Design and Development of Rotary Peristaltic Pump

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Abstract— This paper presents the design and development of Rotary peristaltic pump. An overview of basic principle, construction, and working of peristaltic pump is provided. Brief literature survey was conducted to check the present status of research work in the design of Peristaltic pump. We considered four concepts for brainstorming and selected one out of four based on the advantages and disadvantages. The theoretical calculations carried out for the flow rate of pump are presented. This prototype consists of Peristaltic pump, coupling and geared variable speed motor. Design calculations, selection of materials and fabrication are carried out by author. As a part of future study, Author will carry out several tests on the pump to know its flow characteristics by using different Viscosity fluids, different diameter rollers keeping tube diameter and other parts of pump unchanged.

Keywords: Peristaltic Pump, flow characteristics, pump design and development.

I. INTRODUCTION

A pump is a device used to move fluids, such as liquids, gases or slurries. A pump displaces a volume by physical or mechanical action. Pump is the oldest fluid-energy-transfer device known. Pumps are used in all types of industries and domestic purposes.

A Peristaltic Pump is a type of a Positive Displacement Pump. It is often used to pump different types of fluids. The principle of positive displacement uses a mechanism to repeatedly expand a cavity so as to allow fluids to flow into the cavity, and then seal that cavity. The fluid then moves forward. The only pumping element of peristaltic pump is flexible tube. The pump works by squeezing the tube with rollers or shoes. This means that pump can run dry, self prime and handle viscous or abrasive liquids, plus, as the tube is one complete unit, there are no seals. This makes the pump leak free and hygienic.

The peristaltic pump is easily obtained at developed country rather than local market. This is due to the lack of Original Equipment Manufacturer (OEM) that is capable of manufacture such a product. Peristaltic pump has many domestic usages such as in medical sector and handling of critical fluid. Thus, a study is needed to systematically be conducted in order design and analyzed the principle operation of such device. [1] This paper focuses on the basic principle of peristaltic pump and its function which is helpful to develop new peristaltic pump.

II. WHAT IS PERISTALTIC PUMP?

Peristalsis is the process of involuntary wave-like successive muscular contractions by which food is moved through the digestive tract. The large, hollow organs of the digestive system contain muscle that enables their walls to move. The movement of organ walls can propel food and liquid and also can mix the contents within each organ. Typical movement of the esophagus, stomach, and intestine is called peristalsis. The action of peristalsis looks like an ocean wave moving through the muscle. These waves of narrowing push the food and fluid in front of them through each hollow organ. The process of peristalsis is used by peristaltic pumps.

A peristaltic pump is a type of positive displacement pump used for pumping a variety of fluids. The fluid is contained within a flexible tube fitted inside a circular pump casing (though linear peristaltic pumps have been made). A rotor with a number of "rollers", "shoes" or "wipers" attached to the external circumference compresses the flexible tube. As the rotor turns, the part of the tube under compression closes (or "ocludes") thus forcing the fluid to be pumped through the tube. Additionally, as the tube opens to its natural state after the passing of the cam ("restitution") fluid flow is induced to the pump. This process is called peristalsis and is used in many biological systems such as the gastrointestinal tract. [4] It was invented by the world-famous heart surgeon Dr. Michael DeBakey while he was a medical student in 1932. [7]

In other words, Peristalsis is the progressive constriction and relaxation of a tube, or canal, so that the resulting wave-like motion moves the contents of the tube forward much in the way toothpaste is squeezed out of a tube. A peristaltic pump achieves this by using rotor inside a semi-circular loop of flexible tubing to squeeze the tube. As the rotor turns, the “pinch” moves around the loop and displaces the fluid through
the pump. Since the fluid is displaced by the contraction of the tube, it doesn’t experience shear or cavitations. [6]

There are 2 types of Peristaltic Pumps based on the kind of pressure they use. They are:

**High Pressure Peristaltic Pumps or Hose Pumps:** These pumps are generally used in high pressure environment (up to 16 bar) and use shoes. They have casings which are filled with lubricants to help avoid damage caused by abrasion to the exterior of the pump and to help dissipate the heat created during the process. These pumps use reinforced tubes so that the liquids do not leak out of the tube due to the high pressures used while pumping.

**Low Pressure Peristaltic Pumps or Tube Pumps:** These pumps usually have dry casings and use rollers. Non-reinforced tubes are also used in these pumps because the pressure on the tubes is not very high.

The working principle of peristaltic pump is shown in Figure 1.

