Written examination in *Fatigue Design* for:

* IMP in Automotive Engineering
* IMP in Naval Architecture
* M4 0722 MMA115 (Utmattningsdimensionering)

- **Date: Wednesday 2005-03-16**
- **Time: 1415-1815**
- **Location: V**
- **Teacher: Lennart Josefson, phone 0703-088507 or 7721507**
- **Solutions** will be available 2004-03-17 at 0800 at the Department of Applied Mechanics
- **Corrected examinations** will be available 2004-04-01 at the Department of Applied Mechanics

The written examination consists of two parts: one theoretical part of totally 14 points, and one problem solving part consisting of three problems of 12 points. A fully correct solution of the complete exam gives a maximum of 50 points.

Theoretical part:
This part must be solved first. **No aids are allowed**, i e this part is to be solved without text books, hand calculator, etc. The solution of this part shall be handed in separately, before you continue with the problem part.

Problem part:
This part may be solved using text books and text material distributed during the course, see below. These aids may be collected when the solutions to the theoretical part have been handed in. Short notes in the course material are allowed. Note, however, that solved problems to exercises from the course are NOT allowed as aids. A hand calculator may be used. When in doubt about the hand calculator being a full computer, the teacher should be contacted to permit the hand calculator. **NOTE: To obtain maximum points for each problem, the solutions must be clearly motivated and all the equations used from the literature should have a clear reference.**

Allowed literature during the problem part:

- Dowling, N.E. (1999). *Mechanical Behavior of Materials, second edition*. Prentice Hall, Upper Saddle River, NJ, USA, pp. 830.
- Fatigue design (MMA 115) - Course material on multiaxial fatigue.

  Extract from Socie, D.F. and Marquis, G.B., Multi-axial Fatigue, Society of Automotive Engineers Inc., Warrendale, PA, 2000

  Multi-axial Fatigue, A compendium written by Anders Ekberg, Department of Applied Mechanics, Chalmers
- Extract from The Sheet Steel Handbook, SSAB Tunnplåt, Borlänge, Sweden
- Mathematical Tables
- Handbooks in Engineering like KTH*:s Formelsamling i hållfasthetslära*, or Roark, R.J. and Young, W.C., *Formulas for Stress and Strain*.

The marks are given according to the following scheme (the sum of points from the theoretical and problem parts):

- Not passed 0-19 points
- 3 = Passed 20-29 points
- 4 = Very good 30-39 points
- 5 = Excellent 40-50 points

THEORETICAL PART (14 p)

Question 1 (4 p)

a) Give an explanation of the fatigue notch factor K_f based on the concept of a process zone.
b) Give a fracture mechanics based explanation to the fact that for HCF cases, one has $K_f < K_t$, where K_t is the stress concentration factor.

Question 2 (3 p)

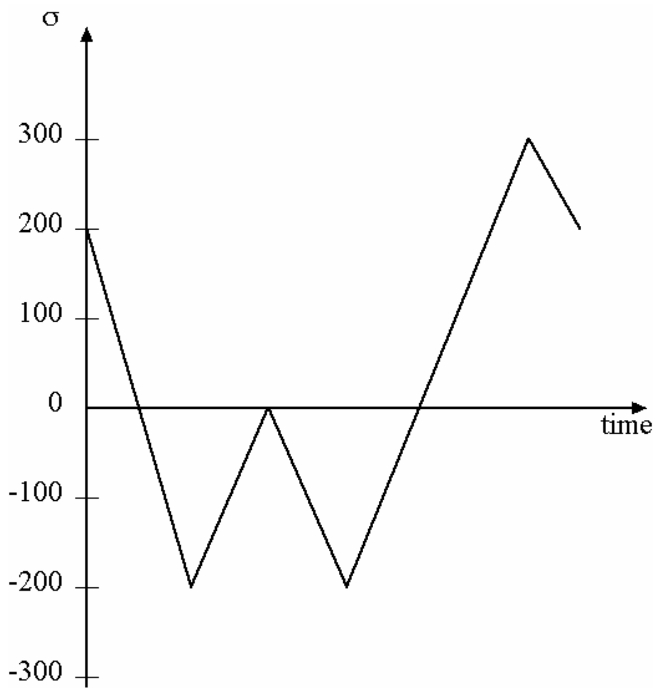
The remaining life of a structure with a crack of length a_i is estimated by integrating the Paris law

$$da/dN = C\,(\Delta K)^m$$

from a_i to a_f, where a_f is the crack length corresponding to $K_{max} = K_{IC}$. Is this estimate conservative or non-conservative? You may assume LEFM conditions to be valid. The answer must be explained.

