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(54) **RADIUSED LEAD-IN FOR INTERFERENCE FIT FASTENERS**

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See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,915,559 A * 4/1990 Wheeler F16B 33/02 411/366.3
5,018,920 A 5/1991 Speakman
(Continued)

FOREIGN PATENT DOCUMENTS

CN 103557219 A 2/2014
CN 202360548 U 4/2016
WO 2016050791 A1 4/2016

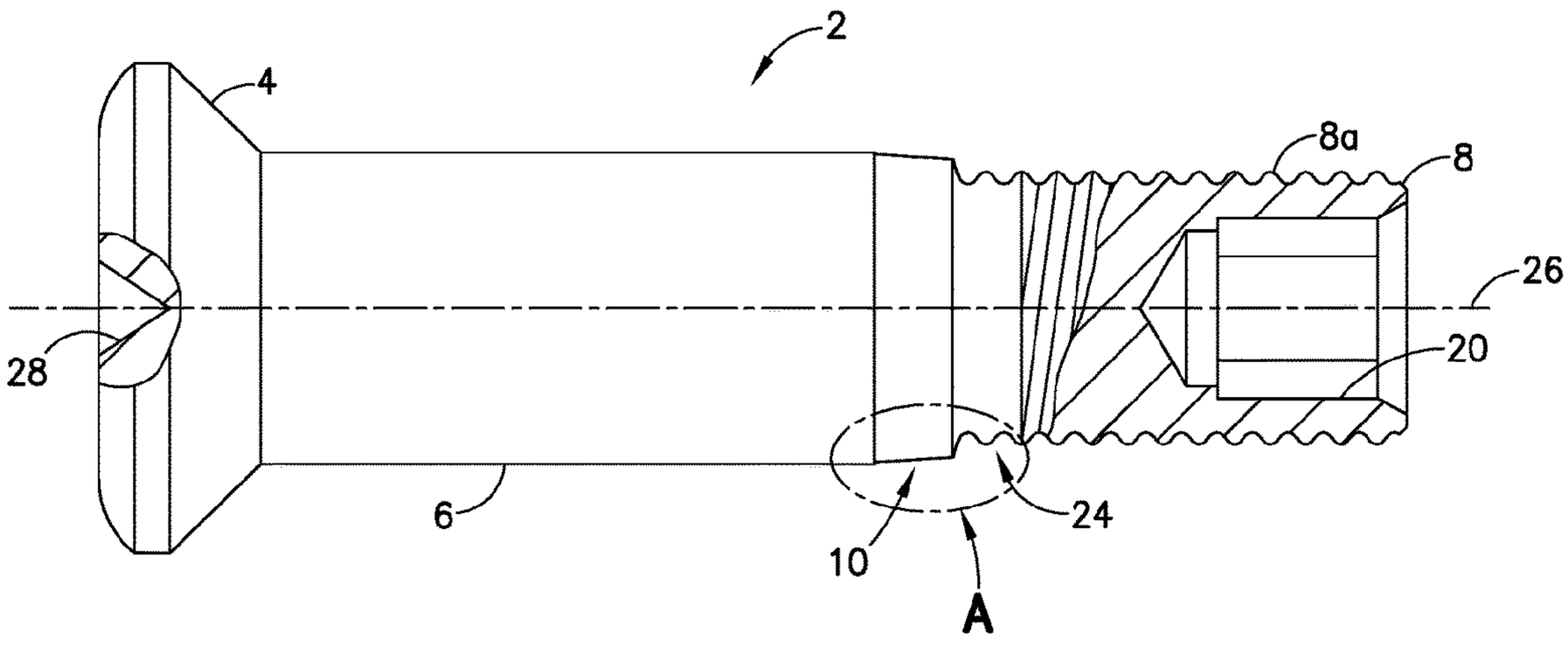
OTHER PUBLICATIONS

Extended European Search Report dated Jul. 2, 2018 in European Patent Application No. 17204375.4 (European counterpart of the instant U.S. patent application).
(Continued)

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(57) **ABSTRACT**

An assembly comprising first and second structural elements having aligned holes, an fastener that occupies at least respective portions of the holes without a surrounding sleeve, and a mating part that is coupled to the fastener. The fastener comprises: a head; a circular cylindrical shank extending from the head; a mating portion comprising external projections; and a transition portion disposed between the shank and the mating portion. The transition portion comprises a first radiused lead-in section that meets the shank at a shank/lead-in intersection and a second radiused lead-in section that meets the first radiused lead-in section. The first radiused lead-in section curves gradually in a first axial direction toward the mating portion and has a first profile that is a circular arc having a first radius, while the second radiused lead-in section curves abruptly in the first axial direction and has a second profile that is a circular
(Continued)



arc having a second radius which is much smaller than the first radius.

20 Claims, 4 Drawing Sheets

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F16B 5/01	(2006.01)
B21J 15/02	(2006.01)
B21J 15/10	(2006.01)

(52) **U.S. Cl.**
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(56) **References Cited**

U.S. PATENT DOCUMENTS

6,149,363	A *	11/2000	March	B21H 3/06 411/366.1
7,695,226	B2	4/2010	March et al.	
9,447,809	B2	9/2016	Regnard et al.	
2009/0178262	A1 *	7/2009	Reid	B21J 15/022 29/263
2015/0147136	A1	5/2015	Maurel et al.	
2016/0169262	A1	6/2016	Regnard et al.	

OTHER PUBLICATIONS

Examination Report dated Sep. 2, 2019 in European Patent Application No. 17204375.4 (European counterpart of the instant U.S. patent application).

