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DEVELOPMENT OF A METHODOLOGY FOR ON LINE FATIGUE LIFE MONITORING OF NUCLEAR POWER PLANT COMPONENTS

N.K. Mukhopadhyay, B.K. Dutta and H.S. Kushwaha

Reactor Engineering Division, Bhabha Atomic Research Centre, Trombay, Bombay-400085, India

ABSTRACT A methodology has been developed for on line fatigue life monitoring of nuclear power plant components. Green's function technique is used to convert plant data to stress time data. Rainflow cycle counting method is used to compute the fatigue usage factor from stress time history by using material fatigue data. An interactive user friendly graphics code has been developed for updating the stored data and also for retrieving relevant informations by plant operators.

1 INTRODUCTION

The accumulation of fatigue damage in critical components of nuclear power plant is always a matter of concern to design engineers. Information about accumulated fatigue damage of various components is very essential in efficient and successful running of a nuclear power plant. Fatigue life depends on the fluctuation of several plant operating parameters such as fluid temperature, pressure, flow rate etc. Design is done according to the guidelines provided in ASME code by assuming certain conservative variation of these parameters. Generally actual plant transients do not match with assumed design transients. It has been observed that calculated design life is often a conservative estimate. In this present paper a methodology is sought for monitoring the accumulated fatigue damage of nuclear power plant components using available plant instrumentation. This information may be useful in deciding the maintenance and surveillance programme. In addition to this, it may also support life extension programme if required in future.

2 ON LINE FATIGUE LIFE MONITORING SCHEME

In a nuclear power plant a number of critical components may experience severe fluctuation of fluid transients. These components should be selected for fatigue life monitoring. The plant process parameters are recorded on line and converted to stress time history using Green's function technique. This stress time history is further converted to stress frequency spectrum using Rainflow cycle counting method. The accumulated fatigue usage factor is computed from stress frequency spectrum using material fatigue data. This information is continously monitored and updated for each selected component. Different steps of an on line fatigue life monitoring scheme is shown in Fig.1.

In on line fatigue life monitoring, Green's function technique is very widely used. This technique can determine the temperature and stress response in much less time as compared to finite element method. Close form solution of Green's functions are available only for certain well defined geometries [1]. However, close form solution of Green's functions are difficult to derive for complex geometries generally used in nuclear power plant. Therefore, for complex structures Green's functions are derived using finite element technique [2]. This technique is used to compute the stress developed due to unit fluctuation of several plant process parameters. Multiple site loading problem is solved using superimposed single site Green's function technique.

Formulation of a multiple site loading problem is given in reference [3]. A multiple site (m) loading problem with the thermal system in a steady state condition with temperature $T_0(x_i)$, stresses $\sigma_0(x_i)$ and fluid temperatures Φ_0^n (where n=1,m) is considered. It is subjected to fluid temperature disturbances $\Delta\Phi_0^n(t)$ at the n-th site. The temperature and stress responses of the structure due to this fluctuations can be expressed by the following equations.

$$T(x_i,t)=T_0(x_i)+\Sigma[\underline{G}_T^n(x_i)\Delta\Phi^n(t)+{}_{t-td}\int^{t}G_T^{n'}(x_i,t-\tau)d\Delta\Phi^n(\tau) \quad ..(1)$$

$$\sigma(x_i,t)=\sigma_0(x_i)+\Sigma[\underline{G}_\sigma^n(x_i)\Delta\Phi^n(t)+{}_{t-td}\int^{t}G_\sigma^{n'}(x_i,t-\tau)d\Delta\Phi^n(\tau) \quad ..(2)$$

Here x_i represents the coordinate, t the time and td the decay time. $\underline{G}_T^n(x_i)$ and $\underline{G}_\sigma^n(x_i)$ are steady state values of temperature and stress Green's functions for the n-th single site problem. Denoting $G_T^n(x_i,t)$ and $G_\sigma^n(x_i,t)$ as the temperature and stress Green's functions at time t, the following relationships are established.

$$G_T^{n'}(x_i,t)= G_T^n(x_i,t)- \underline{G}_T^n(x_i) \quad ....(3)$$

$$G_\sigma^{n'}(x_i,t)= G_\sigma^n(x_i,t)- \underline{G}_\sigma^n(x_i) \quad ....(4)$$

Using local stress strain concept fatigue usage factor is computed from irregular stress loading history by rainflow cycle counting method [4]. An irregular loading history is most efficiently and accurately analysed by this method. The apparent reason for the superiority of rainflow cycle counting method is that it combines load reversals in a manner that defines a cycle as a closed hysteresis loop. Several algorithms have been proposed in literature for rainflow cycle counting method [5,6].

