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Liner hanger slip retention system and method

Abstract

A technique facilitates deploying and setting a liner hanger assembly while securely retaining liner hanger slips during running-in-hole. The liner hanger assembly may comprise a variety of components such as a mandrel, a cone, a plurality of slips, a retention ring, and an actuator. The slips may each be configured with an upper retention end and a lower retention end having a plurality of angles which interlock with corresponding angles of the cone and the retention ring. Additionally, a portion of the actuator may be sized to slide over an axial end of the retention ring to prevent inadvertent decoupling of the slips after installing the slips along the exterior of the cone.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATION (1) The present document is a continuation of U.S. patent application Ser. No. 17/759,450, filed Jul. 26, 2022, now U.S. Pat. No. 12,091,930, which claims priority to the National Stage of International Application No. PCT/US2021/015367, filed Jan. 28, 2021, and is based on and claims priority to U.S. Provisional Patent Application Ser. No. 62/966,677, filed Jan. 28, 2020.

BACKGROUND

(1) In many well applications, a wellbore is drilled and a casing string is deployed along the wellbore. A liner hanger may then be used to suspend a liner downhole within the casing string. The liner hanger may be hydraulically operated via a hydraulic cylinder to set hanger slips. Once the liner hanger is run-in-hole and positioned properly, the hanger slips are set against the surrounding casing string. The set slips are responsible for ensuring sufficient gripping of the surrounding casing string to hold the weight of the liner and to hold against mechanical and hydraulic loads applied to the system. While the liner hanger is run-in-hole, however, the slips should remain in a radially contracted position to avoid premature setting and/or loss of the hanger slips.

SUMMARY

(2) In general, a system and methodology are provided for deploying and setting a liner hanger assembly while securely retaining the slips during running-in-hole. The liner hanger assembly may comprise a variety of components such as a mandrel, a cone, a plurality of slips, a retention ring, and an actuator, e.g. a hydraulic actuator cylinder. The slips may each be configured with an upper retention end and a lower retention end having a plurality of angles which interlock with corresponding angles of the cone and the retention ring. Additionally, a portion of the actuator may be sized to slide over an axial end of the retention ring to prevent inadvertent decoupling of the slips after installing the slips along the exterior of the cone.

(3) However, many modifications are possible without materially departing from the teachings of this disclosure. Accordingly, such modifications are intended to be included within the scope of this disclosure as defined in the claims.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) Certain embodiments of the disclosure will hereafter be described with reference to the accompanying drawings, wherein like reference numerals denote like elements. It should be understood, however, that the accompanying figures illustrate the various implementations described herein and are not meant to limit the scope of various technologies described herein, and:

(2) FIG. **1** is an illustration of an example of a liner hanger deployed in a borehole, e.g. a wellbore, during running-in-hole, according to an embodiment of the disclosure;

(3) FIG. **2** is an illustration of the liner hanger shown in FIG. **1** but in a set position, according to an embodiment of the disclosure;

(4) FIG. **3** is an illustration of a portion of the liner hanger showing a hanging load distributed along slip-cone interfaces once the liner hanger is set and the liner is suspended from the surrounding casing, according to an embodiment of the disclosure;

(5) FIG. **4** is an orthogonal view of an example of a hanger slip, according to an embodiment of the disclosure;

(6) FIG. **5** is an orthogonal view of an example of a retention ring constructed to retain the hanger slips, according to an embodiment of the disclosure;

(7) FIG. **6** is an illustration of an example of an upper end of the hanger slip engaged with the cone and shown in the set position, according to an embodiment of the disclosure; and

(8) FIG. **7** is an illustration of an example of a lower end of the hanger slip engaged with the retention ring and shown in the set position, according to an embodiment of the disclosure.

