Doctoral Research Proposal

on

Erosion Resistant Micro Hydro Turbine Design

Submitted to

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1. Introduction:

Energy is one of the basic components in the development process for providing economic and social benefits to the people. It is also an essential ingredient of human progress and prosperity. Hence the country's economic development requires access to secure affordable and sustainable energy. This is particularly true for the rural areas because these areas do not provide enough economic basis and physical infrastructure for large-scale investments in the exploitation of hydro-potentials and also in laying transmission and distribution networks in these areas. Furthermore, these areas reside around 86% of the population of Nepal, which is accessible only on foot. They are far from the electricity grid and so providing electricity in these areas at present is a challenging task. Micro Hydro Power (MHP) in this context can play a significant role of a catalyst in the rural development. It is one of the alternative sources of power for rural area with increasing quality and reliability in supply. However, since technical and economical capabilities of rural people are very poor, they need long lasting technology free from repair and maintenance.

MHP is a proven source of power for remote rural hills of Nepal. It is estimated that Nepal possesses a potential of more than 50 MW of micro hydropower (REPPON 2000). Out of them only 12 MW has been installed (AEPC 2002).

Nepal has developed a great deal of technological capabilities to plan, design, manufacture and install MHP.

The maintenance and repairing problem at present occur mainly in the turbine components, which is the major component of hydropower system. Its failure in the past has caused a serious problem in the production of power due to poor technical and economical capabilities in rural areas for immediate repair/maintenance of the MHP. One major problem so far recognized in MHP is the ever-declining performance of turbine after few years of installation along with its breakdown due to erosion (Nakarmi 2001).

The erosion of turbine may be caused by several things, namely due to the abrasive nature of silt particles contained in the streams, the process of and / or component itself. How they exactly affect the performance of turbine individually and combined is not yet established. Therefore, unless their exact origin and effects are not known, no correction measures can be taken to improve the performance. Present study is, hence, aimed precisely at identifying the types, origin reasons, nature of erosion and their individual & combined effects on the performance of micro-hydro turbines. This will contribute towards the prediction of erosion and means for their prevention.

2. Problem Statement:

The declining performance of micro hydro turbines has become one of the major technical issues in the development of MHP system. Its exact reasons have not yet been established. It is, however, assumed that apart from the wear and tear of the runner, erosion of buckets/blades, guide-vanes, nozzle, penstock, spiral case might be one of the major reasons reducing the performance as well as the life of the hydro power systems. Their frequent breakdowns lead to increased financial burden for the users.

Literature available so far deals only with cavitation for the increase of erosion. But erosion caused by other parameters such as abrasive material, contamination, debris content in the water and the design of turbine components, including their materials has not yet been studied.

In view of this and the recommendations made in the Study Report submitted to UNDP on Improvement of Economic Viability of Micro Hydropower Plant, 1994, R&D activities in the development of erosion resistance turbine (Joshi R.D. 1994) is of vital importance. Such a study would also contribute towards the production of turbines with guaranteed performance characteristics and with the capability of better wear resistance.

For this there is a strong need of a detailed study of the type and the origin of erosion as well as means to predict the individuals & combined effect of various parameters contributing to the erosion of the turbine.

3. Objectives:

3.1 Main Objective:

The main objective of the study is to design a mathematical model to predict the effect of erosion on the performance of micro hydro turbines.

3.2 Specific objectives:

The specific objectives of the study are:

- to identify the types of erosion and the parameters contributing to their origin
- to determine the individual parameters and the extent of erosion caused by them
- to develop a mathematical model to predict the individual and combined effects of identified parameters on the performance of micro hydro turbines
- to test the mathematical model, and
- to recommend ways and means to prevent erosion and reduce its adverse effects on the performance of the micro hydro turbines

4. Literature Review:

In micro hydropower basically adopted turbines are of impulse and mixed flow types. However, reaction types of turbines also have been started to used in micro hydropower system as per geographical condition. Not much attention has been paid to optimize their performance till the seventees. It was only in the eightees that the importance of micro hydropower system has been realized and research efforts are being concentrated in improving the performance of these systems, which primarily means improvement in the performance of the turbine (Joshi C.B. 1992).

