REVERSIBLE HYDRAULIC APPARATUS

Original Filed Jan. 17, 1964

2 Sheets-Sheet 1

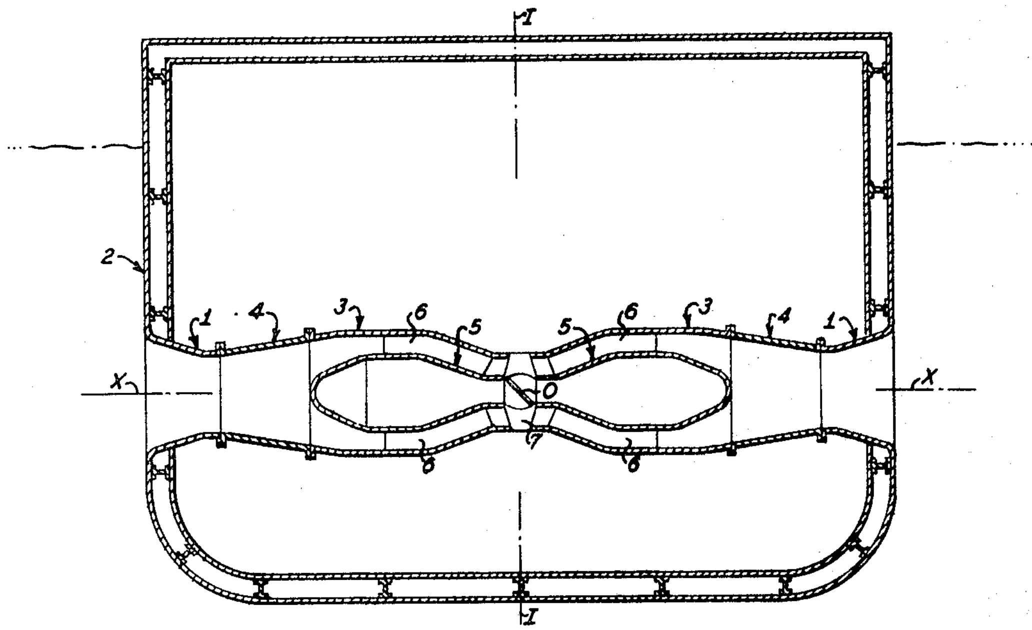


FIG. 1

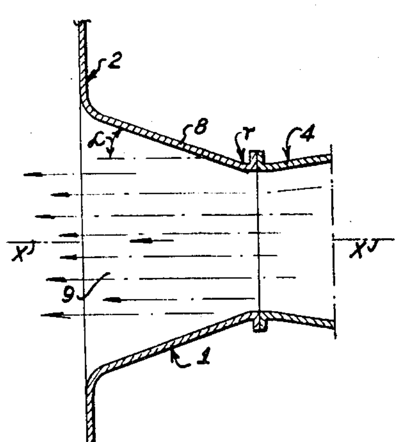


FIG. 2

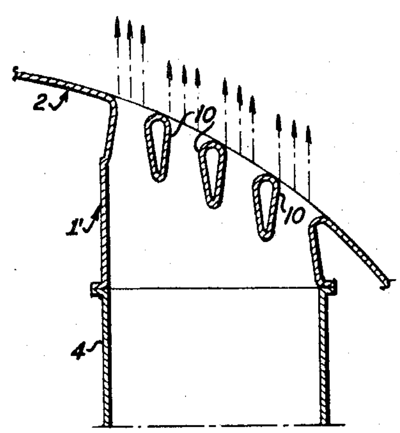


FIG. 3

INVENTORS
JACQUES P. DUPORT
GILBERT MARTIN
BY
John J. Hart
ATTORNEY

Sept. 2, 1969 J. P. DUPORT ET AL 3,464,357

REVERSIBLE HYDRAULIC APPARATUS

Original Filed Jan. 17, 1964 2 Sheets-Sheet 2

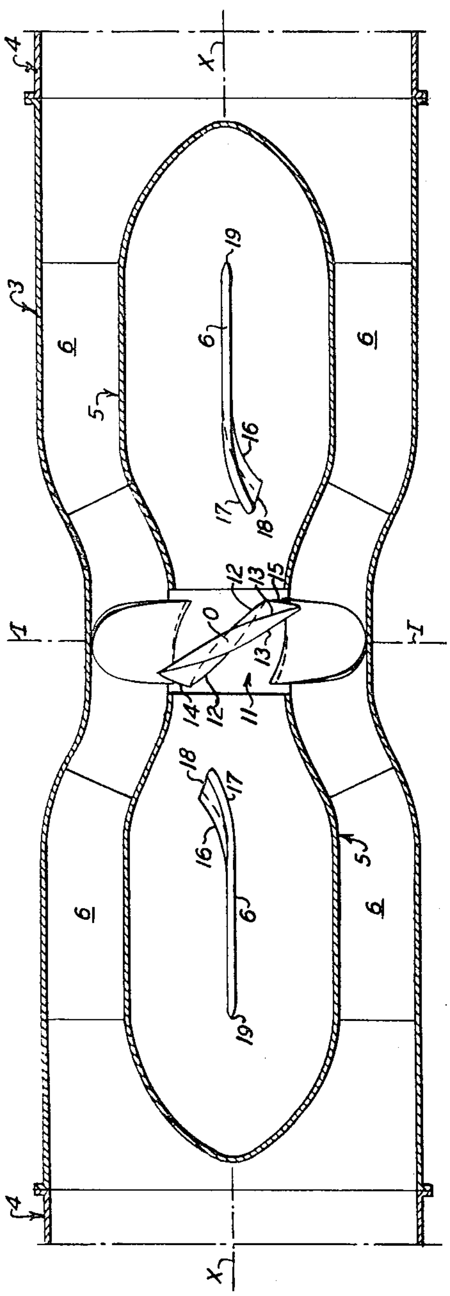

FIG. 4

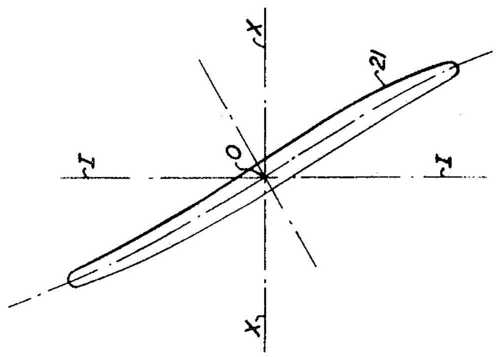

FIG. 6

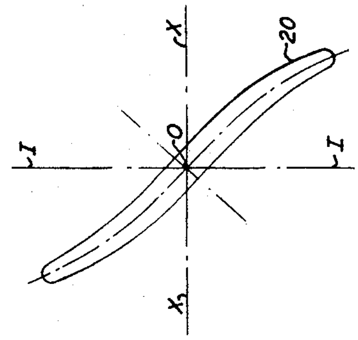

FIG. 5

INVENTORS
JACQUES P. DUPORT
GILBERT MARTIN
BY
John J. Hart
ATTORNEY

United States Patent Office

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Patented Sept. 2, 1969

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# 3,464,357
# REVERSIBLE HYDRAULIC APPARATUS

Jacques P. Duport, Montbonnot, and Gilbert Martin, Grenoble, France, assignors to Societe Grenobloise d'Etudes et d'Applications Hydrauliques (Sogreah), Grenoble, France, a corporation of France

Division of application Ser. No. 577,089, Sept. 2, 1966, now Patent No. 3,406,632. Continuation of application Ser. No. 338,522, Jan. 17, 1964. This application May 28, 1968, Ser. No. 732,577
Claims priority, application France, Jan. 19, 1963, 4,526
Int. Cl. F04d *29/50, 3/02;* F04b *19/12*
U.S. Cl. 103—3 10 Claims

