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A NOVEL DESIGN OF HYDRO ELECTRIC TURBINE USING FLOW LIMITATION OCCURRING IN MODIFIED LARGE COLLAPSIBLE TUBES

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ABSTRACT

Turbines that have evolved from ancient water wheels are one of the most efficient devices available for extraction of energy from flowing fluids. All turbines work on same physical principles and have similar basic components consisting of stators and rotors connected to vertical shaft, which rotates freely. They convert kinetic energy of flowing water to mechanical energy by changing the momentum of flow of water. They suffer drawback of being inefficient and expensive when used for low energy density flows. I had exploited the phenomenon of flow limitation occurring when fluids flow in collapsible tubes and also strong fluid structure interactions occurring when a flow stops suddenly, to design a novel type of hydraulic turbine. Water from small reservoir enters a large collapsible rubber bladder and as the flow is established due to Venturi effect the rubber bladder collapses suddenly on to the mouth 'U' shaped flexible tube held by elastic supports. This action occludes the flow suddenly converting steady continuous flow to unsteady pulsatile flow. The kinetic energy of flowing water is converted to negative pressure wave energy or water hammer, which interacts with walls of flexible tubes at, bends and transmits power to the system. This enables us to develop turbines, which operate at very low heads and low discharge conditions (heads as low as < 1.5 m and flows as low as < 0.3 litre/sec) and generate power efficiently in a very cost effective manner. This radically new principle can be applied to other fluid flows like gas turbines and produce novel efficient machines for harnessing power.

KEYWORDS: Collapsible Tubes, Fluid Structure Interactions, Hydraulic Ram, Turbines

INTRODUCTION

A turbine is a machine, which extracts energy from continuously flowing liquids with help of rotating blades and sometimes has fixed blades to direct jets of water to rotating blades [1]. Modern day hydraulic turbines are one of the most efficient man made devices. But they suffer from one inherent drawback i.e. they require high energy density flows to operate efficiently which means they require either large head or large flow to operate efficiently. Either of these conditions to be satisfied in realty requires huge investments involving lot of civil engineering construction works and has the potential to create long term ecological disasters. Large head hydro electric projects (Ex:- Pelton turbine) require erection of huge dams which is possible only in hilly areas serving as natural reservoirs, otherwise they submerge vast tracts of open plain lands. Also in order to generate power efficiently by current technology principles at low heads we require large flows and large diameter turbines, which escalate the cost of entire project. As head diminishes the cost effectiveness reduces i.e. to generate same watts of power efficiently, our cost inputs must be high. Therefore there is a need for alternative technology, which overcomes these shortcomings and produces power in cheaper manner, besides being environmentally friendly [2].

When a fluid flow is driven through a deformable channel or tube, interactions between fluid-mechanical and elastic forces of deformable tube can lead to different kinds of interesting phenomena, including nonlinear pressure-drop/flow-rate relations, wave propagation, and the generation of instabilities. Understanding the physical origin and nature of these phenomena remains a significant experimental, analytical, and computational challenge, involving unsteady flows at low or high Reynolds numbers, large-amplitude fluid-structure interactions and free-surface flows [3].The collapsible tubes buckles and collapses at the distal most point of tube as the internal pressure is least between entry and exit end due to viscous pressure drop

The classical experiments used to investigate flow limitations are similar to ‘Starling Resistor’ which is demonstrated in figure below (Figure 1). Here a collapsible tube is tied between ends of two rigid pipes and the collapsible tube is enclosed in a pressurized chamber. The upstream pressure, the flow rate and the external pressure outside the collapsible tubes are all regulated. Varying the pressures or flows keeping rest of parameters constant sees two different phenomena. They are flow limitation when pressure drop across the tube is increased keeping the upstream pressure – transmural pressure constant and pressure limitation, which is produced by increasing the volume flux and keeping the transmural pressure – downstream pressure constant. At flow limitation point self excited flutter waves were observed to occur and all these behaviors were extensively studied by Bertram and co workers [4].

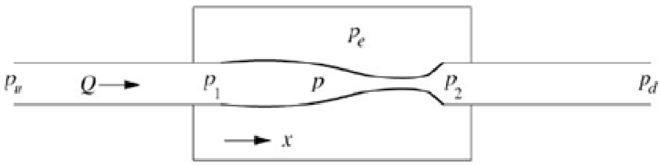


Figure 1: Starling Resistor Schematic Representation P_u is Entry Pressure, P_d is Exit Pressure, P_e Is External Pressure, P_1 & P_2 are Pressures inside the Collapsible Tube, Q is Flow Rate and X is Length of Collapsible Tube

