KAPITEL 1 INTRODUCTION

Fatigue ⇔ Utmattning

BEGREPP:

HCF – LCF

SSY – LSY

LEFM – EPFM

Total life: Crack initiation + Crack growth; Chapters 7, 8

Defect tolerance: Crack growth; Fracture mechanics; Chapter 9

Safe-life

RFC

Leak-before-break

Fail-safe

Redundant

Proportional loading

KAPITEL 7 Stress-life approach, HCF (Not 7.5, 7.7, 7.8)

7.1 The fatigue limit, Livstidsdiagram

S-N, Wöhler, Basquin, $\sigma_a - N_f$, $\sigma_m = 0$

7.2 Mean stress, Medelspänning

Soderberg, Goodman, Gerber, Haigh, $\sigma_a - \sigma_m$, $N_f = \text{const}$

7.3 Cumulative damage, Akumulerad skada

Palmgren – Miner, $\sum \frac{n}{N} = 1$

7.4 Effects of surface treatments, Yteffekter

K_r

7.6 Practical applications, shot peening, kulbombning

7.9 Stress concentrations, Spänningskoncentrationer

$K_f = 1 + q(K_t - 1)$

7.10 Multiaxial fatigue, Fleraxliga tillstånd

vonMieses, Tresca, Critical plane

KAPITEL 8 Strain-life approach, LCF

8.0 Material models

Ramberg-Osgood, $\sigma - \varepsilon$, $\Delta\sigma - \Delta\varepsilon$, Hysteresis

8.1 Strain based approach, Töjningsbaserad analys

Coffin-Manson, Transition, $\Delta\sigma - N_f$, $\Delta\varepsilon - N_f$

8.2 Notched specimens, Spänningskoncentrationer

Neuber

8.3 Varying amplitude, Variabel amplitud

Rain-flow count

8.4 Multiaxial fatigue, Fleraxlig utmattning, Effective strain

KAPITEL 9 Fracture mechanics, Damage tolerance, Brottmekanik, Skadetolerans (Not 9.9, 9.10, 9.11)

9.1 Griffith fracture theory

Fracture stress σ_f

9.2 Energy release rate

G

9.3 LEFM, Linear elastic fracture mechanics, Linjär brottmekanik

9.3.1: Mode (Modus)

