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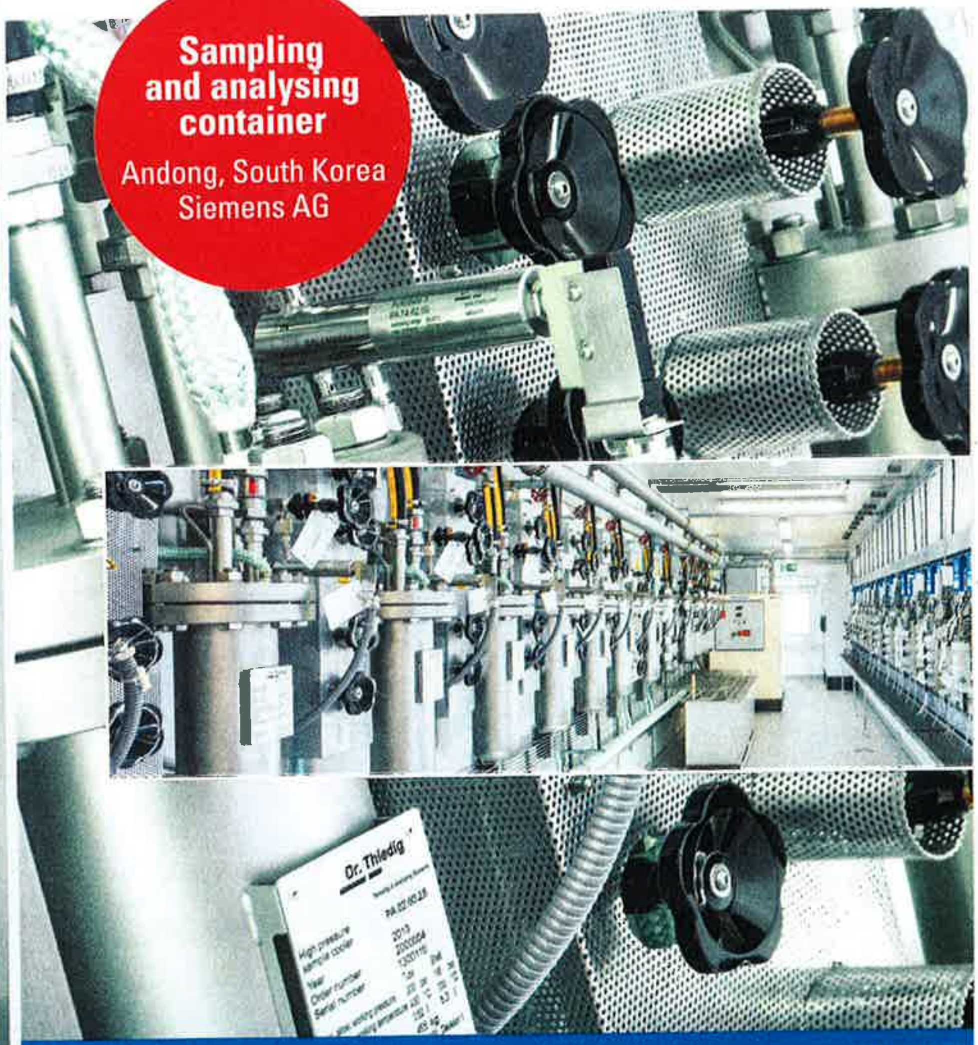
Focus
- Gas turbines
- CCGT
- Co-generation

- Operational flexibility of heavy duty gas turbines
- Modernisation of existing gas turbine power plants
- Functional safety: application on gas turbine protection
- Knowledge management



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Back to basics – Visual inspection for gas turbines

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Kurzfassung

Back to basics – Sichtprüfung für Gasturbinen

Die Energiewirtschaft steht vor einem noch nie da gewesenen Wandel sowie Herausforderungen, die sich über die gesamte Lieferkette für Energiedienstleistungen erstrecken. Während technologische Fortschritte Effizienzsteigerungen und höhere Anlagenzuverlässigkeit mit sich bringen, die nun erforderlich sind, um dem flexiblen Leistungsbedarf dieses neuen Energienachfragemarktes gerecht zu werden, besteht dennoch auch weiterhin ein Bedarf, Anlagen in einem bestmöglichen Zustand zu erhalten, der die Verfügbarkeit maximiert und gleichzeitig Lebensdauerkosten minimiert. Kraftwerksinspektionen sind eine wichtige Komponente in diesem Prozess.