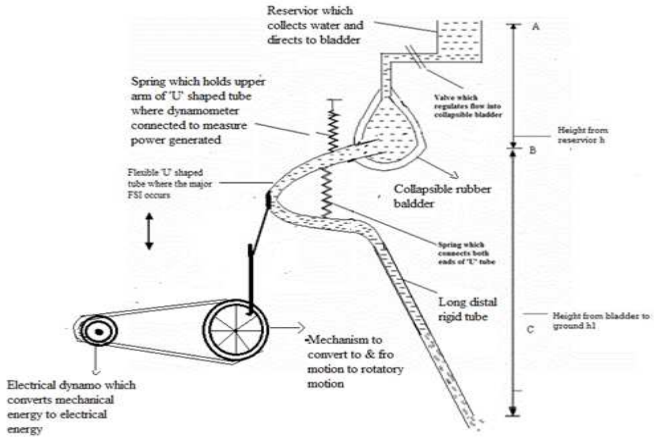
These experiments are widely used to explain various biological phenomenon’s like airway closure, generation of sound and wheeze, generation of blood pressure sounds or Korokoff sounds while recording blood pressure, collapse of veins when blood is flowing against gravity and sometimes flutter waves generated in these collapsed veins [5].

But modifying these collapsible tubes flows for generation of pulsatile flow from continuous flow and utilization for power generation is never described before. The present experiment may be considered as extreme modification of this basic “Starling Resistor”. Previously pulsatile flow produced by rapid flutter of collapsed tube was used to enhance microfiltration performance of Bentonite suspension by Wang et a [6]. But the pulsatile flow produced by Wan g*et al*. was similar to classic “Starling Resistor” models and the rapid flutter of collapsible tube is used to enhance the ultra filtration of bentonite suspension fluid across an osmotic membrane

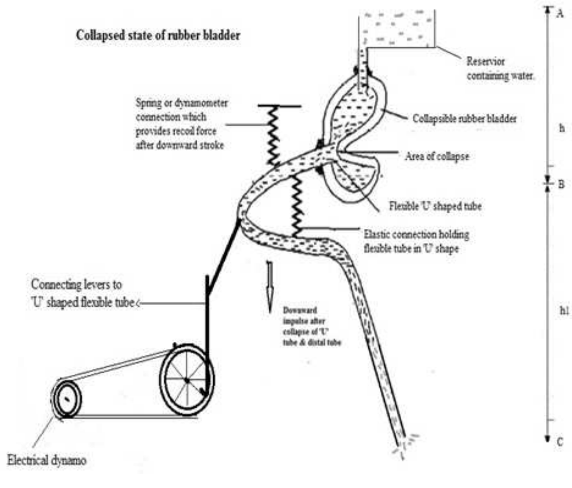
The pulsatile flow model has been successfully utilized as a simulation model for study of cardiovascular hemodynamics in laboratory setup [8]. It can be characterized as a novel technology in design of “hydraulic engines” different from any turbine design used for mechanical energy extraction from kinetic energy of flowing water. This is possible by connecting the distal end of large elastic collapsible rubber bladder to a unique arrangement of flexible ‘U’ tube held by elastic supports. In this part large-scale fluid structure interactions (FSI) manifest, which are different from those occurring inside the collapsible bladder. (The term “hydraulic engine” is used, as the present experimental model cannot be classified as a turbine, as there no water jets, blades/vanes, or any rotating shafts involved in working of this device)

Description of Experimental Setup

It operates on basic principle that, water falling from small heights as low as less than one meter and low flow (< 0.5 litre/sec) is channeled to a small reservoir like arrangement which converts the open channel flow of natural stream flow is to close channel pipe flow. The arrangement begins with this container or small reservoir opening through short pipe vertically down into a collapsible rubber bladder connected to flexible pipes at the lower end. The water enters the collapsible bladder and comes out the lower end of collapsible bladder through ‘U’ shaped flexible tube connected to it by airtight arrangement. The flexible tube is connected to straight rigid tube of light material and it hangs down from above without touching the ground and is freely mobile. The ‘U’ shaped tube made of flexible material is held by elastic supports in order to maintain angle of≈ 180^0 at the bend point of the ‘U’ shaped tube. The upper part of ‘U’ shaped bend is connected to a vertical spring and lower part of bend is connected to a mechanism, which converts two and fro motion to rotatory motion. This mechanism is in turn coupled to an electric dynamo that generates power. The schematic diagram of experimental setup both in expanded and collapsed state of rubber bladder is illustrated in Figure 2



(a)



(b)

Figure 2: Schematic Diagram Representing Expanded (a) And Collapsed State (b) Of Collapsible Bladder