## ABSTRACT OF THE DISCLOSURE

Reversible hydraulic apparatus composed of a duct having end portions capable of functioning either as inlets or outlets and having a hydraulic machine centrally located therein between two streamlined casings which form with the duct, annular flow passages on either side of the hydraulic machine. The casings are supported on the duct by two groups of vanes; the hydraulic machine, casings and vanes being symmetrically arranged relative to a plane perpendicular to and intersecting a point on the longitudinal central axis of the duct. The vanes in each group are inclined radially adjacent to the hydraulic machine and the inclined portions of one group of vanes being similar to the inclined portions of the other group of vanes and such that the vanes in each group can without change operate alternately as upstream vanes for one direction of fluid flow and as downstream vanes for the other direction of fluid flow and can impart to the fluid flow when operating as upstream vanes a swirl varying in intensity across the duct passage.

This application is a division of pending application Ser. No. 577,089, filed Sept. 2, 1966 now Patent No. 3,406,632 and a continuation of application Ser. No. 338,522, filed Jan. 17, 1964, now abandoned.

The present invention relates to improvement in that type of hydraulic apparatus which employs two directions of flow in their use, such as hydraulic installations comprising rotating hydraulic machines, pumps, turbines and turbine-pumps of the propeller or Kaplan type, which are utilized with two directions of flow so that they will operate identically in either of two flow directions. Specifically, apparatus embodying the invention can be employed to advantage, for example, as a hydrojet for propelling or steering a vessel, in which use it is desirable to generate an adjustable and reversible fluid flow such as will cause the jet action to vary continuously, and sometimes rapidly, through a range up to and including a complete reversal of the force produced.

The primary purpose of the present invention is to provide improved reversible hydraulic apparatus which is capable of changing from one direction of flow to the other, rapidly and in continuous variation, or progressively, without producing abnormal forces such as would cause damage to the machinery, or dangerous hydraulic phenomena, such as for example, cavitation.

Conventional devices heretofore employed for the aforesaid purpose rely on pumps which are either able to generate flow in only a single direction, or if capable of pumping in both directions, do so to the detriment of their energy or discharge characteristics. In the case of singleway flow pumps, the only known methods of reversing jet reaction are either by duplicating the installation (one for each direction), or by providing gating arrangements capable of directing the flow of the requisite

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orifices, or by the employment of jet deflectors. These methods require bulky complicated equipment and are often difficult to reconcile with satisfactory performance from the energy point of view.

The present invention enables the directional reversal of the jet to be obtained under the best possible operating conditions without the employment of expensive or complicated mechanisms. Hydrojets embodying the invention are not only capable of propelling and steering vessels, but can be utilized to stabilize pitching, rolling and yawing, and to provide an adequate means of controlling the immersion of underwater vessels or platforms.

In a reversible hydraulic apparatus made in accordance with the invention, the entire fluid circuit is designed to operate at high efficiencies and to produce a powerful thrust in either flow direction. The operation of such apparatus as a whole can be made perfectly symmetrical, that is to say, capable of producing equal thrusts and working at equal efficiencies in opposite flow directions. Its design also enables continuous, and if necessary rapid, thrust variations to be achieved, ranging from maximum thrust in one direction, to maximum thrust in the opposite direction.

To accomplish the aforesaid purposes, the hydraulic duct of an apparatus embodying the invention comprises the following basic components:

(a) Two orifices facing in opposite directions and each capable of working both as an inlet orifice and as a discharge orifice at the outlet. When the apparatus is to be employed as a hydrojet the two orifices are each shaped to ensure a total absence of fluid breakaway when employed as an inlet, and when discharging as an outlet, to cause the fluid to break away cleanly and form a drowned jet outwardly from a predetermined cross-section thereof.

