THE USE OF ROTOR DIAGNOSIS FOR THE ANALYSIS OF HIGH VIBRATION EXPERIENCE AT TURBINE-GENERATOR SYSTEM IN NUCLEAR POWER PLANTS

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Abstract

As the life extension of operating nuclear power plants becomes bigger issue, structural integrity of NSSS component is getting more concern. Along with the NSSS components, turbine-generator (as one of the biggest rotating components in nuclear power plants) can be considered seriously, due to the long period of operation. Many cases of high vibration have been reported. Some experiences of turbine component failure in US and Korean nuclear power plants are shown. The reason for the failure, mechanism of these turbine failures can be poor design, lack of consideration of turbine installing environment and improper maintenance. The vibration data from main turbine component in operating nuclear power plants are analysed in view point of rotor diagnosis. Examples of high vibration of main turbine at some Korean nuclear power plants and the reason of each high vibration case are discussed. From the analysis result and the experience data, the optimum operation and maintenance method is proposed.

1. Introduction

As one of the biggest rotating components in nuclear power plants, turbine-generator can be considered seriously, due to long period of operation in view point of life extension of nuclear power plant. Moreover, turbine trip can give harmful effects (like transient loads, thermal shock and so on) to the main components like pressurizer. Thus, maintenance and operation of turbine-generators can be considered quite important. In reality, however, the regulatory documents on turbine-generators are (In case of US and Korea) Regulatory Guide 1.115 ‘Protection against Low-Traceorty Turbine Missiles’ [1], US NRC Standard Review Plan 10.2 ‘Turbine generator’ [2], 10.2.3 ‘Turbine Rotor Integrity’ [3] and 3.5.1.3 ‘Turbine Missiles’ [4]. But, these documents cover just turbine control like overspeed control, turbine integrity and turbine missile.

The main focus on this paper is turbine maintenance and monitoring by using rotating machinery dynamics concepts [5-10]. By using vibration monitoring, the condition of turbine-generators can be checked before they are disassembled. Here, some examples and experiences of turbine-generator high vibration cases are introduced and their causes are analyzed by using rotating machinery dynamics concept. And finally, some suggestions on turbine-generator maintenance are proposed based on the analysis results of the experience data.
2. Turbine-generator damage cases in US

Turbine diaphragm, blade and bearing damage cases and related high vibration cases reported in NRC License Event Report issued from 1995 to 2003 are shown in Table I [11]. As can be seen from Table I, most of the high vibration cases during the period are rubbing due to narrow gap between rotating part and stationary part, and unbalance due to some design error and installation error. The smaller the gap between rotating part and stationary part is, the bigger the efficiency of turbine is. However, too small gap means higher chance of rubbing.

Moreover, as can be seen from the cases of Brunswick unit-1(1996) and Milstone unit 2(2003), rubbing is highly related to thermal effects like thermal expansion. If rubbing occurs, heat at the rubbing point makes local thermal expansion or thermal bow, while, local heat by any reason can cause local thermal expansion or thermal bow which can result in rotating part and stationary part rub.

3. Turbine-generator damage cases in Korea

3.1 Consider environmental condition of installing plant

Damage and high vibration cases of Korea, related to turbine-generator are listed in Table II [9-10, 12-18].

Among the cases, the turbine at Ulchin unit-1 and 2 have experienced damage from the beginning of their commercial operation, due to not considering power generating frequency. The power generating frequency of Korea is 60Hz, while that of France is 50Hz. Thus, the power generating turbine in Korea rotates in 1800rpm, while the turbine in France rotates in 1500rpm. The problem is that, the turbine in Ulchin unit-1 and 2 are designed in France which considered rotating frequency of 1500rpm only. And that caused resonance at the frequency around 1800rpm at second stage of low pressure turbine blade which resulted in damage at the blade and diaphragm of low pressure turbine. After that, they changed the original design to avoid the resonance by adjusting the number of blades at the second stage of low pressure. However, in 2005, the turbine showed two more times of step change in amplitude and phase. And after they disassembled the turbine, they found some missing parts and damaged parts at the low pressure turbine. To solve this problem, they are planning to replace the whole turbine-generator sets.

As shown above, it is essential to consider the environment of installing plant like rotating frequency, when new or replaced components are to be installed.