Experimental Procedure

As the bladder gets filled up with water when valve from small reservoir above is released, it distends and later it starts collapsing as the water drains out the distal end of bladder through ‘U’ shaped flexible tubes. If the vertical height from the valve to balloon is less than from ground to the balloon (h1 > h2) and during certain range of flow rates it exhibits an interesting phenomenon of alternate collapse (buckling) and opening, along with generation of pulsatile flow of water. The flow of water entering into the large collapsible rubber bladder was regulated by a valve and the flow rate can be measured by flow meter attached to it. Though pressures can be recorded at any point of the arrangement we choose at two points, one at the entry at the collapsible bladder and other at the end of ‘U’ tube to record the pressures. These points were connected by very small diameter (2-3 millimetres) tubes to Phlips portable MP20 monitor and electronic pressure transducer system [8]. The force generated during the movement of ‘U’ tube was measured by spring dynamometer connected to upper arm of ‘U’ shaped tube. The lower arm of ‘U’ shaped flexible tube was connected by a lever and wheel arrangement which converts to and fro motion of the ‘U’ tube to rotatory motion (Actually for convenience a demo model of two stroke diesel engines was utilized for this purpose). The smaller wheel of the mechanism was connected to a electrical dynamo which generates power as the copper coil in centre rotates in the magnetic field and the electrical power generated was recorded with help of standard multimeter used for testing electrical circuits.

The actual photographs of the experimental model are given in Figure 3 & 4.

Figure 3: Photograph of Experimental Model from Front Showing the Pipe Connections and Collapsible Bladder

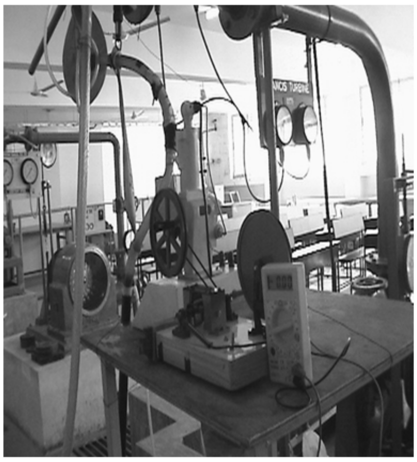


Figure 4: Side View Photograph Showing Collapsible Bladder Connected to ‘U’ Shaped Tube, the Upper Limb of ‘U’ Shaped Tube Connected to a spring and Lower End Connected to Demo Model of two Stroke Engine

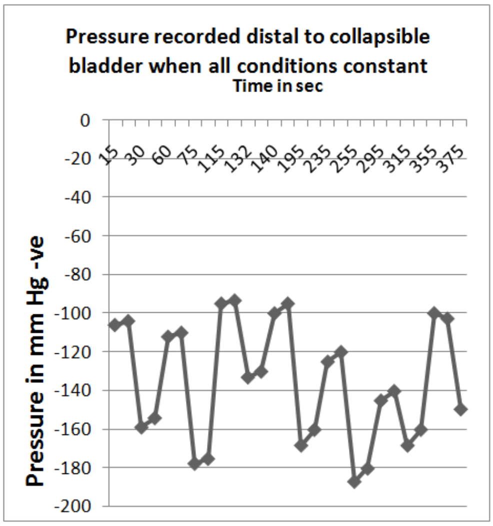


Figure 5: Pressure Tracing in 'U' Shaped Tube When the Pulsatile Flow is Being Produced

The pressure at the entry of the collapsing bladder remains fairly constant at a –ve pressure of -4 to -10 cm of water with slight fluctuations during the entire cycle. The distal end of collapsible bladder exhibits rapid and wide range of fluctuations, which can be explained by very strong fluid structure interactions. At the mouth of 'U' shaped tube collapse occurs far more rapidly than other regions of the collapsible bladder due to Venturi effect and halts the flow suddenly before the collapsible bladder empties out fully. The sudden stopping of flow causes the velocity of flow to change rapidly andwhen time interval t is < 2L/C where L is length of 'U' shaped and distal tube connected to it and C is velocity of sound in water, waterhammer effect is produced. At such rapid changes of flow velocities causes generation of negative water hammer pressure wave inside the flexible 'U' tube and positive pressure wave inside the collapsible bladder [8](Figure 5).