* cited by examiner

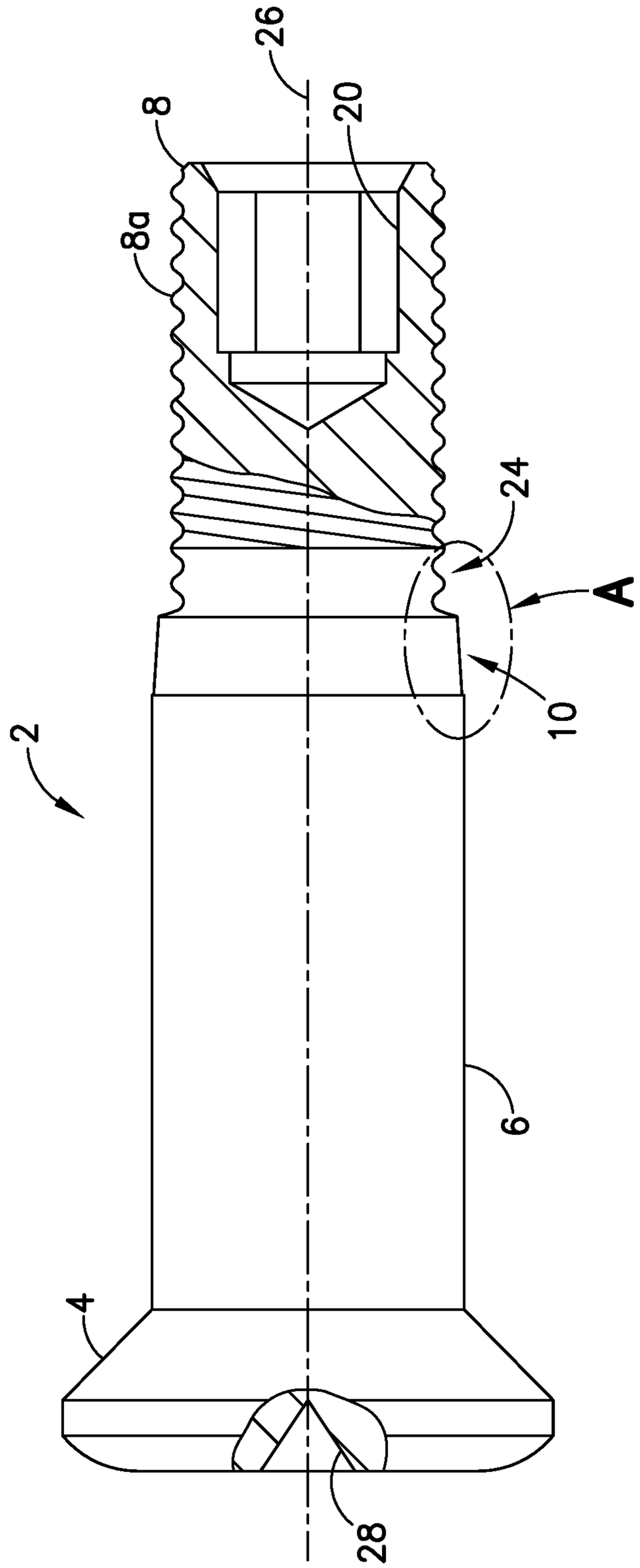


FIG. 1

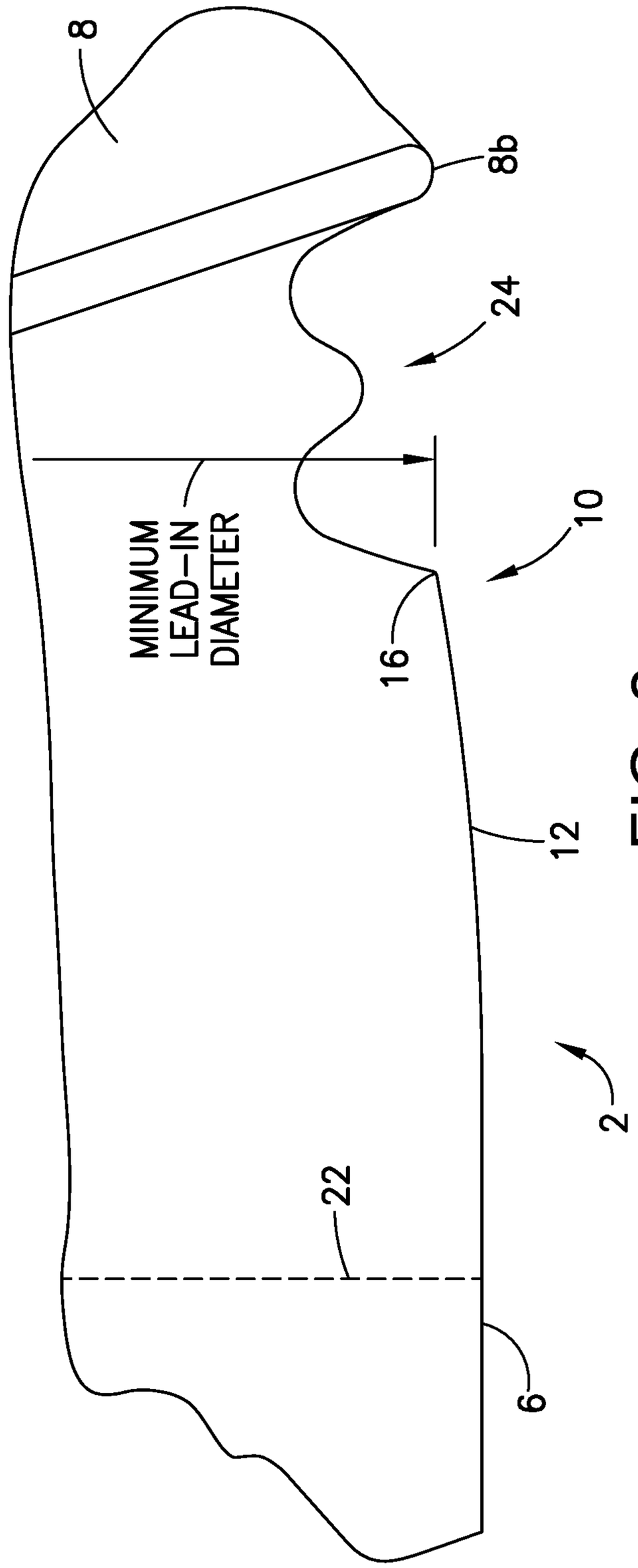


FIG. 2

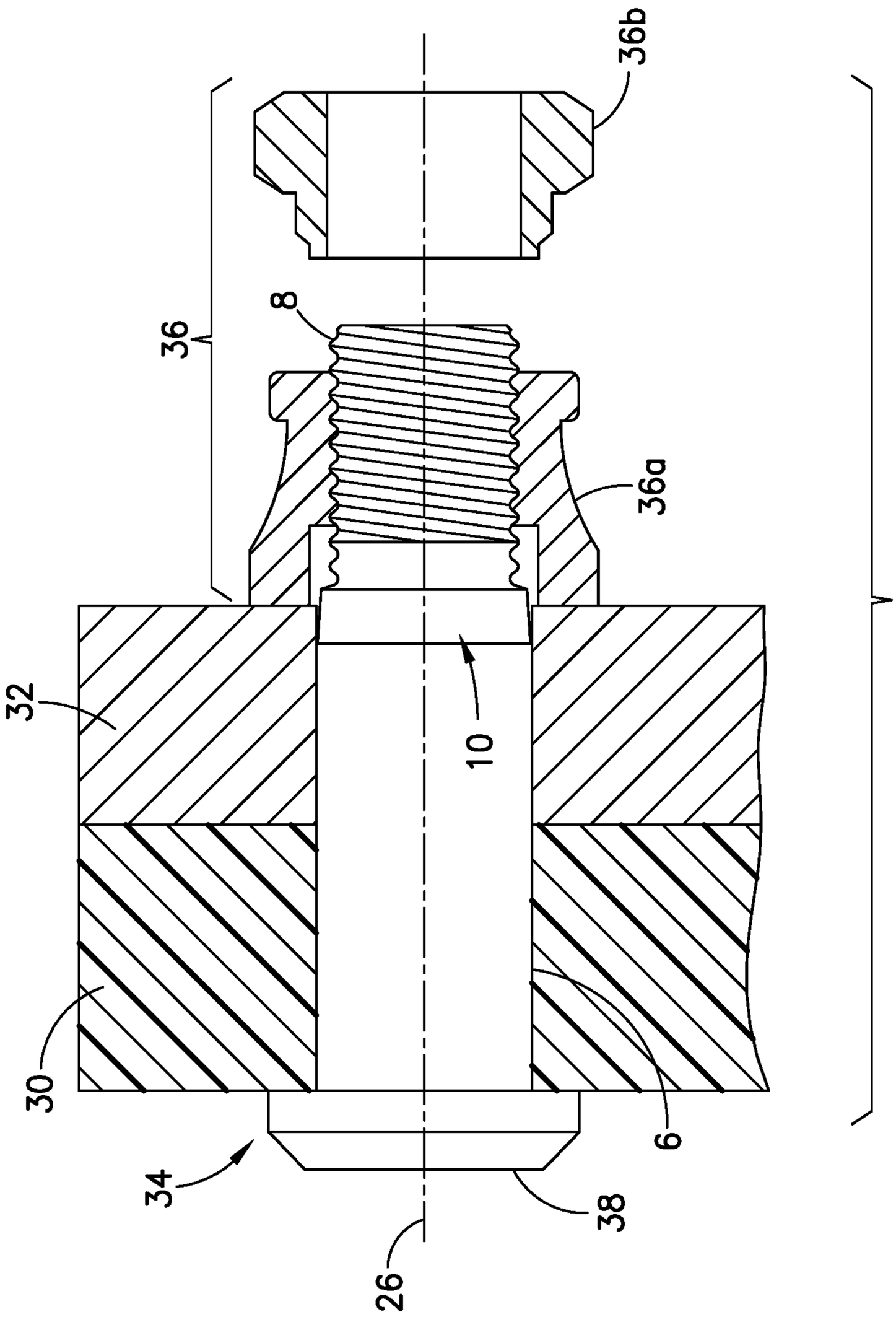


FIG. 3

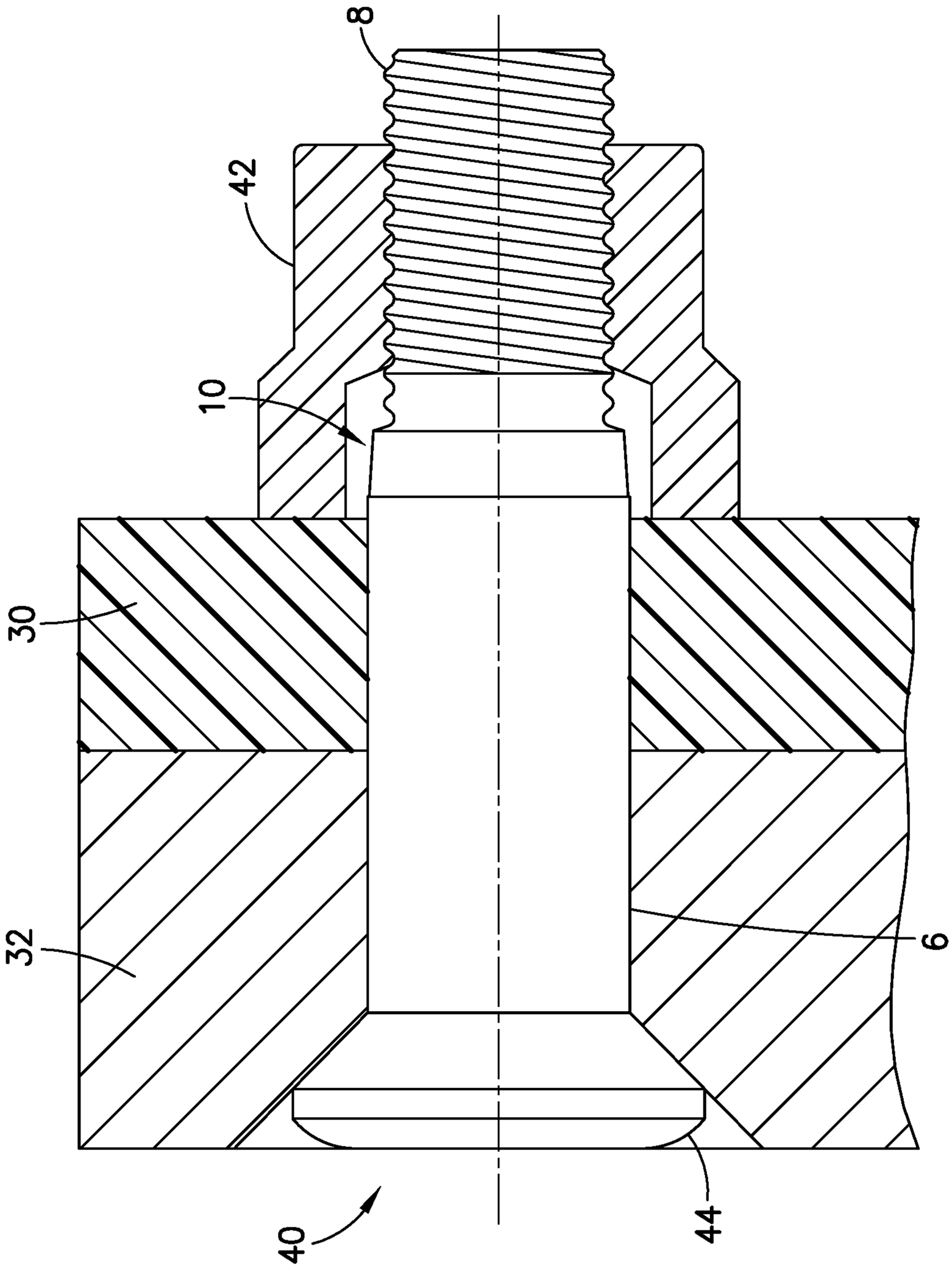


FIG. 4

RADIUSED LEAD-IN FOR INTERFERENCE FIT FASTENERS

BACKGROUND

This disclosure generally relates to the use of fasteners to secure two or more structures or workpieces (at least one of which is made of composite material, such as fiber-reinforced plastic) in a manner such that high interference fit of the fasteners within their respective holes in the layers is achieved. In particular, this disclosure relates to interference fit fastener assemblies comprising a bolt or a pin and a mating part (e.g., a nut or a collar) and not including a sleeve surrounding the fastener.

Normal practice for fastening multiple layers of material together is to clamp up the layers, drill holes, and then insert some type of fastener into the holes and thereby secure the layers together. The fasteners are usually inserted in a net or clearance fit in the receiving holes in the layers. For many applications this will be sufficient. However, when the assembled structure is subjected to cyclic loading, the looseness of the fit of the fasteners within their holes will result in continual working of the fasteners within their holes. This in turn may lead to fretting and fatigue issues with either the fastener or the surrounding region of the layers adjacent a particular hole.

To solve the foregoing problems, it is known that the utilization of a high interference fit of the fastener in the hole can effectively prevent the majority of this fretting due to cyclic loading of the assembled structure. High interference creates a tighter joint that reduces movement, resulting in enhanced fatigue performance. In many cases an oversized fastener will be driven