![Figure 1. Peristaltic working](image)

The tubing is fixed between the tube-bed and the rotor at each roller location the tubing is squeezed at position A, B and C. The tubing is continuously squeezed by the rollers which push the liquid in the direction of the revolving rotor. The rollers on the revolving rotor move across the tubing. The tubing behind the rollers recovers its shape, creates a vacuum and draws liquid in behind it. A ‘pillow’ of liquid is formed between the rollers. The pillow is the pump chamber and determines the volume per roller step and, hence, the flow rate. The pillow volume not only depends on the inner diameter (i.d.) of the tubing, but also on the tubing properties, the drive and pump-head specifications as well as the liquid and the physical application conditions. [3]

The pillow volume determines the roller-step volume which depends on:

- **Pump system**
  - Number of rollers
  - Occlusion setting
  - Rotation speed
- **Tubing**
  - Inner diameter
  - Wall thickness
  - Age of tubing
- **Liquid**
  - Type of liquid
  - Temperature
  - Viscosity
- **Application conditions**
  - Suction lift / vacuum
  - Differential pressure

Tubing: It is important to select tubing with appropriate chemical resistance towards the liquid being pumped. Types of tubing commonly used in peristaltic pumps include:

- Polyvinyl chloride (PVC)
- Silicone rubber
- Fluoropolymer [4]

Key features for selection of peristaltic pump tubing are as follows:

1. Chemical attack: One of the key factors affecting pump tubing performance is the fluid being transported. Chemical attack leads to absorption or swelling of tubing, which shortens tubing life. The chemical resistance to a specific fluid should always be determined when selecting a pump tubing.
2. Pressure: Every pumping system has some degree of back pressure. Pressure will generally increase with the length of transport line or with the elevation of the outlet. Exceeding the pressure limits of tubing will decrease it’s life and leads to tubing rupture.
3. Pump RPM: As the roller makes impact on tube when it comes in contact, it is compressed, squeezed and then released to allow for recovery. This cycle is repeated. Various tubing materials have different degree of resistance to it’s flexural fatigue. The number of impacts given tubing is able to withstand is finite. So the tubing life is dependent on pump rpm and number of rollers.
Limitations of Peristaltic pump include:

1. Slight pulsation is inevitable
2. Tubing requires recalibrating and changing due to wear at certain intervals depending on the application. It is very important for accurate and repeatable pumping
3. Tubing may leak after extensive use
4.accuracy and repeatability of the flow rate also depend on the tubing age and material used
5.Max. Differential pressure is lower in comparison to gear and piston pumps depend very much on tubing material and inner diameter in relation to wall thickness.

Typical applications of Peristaltic pump include:

1. Perfusion flow across tissue or cells
2. Pump in and out with balanced flow
3. Transfer bulk liquids i.e. controlled animal feeding
4. Aggressive chemicals and slurries.
5. Pumping fluids without contamination, e.g. water for drinking purpose.
6. Volume pumping such as pharmaceutical, food, chemical, and waste water. [9]

III. PREVIOUS WORK

DeBakey invented the roller pump in heart-lung machine during his student years in 1932. This device, which rhythmically propels fluid through a flexible tube, would later become a crucial part of the heart-lung machine used during open heart surgery. Its ability to replicate the rhythmic pulsing of the human heart earned it the name “peristaltic pump.” [7]

Chris Garneau, Kevin McNamara, Jae Chung in May 2006, in their “Final Report Team D Peristaltic Pump ME 340.4” work have designed and developed a rotary peristaltic pump for contamination free drinking water supply. The challenge for this project was to design and manufacture a subscale pump prototype to be used in a water filtration system. The system must pump a minimum of one gallon of water per minute, and it must provide sufficient delivery pressure to push the water through the system. The system must be manufactured at minimal cost, and so the prototype made with specified, limited resources. They used batteries charged by a solar cell system. After external search, the team chose to pursue a positive displacement type pump. Foremost among the advantages of this type of pump is significantly easier design, resulting in a (theoretically) better approximation of final performance. Positive displacement pumps are also self priming (able to draw in water without external intervention), whereas dynamic pumps are not. They considered three types of positive displacement pumps as linear piston design, peristaltic design and centrifugal pump. The team considered the positive and negative aspects of each pump and selected peristaltic pump as it is self sealing and requires no valves to operate. Team carried out the comparison of analytical and experimental results.

Major problems faced in existing design by this team are as follows:

1. Friction: Most of the discrepancy between theoretical and predicted performance lies in the huge amount of friction in the worm gear mesh, which was grossly underestimated at the start. Excessive friction in the gears had a couple consequences. The first was that it made the pump a lot
slower. The pump was not getting close to a competitive flow rate with the high friction in the gears. The improvement that made the most sense was to apply some form of lubricant to the gears to reduce the amount of friction.

2. Tube shifting problem: Unsteadiness, of the tube running through the peristaltic pump also proved to be a problem. The rotating arm in the peristaltic pump caused the tube to move and shift, and there was also nothing supporting the tube at the top of the pump when the arm was not at the peak point of its rotation. They provided wood support to solve this issue. [2]

Mohd Firdaus Bin Mansor, in November 2008, in his “Design and prototyping a peristaltic pump” work designed and developed a rotary peristaltic pump. The scope of his research was to design the pump for fabrication and determining the component that will be applied on the pump. Then engineering analysis and testing was done on the prototype to test its functionality. He used mild steel angle bar and aluminium and powered by an electric motor. Further improvement to the part of the pump like housing and motor are recommended for further stage of the study.