The presence of almost 180` bend at the 'U' region causes junctional coupling to be the predominant fluid structure interaction manifesting during the pressure surge. The 'U' shaped tube strikes down with strong force pulling the spring down which was supporting the 'U' shaped tube from above. The power generated by the oscillations of 'U' shaped tube was calculated depending upon the force produced per oscillation and multiplying with frequency of oscillations per second. The hydraulic efficiency in this manner was found to be in range of 60 % - 95% depending upon flow conditions. (The hydraulic efficiency of a standard micro hydroelectric power plant is 55% and hydrokinetic turbines are approximately 22%[2]). These high efficiencies are seen even for such low energy density flows like flow rate < 0.3 liters/second total vertical height of waterfall is 1.5 – 2 meters and average velocity of flow is 1 – 3 meters/ second. In order achieve maximum efficiency it is important there are no further bends in after the main bend in 'U' shaped tube as lot of energy is wasted at the other bends and useful work cannot be extracted. Hence a long rigid tube of light material is connected at the end of 'U' tube without any bends and all connections are airtight. The overall efficiencies when taking into consideration of friction losses due to movement wheels and levers connected to 'U' tube, and also electrical generator losses, would be less than directly measuring the force generated by 'U' tube. Due to technical and financial constraints the frictional losses were considerably high in the mechanical designs we had chosen, and we are working for further improvements in these components of the apparatus.

The downward movement of 'U' shaped tube forces the collapsed portion of bladder to open up and get filled with water flowing from above reservoir. Once the bladder is opened up the hydraulic flow is re established and once again after reaching peak velocity the bladder collapses again and the cycle continues as long as there is water flowing from reservoir above. Thus a continuous steady flow is converted to unsteady pulsatile flow at the discharge end and the average velocity of this pulsatile flow is much less than when the flow is continuous. Thus the kinetic energy is converted to pressure surges or wave energy, which causes forcible up and down strokes of distal pipes through fluid structure interactions.

Theory and Equations of Experimental Setup

Collapse in collapsible tubes is given by flow limitation equation or ‘Tube Law"[9], [10].

$$\frac{1dA}{Adx} = -\frac{1du}{udx} = \frac{-Ru}{c2-u2} \quad (1)$$

c is velocity of sound in water

By applying continuity of mass and momentum principle the basic equations of the above tube law is derived and we can see $\frac{dA}{dt} = -KA$ i.e at the area of collapse, the rate of collapse reduces at a rate proportional to initial area of collapse and this leads to exponential reduction in area of collapse at distance “x”.

For further mathematical derivation and equations governing the exact collapse and energy transmitted to membrane we have to refer to works of M Heil, Bertram, Pedley and others [11]-[14].

Once the bladder is collapsed the flow stops suddenly and there is sudden surge in pressure which is given by extended Joukowsky equation for elastic tubes and non rigid supports

$$\Delta p = \rho\, c\, \Delta v$$

$$c_{elastic} = \sqrt{\frac{\frac{E_F}{\rho}}{1 + \frac{E_F}{E_M}\frac{d}{s}K}} \quad (2)$$

Δp is pressure surge and ρ is density of fluid Δv is change in velocity of fluid flow

E_M is the Young‘s modulus of pipe, E_F bulk modulus of fluid, the inner diameter d, the thickness of the pipe, s and additionally the factor K ($0<K<1$), which depends on the geometry and the fixing of the pipe structure (spring constants of springs attached) [15].

This pressure surge is in negative atmospheric pressure range in the distal pipe whereas it is similar magnitude but positive atmospheric pressure inside the collapsible bladder. This transient positive pressure surge overcomes the negative hydrostatic pressure inside the collapsible bladder and causes it to open up and reestablish the flow, thus producing pulsatile flow

From knowledge of the ‘strength of material’ the total strain energy stored in the flexible pipe during the water hammer is given by equation [7]

$$= \frac{\Delta p^2 d\, l\, A}{2\, E_M\, s} \quad (3)$$

Where *d* is the density of pipe, *l* is length of pipe, *A* is area of pipe and *s* is thickness of pipe

The efficiency of device can be calculated by assuming that the entire strain energy is converted to longitudinal motion of pipe and dividing it by the total kinetic energy of flow of water.

Kinetic of energy of water is given by equation

= **1ṗ a l V²**where ṗ is the density of water, *V* is average velocity of water.

Theoretical efficiency of the device is given by equation

= $\Delta p^2 d$

$E_M s \dot{\rho} V24)$

When water hammer wave is generated then there are three types of fuid structure interactions are possible and which one of these predominates depends upon the nature of the pipes, number of bends and angle of bends and most important the elastic properties of the supports with which the pipes are held. They are

1) Piossons coupling 2) Frictional coupling and 3) Junctional coupling (most important)

These are well described by works of Wiggert D.C, Tijsseling, A. S[16] etc. Junction coupling is taken place due to unsupported discrete points of the piping systems such as unrestrained valves, junctions, closed ends, pumps, etc. MOC (Method of Charecteristics) and FEM (Finite Element Method) are used to solve the complex structural equations and for further details of exact axial motion of pipes, following articles have to be referred [17],[18]. The motion of pipe was also described by various other mathematical models and Janez et al have given eight equation models for predicting the motion of bend pipes during FSI [19].

