An Overview of Disarray in Design, Analysis and Verification of Performance of the Peristaltic Pump

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Abstract— The peristaltic pumps are used in the pharmacy and medical industries. They have good flow rate control and also there is no direct contact between the fluid flowing and the atmosphere. The tubes for peristaltic pump are suggested by the tube manufacturer and tubes are changed after the defined time. In existing design of pump which is manufactured by sponsoring industry, the tube gets worn out before the life span claimed by the tube manufacturer. Also if the occlusion ratio is not appropriate the discharge will not be satisfactory. Thus to make the design safe, many a times the motor is selected for a higher rating and the tube thickness and the occlusion ratio are kept high. As a result the whole structure becomes bulky. This paper tries to give an idea about the previous researches and their finding about Design, analysis and verification of performance of the peristaltic Pump.

Key words: Flow Rate, Occlusion Ratio, Peristaltic Pump

I. INTRODUCTION

A peristaltic pump is a type of positive displacement pump that moves fluid by squeezing a tube or hose causing the fluid inside to follow the motion of the roller. Peristaltic pumps are valuable for pumping abrasive or corrosive fluids that could damage or contaminate rotors or gears and for pumping delicate fluids such as blood. Peristaltic pumps are widely used in medical and pharmaceutical industries. It is also useful for applications requiring rugged pumps with minimal maintenance.

Fig 1: Schematic representation of a peristaltic pump

Peristaltic pump works on the principle of peristalsis process carried out in human body. The human intestine is in fact a peristaltic pump as muscle contractions push the food forward through the bowels. The fluid is contained within a flexible tube fitted inside a circular pump casing. 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 tube under compression closes thus forcing the fluid to be pumped to move through the tube. Figure 1.1 shows the schematic representation of a peristaltic pump. The modern peristaltic pump is moreover designed with the built-in possibility of using different sizes of tubes.

As reported in peristaltic pump manufacturer’scatalogues that tube of peristaltic pump are to be changed after a defined time span or else there may be chance of tube failure. As discussed earlier the tube is pinched to nearly zero cross section for delivering fluid by the roller. The tube is made from a rubber while rollers are made from steel. If tube is pressed excessively by the roller there may be chance of failure of tube. Most analyses on peristaltic pumps are performed using empirical relations or analytical equations based on idealized flow and pump geometry. Analytical methods rely on the various assumptions. By use of analytical method it is difficult to predict when and how the failure will occur. Especially in advanced numerical methods such as finite element method (FEM), used in combination with experiments, will reduce number of experiments and confidence of designer will be increased by simulating all kind of load cases and their combinations which may not be possible by experimentation. FEM should never be used alone without experimentation (especially for initial few cases for getting confidence and correctness of boundary conditions and other assumptions) because there are many chances of errors.

In recent decades with development in mathematics and computers very efficient FEM software’s were developed (E.g. – ANSYS, Abaqus etc). These software’s in combination with high computational powered work stations (computers) are working very efficiently. But for using FEA software, highly experienced people are required because a small mistake in assumption or applying boundary condition may be cause of larger error in results. Most important thing about FEA is that results which are inaccurate as well as correct, may be displayed in colored image.

The design of any product is an output of various considerations, right from the manufacturability, reliability, maintainability, cost, factor of safety, size, shape, weight, efficiency, etc. Thus selection of an appropriate design is a combination of various parameters. As the design result is a compromise of man parameters there will always be scope for optimization. Hence there is not an exact answer to any design or related question. Codes are giving flexibility of using different design approaches and technology by stating that the code is not a handbook and cannot replace education, experience and use of engineering judgment, also it suggests for using of FEA software in many situations.

II. LITERATURE REVIEW

Many of researchers have contributed in development of peristaltic pump.

Morley. A (1980) discussed in his book about the stresses developed in the pipe and deflection caused by the external force. The pipe is considered as a simple thin cylinder. He assumed the pipe as simple thin pipe having uniform thickness. When it is subjected to the external pressure, the circumferential or hoop stresses may be calculated by simple formulae. The total thrust is the critical value necessary to produce instability. This critical value might by analogy be deduced from Euler’s rule applicable to
struts or columns, if the length and end conditions of the equivalent struts are known. If slight distortion of the circular section into an elliptical shape be assumed, then the critical pressure will be such as will maintain the slightly distorted shape in equilibrium against the elastic restoring force of the wall.

King, O (1985) invented a mechanism for the peristaltic pump for increasing the life of the tube. The tubes are fixed at ends of tubing and said relative angular displacement about the center line of the tubing in between 1/10th and 1/12th of a turn about the central axis of the tubing. The curved tube has an inner radius which is little less than its outer radius this results in smaller deviation from relaxed or zero stress. The invention is particularly applicable to pumps which incorporate an encompassing wall against which the tube is squeezed. Passage of the cam roller over the inner surface of the tube will result in twisting of the tube in direction to diminish the degree of pre-twist. The result is less movement out of the curved plane that would occur in the absence of pre-twist.

