Inspection Results for Low-Pressure Turbine Moving Vane Mounting Assemblies (on the moving vane side) in Hamaoka Unit 3 and Unit 4 with Causes and Countermeasures

1. Overview of incident

Moving vane mounting assemblies (on the moving vane side) of Hamaoka Unit 4 low-pressure turbine were dismounted in order to conduct magnetic particle testing of the mounting assemblies (on the shaft side). A portion of the moving vane mounting assemblies (on the moving vane side) were confirmed to have cracking and fractures. Given the results from Hamaoka Unit 4, the corresponding areas in Hamaoka Unit 3 were subjected to ultrasonic testing and similarly significant indicative waveforms were found.
Now the results from investigation of the moving vane mounting assemblies (on the moving vane side) have been compiled, and this is to report the findings as follows.

2. Survey results

■The moving vane mounting assemblies (on the moving vane side) in low-pressure turbines in Unit 3 where significant indicative waveforms were detected in ultrasonic testing were subjected to visual inspection and magnetic particle testing. The results confirmed that the significant indicative waveforms obtained by ultrasonic testing were from the detection of scratches that had no influence on the function of the moving vanes. No cracking or fractures were found.

■The low-pressure turbine moving vane mounting assemblies (on the moving vane side) in Unit 4 were subjected to ultrasonic testing and magnetic particle testing, and cracking was found in 19 of the 144 moving vanes in the 11th stage on the generator side of low-pressure turbine C. Fractures were also found in 10 of the 900 moving vanes in the 12th stages of low-pressure turbines A to C, and cracking in 107 of those moving vanes. (See Table 1 and Figure 1.)

Table 1

Unit 4 low-pressure turbine		(A) High-pressure turbine side	(A) Generator side	(B) High-pressure turbine side	(B) Generator side	(C) High-pressure turbine side	(C) Generator side
11th stage moving vanes (144 vanes)	Hook	No irregularity	No irregularity	No irregularity	No irregularity	No irregularity	Cracking: 19 vanes
	Skirt	No irregularity	No irregularity	No irregularity	No irregularity	No irregularity	No irregularity
12th stage moving vanes (150 vanes)	Hook	No irregularity	No irregularity	No irregularity	No irregularity	No irregularity	No irregularity
	Skirt	No irregularity	Cracking: 3 vanes	No irregularity	Fractures: 5 vanes Cracking:58 vanes	Fractures: 1 vanes Cracking:15 vanes	Fractures: 4 vanes Cracking:31 vanes

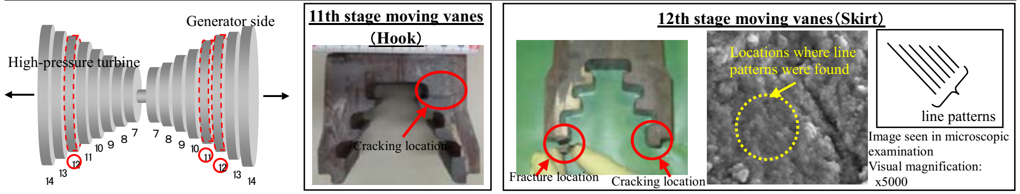


Figure 1. Inspection results for moving vane mounting assemblies (on the moving vane side)

■Areas where cracking and fractures were found were subjected to surface examination by microscope. The results confirmed the presence in fracture surfaces of fine line patterns (striations) that are characteristic of high-cycle fatigue. In addition, the cracking that had occurred in the 11th stage of low-pressure turbine C had rust and other such corrosion extending to the very ends of the cracks. No fresh metal fracture surfaces were found, suggesting that the cracks had occurred in the past and had not advanced into surrounding areas since that time. (See Figure 1.)

3. Causes of the Occurrence of Cracking and Fractures

■Characteristics of high-cycle fatigue were found, so an evaluation was made of the occurrence of high-cycle fatigue fractures. The evaluation results confirmed that the natural frequency (the characteristic frequency of an oscillating body that is allowed to oscillate freely) of the moving vane was close to the frequency that was 9 or 11 times the rotating frequency of the turbine (30 rotations per second, or 30 Hz). This resulted in the generation of resonance and an increase in vibrational stress, which is thought to have caused the high-cycle fatigue fractures. (See Figures 2 and 3.)

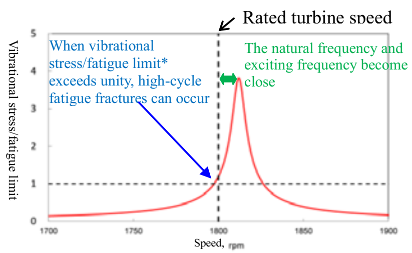


Figure 2. Natural frequency and exciting frequency of 11th stage moving vanes (hooks)

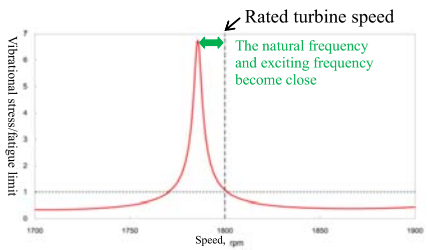
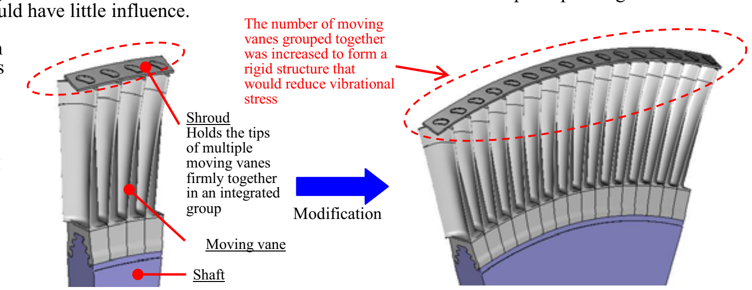


