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Power Generation from the Residual Energy in the Discharge Water of a Turbine

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1. **Abstract**: During operating conditions when turbines are run at varying loads due to separation of fluid flow at the rotor of the turbine high velocity turbulent flow of inlet water is converted into an unsteady flow at the outlet. Such unsteady flow has been known to be the principal cause of vibrations in turbines. Energy harvesting techniques commonly make use of piezoelectric crystals for power generation from vibrations. In case of turbines direct utilization of such techniques lack efficiency from an economic standpoint. So a novel method of energy harvesting is proposed in this paper: 1) an apparatus to generate and amplify vibrations is designed and fabricated. 2) a double bucket symmetric Pelton Turbine with a discharge of 3.81kg/sec is used. 3) arguments in favor of the design specifications of the apparatus used for the particular experiment are given 4) power generating capacity of the apparatus is tested at multiple load and throttle conditions.

Keywords: Energy harvester, piezoelectric, turbine vibrations

2. Introduction

The principal function of a hydraulic turbine is power generation. To achieve this high velocity water is allowed to impinge on the rotor blades of the turbine and the rotational motion of the turbine rotor is converted to electric power by an alternator attached to it. The ever growing necessity of power requires us to extract the maximum energy possible from all known energy sources. Similar is the case with turbines. After the stream of water passes through the rotor of the turbine the water flow still contains high velocity that can be extracted. Thus multi staging of turbines has become popular today as it can efficiently and effectively extract almost the entire energy content of the flowing water. Even then some amount of residual energy remains in the discharge water which cannot be harvested by any known method. On the other hand such discharge water is also the principal cause of vibrations in radial turbines. For instance Francis turbines, which have a fixed-pitch runner, have a high level of residual swirl at the draft tube inlet as a result of the mismatch between the swirl generated by the wicket gates (guide vanes) and the angular momentum extracted by the turbine runner. In the turbine draft tube the flow exiting the runner is decelerated, thereby converting the excess of the kinetic energy into static pressure. The decelerated swirling flow often results in vortex breakdown above a certain level of the swirl number. This vortex breakdown is now recognized as the main cause of the severe

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pressure fluctuations experienced by hydraulic turbines operating at part load [4]. Various known vibration harvesting techniques have been used to extract energy from the vibrations in the body of the turbine, the results however are less than satisfactory as the vibrations generated disperse throughout the body of the turbine and so does the vibrational energy along with them. Thus energy extracting from any one point has been found to be futile.

We propose a biphasic solution to the above problem. In the first phase the amplitude of the generated vibrations is increased. And in the second phase the entire vibrational energy is concentrated at one point and harvested from it. Increasing the amplitude of the vibrations occurring in the body or casing of the turbine would most certainly damage the internal components of the turbine. In view of this fact any attempt to amplify the turbine body vibrations is strictly ruled out. So we move to the source of the vibrations i.e the discharge water of the turbine. If the unsteady flow of the discharge water can create vibrations in the body of the turbine it can also do so in another body. Thus we design an apparatus on which vibrations are generated by the impinging discharge water of the turbine. And these vibrations are then amplified and concentrated at one point so as to harvest energy.

3. Method:

We have designed and fabricated our own apparatus for use in the experiment. The apparatus has been designed to extract the maximum energy from the outlet water of the turbine by inducing vibrations in a cantilever beam and imparting those vibrations to the spring mounted on the beam. Cantilever beams have been previously used for energy harvesting methods [2]. In such cases a layer of piezoelectric materiel is used over a cantilever beam made of various materials such as silicon [3]. Such techniques suffer from the limitations that large piezoelectric beam would not withstand large deflections, such as those caused by large volume of discharge water. Also the shape and size of the PZT used affects the amount of current generated by the whole setup [5]. To overcome such defects we use aluminium as the material for the cantilever beam in our experimental model of the apparatus. The frequency of vibration of the spring in the apparatus is equal to or close to the natural frequency of vibration of the spring so that the effect of resonance can be created and maximum vibration can be induced. Due to the sudden impact of the fluid on the cantilever beam displacement of the beam in the vertical direction takes place, this is maximum at the free end and minimum at the fixed end. This sudden vertical displacement provides a torque to the spring along with vibrational energy. The spring under the influence of the torque makes a to and fro motion to forward and backward positions. Along with the spring the plate mounted on the spring also makes the similar motion. While in motion the pins fixed to the plate strikes on the piezoelectric discs held in forward and backward positions by the holders. Upon being struck the piezoelectric materials produce electricity which is directly proportional to the applied pressure. Thus the

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utilization of pin increases the pressure as it decreases the area of application of force.

