

Locking Clamp for a Rotating Control Device

FIELD OF THE INVENTION

[0001] The invention relates to wellhead components used in drilling of oil and gas wells and more particularly to making a connection between components of a rotating control device.

BACKGROUND

[0002] During oilfield drilling operations, the control of pressures and flows to and from and within the well bore are critical to maintaining a safe drilling environment particularly around the drilling platform and wellhead. Two critical devices operating on a wellhead during drilling are the blowout preventer (BOP) stack and a rotating control device (RCD). Both of these devices control pressures and flows to and from the well during drilling and particularly during events such as well kicks and loss of circulation of drilling fluids and gases.

[0003] The rotating control device provides a sealed connection between the fixed non-rotating BOP stack and any rotating components above or passing through the BOP stack. Generally, the RCD also functions to provide safe fluid containment and diversion of returning drilling fluids and cuttings away from the drill floor during drilling.

[0004] The RCD includes a non-rotating main body which connects to the BOP stack or an upper extension thereof and a bearing assembly which includes a rotating portion that passes through the main body and grips the drill string with an elastomeric sealing element.

[0005] The connection between the main body of the RCD and the bearing assembly is typically accomplished by using a high pressure clamping assembly.

[0006] The clamping assembly will typically engage with corresponding clamping surfaces on both the main body of the RCD and the bearing assembly of the RCD to secure one to the other.

SUMMARY

[0007] One aspect of the invention is a clamp assembly device for connecting a rotating control device bearing assembly to a main body of a rotating control device. The device comprises clamp members configured to retain the bearing assembly in place on the main body, a clamp actuator for driving clamping and unclamping of the clamp members and lock pin controlled by a lock pin actuator. The lock pin actuator is configured to lock and unlock the clamp assembly device by moving the pin between locked and unlocked positions along an axis substantially parallel with the axis of rotation of the bearing assembly.

[0008] The clamp actuator may be provided as a clamping hydraulic cylinder acting to move the clamp members together to a clamped position and to move the clamp members apart to an open position.

[0009] The clamping hydraulic cylinder may be connected between a pair of extensions from adjacent ends of the clamping members. This embodiment may be arranged such that extending of the clamping hydraulic cylinder acts to move the clamp members together to the clamped position with retracting of the clamping hydraulic cylinder acting to move the clamp members apart to an open position.

[0010] In some embodiments, a hinge is connected between the adjacent ends of the clamping members medial to the clamping hydraulic cylinder. The hinge may be connected between the main body and the first and second clamping members, thereby holding the device in place when in the open position.

[0011] The lock pin actuator may be a locking hydraulic cylinder associated with a first clamp member of the clamp members. In this embodiment, the locking hydraulic cylinder is configured to move the lock pin into and out of generally aligned bores of the clamp members. In some embodiments, moving the lock pin into the generally aligned bores provides the locked position and moving the lock pin out of the generally aligned bores provides the unlocked position.

[0012] In some embodiments, the locking hydraulic cylinder may be connected to a lug on the first clamp member and a second clamp member of the clamp members provides

an arm configured to enter a channel of the lug to align a pair of lug bores with a bore of the arm, wherein, when the clamp members are in the clamped position, the bore of the arm and the pair of lug bores provide the generally aligned bores.

[0013] The clamp actuator and the lock pin actuator may be spaced apart from each other. In one embodiment, the clamp actuator and the lock pin actuator are located on substantially opposing sides of the device.

[0014] The locking hydraulic cylinder may be connected to the lug by a lock pin housing which has a housing bore aligned with the pair of lug bores.

[0015] The lock pin may have a tapered surface which engages with a complementary tapered surface of a wear insert in the bore of the arm to drive the arm to further align the generally aligned lock bores to provide mechanical locking of the device.

[0016] An upper bore of the pair of lug bores may be provided with an upper wear insert.

[0017] The housing bore may be circular and provided with a housing wear insert which is rotatable within the housing bore, the housing wear insert having a non-circular shaped lock pin bore formed therein which, when rotated from a normal position, prevents entry of the lock pin into the non-circular shaped lock pin bore from above the housing wear insert.

[0018] The lock pin housing may have a lateral slot, In this embodiment, the housing wear insert has a secondary lock member connected thereto and extending outward from the lateral slot to provide a mechanism for rotating the housing wear insert when the lock pin is extended upward outside of the housing wear insert, thereby moving the non-circular shaped lock pin bore out of alignment with the first and second locking member bores, thereby preventing the lock pin from dropping into the non-circular shaped lock pin bore and providing a secondary lock mechanism. In some embodiments the ends of the lateral slot each have an enlarged radius to prevent the secondary lock member from sliding in the slot when the secondary lock member drops into a lower portion of the enlarged radius.

[0019] In some embodiments, the non-circular shaped lock pin bore is deviated from the center of the housing wear insert to provide different distances between the center of the

locking bore and each of the sides of the locking bore, thereby providing an adjustment mechanism to overcome minor deformations of the sides of the locking bore or minor deformations of the lock pin, the adjustment mechanism controlled by removing, reorienting and replacing the housing wear insert.

[0020] In some embodiments the device further comprises a lock pin position sensor configured to provide a visual indicator to an operator when the locking actuator is in the locked position.

[0021] In some embodiments, the locking actuator is removable, thereby allowing replacement of the lock pin.

[0022] In some embodiments, the clamping actuator and the lock pin actuator are located substantially on the same side of the clamping assembly as the locking hydraulic cylinder and a hinge is located between two ends of the clamp members substantially on the opposite side of the device.

[0023] Another aspect of the invention is a hydraulic system for controlling the sequence of clamping, locking, unlocking and unclamping of the device described herein. The system includes: a hydraulic network having first and second ports, which is configured to pump hydraulic fluid into the network via the first port and direct the hydraulic fluid first to the clamping actuator to clamp the clamping members together and then to direct the hydraulic fluid to the locking actuator to lock the clamping members together. The hydraulic network is further configured to pump hydraulic fluid into the network via the second port and direct the hydraulic fluid first to the locking actuator to unlock the clamping members and then to the clamping actuator to unclamp the clamping members.

[0024] In some embodiments of the system, the direction of movement of the hydraulic fluid is controlled by one or more sequence valves within the hydraulic network.

[0025] The one or more sequence valves may include an unclamping sequence valve in the channel providing hydraulic fluid to the clamping actuator when the clamping members are being unclamped.

[0026] The one or more sequence valves may include a locking sequence valve in the channel providing hydraulic fluid to the locking hydraulic cylinder when clamping members are being locked.

[0027] The sequence valves may be arranged in parallel with each sequence valve having a bypass check valve for reverse flow.

[0028] The hydraulic network may include a clamping one-way valve to maintain clamping pressure on the clamping actuator.

[0029] The clamping one-way valve may be a pilot controlled one-way valve configured to allow counter-flow in response to pressure being applied to unclamp the clamping members.

[0030] The hydraulic network may include a locking one-way valve to maintain locking pressure on the locking actuator.

