DAMAGE EVALUATION AND LIFE EXTENSION OF STRUCTURAL COMPONENTS

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ABSTRACT

This paper describes an approach to life prediction in which critical elements of major structural components are continuously monitored by appropriate damage indicators for structural damage, and, based on the indicated damage state, an on-line assessment is made of the remaining life. Concurrently alternative corrective measures can then be assessed, and if the life has been found wanting, appropriate actions taken. The process is viewed as a continuous one whereby the current remaining life of critical elements is known as the plant ages. The need for applying such procedures becomes increasingly important as some of our major structures approach their design life and concerns arises regarding retirement and replacement vs. life extension.

Important elements of this approach include definitions of damage, appropriate damage monitors, damage assessment, life prediction and consequences of corrective action. The paper treats these elements in the context of past history and current programs associated with pipe cracking in nuclear power plants.

INTRODUCTION

In no industrial product is the topic of failure prevention and reliability more important than in light water reactors power plants. The economic impact of forced outages in these plants is severe. It has been estimated that the revenue losses from non-generated power in a large light water plant can be as high as one million dollars a day. The record in forced outages in these plants has not been good. Table 1, obtained from a 1975 report by Lapedes and Zedroski (1) indicates an availability factor of some 73% in a representative nuclear power plant. Of the total hours per year of forced outages, some 50% were associated with corrosion – a form of materials failure. Although the record is better today, there is still much that can be done. Some possible approaches are the thrust of the present paper.

I was asked, when preparing this paper, to include some background of my own involvement in the subject. The paper is divided into three parts. In the first part, the early history of the development of low-cycle fatigue is treated, including...
the generation of fatigue data curves and stress rules
associated with the ASME Boiler Vessel Code, Section III. In
the second part some actual light water reactor and associated
laboratory piping experience is discussed, with special
attention given to boiling water reactors. In particular the
nature of the damage encountered both in the plant and
laboratory is described. The third part of the paper considers
in a more general way the subject of damage and its assessment
in the context of an operating component, together with matters
relating to damage monitoring, life prediction and life
extension. As a specific example, some of our own ongoing work
directed toward monitoring and damage control of
stress-corrosion cracking in weld-sensitized type 304 stainless
steel piping in boiling water reactors is cited.

PART I
History and design rules

The fatigue data curves used in Section III of the ASME
Boiler and Pressure Vessel Code resulted from the findings of
the Sub-Task Group on Fatigue which served as part of the Task
group on Allowable Stress of the then Special Committee to
Review the Stress Basis of the Boiler and Pressure Vessel
Committee. These activities took place in the late 1950's and
early 1960's. A summary of the findings of our sub-group made
in June 1961 and its personnel are given in Reference 2. Figure
1 shows the fatigue data curve for stainless steel which
developed from the deliberations of that sub-group.

By way of background to the development of these original
fatigue data curves, it should be pointed out that much of the
design interest at that time dealt with cyclic thermal stresses
in piping and pressure vessels. Because of the severity of the
effect, approaches based on strain rather than stress were
found to be appropriate, so that fatigue lives based on strain
controlled fatigue tests were more meaningful. An important
factor in this work was the significant contribution of cyclic
plastic strain, $\Delta \varepsilon_p$. Our earlier work \(^{3}\) has suggested that a
simple relation of the form

$$\Delta \varepsilon_p = 1/2 (\varepsilon_r) N_r^{1/2} \quad (1)$$

where $\varepsilon_r$ was the fracture ductility, provided an adequate
representation of the behaviour for ductile metals. From this a
fatigue curve of $S$ vs. $N_r$ could be constructed where $S$ is the
pseudo stress amplitude (strain amplitude times elastic modulus
$E$) and $N$ is the cycles to failure. Here

$$S = \frac{E}{4\sqrt{N_r}} \cdot \frac{100}{100 - A} + B \quad (2)$$

the first term of eq. 2 is identical with eq. 1, in pseudo
stress terms, $A$ being the materials' percent reduction in area.
The author had proposed \(^{4}\) that $B$ should be related to the
materials' yield stress. Subsequently, Langer \(^{5}\) related $B$ to
the materials' endurance limit such that $B = S_\infty$. The Langer
modification has become widely accepted to form the basis for
constructing the ASME fatigue data curves, typified by Fig.1.