DETAILED DESCRIPTION

(9) In the following description, numerous details are set forth to provide an understanding of some embodiments of the present disclosure. However, it will be understood by those of ordinary skill in the art that the system and/or methodology may be practiced without these details and that

numerous variations or modifications from the described embodiments may be possible.
(10) The disclosure herein generally involves a system and methodology for deploying and setting a liner hanger assembly while securely retaining the slips during running-in-hole. A slip package combines slips and a cone in a manner which ensures the slips are fully retained: while running-in-hole; and in the event the liner hanger is inadvertently set in, for example, a larger casing such as a riser. The improved slip retention ensures the slips are not lost during operations and that the liner hanger can be retrieved in the event of a mis-run.
(11) According to an embodiment, the liner hanger assembly may comprise a variety of components such as a mandrel, a cone, a plurality of slips, e.g. tapered slips, a retention ring, and an actuator, e.g. a hydraulic actuator cylinder. The slips may each be configured with an upper retention end and a lower retention end having a plurality of angles which interlock with corresponding angles of the cone and the retention ring. Additionally, a portion of the actuator/hydraulic cylinder may be sized to slide over an axial end of the retention ring to prevent inadvertent decoupling of the slips after installing the slips along the exterior of the cone.
(12) By employing a unique combination of angles along the interacting components, the slips are securely retained when an upper end of each slip is engaged with the cone and a lower end of each slip is engaged with mating features of a retention ring. According to one embodiment, the combination of differing angles may be in the form of V-angles located at a top end of the slip. These V-angles interact with complementary (equal and opposite) V-angles defining a portion of the cone slot which receives the slip. Similarly, V-angles located at a bottom end of the slip are oriented to interact with complementary (equal and opposite) V-angles located along fingers of the retention ring.
(13) Additionally, a properly sized diameter or other suitable feature of a cylinder may be slid over a portion of the retention ring to limit axial motion of the slips once installed along the exterior of the cone. Accordingly, the interacting V-angles of corresponding components (e.g. slips, cone, retention ring) prevent the slips from coming loose in a radial direction. Simultaneously, the cylinder prevents axial movement of the slips to a decoupling position after assembly of the liner hanger. This ensures secure retention of the slips during, for example, running-in-hole with the liner hanger. By way of example, the cylinder may be a hydraulic actuating cylinder although other types of actuating cylinders or cylindrical components may be used in cooperation with the retention ring.
(14) According to an embodiment, the cylinder is a hydraulic actuating cylinder having an axial end face which can be selectively moved against the slips to shift the slips in an axial direction. When the slips are shifted in this axial direction, sloped surfaces of the cone force the slips radially outward and into engagement with the surrounding casing. As described in greater detail below, the slips and the cone may have cooperating sloped surfaces which effectively move the slips outwardly into engagement with the surrounding casing as the actuating cylinder pushes the slips in a linear/axial direction.
(15) It should be further noted the configuration of the different angles (which effectively interlock cooperating components) also allows the slips to be assembled from the outside or exterior of the cone. For example, each slip may be inserted and twisted into position with respect to the cone and the retention ring so that interacting, angled surfaces prevent excess radial movement of the slip away from the cone. Once assembled, the cylinder may be installed over the retention ring to prevent linear movement of the slips to a decoupling or disassembly position.
(16) Referring generally to FIG. **1**, an embodiment of a liner hanger assembly **30** is illustrated as having a liner **32** coupled with a liner hanger **34**. The liner hanger assembly **30** is deployed downhole into a borehole **36**, e.g. a wellbore, which may be lined with a casing **38**. In FIG. **1**, the liner hanger **34** is illustrated in an unset, run-in-hole position which allows the liner hanger assembly **30** to be deployed via a liner hanger string **40** to a desired location along the borehole **36** and casing **38**.