The free end of the cantilever beam is bent and converges to a point which is aligned with the centre of the spring. The bent in the free end opposes easy movement of the striking fluid and also creates eddies thereby creating more vibration. The bend in the free end converges to a single point so that the direction of application of torque and also the to and fro motion of the spring is inline and does not make any angles thereby striking the piezoelectric materials perpendicular to their surface.

The apparatus in accordance with figure 1 is composed of cantilever beam 6 which is fixed on the base 8 with the help of rivets such as rivet 7. The spring 5 whose natural frequency of vibration is equal or nearer to the frequency of vibration of the cantilever beam 6. The beam 6 vibrates when the flowing fluid impinges on the bent 1 of the beam. This vibration is imparted by the beam 6 to the spring 5. Due to the to and fro motion of the spring 6 the plate 3 along with its pins 2 and 4 also moves forward and backward and strikes the piezoelectric disc 10 in the forward position and piezoelectric disc 9 in the backward position. The piezoelectric disc 9 is held in its position by the holder 11 and the piezoelectric disc 10 is held in its position by the holder 12. When the force generated by vibration of the beam 6 is applied on the piezoelectric discs 9 and 10 by the pins 2 and 4 electricity is generated and can be taken out from the piezoelectric discs with the help of suitable electrical circuit.

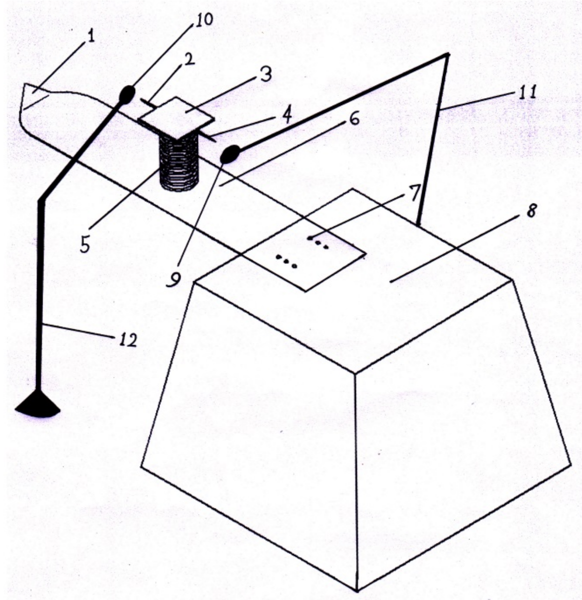

Figure 1

4. Theory and Calculations:

The design of the apparatus is based on the discharge load of water impinging on the apparatus, which was found to be 3.81kg/sec. Material chosen for the cantilever beam is aluminium as it has a modulus of rigidity of 70GPa.

3.1 For the design of the cantilever beam three cases are considered:

Case 1: Square cantilever beam

The natural frequency of vibration of the beam is calculated to be 0.28Hz. And the length and breadth of the beam are assumed to be 0.2m each. The required spring constant of the spring to create a near resonance condition in the spring is found to be k=3.1

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Case 2: Rectangular cantilever beam with length at fixture

In the second case the natural frequency of vibration of the beam is found to be 0.042Hz. The length and breadth of the beam are assumed to be 0.7m and 0.2m respectively. So the required spring constant of the spring is k=0.0696

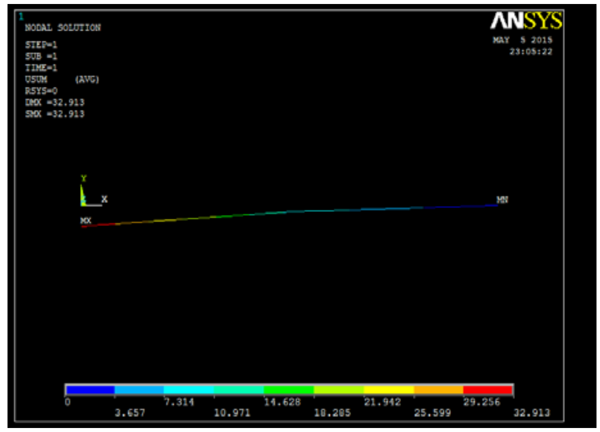
Case 3: Rectangular cantilever beam with breadth at the fixture

In this case the natural frequency of vibration of the beam is found to be 0.08Hz. The length and breadth of the beam are assumed to be 0.2m and 0.7m respectively. And the required spring constant of the spring is k=0.253

Analysing the above three conditions we understand that the cantilever beam having rectangular cross section with breadth at the fixture is the most suitable for the design of the apparatus as its frequency of vibrations is acceptable considering the design parameter of the apparatus. A higher frequency would decrease the energy dissipated per strike of the pin and a lower frequency would cause damping by superposition of the vibration waves in the beam.

