HYDRAULIC TRANSIENT IN PENSTOCK OF MILD STEEL AND GLASS FIBRE REINFORCED PLASTIC FOR HYDRO POWER PLANTS

Ph.D. THESIS

by

RAHUL KUMAR GARG

DEPARTMENT OF HYDRO AND RENEWABLE ENERGY
INDIAN INSTITUTE OF TECHNOLOGY ROORKEE
ROORKEE-247667, INDIA
April, 2021

HYDRAULIC TRANSIENT IN PENSTOCK OF MILD STEEL AND GLASS FIBRE REINFORCED PLASTIC FOR HYDRO POWER PLANTS

A THESIS

Submitted in partial fulfilment of the
Requirements for the award of the degree

of

DOCTOR OF PHILOSOPHY

in

DEPARTMENT OF HYDRO AND RENEWABLE ENERGY

by

RAHUL KUMAR GARG

DEPARTMENT OF HYDRO AND RENEWABLE ENERGY
INDIAN INSTITUTE OF TECHNOLOGY ROORKEE
ROORKEE-247667, INDIA
April, 2021

ABSTRACT

The power demand in an electric grid to which power generating plants including hydropower plant is connected, may change suddenly for a variety of reasons like grid failure, and disconnect of main load etc. The energy delivered at any moment by the hydro turbines depends on the quantity of water passing through and thus the flow in water conductor system including penstock is to be as per power demand. The velocity of water in the penstock before the change in power demand is related to corresponding discharge. If the discharge and thus the velocity increases or decreases to match the power demand, the mass of water moving in the penstock has to be accelerated or decelerated. The acceleration or deceleration of the water column moving in the penstock is produced and governed by elastic forces developing in the penstock itself. Sometime this phenomenon, popularly known as water hammer or hydraulic transient, caused due to these hydraulic transient may be destructive for both civil and mechanical components such as penstock, valves and turbines of the hydro power plants (HPPs).

Penstocks are a major proportion of the capital investment of a HPP project. Therefore, the penstock material is selected not only from the point of view of durability, installation and maintenance cost but with a view to ensuring that the required function and safe performance of the penstock last throughout its life span. The study and analysis of hydraulic transient is necessary for the selection of penstock material, its pressure classes and the specifications of surge protection devices. Formation of hydraulic transient in penstock is greatly influenced by its material. More rigid the material, higher the transients formation and conversely, if the materials are elastic lower transients waves are generated in the penstock.

There are very few studies available where the response of metallic - viscoelastic pipeline under transient conditions are observed and analyzed. Hydraulic transient analyses for different material and combination pipelines configuration being used for penstock are quite limited in the literature. Few studies are reported in literature dealing with computation and simulation of transient effect on the penstock with different materials. For pipelines made of newly developed materials such as GRP and HDPE and their global availability, studies for their use in single or combination with steel pipes in fixed or varied diameters are required to make them useful in replacing/retrofitting existing HPPs/water supply

systems as only limited studies are available. The objective of the proposed research is to study the transient phenomenon in a pressurized pipeline with different materials and combined configuration.

For experimental insight of the behavior of transient pressure in both metallic (e.g. mild steel) as well as in viscoelastic pipe (glass reinforced fibre plastic) and their combination configuration, an experimental setup for hydraulic transients test was designed and fabricated in the Department of Hydro and Renewable Energy at Indian Institute of Technology Roorkee. The parameters selected for investigation were flow velocity, material and their combined configuration of the pipeline. The water hammer events are generated inside the pipeline by fast closing of the butterfly valve located at the downstream end of the pipeline. Due to the limitation of the infrastructure the working pressure of 8 bar has been kept throughout the investigations.

The response of water hammer pressure in metallic-viscoelastic pipeline was investigated experimentally and numerically. At the flow velocity of 0.5 m/s, 21 % reduction in water hammer pressure was observed in GRP pipeline near the valve as compared with MS pipeline and at the same velocity, there are 8.6 and 16 % reduction was observed in pipeline material combination of MS+GRP and GRP+MS respectively as compared with water hammer pressure in MS pipeline. At flow velocity 0.8 m/s, 13 % reduction in water hammer pressure was observed in GRP compared with MS pipeline. About 2 % increment and 7 % reduction in transient pressure was observed in MS+GRP and GRP+MS material configuration pipeline respectively. At flow velocity 1 m/s, about 22 % reduction in water hammer pressure was observed in GRP pipeline as compared with the pressure observed in MS pipeline and 10 and 23 % reduction in transient pressure observed in MS+GRP and GRP+MS material configuration pipeline respectively as compared with water hammer pressure observed in MS pipeline at the same velocity.

