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

1. Overview of incident

In light of the fact that extremely fine fractures had been found in moving vane mounting assemblies in the low-pressure turbines at other nuclear power stations, ultrasonic testing (Note 1) was conducted of moving vane mounting assemblies (on the shaft side) in the low-pressure turbines of Hamaoka Unit 4, and significant indicative waveforms were found.

In light of the results from Hamaoka Unit 4, ultrasonic testing of the corresponding areas was conducted on Hamaoka Unit 3, and similarly significant indicative waveforms were found.

In areas where ultrasonic testing had found indicative waveforms, investigation was going forward by means of magnetic particle testing (Note 2) and other such means. An organized summary of the investigation results has now been prepared and the following is a report of those findings.

2. Survey results

- Magnetic particle testing was conducted on moving vane mounting assemblies in the 7th to 12th stages, which are of the same construction as the areas in which cracking and fractures were found in other nuclear power stations. This testing found that cracking had occurred. (See Figures 1 and 2.)

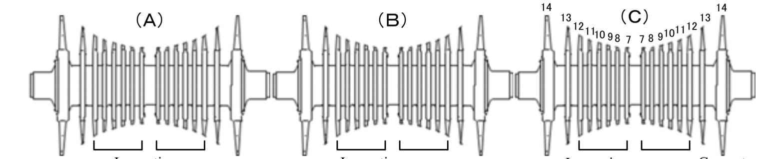


Figure 1. Scope of inspection of low-pressure turbine

11th stage of low-pressure turbine B in Unit 3

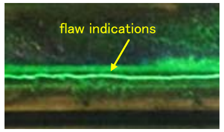


Figure 2. Magnetic particle testing flaw indications (photograph)

- In order to survey the depth of cracks in the areas where their presence was confirmed by magnetic particle inspection, the areas were machined until the cracks were eliminated, and these areas were then subjected to a strength evaluation. The results showed that there were certain areas where it would be difficult to restore the moving vanes. (See Figure 3.)
- Samples (cracked areas) were taken from the moving vane mounting assemblies (shaft side) where the presence of cracks had been verified, and these samples were subjected to surface examination using microscopes. It was determined that the cracks occurred along the grain boundaries of the metal microstructures. (See Figure 4.)

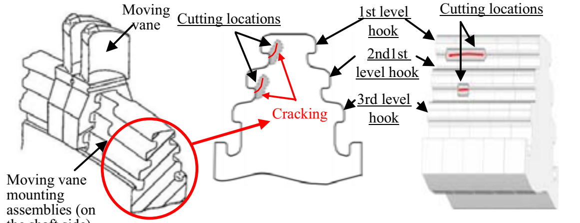


Figure 3. Cross-section of moving vane mounting assembly (on the shaft side) and general diagram of cutting (example of 11th stage of low-pressure turbine B in Unit 3)

3. Causes of the Occurrence of Cracking

The results of surface examination by microscope indicate that the cracking in moving vane mounting assemblies (on the shaft side) occurred along grain boundaries in the metallographic structure. Where the cracking advanced internally, it was found to split into multiple branches. Given these examination results, the material of the moving vane mounting assemblies in the low-pressure turbines, the operating environment, and the circumstances of the stress generated, the cracking that occurred is inferred to have been stress corrosion cracking (SCC). (See Figures 4 and 5.)

12th stage of low-pressure turbine B in Unit 4

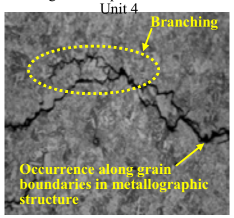


Figure 4. Surface examination by microscope (photograph)
Visual magnification: x100

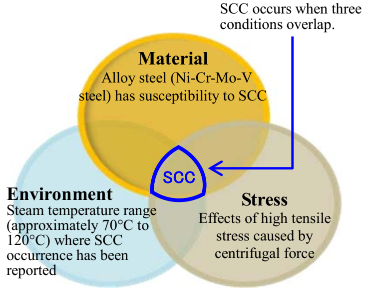


Figure 5

4. Countermeasures

(1) Inspection and Evaluation

The shaft in its current condition was subjected to restoration as described in the following paragraph (2). In that state, the shaft was evaluated to determine whether it could be operated in future on the assumption that stress corrosion cracking would occur again and that it would progress.

＜Locations where cracking was not found＞

On the assumption that 1-mm cracks existed, they were evaluated using the propagation rate of stress corrosion cracking. The evaluation results indicate that operation would be possible for approximately six years (4.5 cycles).

＜Locations where cracking was found and cutting was done＞

Although the cracks were removed by cutting, a conservative evaluation (Note 3) was conducted on the view that cracking would occur and advance immediately after operation began. The evaluation results indicate that operation would be possible for approximately four years (three cycles).

Inspections of the areas in question will be conducted regularly in future, and the soundness of those areas will be evaluated.

(Note 1) Ultrasonic testing is a form of testing in which ultrasound waves are sent into the test object and the interior of the object is examined by the reflection of the ultrasound waves. It is capable of testing the shaft with the moving vanes attached.