9.3.2: Stress-strain fields

9.3.3 K-dominance

9.3.4 Fracture toughness K_c

9.3.5 Paris law, ΔK, ASTM

9.4 G – K

9.5 Plastic zone, monotonic loading, Plastisk zon, monoton last

9.6 Plastic zone, cyclic loading, Plastisk zon, cyklisk last

9.7 EPFM, Elastic-plastic fracture mechanics, Olinjär brottmekanik

HRR, J, J-dominance, CTOD

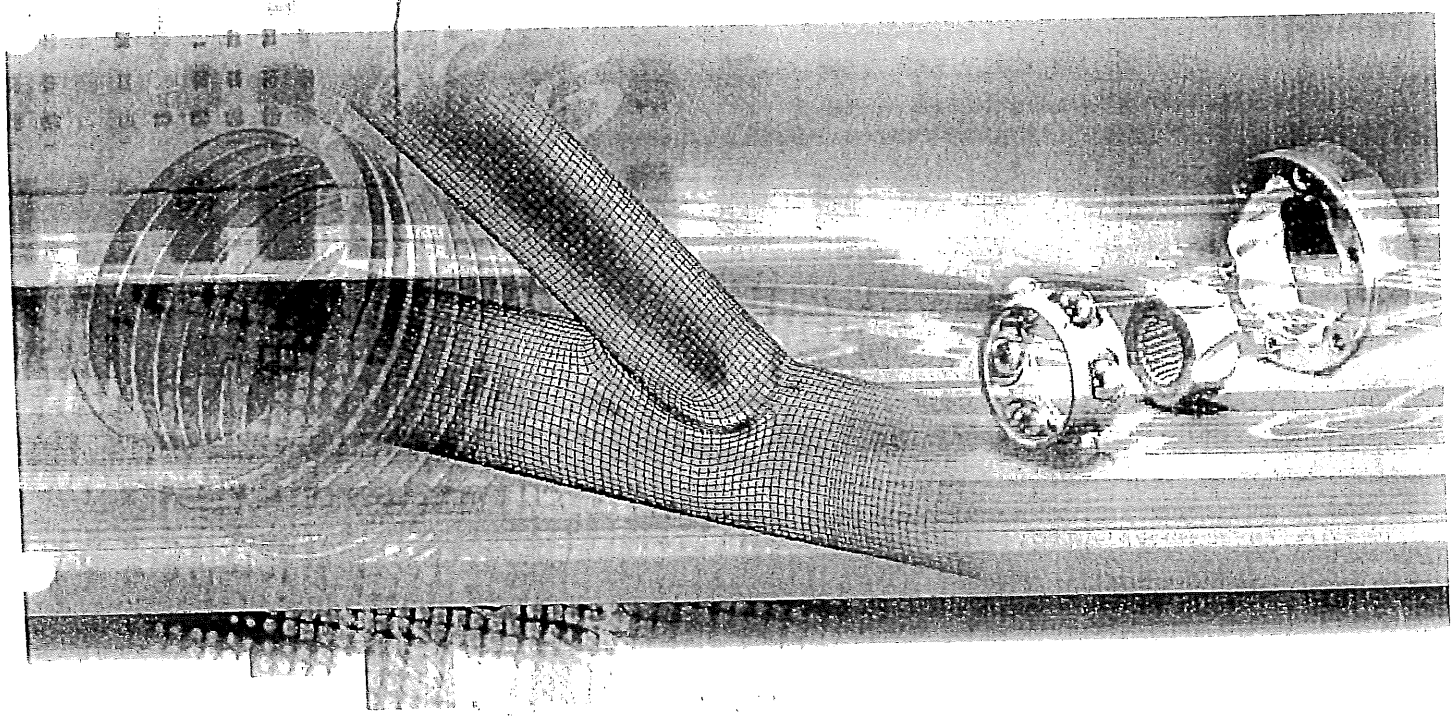
9.8 Two parameters

T, Q

KAPITEL 13 Contact fatigue, Kontaktutmattning

General concepts Chapters 13.1 – 13.6

Sliding fatigue (Glidutmattning), Rolling fatigue (rullutmattning), Fretting fatigue (nötningsutmattning)



fe-safe™

Durability Analysis Software for Finite Element Models

From Safe Technology

Introduction

Industry is putting increasing pressure on manufacturers to use less material to deliver lightweight but stronger components, fewer warranty and recall costs and all in less time.

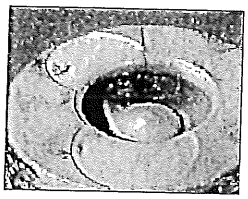
Modern technologies are available to meet these tough demands

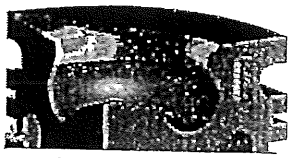
Many companies use advanced finite element analysis to calculate design stresses, but the fatigue analysis is often still done by manually picking stress points for spread-sheet analysis. This is time consuming and unreliable because it's easy to miss failure locations.

Component validation by fatigue testing a prototype design in the test lab is time-consuming. If the prototype fails prematurely, a costly, open-ended cycle of design-test-redesign is required. Project time-scales slip and delivery is late.

In the automotive industry some 40% of the total development cost is spent making prototype parts. In the medical industry an unexpected failure can mean the loss of several months lead-time over competitors.

With fe-safe™ as an integrated part of your design process, you have the ability to optimise designs and test programmes, reduce prototype test times, product recalls and warranty costs - all with increased confidence that your product designs pass their test schedules as "right first time".





fe-safe™ life contours

High temperature fatigue in fe-safe™

Federal Mogul Technology, USA

fe-safe™

- is a highly effective tool for fatigue analysis of Finite Element models
- calculates fatigue lives at every point on a model, and produces contour plots to reveal fatigue lives and crack sites. Critical points need not be missed
- determines how much the stresses must be changed in order to achieve a target design life showing clearly where the component is under strength, or where material and weight can be saved
- estimates warranty claim curves based on probabilities of failure
- calculates which parts of the service duty are most damaging and which could be omitted from a fatigue test
- identifies non-critical loads at significant points on a model. In prototype testing this could mean tests using fewer loads and therefore fewer actuators

fe-safe™... MORE THAN JUST A FATIGUE ANALYSIS TOOL

- not only shows the calculated life but also the rationale behind the calculations. This builds up design expertise, allowing new designs to be highly optimised quickly

- is highly cost-effective: customer feedback shows that fe-safe™ saves many times its cost through reduced man-time hours; the additional saving is immense if one prototype test can be eliminated, or a premature failure avoided

- continues to be selected by Fortune 100 and blue chip companies, renowned for their innovative and advanced design programmes, to optimise the design of components and validate component test programmes

Fast - Assemblies of different parts, materials and surface finish can be analysed in a single run - fe-safe™ automatically changes the method of analysis as it moves from one material to another. Contour plots showing the fatigue life at each node, the factor of strength, and probabilities of survival can be calculated in the same run.