directly into the receiving hole in the layers. Typically, some lubricant is applied to the fastener and hole before assembly to reduce the tendency toward abrasion as the fastener is pushed into the hole. In other cases a sleeve is slipped into the hole in a net or clearance fit followed by the drive-in of an oversized fastener with or without lubricant to radially expand the sleeve in order to create an interference fit condition.

Currently there are two primary solutions for fasteners used in the assembly of composite wing structures in aircraft production: (1) sleeved bolt systems; and (2) clearance fit fasteners with cap seals. The use of sleeved bolt systems has the following drawbacks: (a) the parts require complicated installation methods; (b) the parts require careful handling to prevent damage; and (c) the system requires extensive in-process measurements (resulting in longer assembly time). The use of clearance fit fasteners with cap seals has the following drawbacks: (a) this system allows for increased joint deflection over time, affecting fatigue performance; and (b) the amount of time involved in seal cap application increases assembly time. In addition, existing interference fit solutions used in metallic aircraft structure may not be optimized to reduce the installation force load when a fastener is installed. A high installation force load may cause composite material to crack or excessively delaminate.

It would be desirable to provide improved interference fit fasteners for installation in composite material which reduce installation force loads and address one or more of the drawbacks identified in the preceding paragraph.

SUMMARY

The subject matter disclosed in detail below is directed to interference fit fasteners for attaching two or more structures together. Each interference fit fastener comprises a fastener that has a radiused lead-in section between the shank and the external threads. This radiused lead-in geometry decreases installation forces in interference fit holes, thereby increasing joint fatigue life, enhancing fluid tightness, and reducing susceptibility to electromagnetic effects. A radiused lead-in geometry accomplishes the foregoing by promoting gradual compression of material as the bolt is pushed through the structures to be fastened.

In accordance with at least some embodiments, the interference fit fastener comprises a fastener having a transition portion disposed between a shank and a mating portion having external projections, which transition portion comprises a first radiused lead-in section that meets the shank at a shank/lead-in intersection and a second radiused lead-in section that meets the first radiused lead-in section. The first radiused lead-in section curves gradually in a first axial direction toward the mating portion and has a first profile that is a circular arc having a first radius, and the second radiused lead-in section curves abruptly in the first axial direction and has a second profile that is a circular arc having a second radius which is much smaller than the first radius. In other words, the diameter of the fastener in the first radiused lead-in section gradually decreases starting from the diameter of the circular cylindrical shank; and the diameter of the fastener in the second radiused lead-in section gradually decreases starting from a minimum diameter of the first radiused lead-in section to a minimum diameter of the second radiused lead-in section circular cylindrical shank. The aforementioned diameters are measured in planes perpendicular to the central axis of the fastener, while the aforementioned radii are measured in a plane that is parallel to and intersects the central axis of the fastener.