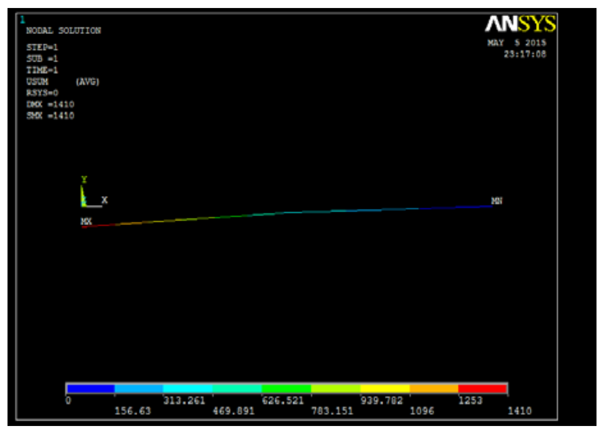
3.2 An analysis of the above three cases in section 3.1 is done in ANSYS in order to determine the displacement provided by the impinging load of water on the cantilever beam.

Case 1:



The maximum displacement of the beam is found to be 32.913mm

Case 2:



The maximum displacement in this case is found to be 1409.1mm

Case 3:

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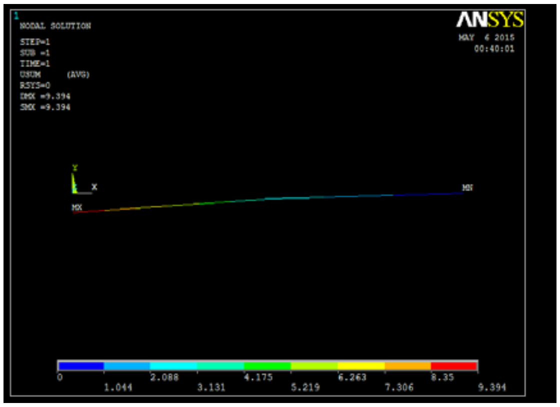
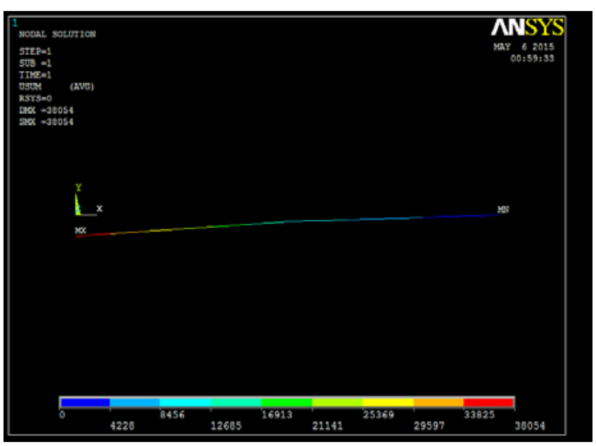


The maximum displacement is this case is found to be 9.3939mm

Analysing the above three cases we once again conclude that case 2 has the most promising results as the displacement values of case 2 is suitable according to the design parameters of the apparatus.

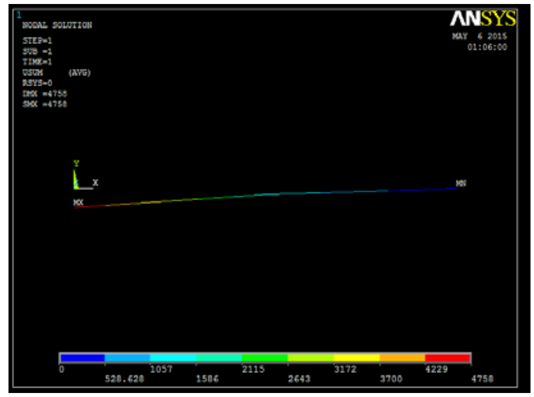
3.3 Next we analyse the thickness of the beam to be used. We conduct an ANSYS analysis of 5 cases of the thickness of the beam ranging from 1mm to 5mm

Case 1: Thickness 1mm



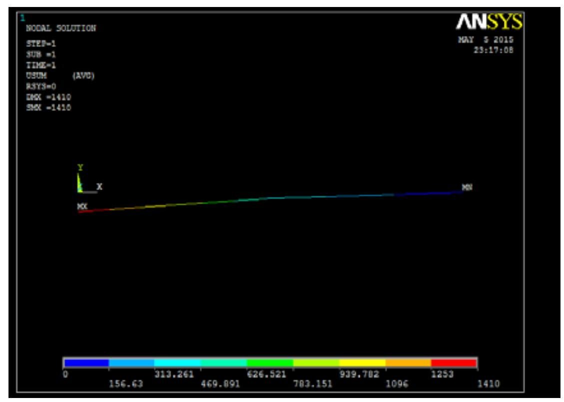
The maximum displacement in this case is found to be 38054mm