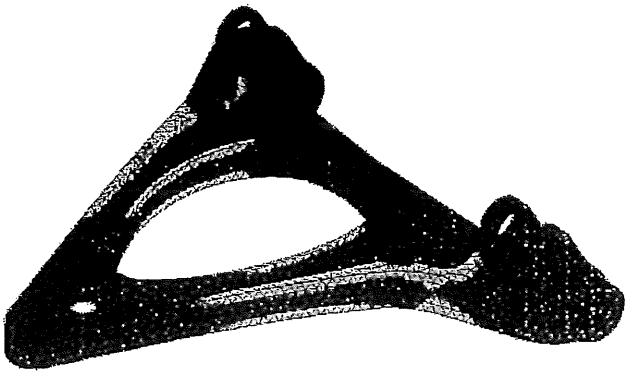
Accurate - Advanced multiaxial algorithms are the core of fe-safe™. Our unique nodal elimination method ensures no trade-off between speed and accuracy. Customers consistently report excellent correlation with test results. Continuous development ensures that fe-safe™ maintains its position as the technology leader.

Easy to Use - fe-safe™ automatically selects the most appropriate algorithm based on the selected material. Direct interfaces to leading FEA suites such as ABAQUS, ANSYS, I-deas, NASTRAN and Pro/Mechanica are driven from an intuitive, single screen, windows based GUI.

Loadings

fe-safe™ can predict fatigue lives from a range of loading types:

- Single load time history applied to a linear elastic finite element model
- Multiple time histories of loading superimposed in fe-safe™ (more than 4000 load histories can be applied)
- Sequence of FEA stresses (elastic or elastic-plastic, linear or non-linear)
- Superimposition of steady state modal solutions
- Superimposition of transient dynamic modal solutions
- PSD loading, block loading test programmes, rainflow cycle matrices
- Effects of forming or assembly stresses can be included



Fatigue contour plot of a bracket

fe-safe™ includes a powerful simple-to-use batch command system, with on-line parametric variation for 'sensitivity' studies.

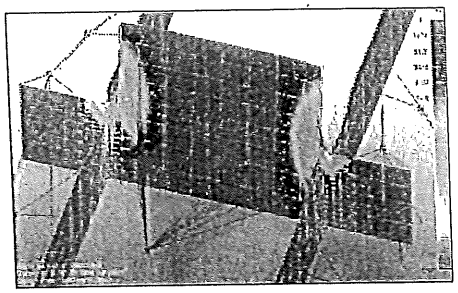
Standard analyses can be set up and saved for re-use.

Analysis methods

fe-safe™ includes an extensive range of analysis methods, all of which are included in the standard package:

- Strain-based multiaxial fatigue algorithms - axial strain, shear strain, Brown-Miller from FEA stresses, with a multiaxial Neuber's rule and cyclic plasticity model
- S-N curve analysis including multiaxial fatigue using axial stress or a new Brown-Miller analysis formulated for use with S-N curves
- Dang Van multiaxial fatigue for high cycle design
- Plots of materials data including the effect of temperature, strain rate etc
- Advanced analysis methods for fatigue of cast irons
- Analysis of welded joints
- High temperature fatigue included as standard
- Analysis from elastic and elastic-plastic FEA stresses, linear and non-linear analysis
- Automatic detection of surfaces
- Automatic detection of fatigue hotspots, based on user-defined criteria
- Comprehensive element/node group management
- Stress gradient corrections
- Interfaces to ABAQUS (.fil & .odb), ANSYS (.rst), MSC.Nastran (.op2 & .f06), NX Nastran (.op2 & .f06), NEiNastran (.op02 & .f06), Pro/Mechanica (ASCII & binary), I-deas (.unv), ADAMS, .dac, MTS RPCIII (.rsp), BEASY, FEMSYS, CADFIX, Altair HyperMesh & Optistruct

