Aug. 17, 1965 D. DI STEFANO ETAL 3,200,753

TURBO-BOOST PUMP

Filed Feb. 7, 1963

2 Sheets-Sheet 1

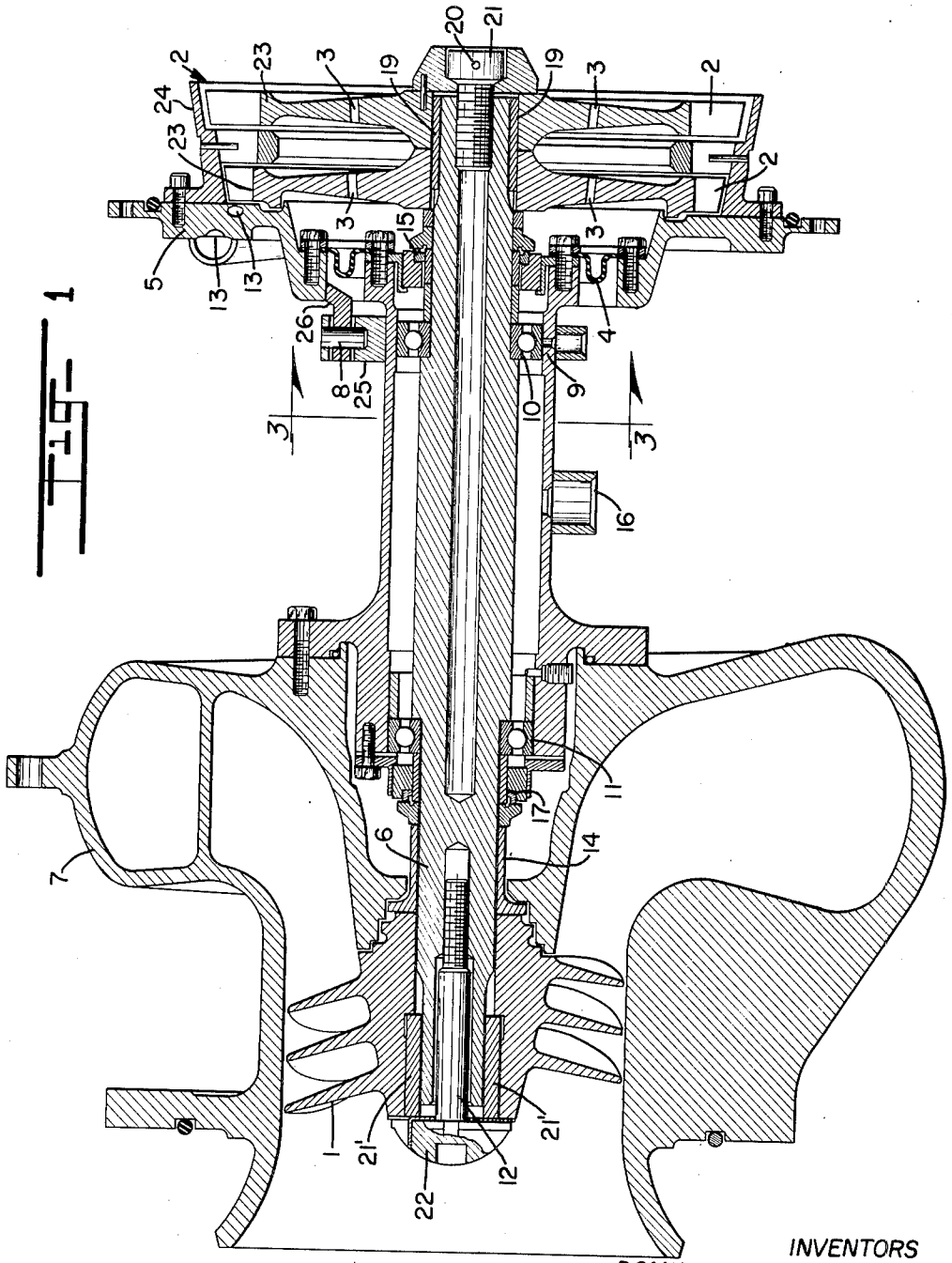


FIG. 1

INVENTORS
DOMINIC DiSTEFANO
JONATHAN E. BORETZ
HOWARD MACKLIS
BY
Philip H. Sheridan
ATTORNEY

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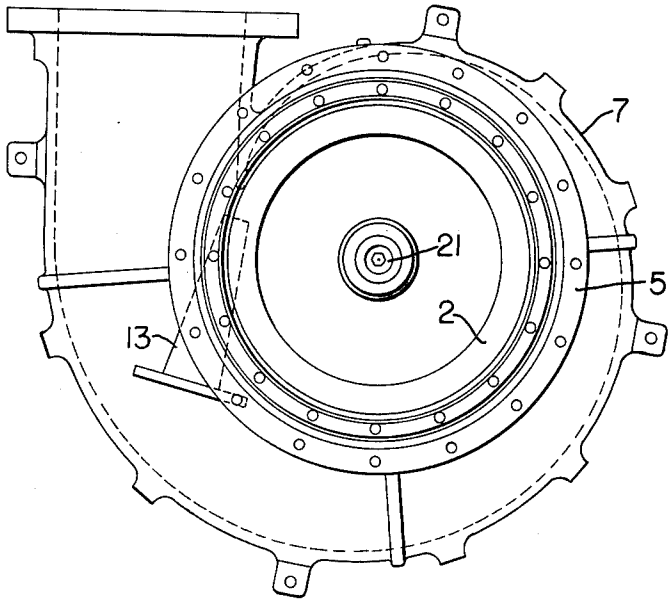


FIG. 2

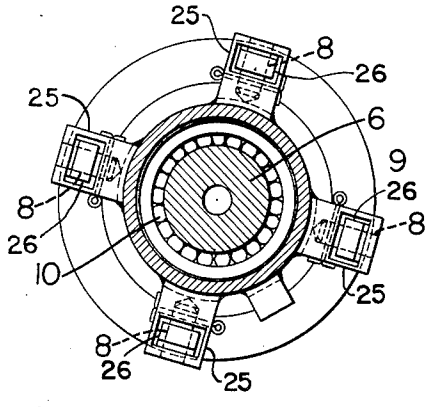


FIG. 3

INVENTOR
DOMINIC DiSTEFANO
JONATHAN E. BORETZ
HOWARD MACKLIS
BY
Philip H. Sheridan
ATTORNEY

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3,200,753

TURBO-BOOST PUMP

Dominic Di Stefano, Denver County, and Howard Macklis, Arapahoe County, Colo., and Jonathan E. Boretz, Cuyahoga County, Ohio, assignors to The Martin-Marietta Corporation, Baltimore, Md., a corporation of Maryland

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6 Claims. (Cl. 103—87)

This invention relates to a pump driven by a turbine, and particularly to a combined turbine and pump assembly, including a common connecting shaft, through which the pump is driven by the turbine.

In certain circumstances it is desirable to employ a turbo-boost pump having the capability of operating at a zero or negative net positive suction head, which will provide sufficient head rise to meet the net positive suction head requirements of a main turbopump, and thus prevent cavitation of the main pump. A particular need for such a turbo-boost pump arises in the large scale pumping of cryogenic liquids, such as liquid oxygen and liquid hydrogen employed in a liquid-fueled rocket. In such case, an important element of the rocket propulsion system is an adequate propellant tank pressurization means.

This problem may be solved by putting a separately driven turbo-boost pump upstream of the main engine turbopumps. It is feasible to drive this turbo-boost pump from the turbine of the main engine turbopump through connecting reduction gears to obtain the desired reduced rotative speed. In an alternative arrangement this problem can be solved by staging the turbo-boost pump to reduce the required head per stage, and employing direct drive from the main engine turbopump turbine. These two approaches, however, invariably impose design complications on the main engine turbopump configurations and make many of the inherent advantageous features of the turbo-boost pump tank pressurization system unachievable, or at best unduly complex.

