On-Line Aging Monitoring of Boiler and Turbine Components Using Creep-FatiguePro

Glenn Beckerdite

Kansas City Power & Light Company

M. L. Berasi and D. A. Rosario

Structural Integrity Associates

L. Evans

KPL, A Western Resources Company

D. R. Broske

Electric Power Research Institute

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M. L. Berasi and D. A. Rosario
Structural Integrity Associates
Akron, Ohio

Glenn Beckerdite
Kansas City Power & Light Company
Kansas City, Missouri

L. Evans
KPL, A Western Resources Company
Topeka, Kansas

D. R. Broske
Electric Power Research Institute
Palo Alto, California

Abstract

Creep-FatiguePro (CFP) is an on-line monitoring system used to track accumulated aging of high-temperature fossil plant components. The original software was developed by Structural Integrity Associates under the sponsorship of EPRI and Pacific Gas and Electric Company. It was further developed by EPRI tailored collaboration projects with Kansas City Power & Light (KCPL), and Western Resources Company. The version that is being used by KCPL monitors critical locations of the main steam and hot reheat piping, the outlet boiler headers, inner and outer turbine casings, and HP-IP rotor bore. Accumulated aging is calculated through monitoring operating data using existing plant instrumentation. By tracking this aging, remaining life of these components is estimated. CFP has the potential to assist in making better decisions on when to repair or replace these components.

PMAX is used to gather the operating data, and perform some of the data processing to make CFP operate. The data is first collected, then organized, and finally converted to a format that can be used by CFP. The data is then organized, and finally converted to a format that can be used by CFP. The data is then transferred to a PC where it is processed, stores and a report is generated. This report contains remaining life estimates that are used for replacement planning or potential changes in operations. This paper presents some details of the development, current use, and future CFP and how PMAX is an important part of the process.

Introduction

Thick-section fossil plant components operating at temperatures of 1000°F or higher are subject to material degradation over time due to creep and fatigue. This includes boiler superheater and reheater headers, main steam and hot reheat piping, and turbine steamchests, casings and rotors. The rates of accumulation of creep and fatigue damage and crack growth in these components are strongly dependent on the specific temperature and pressure operating histories to which they are exposed. As such, significant improvement in predictions of damage accumulation, crack growth, and remaining useful life can be attained when account is taken of the exact temperature and pressure histories of the component. The EPRI software system, Creep-FatiguePro, was developed for this purpose.

By automating the process of estimating damage accumulation, crack growth and remaining life, and basing these estimates on actual plant operating conditions, Creep-FatiguePro benefits the utility in a number of ways:

- By taking period of low-stress operation into account, Creep-FatiguePro provides more accurate damage predictions than those based on maximum design or operating conditions, thus enabling utilities to significantly reduce inspection frequency and extend the useful life of critical components.

- When a crack or fabrication defect is detected during inspection, Creep-FatiguePro monitor results provide critical input for run/repair/replace decisions, possibly enabling utilities to avoid or delay unnecessary repairs and outage extensions.

- Automated tracking of damage and crack growth in critical components eliminates the need for tedious and less accurate manual calculations of remaining life.

- Creep-FatiguePro simulation capabilities allow the utility to evaluate the impact of alternate plant operating procedures on component life consumption, allowing for adjustments to extend component life.

Creep-FatiguePro Description and Methodologies

The monitoring approach employed by Creep-FatiguePro can be summarized as follows:

- Temperature, pressure and flowrate data for the monitored components is collected from the plant computer using PMAX on 1 minute intervals and stores in an appropriate format for processing in Creep-FatiguePro. PMAX is programmed to do an archival file search automatically on a weekly basis. The archive file is converted to a file compatible for processing, and transferred to a PC. Creep-FatiguePro then processes the data and stores the results on the P.C.

- Component-specific analytical *Stress Transfer Functions* programmed into Creep-FatiguePro compute creep and fatigue stresses as a function of time from the collected plant instrument readings.

- Using the monitored temperatures, calculated stresses, and built-in material properties for creep rupture and fatigue crack initiation, creep and fatigue damage is calculated and accumulated over time to provide an indication of the time to crack initiation.

- Monitored damage accumulation and crack growth rates are projected into the future to predict the time required to reach critical levels of damage and crack size. Probabilistic remaining life output, allowing for variations I the initial crack size and the material creep crack growth properties, is also provided.

