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(71) Applicant: **ROCKWELL INTERNATIONAL CORPORATION**
Seal Beach, California 90740-8250 (US)

(72) Inventors:
- **Tuttle, Gary E.**
  WestHills, California 91304 (US)
- **Meng, Sen Y.**
  Reseda, California 91335 (US)

(74) Representative: **Wächtershäuser, Günter, Prof. Dr.**
Patentanwalt,
Tal 29
80331 München (DE)

(54) Enhanced mixing corrugated jet pump

(57) An apparatus for increasing the mixing efficiency of low- and high-energy fluids within a jet pump is described. A jet pump utilizing said enhanced mixing apparatus is referred to as a corrugated jet pump. A corrugated jet pump incorporates a straight or an annular nozzle ring with a variable corrugated ogive that, during pumping operations, creates alternating low and high velocity zones in the ogive of the nozzle. These different velocity zones propagate shear planes that enhance the jet pump's downstream mixing. At the same time the core, or central portion, of the corrugated annular nozzle ring creates alternating vortices in the low- and high-energy fluids which also enhances mixing. The corrugated annular nozzle incorporates composite laminates for its fabrication. Advantages of the (composite laminate) corrugated jet pump design include: an reduction in boost pump length of as much as 75%, a weight savings, and significantly reduced production manufacturing costs.

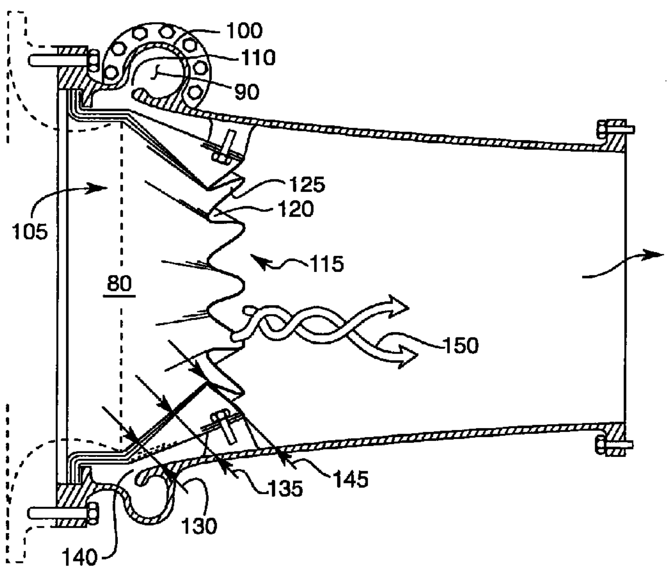

Fig. 1

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Description

1. FIELD OF THE INVENTION

The invention relates in general to the field of jet pump design. Specifically, the invention describes a jet pump design that utilizes a variable corrugated ogive to enhance fluid mixing and, therefore, the operational efficiency of the pump.

2. BACKGROUND OF THE INVENTION

A conventional use of jet pump technology is in combination (series) with a standard rotary pump where the available net positive suction head is low. In these situations a jet pump can be used to increase the pressure of a low pressure fluid to provide the necessary head for a standard (e.g., rotary) pump. Hence, often times jet pumps are used as "booster" pumps; they 'boost' the pressure of a low pressure fluid so that it may be pumped by a standard pump.

In this role a well known function of traditional jet pump technology is to transfer kinetic energy from a high-energy (high velocity, high pressure) fluid (HEF) to a low-energy (low velocity, low pressure) fluid (LEF). Energy transferred into the LEF is stored in the form of potential energy and results in an increase in the fluid's pressure. Energy transfer, and therefore jet pump efficiency, is enhanced by a thorough mixing of the low- and high-energy fluids.

One key operational problem with conventional jet pumps, which utilize standard de Laval nozzle jets, is their low efficiency due to poor mixing of the low- and high-energy fluids.

3. SUMMARY OF THE INVENTION

An apparatus for increasing the mixing efficiency of low- and high-energy fluids within a jet pump is described. A jet pump utilizing said enhanced mixing apparatus is referred to as a corrugated jet pump.

A corrugated jet pump incorporates a corrugated annular nozzle ogive that, during pumping operations, creates alternating low and high velocity zones in the ogive of the nozzle. These different velocity zones propagate shear planes that enhance the jet pumps downstream mixing. At the same time the core, or central portion, of the corrugated annular nozzle ring creates alternating vortices in the low- and high-energy fluids which also enhances mixing. The corrugated annular nozzle incorporates composite laminates for its fabrication. Advantages of the corrugated jet pump design include: (1) an overall reduction in boost pump length of as much as 75%, (2) a tremendous weight savings, and (3) significantly reduced production manufacturing costs.