Ground based cyrogenic turbo-boost pumps having properties similar to those desired for tank mounted turbo-boost pumps for missile applications, also are greatly needed.

Accordingly, it is an important object of this invention to provide a turbo-boost pump capable of operating at substantially zero, or negative, net positive suction head, which can provide sufficient head rise to meet the net positive suction head requirements of a main turbopump, sufficient to prevent cavitation of the main pump.

Another object of the invention is to provide a turbopump suitable for high speed pumping of large volumes of cryogenic fluids either as a ground based cryogenic pump or as a tank mounted boost pump for missile applications.

Additional objects of the invention will become apparent from the following description, which is given primarily for purposes of illustration, and not limitation.

Stated in general terms, the objects of this invention are attained by providing an axial flow-pump that is directly driven by a turbine through a shaft directly interconnecting the pump and turbine. The turbine is adapted for the use of superheated steam or very high pressure gas, which preferably is introduced to the turbine blades through a series of injector ports positioned in an annular or collar arrangement surrounding the outer edges of the turbine blades. Due to the high temperature differences between the pump and the turbine, means are provided to keep the heat exchange between the two units at a minimum. These means preferably include a quadrant arm arrangement and a bellows device, both of which preferably are so disposed as to interconnect the collar arrangement adjacent the turbine blades and a housing which surrounds the

pump and turbine connecting shaft. The thermal path between the turbine blades, which are at approximately 1200° F. when steam driven, and the blades of the pump, which are at about —423° F. when pumping liquid hydrogen, preferably is made tortuous by the bellows device, the quadrant arms and the turbine blade connections, so that the operation of the pump and the turbine will not be affected by heat transfer therebetween despite the use of the interconnecting shaft.

The quadrant arms preferably are pin-connected to the connecting shaft housing in a manner such that when there is unequal heating between the collar and housing, radial relative movement occurs to compensate for the temperature differential, but appreciable axial motion of the collar is prevented. The turbine blades preferably are key-connected to the connecting shaft to provide a thermal barrier between the turbine and shaft.

The pump impeller preferably is bolted to the connecting shaft by a bolt which is of substantially the same length as the axial length of the impeller, and is fabricated of substantially the same material as the impeller, so that loosening of the impeller is prevented due to thermal expansion and contraction.

A more detailed description of a specific embodiment of the invention is given with reference to the appended drawing, wherein:

FIG. 1 is a sectional elevational view showing the turbo-boost pump assembly;

FIG. 2 is an end view showing the turbine and housing of the pump of FIG. 1; and

FIG. 3 is a cross-sectional view taken along line 3—3 of FIG. 1.

This embodiment includes a high performance axial flow pump having impeller 1 directly driven by a two-stage velocity compounded turbine 2 provided with blades 23 and shroud 24. The turbo-boost pump of this embodiment is designed to run at a nominal speed of 20,000 r.p.m., but is capable of satisfactory operation over a wide speed range from about 400 to about 40,000 r.p.m. The turbine 2 can be driven by any adequate gas or steam source at temperatures up to about 1200° F. This embodiment is capable of satisfactory operation when pumping cryogenic fluids at temperatures down to those corresponding to liquid hydrogen, or about —423° F.

Among the main features of this embodiment of the invention are the following. Axial flow impeller 1 is capable of operating at extremely low net positive suction heads of less than about 0.16 ft. with liquid hydrogen and at correspondingly low values with other cryogenic and non-cryogenic fluids. In addition, it has a steep head-capacity characteristic which gives rise to a high degree of stability and ease of control. Impeller 1 is fan shaped and is designed to take advantage of the recompressibility of the vaporized hydrogen formed in the incipient cavitation region. Its large capacity with liquid hydrogen, of about 3300 g.p.m., is believed to be among the largest currently available. The blade pitch and angle procession across impeller 1 is quite critical so that cavitation is controlled.