(17) According to an example, the liner hanger **34** comprises an inner mandrel **42** having an internal passage through which, for example, fluid and/or equipment is able to move. In this embodiment, a cone **44** is slid onto the mandrel **42** to an abutment **46**. In some applications, a spacer or bearing **48** may be positioned between the abutment **46** and the cone **44**. The cone **44** may be generally tubular in structure and sized to slide along the tubular exterior of the mandrel **42**.
(18) Additionally, the cone **44** comprises a plurality of cone slots **50** arranged generally in an axial direction along a portion of the cone **44**. The cone slots **50** are sized to receive corresponding hanger slips **52**. As explained in greater detail below, the slips **52** may be assembled into the corresponding cone slots **50** from an outside or exterior of the cone **44**. Depending on the engagement features of the cone **44**/slips **52** and on parameters of the assembly process, the slips **52** may be assembled after cone **44** is slid onto mandrel **42** or before cone **44** is slid onto mandrel **42**.
(19) As illustrated, the liner hanger **34** also comprises a retainer or retention ring **54** which engages lower ends **56** of the slips **52** so as to facilitate retention of the slips **52** when, for example, the liner hanger assembly **30** is run-in-hole. By way of example, the retention ring **54** may comprise a plurality of retention ring fingers **58**. The retention fingers **58** interlock with a plurality of corresponding slip fingers **60** located at the lower ends **56** of the slips **52**.
(20) On an opposite side of the retention ring **54** from slips **52**, the retention ring **54** may be engaged by a cylinder **62** or other suitable actuator component. The cylinder **62** may have an engagement feature **64** which slides over and engages the retention ring **54**. By way of example, the engagement feature **64** may be in the form of an expanded inner diameter section of the cylinder **62** which is sized to slide over a portion of the retention ring **54** before abutting the remaining portion of retention ring **54**. Additionally, the cylinder **62** may be part of an overall actuator **66**, e.g. a hydraulic actuator, a mechanical actuator, or another suitable actuator. For example, the cylinder may be a hydraulically actuated cylinder **62** or a mechanically actuated cylinder **62**. The actuator **66** also may have other configurations and may use other types of engagement features **64**.
(21) In the illustrated example, the cylinder **62** is a hydraulic cylinder which may be hydraulically actuated in an axial direction to shift the retention ring **54** until a face **68** of cylinder **62** is moved into abutting engagement with the lower ends **56** of the slips **52**. Continued linear movement of the cylinder **62** in the direction toward slips **52** causes linear/axial movement of the slips **52**. The linear movement of slips **52** effectively causes an interaction with cone **44** which forces the slips **52** radially outward into a set position, as illustrated in FIG. **2**. In other words, the slips **52** and liner hanger **34** are transitioned from a radially contracted, run-in-hole position to a radially expanded set position.
(22) In the set position, teeth **70** (or other types of gripping members) of the slips **52** are forced into gripping engagement with an interior surface of the surrounding casing **38**. It should be noted the retention ring fingers **58** and the slip fingers **60** may be designed to allow a certain degree of relative linear movement with respect to each other. For example, during transition to the set position the cylinder **62** may initially shift the retention ring **54** linearly toward the lower ends **56** of slips **52**, and then engage and linearly shift the slips **52**.
(23) In the example illustrated in FIGS. **1** and **2**, each slip **52** is constructed as a tapered slip slidably received in the corresponding slots **50** which have corresponding tapers. For example, each slip **52** may taper along its length between an upper end **72** and lower end **56** such that upper end **72** is relatively narrow in a circumferential direction. From upper end **72**, the slip **52** tapers outwardly in a circumferential direction on both circumferential sides of the slip such that the portion of the slip **52** proximate lower end **56** is wider than the relatively narrow upper end **72**.
(24) Each corresponding slot **50** also may be tapered with a corresponding taper that expands in a circumferential direction moving from an upper region of the slot **50** to a lower region of the slot **50**. Additionally, the circumferential sides of each slip **52** may have angled surfaces **74** which taper inwardly moving in a radially inward direction. In other words, the radial exterior of each slip **52** is