4. BRIEF DESCRIPTION OF DRAWINGS

Figure 1 is a cross-sectional view of one embodiment of the invention.

Figure 2 is an end-view of one embodiment of the invention.

Figure 3 is a cut-away view of fluid mixing within one embodiment of a corrugated jet pump.

Figure 4 is another cross-sectional view of an annular two-corrugation embodiment of the invention.

5. DETAILED DESCRIPTION OF A SPECIFIC EMBODIMENT

One illustrative embodiment of the invention is described below as it might be implemented for a jet pump designed to pump cryogenic fluids, e.g., liquid oxygen (LOX) or liquid hydrogen (H_2). In the interest of clarity, not all features of an actual implementation are described in this specification. It will of course be appreciated that in the development of any such actual implementation (as in any mechanical design) numerous implementation-specific decisions must be made to achieve the developers' specific goals and subgoals, such as compliance with system- and business-related constraints, which will vary from one implementation to another. Moreover, it will be appreciated that such a development effort might be complex and time-consuming, but would nevertheless be a routine undertaking of mechanical design engineering for those of ordinary skill having the benefit of this disclosure.

In reference to Figures 1 and 2, high-energy fluid 90 is injected into a corrugated jet pump via a volute, or constant velocity manifold 100. Low-energy fluid 80 can be provided from a storage tank (not shown) and enters the corrugated jet pump at the main inlet 105. After the HEF is injected into the LEF's path, via an injection nozzle 110, the two fluids begin to mix after leaving the corrugated annular nozzle ogive 115.

As the low- and high-energy fluids mix within the corrugated annular nozzle ogive 115, the velocity of the fluid in the corrugate's valley regions 120 is less than the velocity of the fluid in the corrugate's crown regions 125. These regions of differing velocity set up shear planes within the fluid (comprised of low- and high-energy fluids), thereby enhancing the jet pump's mixing action. The shear planes also generate vortices; two vortices per crown region. These vortices, or swirling actions, further enhance the jet pump's mixing action, as indicated by arrows 150.

In a conventional jet pump the nozzle ogive has a constant cross-sectional area. This is analogous to a piece of cardboard, no matter where you cut a flat piece of cardboard the inner structure is constant. That is, no matter where along a conventional ogive you look, its cross-sectional area is constant. The corrugated annular nozzle ogive of the invention, however, exhibits a position dependent cross-sectional area. For instance, the magnitude of the valley-to-crown distance at cut 130 is less than the magnitude of the valley-to-crown distance at cut 135. Thus, the area of the nozzle's throat 140 is less than the area of the nozzle's exit 145. The invention's fluctuating geometry imparts differing velocities into the low and high energy fluids which creates shear planes and, thereby, improves the ability of a jet pump to mix the two fluids.

Many conventional jet pump designs have length-to-diameter ratios of approximately 7:1. These large values (implying long jets, relative to their diameter) are necessary to ensure that the low- and high-energy fluids have sufficient time to thoroughly mix. Thus, length-to-diameter ratios are one indication of a jet pump's mixing efficiency. Using a corrugated annular nozzle ogive, as shown in Figures 1, 2 and 4, a jet pump's length-to-diameter ratio can be brought down to between 1:1 or 1.5:1 - indicating a significant improvement in the jet pump's mixing efficiency. A shorter pump also consumes less material in its manufacture, making a corrugated jet pump less costly and lighter than a conventional jet pump.

Figure 3 is a straight embodiment for which numeric designators retain previous definitions. This embodiment uses two sets of corrugations 115. Efficient mixing is indicated by arrows 150.

As shown in cross-section in Figure 4, a jet pump in accordance with the invention may have two concentric rings of corrugated nozzles 115 that efficiently mix high 90 and low 80 energy fluids. As previously mentioned, this two-ring configuration can decrease the required length for efficient mixing, indicated by arrows 150 (Fig. 3), thus minimizing the size (length) and weight of the jet pump system.