(b) A single or multi-stage axial pump with impeller bladings and guide vanes symmetrically shaped, or with symmetrical blading pitch control arrangements, ensuring identical pump characteristics in both flow directions. The pump is connected to the aforesaid inlet and discharge orifices by ducts, the shape and length of which may depend on requirements arising from the installation of the apparatus. These ducts should always be designed to provide for the lowest possible loss of head in order neither to upset the velocity and pressure distribution at the pump intake, nor to cause swirl or to interfere in any way with flow conditions in the discharge, especially in the case of hydrojets.

Reversal of the direction of fluid flow may be achieved by reversing the direction of rotation of the pump motor. When this method is employed, the pump impeller blading may remain at the same angular blade position.

Examples of some of the possible forms of apparatus by which the invention may be practiced are hereinafter described more fully and are illustrated in the drawings, in which

FIG. 1 is a schematic vertical sectional view of reversible hydraulic apparatus embodying the invention and illustrates the manner in which such apparatus may be utilized as a hydrojet in a ship;

FIG. 2 is an enlarged detailed view of one of the inlet and discharge orifices shown in FIG. 1;

FIG. 3 is a horizontal sectional view showing an alternative form of inlet and discharge orifice;

FIG. 4 is a longitudinal or vertical sectional view of the central portion of a reversible axial pump constituted to accomplish thrust reversal by reversing the direction of rotation of the pump, and if necessary, to accomplish thrust variation by controlling the pump motor speed;

FIG. 5 is a vertical sectional view of the impeller blade shown in FIG. 4, the section being taken a short distance away from the impeller hub periphery;

FIG. 6 is a view similar to FIG. 5 but showing a section taken near the blade tip.

The hydrojet shown in FIG. 1 of the drawings is constructed and arranged to produce a reaction force acting in either direction along the horizontal axis X—X. The inlet and discharge orifices **1** at the ends of the hydraulic duct of the hydrojet are positioned in the ship's sides **2** as shown, and are connected to the pump casing **3** forming the central portion of such duct by straight duct sections **4**. The duct opening within the pump casing **3** is formed by the latter and the faired or streamlined bulb casings **5** extending longitudinally centrally of such pump casing and disposed on either side of the pump impeller **7**. The bulb casings **5** accommodate the pump motor or motors and the impeller blading control mechanism, and are attached to and supported within the pump casing **3** by a plurality of metal vanes **6** arranged around each bulb casing. The vanes **6** both guide the flow of fluid through the duct, impart the necessary swirl to such flow at the entrance to the impeller **7**, and then restore the flow so that it leaves the downstream vanes at their original axial direction.

In designs in which thrust reversal is achieved by reversing the pump rotation as in the construction of FIG. 4, the whole hydraulic duct system comprising the impeller and bulb casings **3** and **5**, respectively, is symmetrical with respect to a point **0** on the pump axis X—X. The groups of guide vanes **6** around the bulb casings **5** are positioned symmetrically with respect to an axis through point **0**. However, the guide vanes positions can be determined by adding a suitable rotation about the pump axis X—X. In this type of design, the pump impeller **7** is of the propeller type; a special feature of each blade being that its axis of symmetry is perpendicular to the axis of rotation X—X and that these two axes intersect at the above designated point **0** as will hereinafter become more clear. Where the blade angle is adjustable, the axis of symmetry of a blade coincides with its swivelling axis.

FIG. 2 of the drawings shows in detailed outline the formation of the inlet and discharge orifices **1** embodied in the construction of FIG. 1. As shown, the orifice **1** has the form of a symmetrical solid of revolution about the pump axis X—X. Except where the orifice **1** joins the duct **4**, its surface of revolution **8** diverges outwardly at a comparatively wide angle $\alpha$, at least 20°, from the X—X axis. The transition of the surface of revolution **8** from this angle to its juncture with the duct **4** takes the form of a radius $r$, which is small compared to the diameter of duct **4** e.g. no more than one-quarter of this diameter. This construction prevents breakawey when the flow is into the orifice i.e., from left to right as viewed in FIG. 2, and when the flow is in the opposite direction as indicated by the arrow in FIG. 2, such construction causes the flow to break away cleanly so as to produce a discharging jet **9** of practically the same diameter as that of the adjoining end of the duct **4**.

