LIQUID PUMP FOR ASTRONAUT COOLING

By Maurice A. Carson*

ABSTRACT

The Apollo portable life support system water-recirculation pump used for astronaut cooling is described in this report. The problems associated with an early centrifugal pump and how these problems were overcome by the use of a new diaphragm pump are discussed. Performance comparisons of the two pump designs are given. Developmental problems and flight results with the diaphragm pump are discussed.

INTRODUCTION

Early in the Apollo Program, tests and engineering analyses revealed that gas ventilation alone provided inadequate body cooling for the astronaut performing extravehicular work. As a result, a liquid cooling system was incorporated into the extravehicular mobility unit (EMU) to circulate water through a network of tubing sewn into an undergarment worn by the astronaut. The water is cooled by a heat sink located within the portable life support system (PLSS). A simplified schematic of the cooling system is shown in figure 1. As indicated in figure 1, the cooling system is a completely closed loop. The rate of flow through the liquid cooling garment is constant, and a comfortable fluid temperature is maintained by partial water bypass of the heat exchanger.

REQUIREMENTS

Design requirements established for the cooling system pump were as follows.

1. Flow rate: 1.82 liters/min
2. Pressure rise: 0.37 kg/cm^2
3. Inlet pressure: 1.31 kg/cm^2
4. Inlet temperature: 289.15° K (16° C)
5. Input voltage: 16.8 V dc

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*NASA Manned Spacecraft Center, Houston, Tex.

6. Input power:	11.0 watts
7. Weight:	1.1 kilograms (maximum)
8. Operating environment:	0 to 1.013×10^5 N/m^2 (0 to 1.0 atmosphere)

In addition, the usual Apollo environmental, safety, reliability, and compactness requirements were imposed.

Generally, commercially available pumps were unable to satisfy the requirements for one or more of the following reasons.

1. The overall efficiency was too low for the 11.0-watt power limitation.

2. The envelope and weight exceeded established limits.

3. When subjected to design limit requirements, reliability was too low to be qualifiable.

The conclusion was reached that the best method of meeting the established criteria was to design a new pump for the stated requirements.

DESCRIPTION

Centrifugal Pump Design

The initial PLSS pump design featured a brushless direct current motor mated to a centrifugal pump. As shown in figure 2, the pump impeller was an integral part of the motor armature. This simple pumping concept proved in developmental tests to be highly inefficient, requiring an average power input of 28 watts to achieve the specified flow rate and hydraulic head. It was estimated that "tuning" type design changes to the basic unit would have a negligible effect on the overall power requirement.

Other problems associated with this pump that would have necessitated redesign were in the following areas.

1. Bearings: The dry-film-lubricated bearings had an average lifespan of approximately 150 hours; the requirement was 500 hours and a target design life of 5000 hours. Replacement with a long-life bearing having the capability to accept the high thrust and radial loads would have necessitated a housing redesign.

2. Corrosion: The primary pump materials, alodined aluminum and steel, had significant corrosion problems. Elimination of this problem would have required a materials-replacement effort.

3. Electronics: Developmental testing indicated that the electronics module was unable to accept mission vibration and shock loads. A redesign would have required denser packaging and potted electronics.

Considering these problem areas as a group, the principal reason for deciding on a new pump was that of power. Solutions for the other problems were readily available, but it was considered impossible to approach the 11.0-watt input-power requirement with a centrifugal pump.

Diaphragm Pump Design

The approach selected for a new pump was a double-acting, positive-displacement, diaphragm-type unit that was under development at the time. The input power for this development pump was within the specification requirements; further, isolation of the motor from the water promised to eliminate bearing and corrosion problems. The pump, shown in the cutaway view (fig. 3) and in the isometric projection (fig. 4), consists of two diaphragms at the end of a walking beam that is supported by a torsion rod. Inlet and outlet check valves are provided for each diaphragm chamber. Part of the walking-beam structure is the armature of a two-position solenoid. A permanent magnet forms part of the motor frame, as shown in figure 3. When the pump is not energized, the armature rests against one leg of the permanent magnet, and two of the four air gaps are closed. Energizing the coil weakens the magnetic flux across the closed air gaps and strengthens the magnetic flux across the open air gaps. Energy stored in the torsion rod accelerates the armature toward the center position when the magnetic force at the closed air gaps is neutralized. Thus, the position of the bistable solenoid armature changes with the electromagnetic field polarity established by the current direction through the coil. This displacement of the walking beam causes one diaphragm chamber to discharge fluid while the other chamber takes in fluid. Upon reversal of the current, the opposite air gaps are closed and the diaphragms are displaced in the opposite direction to deliver a pulse of flow through the check valves.