5.1 Design Considerations

An exemplary jet pump in accordance with the invention has a discrete mass flow rate, $\dot{w}$, ratio between the HEF ($\dot{w}_{HEF}$) and LEF ($\dot{w}_{LEF}$) which is dependent on the pressure differential between the two fluids and the required net positive suction head of the rotary pump for which the jet pump is a booster. The mass flow rates of the two fluids typically depend upon the required head of the rotary pump and the location where the HEF source is tapped off, i.e., where the HEF source is tapped off relative to the jet pump's injection nozzle 110.

The mass flow rate and the pressure difference between the HEF and LEF define the fluid velocities of the two streams and dictate the cross-sectional areas of the nozzle jets 140 and the LEF suction (inlet) port 105. The aforementioned areas can utilize any variation of geometry's, e.g., circular or rectangular. The area of the nozzle's throat 140 (A_{throat}) is equal to the mass flow rate of the HEF divided by the product of the HEF's velocity (v_{HEF}) and its density (ρ_{HEF}):

$$A_{throat} = \frac{\dot{w}_{HEF}}{v_{HEF}\,\rho_{HEF}}.$$

The area of the LEF inlet port 105 ($A_{LEF\ Inlet}$) is equal to the mass flow rate of the LEF divided by the product of the LEF's velocity (v_{LEF}) and its density (ρ_{LEF}):

$$A_{LEF\ Inlet} = \frac{\dot{w}_{LEF}}{v_{LEF}\,\rho_{LEF}}.$$

The operational velocities of the HEF and LEF are, in part, determined by the pressure difference between the two fluids and can be determined by means of a hydrodynamic analysis which takes into account head and line loss and acceleration within the nozzle. The location and configuration of the corrugated nozzle jets is a variable and depends upon the allowable mixing length (usually between 0.5 and 1.5 inlet flow diameters) and the required pump performance.

The circumferential spacing 200 (Fig. 2), the amplitude of the corrugates 205 and the throat to exit area ratio of the nozzle (ε) is set to maximize mixing effectiveness. The relative spacing of the two nozzle rings is set to eliminate reverse flow in the center of the mixing region.

The thickness of the corrugations is dependent on the pressure difference between the HEF and LEF, the throat to exit area ratio of the nozzle (ε), the nozzle's attachment scheme and the material used to form the corrugated nozzle. Material selection depends on the type of fluids being pumped.

It has been found that a jet pump in accordance with the invention can be positioned as close as one-half of the flow diameter to the inlet of the rotary pump. As one of ordinary skill in the field would understand, the actual position is dependent upon the specific system requirements.

In summary, some of the design parameters that affect the construction of the invention's corrugate apparatus include:

1. Pressure differential between low- and high-energy fluids.

2. Pressure of incoming high-energy fluid.

3. Discharge pressure of mixed fluid.

4. Mass flow rate of the low-and high-energy fluids (the larger the jet pump's total mass flow rate, the larger the jet pump and, therefore, the larger the corrugated annular nozzle).

5. Type/temperature of the fluid being pumped (the temperature of the fluids being pumped determine the materials of choice for the composite laminates of the corrugated annular nozzle).

5.2 Some Benefits of the Invention

Some advantages of the composite laminate corrugated jet pump design include:

1. An overall reduction in boost pump length of as much as 75%.

2. The low density of the composite laminate corrugated surface, and the reduction in length made possible by the increased mixing efficiency of a corrugated jet pump design, reduce weight.

3. Significantly reduced production manufacturing costs.

It will be appreciated by those of ordinary skill having the benefit of this disclosure that numerous variations from the foregoing illustration will be possible without departing from the inventive concept described herein. Accordingly, it is the claims set forth below, and not merely the foregoing illustration, which are intended to define the exclusive rights claimed in this application program.

Claims

1. An apparatus for enhancing fluid mixing in a jet pump comprising a corrugated annular nozzle ogive, said corrugated nozzle ogive having a position dependent cross-sectional area.