Key aspects of this monitoring approach are the concept of stress transfer functions, and the methodologies for calculation of damage accumulation and crack growth. A brief description of each of these is given below:

Stress Transfer Functions

Stress transfer functions are geometry-dependent functions which are applied to plant instrument reading s to determine component stresses. They are specifically determined for each component monitor location when configuring Creep-FatiguePro for a given plant installation. For simple geometries such as straight sections of piping in main steam or hot reheat steamlines, these transfer functions can be adequately determined suing standard closed-form solutions. For more complex geometries such as header tube bore ligaments, turbine inlet steamchests, casings and rotors, detailed elastic and creep finite element analyses are typically performed to derive the transfer functions. The inelastic creep analyses are required to adequately account for the effects of creep stress redistribution and/or relaxation.

For the majority of components monitored with Creep-FatiguePro, internal pressure and operating thermal transients are the primary stress sources for which transfer functions are developed. In the case of high energy piping, transfer functions to address piping deadweight and global thermal expansion effects are included. With respect to turbine rotor bore locations, rotational stresses are also considered.

With the exception of thermal transients, the magnitude of stresses produced by the above-noted loadings are dependent only on the instantaneous reading of the applicable plant instrument (i.e., pressure transducer reading for pressure stress, thermocouple reading for piping thermal expansion stress, turbine RPM for rotor rotational stress). Concerning thermal transients, this stress is dependent not only on the instantaneous temperature reading, but also on the prior temperature versus time history of the fluid in the component. A specialized technique referred to as the Green's Function approach is employed in Creep-FatiguePro for the calculation of these thermal transient-related stresses and is described in reference [1].

Damage Calculation

Creep and fatigue damage is calculated in Creep-FatiguePro using a life fraction approach equivalent to that employed in ASME Code Case N-47 for high temperature nuclear components. This approach is summarized as follows:

$$D = \Sigma\, n/Nf + \Sigma\, t/tr \qquad (1)$$

where, D = Life fraction or Damage Index, representing the fraction of total creep-fatigue life consumed at any given time

n = number of applied fatigue stress cycles for each loading condition

Nf = Corresponding number of cycles to failure for each loading condition, reflected in a fatigue S-N curve for the applicable material

t = Time duration of each temperature-stress loading condition

tr = Corresponding time to creep rupture for each temperature-stress loading condition, reflected in stress rupture or failure LMP curves for the applicable material

Under conditions of pure creep or pure fatigue, failure (or crack initiation for thick-section components) is theoretically predicted when the damage index sums to unity. Detrimental creep-fatigue interaction effects can be incorporated in Creep-FatiguePro by specifying reduced allowable values of D. The creep-fatigue damage envelope of Code Case N47 can serve as one guide for determining this reduction in allowable D.

Crack Growth Calculation

Fatigue crack growth is calculated in Creep-FatiguePro using the approach outlined in Appendix A of the ASME Code, Section XI, Rules for Inservice Inspection of Nuclear Power Plant Components. This approach employs linear elastic fracture mechanics concepts and a Paris Law crack growth equation as follows:

$$da/dN = C \wedge Kn \qquad (2)$$

where,
da/dN = Fatigue crack growth rate, in./cycle
∧K = Range of fracture mechanics stress intensity factor, kis-in
C,n = constants describing the fatigue crack growth behavior of the applicable material

The Ordered Overall Range (OOR) cycle counting routine, described in reference [1], is used to extract peak and valley stresses from which ∧K values are computed. Material fatigue crack growth constants from ASME Section XI are used to bound crack growth for both 2 Cr-1Mo and 1 Cr- Mo piping and header steels. Fatigue crack growth constants for Cr-Mo-V rotor steels are obtained from reference [2].

Creep crack growth is computed using Saxena's transient creep parameter, C_t[3], and is given by the following equation:

$$da/dt = H\,(C)q \qquad (3)$$

where,
da/dt = Creep crack growth rate, in./hr.
C_t = Transient creep crack tip parameter, in-kip/in2-hr.
H,q = constants describing the creep crack growth behavior of the applicable material

The methodology for computerizing C_t is documented in reference [3] as are the material creep crack growth constants H and q for a variety of applicable boiler steels. Creep crack growth constants for turbine rotor steels are obtained from reference [4].

In general, a database of all necessary material properties required for creep and fatigue damage and crack growth calculations is maintained within Creep-FatiguePro. This database covers the majority of allow steels typically used for high temperature boiler and turbine components and distinguishes between base material and weld heat-affected-zone properties. The database can be readily updated or expanded as new data becomes available or to suit a particular application. Similarly, a library of fracture mechanics flaw models, containing linear elastic (K) and creep (c) solutions for a number of flaw geometries, is available in Creep-FatiguePro for application to a variety of component monitoring locations.