The integrated electronics control circuit consists of an amplifier section, which directs current to the electromagnetic coil, and a timing-inverter section, which sets the frequency with which the current is reversed through the coil. By suitably matching the spring constant of the spring-mass system to the electronic timing section, the frequency of the electromagnetic field reversals can be tuned to the natural resonance of the spring-mass system. By using energy stored in the torsion bar to augment the electromagnetic force on the walking beam, a significant pump input power reduction is achieved. The physical envelope of this pump is shown in figure 5.

The significant problems that occurred during development of this pump and the solutions of the problems are as follows.

1. Check valves: The valve seats, which were fabricated from a Teflon-based material, tended to deform conically under pressure loading, causing leakage (thus low pumping head). The problem was solved by changing the seat to 6061-T6 aluminum for increased structural rigidity.

2. Diaphragms: Water leakage occurred in some units through the Dacron diaphragm as a result of cracks in the butyl rubber coating material. The problem was traced to a manufacturing technique whereby a liquid butyl compound was applied to both sides of the Dacron fabric followed by a single operation to mold the convolute contour and cure the butyl. This combination form-and-cure operation had the potential for causing the Dacron fabric to migrate to the inside radius of the diaphragm contour.

The problem was solved by performing 100 percent inspection under a 30× magnification and rejecting the diaphragms that showed thin spots, tears, abrasions, or fibers protruding through the elastomer.

3. Torsion bar: In an early test unit, a fracture of the torsion bar was attributed to residual tensile stresses in the bar caused by soldering at the ends of the bar at the subassembly level. The problem was eliminated by redesigning to a pin and clamp arrangement rather than soldering the end shoulders in place.

4. Electronics: During motor testing, it was discovered that incoming voltage spikes of a microsecond duration were sufficient to burn out transistors in the inverter module. These spikes could be generated by electromagnetic interferences on the line or by transients during other PLSS switching functions. The problem was solved by redesign of the PLSS electrical circuitry. The pump was isolated from other components by an electromagnetic interference filter, and a high-speed switching diode was placed across the spike-producing switch to capture spikes at the source.

All of these problems occurred during the ground-based test operations. The pump operation on all Apollo flights has been without problems.

Performance

As noted previously, the first approach to liquid pumping in the PLSS was rejected, principally because of high input power requirements. With the design change to the diaphragm pump, the specification input power requirement was met. An input power decrease of 18.3 watts for an equivalent output was realized. Defining overall efficiency as output work/input power, overall efficiency for the centrifugal and diaphragm pumps at design point conditions is 3.9 and 11.3 percent, respectively.

Considering that, on Apollo missions, three dual extravehicular activity periods of 7 hours duration each per flight were anticipated and considering the fact that the PLSS power supply is not spacecraft rechargeable, the power reduction achieved with the diaphragm pump resulted in a considerable weight advantage for both the PLSS and the lunar module. At a nominal battery weight of 110 W-hr/kg, the battery weight saving for each PLSS was 1.15 kilograms and for each lunar module was 6.9 kilograms. This neglects any possible structural increases required by a heavier battery. Also, the diaphragm pump was lighter and smaller than the centrifugal unit. Weight was reduced by 0.19 kilogram, and volume was decreased by 6 percent. The performance differences between the units are summarized in table I.

CONCLUDING REMARKS

The diaphragm pump has been proven on several Apollo flights to be a highly reliable device for pumping water through the astronaut liquid cooling garment. By implementation of this unit, the power objectives established in the portable life support system specifications were met. Performance within the power specification resulted in a significant weight reduction for both the portable life support system and the lunar module. The diaphragm pump also proved to be lighter and more compact than the predecessor centrifugal pump.

DISCUSSION

J. H. Parks:

You stated that, essentially, the purer the water, the more corrosive its action. Could you elaborate on that statement?

Carson:

The pure water referred to meant deaerated water used in the portable life support system. Because deaerated water lacks dissolved oxygen, it is a reducing environment for the natural passive oxide film which forms on metals and, thereby, causes a greater corrosive attack on certain alloys.