In GRP pipeline lesser transient pressure was observed as compared with MS pipeline at all three different fluid velocities. In the combination of material configuration, lower transient pressure was observed with fast damping of pressure waves in GRP+MS pipeline as compared with MS+GRP pipeline.

The presence of air in a pipeline may reduce the hydraulic transient phenomena. The propagation velocity of a pressure wave in a pipeline containing fluid can be reduced if gas bubbles are dispersed throughout the fluid. The bulk modulus and density of water and the

magnitude of the wave velocity are influenced by the presence of air content in water. The effect of air entrainment has been calculated and its impact has been analyzed by incorporating gas law equation in transient pressure equations.

It was higher in the metallic pipes and generated sharp pressure spikes as compared with viscoelastic pipeline and different material combination configurations. The amount of air per unit volume for MS and GRP pipeline materials were 8.75×10^{-5} kg and 4.27×10^{-4} kg respectively and for MS+GRP, GRP+MS combination pipeline configurations, the air per unit volume was 9.96×10^{-5} kg and 2.09×10^{-4} kg respectively.

A numerical study on the hydraulic transient analysis caused by rapid valve closure in different pipeline materials as well as in a combination of materials was carried out. Computer programmes for the computation of transient pressure in a single pipeline material and combination materials pipeline in series taken from the reservoir have been developed and modified in MATLAB. Computations have been carried out by method of characteristics (MOC) using finite difference method. Simulated results are found in close agreement with experimental results. From the experimental and numerical transient pressure analysis, it is observed that the pressure waves were not damped quickly in numerical simulation.

Air vessels are useful surge suppression devices. These devices are widely used in hydraulic systems for pressure relief. The air vessels are also called a hydro pneumatic tank, an air bottle or a shock trap. The purpose of the air vessel was to reduce the water hammer effect in the system as air can be compressed to act like a cushion to compress the pressure waves. The damping and smoothing of pressure waves in the pipeline during transient events are influenced by some other factors which are not considered in numerical simulations and are the cause of slow damping and smoothening of the transient pressure in pipelines compared to actual cases. To overcome this gap by introducing and developing wave damping coefficient (α) in the water hammer equation, celerity in the pipeline damped significantly and improved the wave damping results obtained by using water hammer equations and are in close agreement with the experimental observations.

The smaller value of (α) has been observed in metallic pipeline and higher in viscoelastic material. The optimal values of (α) was evaluated for all experimental cases. The variable wave velocity consideration in the analysis of water hammer gives better agreement between experimental and numerical results.

ABSTRACT

A case study of a small hydropower plant, Gangani run of river hydro power plant located on river Yamuna in the state of Uttarakhand, India having long penstock with variable diameters has been studied and transient pressure in penstock has been analyzed for sudden load rejection conditions experienced frequently at the station due to frequent tripping of power evacuation lines. The maximum and minimum surge height was evaluated in the surge tank. Based on cost analysis of penstock with and without surge tank, the penstock with surge tank cost was found cheaper by 18 %. It was also found that cost of variable diameter was cheaper by 2.5 % compared with single diameter penstock.

Use of viscoelastic pipes such as GRP pipelines is not only cost effective due to ease in transportation and speedy installations as compared to metallic pipelines such as mild steel but also reduces the water hammer pressure. Due to the limitation of maximum pressure for GRP pipelines a combination of GRP + MS (MS for reach for high pressure and GRP for reach having low pressure) can be used to reduce transient pressure. The life span of the GRP pipeline is also more than metallic pipeline and has lower maintenance cost. GRP pipeline can be useful for upgrading/renovating existing steel penstock in hydro power plants and pipelines in water supply schemes to bear water hammer pressure effectively and speedy replacement.

It is recommended to carry research to analyze transient behavior in different pipeline materials like HDPE, UPVC and PE with telescopic diameters within the limitation of avaiablity taking into account a large range of system characteristics and operating parameters including combinations of different material pipes as per site conditions. The computation technique developed for transient pressure in a pipeline comprising of single and combination of two materials in series taken from reservoir and modified for wave damping coefficient shall be useful for such research work for different material pipeline in future.