FIG. 3 of the drawings shows a modified form of inlet and discharge orifice embodying the invention. In the construction of FIG. 3, the hydrojet duct sections **4** are connected to inturned flanges **1'** forming the openings in the ship's hull **2**, and such openings are provided with bars **10** forming a screen across them to keep foreign bodies out of the hydrojet. The shape of the transition from the duct wall **4** to the exterior of the hull plating **2**, and the cross-sectional shape of bars **10**, are such as to prevent breakaway in the inflow i.e., from top to bottom as viewed in FIG. 3. To achieve this, the screen bar cross-sections are made symmetrical with respect to their mean chord, with their widest part well towards the outside of the hull (see FIG. 3). Thus, in such an orifice discharging outwardly, the hydraulic passages between adjacent bars and between the end bars and the transition form duct to hull plating, will diverse sufficiently to ensure clean jet breakaway practically as soon as the flow passes the widest part of the bar cross-section.



As previously indicated, FIG. 4 of the drawings shows the central portion of a hydraulic structure such as illustrated generally in FIG. 1, but constructed so that the flow reversal, and if necessary, flow variations, are achieved by reversing the direction of rotation of the pump and by controlling its speed.

As in the construction of FIG. 1, the reversible hydraulic apparatus of FIG. 4 includes a centrally located pump casing **3** containing an impeller **11** intermediate the symmetrical bulb casings **5** which are supported within such casing by the guide vanes **6**. For the sake of clearness, only one guide vane is shown in detail on each side of the impeller, it being understood that the guide vanes **6** associated with each bulb casing **5** are of similar construction. The impeller position is assumed to be such that the axis of symmetry, and possibly also the swivelling axis, of one of the impeller blades is perpendicular to the plane of the diagram; the point **0** in FIG. 4, which has been previously indicated to be the predetermined centre of symmetry for the entire hydraulic duct system, being also the trace of this blade axis of symmetry. The construction of one of the impeller blades is indicated by the lines **12**, **13**, **14** and **15**; line **12** indicating the profile of the portion of the blade on the impeller hub, line **13** showing the blade profile at its tip, and lines **14** and **15** indicating the blade edges, which act either as leading or trailing edges depending on the direction of pump rotation and the direction of flow.

The outlines of the two detailed guide vanes **6** in FIG. 4, which connect the bulb casings **5** to the inner wall of the pump casing **3** are shown by the lines designated **16**, **17**, **18** and **19**. The numerals **16** and **17** indicate the inner and outer longitudinal edges, respectively, of the guide vanes; the inner lines **16** indicating the outline of the guide vane at the bulb casing **5** and the outer lines **17** indicating the outline of the guide vane at the inner wall of the bulb casing **3**. The numerals **18** and **19** indicate the inner and outer end edges, respectively, of the guide vanes, which end edges will act either as leading or trailing edges depending on the direction of flow of the fluid through the duct. Each guide vane has the general shape of a fin; the portion thereof which is positioned farthest from the impeller **11**, extending in the general direction of a plane radial to the X—X axis or one parallel thereto, and the portion thereof which is positioned nearest to the impeller **11**, extending in a general direction inclined with respect to the X—X axis. In the construction shown, the major portion of each guide vane which is spaced farthest away from the impeller, approximately follows a radial plane extending out from the X—X axis and perpendicular to the plane of the drawing, while the remaining portion of each vane adjacent to the impeller curves or inclines away from the radial plane passing through the X—X axis and through the linear or major portion of the vane. As the angle of inclination of such remaining portion of the vane is more pronounced near the bulb casing **5** than near the pump casing **3**, the guide vanes upstream of the impeller in addition to acting as distributor vanes, also impart to the fluid flow a swirl in the direction of pump rotation; the intensity of this swirl increasing from the pump casing to the bulb casing. As has been previously stated, the guide vanes **6** are evenly spaced about the X—X axis of the machine and act both as distributor vanes and flow straighteners (depending on whether they are upstream or downstream of the impeller in a given operation), while also forming a rigid support between the bulb casings **5** and the pump casing **3**.