3 DEVELOPMENT OF CODES

A computer code GREFIN (GREen's functions evaluated by FINite element) has been developed to derive the temperature and stress Green's functions for axisymmetric 2-D structures using finite element method. This code has two modules. The first module computes the temperature distribution and the second module computes the stress developed due to thermal loading, internal pressure and external loads including piping loads. Another postprocessor SREGRE (Structural REsponse by GREen's functions) has been developed to compute the temperature and stress responses from plant data using equations (1) and (2). This postprocessor is capable of handling very long fluid parameter variation histories. Very often the entire fluid parameter history cannot be read into the computer because of limitation in computer memory. This post processor computes the temperature and stress responses while reading the input data. Another post processor FRAIN (Fatigue usage factor by RAINflow method) has also been developed to compute the accumulated fatigue usage factor from stress time history using material fatigue data. Using this post processor the stress history can be read and analysed one block at a time without reading the whole stress history at one stretch.

An interactive user friendly graphics code OLFM (On Line Fatigue Monitoring) has also been developed to interface the above codes. An efficient file management scheme is incorporated to reduce the number of files. This code makes the whole methodology menu driven. Using this code the stored records of a component can be displayed, updated from time to time and updated records can be restored and displayed. Analysis of several components can be done as per operator's choice.

4 ANALYSIS OF REAL LIFE PROBLEMS USING ON LINE FATIGUE LIFE MONITORING METHODOLOGY

A typical nozzle connected to a spherical vessel used in a power plant is analysed first. The geometrical dimensions, material properties and heat transfer coefficients of the nozzle are shown in Fig.2(a). It is exposed to fluid temperature fluctuations on both the vessel surface and the nozzle surface. A typical fluid temperature variations on the vessel and nozzle surfaces are shown in Fig.2(b). A finite element discretisation has been done using axisymmetric four noded elements. Stress Green's functions are derived at the centre of the element surrounding point A and shown in Fig.2(c). The stress responses at "A" is found out using superimposed single site Green's function technique and shown in Fig.2(d). To verify the stress responses, a detail finite element computations are also performed for the same fluid temperature variations. The stress response at "A" using finite element method is also plotted in Fig.2(d). This figure shows how excellently superimposed single site Green's function technique results match with finite element results.

The problem of a reducer connected to a heat exchanger in a plant of a nuclear industry is analysed next. The fluid temperature of the heat exchanger is found to be varying with time. The geometrical details, material properties and fluid heat transfer coefficient are shown in Fig.3(a). The fluid temperature is continuously recorded by gas thermometer. Nearly twenty seven days fluid temperature data is recorded and shown in Fig.3(b). A finite element discretisation of the reducer has been done using axisymmetric four noded elements. The stress Green's functions are derived at the node "A" using the developed code GREFIN and shown in Fig.3(c). The stress response at "A" due to fluid temperature fluctuations are found out using the developed code SREGRE. The peak and valley of stresses are shown in Fig.3(d). This data is converted to stress frequency spectrum using rainflow cycle counting technique using the code FRAIN. The stress range and mean stress of the cycles experienced by the component is found out. For each cycle fatigue usage factor is computed using material fatigue data. They are added to compute the accumulated fatigue usage factor.

The counted cycles as derived by rainflow cycle counting method are grouped into several bands of stress ranges and is shown in Fig.3(e).

5 CONCLUSIONS

From the above two examples, it is concluded that Green's function technique is effective in on line fatigue life monitoring of nuclear power plant components. It is also concluded that multiple site loading problems can be very accurately and efficiently solved using superimposed single site Green's function technuque. Using the developed codes, fatigue usage factor for a real life problem can be efficiently computed, stored, updated and displayed according to the operator's desire.

