

Analysis on Service Life of Hot-end Components of Gas Turbine Using Equivalent Operation

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Abstract

The reliability of the gas turbine depends on the technical status and the maintenance level of the hot-end components in a large part. The three main factors influencing on the service life of the hot-end components of the gas turbine were analyzed first. On this basis, various common service life assessment methods for gas turbine were discussed in detail. Aiming at the features of the M701F gas-steam combined cycle unit in Huizhou LNG power plant, a gas turbine life assessment method based on equivalent operation time analysis was put forward. The calculation result of an example shows that the equivalent operation time analysis method is a simple and practical assessment method.

Keywords: gas turbine; assessment; equivalent operation time method; overhaul

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1. Introduction

Hot-end components (combustion chamber and turbine stator blade) are the core parts of gas turbine, which possess difficult design, expensive material, and complex process. The reliability of the gas turbine depends on the technical status and the maintenance level of the hot-end components in a large part. Research of service life assessment method for hot-end components is of significantly practical meaning for prolonging service life of hot-end components and making reasonable maintenance plan.

2. Factor Influencing the Service Life of Hot-End Components of Gas Turbine

For high-temperature components which operate under high temperature, high pressure and corrosive medium for a long time, factors involving work temperature, bearing load and medium property take quite large and complex effects on metal material damage, however, main types which lead to high-temperature metal material damage can be divided into three types including high temperature creep damage, low cycle fatigue, and corrosion damage.

2.1. High Temperature Creep

Compressor, hot channel, burner, turbine are main hot-end components of gas turbine that operate under high temperature for a long time, and work temperature of burner and turbine even is up to 1400°C. Under high temperature, creep stress is one of the important reasons for component breakage; therefore, research of high temperature creep characteristics of gas turbine material is one of the important methods to assess expected service life of hot-end components of gas turbine. [1]

2.2. Thermal Fatigue

Hot-end components of gas turbine are affected by on/off operation of the unit and pressure and temperature fluctuation while operation with load. Frequent cycle change of temperature makes hot-end components affected by cycle alternating stress, whose long-term accumulated effects finally lead to failure of effectiveness of the components. [2] Generally, fatigue with damage cycle number more than $10^4 \sim 10^5$ is called as high cycle fatigue, and that with less than the limit is called as low cycle fatigue. Thermal fatigue of gas turbine which is

generated in on/off operation is of low cycle fatigue. Thermal fatigue is another one of the important factors influencing hot-end components life.

2.3. Coating Oxidation and Corrosion

Coating of hot-end components includes internal surface coating on the transition section of flame tube, high-temperature anti-oxidation coating and thermal barrier coating on the surface of stator blade and rotor blade as well as anti-corrosion coating on the surface of rotor blade internal cooling air channel. Under high temperature and airstream erosion, coating oxidation and sinter make thermal conductivity increase and porosity decrease, wearing and erosion make coating thin, thermal fatigue and deformation of basic material make coating crack, and bad-quality coating makes local flake and erosion of the coating, all of them can influence service life of hot-end components under the protection of the coating.

3. Common Service Life Assessment Methods for Gas Turbine

Operation life of hot-end components of gas turbine is mainly influenced by stable creep, thermal fatigue, coating oxidation (environmental corrosion and external corrosion), as well as other damage resulted from unit operation. Research of influence of stable creep and thermal fatigue on equipment operation life is common and wide relatively, and the assessment methods from summary of former researches are: McEvily formula, statistical method, Coffin-Manson formula, and rapid assessment method, etc. [3]

McEvily formula is a method to calculate service life of the components (materials) with creep as main factor influencing component damage, and it is one life assessment method with the widest application presently. To apply this method for life assessment, $\lg \sigma - p$ curve test of the material must be taken or $\lg \sigma - p$ measured curve and material constant C value of the material must be offered by equipment manufacturer, otherwise McEvily formula cannot be taken for life assessment of the equipment. Statistical method is a method to assess equipment service life with thermal fatigue as main analysis parameter. Statistical method firstly gathers statistics of cycle stress amplitude born by the components, and then find breakage cycle number according to S—N curve. Application of this formula shall be based on abundant operation statistics, and then calculate fatigue life of the material from abundant statistics