It has been previously pointed out that a special feature of the impeller blades is that their axis of symmetry is both perpendicular to and intersects the X—X axis of the machine. In the case of adjustable impeller blades, the axis of symmetry of the blade also coincides with its swivelling axis. Another feature of these blades is their novel configuration which can best be demonstrated by considering straight cross-sections of these blades in planes perpendicular to the blade symmetry and swivelling axis, it being assumed, in the case of an adjustable blade, that the blades are at their maximum angle of inclination. Two such straight cross-sections are shown in FIGS. 5 and 6 of the drawings. In FIG. 5, the line **20** indicates the outline of a blade cross-section lying in a plane intersecting the axis of symmetry of the blade a short distance away from the impeller hub perpihery. In FIG. 6, the line **21** indicates the outline of a cross-section of the blade lying in a plane intersecting the axis of symmetry of the blade near the blade tip. Both of the cross-sections shown are aerofoil sections, and the respective centres of symmetry thereof are the traces of their respective axes of symmetry **0** on the corresponding cross-sectional planes. It will be noted that unlike the more conventional type of aerofoil, which almost invariably features at least one sharp edge, the leading and trailing edges of these cross-sections are rounded-off. The medians of these sections are in the general shape of a letter "S" with its point of inflexion coinciding with the centre of symmetry.

In the construction of blade considered to be suitable to reversible speed pumps in accordance with the invention, the angle of inclination of the blade profile medians with respect to a plane containing the line I—I and perpendicular to the X—X axis and intersecting it at the previously defined centre of symmetry **0** increases towards the impeller hub. In other words, the impeller blades for such purpose are given a twisted shape to allow for the variable tangential fluid entrainment velocities along their leading and trailing edges.

In the aforesaid types of twisted blades, the range of angular blade travel in the case of an adjustable blade should be such that the blade can assume any position between zero incidence of its outer profile and the maximum angle of inclination of that profile; the usual ranges being somewhere between 20° and 35°. It should also be noted that the special shapes of the above described blades are the result of the necessity of achieving symmetrical operation of the hydraulic apparatus in both directions of pump rotation and flow.

It will be understood from the foregoing, that the use of reversible flow axial pumps embodying the invention and described above by way of example, are not restricted to hydrojets. These pumps can be used for any application requiring a reversible flow. It will also be understood that the special features described herein, especially where referring to symmetry of form, arrangement of impeller blades and guide vanes, and their mutual adaptation, can also be applied to axial or pump turbines, for instance with a view to harnessing hydraulic power under reversible heads. It is of course possible, with respect to reversible flow axial pumps embodying the invention to adjust the pump speed, and/or the blading angles, to obtain, at all times, the optimum operating conditions.

What is claimed is:

**1.** Reversible hydraulic apparatus comprising an elongated duct having at its ends two orifices facing outwardly in opposite directions and having end portions of such similar construction that each such duct end portion is capable of functioning as an inlet and as an outlet for fluid passing therethrough, a hydraulic machine constructed to have its direction of rotation reversed to cause reversible hydraulic flows through said orifices and constituted of a pump or turbine centrally located within said duct and having pitch type rotor vane blades of twisted configuration and having an axis of symmetry perpendicular to and intersecting a point on the longitudinal central axis of said elongated duct, a pair of streamlined casings symmetrically disposed on both sides of said point with said hydraulic machine therebetween, said casings extending longitudinally centrally of said duct between said orifices with their longitudinal central axes coinciding with the



