Two Shifting of Power Plant: Damage to Power Plant Due to Cycling - A brief overview

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Background

As power utilities around the world become deregulated, they enter into a far more competitive marketplace. Coal and oil fired power plant which may once have been operated under base load conditions may now find itself required to operate on a more flexible basis with load variations and two shift operation increasingly becoming the norm. This is especially true of older plants, originally designed as base load units, which are increasingly being displaced by modern more efficient and more flexible plant. In order to survive in the new commercial marketplace, it is essential that they not only adapt to flexible operation, but that they also understand both the engineering and commercial consequences of new operating techniques.

This is a world-wide phenomenon. Whilst some countries have adapted well to the new marketplace, many countries are only just gearing up to managing the situation. It is a major concern to many utilities and power plant operators.

In the year 2000, European Technology Development (ETD) led an international industry sponsored project involving partners and sponsors from Europe, USA and Canada. The project was aimed at reviewing damage to power plant components due to two shift (i.e. cyclic) operation. The project involved a review of technical issues, costs, management and manpower implications. The review involved visits to experts and plant staff and discussions on their operating practices and problems involved when two shifting. A comprehensive report was produced both on plant experience and related research findings.

1. Objectives of the Study

The principal objectives of the study were:

- to identify the key engineering threats
- to identify operational constraints
- to identify engineering and operating costs
- to identify problem areas requiring R&D.
- to set out strategies for power plant managers to optimise plant performance and operational procedures to successfully meet the requirements of economic two shift operation.

The **prime aim** of the study was to set out the report in a form to be of direct assistance to management and senior engineering staff of individual stations, who may need guidance for more cost effective cyclic operation of their plant or when contemplating a move from base load operation to two shifting or load cycling.

The report discusses ideal and achievable targets for start up and shut down times. It focuses on major technical issues, costs, management and plant operation which are discussed in detail in comprehensive appendices to provide to designers, plant management and staff stand alone guidance on topics such as:

- Good design practice for new and existing plant
- Problems arising from thermal cycling and low load operation of fossil fired plant
- Typical replacement and plant upgrading costs
- Fatigue and creep lives of high temperature components
- Plant life monitoring systems
- P91 performance in new/replacement plant
- Weld repair aspects
- Sliding pressure control
- Gaseous emission aspects of two shift operation
- Start up aspects on a typical power plant
- In-situ measurement of fireside corrosion and heat transfer under two shifting conditions

In addition a comprehensive bibliography is included to enable the reader to research any particular aspect in greater detail.

2. Scope of Study

Because of the range of technical and economical issues involved, a multi-disciplinary team was engaged in carrying out this study.

The study was targeted towards Rankine Cycle (i.e. steam only) plant falling generally within the following criteria:

- Coal, oil or gas fired plant
- Plant capacity in the range 100 to 660 MWe output
- Superheater steam conditions > 500°C
- Plant age > 10 years old with typically more than about 100,000 operating hours
- Plant which has previously been operated on base load but which is currently or expects to two shift in the future

Face to face interviews were conducted with plant operators and R&D organisations, and data/ information collected from organisations in the UK, USA, Italy, Ireland, Canada, Hong Kong, Germany, Austria, Spain, Japan, Australia, South Africa, and other Eastern and West European countries. The team also conducted surveys of plant operators, manufacturers and R&D organisations. The surveys were conducted mainly through questionnaires, one targeted at plant operation and costs, and the second at R&D issues. A comprehensive survey of published and unpublished (in-house reports etc.) literature on fatigue/cycling damage to power plant materials was also carried out.

3. Failure Mechanisms and Implications for Key Components

The study examines the failure mechanisms commonly experienced by utilities when operating in two shift or partial load mode. By far the most significant problems are encountered as a result of creep fatigue mechanisms leading to cracking of thick wall components, superheater and reheater header ligament cracking, water wall header stub cracking, economiser headers ligament cracking, feedheater tubeplate cracking and tube attachment failures

Older base-load fossil units were designed, almost by definition, to operate predominantly under creep conditions. None of the older design codes for power plant (ASME, BS, DIN) placed any specific requirement on the designer to consider fatigue as a failure mechanism. The design codes merely made an implicit assumption that the effects of fatigue were contained within the conservatism of the design stresses.

