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Dye Penetrant Inspection Technique of Turbine Rotating Component

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Abstract- Reliable performance of mechanical component or structure depends on pre-service quality of the component and in-service degradation of component under operating conditions. The role of non-destructive evaluation (NDE) in ensuring pre-service quality and also monitoring in-service degradation to avoid premature failure of the components or structures is ever increasing. Critical gas turbine rotating component, such as turbine blades, compressor disks, spacers and cooling fan blades are subjected to cyclic stresses during engine start-up, operation and shut-down. The lifetime of these components are usually established on the basis of probabilistic crack initiation criterion for a known fracture-critical location. Therefore periodic inspections are carried out to detect probable cracks and to prevent sudden failure. The dye penetrant testing technique basically revealed the cracked, fractured and sound parts of the steam turbine blades which did not completely fracture during the inspection period.

Keywords- Non-destructive evaluation, Critical gas turbine rotating component, cyclic stresses, Probabilistic crack initiation criterion and fracture-critical location.

I. INTRODUCTION

The Power Station under investigation is located 17 kilometers (11 miles) east of Sekondi-Takoradi in Ghana and consists of three power plants. It has a combined power cycle with an installed capacity of 330 MW combined by two 110 MW GE Frame 9E combustion gas turbines, and one 110 MW steam turbine generator [1]. The plant is primarily fueled by light crude oil and is received through a single point mooring connected to the plant by approximately 4.5 kilometers (2.8 miles) undersea pipeline [2]. The plant has a dual firing capacity and for that matter can also run on natural gas. Periodic overhauls are vital for the safe operation of steam turbines. In order to minimize downtime during such overhauls, the inspections need to be carried out quickly and efficiently.

Critical gas turbine rotating component, such as turbine blades, compressor disks, spacers and cooling fan blades are subjected to cyclic stresses during engine start-up, operation and shut-down. The lifetime of these components are usually established on the basis of probabilistic crack initiation criterion for a known fracture-critical location [3]. Therefore, periodic inspections are carried out to detect the probable cracks and prevent suddenly fractures. Shaft driven rotating fans are commonly utilized to provide the required cooling for generators. These fans circulate cooling gas, air or hydrogen, throughout the machine to maintain the electrical windings at safe operating temperatures. Cooling air is circulated in a closed cycle, in a way that after passage of air through rotor, it is heated and exhausted from top of the generator, which then passes through a cooler, which would cool it down using water flow.

Cool air again flows towards rotor and by use of fans, which are installed on retaining ring at the generator sides, is blown around the rotor. Each fan is comprised of several blades, which have been separated by using spacers. Failure of a rotating fan inside a generator will cause extensive damage. The stored rotational energy in a fan that lets loose will typically destroy the stator winding, sometimes damage the stator core and cause damage to other rotor components such as retaining rings, the rotor winding and possibly even the rotor forging [4]. Fan blades are regularly inspected during overhauls by visual and dye penetrant inspections and are required to be replaced due to defects caused by crack, corrosion and impact. The unit is equipped with two rotating fans, one at each end namely at the turbine side and the exciter side of the generator.

II. TESTING PROCEDURE

Visual inspections were made on the generator parts especially on the fan blades and the probable effect of accidents on them were studied. Three kinds of blades were found in the turbine casing after the inspection: fractured blades, cracked blades and un-cracked blades. The failure was at the turbine side of the generator and according to the visual inspections, the fan blades at the exciter side were not damaged. Dye penetrant non-destructive test was used for detection of surface cracks on the blades.

In this method the surfaces to be inspected were ensured to be free from any coatings, paint, grease, dirt, dust, etc., it was therefore thoroughly cleaned to prepare it for the inspection process. Extreme caution was exercised not to give additional damage to the surface to be inspected during the cleaning process. Otherwise, the original nature of surface could be disturbed and the results could be erroneous with the additional interferences of the surface features formed during the cleaning process. Surface cleaning was performed with chemicals like cleaner-remover and let to dry for 2 minutes.

2.1. Pre-Cleaning

The test surface is cleaned to remove dirt, oil, grease, paint or any loose scale that could either keep penetrant out of defects, or cause irrelevant or false indications. The end goal of this step is to obtain a clean surface where any defect present are open to the surface dry and free of contamination.

Fig -1: Generator fan Assembly rings pre-cleaned

Fig -2: Compressor rotor pre-cleaned

2.2. Application of Penetrant

The dye is now applied to the surface of the item being tested. The penetrant is then allowed a dwell time between 15 – 20 minutes to seep into flaws. The dwell time mainly depends on the penetrant being used, material being tested and the size of the suspected flaws present.