KCPL Montrose Unit 2 Installation and Monitor Results

Monitor Locations

Creep-FatiguePro was configured for monitoring of the high-temperature boiler headers, main steam and hot reheat piping, and turbine inlet steamchest, HP inner cylinder, and HP/IP rotors on Unit 2 at our Montrose Plant. This unit is equipped with a Combustion Engineering boiler and General Electric turbine with nameplate rating of 175 MW at 1800 psig/1000°F main steam and 1000°F reheat steam conditions. The unit was placed into commercial operation in 1960 and had accumulated approximately 241,000 operating hours and 636 unit starts up to the time Creep-FatiguePro monitoring was initiated in May, 1993.

The locations selected for monitoring in each component are as follows:

Boiler Headers (Primary SH, Secondary SH, and Reheater Outlet Headers)
- Header Body Longitudinal Seam Welds
- Header Body Tube Bore Ligaments

Main Steam and Hot Reheat Piping
- High Stress Girth Welds (2-3 locations per steamline)

HP/IP Turbine
- Turbine Inlet Steamchest at the Girth Weld and inner surface corner radius
- HP Inner Cylinder at 1st Stage Diaphragm Pockets
- HP Rotor Bore at 1st Stage, IP Rotor Bore at 7th and 12th Stage

Prior examinations of the three boiler headers, limited primarily to external surface replications and MT/PT, had identified no significant damage. However, it is known from industry experience that these high-temperature headers, primarily the secondary superheater header, are susceptible to creep-fatigue damage and ligament cracking after service periods which are largely dependent on individual unit operating history. Creep-FatiguePro monitoring of the headers will support KCPL's inspection AND longterm replacement planning for these headers.

The girth weld locations selected for monitoring in the main steam and hot reheat piping represent the expected high stress locations determined from review of the piping system stress reports. Some of these monitoring locations, specifically welds located in the turbine lead piping between the wye block and the main steam stop valve, were found to contain 2nd/3rd stage creep damage based on replications performed in 1991. As with the boiler headers, Creep-FatiguePro monitoring of the welds will provide criteria for establishing inspection intervals and dispositioning damage detected through inspection.

With regard to the turbine components, the girth weld between the inlet steamchest and outer turbine casing is an area of primary concern as appreciable creep damage and microcracking has been detected previously on this unit and the duplicate unit #1. Creep-FatiguePro monitoring of this location is expected to provide critical input concerning run/repair/replace options for this component.

Finally, the three HP/IP rotor bore locations selected for monitoring were determined through detailed evaluations of the rotor using the EPRI SAFER Code (Stress and Fracture Evaluation or Rotors) and represent the critical bore locations with respect to creep and brittle fracture considerations. Boresonic examination of this rotor in 1980 revealed some ultrasonic indications, for which the rotor was overbored to remove the indications. Follow-up boresonic examination in 1986 revealed no significant damage. Creep-FatiguePro monitoring of the bore locations can provide quantitative justification for extension for the boresonic inspection interval, as well as advance notice of when rotor replacement may be necessary.

Monitor Results

Plant instrument data for the monitored components at Montrose Unit 2 is collected from a Bailey Net-90 plant computer using PMAX. PMAX is programmed to perform an archival file search automatically on a weekly basis. The archival file created is converted into an appropriate format for processing in Creep-FatiguePro. Although these input files can cover any desired time frame, they are collected for an operating period of 1 week. These files are periodically downloaded to a remote PC at the KCPL main office for batch processing in Creep-FatiguePro.

As stated previously, Creep-FatiguePro monitoring was initiated in mid-May 1993. Processed data is currently available and discussed below for an operating period up through mid-January 1994, representing a 242 day time period. Over this time period, the unit accumulated 4920 hours of operation and 8 shutdowns.

Standard text reports summarizing the monitor results at each location, and plots of various data, can be reviewed or printed from within the Creep-FatiguePro program. Plot options include longterm trending of average hourly temperatures and pressures, and monitor location stresses, damage fractions and crack growth over any specified number of days. Short term detail plots of the raw 1-minute instrument data and location stresses, for any specified number of hours, are also available.

Tables 1 and 2 show the summary reports for the *high-energy piping* and *turbine component* monitoring locations, respectively. The reports identify the increments of creep and fatigue damage and crack growth calculated over the monitored period, and the total current damage fraction AND crack size along with a comparison to allowable limits. lastly, projects of the time to reach the allowable limits are made based on the monitored period, and the total current damage fraction and crack size along with a comparison to allowable limits. Lastly, projects of the time to reach the allowable limits are made based on the monitored rates of damage accumulation and crack growth. For the initial configuration, initial (pre-monitor) and allowable damage levels were arbitrarily set to zero and 0.100, respectively, with the intent that these values could be refined after a sufficient amount of processed data became available. Specified initials crack sizes are postulated values corresponding to expected inspection threshold levels at each location. Allowable crack sizes were set to approximately one-third component wall thickness based on fracture mechanics instability and rapid crack growth considerations.