As used herein, the term "external projections" should be construed broadly to encompass at least the following types: (1) external threads and (2) external annular rings. For the purpose of illustration, examples of fasteners having externals threads are described below. However, the concepts disclosed and claimed herein also have application to interference fit fasteners having external annular rings. Thus the subject matter disclosed in detail below may be characterized by one or more of the following aspects.

One aspect of the subject matter disclosed in detail below is a fastener comprising: a head; a shank extending from the head, the shank comprising an external surface that is circular cylindrical; a mating portion comprising external projections; and a transition portion disposed between the shank and the mating portion, wherein the transition portion comprises a first radiused lead-in section that meets the shank at a shank/lead-in intersection and a second radiused lead-in section that meets the first radiused lead-in section. The first radiused lead-in section curves gradually in a first axial direction toward the mating portion and has a first profile that is a circular arc having a first radius, while the second radiused lead-in section curves abruptly in the first axial direction and has a second profile that is a circular arc having a second radius which is much smaller than the first radius. In addition, the mating portion has a maximum diameter less than a minimum diameter of the second radiused lead-in section. The first profile is a profile of an external surface of the first radiused lead-in section in a plane that intersects a central axis of the fastener, while the second profile is a profile of an external surface of the second radiused lead-in section in the plane that intersects the central axis of the fastener. In accordance with one

embodiment, a profile of the shank in the plane that intersects the central axis of the fastener is tangent to the first profile.

Another aspect of the subject matter disclosed herein is a method for fastening a first structure having a first hole and a second structure having a second hole, the first and second holes having the same hole diameter, comprising: placing the first and second structures together with the first and second holes aligned; inserting a mating portion of a fastener into the first hole until an edge of the first hole in the first structure is in contact with and surrounds a radiused lead-in section of the fastener that tapers gradually toward the mating portion, the fastener further comprising a head and a circular cylindrical shank connecting the head to the tapered lead-in section, the shank having a shank diameter greater than the hole diameter; forcing the fastener further into the aligned holes of the first and second structures to cause the shank to contact the edge of the first hole, push through the first hole, and then push through the second hole until the mating portion of the fastener projects beyond the second structure; and coupling a mating part to the mating portion of the fastener. The amount of interference between the shank and the first hole is no more than 0.004 inch. A maximum diameter of the radiused lead-in section equals the diameter of the shank and a minimum diameter of the radiused lead-in section is less than the diameter of the first and second holes.

A further aspect of the subject matter disclosed herein is an assembly comprising a first structural element having a first hole, a second structural element having a second hole aligned with the first hole of the first structural element, a fastener that occupies at least respective portions of the first and second holes in the first and second structural elements without a surrounding sleeve and extends beyond the second structural element, and a mating part that abuts the second structural element and is coupled to the fastener, wherein the fastener comprises: a head; a shank extending from the head, the shank comprising an external surface that is circular cylindrical; a mating portion comprising external projections; and a transition portion disposed between the shank and the mating portion, wherein the transition portion comprises a first radiused lead-in section that meets the shank at a shank/lead-in intersection and a second radiused lead-in section that meets the first radiused lead-in section. The first radiused lead-in section curves gradually in a first axial direction toward the mating portion and has a first profile that is a circular arc having a first radius, while the second radiused lead-in section curves abruptly in the first axial direction and has a second profile that is a circular arc having a second radius which is much smaller than the first radius. In accordance with some embodiments, one of the first and second structural elements is made of composite material and the other of the first and second structural elements is made of metallic material. In accordance with other embodiments, both structural elements are made of composite material. The shank of the fastener and the first and second structural elements are in contact without a sleeve therebetween.

Other aspects of improved interference fit fasteners for attaching two or more structures to each other are disclosed below.

BRIEF DESCRIPTION OF THE DRAWINGS

The features, functions and advantages discussed in the preceding section can be achieved independently in various embodiments or may be combined in yet other embodiments. Various embodiments will be hereinafter described with reference to drawings for the purpose of illustrating the above-described and other aspects.

FIG. **1** is a diagram representing a partially sectioned view of an interference fit bolt.

FIG. **2** is a diagram representing a view of the portion of the interference fit bolt within the dashed ellipse A depicted in FIG. **1**, which view shows the geometry of a first radiused lead-in section in accordance with one embodiment.

FIG. **3** is a diagram representing a partially sectioned view of an assembly comprising composite and metallic structures gripped by a sleeveless interference fit fastener assembly in accordance with an alternative embodiment, which fastener assembly comprises a pin having external threads and a collar having internal threads interengaged with the external threads.

FIG. **4** is a diagram representing a partially sectioned view of an assembly comprising composite and metallic structures gripped by a sleeveless interference fit fastener assembly in accordance with a further embodiment, which fastener assembly comprises a pin having external threads and a swaged collar interengaged with the external threads.

Reference will hereinafter be made to the drawings in which similar elements in different drawings bear the same reference numerals.

DETAILED DESCRIPTION

Various embodiments of an interference fit fastener will now be described in detail for the purpose of illustration. At least some of the details disclosed below relate to optional features or aspects, which in some applications may be omitted without departing from the scope of the claims appended hereto.

In particular, illustrative embodiments of an interference fit fastener for attaching two structures to each other are described in some detail below. In the examples given below, one of the structures is made of metallic material (e.g., a metal alloy) and the other structure is made of composite material (e.g., fiber-reinforced plastic). However, in alternative examples, both structures can be made of composite material or both structures can be made of metallic material. In addition, it should be appreciated that the concept disclosed herein also has application in the attachment of three or more structures together.