[0031] The locking one-way valve may be a pilot controlled one-way valve configured to allow counter-flow in response to pressure being applied to unlock the clamping members.

BRIEF DESCRIPTION OF THE DRAWINGS

[0032] Various objects, features and advantages of the invention will be apparent from the following description of particular embodiments of the invention, as illustrated in the accompanying drawings. The drawings are not necessarily to scale, emphasis instead being placed upon illustrating the principles of various embodiments of the invention. Similar reference numerals indicate similar components.

Figure 1 is a side elevation view showing an example of an arrangement of a BOP stack **6** with a rotating control device (RCD) attached thereto and showing the RCD main body **9**, the RCD bearing assembly **3** and an example of a clamp assembly **1** which is known in the prior art.

Figure 2 is a perspective view of the clamp assembly **1** clamping the RCD bearing assembly **3** to the RCD main body **9**. The clamp assembly **1** is locked using clamp bolts **8**.

Figure 3 is a cross sectional view of the clamp assembly **1** showing more detail of the interior of the bearing assembly **3** and the RCD main body **9**.

Figure 4A is a top view of another clamp assembly **10** known in the prior art shown placed on top of the rim of the RCD main body **15**. The clamp assembly **10** has its clamping cylinders **14a** and **14b** extended, placing the claim assembly **10** in the open position.

Figure 4B is a top view of the same clamp assembly **10** of Figure 4A shown with the clamping cylinders **14a** and **14b** retracted, placing the claim assembly **10** in the closed position.

Figure 5 is a perspective view of a clamping assembly **100** according to a first embodiment of the invention.

Figure 6 is a partially exploded view of the clamping assembly **100** indicating that the locking cylinder barrel **122b** has a lock pin housing **128b** attached thereto and a lock pin **134b** which is driven by the locking cylinder rod **130b** to lock the clamping assembly **100** in the closed position.

Figure 7 is a cross sectional view of the clamp lug **124b** and lock arm **126b** indicating how the lock pin **134b** extends through the lug bore **127b** and the lock arm bore **132b** to lock the clamp assembly **100** (indicated by the double arrow).

Figure 8A is a cross-sectional view through the lug **124b** and lock arm **126b** showing a first position of the lock pin **134b** as it moves upward as indicated by the arrow.

Figure 8B is a cross-sectional view through the lug **124b** and lock arm **126b** showing a second position of the lock pin **134b** as it moves upward into the lock arm bore **132b** as indicated by the arrow.

Figure 8C is a cross-sectional view through the lug **124b** and lock arm **126b** showing a third position of the lock pin **134b** as it moves upward into the upper lug bore **127b** as indicated by the arrow.

Figure 8D is a cross-sectional view through the lug **124b** and lock arm **126b** showing a fourth position of the lock pin **134b** as it moves upward into the upper lug bore **127b** indicated by the arrow.

Figure 8E is a cross-sectional view through the lug **124b** and lock arm **126b** showing the final upper position of the lock pin **134b** above the lug **124b**.

Figure 9A is a perspective view of a second embodiment of a clamp assembly **300** shown connecting the RCD bearing assembly **3** to the RCD main body **3** with the clamping and locking components shown at the front left.

Figure 9B is another perspective view of the same clamp assembly **300** of **Figure 9A** with the hinge **333** shown at the front.

Figure 10 is a magnified view of the hinge **333** shown with clamp member **312b** shown in phantom view (left side) with components of the hinge **333** and the clamp member **312a** shown in cross section.

Figure 11 is a top view of the clamp assembly **300** with clamp members **312a** and **312b** separated (open position) which would allow removal of the RCD bearing assembly **3** from the RCD main body **9**, which is not visible in this view. The clamping cylinder rod **330** is extended from the clamping cylinder barrel **313**.

Figure 12 is a top view of the clamp assembly **300** with clamp members **312a** and **312b** clamped together (closed position position) which clamps the RCD bearing assembly **3** to the RCD main body **9**. The clamping cylinder rod **330** is retracted inside the clamping cylinder barrel **313**.

Figure 13 is a side elevation view of the clamping assembly **300** in the closed position clamping the RCD bearing assembly **3** to the RCD main body **9**.

Figure 14A is a partial cross-sectional view of clamping and locking components of the clamping assembly **300** shown in the closed and unlocked position with the body of the lock pin **334** located below the lock arm bore **332**.

Figure 14B is a partial cross-sectional view of clamping and locking components of the clamping assembly **300** shown in the closed and locked position with the body of the lock pin **334** extending through the lock arm bore **332** and into the upper lug bore **327**.

Figure 15 is a perspective view of a portion of the clamping assembly **300** showing the upper lug bore **327** and wear insert **341** as well as the secondary lock member **350**.

Figure 16 is a perspective view of a portion of the clamping assembly **300** showing the secondary lock member **350** and slot **1328** for sliding the secondary lock member **350** to the left to a locked position.

Figure 17 is a cut-away perspective view of the lock pin housing **328** showing the secondary lock member **350** wear insert **343** and slot **1328** to indicate how shifting the position of the secondary lock member **350** will rotate the wear insert by 45 degrees when the bottom of the lock pin **334** is located above the wear insert **343** as shown in Figure 14B. When the secondary lock member **350** is in the rotated and locked position, the orientation of the wear insert **343** prevents the lock pin **334** from dropping downward from the lock arm bore **332**.

Figure 18A is a perspective view of another embodiment of a clamp assembly **400** in the clamped and locked position.

Figure 18B is a perspective view of clamp assembly **400** in the clamped and locked position which is rotated by about 180 degrees about its vertical axis relative to the perspective shown in Figure 18A.

Figure 19A is a perspective view of clamp assembly **400** in unclamped and open position.

Figure 19B is a perspective view of clamp assembly **400** in the unclamped and open position which is rotated by about 180 degrees about its vertical axis relative to the perspective shown in Figure 19A.

Figure 20 is a top view of clamp assembly **400** in the clamped and locked position.

Figure 20B is a top view of clamp assembly **400** in the unclamped and open position.

Figure 21A is a circuit diagram of a hydraulic network system **500** used to drive hydraulic cylinders in embodiments of the invention. The three-way valve **540** controlling the system is set in position **541** to control the flow of hydraulic fluid (shown with arrows) to attain the clamped and locked position of the clamp assembly **300**.

Figure 21B is the same hydraulic network system **500** of Figure 21A with the three-way valve **540** set in position **542** to provide a steady state clamped and locked position where hydraulic fluid remains in place and does not flow.

Figure 21C is the same hydraulic network system **500** of Figure 21A and 21B with the three-way valve **540** set in position **543** to control the flow of hydraulic fluid (shown with arrows) to attain the unlocked and unclamped position of the clamp assembly **300**.