Figure 1 shows trend plots of temperature/pressure, creep/fatigue stresses, damage increments and crack growth for monitor location VC-ODGW (O.D. surface of the turbine valve chest girth weld) over the entire 242 day period. The temperature/pressure plot provides a general indication of how the plant was operated over the monitor period but cannot resolve temperature swings, ramp rates and other details. These features could be resolved by choosing to plot smaller time frames in the trend plots, or by plotting detail data such as that shown in Figure 2. This figure plots turbine temperatures during the unit shutdown/startup in mid-October, and the corresponding creep and fatigue stresses experienced at the IP turbine rotor bore, 7th stage.

Discussion

In discussing the monitor results, attention is directed to three locations of primary importance, namely MS-11-OD, VC-ODGW, and Ipstg_7.

Referring to Table 1, MS-11-OD is seen to be the worstcase location with respect to the high energy piping. It was noted previously that 2nd/3rd stage creep damage (isolated/oriented cavaties) was detected in the girth welds corresponding to this monitor location through replications in 1991. If it can be assumed that unit operation over the 242 day monitoring period was representative of prior service, then monitored damage rates can be used to estimate the accumulated damage fraction at the time this damage was detected. Extrapolating the .00805 damage fraction accumulated during the monitoring period (4920 operating hours/8 shutdowns) to the prior service period up through 1991 (227,000 hours/606 shutdowns) produces a total damage fraction of approximately 0.372. This result is in reasonable agreement with studies undertaken to correlate damage fraction calculations with metallurgical data. This is illustrated in Figure 3, which plots microstructural damage classification versus expended life fraction [5]. Using these results, the initial and allowable damage specifications can be adjusted and Creep-FatiguePro monitoring continued to support future inspection planning and repair/replace decisions for this location.

At monitor location VC-ODGW, monitored damage levels were less than at MS-11-OD although more extensive creep damage and microcracking had been reported. This could be due to lower creep strength properties for the valve chest material, or could be related to the presence of original fabrication and welding defects which served as initiation sites for creep damage and cracking. Considering that some extent of cracking already exists, the Creep-FatiguePro crack growth as opposed to damage results are of greater significance. The crack growth projections shown I Table 2 were developed using mean creep crack growth properties. Results were also generated using upper bound properties which are considered more appropriate for the creep damaged valve chest girth weld. These results indicate a deterministic remaining life of approximately 9 years for an initial flaw depth of .100". A probabilistic remaining life evaluation, to account for uncertainty in current crack size, was performed in Creep-FatiguePro and the resulting output is shown in Figure 4. These monitor results, combined with future inspections to detect and accurately characterize flaw indications, will support near-term run/repair decisions for the valve chest.

With respect to the HP/IP turbine rotor bore monitor locations, the important thing to note at this time is that the IP 7th stage bore location appears to be the critical location and the monitor results to date indicate a minimum remaining life in excess of 12 years for this location.

Summary

The Creep-FatiguePro monitoring system was developed to automate the process of tracking creep-fatigue damage and crack growth in critical thick-section fossil plant components, and to improve the accuracy of these projections by basing them on actual plant operating conditions. The technology has been applied to the high temperature headers, piping, turbine steamchest and rotors at the KCPL Montrose plant. Results from the first 8 months of monitoring indicate that the system can provide valuable input to inspection planning, run/repair/replace decisions and overall life management of the monitored equipment.

The Creep-FatiguePro software is currently available under license to EPRI for application by EPRI member utilities.

Acknowledgments

The support of the Electric Power Research Institute, Kansas City Power and Light Company, and the Western Resources Company to the continuing development of Creep-FatiguePro is acknowledged and gratefully appreciated.

References

1. J.F. Copeland, et al, "Creep-FatiguePro: On-line Creep Fatigue Damage and Crack Growth Monitoring System", Structural Integrity Associated, Inc., EPRI Research Project 1893-11, Final Report Nol TR-100907, July 1992.

2. F.V. Ammirato, et al, "Life Assessment Methodology for Turbogenerator Rotors", Volumes 1 through 4, EPRI CS/EL-5593-CCM, Projects 2481-3, 2785-1, March 1988.

3. A. Saxena, J. Han, and K. Banerji, "Creep Crack Growth Behavior in Power Plant Boiler and Steam Pipe Steels", Journal of Pressure Vessel Technology, Vol. 110, ASME, May 1988, pp. 137-146.