Es existiert eine Vielzahl an Prüfmethoden, inklusive speziell auf Analysen basierende Verfahren. Trotzdem sollte die Rolle der visuellen Sichtprüfung innerhalb der Bandbreite der verfügbaren Prüftechniken nicht unterschätzt werden.

Visuelle Prüfungen bilden einen wesentlichen Bestandteil zur Beurteilung des Lebenszyklus der Komponenten. Informationen aus den Prüf-Fenstern, die während der Lebensdauer der Anlage gesammelt werden können genutzt werden, um eine Historie der Komponente zu erstellen und dessen Leistungsverschlechterung im gegebenen Betriebsmodus zu beschreiben. Diese Informationen können technische Zuverlässigkeitsmodelle validieren, die dabei helfen, eine stabile Wissensdatenbank über eine Flotte von Komponenten aufzubauen, wodurch die Funktionsweise der kritischen Komponenten genau beurteilt werden kann. Besonders relevant wird dies für Komponenten neuer Technologien, die keine Verlaufsdokumentation aufweisen sowie für Komponenten, die flexiblen Einsatzanforderungen unterliegen und daher unvorhersehbar verschleißen können. Sichtprüfung und -beurteilung ermöglichen somit ein besseres Verständnis der Risiken, die im Zusammenhang mit der Maximierung der Lebensdauer für Komponenten dieser Art bestehen.

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Introduction

Utilities, independent power producers, and merchant power generators face unprecedented change – deregulation and tougher competition, shifting consumption trends and more stringent emissions legislation. There is a need to ensure reliability of supply yet reduce the cost per kilowatt hour [1].

For manufacturers of industrial gas turbines (IGT) used for power generation there is a requirement to design reliable technology improvements that provide higher efficiencies with the operational flexibility and low life cycle costs necessary to meet the challenges facing the power industry. Consequently achieving thermal efficiencies at and above 60 % in combined-cycle has been an industry target with major manufacturers, including Alstom, Siemens, GE, MHI now offering high efficiency turbines in this class.

Combined-cycle gas turbine (CCGT) power plants are well suited for fast-response reserve power to balance large grid load fluctuations due to the rising share of electricity generated from renewable power sources. Short-time weather changes affecting wind power and diurnal interruption of solar power cause load fluctuations that make it difficult to keep the grid in balance [1]. This is where CCGTs have a significant role to play.

Visual inspection in CCGT maintenance

The role of maintenance in ensuring availability and reliability of CCGTs which in power generation terms translates to maximising profits, and also avoiding risk of injury to personnel and damage to equipment is a crucial one.

Generally maintenance philosophy can be split into preventative and corrective maintenance. Preventative maintenance is where the lifetime of a component is known and the component is replaced at the end of its life cycle. Typically a component will have a life-time base on equivalent operating hours (EOH). This is a calculated figure which through various weighting factors takes into consideration the influence of the operation mode as well as the effect of transient events such as trips or load rejections to derive an estimated figure. Conversely where a component does not have a specified lifetime, corrective maintenance can be carried out to replace damaged or faulty components. Usually preventative maintenance would be carried out for example on hot gas path (HGP) components such as turbine blades and combustor components, whereas corrective maintenance would be more applicable to components such as bearings or structural parts which are considered to have a long lifetime but that may experience unexpected or elevated wear and degradation due to factors such as mode of operation or operational error. In both cases the goal is to avoid unplanned maintenance due to a forced event with risk to both plant and personnel and associated increased costs.