FIG. **1** is a diagram representing a partially sectioned view of an interference fit bolt **2** (hereinafter "bolt **2**"). The bolt **2** comprises a head **4** designed to be countersunk into the structure and a shank **6** extending from the head **4**. The head **4** has a drill center dimple **28**. The shank **6** comprises an external surface that is circular cylindrical. The bolt **2** further comprises a threaded portion **8** comprising external threads **8***a* which is connected to the shank **6** by a transition portion **10** disposed between the shank **6** and the threaded portion **8**. The threaded portion **8** has a hexagonal recess **20**, in which an Allen key can be inserted during installation to hold the bolt **2** in place while a mating part is rotated about the external threads **8***a*.

FIG. **2** is a diagram representing a view of the portion of the bolt **2** within the dashed ellipse A depicted in FIG. **1**. The depicted portion of bolt **2** includes a portion of an incomplete thread **8***b*, which represents the start of the threaded portion **8**. This view shows the geometry of the transition portion **10** in accordance with one embodiment. The transition portion **10** comprises a first radiused lead-in section **12** that meets the shank **6** at a shank/lead-in intersection **22** (indicated by a straight vertical dashed line in FIG. **2**) and a

second radiused lead-in section **16** that meets the first radiused lead-in section **12**. The transition portion **10** further comprises a transition section **24** between the second radiused lead-in section **16** and the threaded portion **8**. This transition section **24** has an external surface defined by an undulating curve rotated about the central axis **26** of bolt **2** and has diameters which are less than a minimum diameter D of the first radiused lead-in section. In addition, the threaded portion **8** of bolt **2** has a maximum diameter which is less than the minimum diameter D.

The first radiused lead-in section **12** curves gradually in a first axial direction toward the threaded portion **8** and has a first profile that is a circular arc having a first radius. The second radiused lead-in section **16** curves abruptly in the first axial direction and has a second profile that is a circular arc having a second radius which is smaller than the first radius.

For the avoidance of doubt, the first and second profiles of the transition portion **10** are defined as follows. The first profile is a profile of an external surface of the first radiused lead-in section **12** in a plane that intersects a central axis **26** of bolt **2**. The second profile is an external surface of the second radiused lead-in section **16** in the plane that intersects the central axis **26**. In accordance with one embodiment, the profile of the shank **6** in the plane that intersects the central axis **26** is tangent to the first profile of the transition portion **10**. The non-linear lead-in geometry of the first radiused lead-in section **12** promotes gradual compression of material as the bolt **2** is pushed through the structures to be fastened.

It should be appreciated that the dimensions of bolt **2** will vary depending on the thicknesses of the structures being fastened together and the diameters of the aligned holes in those structures. In accordance with various examples, the length and radius of the first radiused lead-in section **12** may be in respective ranges of 0.062 to 0.092 inch and 0.34 to 0.68 inch for bolts or pins having a shank diameter in a range of 6/32 to 16/32 inch, and the second radius r of the second radiused lead-in section **16** may be about 0.01 inch.

During installation, a manual rivet gun or automated system can be used to push the bolt **2** through the aligned holes of the structures to be fastened. As previously described, the bolt **2** comprises a circular cylindrical shank **6** having a diameter greater than the diameter of the holes in the structures (one-half of the difference between the shank diameter and the hole diameter will be referred to below as the "amount of interference"), a first radiused lead-in section **12**, a second radiused lead-in section **16** and a threaded portion **8**. A maximum diameter of the first radiused lead-in section **12** equals the diameter of the shank **6** and a minimum diameter of the first radiused lead-in section **12** is less than the diameter of the holes in the structures. The edge of the first hole slides along the first radiused lead-in section **12** as the bolt **2** is pushed into the hole. That edge may be radiused. Depending on the amount of interference (preferably not in excess of 0.004 inch) and the radius of the first radiused lead-in section **12**, the edge of the hole will slide gradually along the first radiused lead-in section **12** for a varying percentage of the length of the first radiused lead-in section **12** during bolt insertion.

During installation, the bolt **2** will be pushed through the aligned holes of the structures to be fastened until the threaded portion **8** projects beyond the last structure. A mating part (not shown in FIG. **1**) is then placed onto the threaded portion **8** with a specified clamping force. In some cases, the mating part may take the form of a nut having an opening with internal threads and a non-circular wrenching surface (e.g., hexagonal) designed to be engaged by a wrench or similar tool. It should be appreciated, however, that a variety of collars and nuts are compatible with the fasteners disclosed herein. Two examples of suitable collars will be described hereinafter with reference to FIGS. **3** and **4**.

FIG. **3** is a diagram representing a partially sectioned view of an assembly comprising a composite structure **30** and a metallic structure **32** gripped by a sleeveless interference fit fastener assembly in accordance with an alternative embodiment. The fastener assembly comprises a pin **34** having external threads and a remaining collar portion **36***a* having internal threads interengaged with the external threads of pin **34**. FIG. **3** also shows a collar wrenching element **36***b* which, prior to separation from remaining collar portion **36***a*, was connected to remaining collar portion **36***a*. The collar wrenching element **36***b* has a non-circular wrenching surface (e.g., hexagonal) designed to be engaged by a wrench or similar tool, whereas the remaining collar portion **36***a* does not have a wrenching surface, thereby reducing the weight of the collar as compared to the weight of a nut. For example, the external profile of the remaining collar portion **36***a* may be circular. This initial joinder of remaining collar portion **36***a* and collar wrenching element **36***b* (i.e., prior to the wrenching operation) to form a collar **36** indicated by the upper curly bracket in FIG. **3**.

Although not shown in detail, the pin **34** depicted in FIG. **3** comprises a shank **6**, a threaded portion **8** and a transition portion **10** similar to the corresponding structures in bolt **2** seen in FIG. **1**. More specifically, the transition portion **10** comprises a first radiused lead-in section **12** and a second radiused lead-in section **16** having the geometry shown in FIG. **2** and the dimensions stated above. Although FIG. **3** depicts a pin **34** having a protruding head **38**, pin **34** may in the alternative have a countersunk (i.e., flush) head.

