NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546

REPLY TO
ATTN OF:

March 27, 1971

TO: USI/Scientific & Technical Information Division
Attention: Miss Winnie M. Morgan

FROM: GP/Office of Assistant General Counsel for Patent Matters

SUBJECT: Announcement of NASA-Owned U.S. Patents in STAR

In accordance with the procedures contained in the Code GP to Code USI memorandum on this subject, dated June 8, 1970, the attached NASA-owned U.S. patent is being forwarded for abstracting and announcement in NASA STAR.

The following information is provided:

U.S. Patent No.	:	3,361,067
Corporate Source	:	Honeywell, Inc. 2600 Ridgeway Road Minneapolis, Minnesota
Supplementary Corporate Source	:	
NASA Patent Case No.	:	XNP-05429

Please note that this patent covers an invention made by an employee of a NASA contractor. Pursuant to Section 305(a) of the National Aeronautics and Space Act, the name of the Administrator of NASA appears on the first page of the patent; however, the name of the actual <u>inventor</u> (author) appears at the heading of Column No. 1 of the Specification, following the words ". . . with respect to an invention of. . . ."

Gayle Parker

Enclosure:
Copy of Patent

FACILITY FORM 602

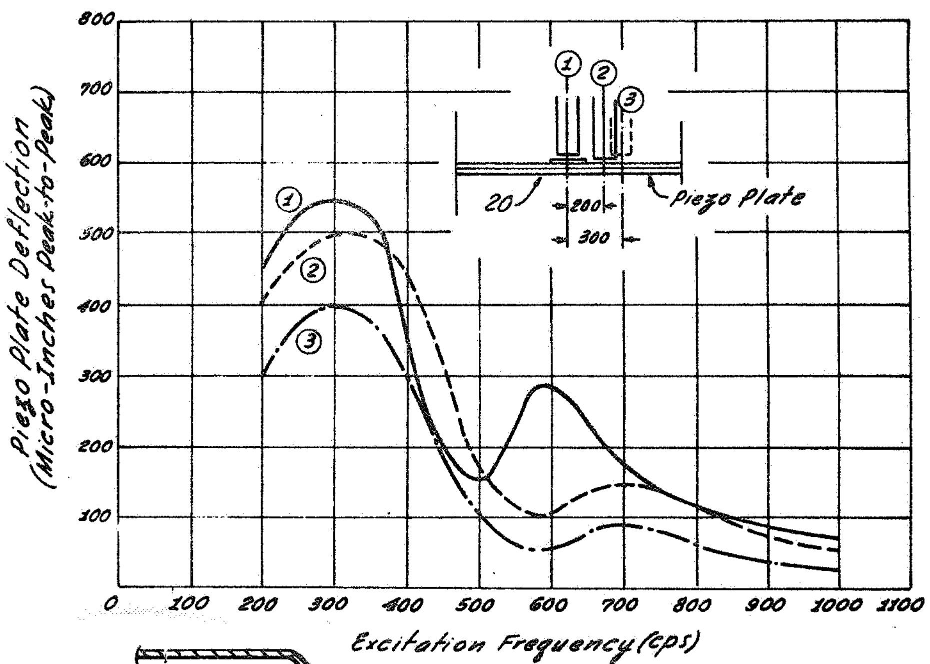
N71 21824 (ACCESSION NUMBER)	00 (THRU)
6 (PAGES)	(CODE)
(NASA CR OR TMX OR AD NUMBER)	26 (CATEGORY)

N71-21824

Jan. 2, 1968 JAMES E. WEBB 3,361,067
ADMINISTRATOR OF THE NATIONAL AERONAUTICS
AND SPACE ADMINISTRATION
PIEZOELECTRIC PUMP