2. A jet pump comprising a corrugated nozzle ogive of claim 1, which nozzle is annular.

3. The jet pump of claim 2 wherein the corrugated annular nozzle ogive comprises composite laminate materials.

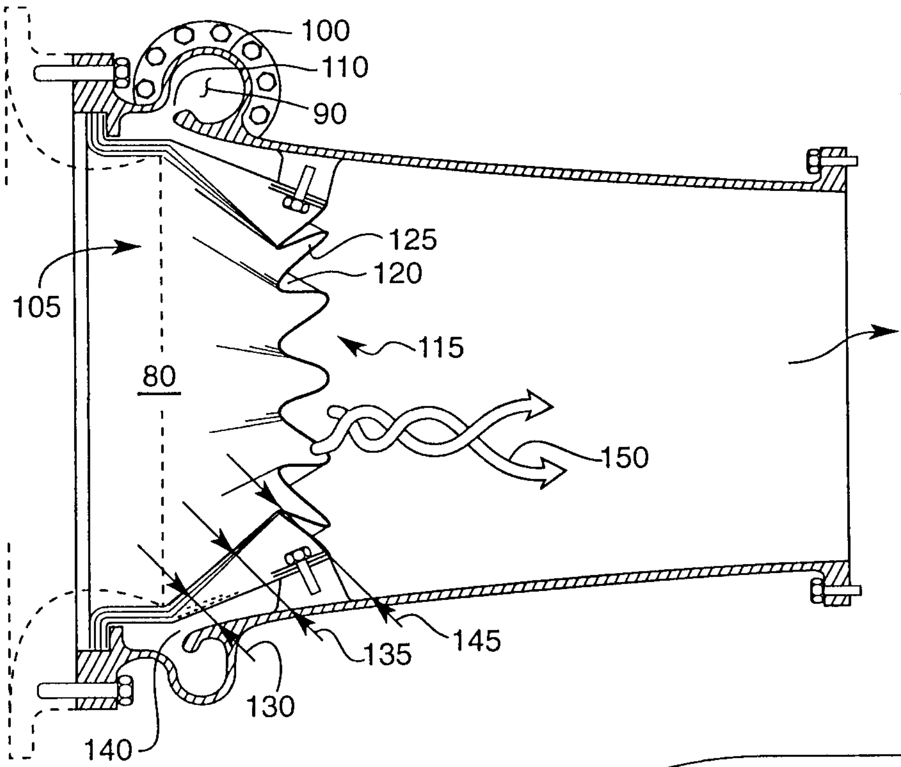
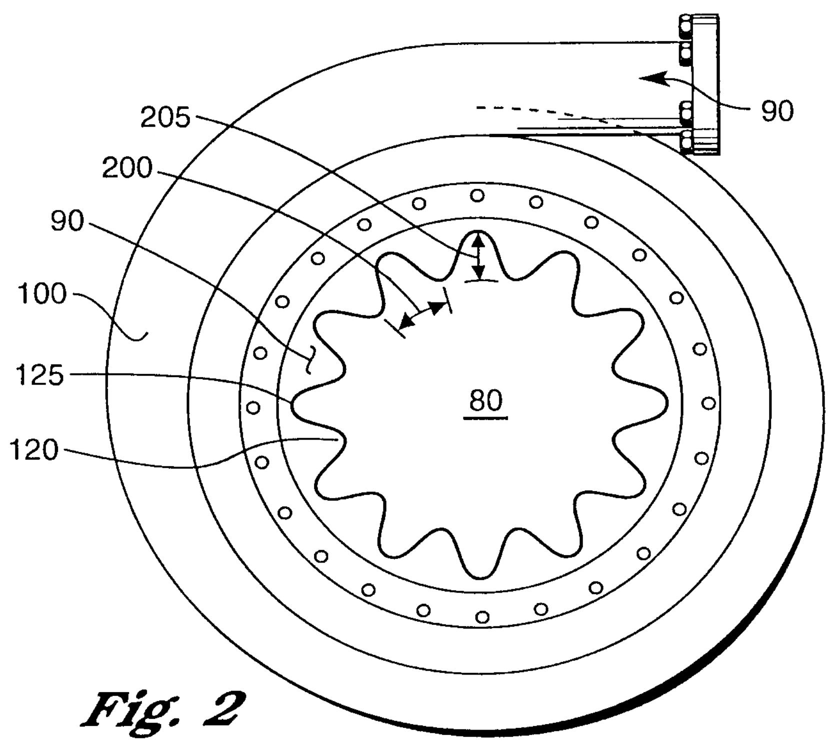