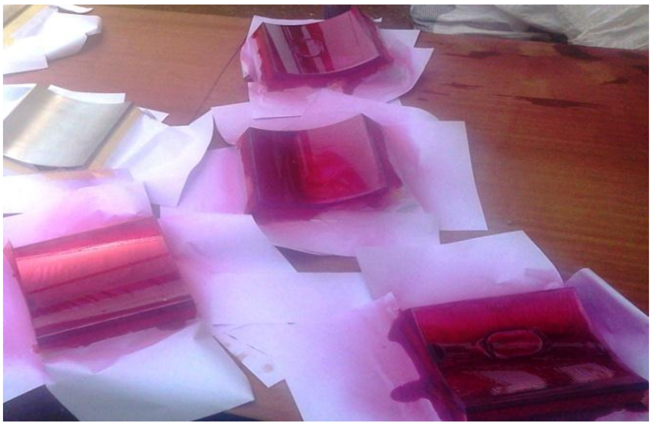

Fig -3: Applied red dye on generator bearings rings

Fig -4: Red dye on rotor exciter end fan blade

2.3. Cleaning of Excess Penetrant

The excess penetrant is then removed from the surface. This method is controlled by the type of penetrant used i.e. Water-washable, solvent removable, post-emulsifiable are the common choices. If excess penetrant is not properly removed, once the developer is applied, it may leave a background in the developed area that can mask indications or defects. In addition, this may also produce false indications severely hindering your ability to do a proper indication.

Fig -5: Cleaning of Compressor Rotor

Fig -6: Cleaned Upper half Compressor

2.4. Application of Developer

After excess penetrant have been removed from the surface, the developer is applied. This is a white powder suspended in an evaporative solvent which has the ability to reverse a capillary action. The developer pulls flaws retained dye penetrant back to the surface where it is seen as a red mark on a white background or draws penetrant from defects out onto the surface to form a visible indication commonly known as BLEED-OUT. Any area that bleed-out can indicate the location, orientation and possible type of defects on the surface.

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Fig -7: Application of developer on the upper half of compressor casing

2.5. Inspection Process

The inspector will use visible light with adequate intensity for the inspection process. The time for the test surface inspection after development is dependent on the product used. At this stage both interpretation and evaluation are made on the indications. The success and reliability for the interpretation and evaluation of liquid penetrant test indications depend upon the roughness of the process.