DETAILED DESCRIPTION

Rationale

[0033] Typical BOP stack components do not experience significant wear during operations and replacement of BOP stack components is not frequently required. However, the bearing assembly component of the RCD experiences a high degree of wear, particularly on the sealing element portion of the bearing assembly (see sealing element **4** of Figure 3 which is connected to the mandrel **2** of the RCD bearing assembly **3**) as well as rotating seals during drilling operations. As a result, the bearing assembly portion of the RCD and requires a relatively frequent maintenance cycle. It is therefore desirable to remove and replace the bearing assembly component of the RCD quickly and conveniently to ensure that minimal disruption to drilling is experienced. Usually a new

bearing assembly component is installed and the damaged bearing assembly component is repaired for later use.

[0034] In the past a wide range of clamping systems have been designed to make a connection between the RCD bearing assembly and the RCD main body. As the RCD will typically have operating pressure performance requirements in the range of 5,000 psi, the clamping systems used to connect the rotating control device to the BOP stack must be able to meet equivalent pressure specifications.

[0035] In addition, it is desirable that the clamping systems are easy to operate in a manner that minimizes risks to operators and personnel. That is, as the working environment of rigs involves heavy equipment that must be lifted into positions, aligned with other equipment and secured in place to operate under high pressures and generally complex working environments, systems that minimize the risks of misalignment, improper clamping and the potential for failure during operation are desired. Similarly, systems that can be readily removed from the wellhead for relocation and/or exchange of other equipment are desirable.

[0036] Disassembly of an RCD is particularly problematic when the RCD is located high above a very large BOP stack **6** as seen for example in Figure 1, where it is shown that the RCD main body **9** is connected to the RCD bearing assembly **3** with a conventional clamp assembly **1** and the RCD main body **9** is coupled to the BOP stack **6** via an annular BOP.

[0037] One conventional design of a clamp assembly **1** is shown in Figure 2 in a perspective view where it can be seen that the clamp assembly **1** clamps a bearing assembly **3** to the RCD main body **9**. The clamp assembly **1** rests upon a pair of clamp support wings **7a**, **7b** which are placed slightly below the radial rim of the bore of the RCD main body **9**. There is a bore **5** in the top of the bearing assembly **3** to allow passage of a drill string and/or a running tool (not shown). It is seen that this clamp assembly **1** uses a pair of clamp bolts **8** to tighten the clamping assembly **1** to retain the RCD bearing assembly **3** in place against the upper rim of the RCD main body **9**.

[0038] A representative cross-sectional view of the RCD bearing assembly **3** clamped to the RCD main body **9** with a conventional clamp assembly **1** is shown in Figure 3 to facilitate an understanding of how the mandrel **2** fits inside the RCD bearing assembly **3** and its lower sealing element **4** extends into the RCD main body **9**.

[0039] Turning now to Figures 4A and 4B, there is shown a pair of top views of another more recently developed clamp assembly **10** which is known in the prior art. Figure 4A shows the clamp assembly **10** in the open position and Figure 4B is the same assembly **10** in the closed position. The RCD bearing assembly is not present in these views to facilitate viewing the operation of the clamp assembly **10**. In the open position of Figure 4A, it is seen that the paired clamp members **12a** and **12b** are under control of a pair of hydraulic cylinders **14a** and **14b** which pull the clamp members **12a** and **12b** together or push them apart. The clamp members **12a** and **12b** slide along support wings **16a** and **16b** which are placed below the upper rim **15** of the RCD main body. Each of the paired clamp members **12a** and **12b** have associated hooks **18a** and **18b**. When the clamp members **12a** and **12b** attain the closed position of Figure 4B, the hooks **18a** and **18b** engage opposing clamp members **12a** and **12b** and positions adjacent to the respective cylinders **14a** and **14b** to hold the clamp members **12a** and **12b** in the closed position. The operation is reversed by actuation to extend the cylinders **14a** and **14b** to disengage the hooks **18a** and **18b**, thereby allowing the clamp members **12a** and **12b** to move away from each other. For further clarity, the open position is used to place the RCD bearing assembly on top of rim of the RCD main body **15** and the closed position is to clamp the RCD bearing assembly in place on rim of the RCD main body **15**.

[0040] While effective, this design has experienced issues with being able to effectively hold pressure at the desired operating pressures. More specifically, the physical design of the hooks and levers has resulted in movement issues to occur between the mating surfaces of the hooks, levers and clamp members. This has caused pressure failures.

[0041] As such, there has been a need for an improved hydraulic clamping system that meets the requirements of enabling rapid connection and disconnection while meeting the performance requirements of higher pressures.

Introduction

[0042] Various aspects of the invention will now be described with reference to Figures 5 to 21. Wherever possible, similar reference numerals are used to refer to similar components in different embodiments. For the purposes of illustration, components depicted in the figures are not necessarily drawn to scale. Instead, emphasis is placed on highlighting the various contributions of the components to the functionality of various aspects of the invention. A number of possible alternative features are introduced during the course of this description. It is to be understood that, according to the knowledge and judgment of persons skilled in the art, such alternative features may be substituted in various combinations to arrive at different embodiments of the present invention.

Locking Cylinder Clamping Assembly with Opposed Paired Clamping and Locking Cylinders

[0043] Views of a first embodiment of a clamp assembly are shown in Figures 5 to 7 where features of this embodiment are illustrated in perspective and cross sectional views. It is to be understood that due to the limitations imposed by these views, certain components are not visible but are to be understood from context to be present. For example, clamping cylinder **114b** is not visible in any of the views of Figures 5 to 7 but is to be understood to be present and responsible for driving the movement of the lock arm **126a**. As a result, while certain reference numerals may appear in this description, they will not be present in the drawings because the components to which they refer are hidden or located outside of magnified cross sectional views or perspective views. Nonetheless, it is believed that mention of these components is helpful in describing the functionality of this embodiment.

[0044] Turning now to Figure 5, there is shown a perspective view of a first embodiment of a clamp assembly **100** which has a number of features providing advantages over conventional clamping systems used to hold an RCD bearing assembly (not shown) in place on the rim of the RCD main body **9**. In this view of Figure 5, the RCD bearing assembly is omitted to preserve clarity and enable viewing of the interior of the clamping members **112a** and **112b**. In this view, the clamping members **112a** and **112b** are in the closed and locked position. The clamp assembly **100** is configured to connect the RCD bearing assembly (not shown) to the top rim of the RCD main body **9**, with support provided by a pair of opposed support wings **116a** and **116b** with only support wing **116a**

being visible in this perspective view (support wing **116b** is to be understood to be present on the opposite side of the assembly **100**). Like the device shown in Figures 4A and 4B, movement of the clamp members **112a** and **112b** towards each other and away from each other is driven by the action of a pair of clamping cylinders with only clamping cylinder barrel **114a** being visible in this perspective view. As described above for the prior art device of Figures 4A and 4B, extending of the clamping cylinder rods (which are not visible in any of the views of this embodiment) out of the clamping cylinder barrels **114a** and **114b** leads to separation of the clamping members **112a** and **112b** to attain the open position and retracting of these same clamping cylinder rods into their respective barrels **114a** and **114b** leads to movement of the clamping members **112a** and **112b** to attain the closed position.