3.2 Cautions required during the design step

Kori unit-1, 2, 3, 4 low pressure turbine rotors were shrink fit type before they replace them with welding type rotors in 1997 and 1998. Before then, high vibration and damage to turbine occurred repeatedly due to stress corrosion cracking. In this case, there exists high possibility to have unbalance and step change of vibration level and phase angle. In reality, as shown in Table II, there are many cases of vibration step change due to unbalance caused by crack and separation of blade root and shroud. Kori unit-1, 2, 3, 4 experienced many damage cases other than the cases shown in
Table II.

3.3 Cautions required at the maintenance and installation

In November, 1985, high vibration occurred at a turbine exciter bearing at Kori unit-1. As shown in Table II, a thermocouple to monitor bearing temperature was installed at 100cm position while the recommended position was 30cm. Too deeply installed thermocouple contacted with bearing and resulted in electrolytic corrosion on the surface of the bearing. Electrolytic corrosion occurs when an electric component contacts with a metal surface. At the contact point, it makes high voltage spark and tiny pock mark on the metal surface. That tiny pock mark was the reason of high vibration. If it goes further, high vibration affects harmful effect to the bearing and the shaft as well. It makes the pock mark bigger, and in sequence, makes the vibration higher. Thus, when any kind of damaged on the surface of bearing, it should be analyzed and further action should be taken: reuse after some surface work or replace it.

The next high vibration case happened in October, 1990, at low pressure turbine of Kori unit-4. At first they thought that the reason was due to unbalance of turbine rotating part. So they conducted mass balancing. But even after several times of balancing, high vibration didn’t reduced and the phase changed at every try. So, they disassembled the turbine and found failure at rotating part. The rotor disc is tight fitted to turbine shaft. ‘Disc locking ring’ is placed at the end of the disc. And to tightly fix the disc locking ring, ‘dwell pin’ is used. In this case, the ‘dwell pin’ has been cut and caused relative rotation of turbine shaft and disc locking ring. That’s why the mass unbalance with changing phase angle was detected. Usually, pure mass unbalance shows no change of phase angle.

Above two cases, Kori unit-1(1985) and Kori unit-4(1990), are typical cases of poor maintenance and installation. Thus, it is very important to be cautious on aintenance, check, measure and test even though, those are thought to be minor.

3.4 Prevent rubbing and heat concentration

The case of Younggwang unit-5 in December 2001, tells the importance of rubbing prevention. At a certain part of turbine shaft, local heat concentration occurred by certain reason, the shaft expanded followed by thermal bow. At this time, gland packing clearance between low pressure turbine rotating part and stationary part was too small compared with the high vibration of shaft caused by thermal bow. In this sequence, rubbing occurred and caused more heat on the rubbing part to make it worse. Thus, it is highly important to check every rubbing suspected gap to prevent rubbing before they finish the assembling process during the outage. On the contrary, it is necessary to check cooling and lubrication system to prevent thermal concentration.
4. Conclusion

Examples and experiences of turbine-generator high vibration cases are introduced and their causes are analyzed by using rotating machinery dynamics concept. In this part, some suggestions on turbine-generator maintenance based on the analysis results of the experience data are introduced as below;

4.1 Use of diagnostic method based on rotating machinery dynamic concept

- Most cases of high vibration and damage of turbine-generator are due to rotating machinery defect like unbalance, rubbing. And rotating machinery defects are relatively well detected by monitoring some parameters like vibration, phase and oil temperature.
- Thus, turbine operators and maintenance staffs should be trained on rotating machinery diagnostic concepts and understand the characteristics of rotating machinery defects and finally, adequately face the high vibration and defect of turbine-generator - By considering plant specific condition, monitoring method and abnormal case procedures should be prepared. For example, the procedure which only compares the vibration level with simple threshold (such as alarm set point) of the turbine-generator should be replaced with the procedure which comprehensive considers step change of vibration level and phase, lubricant oil temperature change, trend of vibration and so on.

4.2 Management of turbine design and maintenance

- Errors on turbine design arise when the installing environment of turbine-generator is different from that of original design. For example, turbine-generator originally designed to be installed in Europe is rotates in 1500rpm while, the turbine in Korea rotates in 1800rpm. Thus, when the turbine for Europe is to be installed in Korea, the effect by changing rotating speed, such as resonance, should be considered. The other case of design error is mis-calculation of stress on rotating blade.
- Errors on maintenance such as too small gap, mis-installation of detectors make rubbing which eventually resulting in turbine high vibration and damage. Thus, the management program for gaps and sub-part(like detector) installation should be established.
- The management program to keep high vibration and damage, in case of modification and replacement of rotating part and its vicinity part, is required.