The procedure for installing fastener assemblies of the type depicted in FIG. **3** is well known. Such a fastener assembly can be installed by one person from one side of the structures being fastened using power tools or hand tools. The procedure does not require calibrated torque wrenches and torque inspection. The collar **36** is screwed onto the threaded portion **8** of pin **34** and then tightened until a specified preload is produced on each fastener. The collar wrenching element **36***b* will break away at the designed preload, leaving the remaining collar portion **36***a* as seen in FIG. **3**. The elimination of the collar wrenching element **36***b* at torque-off results in weight savings of the fastener assembly.

FIG. **4** is a diagram representing a partially sectioned view of an assembly comprising a composite structure **30** and a metallic structure **32** (referred to below as the "joint structure") gripped by a sleeveless interference fit fastener assembly in accordance with a further embodiment. This fastener assembly (which is frequently referred to as a lockbolt) comprises an interference fit pin **40** (hereinafter "pin **40**") having external threads and a swaged collar **42** that is interengaged with the grooves on the threaded portion **8** of pin **40**. In alternative embodiments, the pin **40** may have external annular rings instead of external threads.

Although not shown in detail, the pin **40** depicted in FIG. **4** comprises a shaft **6**, a threaded portion **8** and a transition portion **10** similar to the corresponding structures in bolt **2** seen in FIG. **1**. More specifically, the transition portion **10** comprises a first radiused lead-in section **12** and a second radiused lead-in section **16** having the geometry shown in FIG. **2** and the dimensions stated above. Although FIG. **4**

depicts a pin **40** having a countersunk (i.e., flush) head **44**, pin **40** may in the alternative have a protruding head.

The pin **40** shown in FIG. **4** is inserted into one side of the joint structure and the unswaged collar (not shown in FIG. **4**) is placed over the pin **40** from the other side of the joint structure. Access to both sides of the joint structure is required. During the installation cycle of a lockbolt, the unswaged collar (in the form of a loose-fitting metal ring) is deformed around the pin **40**, which has locking grooves on the threaded portion **8**. Although not shown in FIG. **4**, it is well known that at the start of a typical lockbolt installation procedure, the pin **40** is connected to a pintail. Then a tool is engaged with the pintail. Thereafter the pin head **44** is pulled against the metallic structure **32** and the unswaged collar is pushed against the composite structure **30**, pulling the composite structure **30** and metallic structure **32** together. Then a conical cavity of the tool is forced down the collar, which reduces the diameter of collar and progressively swages the collar material into the grooves of the harder pin **40**, thereby forming swaged collar **42**. As the force required for swaging increases during the process, the installation is completed when the pintail (not shown) breaks off. The pin **40** and swaged collar **42** combine to form the fastener assembly.

The bolts and pins disclosed herein are preferably made of a metal alloy such as titanium alloy, aluminum alloy, Inconel or corrosion-resistant steel. The collars disclosed herein are preferably made of titanium alloy, aluminum alloy or corrosion-resistant steel. The bolts, pins and collars are preferably coated or partially coated. The coating could be any combination of aluminum pigment coating, solid film lubricant, metallic plating (cadmium plate, zinc-nickel, etc.). Each coating could have an additional lubricant such as cetyl alcohol applied over the top.

The interference fit fasteners disclosed herein are especially useful in the assembly of composite wing structures during aircraft production. The proposed system has the following benefits over the existing systems.

The interference fit fasteners disclosed herein have advantages over sleeved bolts in that, by eliminating the sleeve element, the proposed fastener assembly reduces manufacturing complexity and decreases part cost. By installing these bolts or pins in interference, the assembly time is drastically reduced compared to the traditional sleeved bolt assembly process.

The interference fit fasteners disclosed herein have advantages over installing clearance fit fasteners with cap seals in that fatigue results are improved with interference fit fasteners compared to clearance fit fasteners. These fasteners are installed in the most fatigue-critical areas of the aircraft. Currently, the radii of fasteners in the industry are not optimized with the lead-in to promote interference fit in composite material (which may produce high installation forces due to the non-optimal lead-in geometry). The lead-in geometry proposed herein helps preclude fasteners from "sticking" in the hole or causing excessive damage to the structure during installation. Since this system does not need to add cap seals, the assembly time is decreased.

While interference fit fasteners for attaching two structures to each other have been described with reference to various embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the claims set forth hereinafter. In addition, many modifications may be made to adapt the teachings herein to a particular situation without departing from the scope of the claims.

As used in the claims, the term "external projections" should be construed broadly to encompass at least the following types: (1) external threads and (2) external annular rings. As used in the claims, the category "mating parts" comprises internally threaded nuts and collars and swaged collars. As used in the claims, the term "fastener assembly" should be construed broadly to read on at least each of the following: (1) a bolt and a nut coupled to each other; (2) a bolt and a collar coupled to each other; (3) a pin and a collar coupled to each other; and (4) a pin and a nut coupled to each other.

The invention claimed is:

1. A fastener comprising:

a head;

a shank extending from the head, the shank comprising an external surface that is circular cylindrical and having a shank diameter;

a mating portion comprising external projections; and

a transition portion disposed between the shank and the mating portion,

wherein the transition portion comprises a first radiused lead-in section that meets the shank at a shank/lead-in intersection and a second radiused lead-in section that meets the first radiused lead-in section, the first radiused lead-in section curves in a first axial direction toward the mating portion for a length and has a first profile that is a circular arc having a first radius, and the second radiused lead-in section curves in the first axial direction and has a second profile that is a circular arc having a second radius which is smaller than the first radius,

wherein the mating portion has a maximum diameter less than a minimum diameter of the second radiused lead-in section, and

wherein the length of the first radiused lead-in section is in a range of 0.062 to 0.092 inch, the shank diameter is in a range of $^{6}/_{32}$ to $^{16}/_{32}$ inch, the first radius is in a range of 0.34 to 0.68 inch and the second radius is about 0.01 inch.