Question 3 (3 p)

A stress sequence measured in a material point is shown below. This stress sequence is then repeated. Evaluate stress cycles with amplitudes and mid stresses for the shown load sequence using rainflow count.



Question 4 (4 p)

Welds (welded joints) are sensitive to fatigue loads. Give two reasons for this sensitivity and explain why these reasons lower the ability for welds to sustain fatigue loads as compared to the bulk material.

PROBLEM PART (36 p)

NOTE: To obtain maximum points for each problem, the solutions must be clearly motivated and all the equations used from the literature should have a clear reference (author, page and equation number.

Question 5 (12 p)

A LCF (Low Cycle Fatigue) test is to be performed in order to estimate the life in terms of cycles of a material subjected to the strain sequence $\varepsilon = -0.0075 \Rightarrow 0.0075 \Rightarrow -0.0075$. By mistake the test is run for $\varepsilon = 0.0000 \Rightarrow 0.0150 \Rightarrow 0.0000$ instead. What will be the relative error in the life estimate?

From previous tests the data for the S-N curve are known to be $\sigma_f' = 1466$ MPa and $b = -0.143$, and the cyclic stress-strain properties are given by $E = 71\ 000$ MPa, $H' = 977$ MPa and $n' = 0.106$.

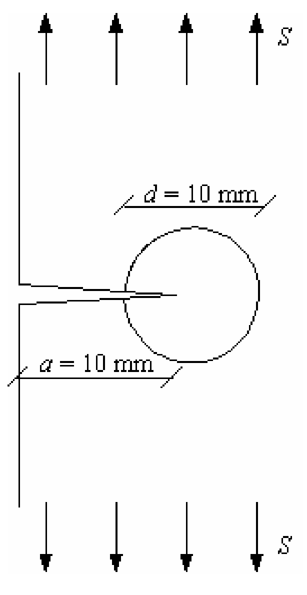
Hint: Use the Morrow approach for taking the influence of mean stress in strain based design into account.

Question 6 (12 p)

In a large plate exerted to zero to tension loading up to $S_{max} = 140$ MPa an edge crack with length $a = 10$ mm is detected. In order to stop the crack from growing further a hole with diameter $D = 10$ mm is drilled, see figure below. Will this improve the situation, i e result in a longer fatigue life?

The following material properties are known: $\sigma_{yield} = 1200$ MPa, $K_{IC} = 60$ MPa m ^{½}, $\sigma_f' = 1800$ MPa and $b = -0.1$, and parameters in Paris law, $C = 5 \cdot 10^{-13}$, m = 3.2 (with da/dN in m and ΔK in MPa m$^{1/2}$),

Use the Smith-Watson-Topper (SWT) approach to take mean value effects into account. For the geometry with the hole you may put $K_f = 4.2$. No effects of size and surface treatment have to be considered.



Question 7 (12 p)

A shaft is subjected to reversed torsion and bending. The resulting stresses are $\tau_{x\varphi} = \pm 100$ MPa and $\sigma_x = \pm 300$ MPa, respectively. Presume these stress components to be proportional in time.
The material has fatigue limits in reversed torsion and in rotating bending of $\tau_{\text{FL}} = 250$ MPa and $\sigma_{\text{FLB}} = 400$ MPa, respectively. All corrections for surface roughness etc are presumed to be included in these fatigue limits.

a) Evaluate the safety factor against fatigue initiation according to the Dang Van criterion!
b) Since this safety factor was deemed as not acceptable, the shaft was subjected to a surface treatment that introduced a compressive residual stress at the surface of $\sigma_x = \sigma_\varphi = -150$ MPa. Evaluate which safety factor against fatigue initiation according to Dang Van this would result in!