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NUC/452/70/30/P13/E36/B148
NUC/452/79/P3/E29/B153 2005
British Energy 2005

Hinkley Point B

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Our Ref: LF/TB/BW
Unique No: HPB 50691N

26th June 2006

Dear [REDACTED]

BRITISH ENERGY GENERATION LIMITED
HINKLEY POINT B POWER STATION
2005 REACTOR 4 START UP MEETING – ACTION 3

With reference to Action 3 of the [REDACTED] Start Up Meeting, please find attached the metallurgical investigation report into Turbine 8 Low Pressure Rotor blade fracture discovered during the [REDACTED].

If you require any further information about this matter please contact [REDACTED] the Steam and Rotating Plant System Health Group on [REDACTED].

Yours sincerely

[REDACTED]
Enc:

RESTRICTED

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ENGINEERING ADVICE NOTE

<p>Title: HPB: Examination of the Fractured Stage 3 Front Blade from the ex-T/A 8 LP2 Rotor (Serial No PF 140290)</p> <p>Author: [REDACTED]</p>	<p>EAN No: E/EAN/BDDDB/0159/HPB/06</p> <p>Revision: 000</p> <p>Task File Number: E/TSK/HPB/1977/100</p> <p>Deliverable No: 25501</p> <p>QA Grade: 3</p>																																	
<p>Distribution:</p> <table border="0"> <tr><td>[REDACTED]</td><td>Maint Dept</td><td>HPB</td></tr> <tr><td>[REDACTED]</td><td>Steam & Rotating Plant</td><td>BWD</td></tr> <tr><td>[REDACTED]</td><td>Steam & Rotating Plant</td><td>Renfrew</td></tr> <tr><td>[REDACTED]</td><td>Steam & Rotating Plant</td><td>Renfrew</td></tr> <tr><td>[REDACTED]</td><td>Materials</td><td>BWD</td></tr> <tr><td>[REDACTED]</td><td>Materials</td><td>BWD</td></tr> <tr><td>[REDACTED]</td><td>Materials</td><td>BWD</td></tr> <tr><td>[REDACTED]</td><td>Materials</td><td>BWD</td></tr> <tr><td>[REDACTED]</td><td>Steam & Rotating Plant</td><td>BWD</td></tr> <tr><td>[REDACTED]</td><td>Alstom Power Ltd</td><td></td></tr> <tr><td>[REDACTED]</td><td>Alstom Power Ltd</td><td></td></tr> </table>	[REDACTED]	Maint Dept	HPB	[REDACTED]	Steam & Rotating Plant	BWD	[REDACTED]	Steam & Rotating Plant	Renfrew	[REDACTED]	Steam & Rotating Plant	Renfrew	[REDACTED]	Materials	BWD	[REDACTED]	Materials	BWD	[REDACTED]	Materials	BWD	[REDACTED]	Materials	BWD	[REDACTED]	Steam & Rotating Plant	BWD	[REDACTED]	Alstom Power Ltd		[REDACTED]	Alstom Power Ltd		<p>Station: HPB</p> <p>Date: 22/02/06</p> <p>Attachments: Figures 1 to 4</p>
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1 INTRODUCTION

Blade 31 from the stage 3 front row on the ex-T/A 8 LP2 rotor (Serial No PF 140290) at Hinkley Point 'B' Power Station was discovered to be fractured during inspection at the rotor exchange outage in [REDACTED]. The blade, which had been ejected from the rotor after failure, has not been recovered but the root of the blade was subsequently removed for examination. This root was sent to Alstom for a detailed metallurgical examination to determine the failure mechanism and identification of the cause of fracture. Initial observations were reported by [REDACTED] of Alstom Power Ltd (Ref 1). The piece of blade containing the fracture surface was subsequently submitted to the Materials

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Group at British Energy for further examination and review of the initial findings. This EAN reports the results of this final examination by Materials Group.

During the general examination of this rotor, the nibs on two other blades, numbers 19 and 20, were also found to be cracked. The investigation of these fractures has been conducted independently with the conclusion that the failure of these blades was unlikely to be connected with failure of blade 31 (Ref. 2).

