Peristaltic pumps – a review on working and control possibilities

József Klespitz*, Levente Kovács**
* Budapest University of Technology and Economics, Budapest, Hungary
** Óbuda University John von Neumann Faculty of Informatics, Budapest, Hungary
jozsef.klespitz@gmail.com, kovacs.levente@nik.uni-obuda.hu

Abstract—**Peristaltic pumps are positive replacement pumps, commonly used in fluid transports. These pump does not contaminate the transported fluid, they are undemanding and ideal for shear-sensitive and aggressive fluids. Through their wide spectrum of use, there are many variants of these pumps based on their special needs, such as high pressure need, long tubing lifetime or low pressure deviation. The object of this paper is to review and summarize the most important properties of these pumps and introduce some of the special solutions of these pumps focusing on control engineering possibilities.**

I. INTRODUCTION

The peristaltic pump represents a type of positive displacement pump, which is commonly used for transporting a variety of fluids [1], [2]. The fluid flow is generated in the equipment by periodically pressing a tube segment to the pump housing (the manifold), where the increased pressure will move the fluid, while the back-flow is prohibited. Most commonly the peristaltic pump contains a pump segment (and tubing), a manifold and a rotary pump head. The pump head is a rotor, which contains two or more rollers and these rollers press the tubing to the manifold; in this way pressure is generated in the tube.

The goal of this paper is to review the properties of peristaltic pumps and to summarize industry-used solutions from control engineering point of view.

II. PERISTALTIC PUMPS. FUNCTIONALITY AND CHARACTERISTICS

A. Basic operation of peristaltic pumps

In this section the operation of peristaltic pumps will be discussed for the most commonly used two rolled tube pump [1], [3]. However, this operation differs somehow for some of the pumps discussed in the rest of the paper.

At the beginning of the sequence the first roller closes the tubing inlet. As a result, the roller moves forward and pushes the pump segment to the manifold. Hence, it pushes the fluid inside the tube forward and generates a pressure wave. Before reaching the outlet the other roller closes the tube inlet, and in this way it prevents the black-flow. After the first roller leaves the outlet, the other roller's task will be to generate the next pressure wave. The described sequence is repeated over time and can be seen in Fig. 1.

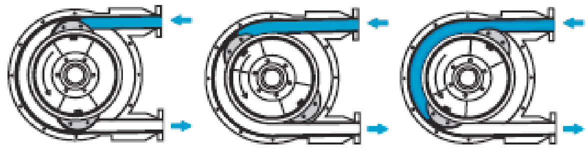

Figure 1. Peristaltic pump flow scheme [4]

B. Types of peristaltic pumps

Peristaltic pumps can be distinguished by many points. One of the most important differences can be characterized by tubing. From this aspect two types can be distinguished: the tube pumps and the hose pumps. The difference between them is the hose pumps contain a pump segment, which is a reinforced tube, called hose. These hoses are harder to be pressed and this way they need bigger and stronger motors for the same flow; hence, they are more expensive to operate. The main advantage of hose pumps is that they can operate against much higher pressure than tube pumps working up to 16 bars [5].

The tube pumps contain silicon, PVC, flouropolymer or other polymer as material of tubing. These are the most common type of peristaltic pumps tubing and as materials are improving the difference between hose pumps and tube pumps are melting. Tube pumps can operate against less pressure, but they need smaller motors and force to operate; hence, this way they are space-saving and cheaper to work with. [6], [7], [8].

Comparing to other pumps the (linear) peristaltic pump is more accurate, when the pressure gradient is under -13.3 Pa (-100 mmdHg). In other cases piston pump is more accurate. [9].

The next difference between peristaltic pumps can be the type of propulsion. The most current type contains a central rotor and on these rotors it has rollers. The task of these rollers is to press the lining and by this way to force the transport, but also to prevent the back-flow.

There is a solution, which only needs one rotor to operate with. This 360 degree peristaltic pump is a rarity [10], common pumps contains at least two rollers. In some occasion one of the rollers roles could be only to prevent back-flow, but usually the entire rollers task is to force the fluid movement [5].

With increased number of rollers it is possible to generate more pressure waves over time and this way to decrease the deviance of pressure on the output. However, this means more occlusion for the same transferred volume; hence, it reduces the lifetime of lining [11].

The pumps can be distinguished by how their rollers are fixed. The simplest solution is the fixed occlusion. The rollers have fixed locus; hence, they keep the same distance from the manifold during the entire rotation(s). This method is simple, robust and undemanding. However, fixed occlusion reduces the lifetime of the tube segment, because it depends on its wall thickness [12].

Alternatively the rollers can be spring loaded. In this case the rollers are mounted on springs, and this way the rollers keep almost constant pressure on the tubing. The advantage of using spring loaded rollers is the elevated tubing lifetime, the constant pressure and that they can handle a broader range of wall thickness. The shape of the rotor and the housing is usually symmetric; however, there are solutions, where the asymmetry of the system is used to increase lifetime and stability [13].