DIMENSIONS OF EXPERIMENTAL SETUP

About the Collapsible Bladder

The dimensions of the collapsible rubber bladder when fully expanded state, which assumes geometric shape of ellipsoid, is: -

Horizontal diameter is = 12 cm

Vertical diameter =20 cm

Volume of fully expanded Balloon is = 1600 cc

The thickness of the rubber used in

The rubber is = 0.75 mm

About Distal 'U' Shaped Tube

The distal 'U' shaped tube is made of relatively flexible PVC pipe with following characteristics

The length of 'U' tube is = 60 cm

Height of U tube is from collapsible

balloon to distal rigid tube is = 30 cm

Vertical height of distal rigid tube

from flexible Ushaped tube is = 140 cm

Inner Diameter of U shaped

flexible tube is = 12 mm

Thickness of U shaped tube is= 2 mm

Inner Diameter of distal rigid tube is = 11 m

Thickness of distal rigid tube was 1.8 mm

Spring constant of first spring connecting U shaped tube to roof 380 N/m

Spring constant of second spring connecting both the ends of U shaped tubewas300 N/m

RESULTS

Table 1: Relationship of Flow Ratevs Power Generated When Vertical Height Fixed at 1.8 M from Bladder to Lower End of Distal Straight Tube of Diameter 12 Mm

Flow Rate in Liter/Sec	Frequency / Minute	Amplitude in cm	Force Per Oscillation in gm	Power Available in Watts	Power Generated in Watts	Hydraulic Efficiency in %
0.1	122	3.5	425	1.7	0.9	**53**
0.13	115	4	500	2	1.1	**56**
0.139	103	4.3	550	2.2	1.2	**54.5**
0.145	108	5	625	2.2	1.7	**74**
0.17	96	5.3	660	2.7	1.7	**62**
0.19	84	7	900	3	2.5	**84**
0.250	70	6.5	800	3.9	1.8	**46**
0.27	62	6.8	850	4.2	1.8	**42**
0.33	58	6	750	5.2	1.3	**25**
0.35	37	7	900	5.6	1.2	**20**

Table 2: Flow Rate Is Increased and Variation of Frequency of Oscillations & Power Generated Studied at Constant Height 160 Cm

Volume of Flow in l/Sec	Frequency no/min	Amplitue in cm	Force Generated in Kg	Power Avialable	Power in Watts	Hydraulic Efficiency %
0.18.	136	3	1	3.1	0.76	24
0.2	128	8.5	1.085	3.6	1.2	35
0.222	114	9	1.125	3.9	1.8	45
0.227	115	8	1.150	4	3	75
0.25	112	10.	12.	4.4	3.9	89
0.3	106	10.5	12.50	5.3	4.77	90

Table 3: When Flow Rate is Held Constant at 250 Ml/Sec and Height Is Varied

Vertical Height in cm	Freq of Oscillation Per Min	Amplitude in cm	Max Force Per Oscillation in Kg	Power Available in Watts	Power Generated Watts	Hydraulic Efficiency
30	96	0.1	0.1	0.1	0.03	**0.42**
50	92	3	0.5	0.49	0.32	**35**
96	91	5.4	0.7	0.7	0.41	**47**
130	86	7	1	0.98	0.67	**63.7**
150	97	7.6	1.12	1.1	0.8	**80**
165	58	8.5	1.25	1.3	1.0	**64**

Table 4: When the Diameter of 'U' Tube and Distal Tube is Increased from 12 Mm to 18 Mm and Height of Tube from Collapsible Bladder is Kept Constant at 150 Cm

Vol of Water Flow in cc/Sec	Freq of Oscill Per Min	Amplitude in cm	Power Available from Flow in Watts	Power Generated in Watts	Hydraulic Efficiency in %
0.18	136	4.5	2.6	1.7	**65**
0.2	128	5.5	3	2.7	**80**
0.22	114	6.5	3.2	2.9	**92**
0.23	115	5.5	3.3	2.16	**65**
0.25	112	7	3.6	3.42	**93**
0.3	106	8	4.4	4.2	**95**
0.33	100	8.5	4.9	4.48	**92**

Conclusions of Experimental Results

- When the flow rate is increased by turning the inlet valve of the collapsible bladder, while keeping all other parameters constant, the frequency of oscillations reduces but the amplitude of each oscillation increases and the hydraulic efficiency increases to maximum and then again falls (Table 1 & 2). Here the vertical heights of waterfall and tube diameters of tubes were held constant.
- Similarly we can infer as the height of waterfall or length of distal tube is increased then the frequency of oscillations is reduced while the amplitude of each oscillations increases and hydraulic efficiency improves gradually (Table 3).
- When the diameter of the 'U' shaped tube and distal long rigid tube are increased even at low flow rates and vertical gradients, higher efficiencies of power generation were achieved (Table 4).