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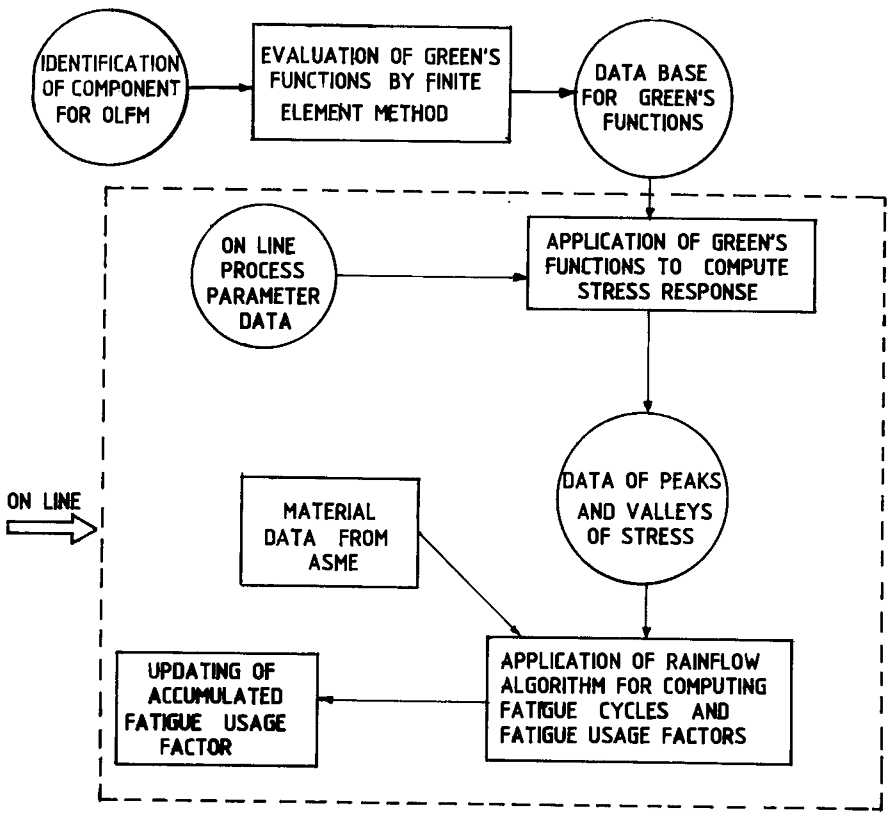