Coffin and Manson, Et Al. have taken a great many researches of low cycle fatigue and set up Coffin-Manson formula to reflect the relation between plastic strain amplitude $\Delta \varepsilon_p$ and fatigue life N_f : $\Delta \varepsilon_p N_f^\beta = C$, among which, C and β are material constant. The formula is very accurate under low temperature, but has to be revised under high temperature operation. Calculation formula under high temperature is: $\Delta \varepsilon_{e+p+c} \cdot N_f^\beta = C_1$, among which, $\Delta \varepsilon_{e+p+c} = \Delta \varepsilon_e + \Delta \varepsilon_p + \Delta \varepsilon_c$ express elastic strain amplitude, plastic strain amplitude and creep strain amplitude respectively; N_f refers to material damage cycle number; β and C_1 are material constant.[4] Creep strain can be ignored on the occasions with short work cycle time of the material (such as unit operation in Huizhou LNG Power Plant), namely: $\Delta \varepsilon_{e+p} \cdot N_f^\beta = C_1$. This assessment method can obtain strain amplitude from the relation between thermal stress and strain, and then calculate out the service life with the formula $\Delta \varepsilon_{e+p} \cdot N_f^\beta = C_1$. The calculation result of the formula is relatively accurate, but is not easy to realize generally, mainly for two constants of the material is hard to determine and have to be obtained from various experiments of high temperature material under enough experimental condition. Furthermore, material constants are different greatly at different temperatures; therefore, unprofessional manufacturer is hard to test the parameters.

Rapid assessment method assess the service life of the machine according to on/off number N and creep time or life t_R of the machine in traditional experiences. The method is a common and simple method at home and abroad, and can be used to assess the whole gas turbine, but with large error. The two parameters N and t_R are determined according to operation experiences for years. Rapid assessment method is hard to taken if the manufacturer fails to offer the parameters. In addition, experience values of the two parameters can not be found in related available documental data at home and abroad.

4. Service Life Assessment of Gas Turbine in Huizhou LNG Power Plant

Huizhou LNG Power Plant adopts gas-steam combined cycle unit manufactured by Japanese Mitsubishi Heavy Industries, Ltd./Dongfang Turbine Co., Ltd. together, with installed capacity as 3×390MW, among which, gas turbine is M701F type and single shaft heavy type while steam turbine is three pressure, reheat, two cylinders downward exhaust type, waste heat boiler adopts horizontal, three pressure, reheat, non-additionally fired, natural cycle and outdoor arrangement, and made by Hangzhou Boiler Group Co., Ltd./US NE Co., Ltd.

4.1. Operation Features

Gas turbine unit is featured by rapid on/off, flexible operation, and high effectiveness, so according to national policies and grid requirements, Huizhou LNG Power Plant is mainly used as variable load power plant of Guangdong Grid presently and carries out two-shift operation method that start in the morning and stop in the evening, and take part in daily grid AGC variable load operation.

Frequent on/off and elevating power can test stress life of hot-end components of the unit (combustion chamber and turbine rotor and stator blade). Life pressure of the gas turbine mainly comes from 1400°C high temperature components and frequent on/off operation, including influence on waste heat boiler and steam turbine. In addition, combined cycle system does not operate under rated work condition as design at most time, which does not accord to design of M701F gas turbine. [5] Therefore, scientifically life evaluation of unit primary device and auxiliary equipment will offer important scientific reference for unit operation repair.

4.2. Gas Turbine Life Assessment Method Selection Based on Equivalent Operation Time Analysis

Gas turbine in Huizhou Power Plant is M701F gas-steam combined cycle unit made by Mitsubishi Heavy Industries, Ltd. Due to Mitsubishi Heavy Industries, Ltd. does not offer the above parameters and S-N (stress-fatigue life) curve in the equipment data, so $\lg \sigma - p$ test curve and material constant C value of the unit are not available, and the above four methods cannot be used to assess the service life of the gas turbine in Huizhou Power Plant. Meanwhile Coffin-Manson formula is hard to apply, for Huizhou Power Plant as unprofessional manufacturer is hard to test the parameters of the material.