longitudinal central axis of said duct and their exterior surfaces forming with said duct annular flow passages on either side of said hydraulic machine, said hydraulic machine, casings and duct portion enclosing the same being symmetrical with respect to said point on the longitudinal central axis of said duct portion, and the blading of such rotor being variably inclined from hub to periphery, such inclination being greater near the periphery, and means for supporting each of said streamlined casings on the portion of the duct wall enclosing the same, said supporting means comprising a plurality of vanes extending longitudinally in the annular flow passage formed by said casings and duct wall portion and connected at their outer longitudinal edges to the latter, said vanes being symmetrical with respect to an axis perpendicular to and intersecting said central axis at said point and each of said vanes having a portion adjacent to the rotor inclined with respect to the longitudinal central axis of said duct and against which the fluid reacts during its passage through the duct, said vanes being in two groups, one of the groups thereof being on one side of said rotor, and the other group thereof being on the other side of said rotor, and each of such groups including a plurality of vanes arranged in spaced relation around its associated casing and being substantially radially disposed as a whole, the configuration of the vanes in both groups being such that the vanes in each group can without change operate alternately as upstream vanes for one direction of fluid flow and as downstream vanes for the other direction of fluid flow, the inclined portions of the plurality of vanes in the group upstream of the rotor in the then fluid flow varying radially from their associated casing to the duct wall to impart to the fluid flow a swirl varying in intensity across the associated portion of the duct passage, and said inclined portions being inclined at a greater angle near said associated casing than near said duct wall so that such intensity of swirl increases from the duct wall to said associated casing, the inclined portions of the plurality of vanes in the group downstream of the rotor in the then fluid flow varying radially from their associated casing to the duct wall to impart to the fluid flow a swirl varying in intensity across the associated portion of the duct passage, and said inclined portions in such downstream vanes being inclined at a greater angle near said associated casing than near said duct wall so that the flow is linear downstream of such downstream group of vanes.

**2.** Reversible hydraulic apparatus such as defined in claim **1**, in which the blading of such rotor is so constructed and arranged that is has an axis of symmetry which is perpendicular to and intersects the longitudinal central axis of said duct portion at said point.

**3.** Reversible hydraulic apparatus such as defined in claim **2**, in which the axis of symmetry of said blading coincides with the rotational axis thereof.

**4.** Reversible hydraulic apparatus as defined in claim **1**, in which the inclination of the end portions of such vanes is such that the group of vanes which is then upstream of the rotor imparts to the fluid flow a swirl in the direction of rotor rotation.

**5.** Reversible hydraulic apparatus such as defined in claim **1**, in which the rotor is constructed to have its direction of rotation reversed for each change in the flow direction, said rotor, casings and duct portion enclosing the same being symmetrical with respect to a point on the longitudinal central axis of said duct portion, and said vanes being symmetrical with respect to an axis perpendicular to and intersecting said central axis at said point.

**6.** Reversible hydraulic apparatus such as defined in claim **5**, in which the inner end portions of said vanes are inclined at a greater angle near said casings than near said duct wall so that the intensity of the swirl in the fluid created by such inner end portions of the vanes which are then upstream of the rotor increases from the duct wall to said casing associated with such vane and portions.

7. Reversible hydraulic apparatus as defined in claim 1, which the leading and trailing edges of said blades are rounded, and in which the medians of the profiles of all sections of the blade are in the general shape of a letter S with its point of inflection coinciding with the center of symmetry.

