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Computational analysis of erosion in a radial inflow steam turbine

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ABSTRACT

In the present work, the erosion of the blades of a radial inflow turbine due to the ingested steam flow containing solid particles was investigated in detail. The study has been conducted by designing and modeling the 3D geometry of the turbine using the CFturbo tool and by carrying out a series of CFD simulations using the software package ANSYS CFX 15.0. As compressibility effects may affect the output results, a study was conducted to ensure the validity of the incompressible flow assumption. Furthermore, the erosion simulation results indicated that there are three main surface areas where significant erosion occurs. The first and by far the most affected part of the studied radial steam turbine is the trailing edge of the stator blade, where a relatively huge number of particles with sharp angles strike the surface. This surface area is found to be affected by a concentration effect, where a high number of particles impinge on a small surface area continuously. The second but less affected part is the leading edge of the suction side of the rotor blade, where the particles strike the blade surface many times. The particles are trapped in a vortex area between the trailing edge of the stator blades and the leading edge of the rotor blades. The third surface area which is eroded significantly is the central region of the pressure side of the rotor blade. However, the blade erosion in this area is less than the other two areas. Additionally, the effects of several factors such as the rotor rotational speed, input mass flow and particle size on the erosion have been studied in detail. The relations between these factors and the erosion rate density have been determined.

1. Introduction

Erosion caused by the particulate flows in industrial systems has been a source of concern in last decades regarding design, efficiency and cost aspects. Flows in many cases are accompanied by undesired solid particles that cause in some cases a severe damage to the system components. A considerable number of experimental and numerical studies have been conducted to investigate the particulate flow behavior and erosion phenomenon in stationary components [1,2] and also in dynamic/rotating systems [3,4]. However, investigation of the erosion in the turbomachinery has to be carried out in more detail. The basis for the most erosion models was provided by Finnie [5], which considered to be the precursor of erosion model function for ductile materials. He concluded that wear erosion is a complex function depending on three variables; particle impact characteristics (velocity and angle), particle material and target wall properties. This model is based on a single particle impingement investigations [5]. His model was later improved by other researchers. Bitter [6,7] improved the Finnie model and stated that the erosion is usually a combination of two mechanical processes, namely cutting and deformation. This model is considered to be one of the most prominent but is usually dismissed as a consequence of its need to many empirical constants. Grant and Tabakoff [8] developed an improved Finnie model of erosion which is still used widely nowadays, especially in the turbomachinery field.

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Regarding radial inflow turbines, one of the fewest and most prominent studies carried out so far was by Clevenger and Tabakoff [9]. They studied the erosion on the inner surfaces of a radial inflow turbine and this became a starting point of some subsequent studies. Their motivation was to determine the erosion rates of turbines functioning in harsh environments through ingestion of dust and other solid particles within the gas flow. They conducted an analytical study and concluded that there were several regions where a greater amount of material loss has occurred. These regions were located on the trailing edges of the nozzle (stator) blades. It was also observed that areas with brittle material suffered less erosion losses than the ductile materials.

Most of the computational fluid dynamics (CFD) studies have been carried out in the field of hydraulic erosion caused by ingested sand particles in large hydro-turbines. In steam turbines there are no sand or similar particles which can enter the system. However, ash particles due to combustion process can be present in the flow.

Unlike radial inflow turbines, axial inflow turbines experience less erosion. The reason is that particles have a tendency to pass through the turbine and not being trapped in vortex regions as it happens in radial turbines [9]. Recently, some researchers have conducted several studies using CFD modeling of flow and erosion on the blade surfaces and other parts of the axial steam turbine. Mazur et al. [10] conducted a CFD simulation to determine the erosion at the main stop valve of a steam turbine. Results indicated that the erosion process depends strongly on the particle trajectories and on the particle impact angle (impingement angle). By improving the initial design of the valve, a reduction of 51% in erosion rate was achieved and in turn, it rendered a 100% extended service time of the valve. Blades have also been of great interest in CFD simulations and erosion prediction studies, since they are the main target of the solid particle impingements. Amezcua et al. [11] carried out a CFD simulation to study the erosion in a steam turbine nozzle due to the solid particles entrained in the flow. They have observed a severe damage on the stator blades and found that the erosion rate decreased as the particle size increased.

