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Numerical optimization of guide vanes and reducer in pump running in turbine mode

V A Patel^a, S V Jain^b, K H Motwani^c, R N Patel^b

^aEssar Steel India Ltd., Surat-394270, India

^bInstitute of Technology, Nirma University, Ahmedabad-382481, India

^cFaculty of Technology, Marwadi Education Foundation Group of Institutions, Rajkot-360003, India

Abstract

The main limitation of centrifugal pump running in turbine mode is lower efficiency at part load operating conditions as compared to conventional hydro turbines. To enhance the utilization of pump as turbine (PAT) in mini/micro hydropower plants, it is very important to improve its performance with some low cost modifications. The part load efficiency of PAT can be improved by guiding the flow at part load by installing the movable guide vanes. However, to avoid the higher cost of movable guide vanes, it was proposed to install fixed guide vanes. The existing volute casing of centrifugal pump was not having sufficient space for provision of guide vane mechanism. Hence, to create an additional space the existing impeller of 250 mm dia. was replaced by 200 mm dia. impeller which has facilitated an additional space for installation of guide vanes. To determine the optimum position of fixed guide vanes, CFD analysis of casing was carried out with NACA-4418 profile by varying the guide vane angles between 45° to 80°. The numerical simulations were carried out using Reynolds averaged Navier-Stokes (RANS) equations with standard k- ϵ turbulence model under steady state conditions. In addition, it was required to place the reducer between the service pump and PAT as the pipe dia. at service pump outlet was 5" and at PAT inlet was 3". To optimize the shape and location of reducer between service pump and PAT, CFD analysis was performed by considering two different reducers at different locations. PAT with 200 mm dia. impeller and 8 numbers of fixed guide vanes provided at 75° angle led to improved performance of PAT. Also the long reducer provided at the inlet of PAT was subjected to less head drop in the piping system.

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1. Introduction

Energy plays an important role in almost all areas of human and commercial activities and it is very important input for those countries that are developing from economic point of view. Worldwide, around 67% electricity is generated from fossil fuels [1]; however, high prices, fast depletion rate and environmental implications of fossil fuels create problems in electricity generation through conventional energy sources. Electricity generation through renewable energy sources is appropriate solution for these problems [2]. In addition to this, economic development through renewable energy industry and sustainable energy sector create more employment, which leads to social development of the nation [3].

One of the most promising non conventional energy that can be used for generating power in this situation is hydro technology. Hydropower is a non conventional, non-polluting and environmentally being source of energy [4]. The Ministry of Non-Conventional Energy Resources, Government of India identified several sites in North India particularly in the Himalayan Range. The streams flowing from a height of 30 to 50 meters with relatively low discharge were

* Corresponding author. Tel.: +91-9998623087; fax: +91-2717-241917.

E-mail address: sanjay.jain@nirmauni.ac.in

considered suitable to generate power in the range of 15 to 50 kW [5], which falls in the category of micro hydropower (less than 100 kW) [6]. In developing countries, small and micro hydropower plants are very effective source for electricity generation. The energy pay-back time (EPBT) and greenhouse gas (GHG) emissions for SHP generation system are less than other conventional electricity generation system [7]. So, encouragement of small hydropower schemes can solve the problem of energy crises of the country.

The problems associated with small/mini/micro hydropower development are technical and economical as compared to conventional power plants. The design of a single machine and its manufacturing to achieve maximum efficiency for each small hydro plant site is costly affair. The electro-mechanical equipment of such plants constitutes about 60-70% of the total project cost. Hence minimising the cost of this equipment can reduce cost of the plant [8]. Centrifugal pump working as turbine is a good alternative for power generation through mini and micro hydropower schemes. Pumps offer many advantages over custom-made turbines that make their use an economical solution in this sector. The market for pumps is large and being a standard product it is always cheap and readily available. Also, operational and maintenance issues in pumps are relatively simpler as compared to turbines [5].

Hydroelectric power plants are often subjected to run at off-design operation in order to satisfy the fluctuating load demands which would naturally require higher performances at part loads.

The main limitation of PAT is lower efficiency at part load operating conditions as compared to conventional hydro turbines. To enhance the utilization of PAT in mini/micro hydropower plants, it is utmost important to improve its performance with some low cost modifications.

Many researchers have attempted different modifications to improve the performance of PAT by carrying out experimental and numerical investigations. Derakhshan et al. [9] redesigned the shapes of the blades using a gradient based optimization method involving incomplete sensitivities for radial turbo machinery to obtain higher efficiency. Singh [10] demonstrated various possibilities of modifying the pump geometry to improve the performance in turbine mode viz. by rounding of inlet edges of impeller, by modifying the inlet casing rings, by enlarging the suction eye, by removing the casing eye rib. Singh and Nestmann [11] studied the effects of impeller rounding on 9 PATs covering a specific speed range of 20 to 94.4 rpm. Suarda et al. [12] experimentally determined the performance of a small centrifugal volute pump running in reverse mode after grinding the inlet ends of the impeller tips to a bullet-nose shape. Sheng et al. [13] applied splitter blade technique to improve the PAT performance which is one of the techniques used in flow field optimization and performance enhancement of rotating machinery. Williams and Rodrigues [14] discussed the effects of enlargement of the suction eye of the pump by removing the material.

The part load efficiency of PAT can be improved by guiding the flow at part load operating conditions by installing the guide vanes. In the present study, two different attempts were made to improve the performance of PAT. In the first method, the guide vane positions were optimized by carrying out numerical simulation of casing by putting the guide vane at different angles. In the second approach, the shape and location of reducer, between service pump and PAT, was optimized by performing CFD analysis by considering two different reducers at different locations.

2. Numerical simulation of PAT [16]

One of the most reliable tools used by many researchers to understand flow behavior in the hydro-mechanical equipment is CFD. It helps to predict fluid flow by means of mathematical modeling, software tools and numerical methods. These numerical methods help to investigate various parameters such as flow pattern and hydraulic losses which cannot be easily measured by experiment also. In this paper, the effects of different modifications on the performance of PAT are studied using CFD as a numerical simulation tool. The end suction, single stage centrifugal pump (head: 15 m, discharge: 1500 LPM) was used as a turbine, by running it in reverse direction, for the experimental and numerical investigations. The view of the centrifugal pump and two-dimensional drawing of casing are shown in Fig. 1.

The existing volute casing of centrifugal pump was not having sufficient space for provision of guide vane mechanism. Hence, to create an additional space the existing impeller of 250 mm dia. was replaced by 200 mm dia. impeller which has facilitated an additional space for installation of guide vanes. Considering the geometry of the casing, NACA 4418 was selected for the analysis as per the guidelines given in [15]. Initially, the numerical simulations of casing were carried out by considering the space for 250 mm and 200 mm dia. impellers. The two-dimensional (2D) geometry of the computational domain was created in GAMBIT, which is a pre-processor of FLUENT, using bottom-up approach. The numerical models of casing with space for different impellers and the guide vane profile are shown in Fig. 2.

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