2 REVIEW OF THE FINDINGS FROM THE PRELIMINARY EXAMINATION BY ALSTOM

The findings from the preliminary examination of the piece of fracture blade at Alstom by [REDACTED] are given in Ref 1. In summary, the crack growth mechanism was reported to be high cycle fatigue that was thought to have initiated at, what was described as, a corrosion pit of approximately 350 microns in the plane of fracture. After closer examination in the Scanning Electron Microscope (SEM) after cleaning, this pit was positively confirmed as the origin of the fracture. Final failure was by ductile overload after the fatigue crack had propagated through approximately 90% of the aerofoil cross-section.

A section through the pit thought to be the origin of the crack showed no intergranular features or oxide fingering.

The blade material was found to be within specification with respect to composition, hardness and correlated strength level.

3 FURTHER EXAMINATION AT BRITISH ENERGY

Two samples were provided by Alstom:

Sample (1) comprising the tip of the leading edge of the blade mounted in bakelite and polished. This piece contained the defect that was the fracture origin.

Sample (2) comprising the piece of blade containing the rest of the fracture surface to final fracture.

3.1 Sample (1)

This mounted section was the leading edge of the blade that had been bent into a 'U' shape during removal. It had been mounted in bakelite, then ground back from the leading edge in an attempt to reveal a section through the defect. Since the section was so small, most of the defect had been ground away. The polished surface in the mount displayed a pit that was located approximately 0.4mm below the fracture surface and also part of an axial fissure, as seen in the photograph taken before sectioning, shown in Figure 1. This Figure also shows the orientation relationship between the sample before and after mounting. The pit seen in the micro-section is in line with, and probably formed part of this fissure.

EDX analysis of the oxide associated with the pit and at the edge of the fracture surface associated with the fissure in the polished section revealed an unusually high chromium to iron ratio compared to the oxide on both the blade surface and the rest of the fracture surface, Figure 2. The chromium to iron ratio determined from several randomly selected areas of the fracture surface and the blade faces was generally of the order of 0.2 to 0.3. The chromium to iron ratio along the edge of the fissure and

the pit was substantially higher at between 1.2 and 1.8. The high chromium content in this oxide suggests a chromium diffusion mechanism that would not be expected at the normal running temperature of the LP turbine (~150°C, Ref. 3). The only exposure to temperatures high enough to generate such a high temperature diffusion process is during casting and forging. Therefore, this fissure and the associated pit are likely to have been original manufacturing defects.

3.2 Sample (2)

Examination of Sample (2) optically and in the SEM confirmed the mechanism of crack growth reported in Ref 1 of high cycle fatigue by virtue of regular beach marks along the fracture surface, followed by final ductile shear failure of the blade. The major beach marks can be seen on the fracture surface in Figure 3. Where beach marks have been observed on other turbine fracture surfaces, they have frequently been associated with small tears in the surface. Such tears suggest high transient stresses thought to be caused by resonance effects during stop/starts of the turbine. Fatigue crack growth is also thought to occur during these transient periods, rather than at full running frequency. Tears were not readily apparent on the current fracture surface. However, close observation in the SEM revealed evidence of ductile dimples that were obscured by oxide and deposits on the surface and surface damage. One such beach mark is shown in Figure 4. On the assumption that all of the beach marks are of this type, they have been counted and compared with the recorded number of stop/starts.

A count of the precise number of beach marks is difficult since they are quite indistinct. However an estimate based on optical microscopic examination is 24. The number of stop/starts for this rotor since installation until the outage at which the failed blade was discovered and removed was reported to be between 53 and 60 (Ref. 4). Assuming the crack started to grow on first start-up after installation in 1993 (Ref. 4), the fraction of rotor life during which the crack grew to failure was between 0.4 and 0.45 of the life. Assuming further that the stop/starts were evenly distributed during this period, this suggests final failure of the blade occurred XXXXXXXXXX

4 DISCUSSION

The mechanism of crack growth through the bulk of the blade to final ductile fracture has the usual features associated with fatigue cracking. The fracture surface is flat and displays the beach marks usually observed on such fractures. The crack origin is at a pit with an associated axial fissure. Although the pit was originally described as a corrosion pit, there was no substantial oxide within the pit and little evidence of oxide 'finger' intrusions, often associated with corrosion pits. It was also generally isolated on the blade surface, although pits were noted in other areas of the blade. A single isolated corrosion pit is unusual. The axial fissuring is also very uncharacteristic of a corrosion mechanism. It might be postulated that the fissuring was caused when the blade tip was bent back upon itself, however the fissure was predominantly on the intrados of the bend. Such a fissure would be unlikely to open up unless there was a pre-existing axial defect.

