

# Life assessment and future inspection programme for 18-5 MnCr generator retaining rings

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*18-5 MnCr generator retaining rings are susceptible to stress corrosion cracking if subject to a wet environment, which could cause a catastrophic failure during machine operation. Therefore, the inspection and maintenance of this component is very important not only to increase the availability of power generation but also to reduce the cost of maintenance. A life assessment of the generator retaining rings on 19 generating units at three different power stations has been carried out by using 'RRing-Life' and 'CrackPred' computer programs. From this, the critical size of crack and the probability of failure were evaluated. Using the theory of cracking by stress corrosion and fatigue, the size of a developing crack was predicted and its effect on security of the retaining ring evaluated using fracture mechanics theory. On the basis of the assessment results, a future inspection/maintenance programme of the generator retaining rings was developed for the power stations.*

**Keywords:** generator retaining ring, life assessment, stress corrosion cracking

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## 1. Introduction

Generator retaining rings (GRR) are shrunk onto the rotor body ends of a generator and have the function of securing the coils against the centrifugal forces set up during operation at the point where they leave the longitudinal slots in the rotor body, as shown in Figure 1. Conventionally 18-5 MnCr alloy steel was used to fabricate the GRR by a forging process. However, the material is very susceptible to stress corrosion cracking (SCC) if exposed to even small amounts of moisture, and the problem with

SCC has been considered to be very serious because it may lead to catastrophic failure in service.

Generally, if any SCC indications are detected, the original equipment manufacturer (OEM) recommends a very strict inspection interval, such as 20,000 calendar hours. The defects on a GRR may be detected by two methods: ultrasonic test (UT) in-situ and dye penetrant inspection (DPI). If it is possible to size the defect from the former method, a fracture mechanics analysis may be carried out to assess the risk of further crack growth by fatigue or stress corrosion. On the other hand, if any defects are detected from the latter method, it is usual to undertake machining of some areas or local grinding to remove all defects after removal of the GRR from the rotor because the acceptance criteria are similar to those for new GRR, i.e. no surface defects are allowed.

Whichever the case is, when any SCC flaws are detected on a GRR, we need to decide whether we can continue to use them safely or replace them. To solve these problems, the life assessment of the GRR at three power stations has been carried out by using the 'RRing-Life' computer program, developed by the Electric Power Research Institute (EPRI). Further, for any cracks that may exist in the GRR, the crack growth has been calculated by using 'CrackPred' computer program, in order to advise the next inspection time, i.e. before the predicted crack growth reaches the limit of the critical crack size.

By undertaking this investigation, we expected to achieve three major goals: safe operation with the existing GRR, increased availability of the power station, and decreased maintenance cost.

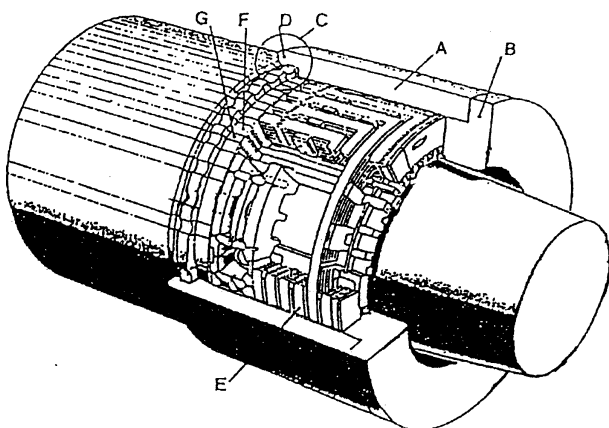


FIGURE 1: A cut-away sketch of a typical generator retaining ring assembly.