Plant inspections to enable the assessment of components are fundamental to any successful CCGT maintenance strategy. Appropriately planned maintenance intervals facilitate scheduling of inspections to minimise downtime and maximise the benefit of implementing these.

The frequency of the planned inspections are determined by the EOH of the components. As an example the Alstom GT26 with an output of around 285 MW has a major hot gas path inspection on the gas turbine (GT) at around 28,000 EOH. This involves the opening of the gas turbine allowing removal, assessment, refurbishment and/or replacement of key components. Several smaller inspections are scheduled at regular intervals leading up to the major inspection. These inspections allow visual inspection of critical components including hot gas path parts using borescope equipment. The information gathered from the preceding inspections is crucial for planning subsequent inspections by monitoring degradation and wear of components to allow selection of an appropriate intervention window.

There exist a wide range of techniques available to assess the integrity of GT components during outages. Inspection methods available for use include visual inspection including borescopy, non-destructive testing (NDT) methods such as dye penetrant (DPI), florescent penetrant (FPI), and magnetic particle inspection (MPI) as well as more specialised techniques like ultrasonic phased array and eddy current testing shown in Figure 1 and 2. The appropriate selection of the best technique depends on various factors such as the design of plant, type of component, ac-

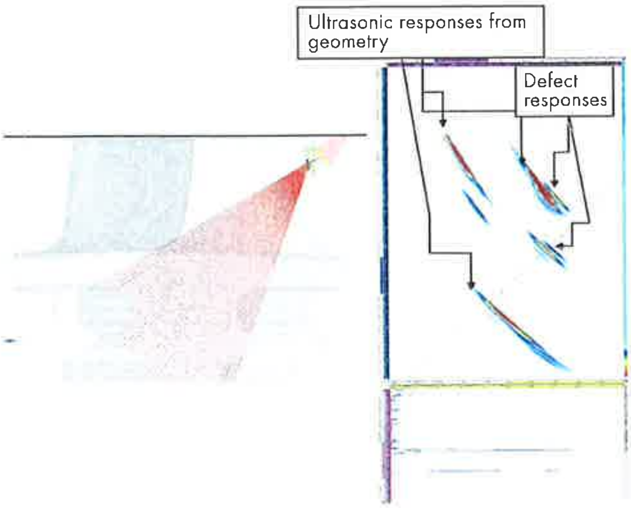

Fig. 1. RWE NDT specialists carry out advanced phased array inspections to identify component defects.

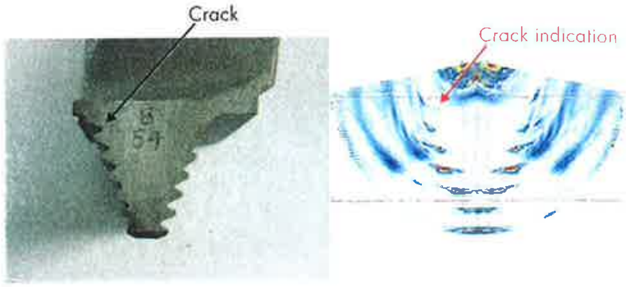

Fig. 2. Phased array inspection on turbine blade root.

cess to the component and type of defect under investigation. Sophisticated in-situ ultrasonic testing can identify sub-surface defects and can be a powerful tool to avoid undesirable downtime from lengthy unit strip-downs by providing sufficient information to give assurance that the risk of running the machine in a known condition is acceptable. Amongst this array of advanced analytical- and technology-based techniques, the importance of normal visual inspection within this process should not be underestimated.

Visual inspection can quickly identify numerous defects to in-service components including cracking, oxidation, impact damage, material loss, fretting wear, and on thermal barrier coated (TBC) components; TBC spallation, oxidation shown in Figure 3. During a major outage a visual inspection of components as shown in Figure 4, can be carried out at various stages, normally at strip-down component deterioration can be identified and the integrity assessed allowing any necessary remedial actions to be carried out prior to rebuild. At the re-build phase, visual inspections can be utilised to ensure the quality of build eliminating the potential for future issues arising from build quality.