TABLE I. - DESIGN POINT PERFORMANCE COMPARISON BETWEEN CENTRIFUGAL AND DIAPHRAGM PUMPS

Characteristic	Centrifugal pump	Diaphragm pump
Voltage, Vdc	16.8 ± 0.8	16.8 ± 0.8
Flow rate, liters/min	1.82	1.82
Pressure rise, kg/cm^2	0.37	0.37
Power consumption, W	28	9.7
Weight, kg	0.8	0.61
Envelope, cm	8.8 diameter by 9.3	10.1 by 5.6 by 8.6
Overall efficiency, percent . . .	3.9	11.3

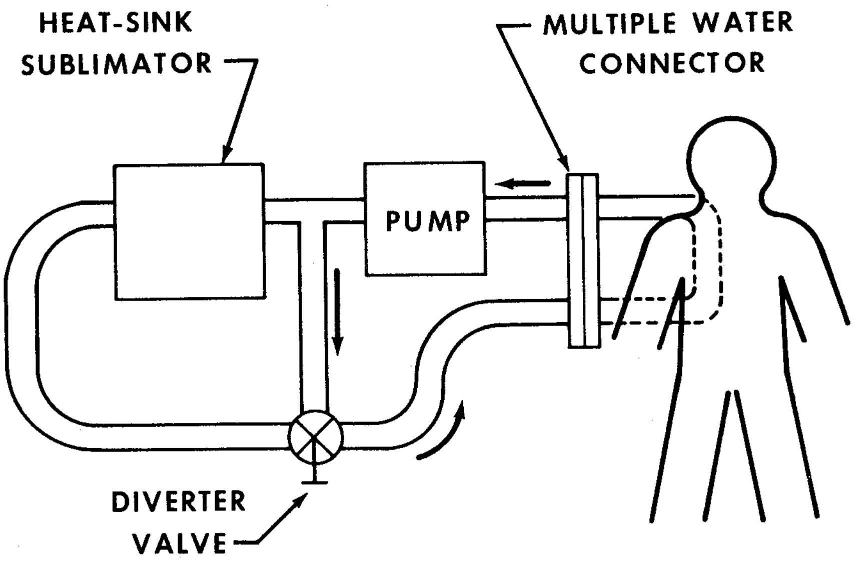

Figure 1. - The PLSS cooling-loop schematic.

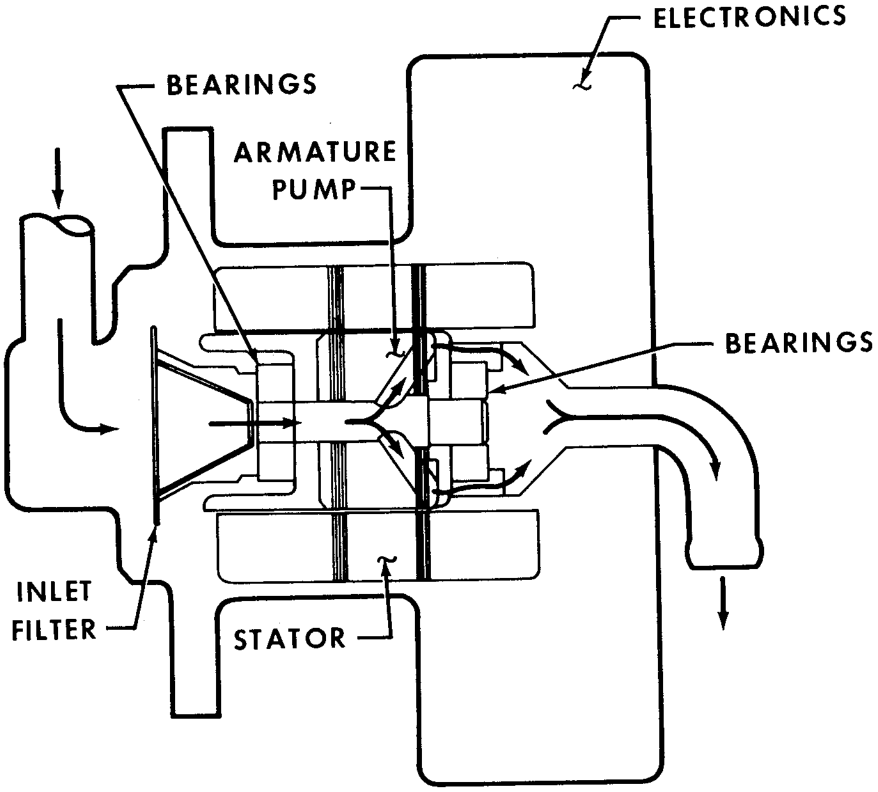

Figure 2. - Centrifugal pump schematic.