A	Retaining Ring	B	End disc
C	Shrink-fit area	D	Retaining ring lug
E	End winding	F	Slot in the rotor body for the coils
G	Rotor tooth		

## 2. Finite element stress analysis

A three-dimensional finite element model was applied for the stress analysis of the GRR [1]. The model was developed using the MicroStation and MSC/Aries and analysed using the MSC/Nastran software package. The hoop, axial and radial stresses at the critical sections shown in Figure 2 were determined. For the life assessment of the GRR, the hoop and axial stresses were used as required by the 'RRing-Life' program, rather than the stresses in the principal directions. The stress values were converted into a third-order polynomial through-wall stress profile for a selected section under run, stop, and overspeed conditions. The through-wall stress profile is defined as:

$$\sigma_{stress}(X) = C_0 + C_1 X + C_2 X^2 + C_3 X^3 \quad (1)$$

where  $X$  is the distance from the inside/outside wall surface and  $C_0 - C_3$  are constants.

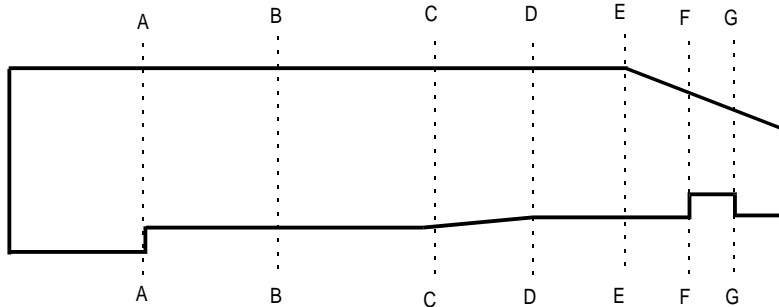


FIGURE 2: Critical sections in GRR.

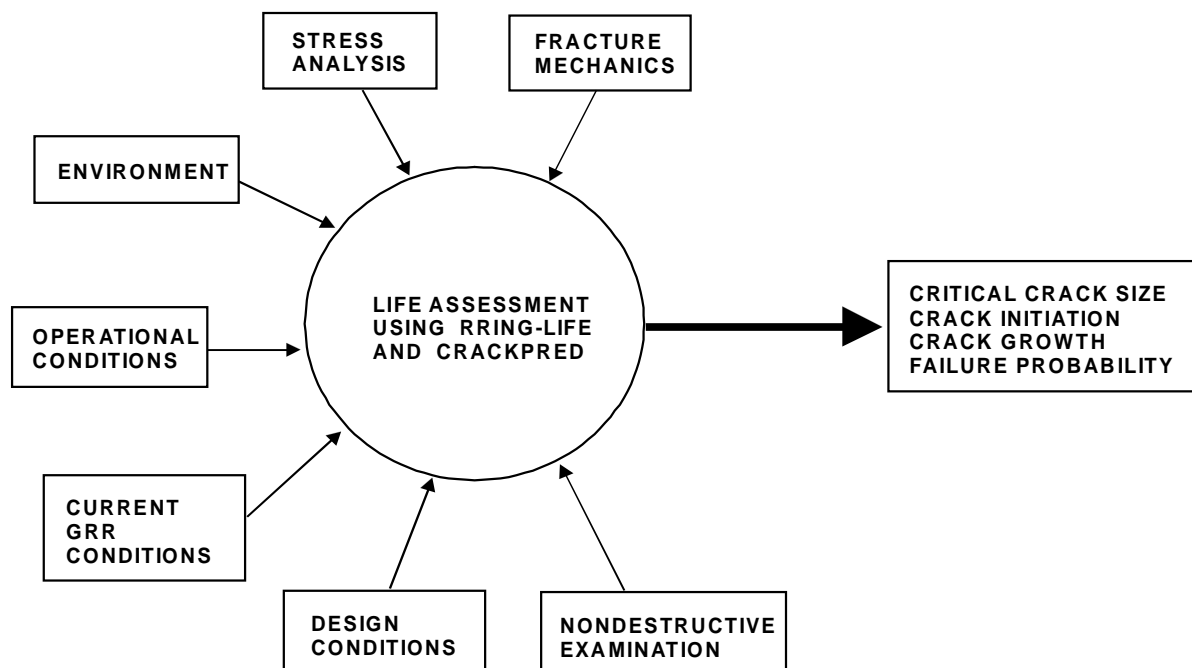


FIGURE 3: Life assessment process of generator retaining ring.