Materials behave in a complex way when both creep and fatigue mechanisms are present. They usually act synergistically to cause premature failure. Creep strains can reduce fatigue life and fatigue strains can reduce creep life. The American Society of Mechanical Engineers (ASME) recognised the effects of interaction and provides guidance on the interaction between creep and fatigue and its effect on the life expectancies of materials [1]. In more recent times this aspect has been examined more widely and good data is now becoming available.

The interaction of creep and fatigue in 2.25Cr1Mo steel - the steel most used in power plant, is quite severe compared to some of the other alloys. Some plants are now using or planning to use ASME Code Case P91 (modified high strength 9Cr Martensitic) steel as a replacement material (or as new material in advanced power plant) for thick section components. This is being done in the belief that thinner section components made from high strength P91 will be less prone to fatigue cracking during the cyclic operation. Comprehensive work on P91 has not been conducted yet. However, recent limited feature tests work on one cast of P91 in the European Commission funded project ‘HIDA’ has suggested that the creep-fatigue interaction in welded components made from this steel could possibly be more sever than P22 weldments [2].

Thermal fatigue cracking of the ligaments between header stubs and penetrations is recognised as one of the primary life limiting mechanisms on headers. The problem manifests itself in the form of cracking in the bore of the header in the ligaments between stubs but can also be found on the outer surfaces around stubs and other attachments. Failure to recognise this problem can lead to catastrophic failures. Considerable header ligament cracking was first observed in the UK in the mid 1980's and has now been observed worldwide. Our survey and investigation has shown that cracks have initiated and propagated to more than 50% wall depth in as few as 300 -500 starts. Extensive investigations have been carried out to gather data on operational stresses and temperatures followed up with finite element computer analysis. The problem is often attributable to poor design and manufacturing detail, in combination with poor header temperature control when two shifting. Strategies have been developed to identify headers considered to be at risk, inspection programmes and techniques developed, design methodologies implemented and operational procedures optimised together with header monitoring techniques to better control the problem and thereby reduce the risk of header failure.

Concern has grown about the integrity of generator ring, despite the introduction of the Fe-18Mn-18Cr end ring alloys. The stress variations which result from two shifting can induce fatigue, even though there is no change in the rotor speed. This is due to eddy current induced heating in the end ring. Older designs of end ring are likely to be more susceptible to damage, since they are prone to high cycle fatigue. Another shortcoming of older designs was that the fixing of the end ring to the rotor was of a relatively simple form. Modified designs are available to reduce stress concentrations in this area.

Corrosion and fouling issues are less prominent, but issues relating to waterside corrosion in economisers, feedheaters and evaporators, deaerator cracking, steam turbine erosion, corrosion and fouling aspects and fireside corrosion can be important factors.

Space dust not allow here to discuss other significant issues relating to general boiler structure movement, pipework support systems, differential expansion of turbine rotors and casings, and alternator end ring components which were reviewed in this study, as were the issues of dust removal, corrosion and fouling of FGD systems, pumps and auxiliaries, electrical equipment, electrical motors, switchgear and general wear and tear.

4. Two Shift Operating Practice

There is extensive experience of two shift operation world wide, and whilst there are potential risks and added wear and tear associated with two shifting, the study concluded that with due care and application of sound engineering and operational practice, economic two shifting can be achieved with confidence.

