Journal of the Energy Institute 88 (2015) 414–424

Contents lists available at ScienceDirect

Journal of the Energy Institute

journal homepage: http://www.journals.elsevier.com/journal-of-the-energy-institute

Experimental and theoretical investigation of the influence of liquid droplet size on effectiveness of online compressor cleaning for industrial gas turbines

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ARTICLE INFO

Article history:
Received 16 July 2014
Received in revised form
21 November 2014
Accepted 24 November 2014
Available online 17 December 2014

Keywords:
Fouling
Demineralized water
High injection pressure
Orifice diameter

ABSTRACT

The effectiveness of online compressor washing is site specific and it is determined by several factors, amongst which is liquid injection droplet size that relates to the nozzle orifice diameter and injection pressure. To investigate the influence of liquid injection droplet size on the effectiveness of online compressor washing, three elliptical flat fan nozzles with different orifice diameters were selected, followed by ascertaining the mean droplet sizes for each of the nozzles with the Malvern Spraytec Particle Analyzer. Two of the three nozzles that generated droplet sizes of 55 and 80 μm were employed to investigate the influence liquid injection droplet on the online compressor washing effectiveness. Prior to the washing effectiveness investigations, the three middle blades of the cascade were fouled in a uniform and repeatable manner, after which washing was conducted with different injection droplet sizes. When the washing effectiveness for droplet sizes of 55.1 and 80.24 μm were compared on the aerodynamic performance plots of exit flow angle, total pressure loss, and non-dimensional velocity; a slight difference was observed for the two droplet sizes. The washing effectiveness of using liquid injection droplet size of 80.24 μm produced a lower exit flow angle and total pressure loss coefficient than the droplet size of 55.1 μm. This implies that the droplet size of 80.24 μm has a higher momentum, thereby dislodging the particles more easily than the 55.1 μm droplet size. The reduction in isentropic efficiency and flow capacity obtained from the experimental data for the fouled and washed cases were used as input into Turbomatch to simulate the effects of washing with different fluid injection droplet sizes. Blades washed with a droplet size of 80.24 μm produced a higher recovery of power output and efficiency from the fouled case than the ones washed with a droplet size of 55.1 μm.

1. Introduction

During operation, gas turbine components deteriorate in performance. The deterioration in the performance of gas turbines is unavoidable even when operated under the most favourable conditions due to several degradation mechanisms. One of the key factors that lead to compressor performance deterioration during plant operation is compressor fouling. Fouling is the adherence of particles and small droplets to the blading surface [1]. These particles, depending on the environment, may range from dust, soot to water droplets, hydrocarbon aerosols, pollen and salt. When ingested, they stick on the surface of the compressor, thereby resulting in the development of surface roughness, changes to the shape of the aerofoil, increased boundary layer and decrease in throat area. These effects may result in reduction in mass flow rate, isentropic efficiency and power output.

Online compressor washing is a promising method of curtailing the effects of fouling as well as increase the interval between offline washes. However, the problem with online compressor washing has been its cleaning effectiveness since it is carried out when the engine is running at full or near full speed. Hence if the correct spray parameters (i.e. liquid droplet size and water-to-air ratio) are not used effective cleaning cannot be achieved and that is where the study finds its relevance.

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http://dx.doi.org/10.1016/j.joei.2014.11.002
1743-9671/

Since the inception of online compressor washing, there have been only few experimental studies on the influence droplet size influence in online compressor washing effectiveness. Most of them have been carried out with hollow cone nozzles at low injection pressures. Even the flat fan nozzles that were used were the air assisted types where the fluid was injected at low pressures. With the inception of modern gas turbine coated compressor blades, problems of blade erosion due large droplet sizes has been a major concern in online compressor. Also, less cleaning effectiveness on the compressor due to large droplets centrifuging from the first stage without wetting the subsequent stages has been reported.

Asplund [2] states that washing systems operated high injection pressure systems are devoid of compressor blades erosion due to fine atomized droplets being generated and fewer numbers of nozzles could be employed.Also, with the use of a small number of nozzles, installation complexity and maintenance cost are reduced. In addition, high injection pressure washing systems use only one ring while low injection pressure ones use multiple of rings. Due to the advantages associated with washing under high injection pressure, most online compressor washing system suppliers or gas turbine users are looking at the possibility of washing at high injection pressure.

Droplet size is considered an important performance recovery parameter in on-line compressor washing. This is because droplet size influences the penetration of wash fluid to the high airstream of the compressor inlet [3]. Lambart and Gordon [4]; Patterson and Spring [5] report droplet sizes of 125–200 μm and 80–200 μm for naval applications; however, they stated that the selection of the droplets would depend on the washing system and the gas turbine. Hsayward et al. [6] suggest droplets sizes ranging from 50 to 500 μm for washing applications.

Mund and Pilidis [7] in their study of a numerical survey of influencing parameters of online compressor washing, modelled two generic compressor washing systems; one is titled configuration A and the other B. The configuration A, washing system nozzles were located parallel to the shaft cone which implies that the fluid was injected directly to the compressor inlet guide vanes. In configuration B, the nozzles were installed in the inlet plenum which is perpendicular to the air flow.

After analyzing the various droplet sizes and injection velocities, the authors conclude that the best results for spray distribution for configuration A was found at droplet size of 300 μm and injection velocity of 100 m/s. The best result for configuration B however was at a droplet size of 50 and velocity 150 m/s.

In this study, droplet sizes produced at higher Injection pressures for nozzles with different orifices were investigated to ascertain which one will produce the most effective cleaning. This study is the first of its kind where the influence of droplet size on the cleaning effectiveness has been investigated under high injection pressures for flat fan nozzles.

2. Experimental setup

Nozzles with different apertures were selected to obtain the droplet sizes generated at varying injection pressures for a given distance. This was done in an attempt to select the nozzles that would be employed for washing of the fouled or degraded compressor blades in order to ascertain which one is most efficient in terms of power recovery.

The injector system comprises a high pressure piston pump, tank and a mechanical traverse unit where the nozzle is attached see Figs. 1 and 2. The tank is capable of containing 40 L of wash fluid and it has a heat coil that can be used for heating the wash fluid before being injected. A piston pump of 5.5 Hp, driven by a 2.2 kw electric motor which runs at 1128 rpm is used to inject the wash fluid from the tank through the nozzle tip at high pressures. A pressure regulator installed within the pump is used to control the pressure at which the fluid is being injected.

Three flat fan nozzles (N1, N2, and N3) with orifice diameters of 0.38 mm, 0.53 mm and 0.66 mm respectively were selected in agreement with veejet specification data [8], to ascertain the spray characterization (droplet size) produced by these nozzles. The investigation was carried out to obtain droplet size variations at varying injection pressures. In order to obtain precise and repeatable injection position, two separate and independent traverse systems were employed for the adjustment of the nozzle to the appropriate position, relative to measurement region where the beam passes through. One of the traverse systems is attached to the bed where the spraytec is mounted, to facilitate movement of the spraytec while the one other is attached to the nozzle to allow adjustment of the nozzle positioning in three

Fig. 1. Injector system: piston pump and tank.