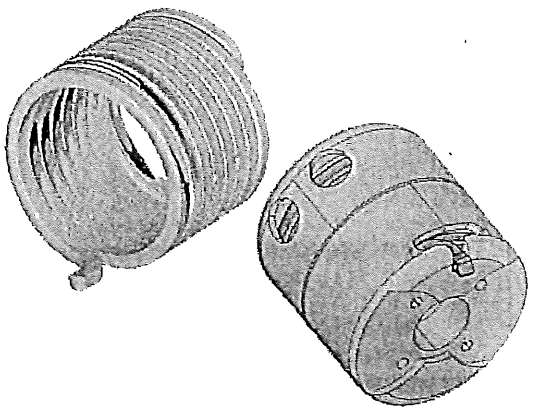
CRITICAL PLANE MULTIAXIAL STRESS-LIFE & STRAIN-LIFE METHODS ARE INCLUDED AS STANDARD



fe-safe™ fatigue contour plot of the internal structure of a transportation container

" fe-safe™ accurately identified the fatigue hotspot critical for the welded section. This allowed the design to be improved early in the design process, thereby avoiding costly redesign downstream"

Portsmouth Aviation, UK



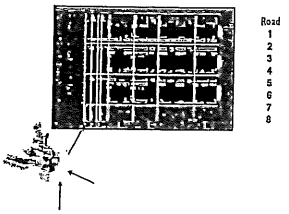
"fe-safe™ - invaluable and indispensable for predictive fatigue analysis"

Eaton Corporation, Automotive Group, USA

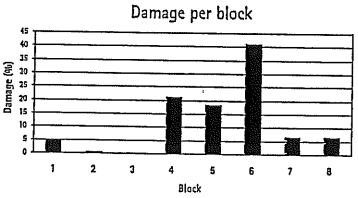
Output

fe-safe™ outputs a wide range of results in a single run:

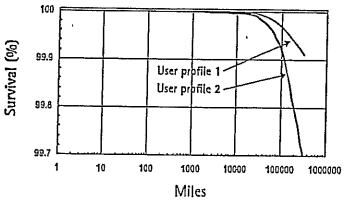
- Contours of fatigue life show crack initiation site
- Contours of stress-based factors of strength for a specified design life - to show how much the stresses must be changed to prevent failure or to reduce material costs
- Probability of survival for specified lives (the 'warranty curve')
- Determines which loads need to be included in a test programme
- Contour plots of maximum stress during loading
- Vector plots identifying critical damage plane
- Detailed results - time histories of stresses and strain, Haigh and Smith diagrams, Dang Van plots and many more in order to explain the rationale behind the life prediction
- Damage at the critical location from each loading block - for example each road surface on a test track



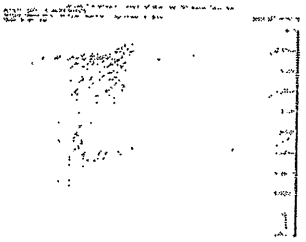
Braking, cornering and vertical loads from each road surface



Damage at the critical location from each road surface



Estimated 'warranty curve' for two user profiles, combines material variability and load variability

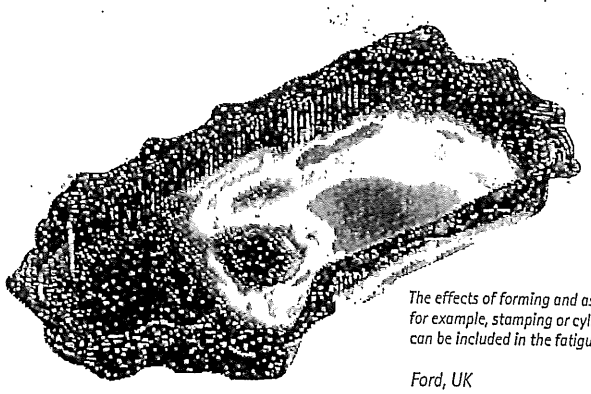


Vector plot identifying the orientation of critical damage planes

Materials database

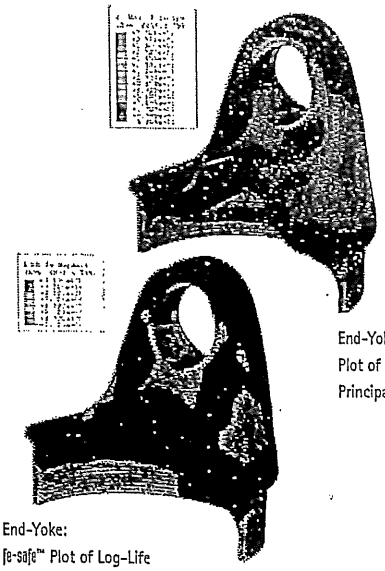
- Comprehensive materials database of strain-life and S-N curve properties – can be extended and modified by the user
- Reliable strain-life material approximation algorithm
- Material data can be temperature dependent
- fe-safe™ automatically selects the most appropriate fatigue algorithm for the selected material
- AFS database of strain-life fatigue properties for cast iron
- Materials support services include material searches and material testing, including high temperature and thermo-mechanical testing

