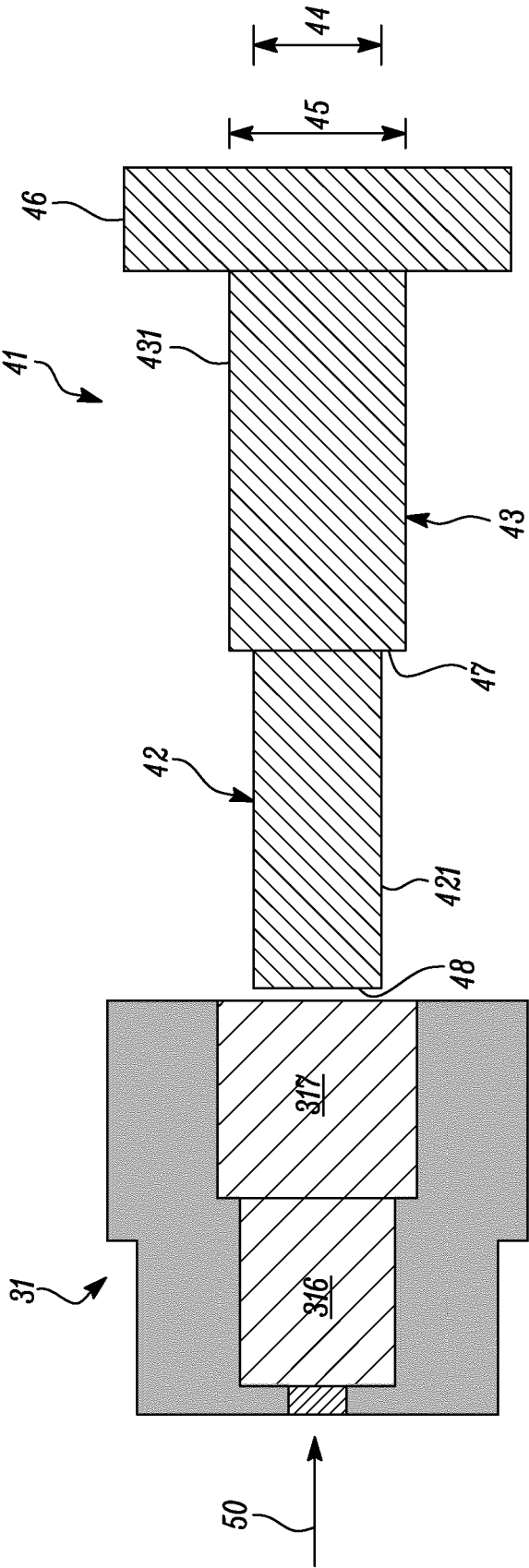


FIG. 3

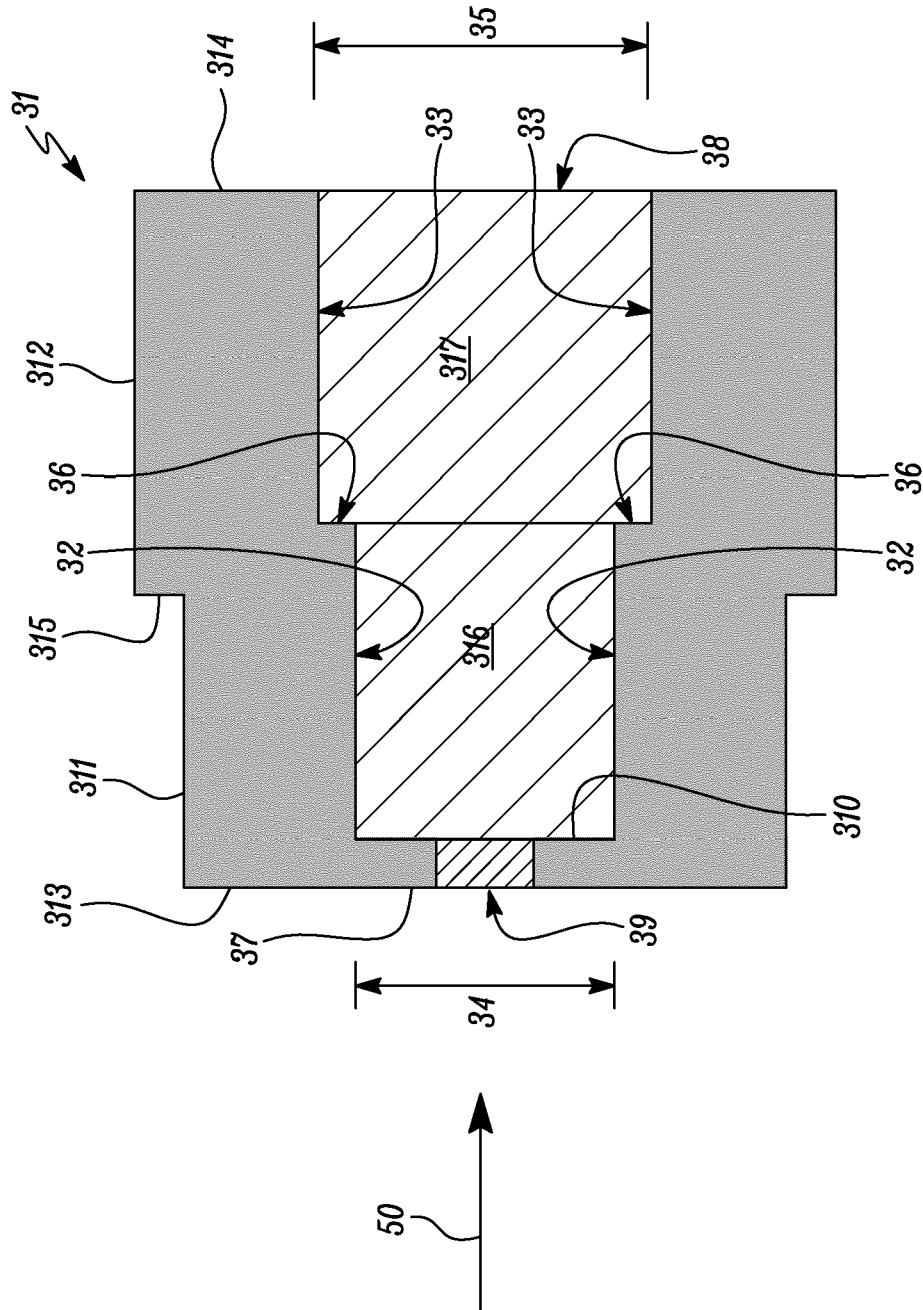


FIG. 4

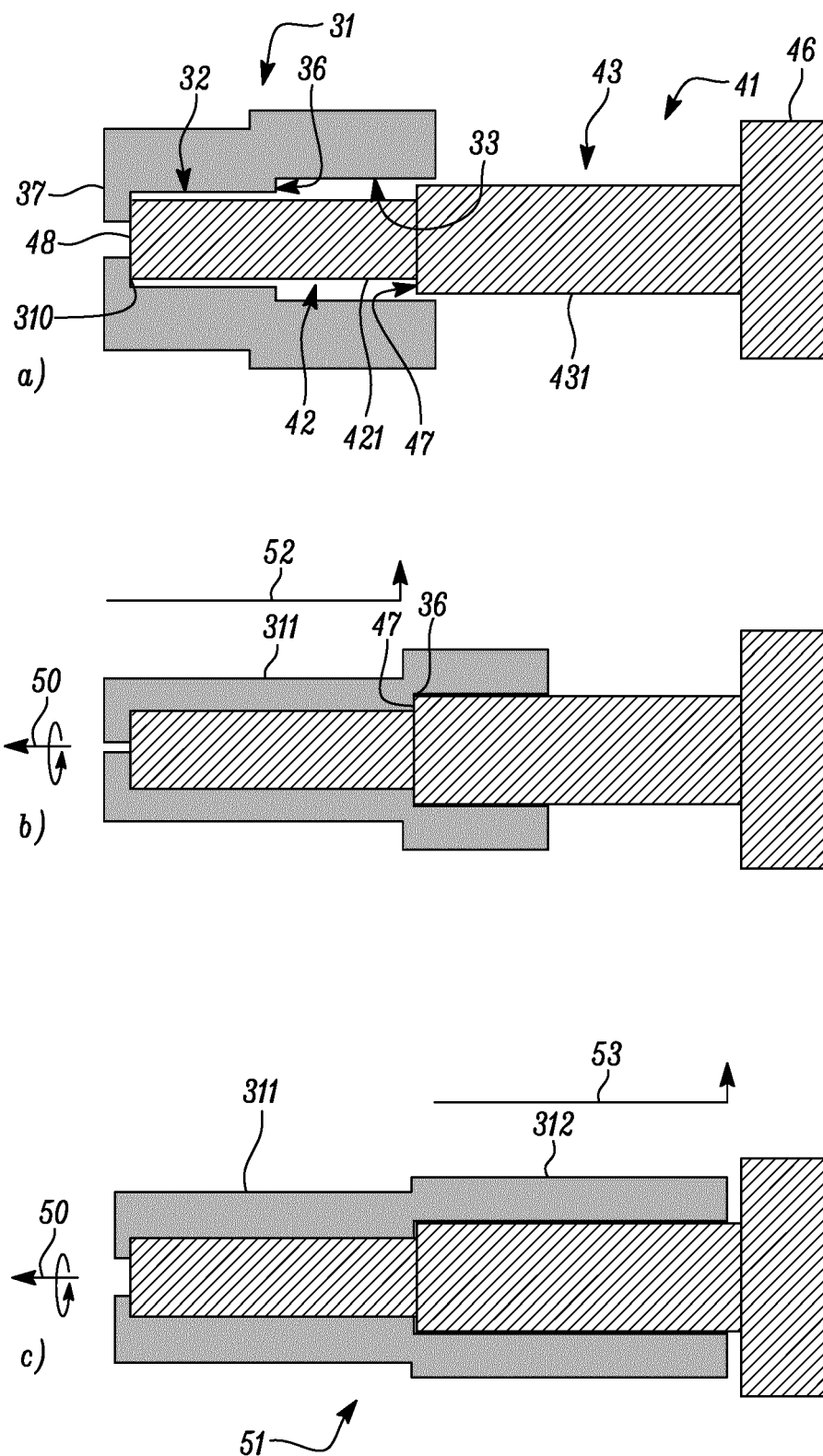


FIG. 5



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Application Number
EP 19 20 3069

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Place of search Munich		Date of completion of the search 24 February 2020	Examiner Stanic, Franjo
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