4. R. Viswanathan, and C.H. Wells, "Life Prediction of Turbine Generator Rotors", Technology for the Nineties, ASME, 1993.

5. R. Viswanathan, Damage Mechanisms and Life Assessment of High-Temperature Components, ASM, Metals Park, Ohio, c. 1989.

Table 1

Creep-FatiguePro Monitor Report for Piping at KCPL Montrose Unit 2

Creep-FatiguePro Monitoring System
Structural Integrity Associates, Version (DOS) 1.34-94084

Installation for: Kansas City Power & Light
Montrose (mean)

Location Damage and Crack Growth Report for:
--- Unit #: 2, --- System: High-Energy Piping System

Start of Monitoring : 05/13/93 00:00:00
Results up to Date : 01/09/94 23:59:30 (242.00 days)

****

DAMAGE ACCUMULATION RESULTS (life fraction)

Location	Initial Damage	Monitored Fatigue Damage	Monitored Creep Damage	Total Current Damage	Allow. Damage	% of Allow
1: MS-16-ID	0.000000	0.000013	0.001973	0.001986	0.1000	1.99
2: MS-16-OD	0.000000	0.000000	0.005398	0.005398	0.1000	5.40
3: MS-11-ID	0.000000	0.000205	0.003199	0.003404	0.1000	3.40
4: MS-11-OD	0.000000	0.000002	0.008050	0.008052	0.1000	8.05
5: RH-16-ID	0.000000	0.000000	0.000447	0.000447	0.1000	0.45
6: RH-16-OD	0.000000	0.000000	0.000569	0.000569	0.1000	0.57
7: RH-24-ID	0.000000	0.000000	0.000325	0.000325	0.1000	0.33
8: RH-24-OD	0.000000	0.000000	0.000420	0.000420	0.1000	0.42

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CRACK GROWTH RESULTS (inches)

Location	Initial Crk Size	Monitored Fatigue Crk Grwth	Monitored Creep Crk Grwth	Total Current Crk Size	Allow. Crk Size	% of Allow
1: MS-16-ID	0.100000	0.000058	0.001717	0.101775	0.7917	12.86
2: MS-16-OD	0.100000	0.000002	0.004667	0.104669	0.7917	13.22
3: MS-11-ID	0.100000	0.000465	0.002826	0.103291	0.5833	17.71
4: MS-11-OD	0.100000	0.000013	0.007777	0.107789	0.5833	18.48
5: RH-16-ID	0.100000	0.000000	0.000879	0.100879	0.2917	34.58
6: RH-16-OD	0.100000	0.000000	0.001066	0.101066	0.2917	34.65
7: RH-24-ID	0.100000	0.000000	0.000585	0.100585	0.5000	20.12
8: RH-24-OD	0.100000	0.000000	0.000711	0.100711	0.5000	20.14

****

Table 1 (Concluded)

Creep-FatiguePro Monitor Report with Predicted Remaining Lives, for Piping at KCPL Montrose Unit 2

DAMAGE/CRACK GROWTH RATES AND PROJECTIONS

Location	Rate Period	Dmg Accum Rate (1/mth)	# of Mths to reach Allow	Crk Grwth Rate ("/mth)	# of Mths to reach Allow
1: MS-16-ID	3 mths	0.000180	>400	0.000141	>400
	1 year	0.000246	398	0.000220	>400
2: MS-16-OD	3 mths	0.000494	191	0.000402	329
	1 year	0.000669	141	0.000579	264
3: MS-11-ID	3 mths	0.000302	320	0.000263	369
	1 year	0.000422	229	0.000408	291
4: MS-11-OD	3 mths	0.000742	124	0.000705	154
	1 year	0.000998	92	0.000966	126
5: RH-16-ID	3 mths	0.000068	>400	0.000083	>400
	1 year	0.000055	>400	0.000109	>400
6: RH-16-OD	3 mths	0.000086	>400	0.000103	>400
	1 year	0.000071	>400	0.000132	>400
7: RH-24-ID	3 mths	0.000049	>400	0.000054	>400
	1 year	0.000040	>400	0.000073	>400
8: RH-24-OD	3 mths	0.000063	>400	0.000066	>400
	1 year	0.000052	>400	0.000088	>400

Note - Average 'per month' damage accumulation and crack growth rates are indicated based on unit operation over the past 3 months and the past year. '# of mths to reach Allow' represents the additional months of operation required to reach the damage/crack size allowable assuming future plant operation will be the same as prior operating conditions.