Starts are usually categorised as cold, warm or hot starts. The definitions vary between utilities and units and are influenced by the extent to which heat is retained in the unit and the controllability of the plant. Starts are typically categorised as:

Hot start	-	Short (<8 Hrs) shutdown and turbine metal temperatures > 400°C
Warm start	-	> 8 hrs, < 24/48 hrs shutdown and turbine metal temperatures > 200°C
Cold start	-	> 48hrs shutdown and turbine metal temperatures < 200°C

Guidance from the original equipment manufacturers (OEM's) for traditional base load units is likely to have been very conservative with a typical cold start time of 12 to 15 hours and 3 hours for a hot start for a large machine. Economic two shift operation requires that units are brought back on load and taken off load as quickly as possible to minimise off load heat costs. This action has to be balanced against the obvious effects of induced thermal stresses resulting in costly plant failures.

Many utilities, especially in the UK, have carried out trials on two shift operation with the objective of reducing start up and shut down times. It is generally found that start up times can be more than halved from original 'base load' procedures so that large machines can be synchronised within 35 to 50 minutes of inserting the first burners depending on unit size and configuration and full load achieved in similar times. A realistic target time to full load on a 500 MW machine is of the order of 60 minutes or less. Figure 1 shows a typical sequence for a 500 MW coal fired machine which has been optimised for two shift operation.