Filed Sept. 9, 1966 3 Sheets-Sheet 1

Fig. 3



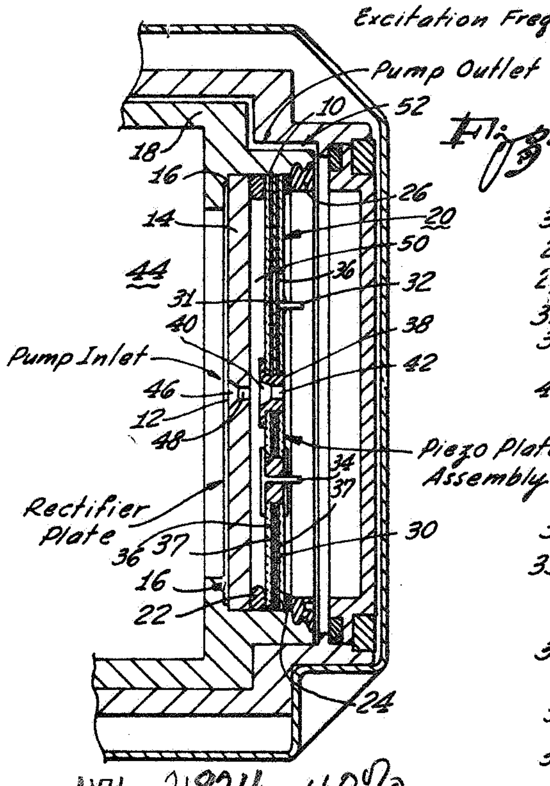


Fig. 1

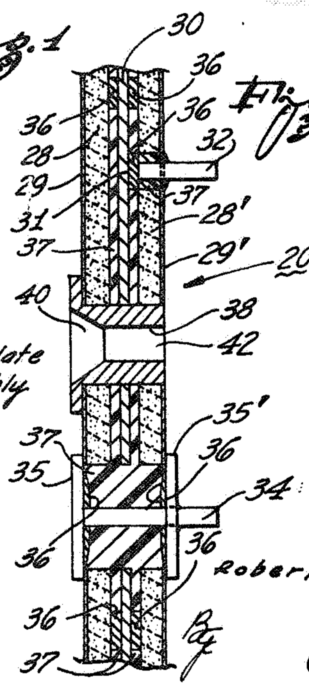


Fig. 2

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Fig. 4

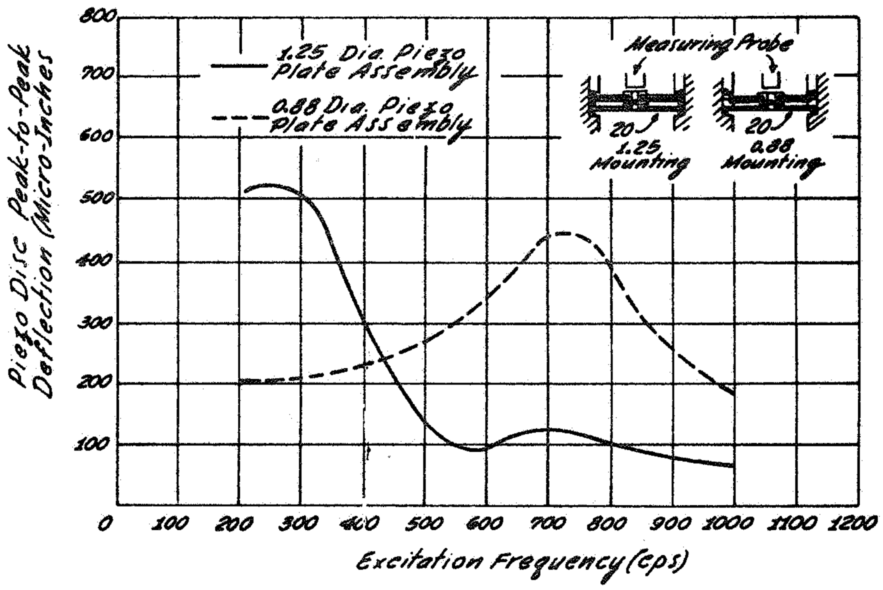

Fig. 5

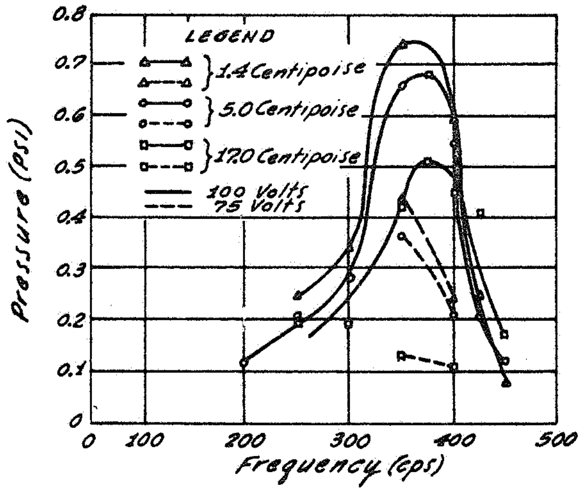

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Fig. 6

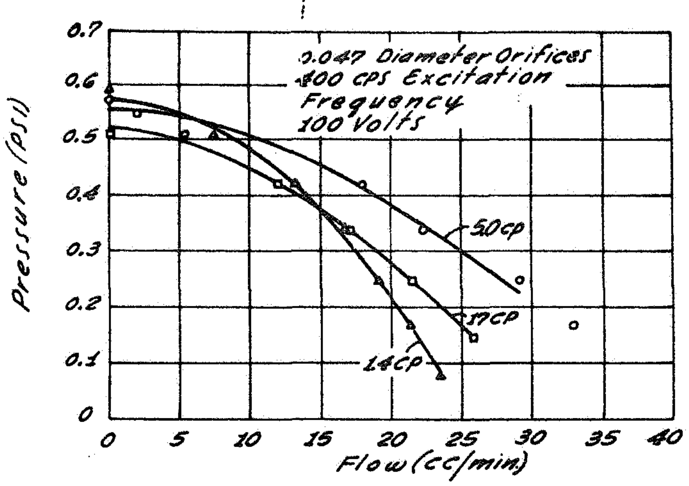
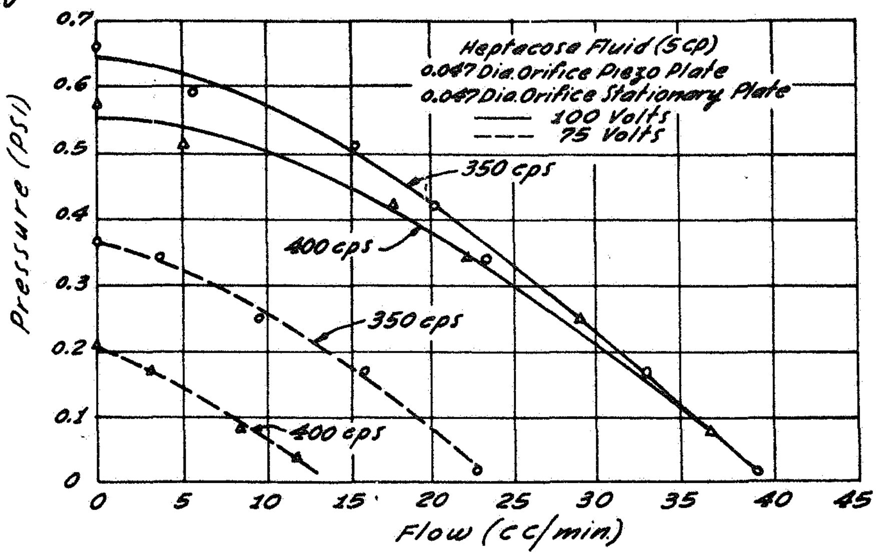


Fig. 7



INVENTOR:
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United States Patent Office 3,361,067
Patented Jan. 2, 1968

1

3,361,067
PIEZOELECTRIC PUMP
James E. Webb, administrator of the National Aeronautics and Space Administration, with respect to an invention of Robert F. Anderson, Minneapolis, Minn.
Filed Sept. 9, 1966, Ser. No. 578,928
6 Claims. (Cl. 103—1)

ABSTRACT OF THE DISCLOSURE

A fluid pumping apparatus operated at high frequencies by piezoelectric effect in which a piezoelectric plate produces high frequency oscillations for pumping fluid through orifices, thereby producing full fluid flow rectification without the use of valving structure having moving parts, for supplying fluid to a gyroscope fluid suspension system utilized within rockets and space vehicles required for interplanetary travel and outer space exploration.

Origin of the invention

The invention described herein was made in the performance of work under a NASA contract and is subject to the provisions of Section 305 of the National Aeronautics and Space Act of 1958, Public Law 85-568 (72 Stat. 435; 42 USC 2457).