wider than the radial interior at each linear/axial position along the slip **52**.
(25) The slot **50** which receives the slip **52** has corresponding angled surfaces **76** which similarly cause the slot **50** to be circumferentially narrower at a radially inward position than a radially outward position. The corresponding tapers and angled surfaces **74**, **76** are thus able to effectively cooperate and force the tapered slips **52** in a radially outward direction as the actuating cylinder **62** forces the slips **52** to move linearly with respect to cone **44** as cone **44** is held by abutment **46**. It should be noted that each slip **52** also may comprise a head **78**, e.g. a head having a hammerhead shape, at its upper end **72**. As explained in greater detail below, the hammerheads **78** may be constructed to facilitate retention of slips **52** along cone **44** when liner hanger assembly **30** is run-in-in-hole.
(26) When the liner hanger **34** is set, liner **32** is suspended by the liner hanger **34** via its engagement with the surrounding casing **38**. The hanging load resulting from the weight of liner **32** pulls down on mandrel **42** which, in turn, pulls down on cone **44** via abutment **46**. This hanging load is distributed along the slip-cone interfaces **80** formed between angled surfaces **74**, **76**, as illustrated in FIG. **3**. Thus, once the liner hanger **34** is set, the hanging load of liner **32** is supported by slips **52** along a plurality of the slip-cone interfaces **80** which are located circumferentially around the mandrel **42**. This arrangement helps distribute the hanging load circumferentially through the cone **44** and slips **52** instead of radially into the mandrel **42**.
(27) As referenced above, the slips **52**, retention ring **54**, and cone **44** may each comprise angled surfaces which help retain slips **52** in position along cone **44**. For example, cooperating components, e.g. slips **52** and retention ring **54**, may have a plurality of angled surfaces oriented at a plurality of different angles to facilitate this retention. The different angles may be positioned along, for example, sides of slip fingers **60** and retention ring fingers **58**. The “different” angles may be different angles with respect to a reference plane, such as a radial plane extending radially outward along and from a longitudinal axis of the liner hanger **34** and through the subject finger **60** or **58**. For example, the differing angles on retention ring fingers **58** and on slip fingers **60** may extend outwardly from each other like a “V” and an inverse “V” thus forming mating V-angle surfaces.
(28) Referring generally to FIG. **4**, an example of one of the slips **52** is illustrated to facilitate explanation of features of the slip **52** including the angled surfaces which facilitate retention. In this example, the slip fingers **60** create spaces **82** therebetween to receive corresponding retention ring fingers **58**. The slip fingers **60** also comprise angled surfaces **84** which interlock with corresponding surfaces of the retention ring **54**, as explained in greater detail below.
(29) By way of example, the angled surfaces **84** may be located at the sides of each slip fingers **60** and may be oriented at different angles (e.g. V-angles) with respect to a given reference plane, such as a radial plane therethrough. In the illustrated embodiment, the angled surfaces **84** of each slip fingers **60** slope towards each other moving in a radially outward direction. In other words, the angled surfaces **84** are arranged to create slip fingers **60** which have a circumferentially wider portion on a radially inward side and a circumferentially narrower portion on a radially outward side. Each slip finger **60** effectively flares to a thicker radially inward portion due to the differing angled surfaces **84**. It should be noted the slip fingers **60** also may be constructed to flare outwardly in an axial direction moving from, for example, an upper end of each slip finger **60** to a lower wider end of each slip finger **60**.
(30) In this example, the hanger slip **52** also comprises head **78** in the form of a hammerhead which similarly flares to a thicker radially inward portion. The hammerhead **78** is flared due to angled surfaces **86** located along the sides of the hammerhead configuration. The angled surfaces **86** may be arranged to form the hammerhead **78** with a circumferentially wider portion on a radially inward side and a circumferentially narrower portion on a radially outward side.
(31) Referring generally to FIG. **5**, an example of retention ring **54** is similarly illustrated to facilitate explanation of features of the retention ring **54** including the corresponding angled

surfaces which facilitate retention of the slips **52**. In this example, the retention ring fingers **58** extend in an axial direction from a base ring **87** and create spaces **88** therebetween to receive corresponding slip fingers **60**. By way of example, the base ring **87** may be a circular body sized to slide over mandrel **42**. The retention ring fingers **58** also comprise angled surfaces **90** which interlock with corresponding angled surfaces **84** of the slips **52**, e.g. of the slip fingers **60**.

(32) By way of example, the angled surfaces **90** may be located at the sides of each retention ring finger **58** and may be oriented at different angles with respect to a given reference plane, such as a radial plane therethrough (e.g. reverse V-angles relative to the angled surfaces **84** of slip fingers **60**). In the illustrated embodiment, the angled surfaces **90** of each retention ring finger **58** slope towards each other moving in a radially inward direction. In other words, the angled surfaces **90** are arranged to create retention ring fingers **58** which have a circumferentially wider portion on a radially outward side and a circumferentially narrower portion on a radially inward side. Each retention ring finger **58** effectively flares to a thicker radially outward portion due to the differing angled surfaces **90**. It should be noted the retention ring fingers **58** also may be constructed to flare outwardly in an axial direction moving from, for example, a lower end of each retention ring finger **58** to an upper wider end of each retention ring finger **58**.

(33) Additionally, the angled surfaces **90** may be oriented generally parallel with the corresponding angled surfaces **84** once the slips **52** and the retention ring **54** are assembled onto mandrel **42**. Because the retention ring fingers **58** flare to a circumferentially wider outer portion (opposite to the flare of slip fingers **60**), the retention ring fingers **58** are able to trap and hold the slip fingers **60**. Consequently, the slips **52** are prevented from experiencing sufficient radially outward movement that would release the slips **52** during, for example, running-in-hole.