Figure 3. Natural frequency and exciting frequency of 12th stage moving vanes (Skirt)

※Fatigue limit: Upper limit for vibrational stress that does not cause high-cycle fatigue

■When the natural frequency of the moving vane and the frequency that is an integral multiple of the rotating frequency of the turbine (hereafter the exciting frequency) are close, there is a possibility that resonance will occur. The natural frequency of the moving vane is therefore checked during the design phase, but the exciting frequencies at or above the 8th order (eight times the rotating frequency of the turbine) that were found here had not been checked in this case because past operating performance suggested that they would have little influence.

■ The 11th stage moving vanes had been subject to countermeasures in the past to reduce vibrational stress due to resonance by changing the number of moving vanes grouped together from four vanes to 16 vanes. The cracking in these parts had not advanced into surrounding areas after its occurrence, which suggested that resonance had occurred, and the high-cycle fatigue fracture had occurred before the number of moving vanes grouped together had been changed. (See Figure 4.)



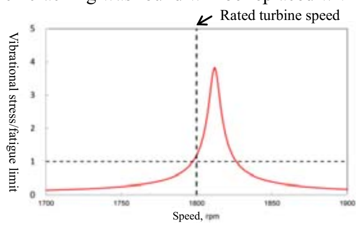
Figures 4

4. Regarding the Countermeasures

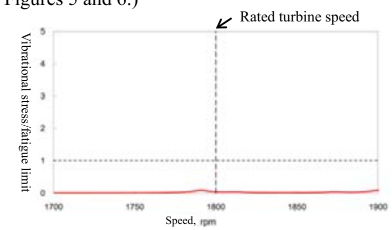
A moving vane design will be adopted that prevents high-cycle fatigue fractures by also taking 8th order and higher exciting frequencies into account. In addition, the natural frequency of the moving vanes will be confirmed after their replacement, and the influence of increased vibrational stress due to resonance will be confirmed. Specific countermeasures will be taken as follows:

(1) 11th stage moving vane mounting assemblies (on the moving vane side)

The cracking that occurred in moving vane mounting assemblies (on the moving vane side) on the 11th stage of low-pressure turbine C occurred before the modification of the number of moving vanes grouped together. Stress analysis was conducted of the current state of moving vanes in modified groupings (from four vanes to 16 vanes). The results confirmed that the stress occurring in the moving vane hooks was sufficiently lower than the vibrational stress capable of causing high-cycle fatigue, and that the vanes could be restored to service by altering the design. The moving vanes in which cracking was found will be replaced with new vanes. (See Figures 5 and 6.)



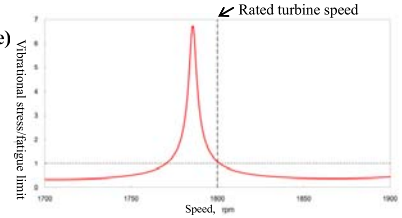
Figures 5 Natural frequency and exciting frequency of 11th stage moving vanes placed in groups of four vanes



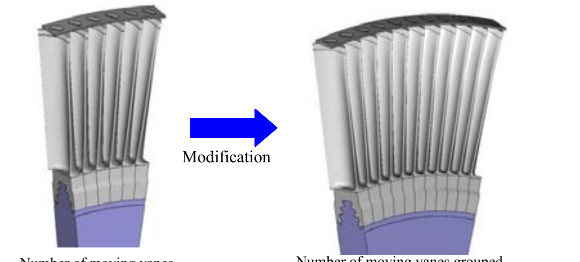
Figures 6 Natural frequency and exciting frequency of 11th stage moving vanes placed in groups of sixteen vanes

(2) 12th stage moving vane mounting assemblies (on the moving vane side)

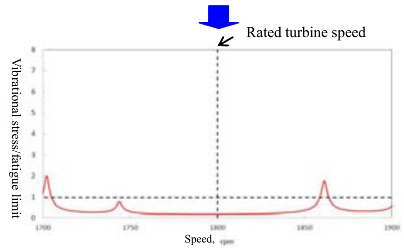
In the 12th stage, countermeasures for the moving vane mounting assemblies (on the shaft side) involved the installation of pressure plates. While this is done, therefore, the turbine will be operated with all of those moving vanes removed. When the turbine is to be operated with the pressure plates removed, new replacement moving vanes will be installed. When replacement takes place, the moving vane groupings will be modified (from six vanes to 11 or 13 vanes) in a design intended to reduce vibrational stress. In addition, the natural frequency of the moving vanes following replacement will be confirmed and the influence of the increased vibrational stress due to resonance will be confirmed. (See Figures 7 to 9.)



Figures 8 Natural frequency and exciting frequency of 12th stage moving vanes placed in groups of six vanes



Figures 7



Figures 9 Natural frequency and exciting frequency of 12th stage moving vanes placed in groups of eleven vanes