To illustrate the importance of this at a recent major hot gas path inspection on a 60 MW IGT a visual inspection of the compressor identified a missing material defect on the stage 5 compressor vane carrier at the split line location slot. This can be seen in Figure 5. Mechanical damage was also found to a number of compressor blades and vanes further downstream of the initial finding as shown in Figure 6. Assessment of the condition determined that the diaphragm was not fit for service and the remedial action taken was to disassemble the diaphragm and carry out a controlled repair in a workshop environment. Additionally corrective dressing and blending work had to be carried out on the damaged compressor blades and vanes. Information from the visual inspection was used in a root cause analysis (RCA) which determined that there was an issue with a previous weld repair to the compressor vane carrier on the location slot.

Extra weld material had resulted in a reduced slot area which meant that as the diaphragms halves were assembled together the top half key which fits into the location slot caused an elevated stress loading culminating in a structural failure of the component at a weak point. The liberated material had then become entrained in the compressor air flow impacting on numerous components as it moved downstream through the compressor. Potentially this build quality issue could have been picked up by a visual inspection following the repair work therefore avoiding the failure. It is worth noting that although significant damage was found on the compressor with remedial repair work carried out the outcome could potentially have been far more severe.

Maintaining quality assurance when undertaking visual inspections is fundamental to achieving the benefits in terms of capturing critical information about the condition of components and by identifying defects or any potential build issues that can help to avoid exposing the plant and personnel to unnecessary risks.

Achieving these required standards is reliant on having competent personnel to carry out the inspection and assessment work and where borescope equipment is used this equipment should be in a serviceable and where applicable in calibrated condition. Underpinning everything is robust reliability engineering principles which draw on engineering understanding to develop theoretical models to predict failure modes and effects of various defects. Practical component knowledge and experience can be built in to validate the models and provide assurance of safety factors and tolerable defect limits.

For visual inspection comprehensive and reliable assessment criteria for components is invaluable. The acceptable size of defects present on various components are first calculated and then validated. As an example when calculating acceptance criteria on a turbine blade as shown in Figure 7, the temperature profile and

Fig. 3. Thermal barrier coating spallation and base material oxidation.

Fig. 4. Visual inspection forms an integral part of power plant maintenance.

Fig. 6. Compressor blade damage resulting from initial component failure.

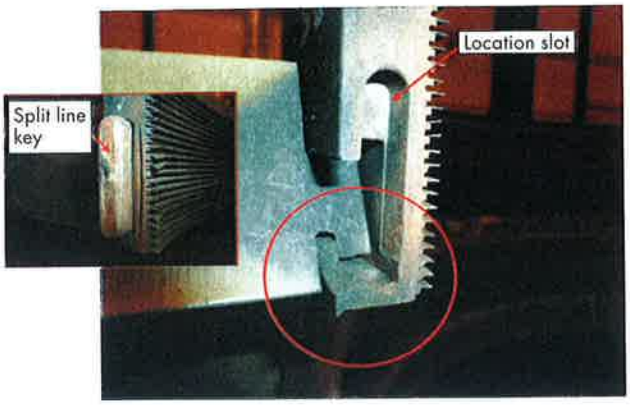

Fig. 5. Compressor diaphragm carrier issue identified during a visual inspection.

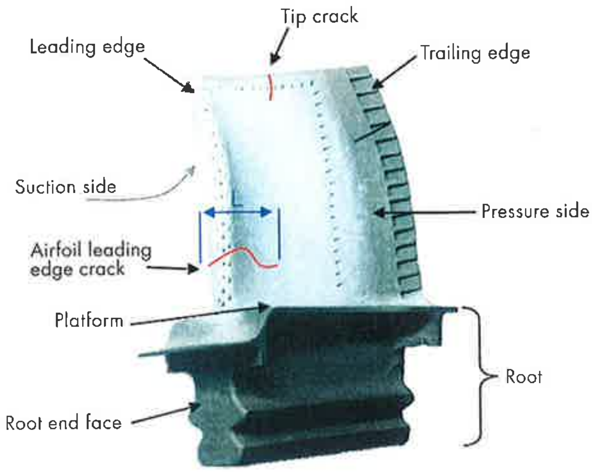

Fig. 7. RWE TSG Ferrybridge undertake visual inspections supported by component assessment criteria.