Due to compressor, hot channel, burner, turbine are main hot-end components of gas turbine, Mitsubishi Heavy Industries, Ltd. has strict requirements for overhaul time (mainly for appointment of equivalent operation time and on/off number) and overhaul technique. It is known based on the above analysis and operation data or equipment parameters related to the same type gas turbine of Mitsubishi Heavy Industries, Ltd. collected online: as to two-shift operation system, equivalent operating hours (EOH) and on/off number of the unit is a practical method to assess gas turbine in Huizhou Power Plant.

4.3. Analysis and Calculation Theory of Equivalent Operation Time

Accumulated running hours, on-off number, load feature, fuel characters, water and steam injection rate, load rate, tripping operation and maintenance level and abnormal operation condition of gas turbine directly influence reliability and using life of hot-end components. Operation life of gas turbine will be greatly influenced for the above reasons in peak load operation method, so we generally use EOH in life evaluation.

Generally, influence of indexes like on-off number, load feature, fuel character, water and steam injection rate, load rate, tripping operation and maintenance level and abnormal operation condition on operational reliability can be reflected in equivalent operating hours (EOH) given by manufacturer of gas turbine as the following computing formula:

$$E=Tp+Nw*Ts \quad (1)$$

$$Ne=Nc+Nf+Nj+Nk \quad (2)$$

Among which, E-Equivalent operating hours;

Tp-Actual operating hours;

Nw-Equivalent on-off number;

Ts-Equivalent operating hours per on-off operation;

Ne- Equivalent on-off number;
 Nc-Normal on-off number;
 Nf-Equivalent on-off number under load rejection;
 Nj Equivalent on-off number under emergency shut down;
 Nk-Equivalent on-off number while rapid load change.

EOH of hot-end components given by Mitsubishi: EOH is 20h for combustion chamber, changeover sheet, fuel nozzle, and flame tube, rotor and stator blade at first turbine level and ring segment and 10h for rotor and stator second, third and fourth turbine level and ring segment per normal on-off operation. Load rejection at full load is equivalent to 6 normal on-off operations, and load rejection at 80% load is equal to 5 normal on-off operations. Emergency shut down at full load is equivalent to 10 normal on-off operations. Due to load change of Mitsubishi gas turbine is taken as procedure, rapid load change will not occur generally.

5. Calculation Result

This paper uses the equal interval method to calculate six groups of traditional equal crack points with turbine blade statistics result table of F and G degree gas turbine of Mitsubishi Heavy Industries, Ltd. reported in Gas Turbine Technology as calculation reference and same crack as judgment standard of EOH. The calculation result refers to Table 1.

Table 1. Crack length and EOH-Equivalent operating hours

		3mm	5mm	10mm	15mm	20mm	25mm
Day On-Off Unit	Actual Operating Hours	App. 3,750h	App. 5,500h	App. 8,000h	App. 9,500h	App. 11,500h	App. 15,000h
	Actual On/Off Number	110 Times	140 Times	190 Times	235 Times	275 Times	300 Times
Basic Load Operation Unit	Actual Operating Hours	App. 7,000h	App. 9,500h	App. 13,000h	App. 15,500h	App. 18,000h	App. 21,000h
	Actual On/Off Number	45 Times	50 Times	60 Times	70 Times	75 Times	80 Times
Equivalent Operating Hours (EOH)		50h	44.4h	38.5h	36.4h	32.5h	27.3h

We can see from Table 1, with 50% occurrence probability for statistics, the relation between day on/off unit turbine accumulated operating hours curve and basic load operating hours curve nearly like a horn, namely, with increasing operating hours, actual operating hours of day on/off operating method at first turbine level becomes lower and lower than operating hours of basic load operating method, which can reduce utilization efficiency and average life of the equipment.