[0045] The clamping members **112a** and **112b** are each provided with a lug **124a** and **124b** and each lug **124a** and **124b** has a channel **125a** and **125b**. The clamping members **112a** and **112b** also have lock arms **126a** and **126b** attached thereto. It is seen in Figure 5 that lock arm **126b** is connected to clamp member **112a** at its left end by a set of four bolts. In Figure 5, the free ends of the lock arms **126a** and **126b** reside inside the channels **125a** and **125b** of the clamp lugs **124a** and **124b**. While not shown specifically in Figure 5 and subsequent views in other figures of this embodiment, it is to be understood that extending of the clamp cylinder rods causes separation of the clamping members **112a** and **112b** and this causes the lock arms **126a** and **126b** to disengage from their respective channels **125a** and **125b** of the clamp lugs **124a** and **124b**. While the lugs **124a** and **124b** and lock arms **126a** and **126b** shown in Figure 5 are shown as separate components bolted onto the clamp members **112a** and **112b** in other embodiments, the lugs **124a** and **124b** or the lock arms **126a** and **126b** or both the lugs **124a** and **124b** and the lock arms **126a** and **126b** are integrally formed with their corresponding clamp members **112a** and **112b**.

[0046] Figure 6 is a partially exploded view of the right side of the clamp assembly **100** and Figure 7 is a cross sectional view of components associated with the clamp locking mechanism. While Figures 6 and 7 are focused on the right side of the clamp assembly, it is to be understood that identical components with identical functions are provided with respect to the clamp lug **124a**, lock arm **126a** and other related components on the left

side of the clamp assembly **100**. Figures 6 and 7 together indicate that there is a lug bore **127b** formed in the lug **124b** and a lock arm bore **132b** formed in lock arm **126b**. The lug bore **127b** and the lock arm bore **132b** are aligned when the clamping assembly **100** is in the completely closed position. These aligned bores **127b** and **132b** allow entry of lock pin **134b** which provides a mechanical locking mechanism. Lock pin **134b** is oriented with its longitudinal axis substantially parallel with the axis of rotation of the rotating control device and driven upward and retracted downward (as indicated by the double arrow) via extending and retracting of the locking cylinder rod **130b** which is connected at its upper end to the lock pin **134b**. The majority of the length of locking cylinder rod **130b** is contained in locking cylinder barrel **122b** in this view. While the term "lock pin" is used as a descriptive term herein, it is to be understood that this elongated component may be provided in any number of shapes to match complementary bore shapes for the purpose of locking the lug **124b** to the lock arm **126b**.

[0047] In Figure 7, it can be seen that the lug bore **127b** has an upper portion and a lower portion. The upper portion of the lug bore **127b** is provided with a wear insert **136b** on the left side of the upper lug bore **127b**. The right side of the lock arm bore **132b** is provided with a wear insert **137b**. The left side of the lower portion of the lug bore **127b** is also provided with a wear insert **138b**. These wear inserts **136b**, **137b** and **138b** provide surfaces for contact with the lock pin **134b** and are replaceable if damaged by excessive wear or galling. In some embodiments, the wear inserts **136b**, **137b** are loosely coupled to the outer sidewall of the bores within which they reside with some movement allowance. Such "floating" inserts provide some flexibility in case some of the wear surfaces acquire some wear damage but not sufficient damage to warrant replacement.

[0048] Figure 7 shows the lock pin **134b** in an unlocked position with its upper end just below the lock arm bore **132b** (in this position, the clamping cylinders can separate the two clamp members **112a** and **112b**). The locked position is attained when the lock pin **134b** passes through the lock arm bore **132b** and enters the upper lug bore **127b**. A number of useful features are provided in the lock pin locking mechanism and will be described in more detail hereinbelow.

[0049] A cap **129b** is provided above the upper lug bore **127b** to protect the components contained therein and to allow access to the lug bore **127b** for maintenance of the

components contained therein. The cap **129b** has an interior hollow volume to allow entry of at least a portion of the lock pin **134b** in this embodiment. In other embodiments, the lock pin **134b** does not extend beyond the lug bore.

[0050] A lock pin housing **128b** is provided to contain the lock pin **134b** and to bridge between the locking cylinder barrel **122b** and the lug **124b**. It is to be understood that an identical arrangement is provided (but not visible in Figures 5-7) on the left side of the clamping assembly **100** in association with locking cylinder barrel **122a**, clamp lug **124a**, and lock arm **126a**.

[0051] Figures 8A-8E are expanded cross sectional views which are generally similar to the view of the cross-sectional view of Figure 7. Figures 8A-8E show successive upward movement of the lock pin **134b** with the objective of illustrating how surfaces of lock pin **134b** encounter the surfaces of the wear inserts **136b**, **137b** and **138b** and provide mechanical alignment of the lock arm bore **132b** with the lug bore **127b**. It is to be understood that extending of the locking cylinder rod **130b** causes the upward movement of the lock pin **134b**. The cap **129b** is omitted from Figures 8A-8E.

[0052] In Figure 8A, the top of the lock pin **134b** is located below the lock arm bore **132b**. The left side of the lock pin **134b** slides against the outer surface of wear insert **138b** and there is a gap between the right side of the lock pin **134b** and the sidewall of the lower portion of the lug bore **127b**. In this view, the lock arm bore **132b** is generally aligned but not completely aligned with the upper and lower portions of the lug bore **127b**. It is seen that wear insert **137b** on the right side of the lock arm bore **132b** is partly aligned with the upper and lower portions of the lug bore **127b**.

[0053] In Figure 8B, relative to Figure 8A, the top of the lock pin **134b** has moved up inside the lock arm bore **132b**. In this view, it is indicated that wear insert **137b** has a tapered surface **2137b** and that lock pin **134b** also has a tapered surface **3134b** on its right side which is angled by about 5 degrees. There remains a gap between these two surfaces within the lock arm bore **132b** and the alignment of the lock arm bore **132b** with the lug bore **127b** remains offset as it is in Figure 8A. It is also seen that the right side of the lock pin **134b** has a second tapered surface **4134b** with an angle of about 15 degrees

located below tapered surface **3134b**. In this view, the lug bore **127b** and the lock arm bore **132b** are in the same alignment as seen in Figure 8A.

[0054] In Figure 8C, the top of the lock pin **134b** has moved up past the lock arm bore **132b** and into the upper portion of the lug bore **127b**. The tapered surface **3134b** of the lock pin **134b** is slidingly engaged with the tapered surface **2137b** of the wear insert **137b** and the second tapered surface **4134b** of the lock pin **134b** is just beginning to encounter the tapered surface **2137b** of the wear insert **137b**. In this view, the lug bore **127b** and the lock arm bore **132b** are in the same alignment as Figures 8A and 8B.

[0055] In Figure 8D, the top of the lock pin **134b** is located approximately halfway up the upper lug bore **127b**. At this stage, the second tapered surface **4134b** is now just beginning to push against wear insert **137b**. This force urges the lock arm **126b** towards the right side and brings the lock arm bore **132b** into closer alignment with the lug bore **127b** (in a comparison of Figure 8C with 8D, it is seen that the volume of the lock arm bore **132b** to the left of the lock pin **134b** is decreased in Figure 8D relative to its volume in Figure 8C).

