BALL-JOINT RETAINERS FOR THE PISTONS OF HYDRAULIC MOTORS AND PUMPS

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ABSTRACT
This device is intended essentially for maintaining the mutual swivel engagement between a swash-plate engaging shoe and a piston in a barrel-type hydraulic pump or motor, of the type comprising a swivel ball rigid with the shoe and adapted to engage a corresponding cavity in the relevant piston, comprises a ring, a groove formed in said piston cavity and engageable by said ring, the configuration of said retaining member and groove being such that the retaining member can be fitted without play, while preserving the possibility of taking up plays due to manufacturing tolerances while safely retaining the shoe by virtue of a wedging effect.

2 Claims, 7 Drawing Figures
BALL-JOINT RETAINERS FOR THE PISTONS OF HYDRAULIC MOTORS AND PUMPS

The present invention relates to hydraulic pumps and motors. It is applicable more particularly to hydraulic pumps and motors of the so-called "in-line" barrel type wherein the pistons are reciprocated in a direction parallel to the pump or motor axis and caused to slide by means of hydrostatically balanced shoes on a variable-inclination plate sometimes referred to as the "swash-plate."

It is the essential object of the present invention to provide a device adapted to prevent the accidental separation between the balanced shoes and the relevant pistons as a consequence of simultaneous inertial and friction effects of said shoes and pistons.

This invention is also concerned with a device for retaining in position a swivel ball or ball joint receiving alternating stresses, and is applicable to barrel-type piston pumps and motors, of the so-called "broken axis" type, for assembling the piston rods on the one hand with the pistons and on the other hand with the impeller or swash plate.

In order to simplify the disclosure, only pumps will be referred to hereinafter, but it will readily occur to those conversant with the art that the constructional details given with reference to pumps are applicable as well to hydraulic motors.

In the preferred field of application of the device of this invention it is current practice to urge the piston and shoe assembly for operative engagement with the swash plate by using spring means or by hydraulic pressure exerting a permanent effect against the piston.

Preferably, this indirect assembling method should be replaced by a retaining member constituting at the same time an efficient means for mechanically connecting the shoe to the piston ball- or swivel joint, this latter solution being more reliable.

A first known type of retaining method consists in crimping a shoe having a part-spherical cavity formed therein on the piston having a likewise part-spherical head matching with said cavity. If a steel piston and a bronze shoe are used, a satisfactory frictional contact is obtained between the shoe and the piston head, on the one hand, and between the shoe and the impeller or swash plate, on the other hand.

However, the chief drawback characterizing this retaining method lies in the crimping operation. In fact, it is clear that an accurate crimping eliminates the use of relatively broad machining tolerances in the manufacture of the component elements and precludes any subsequent disassembling of the shoe. On the other hand, it is obvious that with the crimping technique the overhang component of the radial effort exerted on the head of the presently innermost piston of the cylinder barrel, as well as the overhang component of the radial effort exerted on the head of the momentarily outermost piston emerging from said cylinder barrel, are relatively high, thus producing considerable strain at the points of contact between the pistons and the barrel cylinders.

Another known retaining method consists in crimping to the pump head with a head provided with a cavity of part-spherical configuration on a shoe having a complementary part-spherical head. With this arrangement it is possible to reduce the overhang of the radial effort exerted on the piston head and to have dimensions imparting an adequate strength to the shoe and piston, even in case of relatively pronounced inclination of the swash plate. However, this arrangement is also objectionable on account of the difficult manufacture and machining of the piston. In fact, the radial efforts exerted on the pistons and the considerable relative speeds with respect to the barrel cylinders make it necessary to use a metal having very good mechanical properties for making the pistons, in order to avoid a premature wear and tear thereof. Thus, the piston head cannot be crimped unless a local thermal treatment is applied in order to reduce the yield point of the piston head material. Another inconvenience characterizing this arrangement is that disassembling the parts and performing an easy checking and adjustment of the play between shoe and piston are definitely precluded.

A retaining device is also known wherein a ring of circular radial section is fitted into a groove of semicircular radial section to prevent the part-spherical or swivel-ball from being pulled out from its matching cavity. However, also this arrangement is objectionable in that it is attended by an excessive play between the ring and the ball, which is detrimental to the pump operation if this method is contemplated for assembling the shoe to the pump piston. The circular section of relatively small diameter of the ring limits its use to devic involving but relatively moderate retaining efforts.

In order to avoid the various inconveniences set forth hereinabove, the present invention provides an improved device affording notably:

- a simplified manufacture of the piston and shoe by using materials consistent with the conditions of operation of the piston pump;
- a considerable reduction in the degree of overhang of the radial effort exerted on the piston head, even at considerable swash plate angles;
- simplified assembling and disassembling of the parts;
- an automatic play take up between piston and shoe.