Azevedo and Sinátora [12] concluded that solid particle impingements on the blade surfaces, attacked mostly the low-pressure side of the trailing edge of the blades. Wear grooves, as a consequence of initial particle impingements, were found to act as stress. Additionally, it was observed that the fatigue cracks of the lower trailing edge grew preferentially during the transient regime of the steam turbine operation. Thapa et al. [13] conducted a study to identify an appropriate erosion model for Francis turbine. They applied two standard erosion models to predict erosion rates and consecutive efficiency reduction of the runner. An improved empirical relation to estimate the sediment erosion in the Francis runner was proposed and the results were compared with the experimental measurements on the site [13]. Recently, Guangjie et al. [14] investigated the relation between the wear rates on the surfaces of the runner blade and guide vane and the sediment concentration. Moreover, they analyzed the distribution of the wear rates for normal operating conditions of a Francis turbine.

Study of particulate flow in the radial steam turbines and the erosion investigation in such turbines is limited in the literature. The main goal of the present work was to investigate the wear erosion in radial inflow steam turbines caused by the two-phase particulate flows. Moreover, the effects of various influencing parameters such as input mass flow, rotor rotational speed, and solid particle size on the erosion profiles and trends were studied in detail.

2. Radial inflow turbines

In general, the small radial inflow turbines are suitable for any place where compact power sources are required [15]. In radial turbines, the flow enters the turbine perpendicular to the rotation axis, guided by the nozzle blades (stator blades), and once inside the rotor, the flow changes its direction 90° and exits the rotor in the shaft direction. The main parts of the turbine including volute, stator and rotor are shown in Fig. 1 (left side), from the *z*-axis view. In Fig. 1 (right side), the leading edges and the trailing

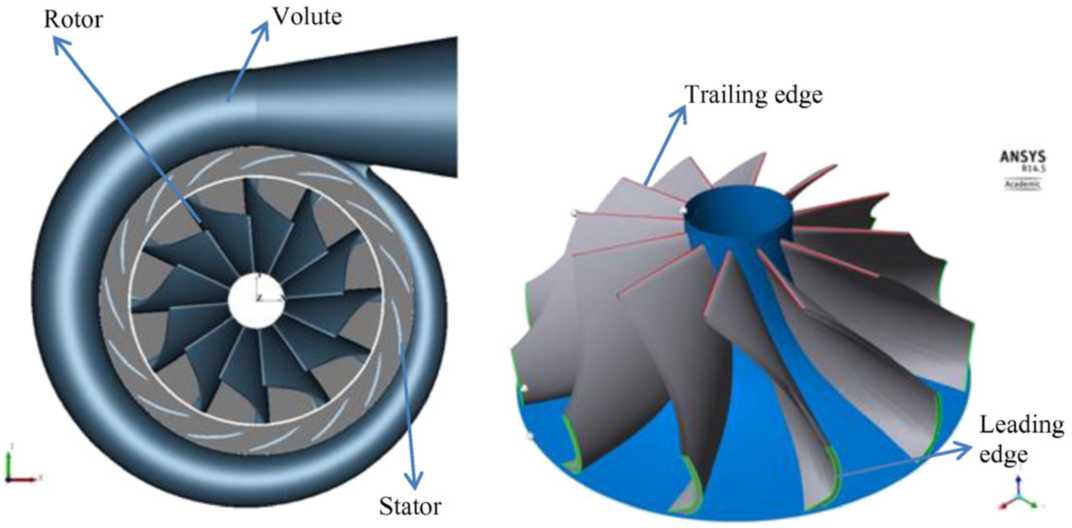

Fig. 1. Turbine main parts from *z*-axis view (left), leading and trailing edges of rotor blades (right).