Table 2

Creep-FatiguePro Monitor Report for Turbine Components at KCPL Montrose Unit 2

```
Creep-FatiguePro Monitoring System
Structural Integrity Associates,  Version (DOS) 1.34-94084

Installation for:  Kansas City Power & Light
                   Montrose (mean)

Location Damage and Crack Growth Report for:
   ---- Unit #: 2,     ---- System:  Turbine Components

Start of Monitoring : 05/13/93  00:00:00
Results up to Date  : 01/09/94  23:59:30    (242.00 days)

*****************************************************************************
                DAMAGE ACCUMULATION RESULTS (life fraction)

              Monitored  Monitored  Total
              Initial    Fatigue    Creep      Current    Allow.    % of
Location      Damage     Damage     Damage     Damage     Damage    Allow

1:  VC-IDGW   0.000000   0.000189   0.000013   0.000202   0.1000     0.20
2:  VC-ODGW   0.000000   0.000136   0.001960   0.002096   0.1000     2.10
3:  VC-IDcnr  0.000000   0.000278   0.000070   0.000349   0.1000     0.35
4:  HPInrCyl  0.000000   0.001583   0.000000   0.001583   0.1000     1.58
5:  HPstg_1   0.000000   0.000021   0.000439   0.000460   0.1000     0.46
6:  IPstg_7   0.000000   0.000053   0.004069   0.004122   0.1000     4.12
7:  IPstg_12  0.000000   0.000064   0.000000   0.000064   0.1000     0.06

*****************************************************************************
                CRACK GROWTH RESULTS (inches)