[0056] In Figure 8E, the top of the lock pin **134b** has attained its uppermost position above the top surface of the lug **124b**. The tapered surface **5134b** of the lock pin **134b** is fully engaged against the tapered surface **2137b** of the wear surface **137b** because the wear insert **137b** and the lock arm **126b** have been pushed further to the right, thereby aligning the lug bore **127b** with the lock arm bore **132b**. It is seen that wear inserts **136b** and **138b** are aligned with the remaining volume of the lock arm bore **132b**.

[0057] It is to be understood that the upward motion of the lock pin **134b** which pushes the lock arm **126b** to the right is duplicated on the opposite side of the clamp assembly **100**. This has the effect of tightening the clamp members **112a** and **112b** against each other to simultaneously effect a final clamping and locking motion. In one embodiment, both clamping cylinders are controlled simultaneously to provide substantially identical extending and retracting movements to lock and unlock both sides of the clamp assembly **100** simultaneously.

[0058] The surfaces of the wear inserts **136a,b**, **137a,b** and **138a,b** and the lock pins **134a,b** will preferably be oversized and have tolerances that allow for wear of these surfaces during repeated operations. In some embodiments, the wear inserts **136a,b**, **137a,b** and **138a,b** and the lock pins **134a,b** are replaceable.

[0059] In some embodiments, the clamping and locking cylinders are provided with connectors that allow convenient removal of the cylinders from the clamp assembly to facilitate maintenance and/or replacement.

Locking Cylinder Clamp Assembly with a Clamping Cylinder, a Locking Cylinder and an Opposed Hinge

[0060] Another embodiment of a clamp assembly **300** will now be described with reference to Figures 9A to 17. The components of clamping assembly **300** are generally similar to those of clamp assembly **100** unless otherwise described herein.

[0061] Figures 9A and 9B are opposing perspective views of clamp assembly **300** in the closed (clamped) position and shown connecting an RCD bearing assembly **3** to an RCD main body **9**. It is seen that this embodiment **300** of the clamp assembly includes clamp members **312a** and **312b** with hoist rings **323a-d** (to facilitate placement and/or removal of the clamping assembly **300**), a single clamping cylinder barrel **313** (with its corresponding cylinder rod **330** retracted therewithin) mounted on a lock arm **326** and a single locking cylinder barrel **322** connected to a lug **324** via a lock pin housing **328**. The lock arm **326** is placed in the channel **325** of the lug **324**. Instead of another similar arrangement of clamping and locking cylinders on the opposite side of the device (as described for the previous main embodiment), there is a hinge **333** including a top hinge bracket **1333** and a lower hinge connector plate **2333**.

[0062] As described above for the previous embodiment, the lug **324** and the lock arm **326** are shown as separate components bolted onto the clamp members **312a** and **312b** in other embodiments, the lug **324** or the lock arm **326** or both, are integrally formed with their corresponding clamp members **312a** and **312b**.

[0063] It should be appreciated that this arrangement will be less costly to manufacture and maintain because fewer hydraulic cylinders are incorporated into the clamp assembly 300.

[0064] The hinge 333 allows direct connection of the clamp assembly 300 to the RCD main body 9 via the connector plate 2333 and therefore allows the commonly employed clamp support wings, such as the clamp support wings 7a and 7b of the clamp assembly embodiment 100 (see Figure 2) to be omitted from the clamp assembly 300. This is a favorable arrangement because it reduces the lateral profile of the entire assembled structure of the clamp assembly 300 with respect to embodiment 100 as well as a number of clamp assemblies known in the prior art.

[0065] Figure 10 is a magnified view of the hinge with clamp member 312b shown in a phantom view to indicate passage of a left hinge axle 3333b therethrough. The opposing clamp member 312a is shown in a partial cross-sectional view and the top bracket 1333, the right hinge axle 3333a are also shown in cross-sectional view. The top bracket 1333 is fixed to the tops of both axles 3333a,b with screws 4333a,b and the connector plate 2333 attached to the RCD main body 9 is fixed to the bottoms of both axles 3333a,b with screws 5333a,b. The clamp members 312a and 312b pivot around the axles 3333a,b during opening and closing of the clamp members 312a and 312b when the hinge 333 is operating.

[0066] Figure 11 is a top view of clamp assembly 300 in the open position. It is seen that the clamping cylinder rod 330 is extended out to the left from the clamping cylinder barrel 313. This extending of the clamping cylinder rod 330 pushes on the left end of the lock arm 326 because it is connected thereto. Because the left end of lock arm 326 is connected to clamp member 312a and the right end of the clamping cylinder barrel is connected to the lug 324 and the lug 324 is connected to clamp member 312b, it should be understood that extending of the clamping cylinder rod 330 separates the two clamp members 312a and 312b. The hinge 333 allows pivotal movement of these clamping members 312a and 312b while they are held in close proximity at the hinge 333. The clamping members 312a and 312b are opened sufficiently to allow the RCD bearing assembly 3 to be removed from the top of the RCD main body 9, whose outer corners are visible in Figure 11 between the circumference of the RCD bearing assembly 3 and the

clamp members **312a** and **312b**. The lock arm **326** is removed from the channel **325** (see Figure 9A) of the lug **324**. In this position, the lock arm bore **332** is visible.

[0067] Figure 12 is a top view of the clamp assembly **300** in the closed position. The clamping cylinder rod **330** is retracted inside the clamping cylinder barrel **313**. The right end of the lock arm **326** is now inside the channel **325** of the lug **324** and the clamp members **312a** and **312b** are pulled together to clamp the RCD bearing assembly **3** in place on the rim of the RCD main body **9** (whose corners are no longer visible in this view).

[0068] Figure 13 is a side elevation view of the clamp assembly **300** to facilitate an understanding of the arrangement of components described for this embodiment. In addition, the position of a secondary lock member **350** on the right side of the lock pin housing **328** is indicated. The function of the secondary lock member **350** will be described in more detail hereinbelow with reference to Figures 16 and 17.