The improving efficiency of turbines used in micro hydropower may lead several causes and parameters. Among them, the erosion cause of turbine as a whole or components is one of the major causes of declining efficiency. Literature related to the erosion of turbines and their peripheral studies was carried out and summarized below.

4.1 Erosion by cavitation:

a) According to Modi and Sethi (1985) "Cavitation is one of the major problems in any type of hydropower plants. The alternate formation and collapse of vapor bubbles may cause severe damage to the surface, which ultimately fails by fatigue, and the surface becomes badly scored and pitted. In reaction turbines, cavitation may occur at the runner exit or at the inlet to the draft tube where the pressure is considerably reduced. Due to this, the metal of the runner vanes and the draft tube is gradually eaten away in these zones, which results in lowering the efficiency of the turbine".

b) "Although the phenomenon of cavitation has received a great deal of attention, the physical process that governs a single cavity collapse near a solid surface is still not fully understood. To understand such process, it is obviously necessary to characterize the hydrodynamic load and analyze the erosion mechanism of the surface. The supersonic rebound of the vapor cavity after its collapse is associated with the generation of a strong shock wave that causes material erosion. Further investigation is needed to understand the interaction between the dynamics of collapsing cavity and the solid surface" (Gemini Research Magazine, 2001).

c) "Cavitation is undesirable because it results in pitting, mechanical vibration, and loss of efficiency. In reaction turbines, the most likely place for the occurrence of cavitation is on the backsides of the runner blades near their trailing edges. Cavitation may avoided by designing, installing, and operating a turbine in such a manner that at no point will the local absolute pressure drop to the vapor pressure of the water. The most critical factor in the installation of reaction turbines is the vertical distance from the runner to the tailwater" (Daugherty, 1985).

d) According to Dandekar and Sharma (2002) Turbine cavitation can be avoided or checked by the following measures:

- A careful streamlined design of the flow passages of the runner as well as that of the draft tube
- The average sub-atmospheric pressure at the runner outlet is kept reasonably above the vapor limit.
- Some metals are more resistant to cavitation damage than others. For instance, cavitation damage on stainless steel is much less than that on plain steel or iron
- By a periodic inspection of the turbine and by aregular spot welding of the erode portions, the damage phenomenon is not allowed to accelerate.

Dandekar and Sharma further stated that, the degree of cavitation depends upon the pressure as well as on the velocities. Higher velocities at the same pressure indicate a higher susceptibility for cavitation. Therefore, there is a correlation between the specific speed and cavitation.

Cavitation parameter σ given by Thoma, which for turbines, is defined as:

$$\sigma = (h_b - h_v - h_s)/ h$$

h_b = barometric pressure head at the installation site

h_v = vapor pressure

h_s =height of setting of the turbine over the tail race level

h = head on the turbine.

According to Thoma, a turbine will be reasonably free from cavitation, if this cavitation parameter exceeds a certain value σ_{crit} for a given reaction turbine. Thus, for cavitation free running the condition should be satisfied.

$$\sigma \geq \sigma_{crit}$$

The value of σ_{crit} would depend upon the type of turbine and hence can be correlated with the specific speed, N_s. Thus,

$\sigma_{crit} = f\ [\ N_s] = k\ N_s^n$

$= (Ns + A)/B + C$

Various empirical relations have been suggested giving values of k and n both for Francis and Kaplan turbines. Typical relations for Kaplan turbine and Francis turbines respectively are:

$\sigma_{crit} = 1.1\ [0.28 + 1/600(N_s/100)^3]$ for Kplan Turbine

and,

$\sigma_{crit} = 0.0318\ (N_s/100)^2]$ for Francis Turbine

Since (σ_{crit}) increases as N_s increases, cavitation free running under a given head would be possible only if the height of setting of the turbine is limited, so as to fulfill the condition of $\sigma \geq \sigma_{crit}$. It follows, therefore, that the higher the specific speed of a turbine, the lower will have to be the permissible height of setting. In extreme cases, h_s may be zero or even have a negative value, which means that the turbine has to be below tail water level and there are such instances available. However, in such cases, the draft tube must have a gate to enable the dewatering of the runner and the draft tube. In normal situation, the runner always remains submerged and the maintenance is more difficult in these cases.

4.2 Erosion by sand:

- Sand erosion is one of the focused areas of the present study. Similar type of research for different conditions has been carried out in NTNU, Norway. According to the Arne Kjolle (2003) damages concerning **water** turbines are **caused** mainly by cavitation problems, **sand erosion**, material defects and fatigue. **Sand erosion** is designated as abrasive wear. This type of wear will brake down the oxide layer on the flow guiding surfaces and partly make the surfaces uneven which may be origin also for cavitation **erosion**. **Sand erosion** therefore may be both a releasing and contributing cause for damages which are observed in power plants with a large transport of wearing contaminants in the **water** flow. The ***erosion*** *damages* are to some extent different for Pelton and Francis turbines. The real mean to minimize **sand erosion** in the turbines is to apply the most suitable material with properties that match the highest possible resistance against **erosion**, and contemporary satisfy manufacturing and operating conditions.

4.3 The adaptation of a new material in a turbine

a) Research into the use of newly adapted low cost materials in small hydropower is required. There are some possibilities for the use of plastic, glass-fibre, etc. the use of plastics in some part of the hydro machinery includes rapid machining steels with good characteristics for cavitation and/or sand erosion. Materials, such as ceramic to protect sensitive areas against erosion and low-cost machine components have already been studied with a limited success (IEA 2000).

b) Kragelsky (1985) stated in his book "Friction Wear Lubrication Tribology Handbook" that the mechanical components of the hydropower systems have the problem of wearing and corrosion of the mechanical components, which ultimately reduce the efficiency of the systems. This is due to the hydro-abrasive destruction action in the system. According to him hydro-abrasive destruction is a mechano-corrosive process. It is largely determined by the chemical composition of the ambient medium, its properties and temperature. The physical properties of a liquid determine the dynamic characteristics of cavitations bubbles. The temperature and acidity of the medium have a substantial effect on hydro-abrasive wear. Even a slight reduction in a hydrogen-ion concentration to pH 6.5 leads to a significantly increased rate of erosion. The heat treatment of carbon steels and cast irons gives no tangible improvement in resistance to abrasive wears in acidic media. Steel parts subject to hydro-abrasive action in hydropower systems should be produced from steels that comply with the requirements of high corrosion resistance, ability to withstand both fatigue and corrosion under micro impact effects, and good productive. The erosion resistance of parts used in aggressive media can be substantially increased by hard facing with stainless steels having a martensitic, austenitic-martensitic, or purely austenitic structure with unstable austenite which is obtained with 12 to 16 percent Cr and 4 to 8 percent Ni.

4.4 According to previous research works, Turbines and their components can be tested as follows.

a) The test case provided by De Petto Escher-Wyss is a Francis Turbine Runner. The design of any component of a hydraulic turbine has the goals of optimizing turbine efficiency and power output according to the conditions defined by a customer. In most cases more than one operating point has to be taken into account (part load, optimum, full load) and an overall weighted machine efficiency must be guaranteed. For the runner, cavitation must be prevented or at least minimized to avoid cavitation erosion. For water resources with a high content of particles, sand erosion may play an important role. In such cases the effective erosion has to be minimized by an appropriate change of the component geometry or by surface coating (http://www.uni-stuttgart.de/).