(34) The retention ring **54** also may comprise an abutment edge **92** to which the engagement feature **64** of cylinder **62** may be abutted when assembled. The abutment edge **92** may be used to define a cylinder engagement region **93** sized to receive engagement feature **64**. In this example, engagement feature **64** may be in the form of an overlapping portion of cylinder **62**. The engagement region **93** may have a reduced diameter relative to the remainder of retention ring **54** to facilitate receipt of the engagement feature/overlapping portion **64**.

(35) When the engagement feature **64** is positioned against the abutment edge **92**, the slip fingers **60** are blocked from moving linearly/axially farther into the spaces **88** between retention ring fingers **58**. By limiting this linear/axial movement of the slips **52**, the slips **52** are prevented from shifting to a decoupling position while at the same time the cooperating angled surfaces **84**, **86**, **90** prevent sufficient radial movement of the slips to enable release the slips. Accordingly, the slips **52** are secured along the cone **44** and cannot be inadvertently released or set until cylinder **62** is actuated to force slips **52** to a set position.

(36) It should be noted the retention ring fingers **58** may have a variety of sizes, shapes and configurations. In the illustrated embodiment, for example, some of the retention ring fingers **58** are axially shorter than other retention ring fingers **58**. Additionally, some of the retention ring fingers **58** are circumferentially broader than other retention ring fingers **58**. The slip fingers **60** also may have a variety of sizes, shapes and configurations. For example, the slip fingers **60** illustrated in FIG. **3** include a notched portion **101** while the fingers illustrated in FIG. **4** include a truncated portion **102** instead of the notched portion **101**. A variety of other changes in the fingers **58**, **60** also may be provided to accommodate parameters of a given construction or operation.

(37) During assembly of liner hanger **34**, the head **78**, e.g. hammerhead, of each slip **52** may be rotated and inserted into an expanded opening **94** at a top of the corresponding cone slot **50**. The slip **52** may then be rotated back to an operational position as illustrated in FIG. **6**. In this position, the angled surfaces **86** of head **78** are trapped by corresponding angled surfaces **96** of cone **44**. The angled surfaces **96** extend to and define the expanded opening **94**. The cooperating angled surfaces **86**, **96** and the size and configuration of the cone slot **50** allow the slip **52** to move between a run-in-hole contracted configuration and an expanded set configuration (see FIG. **6**) without releasing

the head **78** from the cone **44**.

(38) Similarly, the slip fingers **60** may be moved into spaces **88** between retention ring fingers **58** and then shifted axially to interlock angled surfaces **84** of each slip **52** with the corresponding angled surfaces **90** of the retention ring **54**, as illustrated in FIG. **7**. At this stage, the angled surfaces **86**, **96** at the top end of the slip **52** and the angled surfaces **84**, **90** at the bottom and of the slip **52** limit the radially outward movement of the slip **52** and thus prevent it from releasing. Additionally, the engagement feature **64** of cylinder **62** may be moved toward the abutment edge **92** of retention ring **54** to prevent linear shifting of the slip **52** to a decoupling position. Accordingly, the cooperating angled surfaces and the engagement feature **64** ensure that the slips **52** cannot be inadvertently released from the liner hanger **34**.

(39) The cone **44**, slips **52**, and retention ring **54** have relatively complex configurations comprising mating surfaces arranged at different angles and orientations. Milling of such complex configurations can be time-consuming and expensive. However, at least portions of the cone **44**, slips **52**, and/or retention ring **54** may be cut via waterjet and/or laser cutting processes. For example, a waterjet and/or a laser may be operated in a manner which controls the thickness of the cut to allow the shapes and surfaces to be generally identical for corresponding parts, e.g. corresponding surfaces of the slips **52** and retention ring **54**.

(40) This enables a quick, cost-effective method for manufacturing the complex configurations while providing desired fitting between the cooperating components. In some embodiments, for example, the fingers **58** of the retention ring **54** and the corresponding fingers **60** of the slips **52** may be cut via waterjet cutting and/or laser cutting to form the desired angled surfaces. Similarly, other portions of the slips **52** and/or cone **44** may be cut via waterjet cutting and/or laser cutting.