In creating a suspension system for a gyroscope assembly for utilization in space vehicles it must be recognized that the gyroscope assembly will be subject to numerous and variably severe externally imposed forces. In providing full protection for such a gyroscope assembly it has been found that a fluid suspension system provides effective protective facilities. In contriving a gyroscope fluid suspension system, care must be exercised in affecting a proper pumping discharge rate so that fluid pressure pulsations will not produce stray or upsetting forces upon the gyroscope assembly. Extraneous and unwanted external forces on the gyroscope will severely affect the accuracy of the gyroscope output signal.

Attempts have been made to utilize conventionally known pumps in fluid suspension systems. Rotary pumps in particular have been the subject of extensive experimentation. It has been observed that discharge pulsations from rotary pumps and other conventionally known pumps have imposed an oscillatory signal upon the desired true output signal from the gyroscope. It has been found that the superimposed false oscillatory output signal caused by the pulsating discharge from known fluid pumping structures produces difficult attenuation problems.

In attempting to provide proper fluid suspension, power and frequency requirements for pumping assemblies impose important design criteria. Conventional rotary pumps impose high power requirements, on the order of a 2.5 watt power supply source, for example. Additionally, conventionally known fluid pumps operate at a cyclic frequency rate which differs considerably for the operating frequency of associated electrically driven machinery in a gyroscope assembly.

In order to produce a high frequency pumping discharge rate with pumping equipment operating on a frequency and power supply source with associated equipment, such as the spin motor in a gyroscope assembly, it has been recognized that a fluid pump operating on a piezoelectric effect must be contrived. Also, a full fluid flow rectification must be effected by suitable valving structure within the pumping equipment. Since the piezoelectric effect produces very high frequency vibrations conventional valving structure is subject to excessive wear and malfunction when used with a piezoelectric pumping action.

2

The space, weight, operational reliability, ruggedness and durability requirements imposed on the fluid pump needed to supply the gyroscope suspension system precludes the use of conventional pump structures. Additional conditions imposed on this particular fluid pump are that it must continuously supply a gyroscope fluid suspension system for long periods of time during which time it is unavailable for maintenance or repair and during which time the gyroscope must be fully capable of withstanding a turning rate of 15,000 degrees per hour and upward of fifteen (15) times normal atmospheric pressure.

Accordingly, an important object of this invention is to provide a fluid pump which produces a high frequency output with full fluid flow rectification so that the fluid discharge from the pump does not adversely affect the accuracy of the gyroscope output signal.

Another object of the invention is to provide a fluid pump which has low electrical power requirements.

Another object of this invention is to provide a fluid pump which is adaptable for use in a space vehicle and which will operate from the same power supply source as used for associated equipment installed aboard the space vehicle.

Another object of this invention is to provide a fluid pump which is lightweight, compact, rugged, durable and has high performance capability for long periods of time during which it is unavailable for maintenance or repair and during which time it must operate within narrow limits of output conditions.

Another object of this invention is to provide a fluid pump having a valving arrangement which produces full fluid flow rectification and which has no moving valve structure subject to excessive wear or malfunction.

Another object of this invention is to provide a fluid pump which has its various component members securely bound together so that the pump is capable of withstanding numerous and variably severe vibratory jolting and jarring forces and which is capable of continuous operation regardless of physical attitude or special orientation.

That these and other objects and advantages of this invention are obtained will be apparent from reference to the description of a preferred embodiment of the invention set forth herein below and to the accompanying drawings which form a part of this specification wherein:

FIGURE 1 is a cross-sectional view of the piezoelectric fluid pump showing the pump as it is mounted within the gyro assembly of a space vehicle;

FIGURE 2 is an enlarged, cross-sectional view of the piezoelectric plate for the fluid pump shown in FIGURE 1 showing details of the ceramic plates, the fired on conductive coating, the conductive brass shim and the electrical contacts for the piezoelectric plate;

FIGURE 3 shows the effect of excitation frequency on the piezoelectric plate deflection measured in microinches;

FIGURE 4 shows the effect of excitation frequency on piezoelectric plate peak-to-peak deflection for 1.25 inch and 0.88 inch outside diameter piezoelectric plate assemblies;

FIGURE 5 shows a plot of frequency from both 100 volt and 75 volt power supply sources versus static head pressure for three fluids having different viscosities;

FIGURE 6 shows a plot of fluid flow in cubic centimeters per minute for three fluids having different viscosities against fluid pressure as measured in a 0.047 inch diameter fluid flow orifice; and

FIGURE 7 shows a plot of fluid flow in cubic centimeters per minute and fluid pressure as measured in a 0.047 inch diameter fluid flow orifice for a fluid having a viscosity of 5.0 centipoise when the piezoelectric plate is energized by a 100 volt and a 75 volt power supply source and at a 350 c.p.s. and a 400 c.p.s. excitation frequency.