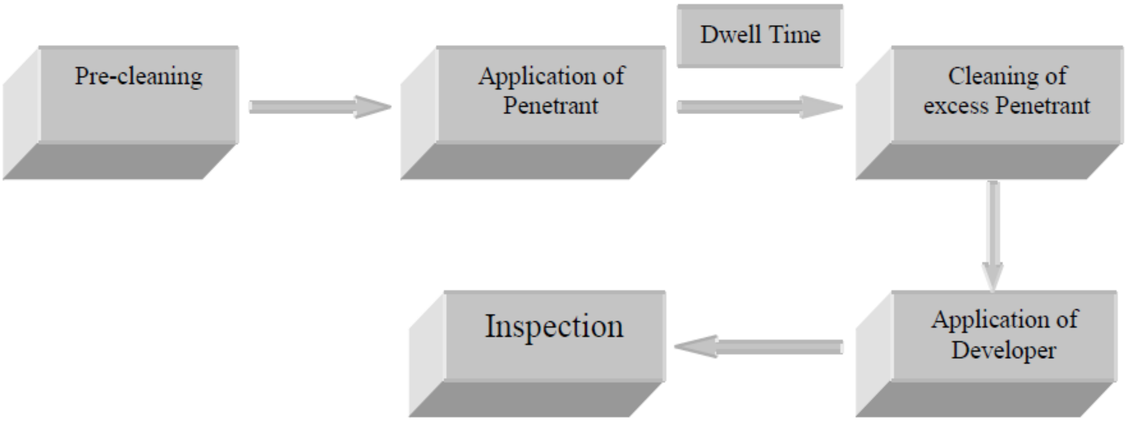

Fig -8: Flow chart of dye penetrant process

III. TEST RESULTS (VARIOUS DEGREE OF FLAWS FOUND)

Fig -9: Scattered cracks on Generator rotor Exciter

Fig -10: Heat treat cracks on Compressor upper half fan blade

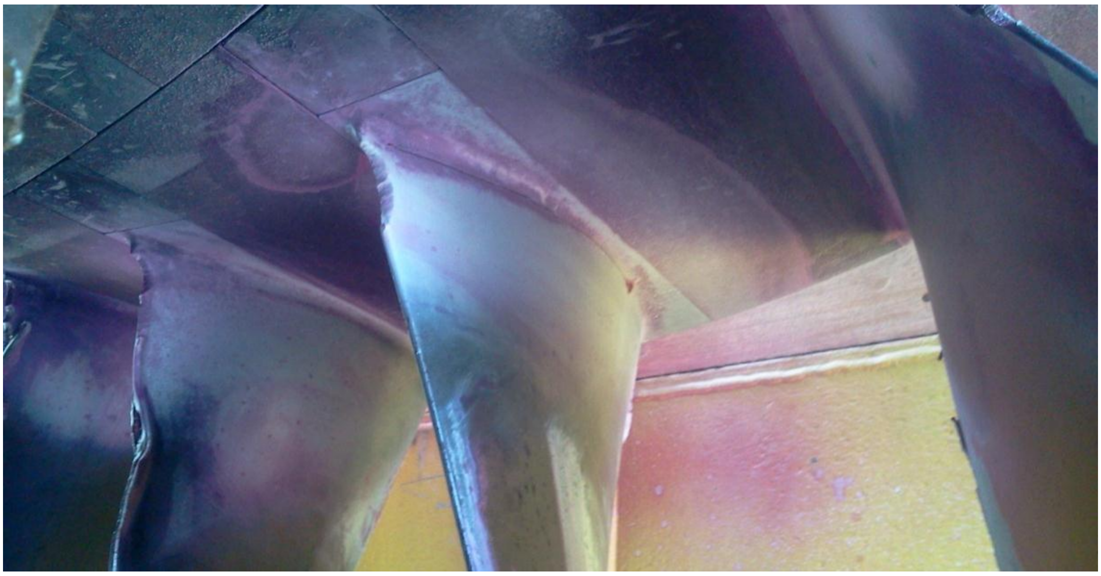

Fig -11: Fractured and Fatigue cracks on Generator Rotor Exciter end fan blades

IV. RESULTS AND DISCUSSION

The various parts of the steam turbine evaluated were both the compressor and generator rotor, turbine blades, the diffuser, the exhaust hoods, the compressor casings, the generator bearings and retaining rings. The dye penetrant testing basically revealed the cracked, fractured and sound parts of the steam turbine blades which did not completely fracture during the accident. Visual inspections of the defective turbine blades indicated the various categories of flaws; these are fractured parts, grinding crack, heat treat crack, and fatigue crack. All these discontinuities are related to the various service conditions these components are subjected to. Grinding crack is a processing-type discontinuity caused by stresses which are built up from excess heat created between the rotary wheel and the adjoining metal. The heat treat cracks are often caused by the stresses built up during heating and cooling. Unequal cooling between light and heavy sections may cause heat treat cracks to emerge. It usually has no specific direction and usually opens to the surface where they start from concentration points. Fatigue cracks are usually open to the surface where they start from concentration points and may be as a result of porosity, inclusions or other discontinuities in a highly stressed metal part. The results illustrated in table 1 indicates various categories of defects and their respective blade numbers.

Defect Category	Blade Number	Specification
Fracture	1, 8, 11, 85,97	Blade partially fractured along the edges
Grinding Crack	4, 9, 13, 21, 33	Scattered cracks on rotor blade surface
Heat treat Crack	2, 3, 7, 25, 44	Very pronounced at the tip edge of the blade
Fatigue Crack	15, 17, 29, 51	Including central and edge crack

Tab -1: The table indicates the various categories of defects associated with the components and their description

There were also scattered cracks on the generator rotor exciter fan blades and heat treat cracks on the compressor upper half discharging casing. All other examinations conducted on the diffuser, the generator bearings and the generator retaining rings showed no defect, also there were no sign of foreign bodies in the turbine casing.

V. CONCLUSION

Low cycle fatigue occurs as a results of turbine start-up or shut-down cycles and is predominant in the bores and bolt hole areas of compressor and turbine disks that operate under centrifugal stresses. It is typically a problem associated with machines that have been in operation for several years. In this situation minute flaws grow into cracks that, upon attaining critical size, rupture. Cracks also develop in the nozzle sections. The blades are subjected to severe thermal stresses during transient conditions such as startups and shutdowns. Thermal stresses are particularly severe in arctic environments where very cold air can come into contact with hot blade, after emergency trip. The dye penetrant testing exercise conducted was timely executed and basically revealed all suspected cracks and fractured parts of the steam turbine blades. The method was able to reveal discontinuities that were open to the surfaces and also can detect wide spectrum of flaws regardless of the configuration and orientation of the work piece.

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