[0069] Figures 14A and 14B provide partial cross-sectional views of the locking mechanism driven by the locking cylinder rod **315**. In Figure 14A, it is seen that the majority of the wedge-shaped lock pin **334** resides inside the bore of the lock pin housing **328** with a top portion residing in the lower part of the lug bore **327** which includes a wear insert **342**. The lock arm bore **332** includes a tapered wear insert **337** on the right side and otherwise is unoccupied. There is also a wear insert **341** in the upper part of the lug bore **327** and a wear insert **343** in the bore of the lock pin housing **328**. The wear insert **343** has a square bore. This bore may have other shapes to align with similar alternative shapes of the bores of the other wear inserts but should be non-circular to provide the capability to take the bore of the wear insert **343** out of alignment with the bores of the other wear inserts and the lock arm bore **332**. The secondary lock member **350** is also seen connected to the lock pin housing **328**. The wear inserts **341** and **343** of the lug bore **327** are square inserts which fit inside the square lug bore **327**. This is seen more clearly in the top perspective view of Figure 15. The cross sectional profile of the base of the lock pin **334** is square but the upper portions are wedge shaped as shown in Figures 14A and 14B. It is to be understood that when the clamping process is complete after full retraction of the clamping cylinder rod **330**, the lug bore **327** and the lock arm bore **332** will not be completely aligned. The final alignment of these bores **327** and **332** is obtained as the lock pin **334** moves upward into the lock arm bore **332** (as driven by the locking cylinder rod

315) and the sloped surface visible on the right of the lock pin 334 begins to encounter the sloped surface of the wear insert 337 in the lock arm bore 332. This contact between the sloped surfaces of the lock pin 334 and the wear insert 337 has the effect of gradually pushing the lock arm 326 to the right to generate alignment of the bores 327 and 332. The effect of this movement also causes the lug 324 to be pushed to the left. When the final locking position of the lock pin 334 is attained, its upper portion will reside within the upper lug bore 327. In some embodiments, a sensor (not shown) is provided to sense the presence of the lock pin 334 at its uppermost position. This sensor is coupled to an indicator visible to a person operating the clamping assembly 300 so that the operator knows exactly when the lock pin 334 has reached the final locking position. In some embodiments, the sensor is a pressure sensor located on the ceiling of a cap (not shown) covering the top of the upper lug bore 327. In some embodiments, the sensor is calibrated to provide an indication of any of the position of the lock pin 334 during its movement through both portions of the lug bore 327 and the lock arm bore 332.

[0070] In this embodiment, the lock pin 334 is replaceable and is connected to the locking cylinder rod 315 with a T-slot nut which resides within a cavity in the lock pin 334. Other reversible means for connecting the lock pin 334 to the locking cylinder rod 315 may also be used. The ability to replace the lock pin 334 is helpful because the lock pin 334 is expected to experience a significant degree of wear as it contacts the surfaces of the wear inserts 341, 337, 342 and 343.

[0071] The secondary lock member 350 is connected to the wear insert 343 within the lock pin housing 328. The function of the secondary lock member 350 will be described in more detail below.

[0072] Figure 15 is a perspective view of the clamping assembly 300 with a focus on the upper surface of the lug 324 and showing the generally square shape of the lug bore 327 and the lug bore wear insert 341, as well as the lock pin housing 328 connected to the lower surface of the lug 324. The secondary lock member 350 is shown connected to the right side of the lock pin housing 328.

[0073] Figure 16 is a perspective view of the clamping assembly 300 with a focus on the lock pin housing 328. The secondary lock member 350 is connected to the wear insert

343 contained within the bore of the lock pin housing **328**. Lock pin housing **328** has a barbell-shaped slot **1328** and the secondary lock member **350** housing extends through the slot **1328**. The radiused ends of the slot **1328** allow the secondary lock member **350** to drop and be held in place therewithin. In Figure 16, the secondary lock member **350** is shown in the unlocked position in the radiused left end of the slot **1328**.

[0074] Figure 17 is a cross sectional perspective view of the lock pin housing **328** with the cut made across the lock pin housing **328** to show features of the wear insert **343**, the lock pin **334** and the secondary lock member **350** which occupies the radiused left end of the slot **1328**. It is seen that the wear insert **343** has a circular outer sidewall which allows it to rotate within the bore of the lock pin housing **328** while holding the square lock pin **334**. Therefore, the secondary lock member **350** can be grasped by its outer knob, lifted out of the lower edge of the radiused end, and moved counterclockwise through the slot **1328** until it reaches the opposite radiused right end of the slot **1328** where it drops and holds the wear insert in place at location disposed at a 45 degree angle from its originating position. The purpose of this operation is to rotate the square profile of the bore of the wear insert **343** when the bottom of the lock pin **334** is located above the wear insert **343**. When the wear insert **343** is rotated by 45 degrees in this situation, the square bore of the wear insert **343** is no longer aligned with the profile of the lock pin **334** and therefore, the lock pin **334** cannot drop down into the lock pin housing **328**. This arrangement provides a secondary locking mechanism to prevent the lock pin **334** from inadvertently dropping into the lock pin housing **328**. It is to be understood that this mechanism may be provided with any shaped bore other than a circular bore.

[0075] In this embodiment, the locking pin **334** is replaceable and is connected to the locking cylinder rod **315** with a T-slot nut **344** (see Figure 14A).

Locking Cylinder Clamp Assembly with Opposed Clamping and Locking Cylinders

[0076] Another embodiment of a clamp assembly **400** will now be described with reference to Figures 18 to 20. Clamp assembly **400** has a number of similarities shared with the previously described clamp assembly **300**. One major difference however, is that the clamping cylinder **413** and the locking cylinder barrel **322** and lock pin housing **328** (as well as components associated with the latter) are located on opposite sides of the clamp assembly **400** whereas they are located on the same side in clamp assembly **300**.

There are a number of advantages associated with this clamp assembly embodiment **400** which will be described in detail hereinbelow. Figures 18A and 18B are opposing perspective views of clamp assembly **400** in the closed (clamped) position and Figures 19A and 19B are opposing perspective views of the clamp assembly **400** in the open (unclamped) position. In Figures 18-20, the clamp assembly **400** is shown connecting an RCD bearing assembly **3** to an RCD main body **9**. It is seen in Figure 18A that this embodiment **400** of the clamp assembly includes clamp members **412a** and **412b** with a single clamping cylinder barrel **413** (with its corresponding cylinder rod **430** extended therefrom) mounted between a pair of opposed extensions **435a** and **435b** which are integrally formed with the clamp members **412a** and **412b**. The clamping arrangement of this clamp assembly embodiment **400** functions differently than the clamping arrangement of clamp assembly **300** in that extending of the clamping cylinder rod **430** – shown in the fully extended position in Figures 18A and 18B – pushes the extensions **435a,b** away from each other to cause the clamp members **412a,b** to attain the clamped and closed position. The differences in positioning of the clamp members **412a,b** and the clamping cylinder rod **430** are best observed in the adjacent top views shown in Figures 20A (closed and clamped, rod **430** extended) and Figure 20B (open and unclamped, rod **430** retracted).

[0077] Figure 18B illustrates that the single locking cylinder barrel **322** is connected to a lug **424** via a lock pin housing **328** on the side of the clamp assembly **400** opposite the clamping cylinder barrel **413** and rod **430**. The lock pin housing **328**, the lock pin **334** (seen only in Figure 19B) and the locking cylinder barrel **322** are the same as described for clamp assembly embodiment **300** and likewise all components shown in Figures 14A-17 are also included in clamp assembly embodiment **400** and are the same and function in the same manner as in clamp assembly embodiment **300**.