Referring to FIGURE 1 of the drawings, the piezoelectric fluid pump of this invention, generally designated by the numeral **10**, is shown mounted within a gyroscope assembly within which the fluid pump supplies fluid for the gyroscope fluid suspension system. Fluid from the fluid suspension system flows through an orifice **12** provided in plate rectifier **14**. The rectifier plate is a stationary member within the fluid pump assembly and is mounted against a shoulder **16** formed on the interior surface of retaining structure **18** provided within the gyroscope assembly. The rectifying plate is separated from the piezoelectric plate **20** by an O-ring **22**. The piezoelectric plate **20** is held in position by an O-ring **24** which is mounted against a gasket **26** retained in a pressed fitted position against retaining structure **18**.

It has been found that the maintenance of resiliency and stability of O-rings within a gyroscope assembly can present troublesome problems particularly where the O-rings are subject to exposure for long periods of time to fluid temperatures in the range of 300° F. It has been found, however, that a silicone rubber will meet the requirements for resiliency and stability need in O-rings required for use within this piezoelectric pump. Also, lead coating aluminum sealing rings can be used as alternate plate mountings within the pump assembly. The lead coating aluminum sealing rings have the advantage of temperature stability and do not change pumping characteristics within the piezoelectric fluid pump.

FIGURE 2 shows the details of construction of the piezoelectric plate **20**. In the construction of the piezoelectric plate **20** a 0.003 conductive brass shim **30** is bonded between two 0.022 inch thick lead coated zirconium titanate ceramic plates **28** and **28'** each having a 0.0005 to 0.0020 inch fired on conductive coating **29** and **29'** respectively. The entire piezoelectric plate **20** thus has a thickness of approximately 0.053 inch. An electrical lead **32** is attached at a terminal **31** to the brass shim **30** and an electrical lead **34** is attached at terminals **35** and **35'**, connected in series, to the conductive coatings **29** and **29'** on ceramic plates **28** and **28'**, respectively. A high temperature electrically conductive epoxy cement **36** is applied at a few spots on each side of the brass shim **30** and at the electrical terminals **31**, **35** and **35'** so as to insure good electrical conducting characteristics for the piezoelectric plate. For further bonding the conductive brass shim **30** to the ceramic plates **28** and **28'**, the electrical lead **32** and terminal **31** to brass shim **30**, and the electrical lead **34** and terminals **35** and **35'** to the conductive coatings **29** and **29'** on the ceramic plates **28** and **28'** respectively, a high temperature non-electrically conductive epoxy **37** is used. The high temperature non-electrically conductive epoxy **37** provides good bonding for all contacting surfaces within the piezoelectric plate **20** not bonded by the electrically conductive epoxy cement **36**. Also, the non-electrically conductive epoxy **37** insulates the electrical terminals **31**, **35** and **35'** thus forming a sturdy, durable piezoelectric plate **20**.

The ceramic plates **28** and **28'** contract and expand cyclically in a radial direction when an AC potential is applied to them in an axial direction through electrical leads **32** and **34**. The polarities of the ceramic plates are oriented oppositely from center to outside as viewed in FIGURE 2 so that the applied AC potential will cause a bi-metal type of flexing of the plates with reversals at the frequency of excitation. This motion is used for developing the high frequency fluid pumping action which causes the continuous fluid flow through the gyroscope fluid suspension system.

The piezoelectric plate **20** is provided with an orifice **38**. The orifice **38** has a fluid ingress opening **40** through which fluid flows to the egress opening **42**. A net rectification of fluid flow through the orifice is produced by movement of the orifice within the fluid. The net rectification of fluid flow produced by the motion of an orifice within a fluid is a function of total fluid flow, the difference in orifice coefficients, plate velocity, fluid velocity, fluid viscosity and a fluid function factor for cavitation.