The results of the experiments are better exemplified by plotting graphs of various parameters measured (Figure 5).

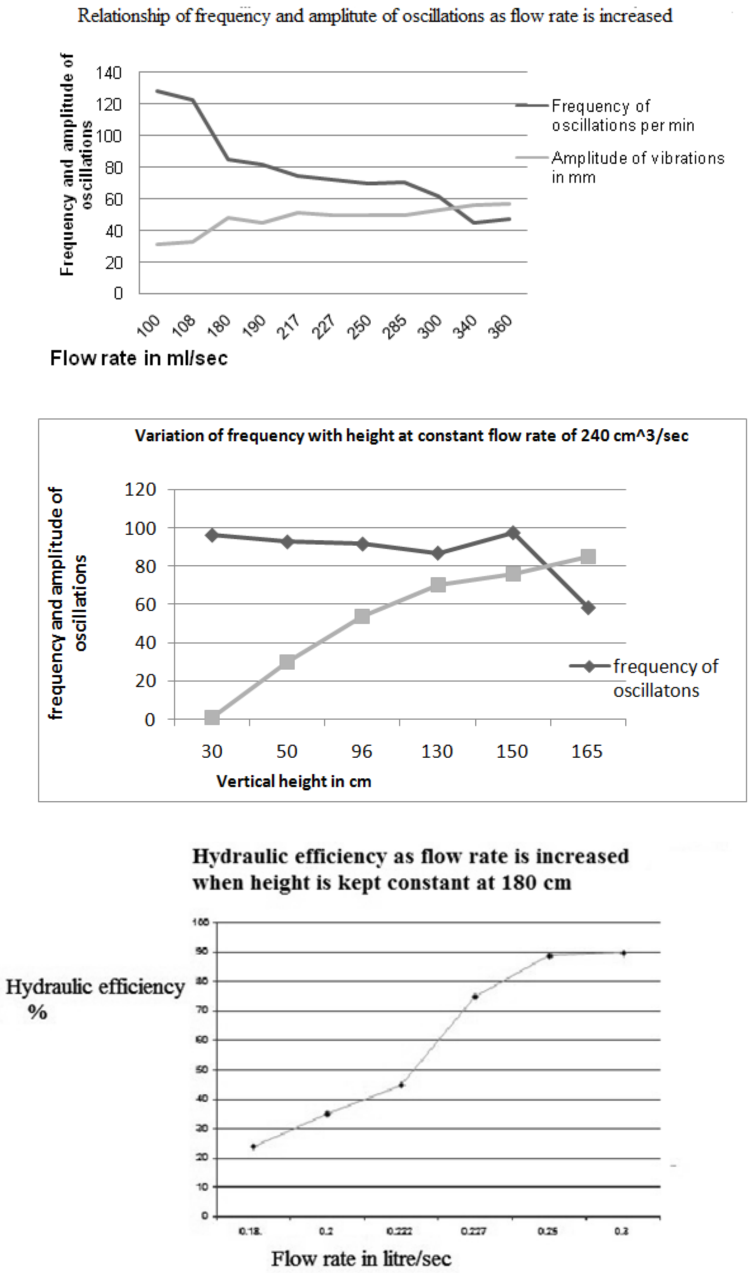


Figure 5: Graphs of Experimental Results

- The effieiciency graphs (Figure 5) resemble the efficiency curves of stand ardhydroelectricturbines like Pelton wheel and Francis turbine.
- The variation of frequency and amplitude of oscillations with flow rates, vertical gradients and diameters of pipes gives scope for tuning of the apparatus to wide range of flow conditions for achieving maximum efficiency.

Also at such low flow and head conditions none of the conventional turbines operate, leave alone functioning efficiently. Even though very high hydraulic and overall efficiencies achieved with using slightly larger diameter pipes the stresses on the balloon are very much. During my experiments with similar head and slightly larger diameter distal pipe > 6 mm from previous tube diameter the bladder ruptured suddenly in the middle unable to take the stresses of pressure surges. The collapsible bladder is the weakest part and it has to be of significant strong material and also have to property of elasticity to work for larger flow rates. For large collapsing forces the strength of balloon must be enhanced with greater elasticity, thickness and also by increasing the balloon dimensions. Similar experiments were conducted in much small scale using small sized balloons and tubes which worked very well, though data was not recorded, due to technical difficulties

DISCUSSIONS

The present experimental setup involves two principles of operation.

- Flow induced collapse in collapsible tubes which produce unsteady pulsatile flow from continuous flow.
- Strong fluid structure interactions occurring in flexible tubes held by elastic supports.

These principles are in complete contrast to the basic mechanism of turbine design, which operate upon the reaction force generated on the blades or buckets when the momentum of striking jet of water is changed as illustrated in Figure 6. The addition of fixed gates or wicket gates in Francis and Kaplan type turbines increases the efficiency of turbines greatly[1].