b) During August of 1993 the United States Bureau of Reclamation (USBR) tested turbine aeration for dissolved oxygen (DO) enhancement at Deer Creek Power-plant near Provo, Utah. Objectives of testing included determining the effectiveness of aeration, evaluating the impact on power output and mechanical behavior of turbines, and obtaining data needed to design a permanent turbine aeration system. Variables of interest included standard power plant parameters (head, discharge and power output), airflow parameters (pressure, temperature, and flow-rate), water quality parameters (DO concentration and temperature), and mechanical parameters (shaft run-out and bearing temperature). This paper discusses the design of the tests and the instrumentation involved, as well as plans for additional testing during the implementation of turbine aeration at the site in the summer of 1994 (http://www.usbr.gov).

c) A hydraulic testing of static self-cleaning inclined screens report was published in website of the Water Resources Research Laboratory (WRRL). The report said that several configurations of static, self-cleaning, inclined screens were tested in the hydraulics laboratory of the Bureau of Reclamation. The screens were tested in an overflow weir configuration with potential for fish exclusion and fine debris removal application at water intakes and diversion structures. Similar screens are used in the mining industry, primarily in coal handing applications, and this type of screen has been successfully used for debris and fish exclusion at several prototype sites. This paper discusses the testing program and results(http://www.usbr.gov/).

d) The Water Resources Research Laboratory (WRRL) of United States Bureau of Reclamation (USBR) stated that detection of the cavitations phenomenon is straightforward. Large increases in noise, particularly in moderately high frequency ranges (15- to 100-kHz) are characteristic of cavitations. In addition, vibration levels generally increase. The USBR have developed machine condition monitoring system for the detection of cavitations in hydraulic turbines. According to research report, new techniques and sensors had made the detection of damaging cavitation in hydro turbines a reality. There still exist some questions regarding the absolute comparisons from unit to unit and among different turbines types (http://www.usbr.gov).

4.5 Efficiency prediction:

- Vincent et al. (1998) investigated the hydraulic turbine design with computer simulations to predict the efficiency using CFD. He stated that with the correlation between the flow rate and wicket gate opening at a given water head, it becomes possible to evaluate the influence of modifications to any components of the turbine on the efficiency without the necessity of a model test. The efficiency for the complete turbine is calculated on the basis of the computed head drop for the complete unit and power output. The head drop in the casing is estimated for one operating condition and assumed to vary with the square of the flow rate. He further stated that, in a previous study, comparisons between predictions of profile cavitation and model test observations showed a good agreement in the case of Kaplan turbine runner. In the case study of the propeller turbine comparisons were made for inlet cavitation. The CFD generated predictions indicated a static pressure distribution on the inlet edge of the blade. At this point, the pressure was below vapor pressure, enabling cavitation bubbles to originate. This corresponds well to the observation during model testing. Using this information, blade angle modifications could be investigated to eliminate undesirable cavitation phenomena. Regarding the limitation of CFD modeling it is stated that CFD could be used with a high degree of confidence to predict many aspects of hydraulic turbine performance. However, it is important to note that, in terms of absolute efficiency predictions, more studies are needed to bring the accuracy of the numerical tool to the same as the model test.

5. Methodology to be used:

Methodology to be used for this present study is proposed as follows.

1. The review of literature for the collection of secondary information by library consultation, electronics journals and Internet. The details of the review is made in an extensive way will focus on following:

    - Details of problems related to erosion,
    - Types of erosion,
    - Reason so far identified,
    - Studies done so far and their basis,
    - Model so far worked-out and identification of strength and weakness, etc.

2. Specific formulation of the problem of the research topic

3. Development of new mathematical model

The contributing parameters of erosion in turbines may be cavitation, sediment and their size & distribution, types of material used, nozzle direction, direction of the wicket gate, head, discharge, power, etc. Therefore, the following equation may be valid.