8. Reversible hydraulic apparatus comprising an elongated duct having at its ends two orifices facing outwardly in opposite directions and having end portions of such similar construction that each such duct end portion is capable of functioning as an inlet and as an outlet for fluid passing therethrough, both of said duct end portions being constructed to provide diverging cross-sectional hydraulic passages therethrough such as to insure a total absence of fluid breakaway when used as an inlet, and to cause the fluid to break away cleanly and discharge in the form of jet when used as an outlet, a hydraulic machine operable to cause reversible hydraulic flows through said orifices and constituted of a pump or turbine centrally located within said duct and having rotor blades arranged about an axis perpendicular to and intersecting the longitudinal central axis of said elongated duct, a pair of streamlined casings symmetrically disposed on both sides of said rotational axis with said hydraulic machine therebetween, said casings extending longitudinally centrally of said duct between said orifices with their longitudinal central axes coinciding with the longitudinal central axis of said duct and their exterior surfaces forming with said duct annular flow passages on either side of said rotor, said rotor, casings and duct portion enclosing the same being symmetrically arranged with respect to a point on the longitudinal central axis of said duct portion, and means for supporting each of said streamlined casings on the portion of the duct wall enclosing the same, said supporting means comprising a plurality of fixed vanes extending longitudinally in the annular flow passage formed by said casings and duct wall portion and connected at their outer longitudinal edges of the latter, each of said vanes having a portion adjacent to the rotor inclined with respect to the longitudinal central axis of said duct and against which the fluid reacts during its passage through the duct, said vanes being in two groups, one of the groups thereof being on one side of said rotor, and the other group thereof being on the other side of said rotor, and each of such groups including a plurality of vanes arranged in spaced relation around its associated casing and being substantially radially disposed as a whole, said groups of vanes being symmetrically spaced relative to said point so that the inclined profiles of the vanes in one group are symmetrical with respect to the inclined profiles of the vanes in the other group, the configuration of the vanes in both groups being such that the vanes in each group can without change operate alternately as upstream vanes for one direction of fluid flow and as downstream vanes for the other direction of fluid flow, the inclined portions of the plurality of vanes in both groups being substantially similar and varying radially from their associated casing to the duct wall, the inclination of such inclined portions being such that the group of vanes upstream of the rotor in the then fluid flow imparts to the fluid flow a swirl varying in intensity across the associated portion of the duct passage, and the group of vanes downstream of the rotor in the then fluid flow causes the fluid flow to be linear downstream of such downstream group of vanes.

9. Reversible hydraulic apparatus such as defined in claim 8, in which each duct end portion is composed of a frusto-conically-shaped wall diverging outwardly at an angle greater than 20°, said wall merging from such angle at its inner reduced end into a wall portion defining a diverging opening curved through a given radius.

10. Reversible hydraulic apparatus such as defined in claim 8, in which each orifice has a screen of bars across the opening thereof, said bars having cross-sections symmetrical with respect to a mean chord extending parallelly to the central axis of the associated duct end portion and of tear drop shape with the widest part of said cross-sections at the outer end of said associated duct end portion, and the surface portions of the outer end of said associated duct end portion in opposed relation to the outer sides of the end bars in said screen having configurations comparable to the configurations of the latter, whereby the hydraulic passages formed between adjacent bars and between the end bars and said duct surface portions provide jet breakaway at the widest part of the bar cross-sections.


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WILLIAM L. FREEH, Primary Examiner

U.S. Cl. X.R.

115—14; 253—16.5; 103—89

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(5/69)

# UNITED STATES PATENT OFFICE
# CERTIFICATE OF CORRECTION

Patent No. 3,464,357 Dated September 2, 1969

Inventor(s) Jacques P. Duport and Gilbert Martin

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 1, line 43, "improvement" should read --improvements--.

Column 3, line 51, "breakawey" should read --breakaway-- and line 75, "diverse" should read --diverge--.

Column 6, line 75, "and" should read --end--.

SIGNED AND
SEALED
JUN 23 1970

(SEAL)
Attest:

Edward M. Fletcher, Jr.
Attesting Officer

WILLIAM E. SCHUYLER, JR.
Commissioner of Patents