## 3. Life assessment using 'RRing-Life'

Remaining life assessment is required in order to determine whether the existing GRR can continue to be used safely. Generally, as illustrated in Figure 3, the remaining life of GRR is determined by evaluating the material properties, current SCC related condition, operating environment, etc. The 'RRing-Life' program is utilised not only to determine the size of critical crack but also to analyse the probabilities of crack initiation, growth and failure. In the calculation, the 'RRing-Life' treats all significant non-deterministic parameters in the analysis as random variables, and the automated Monte Carlo procedure estimates the probabilistic result [2].

### 3.1 Input data

Specific details from one of the power stations are used here to illustrate the work done in evaluating the condition and remaining service life of these components.

#### Found condition of GRR

From the last inspection for each unit, the following conditions were reported [3]:

Unit 1 - In 02/96 inspection by the Pulse-Echo A-scan UT, no indications of defects larger than 3.0 mm were found.

Unit 2 - In 02/95 inspection by DPI, large amount of stress corrosion pits were found from various locations, then the defects were removed from machining of 0.254-0.660 mm (external surface) and 0.254 mm (internal surface) except the shrink-fit area.

Unit 3 - In 10/94 inspection by DPI, large amount of stress corrosion fits

were found, then the defects were removed from machining of 0.508mm (external surface) and 0.254mm (internal surface) except the shrink-fit area.

Unit 4 - No previous inspection records were available.

Unit 5 - In 10/95 inspection by DPI, minor discontinuity was found, then the defects were removed by blending the areas.

### Operating conditions

The total operating hours and total number of starts were required for the analysis, and the data for each unit were summarised in Table 1.

TABLE 1: Operating conditions for each unit.

Unit	Last inspection date	Total operating hours since last inspection*	Total number of starts since last inspection*
1	02/96	123	7
2	02/95	318	29
3	10/94	1276	55
4	10/85	21054	777
5	10/95	284	14

Note: \*The evaluation date is 1 April 1996.

### Climate and moisture exposure data

The following climate and moisture exposure data are required for the analysis:

- Number of days of rainfall/fog
- Number of days of bands of humidity/dew point
- Cooling type for stator and rotor
- Normal ring operation temperature and dew point
- Duration for exposure by water slug, seal oil moisture and H<sub>2</sub> cooler leak
- Control during turning gear and control during removal

All the information has been determined on the basis of the location of the power station as well as the design and operating conditions.

### 3.2 Assessment of results

By applying the input data to the 'RRing-Life' program, the critical crack size, the probabilities of crack initiation, crack growth and failure could be assessed (Table 2). Section F-F in Figure 2 represented the most critical section because it was the major shrink-fit area and its stress distribution is the highest in each GRR.

TABLE 2. Results of the life assessment.

Unit	Most critical section	Critical crack size at 99.9% data distribution (mm)	Probability of crack initiation (%)	Probability of crack propagation (%)	Probability of failure (%)
1	F-F	6.22	0.3	0.0	0.0
2	F-F	4.90	3.0	0.0	0.0
3	F-F	3.73	4.7	0.0	0.0
4	F-F	5.97	8.6	0.2	0.1
5	F-F	3.68	1.0	0.0	0.0

### 3.3 Understanding the result of the assessment

The probability values of failure were evaluated by comparison with the acceptable probability values in other areas and other power stations. For example, probabilities of 10<sup>-6</sup> for airline crash, 10<sup>-5</sup> for nuclear reactor failure, and 10<sup>-4</sup> for turbine rotor failure are acceptable limits in other areas. Generally, a probability of 2x10<sup>-3</sup> (0.2%) for generator retaining rings is an acceptable limit in thermal and nuclear power stations.

When the probabilities of failure in Table 2 are evaluated, the GRR of Unit 4 showed 0.1% probability of failure, which means that an inspection of this unit was required at the earliest time.

### 4. Prediction of crack growth

The crack growth of each GRR is predicted in accordance with the theory of the conventional fracture mechanics. A FORTRAN program, called 'CrackPred', is written for the evaluation, and the previous operation data for each unit were used in order to determine the values of parameters in equations 2 to 4.