E = ƒ (cavitation, geometry, sediment and their size & distribution, types of material used, nozzle direction, direction of wicket gate, head, discharge, power)

However, this present study will focus on the specific parameters only, namely cavitation, geometry, sediment, head and discharge.

4. Development of Physical model

   The physical model will be developed in laboratory scale to test the validity of mathematical model in the Department of Mechanical Engineering, Pulchowk Campus, Institute of Engineering. The model will be facilitated with all testing requirements for the present study. The head and flow of water will be created by means of centrifugal pumps. An electronic flow meter will be fitted to the delivery pipe to indicate flow measurement directly. The water pressure in the inlet pipe is indicated on a Bourdon type gauge mounted on the inlet of the supply pipe. Besides, auxiliary flow measurement device with V-notch plate will be incorporated in the tank. Water discharged from the turbine falls into the tank and flows over the 90 V notch. The height of the water over the notch is measured by means of stilling vessel and the venire type depth gauge. The bench-mounted cabinet adjacent to the equipment also incorporates a push button starter for the centrifugal pump, safety trip button, wattmeter and other accessories. Powering sand particle will be done manually. However, their mixing will be created by means of turbulence within the system.

5. Design of experiments so that a complete and accurate description of the condition can be quantified

   The experiment will be designed to meet the study objective of the model itself. Measurement of input/output power, effect of geometrical change, sediment and cavitation effect will be incorporated.

6. Testing of model with data for a certain case study

7. Analysis of the results

   The data collected will be analyzed and subjected, possibly, to several statistical tests to determine whether the proposed answer holds true or not and with what degree of confidence or faith it can be accepted. Computer software such as SPSS, MS Excel, MS Project, Visio Professional and other software will be used as analyzing tools

8. Drawing innovative recommendations and conclusions

9. Deliberation of the conclusion and innovative recommendations through research papers

10. Preparation of the thesis report

11. Submission of the thesis

6. Expected Outcome:

The outcome of this present study will be a proven mathematical model with a new design to predict the extension of erosion and its effect on the performance of micro-hydro turbines.

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RESEARCH PLAN AND ACTIVITIES

S.N.	Research Content	Brief Description	Time frame
1.	Literature survey	Attendance of necessary course work	6 months
2.	Literature survey contd.	Review of related literatures from various sources	3 months
3.	Adaptation of final formulation and presentation of research approach	With the close coordination of Research Supervisor, an idea that gathered during the review of literatures, modification on the formulation of the research might be adapted. A presentation will be made to explore the research approach for further analysis.	1 month
4.	First phase of analytical analysis	Collecting required data, the analytical analysis will be carried out and mathematical model will be developed.	6 months
5.	Progress Report and presentation of findings	With the close coordination of Research Supervisor, finding from the intensive analysis will be carried out and made a presentation. Modification will be done, if required, as per the suggestions of experts.	1 month
6.	Presentation and publication of 1st paper	First technical paper will be prepared with the close coordination of Research Supervisor for the publication.	1 month
7.	Development of physical model and conduct expriments	Model will be tested against reality by primary information from laboratory works.	8 months
8.	Final phase of analysis	Data collected will be analyzed and subjected, possibly, to several statistical tests to determine whether the proposed answer holds true or not.	4 months
9.	Progress Report and presentation of findings	With the close coordination of Supervisor, a presentation will be made to explore the findings of analysis. Modification will be done, if required, as per the suggestions of experts.	1 month
10.	Preparation and publication 2nd paper	Second technical paper will be prepared with the close coordination of Research Supervisor for the publication.	1 month
11.	Dissertation (Doctoral) writing and submission	With the close coordination of Research Supervisor, write-up of the Dissertation will be carried out, incorporating all the bodies and findings as per the standard format and submitted. Modification will be done, if required, and final version will be prepared and submitted for the acceptance.	3 months
12.	Final presentation of the dissertation	Final presentation will be prepared as per the standard format and made presentation.	1 month