FIG.1 DIFFERENT STEPS IN ON LINE FATIGUE LIFE MONITORING

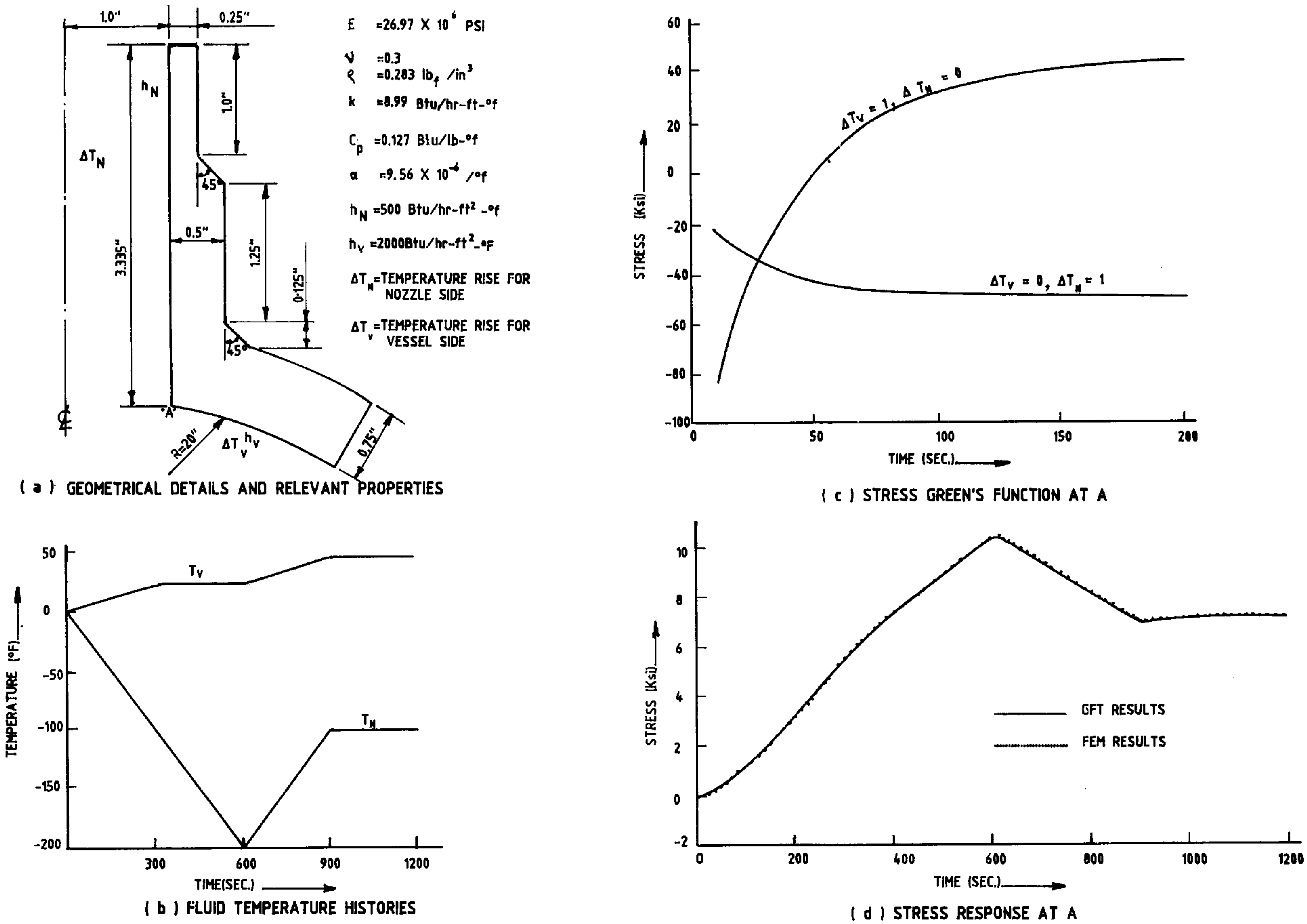

FIG. 2 COMPARISION OF FINITE ELEMENT AND GREEN'S FUNCTION RESULTS FOR A TYPICAL POWER PLANT NOZZLE

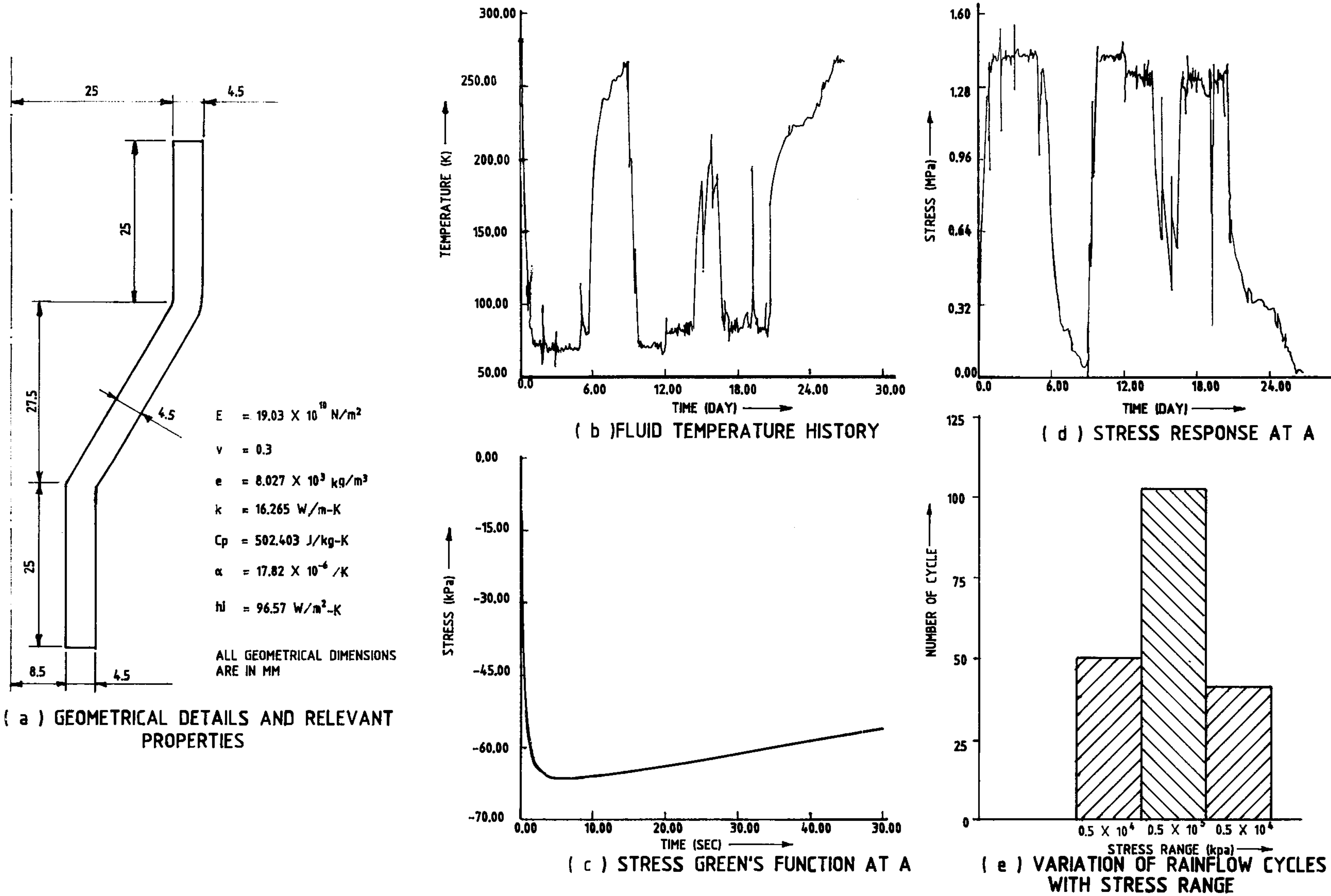

FIG.3 FATIGUE CYCLE FVALUATION FOR REDUCER OF A PLANT SUBJECTED TO FLUID TEMPERATURE VARIATION.