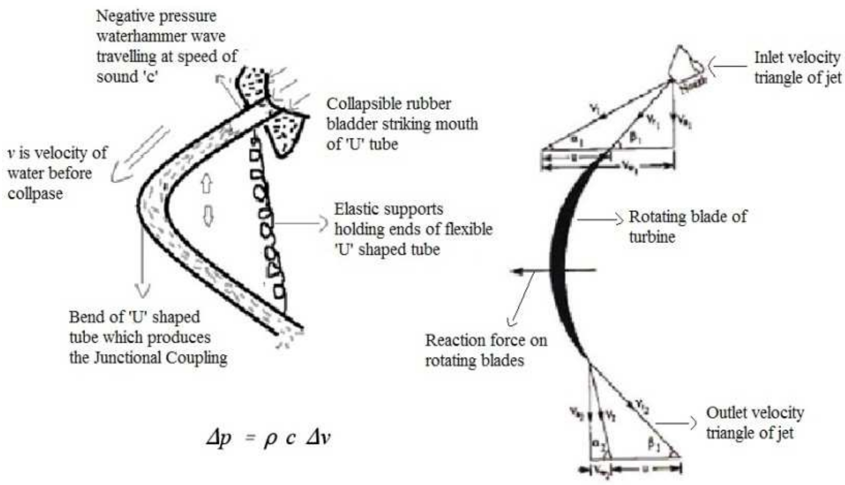


Figure 6: Comparison of Basic Working Principle of Resent Model and to That of Any Conventional Turbine

Unlike any conventional turbines or water wheels there are no jets involved striking the moving buckets, vanes or rotor blades. Only specially designed flexible and conducting pipes are involved in energy conversion and hence operate at very low head and flow conditions quite efficiently. Also they do not require large flows, they are small to build and cost also reduced very much. It does not create any ecological disturbances as water falling from small heights is sufficient and no need to built large dams or reservoirs [2]. Large civil work required to direct large quantities of water through a turbine as required in efficient operation of low head turbines are not necessary. Also it can operate in wide range of flow conditions quite efficiently and there are no specific speeds of turbines involved for operational efficiency as the mechanism involved is quite different from traditional turbines [7].

Due to this principle any turbine designed needs either large head or large flow to operate efficiently. It is true hydraulic turbines are one the most efficient machines designed (hydraulic efficiencies range 90 - 95%) but these require high energy density flows to function efficiently. To have large head we need to submerge large areas of land to create large reservoirs and dams which prove to be very costly and create lot of ecological disturbances. To channel large flows into turbines also requires significant civil engineering works disturbing the natural course of flow of entire rivers. Besides the cost of entire project depends upon the diameters of turbines and they increase disproportionately at lower heads [2]. Also low head turbines also have high specific speeds for optimal operational efficiency and higher the specific speeds of turbines, higher are the input costs.

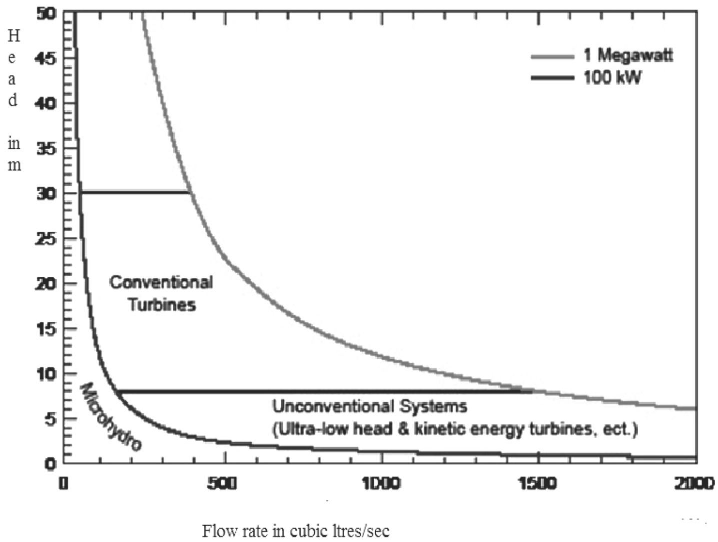


Figure 7: Illustrating Operation Requirements of Various Types of Hydraulic Turbines

Figure 7 shows that large scale hydro electric power plants typically generate power in megawatt and require 10 meters and above Head and flow rates above 500 liters/sec.

Micro hydro power generate power in 100 kw range require 5 meters and above head and flow rates above 100 - 500 liters/sec and ultra low head or hydrokinetic turbines require very low heads 2 meters and flow rates above 200 liters/sec and they are not as efficient as large scale hydroelectric power plants[1].