[0078] The lock arm **439** is integrally formed with clamp member **412a** and its free end is placed within the channel **425** of the lug **424** to align its lock arm bore **432** (Figure 19B) with the lug bore **427**. The lug bore **427** is provided with wear inserts (not shown) which are similar to the wear inserts **341**, **342** and **343** of clamp assembly embodiment **300**.

[0079] Clamp assembly **400** includes a hinge which the same and functions in the same manner as hinge **333** of the clamp assembly **300** (Figure 10). There is a top hinge bracket **1333** and a lower hinge connector plate **2333**. The top hinge bracket **1333** is located

adjacent to the clamping cylinder barrel **413**. The hinge of this clamp assembly embodiment **400** provides all of the advantages described hereinabove with respect to clamp assembly embodiment **300**.

Hydraulic Cylinder Control System for Clamp Assembly

[0080] One embodiment of a hydraulic cylinder control system **500** for driving the hydraulic cylinders used to clamp and lock embodiments of the clamping assembly of the invention will now be described with respect to Figures 19A-19C. For the sake of simplicity, the description refers to only a single clamping cylinder and a single locking cylinder which would be used in conjunction with clamp assembly **300** (the entire clamp assembly **300** is not shown in Figures 21A-21C but the clamping **313**, **330** and locking **315**, **322** cylinders are shown). However, the system **500** may be readily adapted to operate the clamp assembly **100** or the clamp assembly **400** described hereinabove. To facilitate understanding of the operation of the control system **500**, the operation is described in the following example where the clamping and locking cylinders of clamp assembly **300** are driven by the control system **500**.

[0081] Figures 21A-21C show an embodiment of a hydraulic control system **500** which has a first port **501**, a second port **551** and a hydraulic network connected to both of these ports **501** and **551**. The hydraulic network **500** has two separate connections to the clamping cylinder barrel **313** and two separate connections to the locking cylinder barrel **322** (both of which are located near the top of Figures 21A-21C).

[0082] The clamping cylinder rod **330** driven by hydraulic fluid drives opening and closing of the clamp assembly **300**, depending on the entry point of the hydraulic fluid into the clamping cylinder barrel **313**. Moving the clamping cylinder rod **330** in the closing direction (to the left) retracts the clamping cylinder rod **330** into the clamping cylinder barrel **313** to close the clamp assembly **300**. Moving the clamping cylinder rod **330** in the opening direction (to the right) extends the clamping cylinder rod **330** out of the barrel **313** and opens the clamp assembly **300**.

[0083] The hydraulic network **500** is also connected at two points to the locking cylinder barrel **322** as noted above. The locking cylinder rod **315** driven by hydraulic fluid in the

system **500** drives locking and unlocking of the clamp assembly **300** wherein moving the locking cylinder rod **315** in the locking direction (upward) locks the clamp assembly **300** and moving the locking cylinder rod **315** in the unlocking direction (downward) unlocks the clamp assembly **300**.

[0084] In Figure 21A, hydraulic fluid is pumped into the control system **500** via the first port **501**. This causes fluid to be first directed to the clamping cylinder barrel **313** via conduit **502** to move the clamping cylinder rod **330** to the left to drive closing of the clamp assembly **300**. When the closure of the clamp assembly **300** is complete, hydraulic fluid is then permitted to enter the locking cylinder barrel **322** where it drives the locking cylinder rod **315** upward towards the locked position. The components responsible for this fluid movement will be described in more detail below.

[0085] In Figure 21B, hydraulic fluid is pumped into the control system **500** via the second port **55**. This causes the operations described above to be reversed. First hydraulic fluid is directed to the upper part of the locking cylinder barrel **322** where it pushes the lock cylinder rod **315** down to unlock the clamp assembly **300**. When unlocking of the clamp assembly **300** is complete, hydraulic fluid is permitted to enter the clamping cylinder barrel **313** where it drives the clamping cylinder rod **330** to the right towards the open position.

[0086] As indicated in Figures 21A-21C, the hydraulic system **500** is connectable to a high-pressure hydraulic fluid source and a low pressure drain. The high-pressure hydraulic fluid source is provided by having a pump reservoir **570** of hydraulic fluid which is pumped into a pump channel **571** with a pump **572**. The low pressure drain is provided by a drain channel **581** connected to a drain reservoir **580**.

[0087] The pump channel **571** and the drain channel **581** are connected to the hydraulic network in this case by a four-port, three position directional control valve **540**. The three positions are "Clamping/Locking," "Steady-State Locked" and "Unlocking/Unclamping." The fluid flow directions provided by each of these three positions of the directional control valve **540** are now described below.

Attaining the Clamped and Locked Position

[0088] When the three position directional control valve 540 is moved to the clamping/locking position 541 (Figure 21A), the pump channel 571 is connected to the first port 501 and the second port 551 is connected to the drain channel 581.

[0089] High-pressure fluid is pumped through the first port 501 from where it is connected to a channel which bifurcates into two-sub-channels: a clamp closing sub-channel 502 being connected near the right end of the clamping barrel 313 to effect closing of the clamp via retraction of the clamping cylinder rod 330, and a locking sub-channel 503 being connected to the bottom of the locking cylinder barrel 322 to effect locking via extending of the locking cylinder rod 315. It will be appreciated that, in other embodiments, the system can be reconfigured to provide closure of the clamp assembly by extending a clamping rod and/or engaging the lock may be achieved by retracting a locking rod.

[0090] In this case, the redirection of the fluid first to the clamp closing sub-channel 502 is controlled by having a locking sequence valve 510 placed between the locking cylinder barrel 322 and the first port 501 within the locking sub-channel 503. The locking sequence valve 510 in this case uses the fluid pressure in the locking sub-channel 503 for control. Therefore, fluid can only pass through the locking sequence valve 510 to effect locking when the load pressure in the locking sub-channel 503 exceeds a predetermined threshold. As the clamping cylinder rod 330 is retracting to close the clamp assembly 300, the pressure in the locking sub-channel 503 and the clamping sub-channel 502 remains relatively low. The locking sequence valve 510 remains closed so the fluid will initially flow to the clamping cylinder barrel 330 to cause the clamping assembly to close. Fluid is pushed from the other end of the clamping cylinder barrel 313 via conduit 552 and a one-way clamping bypass drain valve 522, through conduit 552 and through the second port 551 and into the drain reservoir 580. The one-way clamping bypass drain valve 522 may be considered to be a bypass check valve arranged in parallel with the unclamping sequence valve 520 which will be described below.

[0091] The pressure in sub-channel 503 builds up after the clamping cylinder rod 330 is fully pushed into its retracted position to close the clamp members of the clamping assembly 300.

[0092] Once the clamping cylinder rod 330 is fully retracted into the clamping cylinder barrel 313, pressure in the clamping sub-channel 502 and the locking sub-channel 503 will increase.

[0093] This build-up of pressure will control the locking sequence valve 510 to allow fluid flow from the first port 501 to the locking cylinder barrel 322 to effect extending of the locking cylinder rod 315 to push the lock pin 334 (not shown in Figures 21A-21C) into its locked position. A pressure regulator may be used in certain embodiments to limit the force applied to the locking cylinder rod.