Fluid pumping action is produced by the dithering motion of the piezoelectric plate **20**. Fluid **44** within the gyroscope fluid suspension system is caused to flow through the orifice **12** in the rectifier plate **14** as the piezoelectric plate **20** moves to the right as seen in FIGURE 1. The orifice **12** is provided with a wide ingress opening **46** and a more restricted egress opening **48**. As the piezoelectric plate **20** moves to the left as seen in FIGURE 1 fluid is restricted from flowing back through orifice **12** because of the restricted egress opening **48**. Since orifice **38** in the piezoelectric plate **20** is provided with similar wide ingress and restricted egress openings fluid is similarly caused to flow from the fluid reservoir **50** between the stationary rectifier plate **14** and the piezoelectric plate **20** through the orifice **38** to the right as seen in FIGURE 1 to be recirculated through the fluid recirculating line **52** within the gyroscope fluid suspension system.

It has been found that if the orifices **12** and **38** are provided with internal diameters of 0.047 inch ample fluid flow and pressure is achieved for the gyroscope fluid suspension system. Both orifices **12** and **38** have conical ingress openings with a 50 degree included angle. It has been noted that somewhat better fluid flow performance has been obtained with orifices having a conical entrance opening than with orifices having a 0.025 inch radius entrance opening, for example. Best pumping performance has been observed with the orifices **12** and **38** being in axial alignment. A spacing of 0.050 inch between the orifices **12** and **38** has been found to be desirable.

The valving structure contrived for the piezoelectric pump of this invention eliminates the use of check valves and other valving structures having moving parts. Conventionally known check valves and fluid flow rectifier structures do not provide the rugged, durable, compact valving structure required for use within the limited space available for fluid suspension within the gyroscope assembly. Further, conventional valving structures have poor response to the fluid pumping frequencies required to produce smooth even fluid flow which will not distort or produce inaccuracies in the gyroscope output signal.

From tests made on the piezoelectric pump of this invention, it has been found that the piezoelectric plate and the rectifier plate must be clamped together with a nominal force. The fluid pump output drops and peak pumping frequency is reduced with a loosening of the pump assembly. A reclamping of the pump assembly with a nominal force has been found to return the pump to normal performance. It has been noted that any excessive tightening of the pump assembly does not appreciably affect pump performance.

Referring to FIGURE 3, it is seen that experimental test data is recorded showing the effect of excitation frequency on piezoelectric plate deflection. Deflection readings were taken at points **1**, **2** and **3** as shown in FIGURE 3 on the piezoelectric plate **20**. It has been found that frequency band width of performance for the piezoelectric pump should vary inversely with the square of the radius of the piezoelectric plate. It has been noted that the predominant piezoelectric plate motion involved spherical "dishing." However, in addition to "dishing" a small waviness in the profile of the piezoelectric plate motion can be noted from the change in phase relation of radial position peaks with respect to each other. At high frequencies, the piezoelectric plate moves in phase with the input excitation frequency.

FIGURE 4 shows the results of tests made on piezoelectric plates havig outside diameters of 1.25 inch and 0.88 inch. FIGURE 4 shows that the maximum deflections of the piezoelectric plate are at frequencies slightly below the reference output frequencies 400 and 800 c.p.s. In the case of the 1.25 inch piezoelectric plate it is to be noted that plate motion is significantly attenuated above 450 c.p.s. The piezoelectric pump of this invention is provided with a piezoelectric plate having an outside diameter of 1.25 inches.

The piezoelectric pump of this invention was tested with fluids having viscosities of 1.4, 5 and 17 centipoises. No large change in pump performance was noted with fluids of differing viscosities although some degradation occurred at high flow rates when using fluid having a viscosity of 1.4 centipoise.

The piezoelectric pump of this invention has been found to operate best at 100 volts and at 400 c.p.s. excitation frequency. Pumping capability drops sharply when a power supply source of less than 75 volts is used. The pump has a power requirement of 0.2 watts. A certain minimum piezoelectric plate vibratory motion is required to sustain the pumping capabilities for supplying a gyroscope fluid suspension system for a gyroscope which must be fully capable of withstanding a turning rate of 15,000 degrees per hour and upward of fifteen (15) times normal atmospheric pressure. The piezoelectric plate has a threshold of peak-to-peak motion before pumping is initiated. After the threshold of peak-to-peak motion is reached, pumping action increases somewhat linearly with voltages up to 100 volts. The maximum dynamic pressures observed with the peak-to-peak optimum plate motion have been on the order of 3 p.s.i.