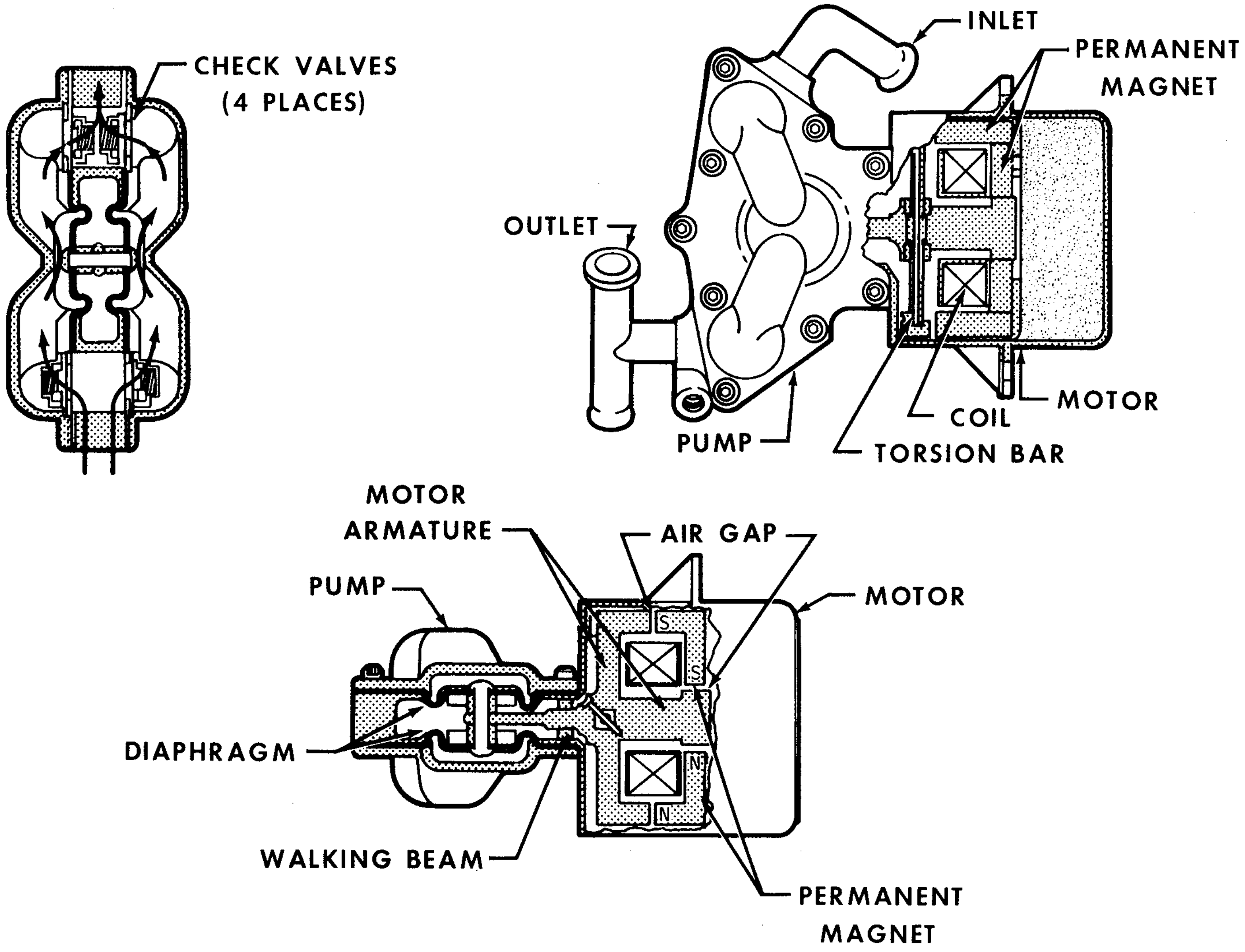

Figure 3. - Diaphragm pump cutaway.