The two-stage turbine 2 has aerodynamic overspeed limiting characteristics, thus eliminating the necessity for separate external overspeed control devices. The turbine blades employ axial thrust balancing holes 3 to reduce the axial thrust on the bearings. As will be seen from FIG. 1, these holes are at a slight angle to the long axis of the turbine blades, the purpose of this being to provide an aspirating effect to aid in removal of steam to the outside of the blades.

The turbine blades 23 are housed in shroud 24 and nozzle block 5 provided with nozzles 13 for introduction of steam into the interior of the turbine. The housing for the turbine blades is sometimes referred to as a collar ar-

rangement. Drive shaft 6 in shaft housing 9 connects turbine blades 23 with the impeller 1 which is provided with housing 7. During operation, the temperature of the nozzle block and turbine assembly is approximately 1200° F. and that of the pump structure approximately —423° F.

The structure comprising a heat dam by which heat transfer from the turbine structure to the pump structure is prevented will now be described.

Four circumferentially spaced quadrant support posts 25 are attached by welding or otherwse to shaft housing 9 at equal distances apart. The nozzle block 5 is pin-mounted on posts 25 by means of quadrant arms 26 and pins 8 extending through cooperating holes in the ends of the quadrant arms and posts. It will be seen from FIGS. 1 and 3 that a loose joint is formed between each quadrant arm 26 and its corresponding post 25 due to the spacing between the surfaces of the connecting end of the quadrant arm and the top of the post on the one hand and the bottom surface of the head of the pin on the other hand. This loose connection and the radial spacing of the posts permits circumferential uniform radial expansion of the nozzle block assembly so that concentricity of the housing is maintained during radial expansion. The loose joint provides for thermal differential expansion and contraction between the nozzle block assembly and the shaft housing, and the increased number of interfaces in the joint with a minimum of contact area prevents heat transfer from the nozzle block assembly to the shaft and its housing.

As a part of the heat dam, a bellows 4 is mounted by suitable means as shown to the lower peripheral edge of the nozzle block and the periphery of the end of the shaft housing 9 so that it forms a heat barrier between the nozzle block and shaft housing. The combination structure of the pin connection between quadrant arms and posts, and the bellows, forms a tortuous thermal path between the heated turbine assembly and the pump to effectively diminish heat transfer therebetween.

Turbine blades 23 are key connected at 19 to connecting shaft 6 to provide a thermal barrier between the turbine and the shaft. Bolt 20, through hub cap 21, is threadedly engaged in the end of shaft 6 to hold turbine 2 in position.

For liquid hydrogen, or other cryogenic fluid pumping, no lubricant is required for the shaft bearings 10 and 11. To allow for thermal expansion and contraction of interconnecting shaft 6, bearing 10 is made of the outer-race floating type permitting axial movement. Shaft bearing 11 has fixed inner and outer races for taking both axial and radial thrust loads.

The impeller retaining bolt 12 and the hub of impeller 1 are made of the same material, preferably aluminum alloy, and of approximately the same length to prevent any loosening of the impeller on the interconnecting shaft 6, preferably made of stainless steel, due to the higher coefficient of contraction of the aluminum over the steel, and to assure adequate axial forces on the seal and bearing retaining ring 14. Impeller 1 also is key connected at 21' to shaft 6 and bolt 12 is provided with a hub cap 22.

The pump is capable of operation in any position. To minimize wear on rear seal 15, a drain port 16 is provided to vent off fluid leakage through the front seal 17. Front seal 17 and rear seal 15 preferably are made of carbon.

It is to be noted that the large number of interfaces between collar arrangement and shaft housing contribute materially in preventing heat transfer between these parts. Another advantageous feature of the invention is that its structure provides for an expansible turbine, that is, the horepower can be expanded by either adding more nozzles or incorporating more blades.

