Abstract — During a major overhaul, routine inspection, cracks were found in a turbine wheel from a Stal Laval radial turbine type DDM 2070. An investigation into the nature and cause was needed to proceed finding the solution.

Keywords — Stal-Laval DDM 2070, turbine wheel, turbomachinery

I. INTRODUCTION

The inspected turbine wheel was first put in service in the mid-nineties. The turbine wheel was made of stainless steel grade X22CrMoV12-1. During the time in service, no apparent malfunction related to the cracking occurred. The cracks were found in 2018 for the first time, after ±23 years that the turbine wheel was in service. Furthermore, according to the client, a second turbine wheel from the same customer showed similar cracks. All cracks were located in the intrados of apertures at the inner circumference of the wheel, on the wheel shaft side.

Fig. 2 shows an image of the submitted turbine wheel section, prepared for examination. The entire specimen showed a dull grey appearance, free of accumulated products. The cracks where clearly visible and identified as crack number 1 and 2 for reference purposes.

Fig. 3 shows a close-up image of the areas containing the cracks. The cracks showed the same characteristics: both cracks were located at the meeting point of the smaller radii transition, at wheel shaft side. This is also the region with higher stress concentration. Here the cracks appeared to be wider. A view from the top side of the part reveals that both cracks developed on the right side of the apertures (left side of the support). The cracks progressed along the sharp transition radius, in the circumferential direction. The cracks then branched further, crack 1 extending up to ±18 mm and crack 2 up to ±20 mm.

The turbine process conditions were as follows: at the inlet, superheated steam flows with a constant temperature of 471°C and pressure of 6 MPa. No temperature or pressure fluctuations are normally expected. However, as informed by the client, the steam flow fluctuated. The steam fluctuation caused a cyclic loading in the turbine, which translated into a load cycle of ±500kW every 10 seconds more or less. The turbine was only stopped for maintenance inspections, with approximately 5 start/stops per year.
II. EXPERIMENTAL DETAILS

The cracks found were examined by means of plastic replication. Turbine wheel sections containing the found cracks were cut out for further investigation. The sections were examined in detail under a stereomicroscope. One of the sampled cracks was cooled in liquid nitrogen and opened by hammer impact. The opened crack surface was examined in detail. The approximate chemical composition of the turbine wheel base material was determined by means of X-ray fluorescence (XRF). Scanning electron microscope was performed on the affected area, before and after cleaning. Before cleaning, semi quantitative chemical analyses were performed on the found products by means of energy dispersive X-ray microanalysis (EDX). Two sections across the affected areas were extracted and prepared for macroscopic and microscopic examinations. Vickers hardness measurements were also performed.

Figure 4: Detail region of the cracks

Fig.4. shows a close-up image of the areas containing the cracks. As observed from the aperture’s intrados, the cracks follow a straight path along the wheels longitudinal direction. Crack nr1 extends to 23.9mm and Crack nr 2 to 39.8mm. No local plastic deformation or signs of necking of the structure was observed.

Figure 5: Detail image of crack 1 after opening by hammer impact

In Fig.5, a detailed image of crack 1 is shown as it is opened after hammer impact. The crack was flat and perpendicular to the wheel ring surface (main stress oriented in radial direction). A faint ratchet mark (ridge, see white arrow) was visible, coinciding with the meeting point of the sharp transition radii on wheel shaft side. The latter indicated and corroborated the site of crack origin. At the area of crack initiation, the crack surface was partially covered with dark brown products, while the rest was covered with dark grey products. Multiple macroscopic parallel and stepped semi-elliptical markings where visible (faint beach-marks) delineated by the accumulated products. Within the beach-marks, faint river-like patterns extended from the wheel top surface inwards the bulk material. These clearly indicated the direction of crack propagation: from the wheel shaft(top) side towards the bottom side.
III. CONCLUSIONS OF EXAMINATIONS

The turbine wheel base material corresponded to the specified grade. No signs of material defects and/or degradation that could relate to the damage were present. The occurred damage has been the result of fatigue cracking, originated at the meeting point of small transition radii on the wheel shaft side.

Several interconnected factors; cyclic loading (resulting from superheated steam flow fluctuations), point of local high stress concentration (unfavorable geometry at the site of ignition) and service at elevated temperatures (resulting in severe oxidation of the crack-flanks) are regarded as the main contributing factors.

IV. SOLUTIONS

Before the destructive testing was started, the rotor was completely scanned to create a 3D model of the point cloud recorded by a blue light camera.

Fig.6. shows a 3D image of the scan data generated by a blue light scanner, which is the base from which the 3D model of the turbine wheel was made. After scanning all the blade rings were dismounted to recuperate them for re-instalment on the new manufactured turbine wheel.

After analysing the results of our research on the course of the cracks, the customer decided not to change the shape and design of the turbine wheel, but to look at the cyclical variation in the load. That’s why we included all the data to design and manufacture a new turbine wheel.

Specific 2D drawings of the turbine wheel were made, forged and certified material was used. (X22CrMoV12-1 EN 10302)
Using the 3D model and 2D drawing, a CAM model was built, which controls the CNC machine to achieve the correct machining. The machining process has been interrupted a few times to anneal the rough rotor tension arm, this to avoid deformation. Figure 9 shows the turbine wheel been made by a CNC machine. Figure 10 shows the newly machined turbine wheel.

After the machining is finished, the rotor is ready for the final inspection. The newly machined turbine wheel has been scanned and compared to the 3D-model. This way we do a quality control to verify that the rotor has been produced in accordance with the specifications and tolerances.

After the non-destructive crack test, the final mounting of the side labyrinth plates and blade rings can start, as seen in Figure 12.
After this mounting, an after run-out check and balance check according the standard ISO 1940-1 G 2.5 has been done, as seen in Figure 13. After this, the turbine wheel is released for further assembly.

The steam box is fully assembled in the workshop of Energetic and is ready to be transported to the costumer, as seen in Figure 14.

The assembly of the steam box on site at the customer’s site, in addition to the other repairs to various turbine and generator elements carried out, we can start with the final assembly and the preparation of the start up. Figure 15 shows the assembly on-site.
Vibrations levels are checked and has a value of 15 Mw which is stable and ok, as seen in Figure 16.

An electronic overspeed test has also been done and has a result of 3204 rpm, as seen in Figure 17.

V. ENERGETIC NV

Energetic not only provides new turbine wheels, but reengineers all turbine parts and auxiliary parts needed to keep your turbine in operation. We have a highly specialized engineering that supports the workshop and our people on site. All our staff are busy daily and exclusively with overhauls of turbo machinery.

The Stal-Laval turbine is a unique but very well-known turbine at Energetic.

Our references are available on request, we would also like to visit you on site to present our services.

Energetic provides a unique service:

- Small and large service inspections / maintenance of the entire installation (turbine, generators, auxiliaries).
- Reverse engineering and making of new parts
- Trouble shooting by vibrations, leaks etc.
- Resolve alignment problems.
- To remedy asymmetric dilatation.
- Re-blading and balancing of the rotors.
- Renewal of the seal strips seals
- renewal of shaft seals, sealing side plates
- Repair and renewal of valves
- Modernisation of control and safety mechanisms
- Material and tear research
- Repair of cracked turbine casings

The following pictures give examples carried out on various radial turbines in the past.
Figure 20: Renewal of coupling strips

Figure 21: Inspection of generator coolers

Figure 22: Radial & axial bearing repair and manufacturing

Figure 23: Lube oil pump repair