2. The fastener as recited in claim **1**, wherein the first profile is a profile of an external surface of the first radiused lead-in section in a plane that intersects a central axis of the fastener, and the second profile is a profile of an external surface of the second radiused lead-in section in the plane that intersects the central axis of the fastener.

3. The fastener as recited in claim **2**, wherein a profile of the shank in the plane that intersects the central axis of the fastener is tangent to the first profile.

4. An assembly comprising a first structural element having a first hole having a hole diameter, a second structural element having a second hole aligned with the first hole of the first structural element, a fastener that occupies at least respective portions of the first and second holes in the first and second structural elements without a surrounding sleeve and extends beyond the second structural element, and a mating part that abuts the second structural element and is coupled to the fastener, wherein the fastener comprises:

a head;

a shank extending from the head, the shank comprising an external surface that is circular cylindrical and having a shank diameter greater than the hole diameter;

a mating portion comprising external projections; and

a transition portion disposed between the shank and the mating portion,

wherein the transition portion comprises a first radiused lead-in section that meets the shank at a shank/lead-in intersection and a second radiused lead-in section that

meets the first radiused lead-in section, the first radiused lead-in section curves for a length in a first axial direction toward the mating portion from a maximum diameter to a minimum diameter and has a first profile that is a circular arc having a first radius, and the second radiused lead-in section curves in the first axial direction and has a second profile that is a circular arc having a second radius which is smaller than the first radius,

wherein the maximum diameter of the first radiused lead-in section is greater than the hole diameter and the minimum diameter of the first radiused lead-in section is less than the hole diameter, and

wherein the length of the first radiused lead-in section is in a range of 0.062 to 0.092 inch, the shank diameter is in a range of 6/32 to 16/32 inch, the first radius is in a range of 0.34 to 0.68 inch and the second radius is about 0.01 inch.

5. The assembly as recited in claim **4**, wherein the shank of the fastener and the first and second structural elements are in contact without a sleeve therebetween.

6. The assembly as recited in claim **4**, wherein the mating part comprises internal threads that are interengaged with the external projections of the mating portion of the fastener.

7. The assembly as recited in claim **4**, wherein the mating part comprises a swaged collar that is interengaged with the external projections of the mating portion of the fastener.

8. The assembly as recited in claim **4**, wherein the mating portion has a maximum diameter less than a minimum diameter of the second radiused lead-in section.

9. The assembly as recited in claim **4**, wherein the first profile is a profile of an external surface of the first radiused lead-in section in a plane that intersects a central axis of the fastener, and the second profile is a profile of an external surface of the second radiused lead-in section in the plane that intersects the central axis of the fastener.

10. The assembly as recited in claim **9**, wherein a profile of the shank in the plane that intersects the central axis of the fastener is tangent to the first profile.

11. The assembly as recited in claim **4**, wherein one of the first and second structural elements is made of composite material and the other of the first and second structural elements is made of metallic material.

12. The assembly as recited in claim **11**, wherein the mating part comprises internal threads that are interengaged with the external projections of the mating portion of the fastener.

13. The assembly as recited in claim **11**, wherein the mating part comprises a swaged collar that is interengaged with the external projections of the mating portion of the fastener.

14. The assembly as recited in claim **11**, wherein the first profile is a profile of an external surface of the first radiused lead-in section in a plane that intersects a central axis of the fastener, and the second profile is a profile of an external surface of the second radiused lead-in section in the plane that intersects the central axis of the fastener.

15. A method for fastening a first structure having a first hole and a second structure having a second hole, the first and second holes having a same hole diameter, comprising:

selecting a fastener comprising: a head; a shank extending from the head, the shank comprising an external surface that is circular cylindrical and having a shank diameter; a mating portion comprising external projections; and a transition portion disposed between the shank and the mating portion, wherein the transition portion comprises a first radiused lead-in section that meets the shank at a shank/lead-in intersection and a second radiused lead-in section that meets the first radiused lead-in section, the first radiused lead-in section curves in a first axial direction toward the mating portion for a length and has a first profile that is a circular arc having a first radius, and the second radiused lead-in section curves in the first axial direction and has a second profile that is a circular arc having a second radius which is smaller than the first radius, wherein the mating portion has a maximum diameter less than a minimum diameter of the second radiused lead-in section, and wherein the length of the first radiused lead-in section is in a range of 0.062 to 0.092 inch, the shank diameter is in a range of 6/32 to 16/32 inch, the first radius is in a range of 0.34 to 0.68 inch and the second radius is about 0.01 inch;

placing the first and second structures together with the first and second holes aligned;

inserting the mating portion of the fastener into the first hole until an edge of the first hole in the first structure is in contact with and surrounds the first radiused lead-in section of the fastener, the circular cylindrical shank connecting the head to the first radiused lead-in section and the shank diameter being greater than the hole diameter;

forcing the fastener further into the aligned holes of the first and second structures to cause the shank to contact the edge of the first hole, push through the first hole, and then push through the second hole until the mating portion of the fastener projects beyond the second structure; and

coupling a mating part to the mating portion of the fastener.

16. The method as recited in claim **15**, wherein an amount of interference between the shank and the first hole is no more than 0.004 inch.

17. The method as recited in claim **15**, wherein the mating part is a collar that is initially connected to a collar wrenching element, and coupling the mating part to the mating portion of the fastener comprises screwing the collar onto the mating portion and then tightening until a preload is produced sufficient to cause the collar wrenching element to break way.

18. The method as recited in claim **15**, wherein the mating part is a collar, and coupling the mating part to the mating portion of the fastener comprises swaging the collar.

19. The method as recited in claim **15**, wherein a maximum diameter of the first radiused lead-in section equals the diameter of the shank and a minimum diameter of the first radiused lead-in section is less than the diameter of the first and second holes.

20. The method as recited in claim **15**, wherein the first profile is a profile of an external surface of the first radiused lead-in section in a plane that intersects a central axis of the fastener, and the second profile is a profile of an external surface of the second radiused lead-in section in the plane that intersects the central axis of the fastener.

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