Influence of Startup management on the Residual Life of a Large Steam Turbine Shaft

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Long Abstract

Introduction

The liberalization of electricity market in Europe led to a growing competition between energy producers, making crucial the ability to optimize the management strategies of power plants. Combined cycle power plants (CCPP) have to operate in a flexible way, with frequent and rapid variations of the produced power, in order to quickly react to the frequent load changes imposed by the demand. Nowadays, they typically operate in cycling mode with daily start-up and shut-down. The components of the plant are subjected to great cyclical variations in temperature, which induces stresses on materials, especially during the start-up phases. The activity concerns the assessment of life consumption caused by these operations on the rotor of the steam turbine of the CCPP (800 MW) inside the Tirreno Power thermal plant located in Vado Ligure, Italy. The aim is to draw a set of curves representing the percent life expended per cycle as a function of the rate of steam temperature change and magnitude of the overall temperature increase. These curves are called Cyclic Life Expenditure curves (CLE). In the future, the developed methodology will be used to reduce the start-up times, keeping under control the life consumption of the rotor and optimizing the maneuvers that generate thermal transients.

1. Methods

Several systems were installed by OEM of Steam Turbines or other companies to keep under control the stress of this component during plant start-ups and shut-downs, which are the most stressful maneuvers. For example the Siemens Turbine Stress Controller allows different start-up modes which can be preselected by the operator on the base of the grid requirements [1]. A similar approach is proposed by Ansaldo Energia: the temperature change is monitored with a so called Rotor Stress Evaluator (RSE) and the stress in maintained under some fixed thresholds limiting the Gas Turbine and Steam Turbine load rate.
In fact, the life consumption due to the start-up maneuver is not just related to the initial conditions (initial rotor temperature), but also to the way the temperature ramp is performed (i.e. temperature mismatch and temperature gradient). A simple technique to visualize this effect is represented by the Cyclic Life Expenditure (CLE) curves, (e.g., see Figure 6.13 in Viswanathan [3]) often given by the manufacturer. Those curves represent the per-cent life expended per cycle as a function of the rate of steam temperature change, and magnitude of steam temperature change and can be used operatively in the start-optimization process.

To define the CLE curves, the stress for the different loading pattern was evaluated taking into account:

- thermal dilatation of the material,
- centrifugal force
- steam pressure on the rotor surface.

Those factors are evaluated separately and then combined by superposing their effects; at last the tri-axial stresses are converted to an equivalent uni-axial stress by using the Von Mises criterion.
At first, to evaluate the thermo elastic stresses due to the thermal transient of the rotor, the heat transfer partial differential equation for the cylinder was solved by means of the finite difference method. Also the exact solution, of the heat transfer problem in cylindrical coordinates for fixed boundary temperatures, based on Bessel equations, was used as comparison for the simplified model under well-defined boundary conditions. The equations were solved for the actual High Pressure and Intermediate Pressure rotor radius taking into account the material properties (DIN 30CrMoNiV5-11), function of the temperature itself [4].

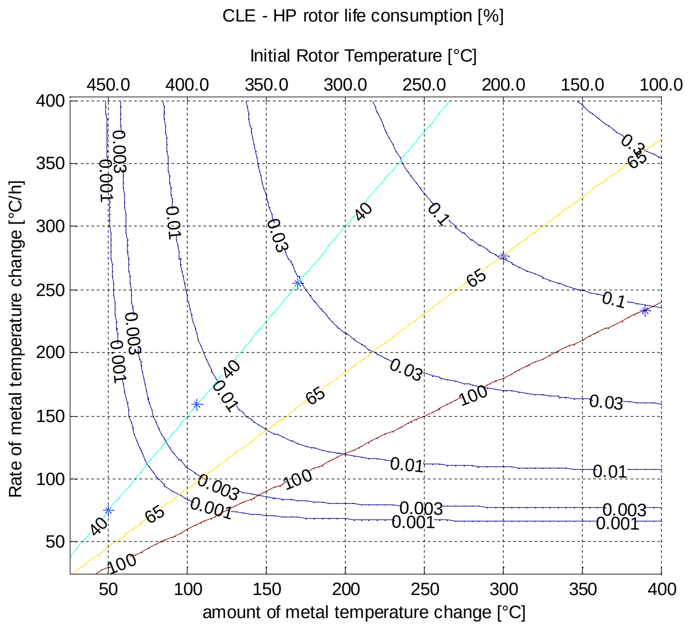

Figure 1. Cyclic Life Expenditure for the High Pressure part of the Rotor, blue lines; experimental start up data, blue stars; minutes to full temperature, colored straight lines.

The actual strain is then evaluated basing on the Neuber hyperbola method taking into account the stress concentration factor due to the first blades groove. Then number of cycles is derived from the actual strain using a Low Cycle Fatigue curve for a Cr-M-V rotor steel at 540°C that includes hold-time effects [3] (a value of 24h hold time was used as suggested by several authors [3,6,7]). The results were used to create the CLE curves, as in figure 1. Moreover experimental data for several startups were used to evaluate the actual life expenditure. The generalized information were combined through the Miner-Robinson rule taking into account also the creep effect due to high temperature normal operation, (creep-rupture life under the nominal operating conditions is 300,000 h [3]) and with respect to the yearly startups as reported in the following table.

Start up	standstill time	initial rotor temp [°C]	yearly start up number (n_y)	life expenditure/ startup ($1/N_i$) [%]	yearly life expenditure [%]
Hot press	<16 h	T>370	53	0.0050	0.265
warm	16 h < t< 108 h	370>T>150	123	0.030	3.69
cold	t>108	T<150	11	0.100	1.1

2.Conclusion

The impact of combined cycle startup on the steam turbine life was assessed on the basis of the actual operational data and a simple but rigorous approach, evaluating the Cycle Life Expenditure (CLE) Curves. The data were used to estimate the yearly average life expenditure. The algorithm was then implemented on the Power Plant Distributed Control System (DCS), and is going to be used for on line optimization of startup time.

References

[1] Kelhofer, R. et al., 2009, “Combined-Cycle Gas & Steam Turbine Power Plants”, McGraw-Hill

[2] Gulen, S.C., Kim, K., 2013, “Gas Turbine Combined Cycle dynamic simulation: a physics based simple approach”, Journal of Engineering of Gas Turbines and Power, vol. 136.

[3] Viswanathan, R., 1989, “Damage Mechanisms and Life Assessmentof High-Temperature Components,” ASM International, Metals Park, OH, USA

[4] S. Canevese, V. Casamassina, A. Cavaliere, A. Frigerio, G. Bruno, V. Prandoni, “Simulatore dell’impianto di riferimento a ciclo combinato”, CESI RICERCA

[5] Einfluß moderner Verfahren der Stahlerschmelzung auf das Zeitstandverhalten dickwandiger Bauteile aus 1 %-CrMoV-Stählen, Kommission der Europäischen Gemeinschaften.

[6] Steam Turbine Rotor life Assesment, Volume1, task 1: thermal and stress analysis of rotor, EPRI TR-103619-V1, March 1994

[7] Stefano Bonzani, Turbine a Vapore, Ansaldo Energia, internal publication