It is the essential object of the present invention, which is described hereinafter in detail, to provide a device comprising a shoe of which the rear, part-spherical portion is adapted to co-operate with a matching or complementary surface of the piston and is retained by means of a member engaging a groove formed in the piston.

This invention is concerned more particularly with a device wherein the piston groove and the swivel-ball retaining member have specific configurations whereby the retaining member can be fitted without play, the possibility being preserved of taking up plays due to manufacturing tolerances while safely retaining the shoe by virtue of a wedging effect.

Basically, the device according to this invention for retaining a swivel ball in a cavity having a surface of revolution formed with a part-spherical bottom adapted to co-operate with the swivel-ball surface comprising a swivel-ball retaining member in the form of a split ring, it characterized in that said cavity comprises a frustoconical surface portion having its major base connected to said part-spherical bottom, and that said retaining member, in the portion thereof which is to engage the surface of said swivel ball is so shaped that there is at least one fictitious tapered surface tangent to both said retaining member and said swivel ball in their zone of mutual engagement, the radial cross-sectional shape of said retaining member being such...
that the difference between the apex half-angles of said fictitious tapered surface having the greatest possible apex angle, and the frustoconical surface of said cavity, is less than or equal to the sum of the friction angles at the points of contact between said retaining member and said tapered surfaces.

Other details will appear as the following description proceeds with reference to the accompanying drawings showing a typical form of embodiment of the invention given by way of example. In the drawings:

FIG. 1 is a part-sectional, diagrammatic view showing the retaining device of this invention;

FIG. 2 is a plan view of the retaining member;

FIGS. 3 to 6 inclusive are diagrammatic views showing a radial section of the retaining member fitted in its piston cavity, and

FIG. 7 is a fragmentary section showing a modified form of embodiment of the device.

In the retaining device of this invention a piston 1 having a cavity 3 formed therein, of which the surface of revolution comprises a part-spherical bottom 2 having a radius R₁, is adapted to co-act with a swivel ball 10 engaging said cavity. The surface of revolution of said cavity 3 consists of a frustoconical surface 3a, having its major base connected to the part-spherical bottom 2 through a part-toroidal surface 3b.

The apex half-angle of the frustoconical surface 3a will be denoted α in the following disclosure.

A retaining member engaging the groove 3 consists of a split ring 4.

This ring of substantially toroidal configuration has its axis of revolution merged into the axis XX' of the piston cavity.

The function of retaining ring 4 is to hold in position the end swivel ball 10 carried by a shoe 5 having its base plate 6 of substantially cylindrical, flat configuration adapted to slide on a swash plate 7.

The part-spherical surface of swivel ball 10 is connected to the base plate 6 through a neck portion having a diameter D₁.

The retaining member 4 consisting of toroidal surface cut along a length L (FIG. 2) comprises an inner surface adapted to engage the swivel ball 10.

As illustrated in FIGS. 1, 3, 4, 5 and 6, one portion of the periphery of the radial section of the retaining member 4 engages a fictitious tapered surface C₁, and another portion of said periphery engages the tapered surface 3a of the piston cavity.

According to this specific form of embodiment, the retaining member 4 has a substantially circular radial section comprising an inner tapered surface 11 having an apex half-angle β.

The piston 1 has formed in its outer end 8 a cavity 9 communicating via a small orifice 13 with the part-spherical bottom 2 in order to form between the swivel ball of the shoe 4 and the aforesaid piston 1 an oil film at the pressure prevailing in the piston cylinder.

The shoe 5 is also provided with a small orifice 14 so that the same oil pressure may be obtained between the shoe 5 and the swash plate 7 sidewise engaged thereby.

The above-described device is assembled as follows:

a. Firstly, the ring 4 is positioned on the shoe 5, across the neck thereof, by diverting the ring ends sufficiently to cause the gap L to correspond to the diameter D₁ of said neck. Then the swivel ball of the shoe is inserted into the piston cavity 2, with the ring 4 still at the level of said neck.

b. Then, the ring is compressed to reduce its outer radius to a value inferior to the radius R₂ of the circular aperture leading to the frustoconical surface 3a, and eventually the ring 4 is pushed home against the swivel ball of shoe 5.

During this movement the ring 4 is expanded as a function of the annular gap available between the groove 3 and the part-spherical surface 10 of the swivel ball. Thus, the shoe is ready to operate, or otherwise stated its axis can assume in relation to the piston axis anyone of the angular positions available in a cone having an apex half-angle of the order of 20°. Even if the shoe is pulled for attempting to disconnect it from the piston, the two parts will remain in their assembled condition for by properly selecting the value of angles α and β (with β always greater than α) it is possible to obtain a wedging effect while permitting a play-free assembling of the component elements of the device, with due consideration for manufacturing tolerances.

In the drawings, a retaining member 4a adapted to keep the shoes on the plate 7 with the desired play is illustrated.