FIGURE 5 shows the effect of frequency on static head pressure for fluids of varying viscosities. Also, FIGURE 5 shows the relationship of a 100 volt and a 75 volt power supply source to frequency and static head pressure for fluids of varying viscosities.

Additional performance characteristics of the piezoelectric pump of this invention can be seen by reference to FIGURES 6 and 7. FIGURE 6 shows fluid flow and pressure conditions at the 0.047 inch diameter orifices within the rectifier plate **14** and piezoelectric plate **20** for fluids having viscosities of 1.4 centipoise, 5.0 centipoise and 17.0 centipoise when the piezoelectric plate **20** is energized by a 100 volt power supply source at a 400 c.p.s. excitation frequency. FIGURE 7 shows fluid flow and pressure conditions at the 0.047 inch diameter orifices within the rectifier plate **14** and piezoelectric plate **20** for a fluid having a viscosity of 5.0 centipoise when the piezoelectric plate **20** is energized by a 100 volt and a 75 volt power supply source at a 350 c.p.s. and a 400 c.p.s. excitation frequency.

While a particular embodiment of this invention has been illustrated and described, it is apparent that modifications may be made without departing from the scope of the invention. For example, it is to be recognized that the piezoelectric pump of this invention is adaptable to all fluids, gasses or liquids with proper adjustments for vibratory frequencies, fluid parameters, piezoelectric plate assembly parameters and mountings. Also the piezoelectric plate may either have individual orifices formed or attached to it using edge mounting or may be centered mounted with orifices or may have its peripheral edges formed to an effective orifice with the wall of the pump housing. Further, the piezoelectric pumping plate, when used in conjunction with a rectifying plate having an orifice therein, may or may not be provided with an orifice.

The following claims are intended to cover all modifications which come within the spirit and the scope of this invention.

What is claimed is:

1. In a fluid pump a piezoelectric plate for producing fluid flow within said fluid pump, said piezoelectric plate comprising: an electrical conductive shim; two ceramic plates, each of said ceramic plates having an electrical conductive outer coating, said electrical conductive shim being mounted between the two ceramic plates, an orifice extending through said ceramic plates and said shim, said orifice having an ingress opening and an egress opening smaller than said ingress opening, and means for applying operating potential to said piezoelectric plate including an electric lead attached to said electrical conductive shim, and an electrical lead connected to both the outer coatings on said two ceramic plates.

2. A piezoelectric plate in accordance with claim 1 in which said electrical conductive shim is made of brass and said ceramic plates are lead coated zirconate titanate ceramic plates.

3. A piezoelectric plate in accordance with claim 1 wherein a high temperature electrically conductive epoxy cement is applied at one or more spots on each side of said electrical conductive shim and at each of said electrical terminals so as to insure good electrical conducting characteristics for said piezoelectric plate.

4. A piezoelectric plate in accordance with claim 3 wherein a high temperature non-electrically conductive epoxy cement is used in bonding said conductive shim to said ceramic plates, and in bonding said electrical lead and electrical terminal to said conductive shim, and in bonding said electrical lead and said electrical terminals to said electrical conductive outer coatings on said two ceramic plates.

5. A piezoelectric plate in accordance with claim 1 wherein the polarities of the two said ceramic plates are oriented oppositely from center to outward side of said piezoelectric plate so that said ceramic plates will contract and expand cyclically in a radial direction when an AC potential is applied to them in an axial direction through said electrical leads and the applied AC potential will cause a bimetal flexing of said ceramic plates with reversals at the frequency of excitation so as thereby to produce high frequency fluid pumping action.

6. In a fluid pump as recited in claim 1, wherein there is included a rectifier plate positioned opposite said piezoelectric plate on the side at which the ingress opening of said orifice is provided, said rectifier plate including an orifice positioned in alignment with the orifice in said piezoelectric plate, said rectifier orifice having an ingress opening, and an egress opening smaller than said ingress opening, said rectifier plate egress opening being on the side opposite said piezoelectric plate ingress opening.

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