(41) It should be noted the liner **32**, liner hanger **34**, and running string **40** may be constructed in various sizes and configurations. Additionally, each of the components of the overall liner hanger **34** may utilize: various engagement features, differing angled surfaces, different numbers of cooperating angled surfaces, various actuators, e.g. actuating cylinders, and/or other features to enable the desired operation. For example, various numbers and types of slip fingers and corresponding retention ring fingers may be used to achieve the desired retention. Similarly, various types of hammerheads or other heads may be used with desired engagement features to facilitate retention of the upper ends of the slips.

(42) Although a few embodiments of the disclosure have been described in detail above, those of ordinary skill in the art will readily appreciate that many modifications are possible without materially departing from the teachings of this disclosure. Accordingly, such modifications are intended to be included within the scope of this disclosure as defined in the claims.

Claims

1. A system for use in a well, comprising: a liner hanger comprising: a mandrel; a cone mounted about the mandrel, the cone having tapered slots; a plurality of tapered slips slidably received in the tapered slots, each tapered slip having a retention end with a plurality of slip retention fingers, each slip retention finger having angled surfaces oriented at a plurality of differing angles; a retention ring having a plurality of ring retention fingers which slidably engage the slip retention fingers, the plurality of ring retention fingers including a first ring retention finger engaged with first and second slip retention fingers of a first slip of the plurality of tapered slips, the plurality of ring retention fingers further including a second ring retention finger engaged with the first slip retention finger of the first slip and with a first slip retention finger of a second slip of the plurality of tapered slips, each ring retention finger having corresponding angled surfaces, the corresponding angled surfaces being arranged to engage the angled surfaces of the slip retention fingers, the angled surfaces of the ring retention fingers and the angled surfaces of the slip retention fingers extend outwardly from each other forming mating V-angle surfaces in a manner which prevents

release of the plurality of tapered slips from the retention ring during deployment of the liner hanger; and an actuator mounted about the mandrel to selectively shift the plurality of tapered slips between a radially contracted position and a radially expanded, set position.
2. The system as recited in claim 1, wherein each tapered slip is wider, in a circumferential direction, at a lower end than at an upper end.
3. The system as recited in claim 2, wherein each tapered slip comprises a hammerhead located at the upper end, the hammerhead having sloped surfaces arranged to slidably capture the hammerhead in an upper region of the corresponding tapered slot.
4. The system as recited in claim 1, wherein the ring retention fingers of the retention ring have differing axial lengths.
5. The system as recited in claim 1, wherein the actuator comprises a hydraulically actuated cylinder which overlaps the retention ring in a manner preventing decoupling of the plurality of tapered slips.
6. The system as recited in claim 5, wherein the hydraulically actuated cylinder comprises a face which moves against the tapered slips and forces the tapered slips in an axial direction during setting of the plurality of tapered slips.
7. The system as recited in claim 1, wherein the cone is configured to enable installation of the plurality of tapered slips from the exterior of the cone.
8. A method, comprising: providing a cone of a liner hanger with slots for receiving slips; trapping an upper end of each slip in an upper portion of the corresponding slot, wherein trapping comprises forming the upper end as a flared hammerhead which is trapped under corresponding sloped surfaces of the cone; retaining a lower end of each slip against unwanted release from the cone by a retention ring having a plurality of ring retention fingers which slidably engage corresponding slip retention fingers of each slip, the plurality of ring retention fingers including a first ring retention finger engaged with first and second slip retention fingers of a first slip, the plurality of ring retention fingers further including a second ring retention finger engaged with the first slip retention finger of the first slip and with a first slip retention finger of a second slip; and further securing the slips against release by blocking disassembly via a hydraulic cylinder used for setting the liner hanger.
9. The method as recited in claim 8, wherein retaining comprises using cooperating angled surfaces of the slip retention fingers and the ring retention fingers to prevent each slip from releasing from the cone in a radially outward direction.
10. The method as recited in claim 9, wherein securing comprises using the hydraulic cylinder to block the slips against undue movement in an axial direction, thus ensuring the slips remain held in place by the cooperating angled surfaces.
11. The method as recited in claim 9, wherein the cooperating angled surfaces form mating V-angle surfaces.