Above, the rotor type peristaltic pumps were discussed, but it is not possible to transport fluid in circular tubing, where there could be linear pumps as well. These linear pumps are often called “finger pumps”. In linear peristaltic pumps cams generate the necessary pressure and also cams prevent the back-flow. The name finger pump shows well how they work. The cams close each other one-by-one; hence, pushing the fluid forward. After this the cams release the lining. At the other end of the pump before the last cam release the tube segment the first cam closes again, and this way the pressure is kept and back-flow is prohibited. This process is called peristalsis and is used in many biological systems such as the gastrointestinal tract [14].

The advantage of linear peristaltic pumps is they are space-saving, but on the other hand they need more complex mechanics.

C. Advantages and disadvantages

Advantages of peristaltic pumps can be summarized as follows [15], [16], [17]:

As the transported fluid flows in the tubing and the driving force is generated by the compression the fluid will not get contaminated, neither the pump head nor the pump mechanism. It is appropriate to use only clean tubing, and the pump mechanism does not need any cleaning. Hence, it is easy to keep them clean and sanitized. As the fluid does not leave the tubing these pumps are virtually immune to abrasive media and many chemicals. Some of the tubing material can be autoclaved; consequently, sterility can be kept.

Peristaltic pumps do not need any specific action for priming as they are capable of self-priming. They are also insensitive to dry running as the fluid is not necessary as lubricant and the tubing does not damage if compressed empty. Moreover, pumps do not contain any valves, seals or glands; hence, they are easy and cheap to maintain and the chance of malfunction is also lower.

They can operate reversibly against other type of pumps. Furthermore, during the use mostly the tube is worn by time, which is cheap to replace. Multi-channel systems can be built easily as well [17].

Their suction height is excellent and when stopped, no siphoning effect will occur. The viscosity of the fluid does not influence the transport; hence, suspensions and sludges cannot influence the transport.

The delivery is gentle due to the low shearing forces; by this way they are ideal for shear-sensitive fluids such as blood (due to the blood cells). Moreover, their high repeatability make them suitable for auto-analyzers.

However disadvantages of peristaltic pumps can be formulated as well [18], [19], [20]:

Due to deviation caused through the production and the replaceable tubing, the pump system must be calibrated to reach acceptable accuracy. Due to the wear the tubing it needs to be changed and recalibrated over time. In case of extensive use or in absence of exchange the tube may leak. In some case their chemical inertness can be disadvantage as well.

Slight pulsation is inevitable at work. The flow rate is sensitive to varying differential pressure conditions and their maximal differential pressure is lower comparison to gear and piston pumps.

III. Applications of Peristaltic Pumps

Peristaltic pumps can be found in many applications. Below a review can be found with the practical property which is necessary in the given application [7], [13].

By the utilization of the minimal shearing forces we could have:

- Hemodialysis machines
- Open-heart bypass pump machines
- Beverage dispensing

By the utilization that they are capable to deliver both suspensions and sludges we can distinguish:

- Concrete pump
- Sewage sludge
- Pulp and paper plants

Regaring if one would like to help that fluid does not get contaminated we could have:

- Medical infusion pump
- Pharmaceutical production
- Chemical analytical equipments

Using pressure deviation categories are:

- Liquid food fountains
- Decorative fountains
- Waterfalls

From high repeatability point of view:

- Autoanalyzers

Regarding the chemical compatibility there is:

- Carbon monoxide monitor
- Dosing systems
- Calcium reactors

Regarding the space spare solution one should consider:

- -Mobile peritoneal dialysis pump [22].

IV. Need for Calibration and Control

In peristaltic pumps the accuracy mainly depends on the tube segment due to deviation caused through production. On the other hand, the pump housing and the pump head is the only permanent part of the pump and different tube segments that can be loaded for use.

This way it is always necessary to calibrate or control the pump. Calibration methods will be not discussed in this paper, but it will focus on the control technics.

When controlling a peristaltic pump the controlled property will be the delivered through the fluid volume. However, the pump itself cannot give any information about the delivered volume; it is only possible to measure the number of rotation or pump head velocity.

The pressure pulsation and the differential pressure sensitivity are also unwanted properties, controllers will be showed to eliminate these phenomenon.

V. CONTROL POSSIBILITIES

A. *Control using flow meter*

The most common solution for controlling the delivered fluid volume is to measure the fluid flow at the output of the controller. Depending on the actual implementation, the flow meter can take place separately from the pump, or it can be built in common housing. [23].