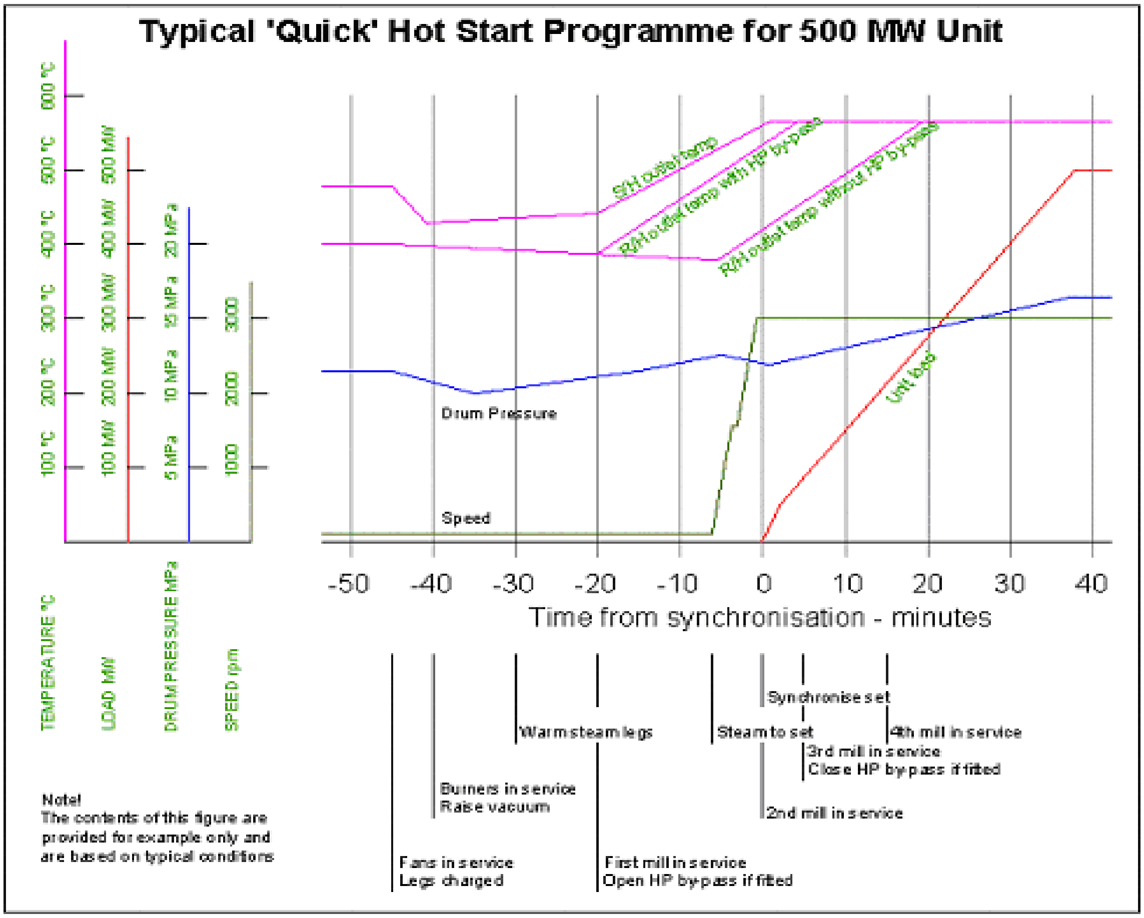

Figure 1: Typical sequence for accelerated hot start-up for 500 MW machine

5. Operational Issues Associated with Two Shift Operation

During boiler start up, there are potential problems when flow through the boiler may not have been established or be at low rates. At these times particular care is needed to avoid localised overheating. A number of common concerns are identified:

In the evaporative sections, especially with natural circulation drum boilers, residual heat in the upper sections will bias circulation such that some tubes have a stagnated flow. If these are close to the burners, the high heat flux can result in localised overheating.

Superheater platens may accumulate condensation in bottom loops, especially if temperatures are allowed to fall below the ambient saturation temperature during shutdown periods. The temperatures will naturally drop whilst the unit is off load but will be further cooled when, at the beginning of the start up cycle, the ID fans are put in service. This water logging will restrict flow through the elements until such time as it is boiled out. There will be periods when only some of the platens have established a flow whilst others are stagnated and may experience localised overheating. This problem tends to occur in the wing elements where the temperatures are lowest.

The reheater flow is not normally established until after steam admission to the turbine. If this is delayed, then there is a significant risk of overheating the reheater elements. This problem can in part be resolved by the use of a turbine by-pass system.
Under low load running the volumetric flows are much reduced, especially under constant pressure (throttle control) operation. In extreme circumstances, the flows through the boiler will cease to be stable (as a result of multiple flow paths) and local stagnation may occur. Sliding pressure control at reduced load reduces this threat by increasing the volumetric flow for a given load.

The above problems can be controlled by systematic operation of the plant: Accelerated start up is typically achieved through a combination of changes in procedure and plant modifications. Whilst each unit will need to be assessed on its own merits and limitations, the report outlines a typical procedure to facilitate safe and economic two shift operation.

The principal features of the procedures include de-loading the unit to 50% load (using sliding pressure control if available) and rapid shut down whilst maintaining maximum superheat and reheat temperatures. Rapid start is achieved through optimised procedures in conjunction with improved instrumentation, control and automation applied in a scientific way to ensure the ongoing integrity of the plant. Coal/oil burners are commissioned as quickly as possible to bring the loading rate up. It is obviously necessary to develop these procedures over a period of time, but expertise is available to give a high level of confidence of success.

6. Strategic Actions by Local Station Management

When a unit goes over to two shifting the local station management should take certain immediate actions to reduce the risk of problems developing.

Faced with the prospect of possible plant damage due to thermal cycling and other factors, over a number of years, strategies are needed to reduce the level of damage and to control costs. It should be recognised that there is a need to balance the costs of preparing a longer term strategy with the likely future of the plant. The most comprehensive approaches include the following activities:

- Preparation of a thorough "Plant Status Database" to identify the current condition of major plant components and operational history and to establish the residual plant life of components in terms of hours (creep) and fatigue (starts).

- Monitoring of perceived critical components by on-line continuous data logging and regular inspection (visual and NDT) at planned outages.

- Based on the above observations and conclusions, three further stages can be developed to include detailed component review to assess fitness for purpose, plant modifications to facilitate two shift operation and repairs & refurbishment necessary to assure plant integrity and safety.

- Operational - identification of need for additional instrumentation, automation, changes to operational procedures to reduce minimum start-up times with minimum physical damage to plant, impact on maintenance practices and staff training requirements.

- Engineering - detailed assessment of component integrity, plant (system) modifications, major repairs & refurbishment.

- Budgetary - system requirements, economics of operation, engineering budgets.

7. Equipment Modifications and Improvements

A key requirement to achieving successful two shift operation is to modify or improve existing plant. The following are aspects which can have a major impact on improved two shift performance:

- Increased drainage capacity to promote steam flow through the boiler and pipework.