The above-described device operates as follows:

1. To simplify the disclosure, it will firstly be assumed that the mean diameter of the retaining ring 4 is the same as its mean diameter in the unstressed condition, and that the wire constituting this retaining member 4 is not deformable by torsion.

Whatever the direction of the reactive efforts exerted on the shoe 5, the contact forces between swivel ball 10 and ring 4, and between this ring 4 and the groove 3 of piston 1, respectively, lie within friction cones at the corresponding points of contact B and A, respectively.

In FIG. 3 there is illustrated the effort producing an action F₁ of swivel ball 5 on ring 4 in a toroidal sector such as S (FIG. 2), and the reaction F₂ of groove 3 on ring 4 in the same angular sector.

Let f₁ and f₂ denote the coefficients of friction between ring 4 and ball 10, and between ring 4 and piston 1, respectively; the apex half-angles of the friction cones will be m₁ and m₂, such that:

\[ f₁ = \tan m₁ \]
\[ f₂ = \tan m₂ \]

When the shoe 5 is pulled, due to the inertia and friction stresses, the shoe tends to move away from piston 1. If this separation took place the ring 4 would move towards the shoe 5 in the direction of the arrow 15 and would even precede said shoe during this movement since the ring must reduce its diameter owing to the particular shape of the surface 3a, but this reduction in diameter can take place only if the ring is moved towards the neck of the shoe 5.

Under these conditions the ring 4 tends to slip towards the neck of shoe 5. The action F₁ exerted by the shoe on ring 4 will lie behind the normal N₃ common to the point of contact B, considering the direction of the arrow 15.

Similarly, the reaction F₂ of groove 3 on ring 4 will lie behind the normal N₂ to the point of contact A in relation to the direction of the arrow 15, as the groove 3 is stationary.

To produce a wedging effect it is only necessary that the resultant of forces F₁ and F₂ be zero. However, since the ring 4 is assumed to be free of torsional defor-
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mation, the couple of forces \( F_1 \) and \( F_2 \) is not necessarily zero. In other words, to produce a wedging effect it is only necessary that the forces \( F_1 \) and \( F_2 \) be parallel while remaining within the friction cones corresponding to the angles \( m_1 \) and \( m_2 \).

The limit of the wedging and slipping of ring 4 will be attained when the forces \( F_1 \) and \( F_2 \) are merged into a generatrix of their respective friction cone, as illustrated in Fig. 4.

The forces \( F_1 \) and \( F_2 \) constitute this case, in conjunction with the respective normals DB and AO, the sides of angles \( m_1 \) and \( m_2 \), \( F_1 \) and \( F_2 \) being parallel, and \( F_1 \) forming an angle \( m_1 \) to the normal DB. If we consider the triangle ACD it will readily appear that the angle of both normals AO and DB equal to \( \beta - \alpha \) is also equal to \( m_1 = m_2 \).

Hence the wedging condition:

\[
\beta - \alpha \leq m_1 + m_2
\]

It will be noted that the ring torsion actually takes place in the form of a slight distortion under the influence of the couple of forces \( F_1 \) and \( F_2 \) causing a relative movement of the swirl ball in relation to the piston. However, this effect is negligible. On the other hand, the ring, as a consequence of its bending-strength, causes it to be pressed against the groove 3 by a return force urging it to its position of equilibrium in the unstressed condition, if in this condition this ring has a means diameter greater than the mean diameter it has when fitted in the operative position. In Fig. 5 it will be seen that this return force \( T \), in the angular sector defined hereinafore for \( F_1 \) and \( F_2 \), exerts a beneficial influence on the wedging effect. In fact, \( T \) is perpendicular to the piston axis and causes \( F_1 \) and \( F_2 \) to be shifted towards the normals to the points of contact. The wedging effect is thus improved. It will be seen that the greater \( T \) ahead of \( F_1 \) and \( F_2 \), the greater this improvement.

This constitutes an additional safety characteristic of the system since the more the shoe is detached from the piston, the higher the return force \( T \) and the better the wedging effect.

Of course, advantage may be taken of this property for increasing the angular distance from the tangents to the points of contact and facilitate the fitting of the ring as well as the taking up of play.

In this case, the wedging effect will not take place as long as the force tending to move the shoe away from the piston remains inferior to a predetermined value depending on said return force \( T \).

A considerable advantage deriving from the use of the device of this invention lies in the fact that it takes up the dimensional differences resulting from manufacturing tolerances, notably discrepancies in the axial positioning of the groove 3 of piston 1 in relation to the centre of swirl ball 10. FIG. 6 clearly illustrates the manner in which this play take-up action is produced.