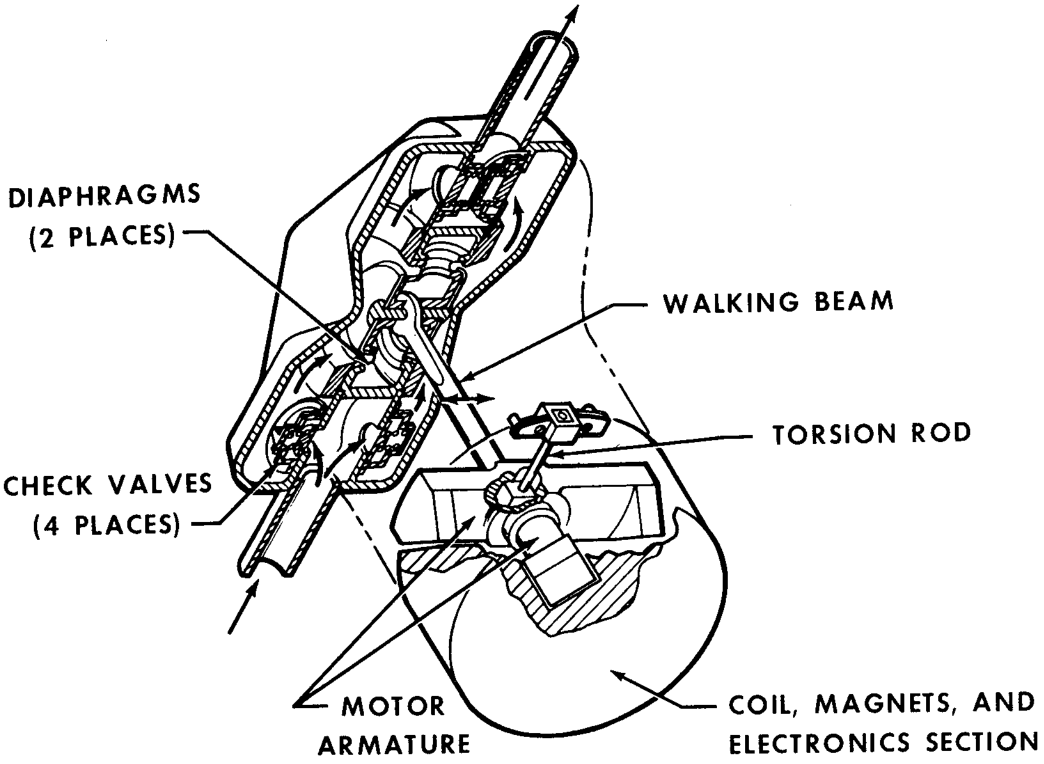

Figure 4. - Diaphragm pump isometric projection.

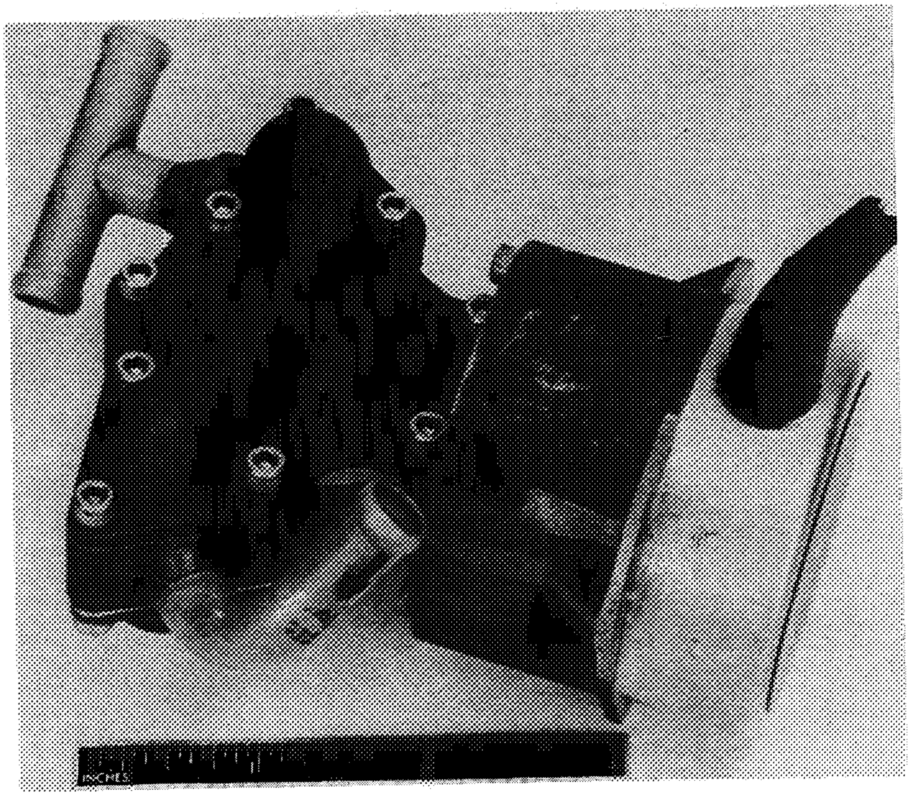

Figure 5. - Diaphragm pump.