Considered that stable operation of gas turbine of Mitsubishi Heavy Industries, Ltd. is 99% according to statistics, we can ignore the influence of factors of load rejection and emergency shut down and ignore equivalent factors besides on/off operation in calculation process. Seen from calculation result, for six equal crack points to calculate, on/off EOH of rotor blade at first turbine level is more than 20h, but with prolonging of operation time, EOH trends to descend. We have drawn the crack statistics rule with the data referring to Table 1, as Figure 1.

According to EOH of Mitsubishi Heavy Industries, Ltd., hot-end components including Huizhou Power Plant unit blade at first turbine level, combustion chamber, changeover sheet, fuel nozzle, and flame tube nearly operate equivalently 35 hours per day normally, which is unreasonably from the angle of unit life management. As to power plant, it is a great waste of loss cost of the unit, equal to over 50% more operation equipment cost, and greatly influences enterprise benefit.

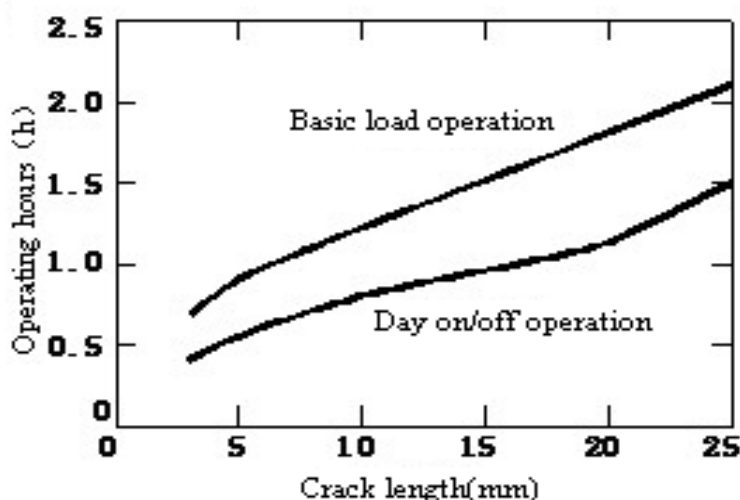


Figure 1. Crack in operating modes-hours

6. Conclusion

Seen from the above analysis result, as to day on/off variable load gas turbine unit, influence of various factors (stable creep, thermal fatigue, coating oxidation and other damage resulted from unit operation) on hot-end components life is mostly led by life loss of thermal fatigue. While due to frequent on/off operation, material creep takes small influence on equipment life. In order to improve equipment utilization efficiency of gas turbine unit, we suggest to change operation method of the unit into variable load operation method under basic load condition so as to reduce the influence on equipment life of frequent on/off operation. Seen from foreign operation experience data, accumulated operating hours of gas turbine and on/off EOH are in reverse relation, namely with increasing accumulated operation time, on/off EOH decrease by degrees, therefore, we shall take the influence of the factor into consideration while making maintenance plan. We suggest prolonging maintenance interval properly when the equipment operate stably, namely "bottom" curve part of "bath tub curve" in reliability assessment, so as to improve utilization efficiency of the equipment and reduce maintenance cost.

References

- [1] Yang Ce, Ma Chaochen, Baojie, Et Al. The Development of a Small and Preliminary Scheme Two-Shaft Gas Turbine. *Journal of Engineering Thermophysics*. 2002; 23(4): 445-448,
- [2] Zheng Junlin. Optimum of Close Type Gas Turbine Cycle under Power and Density Condition. Degree Paper of Naval University of Engineering. 2000.
- [3] BROWN RA. SOFC combined cycle system for distributed generation. DOE/MC/28055- 97/CO837; 1997.
- [4] Feidt M. "Optimisation d'un cycle de Brayton moteuren contact avec capacites thermiques finies". *Rev. Cen Therm*. 1996; 35(12): 662-666.
- [5] Chen Lingen, Sun Fengrui, Wu Chih. A generalized model of real heat engines and its performance. *J. of Institute of Energy*. 1996; 69(481): 214-222.