ACCURATE FATIGUE ANALYSIS IS AS EASY AS...
FE ANALYSIS + LOADINGS + MATERIAL DATA + fe-safe™



The effects of forming and assembly stresses, for example, stamping or cylinder head bolt-down, can be included in the fatigue analysis

Ford, UK



End-Yoke:
Plot of Maximum Principal Stress

End-Yoke:
fe-safe™ Plot of Log-Life

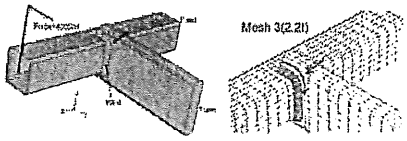
Plots show half-section of a tube-yoke, part of an automotive driveshaft assembly joint

"Just using the hotspot principal stress approach would have led us to identify the outer right side as the problem zone, whereas fe-safe™ identified the lower left side, inner cylindrical tube area as having the lowest predicted life. This was corroborated by lab tests on actual loaded specimens"

Dana Corporation, Automotive Systems Group, USA

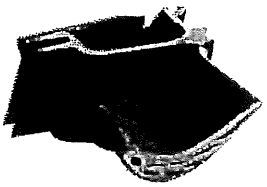
Optional add-on modules

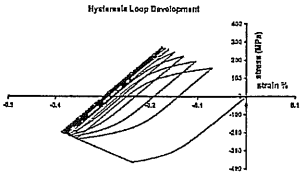
VERITY® module in fe-safe™ is a revolutionary new mesh-insensitive structural stress method developed by **Battelle** that allows engineers to predict failure locations and calculate fatigue lives for welded joints and structures. It is available from **Safe Technology** as an add-on module to fe-safe,™ and allows both welded and non-welded areas to be analysed in a single operation and displayed as a single fatigue life contour plot.



fe-safe TURBOlife by safe technology

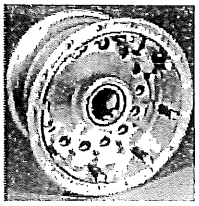
- fe-safe/TURBOlife™ has been developed in partnership with Serco Assurance to assess creep damage, fatigue damage and creep-fatigue interactions. fe-safe/TURBOlife™ creep-fatigue algorithms have been successfully applied to nuclear power plant components, power station boilers, gas turbine blades, steam turbine components, automotive exhaust components and turbocharger impellers





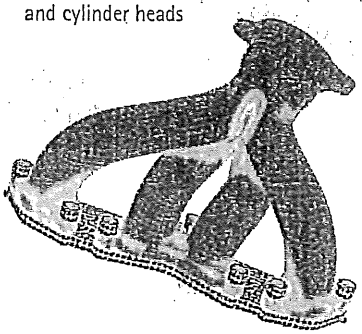
fe-safe ROTATE by safe technology

- fe-safe/Rotate™ is an enhanced module for fe-safe™ that speeds up the fatigue analysis of rotating components by taking advantage of their axial symmetry. It is ideal for wheels and bearings



fe-safe TMF by safe technology

- fe-safe/TMF™ provides a full thermo-mechanical fatigue analysis using instantaneous temperature and strain rates, bulk stress relaxation and the effect of strain ageing from an elastic finite element model. It is ideal for pistons, exhaust manifolds and cylinder heads



safe4 mat by safe technology

safe4mat™

safe4mat™ is a comprehensive material data management capability, included as standard in fe-safe™ and safe4fatigue™. Also available as a stand-alone product, safe4mat™ is a powerful but cost-effective tool for sharing material data across your organisation.

safe4mat™ includes materials data management and editing capabilities, material data plotting and presentation functions, and an enhanced 'Material Comparator' function. The open format and structure of the database allows compatibility with a wide range of existing and legacy databases and software products.

An extensive database of material properties is supplied with safe4mat™ free-of-charge.

safe4 fatigue by safe technology

safe4fatigue™

Safe Technology's proven signal processing suite safe4fatigue™, is included as standard in fe-safe™. Capabilities include amplitude analysis, rainflow cycle counting, PSD's and transfer functions, signal cleaning, digital filters (Butterworth and FFT), uniaxial and multiaxial fatigue from strain gauges, generation of test command signals with optional cycle omission criteria and macro recording.

safe4fatigue™ is also available as a stand-alone product.

'safe4fatigue™ IS REMARKABLY EASY TO USE FOR SUCH A POWERFUL SUITE OF SOFTWARE'