(Note 2) Magnetic particle testing is a form of testing that uses the patterns of magnetic particles formed on the test object when exposed to a magnetic field to investigate the surface of the object (including the interior close to the surface).

(Note 3) Based on the performance record of Unit 3, the time that will be taken for stress corrosion cracking to occur in the moving vane mounting assemblies (on the shaft side) is estimated generally to be about 11 years from the time operation begins.

(2) Restoration Method

In light of the condition of the low-pressure turbine shaft, the following restoration methods will be applied. (See Table 1 for the application locations.)

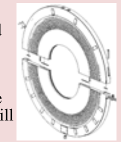
① Installation of Shims

Shims will be installed to replace the present moving vanes.

(However, there is no record of shims installed for two or more vanes consecutively, and since verification testing would require a long period of time, shims will not be applied in such cases.)

②Pressure plate installation

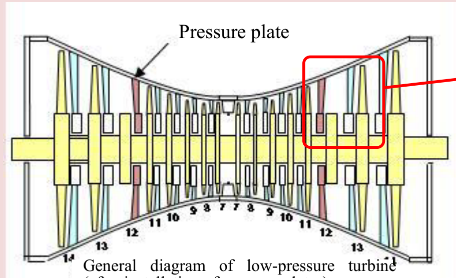
The moving vanes on the turbine stages concerned will be removed and pressure plates will be installed. In order to achieve balance, both the generator side and the high-pressure turbine side of the turbine stages concerned will need to be replaced.



(However, there is no record of pressure plates installed for two or more turbine stages, and since verification testing would require a long period of time, pressure plates will not be applied in such cases.)

③ Replacement of Shafts

Shaft replacement will be carried out. In the course of shaft replacement, we will plan countermeasures to limit the occurrence of stress corrosion cracking, such as by changing the moving vane mounting assemblies to a shape that is less likely to generate stress, by applying a surface treatment that changes the stress in the surface of the material to compressive stress, and by other such measures intended to mitigate the tensile stress generated in those moving vane mounting assemblies.



General diagram of low-pressure turbine (after installation of pressure plates)

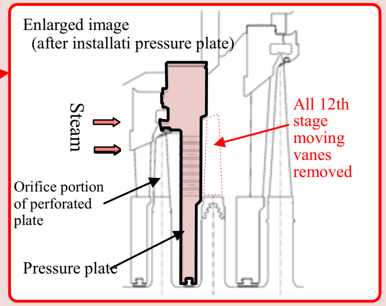


Table 1. Restoration methods for Unit 3 and Unit 4 low-pressure turbines

Unit 3 low-pressure turbine		7th to 9th stages	10th stages		11th stages		12th stages	
			High-pressure turbine side	Generator side	High-pressure turbine side	Generator side	High-pressure turbine side	Generator side
(A)	Investigation results	No cracking	Cracking occurred	No cracking	Cracking occurred	Cracking occurred	Cracking occurred	Cracking occurred
	Restoration methods	Cracking removed by cutting					Pressure plates installed	
(B)	Investigation results	No cracking	No cracking	No cracking	Cracking occurred	Cracking occurred	Cracking occurred	Cracking occurred
	Restoration methods	Cracking removed by cutting			Shims installed in some parts		Pressure plates installed	
(C)	Investigation results	No cracking	No cracking	No cracking	Cracking occurred	Cracking occurred	Cracking occurred	Cracking occurred
	Restoration methods	Cracking removed by cutting					Pressure plates installed	

Unit 4 low-pressure turbine		7th to 9th stages	10th stages		11th stages		12th stages	
			High-pressure turbine side	Generator side	High-pressure turbine side	Generator side	High-pressure turbine side	Generator side
(A)	Investigation results	No cracking	Cracking occurred	No cracking	Cracking occurred	Cracking occurred	Cracking occurred	Cracking occurred
	Restoration methods	Cracking removed by cutting					Pressure plates installed	
(B)	Investigation results	No cracking	No cracking	Cracking occurred	Cracking occurred	Cracking occurred	Cracking occurred	Cracking occurred
	Restoration methods	Cracking removed by cutting					Pressure plates installed	
(C)	Investigation results	No cracking	Cracking occurred	Cracking occurred	Cracking occurred	Cracking occurred	Cracking occurred	Cracking occurred
	Restoration methods	Shaft replacement					Pressure plates installed (Synchronized with shaft replacement)	

5. Shaft replacement

Plans will also be made to replace shafts in low-pressure turbines A to C of Unit 3 and low-pressure turbines A and B of Unit 4. In the course of shaft replacement, we will plan countermeasures to limit the occurrence of stress corrosion cracking, including also the shaft of low-pressure turbine C in Unit 4. These countermeasures will include modifying the moving vane mounting assembly to a shape less likely to generate high stress, applying surface treatment so that the stress in the material surface will become compressive stress, and other such measures to mitigate the tensile stress generated in moving vane mounting assemblies.