By employing lathe-mounted and standard boring bar design techniques the necessity for elaborate and costly profile milling and expensive jigs and fixtures is eliminated, making this embodiment of the invention comparatively inexpensive to build. In addition, the use of these techniques permits ease of assembly and disassembly for manufacturing, or service and overhaul purposes.

Obviously many modifications and variations of the turbopump of this invention are possible in the light of the above teachings. It is, therefore, to be understood that, within the scope of the appended claims, the invention can be practiced otherwise than as specifically described.

What is claimed is:

1. A turbopump comprising an axial flow pump for high speed pumping of large volumes of cryogenic fluids, a gas turbine, a shaft directly interconnecting the pump and the turbine, a shaft housing, a collar arrangement surrounding the turbine, a plurality of spaced injector port means positioned in the collar arrangement for injection of hot gas onto the turbine, housing means positioned around the shaft, a loose joint connecting said housing and collar arrangement, and bellows means disposed to also interconnect the collar arrangement and the housing means and to maintain with said loose joint heat exchange between the pump and the turbine at a minimum.

2. A turbo-boost pump comprising an axial flow pump for high speed pumping of large volumes of cryogenic fluids and capable of operating at substantially zero net positive suction head, a gas turbine for operation at temperatures of about 1200° F., a shaft directly interconnecting the pump and the turbine, a collar arrangement surrounding the turbine, a series of spaced injector port means positioned in the collar arrangement for injection of hot gas onto the turbine, housing means positioned around the shaft, a plurality of arm support means interconnecting the collar arrangement and the housing means by a loose joint, and a bellows means disposed to interconnect the collar arrangement and the housing means at a point removed from said loose joint, said arm support means and said bellows means effective to maintain at a minimum any heat exchange between the pump and the turbine.

3. A turbo-boost pump comprising an axial flow pump for high speed pumping of large volumes of cryogenic fluids and capable of operating at substantially zero net positive suction head, a gas turbine for operation at temperatures of about 1200° F., a shaft directly interconnecting the pump and the turbine, a bolt of substantially equal length as the impeller of the pump connecting the impeller to the shaft and made of the same material as the shaft so that loosening of the impeller by thermal expansion and contraction is prevented, a collar arrangement surrounding the turbine and including an inlet nozzle block, a series of spaced injector ports formed in the nozzle block for injection of hot gas onto the turbine, housing means positioned around the shaft, a plurality of arm support means connecting the collar arrangement and the shaft housing means by a loose joint, and bellows means connecting the collar arrangement and the shaft housing means at a point removed from said loose joint.

4. A high temperature turbine and low temperature pump turbo-boost system comprising, in combination, an axial flow pump including an impeller for high speed pumping of large volumes of cryogenic fluids adapted to operate at tempehatures down to at least —423° F.; a gas turbine adapted to operate at temperatures up to at least about 1200° F. and having turbine blades; a drive shaft connecting said pump and blades, said blades being key-connected to said shaft to minimize heat transfer; a bolt of substantially equal length as the impeller of the pump connecting the impeller to the shaft and made of the same material as the shaft so that loosening of the impeller by thermal expansion and contraction is prevented; a collar arrangement surrounding the turbine and including an inlet nozzle block; a housing for said shaft; a plurality of equally spaced quadrant support posts mounted circum-

ferentially of said housing; quadrant arms corresponding to each of said posts attached to said nozzzle block; a loose joint connecting each of said quadrant arms and its corresponding post; and a circumferential bellows connected between the lower periphery of said nozzle block and the periphery of the end of said housing at a point forward of said loose joint.

5. The system of claim 4 in which said loose joint comprises a pin fitting in cooperating holes in the end of said quadrant arm and post with space being provided for vertical movement of the end of the quadrant arm.

6. The system of claim 5 in which a bearing is provided between said shaft and housing adjacent the turbine having a floating outer race to permit sliding axial expansion and contraction of said shaft due to temperature changes.

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LAURENCE V. EFNER, *Primary Examiner.*

ROBERT M. WALKER, *Examiner.*