Engineering Failure Analysis 18 (2011) 256–270

Contents lists available at ScienceDirect

Engineering Failure Analysis

journal homepage: www.elsevier.com/locate/engfailanal

Failure analysis of a Pelton turbine manufactured in soft martensitic stainless steel casting

D. Ferreño [a,*], J.A. Álvarez [a], E. Ruiz [a], D. Méndez [a], L. Rodríguez [b], D. Hernández [b]

[a] LADICIM, University of Cantabria, ETS Ingenieros de Caminos, Av/Los Castros s/n, 39005 Santander, Spain
[b] Technical & Scientific Research Services, University of Cantabria, R&D Research Building, Plaza de la Ciencia s/n, 39005 Santander, Spain

ARTICLE INFO

Article history:
Received 4 March 2010
Received in revised form 9 September 2010
Accepted 9 September 2010
Available online 17 September 2010

Keywords:
Pelton turbine
CA-6NM stainless steel
Finite elements
Temper embrittlement

ABSTRACT

In this paper, the failure of a large Pelton turbine, arising immediately after receiving a quenching and tempering heat treatment, is analysed. The turbine was manufactured in ASTM CA-6NM soft martensitic stainless steel. A thermo-mechanical finite elements model was developed to evaluate the homogeneity of the heat treatment; for this purpose, the thermal histories of internal and external points of the component were compared, and the possible existence of temper embrittlement was assessed. Moreover, the thermal stresses during heat treatment were obtained in order to perform a failure analysis. After analysing the fracture surface through visual inspection and scanning electron microscope fractography, the material properties were characterised all around the fracture surface including optical and transmission electron microscopy, chemical composition and Vickers and Charpy impact tests. All this experimental information allowed a satisfactory understanding of the phenomenon to be obtained and a failure analysis to be performed in order to justify the fracture of the component.

1. Introduction and objectives

The Pelton wheel is among the most efficient types of water turbines. This kind of impulse machine uses Newton's second law to extract energy from a jet of fluid. Many variations of impulse turbines existed prior to Pelton's design, but they were highly inefficient as the water leaving these wheels typically had high speed, and carried away much of the energy. Fig. 1 shows a scheme of the Pelton wheel whose failure is analysed in this paper. A Pelton turbine consists of a Pelton wheel mounted on a rotating shaft or rotor. The wheel (or runner) is composed of a circular disc and a set of cup-shaped blades, called buckets, placed at equal spacing around its circumference (see Fig. 1).

The high speed water jets running the Pelton wheel turbine are obtained by expanding the high pressure water through nozzles to the atmospheric pressure. Nozzles are arranged around the disc such that the water jet emerging from a nozzle is tangential to the circumference of the wheel (see Fig. 2). According to the available pressure of water and the operating requirements, the shape and number of nozzles placed around the Pelton wheel can vary, usually in the range 8–20; in this case, the wheel includes 18 buckets (see Fig. 1).

The high pressure water can be obtained from any water body situated at some height or streams of water flowing down the hills. As schematically depicted in Fig. 2, the water jets emerging form the nozzles strike the buckets at splitters, placed at the middle of a bucket, from where jets are divided into two equal streams. These streams flow along the inner curve of the bucket and leave it in the direction opposite that of the incoming jet; therefore, the change in momentum of the water

* Corresponding author.
E-mail address: ferrenod@unican.es (D. Ferreño).

1350-6307/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.engfailanal.2010.09.005

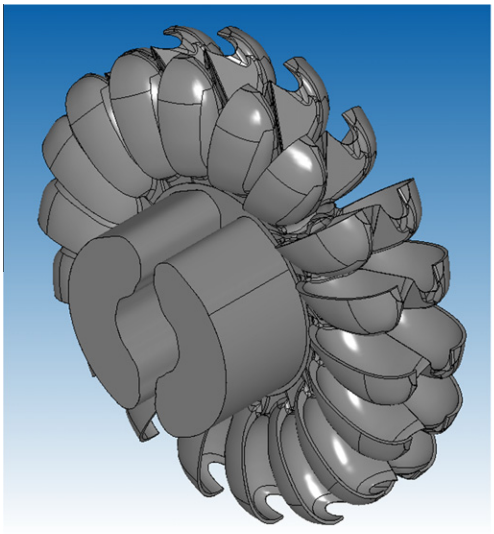

Fig. 1. Schematic perspective of the Pelton wheel whose failure is analysed in this research.

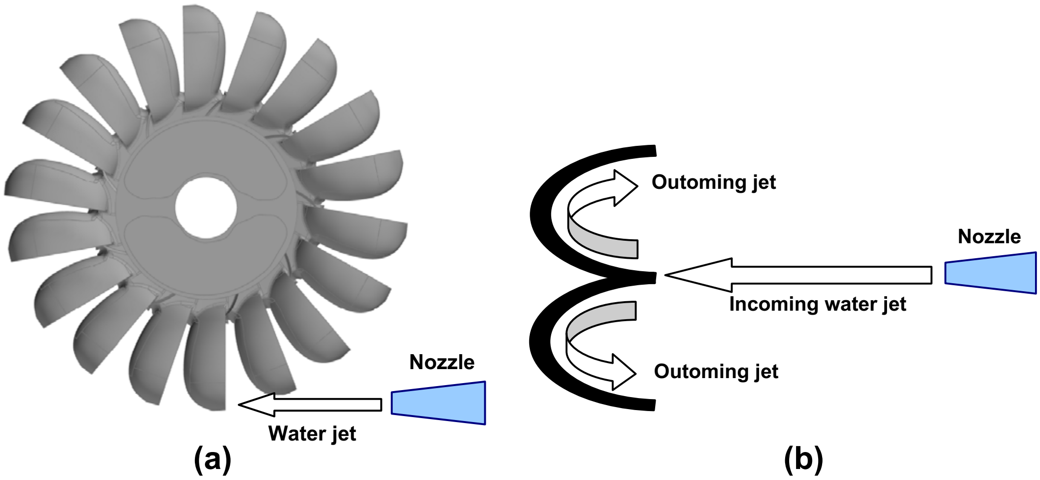

Fig. 2. Sketch showing the process of momentum transfer from the water stream to the bucket.

stream – and, as a consequence, the impulse received by the blades – is the maximum possible. This impulse generates the torque and rotation in the shaft of a Pelton turbine.

The runner is the most relevant component in a complete Pelton turbine device; the other elements (as the manifold, the housing, the nozzles or the turbine shaft) play a complementary role in the process for energy production. In order to facilitate the manufacture and maintenance, the disc and the buckets composing a Pelton wheel were traditionally manufactured separately and then joined through rivets (as in the original design by Lester Allan Pelton), screws or welding. However, in recent designs, where higher specific speeds are required, the complete Pelton wheel is fabricated in one part, using casting techniques, thus leading to an improvement in stiffness and simplicity in the assembly.

In this paper, the failure of a large Pelton turbine (sketched in Fig. 1), immediately after receiving a quenching and tempering heat treatment, is analysed. The external diameter of the wheel (including the disc and the blades) is approximately 1400 mm whereas the total weight is about 5200 kg. The turbine was manufactured in ASTM CA-6NM soft martensitic cast stainless steel (G-X4 Cr Ni 13-4, according to the German DIN designation). Quenched and tempered CA-6NM steel is widely used for hydraulic turbine runner castings, since it possesses high toughness together with excellent resistance to cavitation and erosion [1–4]. A complete revision of the microstructure, mechanical and fracture properties is presented in [5]. In Fig. 3, a set of photographs of the broken component and the fracture surfaces can be appreciated.