Small sized Pelton wheels can work at very low flow rates like <0.5 liter/second but they require large heads to operate which are not easily available under natural conditions. The present device works at very low flow and heads i.e flow rate of 0.3 liter/ second and head 1.5 – 2meter/second. This is because our model operates on different physical principles and the fluid dynamics equations involved are quite complicated than traditional models and still lot of research need to be done in this particular area. Another advantage of using a pulsatile flow model instead of continuous flow model is at low energy density flows they work much efficiently analogous to reciprocal engines being used in small automobiles as opposed to high power jet engines used in aeronautics.

A practical application of water hammer effect, which has been there for nearly 200 years, is hydraulic ram pump. In this large quantity of water flows down certain minimal height and the flow of water causes the waste valve to automatically shut and the water comes to halt suddenly and this causes steep rise in internal pressure of the water trapped below the valve and it opens another delivery valve at the mouth of smaller diameter pipe. This high-pressure surge causes water to rise to far greater heights than what it started flowing initially and water is pumped up in this unique manner in a pulsatile manner. These are cheap, easy to construct require minimal maintenance and no electricity is required to operate. After video demonstration of this novel device some of them have described it as ‘oscillating waterfall’ and many of the equations of hydraulic ram can be applied to it.

The hydraulic ram mathematics is modeled using unsteady-pipe-flow equations based on continuity principle and momentum equations. The quasi-linear partial differential equations are solved using method of characteristics (MOC) transformations by Veliko Filip an [20] and others. The simpler algebraic equations for describing the hydraulic ram functioning are given by Development Technology Unit (DTU) research [21] and can be adapted to present model in deriving simplified equations for frequency and efficiency depending on pipe characteristics.(Figure 8) Also we can derive the time period of oscillations, the efficiencies of the device at various heads and diameters of the pipes. The device can be tuned to achieve maximum efficiency by adjusting the flow rate for given set of heads, diameters of pipes and elastic constants of the supports used.

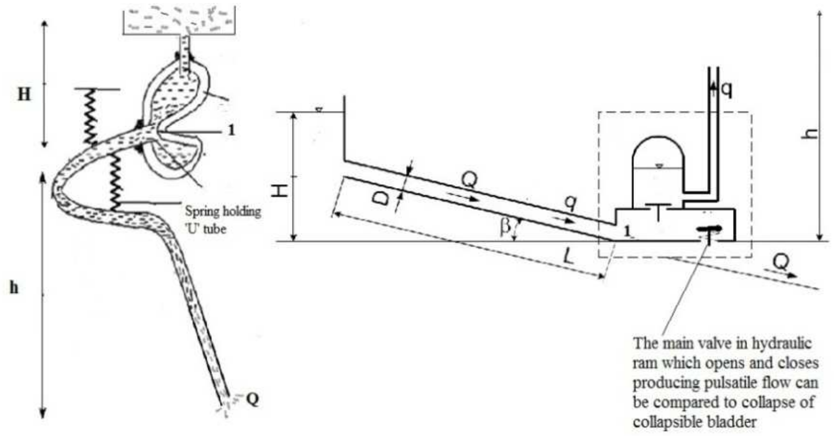


Figure 8: Comparison of Working Hydraulic Ram with That to 'Oscillating Waterfall

The theoretical and mathematical explanation of this novel principle appears very complicated requiring integration of diverse subjects of fluid mechanics which are individually complicated involving simultaneous solving of several partial differential equations requiring computers. A unified and simplified explanation must be developed for better understanding of this infant subject. Larger scale testing requires procurement of special equipment, for example a large sized, more thicker and tougher rubber bladder to function at larger flow conditions, otherwise it simply tears under extreme stressful conditions which tend to develop during the collapse period. Application of similar technological principles in designing novel gas turbines may yield revolutionary results with better efficacies than demonstrated by any other existing turbine technology. Preliminary experiments on gaseous flows showed that the design has to be modified significantly to be able to work on these novel principles. The collapsible bladder must be enclosed in a pressurized chamber where the surrounding external pressure is regulated and the bladder must be bended in a particular shape to produce spontaneous pulsatile flow from continuous flow of pressurized gas.

The experiments pertaining to this novel technology have been uploaded at You tube site http://www.youtube.com/watch?v=kcf5bGglRXg and anyone can go to the website to view the video recordings for better comprehension

CONCLUSIONS

A novel method of harnessing power can be developed by combining the principle of flow limitation in collapsible tubes and fluid structure interactions in flexible pipes held with elastic supports. This produces a very efficient low head and low flow hydraulic engine. This novel technology needs to be studied further in a larger scale with advanced mathematical approach and also has potential for development of more new applications in future.

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