Becker (1985) invented a mechanism for peristaltic pump. In his patent he mentioned the spring loaded occluding rollers, each having an axis substantially parallel to the axis of the motor. The said base has concave shape which helps the tube to occlude properly. The latch is provided on door stator, so that door may be pivoted and the tube may be removed easily.

Maguire (1986), in his patent made simple construction of the peristaltic pump. The invention has a provision for quick and easy insertion and removal of peristaltic tube. The pump is quickly and easily engaged in driven rotation with the motor. The roller cage applies unique rotary and thrust bearing effecting substantial savings in cost and minimizing wear. The annular array of rollers is always in contact with the tube, thus resulting in avoidance of the fluid slippage.

Francesco Moscato, et al. (2008) studied pressure pulsation in peristaltic pump. Inlet and outlet pressures obtained by the mathematical model have been compared with those measured in various operating conditions: different rollers’ rotating speed and different tube occlusion rates. The complete electric analogue model was built for the pump. The researchers’ found that the flow pulsation is caused during the roller engaging with the tube and disengaging with the tube. The angle that the roller covers to fully engage (disengage) with tube was imposed by the geometry of the pump and was set equal to 32°. Using the lumped model the researchers showed that the tube’s inner walls do not adhere perfectly and hence a regurgitate flow occurs through the meatus. Direction and magnitude of this flow depend on both the pressure gradient across the squeezing roller and the fluid resistance through the meatus. At this position roller-I had fully engaged and roller-II was at the beginning of its disengaging phase. The inlet pressure decreased for the peristaltic effect due to the engaged roller, while outlet pressure decreased for the suction effect due to the tube shape recovery mechanism at the disengagement of the other roller. The researchers suggested through this paper that changes in the roller can help to reduce the pressure pulsations.

U. Suripa and A. Chaikittiratanu (2008) carried out the finite element analysis of the solid tire. The researchers’ considered the tire as a hyper elastic material. The 3D FE model for static loading analysis of solid tire constructed in this study gave reasonably good prediction of load-deflection behavior of a real solid tire. It can also be deduced that the distributions of analysis parameters such as strain energy density and Von Mises stress given by the FE analysis are acceptable and can be used to improve the design of solid tiers. The tire made entirely with the rubber of the same hyperelastic property as the tread layer can give more flexible deformation and thus more comfortable ride with lesser risk to damage due to heat generation. The results obtained from FEA for the load-deflection behavior were validated by the experiment that was carried out for the same. This paper revealed that the 3D FE model for static loading analysis of solid tire constructed in this study can give reasonably good prediction of load-deflection behavior of a real solid tire.

Vidal (2010) invented a methodology for occlusion adjustment of the same. The improved peristaltic pump includes at least one elastically flatenable tube and at least two assemblies of two pressing elements (rollers) placed opposite to each other. Each of said assemblies is configured to compress the tube at different points from the pump. These two pressing elements of a single assembly are placed on either side of the tube. At least one of the pressing elements of this single assembly is mobile such that the distance separately the pressing element of the single assembly is adjustable, so to allow the pressing member to be placed in position of compressing the tube. Advantageously, the adjustment is made automatically when the peristaltic pump or pumping is started or stopped.

Nagi Elabbasi, et al. (2011) studied fluid-structure interaction analysis of a peristaltic pump. The model captures the peristaltic pumping action, and the interaction between the rollers, tube and fluid. It was used to predict the stresses and strains in the tube, as well as the flow and flow fluctuations. The author has considered the 2 roller peristaltic pump interacting with the Newtonian fluid. He has considered the standard elastomeric material and used a standard Mooney- Rivlin hyperelastic material model. The analysis is carried out with frictionless condition. The results were found only for 50 % of occlusion. Also no experimental analysis was carried out.

III. CONCLUSION

From the literature review it can be seen that inventors have worked on developing various methodologies for improving the efficiency of the pump as well as to minimize the wear of the tube. As mentioned the most critical part in this pump is the tube. Generally tubes used in this pump are made from rubber materials. There are theories defined for design of simple tubes.

The main research issues are;

1) The design of pumps is generally based on empirical relations. For peristaltic pump, which is positive displacement pump has no such design procedure. It has a hyper-elastic material used for conducting the fluid. This increases the complication of the design of pump.

2) The work was done for studying the effect of solid-fluid interaction at tube walls of peristaltic pump at 50% of occlusion only and at constant rpm.
3) Many mechanisms were developed to reduce wear, but no discussion on efficiency of pump done.
4) Design by formulae is forcing for higher factor of safety and hence higher material and manufacturing cost, but researches have shown that increased thickness can contribute to premature failure of tube and more consumption of energy. Hence it is always not efficient to use higher factor of safety.

It can be seen that there is a scope for evaluating the stress and strain generated in the tube. The modern techniques will help to optimize the design of peristaltic pump. Even some have invented the mechanisms and techniques to reduce the wear of the hose, but the prominent thing from the above literature for review is that there is no standard procedure for designing the peristaltic hose as well as for the rollers. As there is no standard procedure for designing this pump it was decided to go with modern techniques and look out for modification in the existing design. Also no one has studied the effect on performance of peristaltic pump at different occlusion ratios.

REFERENCES