                         Monitored  Monitored  Total
              Initial    Fatigue    Creep      Current    Allow.    % of
Location      Crk Size   Crk Grwth  Crk Grwth  Crk Size   Crk Size  Allow

1:  VC-IDGW   0.100000   0.000336   0.000068   0.100404   0.9160    10.96
2:  VC-ODGW   0.100000   0.000318   0.003943   0.104261   0.9160    11.38
3:  VC-IDcnr  0.100000   0.000506   0.000083   0.100589   1.0140     9.92
4:  HPInrCyl  0.100000   0.003435   0.000004   0.103439   2.1670     4.77
5:  HPstg_1   0.060000   0.000105   0.003026   0.063131   0.1800    35.07
6:  IPstg_7   0.060000   0.000158   0.006540   0.066698   0.3100    21.52
7:  IPstg_12  0.060000   0.000155   0.000000   0.060155   0.1800    33.42

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Table 2 (Concluded)

Creep-FatiguePro Monitor Report with Predicted Remaining Lives, for Turbine Componets at KCPL Montrose Unit 2

DAMAGE/CRACK GROWTH RATES AND PROJECTIONS

Location	Rate Period	Dmg Accum Rate (1/mth)	# of Mths to reach Allow	Crk Grwth Rate ("/mth)	# of Mths to reach Allow
1: VC-IDGW	3 mths	0.000006	>400	0.000016	>400
	1 year	0.000025	>400	0.000050	>400
2: VC-ODGW	3 mths	0.000191	>400	0.000346	355
	1 year	0.000260	377	0.000528	277
3: VC-IDcnr	3 mths	0.000015	>400	0.000036	>400
	1 year	0.000043	>400	0.000073	>400
4: HPInrCyl	3 mths	0.000105	>400	0.000293	>400