- Improved thermal insulation to retain as much heat as possible and minimise thermal cycling.

- Improved oil burner reliability, stability and turndown to facilitate rapid and controlled boiler warming.

- Boiler off load and economiser recirculation to reduce temperature differentials.

- Boiler hot filling to avoid thermal quenching, especially in the economiser region.

- Inter-Stage drains to enable progressive warming through of the boiler.

- Modification of tube attachments to reduce failures.

- HP turbine bypass to promote steam flow through steam pipework and into the reheat circuit.

- Condenser air extraction and vacuum raising to speed up vacuum raising.

- Provision of auxiliary steam supplies to facilitate rapid warming from cold conditions.

8. Costs of Cyclic Operation

The changes to the electricity generation industry have resulted in a high level of interest in the costs associated with non-base load operation. In the recent past the vast majority of plant operators had poor cost allocation systems such that generally only a broad high level O&M annual costs were obtainable. Estimates of costs were found to vary significantly indicating a poor understanding and differing interpretations between utilities.

The principal factors to be considered during cyclic operation are:

- Increased capital spend for component replacement.

- Increased routine O&M cost from higher wear and tear.

- Lower availability due to increase in failure rate and increased outage time.

- Increased fuel cost from reduced efficiency and non optimum heat rate.

Recent studies suggest that the average cold start cost is 70 000 US$, warm start costs of 4000 US$, hot start costs of 3500 US$, based on 1000 MW nominal output of coal fired plant. However, estimates have ranged widely about these figures.

A typical method of estimating O&M cycling costs is centred on evaluation of historical data. If good historical cost data is available it is possible to establish a mathematical relationship which will be able to predict the probable short-term future cost.

Similarly estimates of capital costs for major items can be based on known or historic estimates but it must be recognised that replacing a header will be different in different countries due to different staffing levels, different working methods and even different OEM charging practices.

It might be expected that units with a significant history of cycling would require more scheduled outage time in order to replace damaged components. However, based on a review of NERC (North American Reliability Council) data no trend was evident between the degree of cycling and outage time taken by units.

Additional costs can be attributed to reduced efficiency which is lower under start-up and shutdowns and under low load conditions. General wear and tear e.g. worn seals etc. will also have a cumulative effect on the efficiency.

In order to be able to predict the cost of cyclic operation in all of its possible combinations a model is required that will determine with reasonable accuracy the overall impact of any given cycle on the costs that will result both in the short and in the long term. Models have been developed to address this.

The main elements comprising such models can be summarised as follows

- Establish historical cycling pattern at a high level (e.g. hourly MW data).

- Collate, analyse and ‘smooth’ available historical cost data.

- Establish a base cycle to compare and relate to actual cycles and determine equivalent base cycles.

- Introduce a damage accumulation model which includes terms covering steady state (creep), cyclic (fatigue) and off load (corrosion) conditions, (Optional).

- Determine the cost of the equivalent base cycle and, via the degree of deviation of the actual cycle from the base case, estimate the cost of each type of start or load change.

The study evaluates various cost estimating techniques and outlines a methodology for cost estimates and concludes that further work still needs to be done to develop a universal model. Nevertheless it is possible to establish a reasonable basis for initial cost estimations. It is believed that sound costing models will evolve over the next few years.

9. Conclusion

This Paper summarises the scope of the ETD study and is indicative of some of the main findings. It shows that plant owners and operators need to be aware of the significant issues involved in damage to plant due to cyclic operation and the necessity to take remedial actions and reduce costs.

10. References

1. ASME Cases of ASME Boiler and Pressure Vessel Code, Case N-47, Rev 29, 1990.

2. Shibli I A, 'Performance of new high strength high temperature martensitic steels under two shifting regime and the issue of weld repairs', Paper S2-2, published in the Proceedings of the Two Shifting Seminar, June 2001, London. Published by Science Letters, London. Editors: Shibli I A, Satrr F, Viwanathan R, Gray D.