According to Mohd Firdaus pump designed should have one or more of following advantages:
1. There should be very accurate positioning of the occlusion bed with respect to the rotor assembly to properly occlude the tubing.
2. It should retain automatically a wide range of tubing.
3. It should be simple to operate.
4. It should provide consistent tube tensioning independent of the type of tube used and
5. It should be installed from a single side or single end of the pump. [1]

IV. SPECIFICATIONS AND REQUIREMENTS ANALYSIS

Systems block diagram is shown in Figure 2.

The test setup consists of:
- Variable speed motor
- Speed reduction gear box
- Pump
- Couplings.

It is desired that pump should be able to pump liquid with minimum disadvantages listed above in the existing designs. We considered four concepts during brainstorming and chosen one which fits the requirement.

V. CONCEPT GENERATION AND SELECTION

Figure 3. A schematic of Pump concept 1

The 1st concept under consideration is shown in Figure 3. Pump in this design is vertical. It consists of single lobe mounted on central cam. Cam is keyed to pump shaft. Lobe is kept in position by links provided. Thus when cam rotates it moves lobe in such manner that it pushes fluid in the tube by squeezing it from suction to discharge. Lubricating oil will be used to lubricate interfaces to reduce friction. Due to single lobe design tube will be kept at its location.
The 2nd concept under consideration is shown in Figure 4. Pump in this design is horizontal. It makes use of spring loaded shoes. Shoes are mounted on vertical rotating shaft. As shaft rotates spring loaded shoes pushes fluid in the tube by squeezing it from suction to discharge. Lubricating oil will be used to lubricate interfaces to reduce friction. As there is groove in the casing for tube, it will remain at its position during operation.

The 3rd concept under consideration is shown in Figure 5. This design is improvement of design 2. It makes use of rollers instead of shoes to reduce friction. Rollers are mounted on vertical rotating shaft. As shaft rotates roller pushes fluid in the tube by squeezing it from suction to discharge. Lubricating oil will not be required as rollers will rotate over the tube. As there is groove in the casing for tube, it will remain at its position during operation. There is need to change rollers as per tube diameter.

The 4th concept under consideration is shown in Figure 6. Pump in this design is vertical. It makes use of rollers mounted on bearings instead of shoes to reduce friction. Rollers are mounted on rotor disc as shown in figure. Rotor disc is mounted on shaft. As shaft rotates roller pushes fluid in the tube by squeezing it from suction to discharge. Lubricating oil will not be required as rollers will rotate over the tube. There is need to change rollers as per tube diameter.

Each concept has its own advantages and disadvantages. During brainstorming we considered following factors to choose the optimum design. The factors are Low friction, Complexity of design, ease of Tube replacement, Vibration/noise, Unbalance, Floor space, Axial thrust and pulsating flow.
Figure 6. A schematic of Pump concept 4

<table>
<thead>
<tr>
<th>Concepts (Peristaltic Pumps)</th>
<th>Design 1</th>
<th>Design 2</th>
<th>Design 3</th>
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Table 1. Concept screening matrix

Screening matrix as shown in Table 1 used to select concept. [2]. Concept 4 design is selected for future development and design calculations are carried out to develop this pump.

VI. MERITS OF CONCEPT 4 DESIGN

A concept 4 design has many advantages over other concepts as in concept screening matrix table 1. Author has designed and fabricated this concept. This concept makes use of bearing in the rollers to reduce friction. Also rollers are made up of Nylon material which will further reduce friction between tube surface and roller. Due to this, there will not be any heat transfer from fluid to pump parts or pump parts to tube and fluid. Tube replacement can be done easily in shorter period of time. Different diameter rollers can be used to accommodate different diameter tubes for different applications. Thus this enables to standardise other parts of pump. Using disc type rotor number of rollers can be varied. Rotor disc design is simple to manufacture.

VII. THEORETICAL DISCHARGE OF PUMP

Considering Tube inner diameter 10mm and three numbers of rollers, theoretical discharge calculated over the range of 10 to 140 rpm to know the theoretical performance of the peristaltic pump.

Theoretical flow rate (ml/min) = V * L * N * RPM

Where,

V= Volume of occluded tubing (mm³/mm)
L= Tubing length that will be occluded by pump rollers (mm)
N= Number of rollers on the rotor.
RPM= pump rpm

Figure 7. Graph of Theoretical Discharge of Pump

The above graph shows that with increasing speed discharge increases.

VIII. CONCLUSIONS

This paper presents brief idea of peristaltic pump such as basic principle, construction, and working. Literature survey gives idea of present status of work and challenges in design...
and development of peristaltic pumps. Concept generation and selection caters with the challenges in the design and development of peristaltic pumps. Author has designed and fabricated concept 4 design. As a part of future study, Author will carry out several tests on the pump to know its flow characteristics by using different Viscosity fluids, different diameter rollers keeping tube diameter and other parts of pump unchanged.

REFERENCES