#### Crack growth by stress corrosion cracking:

$$da_{SCC} = \frac{da}{dt} PW_i TP_{op} \quad (2)$$

where  $da/dt$  is the crack growth rate by SCC,  $PW_i$  is the percent of wet time and  $TP_{op}$  is the evaluation period.

#### Crack growth by fatigue:

The crack growth by fatigue was determined in accordance with the following equations for austenitic stainless steel in a non-corrosive environment [4]:

$$da_{fatigue} = \frac{da}{dn} N_{starts} \quad (3)$$

where  $da/dn$  is the fatigue crack growth rate determined by equation 4, and  $N_{starts}$  is the total number of starts.

$$\frac{da}{dn} = C_o (\Delta K_I)^n \quad (4)$$

where  $K_I$  the applied stress intensity factor, and  $n$  and  $C_o$  are constants dependent on the material and environmental conditions.

From the evaluation of crack growth, the results shown in Table 3 were determined.

TABLE 3: Crack growth prediction in six years and recommendation for the next inspection.

Unit	Crack size (mm) at present <sup>1</sup>	Crack size (mm) in 2 years	Crack size (mm) in 4 years	Crack size (mm) in 6 years	Critical crack size (mm) and next inspection <sup>2</sup>		Critical crack size (mm) and next inspection <sup>3</sup>	
1	3.12	4.37	5.64	6.89	6.22	Feb. 2001	7.17	After 2002
2	2.01	3.48	4.95	6.43	4.90	Feb. 2000	5.44	Dec. 2000
3	2.46	4.34	6.22	8.08	3.73	July 1997	3.96	Sept. 1997
4	5.41	6.68	7.95	9.22	5.97	Jan. 1997	6.84	May 1998
5	1.58	3.51	5.41	7.32	3.68	May 1998	3.89	July 1998

Notes: 1. The ‘present’ time is 1 April 1996.

2. The next inspection time recommended on the basis of the 99.9% data distribution of fracture toughness from ‘RRing-Life’ program (refer critical crack size in Table 2).

3. The next inspection time recommended on the basis of the conventional fracture mechanics from ‘CrackPred’ program.

## 5. Future inspection/maintenance programme

Generally inspection covers two aspects: (1) geometrical conformance, such as adequacy of shrink fit and correct fitting; (2) defect identification. Normally DPI and UT are considered best able to satisfy the second requirement, although the eddy current test (ECT) is increasingly used. Previously an inspection/maintenance programme developed by the authors was used as a general guideline of GRR inspection (Figure 4).

However, with the more technical assessment methods described in this paper, it was possible to avoid unnecessary inspections and therefore to increase the availability of the plant. For the GRR in the power station example used here, after considering several analysis results from ‘RRing-Life’ and ‘CrackPred’ and recommendations (GEC comments and 6–8 year industrial practice), the following inspection programme was recommended (Table 4).

As shown in Table 4, it is confirmed on a fitness for purpose basis that the GRR are safe up to the next inspection because the values of probability of failure are acceptable.

## 6. Discussion and conclusion

Through this investigation, the remaining lives of the GRR at three thermal power stations have been assessed, and the crack growth of each GRR has also been predicted. On the basis of the result of the evaluation, a future inspection programme has been developed. However, the

inspection programme may be altered not only if the next inspection date is required to be slotted into the period of the major plant outage schedule, but also if any existing GRR is needed to be replaced by a new 18-18 MnCr GRR. By carrying out this investigation, three major goals have been achieved:

- safe operation with the existing GRR,
- increased availability of two power stations,
- decreased maintenance cost.

Also this investigation indicates that on-line life assessment of GRR is possible through use of a computerised system.

## 7. Acknowledgement

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## 8. References

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4. ASME Boiler and Pressure Vessel Code, Section XI, July 1989

TABLE 4: Recommended inspection programme.