blade geometry are used in a computational fluid dynamics (CFD) model, which then outputs the forces on the component. The stresses within the blade are calculated using the geometry, material properties, rotational speed, temperatures, and safety factors and defects are then modelled in a simulation to ensure the maximum stresses are within acceptable limits. The position and direction of the defect can largely influence the remaining life. Horizontal cracks on turbine blades in highly stressed areas will propagate faster as the crack reduces the volume of material left to resist the high tensile stresses. Any such cracks are usually unacceptable due to the high likelihood of failure and damage during operation. In contrast cracks near the tips of blades and between cooling holes are often acceptable.

The existence of accurate defect criteria enables the monitoring of crack growth, a practice where known components found to have cracks within an acceptable tolerance limit are allowed to remain in service whilst the development of the defect is carefully monitored during strategic inspection windows to ensure that the risk of running the plant with the defect remains acceptable. Under normal circumstances unless the risk is deemed to be very low, this measure would be adopted to allow a plant to remain available for operation until a planned outage during which the components could be replaced or refurbished.

In a similar way to turbine blades a complete suite of inspection and assessment criteria can be produced for all critical components. Inevitably there will be borderline cases found on inspection and this is where fleet knowledge and the experience of the assessment engineer will have a crucial role to play. For example an over-enthusiastic assessment recommendation may be to replace all stage 1 power turbine vanes due to high levels of cracking found on borescope inspection after first full load operation. However fleet experience may identify that these blades can run for another 20,000+ EOH without any loss in performance or adverse risk to the plant.

Summary

Maintaining CCGT plant in an optimum condition is necessary to meet the requirement for avoiding risk and injury to personnel and equipment whilst ensuring that the plant is available for flexible and reliable operation to deliver high efficiency performance within challenging market conditions.

Visual inspection and assessment play an important role in a planned maintenance strategy and should not be undervalued alongside more sophisticated inspection techniques.

Information gathered from each inspection can be used to develop a plant-specific history which can help establish the performance of different components in a particular environment under a specific plant setting or operating regime. This information can be utilised for decision making at a local level. While at a global level individual plant inspection data could be fed into a database for a number of similar plants to help develop a fleet based maintenance strategy.

There are a number of windows of opportunity available to carry out visual inspections during the lifecycle of a plant and its components. Effective use of inspections allows efficient planning of maintenance activities ensuring that degraded components can be replaced or remedial actions prior to any significant plant failures occurring. Specific quality issues associated with rebuild during an outage can also be avoided by carrying out visual inspections which can identify any apparent issues which may result in plant damage unless remedial actions are taken.

Quality assurance of visual inspections depends not only on competent and experienced personnel but also being able to relate identified component defects to accurate and reliable assessment criteria to determine whether the risk of operating is within acceptable limits. This can be a powerful tool to enable flexible decision making for example by monitoring defects during operation to avoid incurring additional maintenance related costs whilst maintaining the plant availability.

The principle of effective use of high quality visual inspection and defect assessment is not limited to only CCGT plant, but extends across a range of other plant and its use within the maintenance plan during its lifecycle. These principles should therefore be adopted as best practice across the power generation industry to help deliver the benefits previously discussed.

References

[1] Alstom Power, www.alstom.com; GT24/GT26 Gas Turbine; PT-PE/BPR0B/GSTRBN07/eng/TMG/09.07/CH/6261

[2] *Bartos, F.J.*: PE; High Efficiency Gas Turbines add Flexibility; accessed from: http://m.controleng.com/index.php?id=2819&tx_ttnews[tt_news]=53975&cHash=9a6d35a104) on 17/06/2013.