Steady State in Clamped and Locked Position

[0094] When the clamping assembly 300 is fully closed and locked, the four-port, three position directional control valve 540 can be turned to position 542 (Figure 21B), wherein the system 500 is no longer connected to the pump reservoir 570 and the drain reservoir 580 (ports 501 and 551 are at dead ends as shown in Figure 21B). In order to maintain pressure in the locking cylinder barrel 322 and the clamping cylinder barrel 313, the clamping sub-channel 502 is provided with a clamping one-way valve 524 and the locking sub-channel 503 is provided with a locking one-way valve 514. These one-way valves 524 and 514 prevent hydraulic fluid from flowing out from the clamping cylinder barrel 313 and the locking cylinder barrel 322, respectively. This ensures that the clamping cylinder rod 330 remains retracted and the locking cylinder rod 315 remains extended upward. In this case, the one-way valves 524, 514 maintain pressure in the clamping cylinder barrel 313 and the locking cylinder barrel 322.

[0095] It will be appreciated that the redirection of fluid may be controlled in a different way. For example, each sub-channel may have separate directional control valves and limit switches or limit valves.

Attaining the Unlocked and Unclamped Position

[0096] To disengage the clamp assembly 300, the four-port, three position directional control valve 540 is moved to an unlock/unclamp position 543 (Figure 21C), wherein the pump channel 571 is connected to the second port 551 and the first port 501 is connected to the drain channel 581.

[0097] High-pressure fluid is pumped through the second port **551** which bifurcates into two-sub-channels: an unclamping sub-channel **552** connected to the left end of the clamping cylinder barrel **313** to effect extending of the clamp cylinder rod **330** to open the clamp assembly **300**, and an unlocking sub-channel **553** being connected to the upper end of the locking cylinder barrel **322** to cause retraction of the locking cylinder rod **315** to effect disengagement of the lock pin **334**.

[0098] In this case, the redirection of the fluid first to the unlocking sub-channel **553** is controlled by the unclamping sequence valve **520** placed between the clamping cylinder barrel **313** and the second port **551** in the unclamping sub-channel **552**. The unclamping sequence valve **520** uses the fluid pressure in the unclamping sub-channel **552** for control. Therefore, fluid can only pass through the unclamping sequence valve **520** to effect unclamping when the load pressure in the locking sub-channel **503** exceeds a predetermined threshold.

[0099] As the locking cylinder rod **315** retracts to disengage the lock pin **334**, the pressure in the unlocking sub-channel **553** and the unclamping sub-channel **552** will be kept relatively low. Therefore, the fluid will initially flow via the unlocking sub-channel **553** to the upper part of the locking cylinder barrel to disengage the lock pin **334**. With retraction of the locking cylinder rod **315**, fluid is pushed out of the one-way unlocking bypass drain valve **512** and then via sub-channel **503** through the first port **501** and into the drain reservoir **580**. This one-way unlocking bypass drain valve **512** may be considered to be a bypass check valve arranged in parallel with the sequence valve **510**.

[0100] In this case, fluid from the locking cylinder barrel **322** is drained in a counter-flow with respect to the locking one-way valve **514**. This is achieved by the locking one-way valve **514** being pilot-controlled based on the pressure in the unlocking sub-channel **553**.

[0101] Once the clamp assembly **300** is unlocked, retraction of the locking cylinder rod **315** in the locking cylinder barrel **322** will cease and pressure in the unlocking sub-channel **553** and the unclamping sub-channel **552** will increase.

[0102] This build-up of pressure will control the unclamping sequence valve **520** to allow fluid flow from the second port **551** to the clamping cylinder barrel **313** to effect opening of the clamp assembly **300** as a result of extending of the clamping cylinder rod **330**.

[0103] Fluid is pushed out of the clamping cylinder barrel **313** to the first port **501** and to the drain reservoir **580** through the clamping one-way valve **524**. This is achieved by the clamping one-way valve **524** being pilot-controlled based on the pressure in the unclamping sub-channel **552** upstream from the unclamping sequence valve **520**.

Advantages of Embodiments of the Clamp Assembly

[0104] It is to be understood that the mechanical locking features described for the three main embodiments provide the ability to keep the clamping assembly locked in the event of a hydraulic system failure.

[0105] The three main embodiments described hereinabove have lock pins oriented and moving substantially parallel with the central axis of the clamp assembly. As such they do not extend beyond the lateral edges of the clamp assembly. This allows the clamp assembly to have a relatively compact lateral profile.

[0106] The hinged clamp assembly **300** provides the advantage of being less expensive to manufacture and maintain relative to the dual cylinder clamp assembly **100** because only a single clamping cylinder, single lock cylinder and single lock pin and housing are required and because the hinge **333** of clamp assembly **300** is mechanically simple. Furthermore, the secondary lock member **350** of the hinged clamp assembly provides an additional margin of safety in the event of failure of the mechanical locking arrangement of the lock pin **334**. Furthermore, clamp assembly **300** has a reduced lateral profile relative to clamp assembly **100** which requires the presence of support wings **116a,b**.

[0107] The hinged clamp assembly **400** has certain advantages over the previously described clamp assembly embodiments **100** and **300** and over the prior art. One advantage is that a smaller clamping cylinder barrel **413** and rod **430** are used with extending of the rod closing the clamp assembly **400** and retracting of the rod opening the clamp assembly **400** with the reduced extent of rod leverage compensated by the clamp members **412a,b** themselves. In this arrangement, the clamping cylinder barrel **413** and

rod **430** have a reduced profile conforming more closely to the circumferential profile of the clamp members **412a,b**. This more compact arrangement reduces the likelihood of damage from incidental contact with other equipment during installation and maintenance. Furthermore, the compact arrangement permits a clamping cylinder cover to be conveniently installed over the clamping cylinder **413** and rod **430**. Such a cover (not shown) may be bolted to or integrally formed with the clamping members **412a,b**. Another advantage of physically separating the association of the clamping cylinder **413** and the locking cylinder barrel **322** is that an accidental impact at the clamping cylinder **413** would not cause damage to the locking cylinder **322** and *vice versa*.

Equivalents and Scope

[0108] The terms "one," "a," or "an" as used herein are intended to include "at least one" or "one or more," unless otherwise indicated.

[0109] Any patent, publication, internet site, or other disclosure material, in whole or in part, that is said to be incorporated by reference herein is incorporated herein only to the extent that the incorporated material does not conflict with existing definitions, statements, or other disclosure material set forth in this disclosure. As such, and to the extent necessary, the disclosure as explicitly set forth herein supersedes any conflicting material incorporated herein by reference. Any material, or portion thereof, that is said to be incorporated by reference herein, but which conflicts with existing definitions, statements, or other disclosure material set forth herein will only be incorporated to the extent that no conflict arises between that incorporated material and the existing disclosure material.

[0110] Unless otherwise defined, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs.

[0111] While this invention has been particularly shown and described with references to embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the scope of the invention encompassed by the appended claims.