These solutions can be distinguished by flow meter type and the type of the controller. The flow meter can be in contact with the transferred fluid [24] or it can leave the fluid intact [25]. The necessity of cleanness decides which solution can be chosen. The contact fluid meters are usually turbine fluid meters. The intact fluid meters can use electromagnetic, Doppler- or optical sensors to determine the flow of the fluid.

Using these variables the simplest solution is to use open loop control. However, everything is given to design closed loop control, where the known methods can be used (e.g. PID control, robust control, etc.).

B. *Minimizing the pulsation*

As it was discussed above the peristaltic pump generates pulsation due to the pressure waves which are generated by the rollers. In some application this pulsation cannot be tolerated, but other properties of the peristaltic pump are necessary (for example in chemical analytical systems). Such pulsation can be seen on Fig. 2 and the effect of minimization can be seen on Fig. 3.

One solution can be the use a classical control methodologies with closed loop feedback mechanism [26]. In this case the pressure and it's deviation can be kept in a given interval, which can be planned this way.

Another approach can be the elevation of the number of pump heads; however this reduces the tubing lifetime [27] as mentioned before.

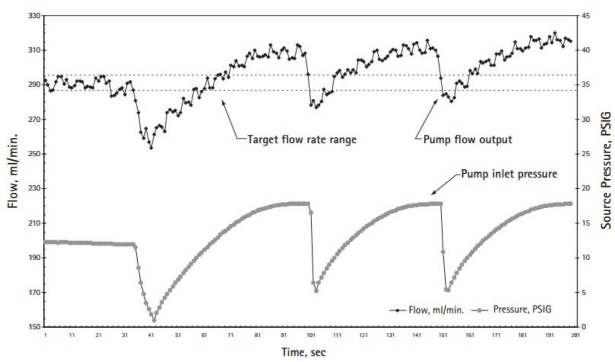

Figure 2. Pulsation in the flow and pressure output [27]

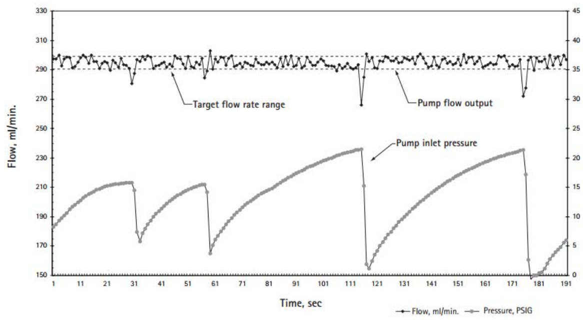

Figure 3. Result of pulsation control mechanism [27]

A very different approach is to use an atrium after the pump. The atrium is an elastic tube segment, which expands due to the pressure elevation and after this it transfers the fluid forward due to the elastic energy, but with less pulsation [27]. This solution is very similar to the mechanism of the heart in mammals. The drawback of this solution is that the reduction in deviation is more difficult to plan and it will highly depend on the used materials.

C. *Repetitive control*

Repetitive control deals with periodical signals. It intends to track/reject arbitrary periodic signals of fixed period [28]. Repetitive control was extended for periodical signals with varying frequency as well [29]. By this way it is suitable for controlling peristaltic pumps and it is also effectively used in practice [30].

D. *Control in hemodialysis machines*

Hemodialysis machines are special as they are safety relevant systems, where the patient's life depends on the machine. Not only the blood, but other medical solutions are transferred with peristaltic pumps. The calibration or control of the blood pump is always a relevant question. Most commonly the inlet pressure (the pressure of the arterial line) is used to control the pump; by this way it is possible to eliminate the differential pressure dependence [31].

For the same pump a solution could be to use of classical PI control [32], [33] or fuzzy control [33].

A whole new approach is to control not only the blood pump, but every other pumps in the system as well, by measuring the fluid bags on the machine and by calculating the required delivered volume the pump speed can be controlled by the weight loss of the fluid bags [33].

VI. CONCLUSIONS

Peristaltic pumps are commonly used pumps in medical systems. Although they have many advantages, there are properties that cannot be ignored. One of these is the need of calibration or control when using a new tube segment in the pump, the pressure pulsation, the differential pressure dependence and the inaccuracy due to the deviation caused through production should be compensated.

There are different possibilities to solve these problems. In the current paper the control mechanisms were examined. In addition to the classical control methods some special solution were also highlighted.

ACKNOWLEDGMENT

The authors are grateful for the B.Braun Melsungen AG for their help. Levente Kovács was supported by the János Bolyai Research Scholarship of the Hungarian Academy of Sciences.

REFERENCES

[1] M. Misra, "The basics of hemodialysis equipment", *Hemodialysis International*, vol. 9, pp. 30-36, 2005.

[2] C. Jacobs, C. M. Kjellstrand, K. M. Koch and J. F. Winchester, "Replacement of Renal Function by Dialysis", *Springer Netherlands*, 1996.