Case 2: Thickness 2mm



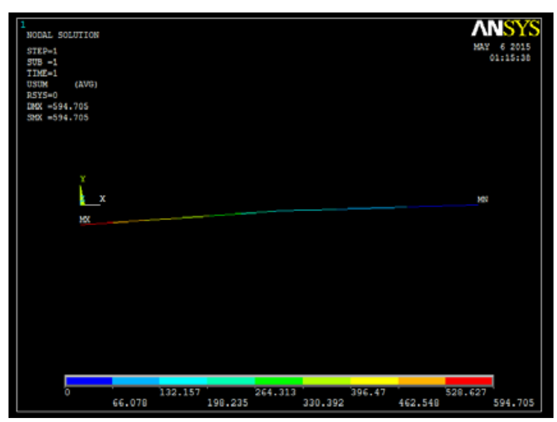
The maximum thickness in this case is found to be 4757.7mm

Case 3: Thickness 3mm



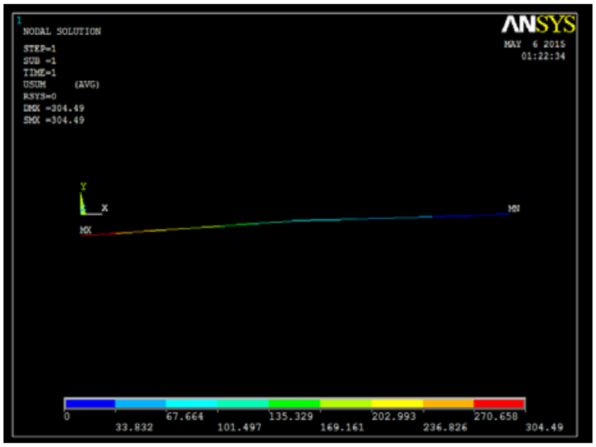
The maximum displacement in this case is found to 1409.7mm

Case 4: Thickness 4mm



The maximum displacement is this case is found to be 594.71mm

Case 5: Thickness 5mm



The maximum displacement in this case is found to be 304.49mm

Analysis results of the five cases is considered and we understand that 1409.7mm displacement of the case 3 is the most acceptable one as it as displacement above this might cause permanent deformation to the cantilever beam and displacement below this would not generate sufficient vibrations to harvest the maximum possible energy.

5. Results and Discussion:

The experiment is conducted using a double bucket symmetric Pelton Wheel turbine that has a maximum discharge of 3.81kg/sec. Readings are taken first at no load condition and then at various loads and the at full and half throttle conditions. A multi-meter connected by copper wires of 0.25mm diameter and 200mm lenght to the piezoelectric crystals is used to detect the amount of voltage generated by the striking action of the pin attached to the plate, corresponding to each partial and zero load conditions.

The results for full throttle conditions are:

Load(Kg)	Voltage(mV)
0	1.4
	1.7
	1.9
	2.3
	2.8
	5.0
	7.0
	10
	14
1	2
	7
	8
	10
	12
2	10
	12
	10
	16
4	2
	6
	9
	12
	20
	26

As the flow of water is unstable the variation of the voltage generated with time could not be determined. However we do notice certain interesting facts about the results obtained. In each of the load conditions except at the load condition of 2kg the voltage generated remains low at first and then suddenly rises to a higher value and then near constant generation of voltage occurs. In the case of the load condition of 2kg the initial value is high as well and overall remains constant throughout. So we understand that for the optimum working of the apparatus we need to wait for a while for the readings to stabilize.

The results for half throttle condition are:

Load(Kg)	Voltage(mV)
2	7
	11
	9
	18
	11
4	3.2
	3.7
	3.9
	15
	12

For half throttle condition and partial load condition of 2kg the gradient in the rate of power generation is considerably low. However the difference in the values is quite high. And for the condition of 4kg the gradient exist as in the case of full throttle condition and the values initially remain low and then gradually increases to a stable condition.

A major difficulty that was encountered in power generation using this technique is the prediction of the results. Since the flow of water is unstable it is difficult to understand the pattern of vibration that is generated in the apparatus. Also since the flow conditions differ with various turbines and also their capacity thus the nature of power generation using this apparatus would also differ. Although by analysing the results we can claim to have a better and higher generation rate than most other piezoelectric devices.