	1 year	0.000196	>400	0.000426	>400
5: HPstg_1	3 mths	0.000040	>400	0.000173	>400
	1 year	0.000057	>400	0.000388	207
6: IPstg_7	3 mths	0.000596	161	0.000407	319
	1 year	0.000511	188	0.000830	149
7: IPstg_12	3 mths	0.000001	>400	0.000007	>400
	1 year	0.000008	>400	0.000019	>400

Note - Average 'per month' damage accumulation and crack growth rates are indicated based on unit operation over the past 3 months and the past year. '# of mths to reach Allow' represents the additional months of operation required to reach the damage/crack size allowable assuming future plant operation will be the same as prior operating conditions.

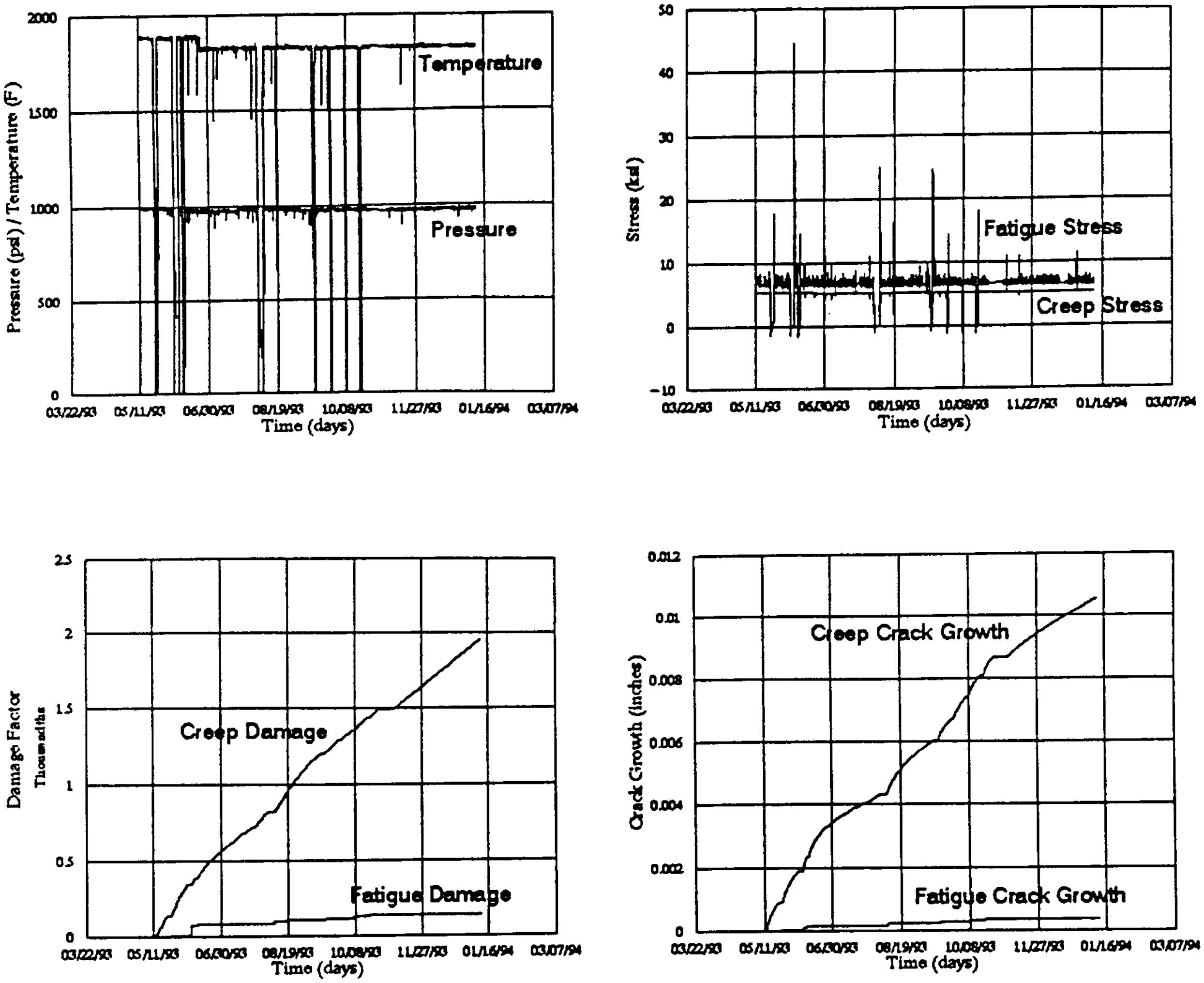


Figure 1 **Trend Plot of Temperature/Pressure, Creep/Fatigue Stresses, Damage Increments and Crack Growth at Monitor Location VC-ODGW**

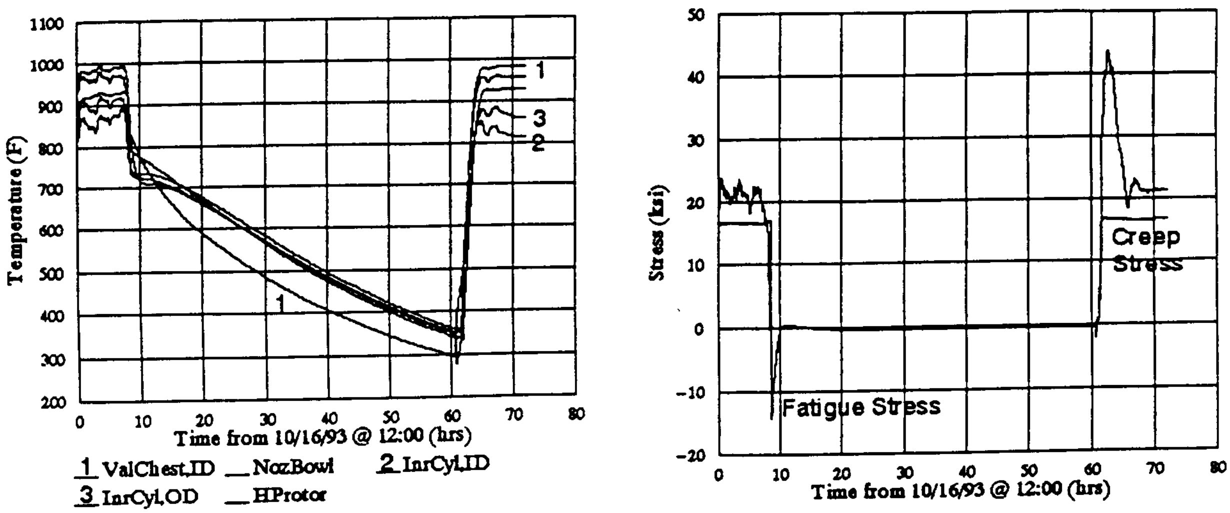


Figure 2 Detail Plot of Turbine Temperatures and Creep/Fatigue Stresses for Monitor Location IPstg_7 during Shutdown/Startup Cycle at Montrose Unit 2

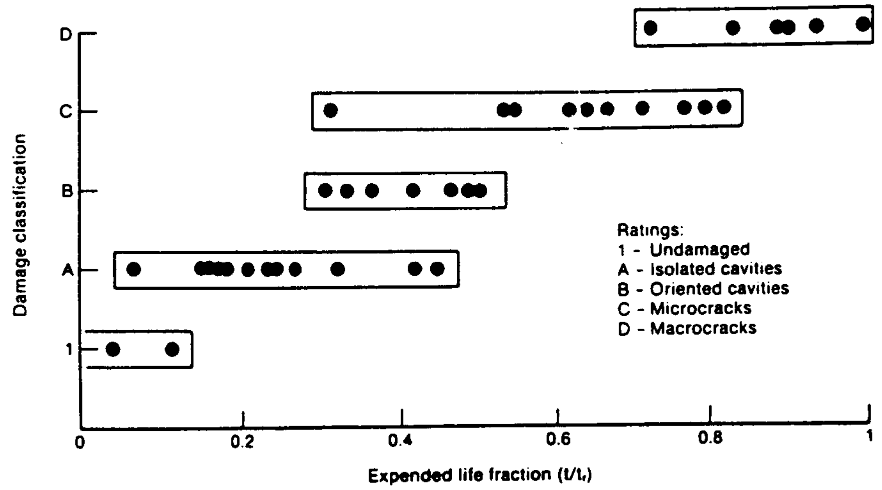
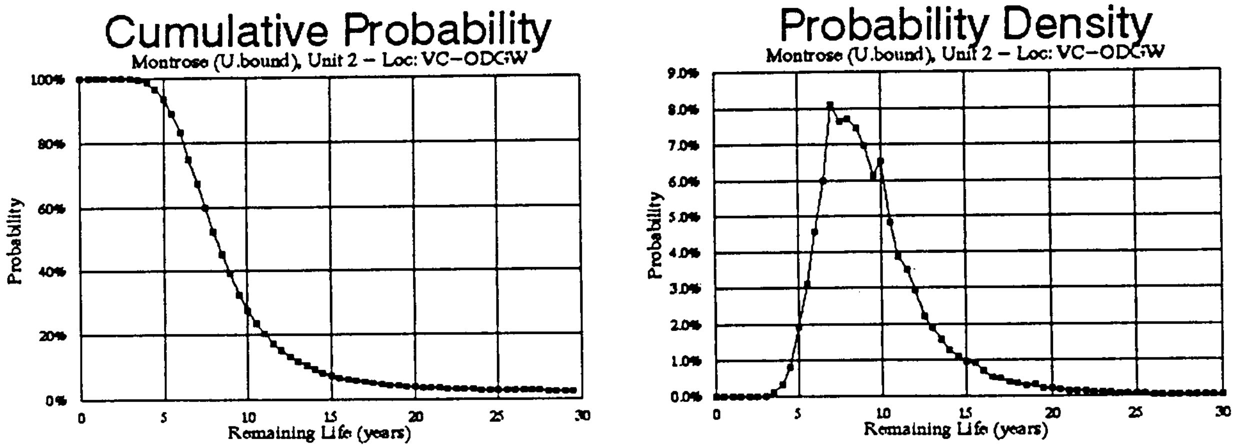


Figure 3 Correlation between Damage Classification and Expended Life Fraction [5]


Cumulative Probability

Montrose (U.bound), Unit 2 – Loc: VC-ODGW

Probability Density

Montrose (U.bound), Unit 2 – Loc: VC-ODGW

Figure 4 Probabilistic Remaining Life Output For Monitor Location VC-ODGW