Unit	Recommended next inspection	Probability of failure up to next inspection (%)
1	March 1998 (during the planned outage)	0.02
2	January 1999 (during the planned outage)	0.14
3	September 1997 (before the planned outage)	0.13
4	October 1997 (during the planned outage)	0.17
5	July 1998 (before the planned outage)	0.09

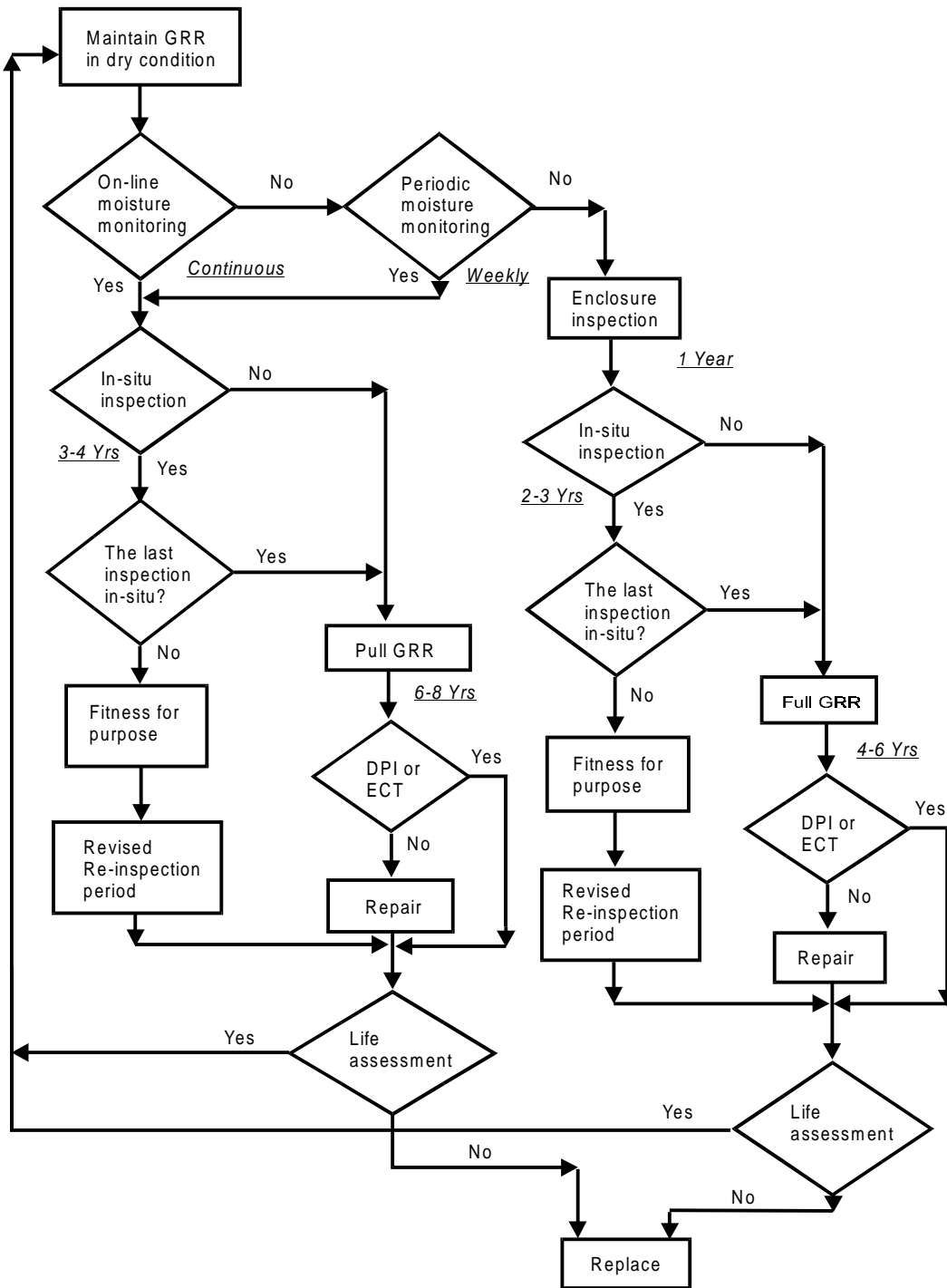


FIGURE 4: Flow diagram for a scheme of life extension.