The chromium to iron ratio in the region of the fissure and pitting was very high. This suggests that either the iron had been leached out from within the oxide or the oxide had formed at a high enough temperature sufficient for chromium diffusion to occur. Since the oxide at all other regions of the blade surface and fracture surface that were analysed did not show the same high levels of chromium, an iron leaching process seems unlikely. Therefore, the most likely reason for such high chromium

levels is high temperature diffusion. The running temperature of the LP turbine (~150°C) is insufficient to cause such diffusion and the existence of a defect during high temperature forging is the most likely explanation. This explanation is also in keeping with the axial orientation of the fissure seen.

Forging bursts due to entrapped oxide during the forging operation would generally be revealed by subsequent inspection. However, subsequent lapping of the surface layers during forging can effectively hide such a defect on rare occurrences. Such a defect in a critically stressed region may act as a stress raiser from which a fatigue crack can initiate given appropriate alternating stresses. This is thought to be the likely scenario for the fractured blade. The pitting is probably part of the defect revealed either by normal erosion of the surface at the blade tip or fatigue crack growth from the embedded defect to the surface.

Beach marks could be clearly seen optically on the fracture surface. Beach marks can be formed during fatigue crack growth by a number of different mechanisms. They can be due to variations in oxide thickness due to periods when oxidation rate has changed or to changes in stress state that may cause differences in crack propagation rate. They can also be due to microstructural variations within the material. However, it is not feasible for there to be such regular microstructural variations as to generate the regular banding seen here. Therefore, each beach mark represents a significant change in conditions and the most substantial change in conditions occurs during turbine stop/starts. Where blade fractures have occurred on gas circulators, the beach marks have been shown to correspond to the major changes in conditions occurring during stop/starts or low power refuelling. These were then used to establish a time-line for growth of the crack. In that instance, the beach marks were generally shown to correspond to small tears of varying degree at the fatigue crack tip.

In this particular examination, the existence of such tears is much less obvious. However, detailed examination in the SEM revealed that there is evidence of small ductile dimples along beach marks, but they have been obscured by both oxidation and deposition products and by some contact between mating crack surfaces. As a result of this, the beach marks are not all distinct and it is possible that some were sufficiently obscured that they could not be distinguished optically on the fracture surface. In addition, in estimating the time to failure of the blade based on assigning beach marks to stop/start events, it has been assumed that the crack initiated immediately at first run-up after installation. This may be the case for a sharp, in-plane defect. However the defect here, from which the crack has grown, is more axially aligned and may have been sub-surface. It is impossible to confidently predict whether a number of cycles would have been required to initiate a fatigue crack in the appropriate plane for propagation under the existing alternating stress conditions. The time estimated to failure of the blade must therefore be considered a minimum in view of the assumptions made.

Although the presence of similar manufacturing defects could not be ruled out in other blades, the coincidence of another such defect being present in a critically stressed region of another blade and also being undetected during inspection is considered highly unlikely.

5 CONCLUSIONS

The following conclusions were drawn from the examination of the blade:

- The blade failed due to high cycle fatigue crack growth followed by ductile tearing.

- The fatigue crack initiated from a defect, believed to be an original manufacturing defect.
- The high levels of chromium in the oxide and the axial nature of the fissure at the origin provide evidence that the defect was produced during manufacture of the blade.
- From analysis of the fatigue beach marks on the fracture surface, assuming them to be caused by turbine stop/starts, the blade fracture is estimated to have occurred [REDACTED]. A number of assumptions have been made in arriving at this estimate, including crack initiation on first run-up. This time to failure must, therefore be considered a minimum.

6 REFERENCES

- 1 'Hinkley Point B8 LP Stage 3 Front Blade Examination - Interim summary of metallurgical examination', [REDACTED] 1st Dec 2005.
- 2 'Examination of the Failed Nibs from LP Rotor PF146311 Stage 3 Blades 19 and 20', E/TSK/HPB/1977/114, [REDACTED] 3rd April 2006.
- 3 Task item E/TSK/HPB/1977/100.27, email from [REDACTED] (Steam & Rotating Plant Branch) regarding LP steam temperature, 3rd April 2006.
- 4 Task item E/TSK/HPB/1977/100.16, email from [REDACTED] (Steam & Rotating Plant Branch) regarding turbine age and stop/starts, 6th Dec. 2005.

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