6. Conclusion

The exit water of the turbine contains energy that can be used to meet the energy requirements of the world to an extent, in order to do that, innovations such as mentioned in this report are highly necessary. Using the apparatus mentioned in the report we can extract huge amounts on energy even from the output water of a turbine. The innovations done in the apparatus has been used for the first time and are still in experimental level. However if further research is conducted and this technique developed to the extent of industrial production and power plant usage the energy requirements of our nation and be met to a large extent and it would open doors for newer inventions in the field of renewable energy.

Reference

1. Henry A. Sodano and Daniel J. Inman, *"A Review of Power Harvesting from Vibration using Piezoelectric Materials", LA-UR-03-5397, The Shock and Vibration Digest, 36(3), 197-205, 2004*
2. Andreza Tangerino Mineto, Meire Pereira de Souza Braun, Hélio Aparecido Navarro, Paulo Sérgio Varoto, "*MODELING OF A CANTILEVER BEAM FOR PIEZOELECTRIC ENERGY HARVESTING*", 9th Brazilian

Conference on Dynamics Control and their Applications Serra Negra, SP - ISSN 2178-3667

3. Hua Yu, Jielin Zhou, Licheng Deng and Zhiyu Wen, "*A Vibration-Based MEMS Piezoelectric Energy Harvester and Power Conditioning Circuit*", Sensors 2014, 14, 3323-3341; doi:10.3390/s140203323
4. Romeo SUSAN-RESIGA, Thi C. VU, Sebastian MUNTEAN, Gabriel Dan CIOCAN and Bernd NENNEMANN, *"Jet Control of the Draft Tube Vortex Rope in Francis Turbines at Partial Discharge"* ,23rd IAHR Symposium - Yokohama October 2006
5. Amat A. Basari, Sosuke Awaji, Song Wang, Seiji Hashimoto, Shunji Kumagai, Kenji Suto, Hiroaki Okada, Hideki Okuno, Bunji Homma, Wei Jiang and Shuren Wang, "*Shape Effect of Piezoelectric Energy Harvester on Vibration Power Generation*", Journal of Power and Energy Engineering, 2014, 2, 117-124
6. A. Erturk, D. J. Innam, "*An experimentally validated bimorph cantilever model for piezoelectric energy harvesting from base excitations*," Vol. 18, 025009 (18pp), 2009
7. M. Umeda, K. Nakamura, and S. Ueha, "*Analysis of the transformation of mechanical impact energy to electric energy using piezoelectric vibrator*," Japan J. Appl. Phys., Vol. 35, pp. 3267–3273, 1996.
8. S. Roundy, P. K. Wright, "*A piezoelectric vibration based generator for wireless electronics, Smart Mater. Structure*, Vol.13, pp.1131–1142, 2004.
9. S. Roundy, "*On the effectiveness of vibration-base energy harvesting,*" *J. Intell. Mater. Syst. Structure*., Vol. 16, pp.809–823, 2005.
10. S. Roundy, E. S. Leland, J. Baker, E. Carleton, E. Reilly, E. Lai, B. Otis, J. M. Rabaey, P. K. Wright, and V. Sundararajan, "*Improving power output for vibration- based energy scavengers*," IEEE Trans. Pervasive Computer., Vol. 4, pp. 28–36, 2005.
11. S.R. Anton, H.A. Sodano, "*A review of Power harvesting using piezoelectric materials (2003-2006),*" Smart Materials and Structures,Vol.16, pp.R1-R21, 2007.
12. A. Erturk, D.J. Inman, "*A distributed parameter electromechanical model for cantilevered piezoelectric energy harvesters*," Journal of Vibration and Acoustics, Vol. 130, 041002, 2008.
13. A. Erturk, D. J. Innam, "*Issues in mathematical modeling of piezoelectric energy harvesters*," Smart Materials and Structures, Vol.17, 065016 (14pp), 2008.
14. A. Erturk, D. J. Innam, "*On mechanical modelling of cantilevered piezoelectric vibration energy harvesters*," Journal of Intelligent Mater. Syst. Structure., Vol. 19, pp.1311–1325, 2008.
15. A. Erturk, J.M. Renno, D. J. Innam, "Modelling of piezoelectric energy harvesting from an L-shaped beam-mass structure with an application to UAVs,"Vol. 20, pp. 529-544, 2009.

16. Kim, S.B.; Park, H.; Kim, S.H.; CLYDE WIKLE, H.; Park, J.H.; Kim, D.J. " Comparison of MEMS PZT cantilevers based on d31 and d33 modes for vibration energy harvesting." Journal of Micro electromechanical Syst. 2013, 22, 26–33.