4.3 Aging management program by each sub-part of turbine-generator

- Root and the end part (tenon or shroud band) of rotating blade are susceptible to defect. To detect the defect, NDT is conducted for every outage for those parts. However, the part for the NDT should be re-selected by using thorough analysis and by adapting the experience database. For the re-selected NDT part, the comprehensive management program for the inspection, fatigue and aging.

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NPP unit | Date | Damage and its Cause
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Dresden 3 | 1995.05.28 | Turbine high vibration and reactor emergency auto trip LER, A rotating blade failure at low pressure turbine-C
Nine Mile Point 2 | 1995.05.30 | Turbine bearing high vibration and reactor emergency manual trip Not enough clearance in new installed low pressure turbine LER-1995-005
Nine Mile Point 2 | 1995.09.01 | Turbine-generator high vibration and reactor emergency manual trip Radial packing rubbing due to not enough clearance inside low pressure turbine LER-1995-008
River Bend | 1996.01.04 | Turbine high vibration and reactor emergency manual trip Tight clearance between low pressure turbine rotor and stationary parts LER-1996-001
Brunswick 1 | 1996.01.23 | Turbine bearing high vibration and reactor emergency manual trip Diaphragm packing rubbing followed by rotor shaft thermal bowing LER-1996-002
Pilgrim | 1996.04.19 | Turbine high vibration and reactor emergency manual trip Rubbing due to not enough clearance between low pressure turbine rotor and diaphragm at new installed low pressure turbine LER-1996-005
St. Lucie 1 | 1999.10.29 | Turbine-generator and reactor emergency
manual trip
- Turbine low bearing oil trip diaphragm fault and oil leakage
LER
1999-006
Clinton 2003.04.11
- High vibration due to rubbing and turbine trip
- Rubbing due to excessive temperature difference between low pressure rotor and stationary part during power descending
LER
2003-002
Milstone 2 2003.11.27
- Turbine trip due to high vibration at low pressure turbine bearing
- Local thermal expansion at new installed low pressure rotor and bearing
- Rubbing due to thermal expansion and not enough clearance at new installed packing.
LER
2003-006
Table II. Turbine-generator damage cases in Korea

<table>
<thead>
<tr>
<th>NPP unit</th>
<th>Date</th>
<th>Damage and its Cause</th>
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| Ulchin unit-1 | 1990.11 | - Damage at high pressure turbine diaphragm  
- Excessive stress concentration at the floating vane weldingment of high pressure turbine diaphragm  
1989.11 - High vibration at low pressure turbine  
- Damage at second stage blade of low pressure turbine |
| Ulchin unit-2 | 2005.06 | - High vibration at front and end side of low pressure turbine bearing  
- Damage and loss of rotating blade due to stress cracking caused by long term operation and aging  
- Damage at the diaphragm nozzle due to broken pieces from damaged rotating blade |
| Kori unit-1   | 1985.11 | - High vibration at turbine exciter bearing  
- Electrolytic corrosion on the surface of exciter bearing  
- Thermocouple to monitor bearing temperature was not properly installed  
1984.03 - High vibration at low pressure turbine bearing  
- Damage to fifth stage rotating blade of low pressure turbine |
| Kori unit-2   | 1994.11 | - High vibration at low pressure turbine bearing  
- 13 cracks found at the root of low pressure turbine#2 rotating blade stage 5  
- 4 cracks found at the disc rim of low pressure turbine#2 |
| Kori unit-3   | 1986.07 | - Step change of vibration level and phase angle  
- Separation of a rotating blade at fifth stage of low pressure turbine#3 |
| Kori unit-4   | 1990.12 | - Abnormal vibration at low pressure turbine bearing  
- Relative rotation of disc locking ring due to dwell pin cut and shrink force loss  
- Relative change of weight balancing position |
| Younggwang unit-1 | 1989.07 | - Vibration level and phase angle change at turbine exciter bearing  
- Misalignment of low pressure turbine due to lightening strike |
Younggwang
unit-5 2001.12
- High vibration of low pressure turbine#2
- Wear due to not enough gland packing clearance and increase of thermal unbalance during idle operation
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- River Bend, LER 1996-001
- Brunswick 1, LER 1996-002
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- Milstone 2, LER 2003-006
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