[3] Y. M. Kadahm, "Medical Equipment II- Hemodialysis", unpublished, 2012.

[4] PSG, "Paint & Coatings industry: Abaque Series Peristaltic Pump", http://www.psgdover.com/assets/blackmer/images/pump_action_peristalt.jpg, 17.12.2013.

[5] Alaska Department of Environmental Conservation, "Introduction to pumping systems", pp. 210-211, 2008.

[6] Frank's Hospital Workshop, "Peristaltic pump", http://www.frankshospitalworkshop.com/equipment/documents/infusion_pumps/wikipedia/Peristaltic%20pump.pdf , 17.12.2013.

[7] Elkay Laboratory Products Ltd., "Peristaltic Pump Tubing", 2013.

[8] Spectrum Chromatography Ltd., "Peristaltic Pump Tubing", http://www.lplc.com/tubing/pumptube.html , 17.12.2013.

[9] R. Jenkins, H. Harrison, B. Chen, D. Arnold, J. Funk, "Accuracy of intravenous infusion pump in continuous renal replacement therapies", American Society of Artificial Internal Organs, pp. 808-810., 1992.

[10] Apex pumping equipment, "Larox peristaltic pumps", http://www.262apex.com/metering__dosing_pumps.html, 17.12.2013.

[11] J. M. Berg, T. Dallas, "Peristaltic Pump", SpringerReference, 2013.

[12] E. N. Aitavade, S. D. Patil, A. N. Kadam, T. S. Mulla, "An overview of peristaltic pump suitable for handling of various slurries and liquids", Journal of Mechanical and Civil Engineering, pp. 19-24, 2012.

[13] M. Ghare, "Peristaltic pump: Basics and applications", http://www.buzzle.com/articles/peristaltic-pump-basics-and-applications.html, 17.12.2013.

[14] Saylor Free Education, "Pump", http://www.saylor.org/site/wp-content/uploads/2011/04/Pump.pdf , 17.12.2013.

[15] Ragazzini, "Rotho Peristaltic Pumps",, http://kecopump.com/docs/RothoOverviewEmail.pdf , 17.12.2013.

[16] Micheal Smith Engineers Ltd., "How a peristaltic pump works", http://www.michael-smith-engineers.co.uk/pdfs/howperistalticpumpworks.pdf , 17.12.2013.

[17] Watson-Marlow, "Peristaltic Pumps for Engineers", http://www.watson-marlow.com/Documents/knowledge-hub/Brochures/gb%20-%20UK/Product/Watson%20Marlow%20UK/b-OEM-gb-02.pdf , 17.12.2013.

[18] D. Gelfand, "Multitube peristaltic pump with individual programming control", US Patent 3832096, 1974.

[19] T. Turner, "Hidden dialysis", http://www.yankodesign.com/2013/06/18/hidden-dialysis/, 18.06.2013.

[20] Equflow sensors, "Finally to be able measuring and totalizing pulsating flows",

[21] http://www.equflow.com/applications/peristaltic-pump-control , 17.12.2013.

[22] Watson-Marlow, "120 peristaltic pumps", http://www.watson-marlow.com/Documents/knowledge-hub/Brochures/us%20-%20USA/b-120-us-02.pdf , 17.12.2013.

[23] Equflow sensors, "Peristaltic pump control system",

[24] http://www.equflow.com/sites/default/files/bijlagen/bestanden/peristaltic_pump_control_system.pdf , 17.12.2013.

[25] Entegris, "Flow control for peristaltic pump on CMP process tools", http://www.entegris.com/resources/assets/3962-1602.pdf , 17.12.2013.

[26] Kinesis Scientific Exprets, "IPC and IPC-N peristaltic dispensing pump", http://fluidics.kinesis-usa.com/ismatec-ipc-pump , 23. 04.2013.

[27] J. A. Klein, "Roller pump and peristaltic tubing with atrium", US patent 20090053084, 2009.

[28] Y. Yamamoto, "An overview on repetitive control- what are the issues and where does it lead to?", Kyoto University, 2001.

[29] G. A. Ramos, R. Costa-Castelló, J. M. Olm, "Repetitive control", Lecture Notes int Control and Information Sciences, pp 5-12. 2013.

[30] G. Hillerstrom, J. Sternby, "Application of repetitive control to a peristaltic pump", American Control Conference, pp. 136-141, 1993.

[31] T. J. Patno, M. P. Sahlin, "Peristaltic pump controller with nonlinear pump calibration coefficient", Patent WO1999023386, 1999.

[32] G. Ingesson, H. Sandberg, "Speed control of a peristaltic blood pump", Lund University Master thesis, 2013.

[33] J. Klespitz, L. Kovács, "Identification and control of peristaltic pumps in hemodialysis machines", International Symposium on Computational Intelligence and Informatics, pp. 83-87., 2013.