100
110
90
125
120
105
115
80
150
135
145
130
140

Fig. 1


205
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200
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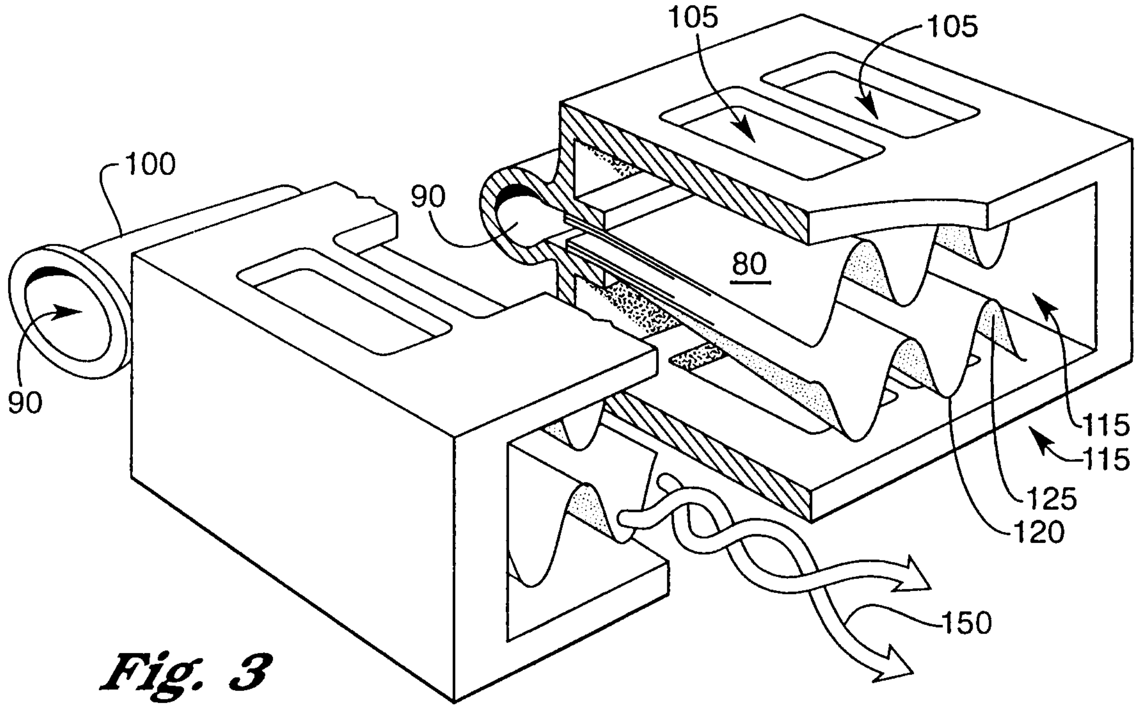
100
125
80
120

Fig. 2


105
105
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90
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115
115
125
120
150

Fig. 3

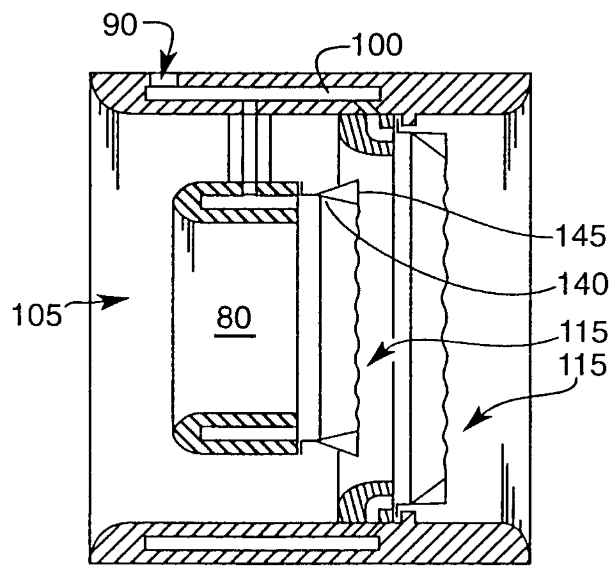
90
100
145
140
105
80
115
115

Fig. 4

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 95 12 0233

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X	GB-A-2 260 369 (UNITED TECHNOLOGIES CORPORATION) * the whole document * ---	1,2	F04F5/24
X A	DE-A-32 39 197 (ROLLS-ROYCE) * the whole document * & GB-A-2 114 229 (ROLLS-ROYCE) ---	1,2 3	
X	DATABASE WPI Section PQ, Week 7634 Derwent Publications Ltd., London, GB; Class Q56, AN 76-h5247x XP002001865 & SU-A-449 177 (ODESS UNIV) , 25 April 1975 * abstract; figure * -----	1,2	

TECHNICAL FIELDS SEARCHED (Int.Cl.6)
F04F
F02K

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	29 April 1996	Von Arx, H

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