The equations of triangles EFG resulting from two successive positions of ring 4 in relation to groove 3 and swirl ball 10 are written as follows:

Let \( \varepsilon \) be the machining error and \( \Delta r \) the radial shift of the ring; thus:

\[
\varepsilon = EG \cos \alpha = EF \cos \beta
\]

\[
\Delta r = EF \sin \beta
\]

\[
\Delta r = EG \sin \gamma
\]

from which a simple calculation proves that:

\[
(\varepsilon/\Delta r) = (1/\tan \alpha) - (1/\tan \beta)
\]

A numerical example shows that if \( \beta = 30^\circ \) and \( \alpha = 20^\circ \), \( \varepsilon = \delta r \).

This clearly proves that the device can operate satisfactorily even if the groove 3 is not machined with a high degree of precision; the radius of the toroidal ring section may vary by 0.1 mm without any inconvenience.

Under these conditions it is clear that the device of this invention can be manufactured at a relatively low cost. The piston with its part-spherical bottom surface may be cold forged. A multi-spindle lathe may be used for machining the groove 3, reducing the piston 1 to its final length and drilling the orifice 13 interconnecting the two piston cavities. After a suitable heat treatment of its surface for increasing the surface hardness and therefore the friction properties, the machining operation is completed with a grinding step. It will be noted that the groove 3 may be formed as well by rolling or any other known and suitable cold working operation, with due consideration for an acceptable tolerance.

The shoe 5 may also be manufactured under very economical conditions. Thus, a sintered or forged blank, whether of steel or bronze, may be used to this end, complete with the sliding-contact surface and the real part-spherical swirl ball.

Furtive more, the ring itself may also be produced by forging by imparting to this member a shape consistent with this specific manufacturing technique.

In the specific case of the preferred application of the invention to "in-line" pumps, it will be seen from FIG. 1 that the device is such that the radial effort exerted on the head of the momentarily innermost piston in the cylinder barrel lies within this barrel, thus minimizing the overhang of this radial effort when the piston is in its outermost position, even in case of considerable swash plate inclination, for example for the order of 20°.

In the above disclosure the ring having a partly circular radial cross-section is cut internally by a cone. The same device may be obtained, as shown in FIG. 7, by using a ring 4a of any desired initial radial cross-section, cut by a sphere corresponding to that of the swirl ball 10 of shoe 5, and by a cone consistent with that of the piston cavity 3a, or substantially by two surfaces of revolution 11a, 13a such as the tangents C11, C12, at the points of contact A1, B1 forming therebetween an angle \( \beta_1 - \alpha_1 \) at the most equal to the sum of the two apex half-angles of the friction cones at said points of contact.

The chief advantage arising from the use of a ring of circular base section cut by a sphere in conformity with that of swirl ball 10 of shoe 5 lies in the fact that the contact between the ring and the shoe sliding in relation to each other is a contact between two surfaces, whereby considerable stress can be transmitted with moderate strain, this contact being less sensitive to surface unevenesses.

Therefore, the ring shape will be selected as a function of the retaining effort, of the necessary plays and machining tolerances.

The above-described retaining device may be used for retaining without appreciable play any pair of members interconnected by a swirl ball and subject to efforts tending to move them away from each other.

Its preferred application is that consisting in retaining shoes on the pistons of "in-line" hydraulic pumps and motors; however, this invention is also applicable to
the retaining of connecting-rods on the pistons of so-called "broken axis" pumps, or to the retaining of connecting-rods or links on the impeller or swash plate of pumps of the same type.

Although a preferred form of embodiment has been described hereinabove with reference to the attached drawings, it will readily occur to those conversant with the art that various modifications and variations may be brought thereto without departing from the basic principles of the invention as set forth in the appended claims.

What is claimed as new is:
1. Device for retaining a swivel ball in a socket cavity having a surface of revolution without a supporting ledge extending perpendicular to the axis of the swivel ball comprising a part-spherical bottom adapted to cooperate with the surface of said swivel ball, said cavity comprising a frustoconical surface portion extending from said bottom with its major diameter base end contiguous with a surface intersecting said part-spherical bottom and its minor diameter base end defining the minor diameter of the entrance opening of said cavity; and a retaining member in the form of a split resilient ring mounted in contact with said frustoconical surface and said swivel ball to retain said swivel ball, said retaining member being a unitary member and being shaped in the portion thereof which engages the surface of said swivel ball so that there is at least one fictitious tapered surface tangent both to said retaining member and to said swivel ball in their zone of mutual engagement, the radial cross-sectional shape of said retaining member being such that the apex half-angle of said fictitious tapered surface is greater than the apex half-angle of the frustoconical surface of said cavity, and the difference of these respective apex-angles being less than or equal to the sum of the friction angles at the points of contact between said retaining member and said fictitious tapered surface and between said retaining member and said frustoconical surface.
2. Device according to claim 1, wherein at least one portion of the surface of said unitary retaining member engages the surface of said cavity and said swivel ball.

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