DESIGN AND IMPLEMENTATION OF LIGA FABRICATED, SELF-PRIMING IN-LINE GEAR PUMPS

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ABSTRACT

This paper presents the first self-priming, positive displacement micromachined pump. The in-line gear pump is a magnetically-actuated, two-gear plastic pump which is fabricated by the SLIGA process. The components of the pump are assembled and inserted in a tube, with the magnetic driving mechanism outside the tube. This method of magnetic actuation eliminates the seal issues. The preliminary test results show that the pump flow rate can be at least 70 $\mu\text{l}/\text{min}$. The pump pulls a vacuum at the inlet of at least 45 mm of water and is self-priming.

INTRODUCTION

There are many applications waiting for a viable MEMS based pumping system — a pump which is easily integrated into existing systems, requires no special skills to operate, and is easy to use. Some of these applications include micro analytical instrumentation, genetic engineering, protein synthesis, portable chemical and biological sampling systems, drug delivery, and environmental monitoring. To take these application out into the field, it is critical that the MEMS pumping system improves the usability of the instrument, along with reduce weight and volume, decrease power consumption, and reduce costs.

There have been a number of MEMS based liquid pumps published in the literature. Most are silicon based diaphragm pumps utilizing a many different inlet/outlet valves and actuation methods. The published literature on MEMS pumps can be summarized as a group: no self-priming liquid pumps have been reported. This is truly the limitation on commercialization of MEMS pumps, since requiring the technician in the field to prime the MEMS based pump in the instrument will override any advantages of MEMS fabrication.

The in-line pump is a LIGA fabricated, magnetically-actuated, gear pump which is designed to be inserted in a tube, and driven by an external magnetic field. The design philosophy of the in-line gear pump provides unique advantages for a micromachined pump. First, the seal problem is eliminated, since the whole pump body is in the fluid path. This includes both static seals for the pump body and moving seals for a driving mechanism. In fact, since the magnetic actuation is coupled through the tube walls, the fluid in the tube remains completely isolated from the environment. Therefore, actuation mechanism will minimize heating the fluid. Since the driving mechanism is not part of the pump itself, the pump can be made much less complex. This allows the pump to be disposable. Furthermore, for biomedical application, the pump and the tube can be sterilized together, without the drive mechanism. An added advantage is that the drive is reusable, reducing the cost of the ownership. Some of the target applications include: IV drug delivery, biomedical instrumentation, clinical analyzers, chemical instrumentation, and any applications where it is critical that the fluid path isolated from the environment.

This actuation scheme also provides a method for magnetic coupling of eccentric rotors with a nearly constant torque

transmitted to the rotor. The driving method provides coupling with air gaps much larger than that reported for micromechanical rotational devices (i.e., magnetic micromotors). The coupling method demonstrated with the in-line pump allows the development of many new rotationally coupled micromechanical mechanisms and systems.

IMPLEMENTATION OF THE IN-LINE GEAR PUMP

Figure 1 is an exploded view of the gear pump. The inlet and outlet plates, the cavity plate, and the driving and driven gears are all fabricated via the SLIGA process using PMMA as the structural material[1,2]. Since the PMMA is the structural part, thickness control, surface finish and parallelism are critical for this device. In this case of the in-line pump, the gears are fabricated to 2-4 μm thinner than the cavity plate. The 78/22 Ni/Fe permalloy bar is also fabricated by the SLIGA process and is a further 2-4 μm thinner than the gears.

Figure 1: An exploded view of the gear pump. The inlet, outlet, cavity and gears are plastic fabricated using the SLIGA process. The pump gears are 24 tooth gears with a pitch diameter of 1.392 mm. The inlet and outlet ports are 0.696 mm in diameter. The driving gear contains a electroplated 0.3mmx1.0mm Ni/Fe bar for magnetic coupling.

Figure 2 shows the plan view and a cross sectional view of the pump/magnetic coupling structure. The micromechanical pump body is located in a tube, 1/8" ID 3/16" OD plastic, surgical grade tubing. The pump body is 1/8" OD to match the tubing. The tube is clamped in place by a bearing which is connected to the rotational magnetic coupling. The coupling consists of two permanent magnets bonded to a ring made of a material with a high permeability, to complete the magnetic path. The air gap is large relative to the scale of the micromechanical device.

One feature of this gear pump design, by stacking stages (i.e., alternating pump cavities and end plates), the outlet pressure head of the pump can be increased roughly proportionally to the number of stages, until the limits of the width of the magnetic coupling or the ultimate pressure limit of the pump seals is

reached. For correct operation, the driving gear in successive stages must alternate sides.

Figure 2: Plan view and cross sectional view of the LIGA gear pump with magnetic coupling structure of in-line gear pump. The tubing containing the micromechanical gear pump is clamped in a bearing which supports the rotating magnetic coupling.

Figure 3 shows an assembled in-line gear pump. The total thickness of the pump is 600 μm , 200 μm each for the two end plates and the cavity. The outside diameter of the pump body (inlet, outlet and cavity plates) is 1/8th on an inch (3.1750 mm). The inlet and outlet ports are 0.696 mm in diameter. The pump gears are 24 tooth gears with a pitch diameter of 1.392 mm. The driving gear has a 78/22 Ni/Fe permalloy bar centered in it of size 0.3 mm by 1.0 mm. The magnetic drive mechanism is fabricated carbon steel to which the permanent magnets are bonded.

2-D FEM simulations of the magnetic coupling in the in-line gear pump structure are used to verify the design concept. The maximum coupling torque of 12.4 $\mu\text{N}\cdot\text{m}$ is generated when the Ni/Fe bar is 45° to the magnetic field. The variation of torque throughout the rotation of the coupling at a fixed angle between the Ni/Fe bar and the magnetic field is less than 7%. Thus, uniform, magnetically coupled torque is produced.

The preliminary experimental results show that the gears could be driven at rotation speed of 3500 rpm, limited by test set up. The in-line pump produces flow rates of at least 70 $\mu\text{l}/\text{min}$. Most significantly, the in-line pump proves to be self-priming. The gear pump created a suction at the inlet tube of at least 45 mm of water. Further testing is underway to determine pressure head and flow rate limits, and as well as refined estimate of the suction.

CONCLUSIONS

This paper presents the first self-priming micromechanical liquid pump. The SLIGA-fabricated, magnetically-driven gear pump produced a suction of 45 mm of water at its inlet. The preliminary hydraulic data indicate that the pump is capable of generating flow rates of at least 70 $\mu\text{l}/\text{min}$. The in-line pump is inserted into tubing and the magnetic actuation is coupled through

the tube walls, which eliminates the pump and connector seal issues and isolates the fluid from the environment.

Figure 3: An optical photograph of an assembled in-line gear pump fabricated by SLIGA. The total thickness of the gear pump is 600 μm , 200 μm each for the two end plates and the cavity.

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