Written examination in *Fatigue Design* for:

* IMP in Automotive Engineering
* IMP in Naval Architecture
* M4 MMA115 Utmattningsdimensionering

- Date: Wednesday 2007-03-14
- Time: $14^{00} – 18^{00}$
- Location: V – Building
- Teacher: Lennart Josefson, phone 7721507
- Solutions will be available 2007-03-15 at 08^{30} at the Department of Applied Mechanics
- Corrected examinations will be available 2007-04-05 at the Department of Applied Mechanics

The written examination consists of two parts: one theoretical part of 14 points in total, and one problem solving part consisting of three problems each with a value 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, ie this part is to be solved without textbooks, 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 consulted to permit the hand calculator.
NOTE: To obtain maximum points for each problem, the solution 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. (2006) *Mechanical Behavior of Materials*, Third Edition, Prentice-Hall, Upper Saddle River, NJ, USA, 912 pp.
- Fatigue Design (MMA115) Course Material on Multiaxial Fatigue
- Extract from SSAB Sheet Steel Handbook
- Mathematical Tables and Handbooks in Engineering like KTH:s *Formelsamling i hållfasthetslära*, or Roark R.J. and Young, W.C., *Formulas for Stress and Strain*.

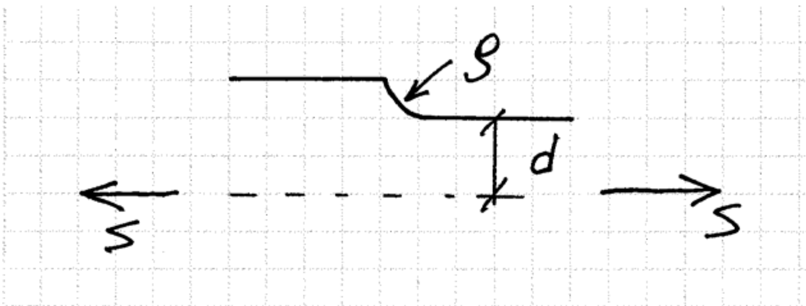
The marks are given as (the sum of points from the theoretical and problem parts):

- 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)

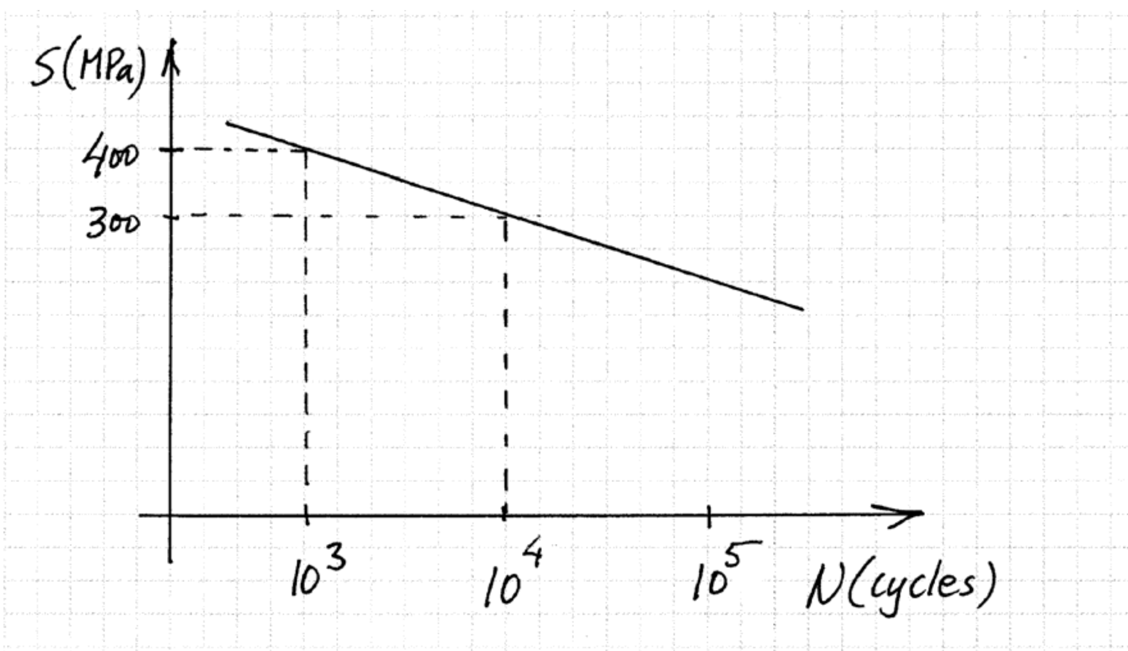
Question 1 (4p)

a) The Figure below shows an axle containing a shoulder with radius ρ. The axle is subjected to an axial stress S. How is the stress concentrations factor k_t related to the geometrical measures ρ and d?
b) Give an explanation of the fatigue notch factor k_f based on the concept of a process zone.



Question 2 (4p)

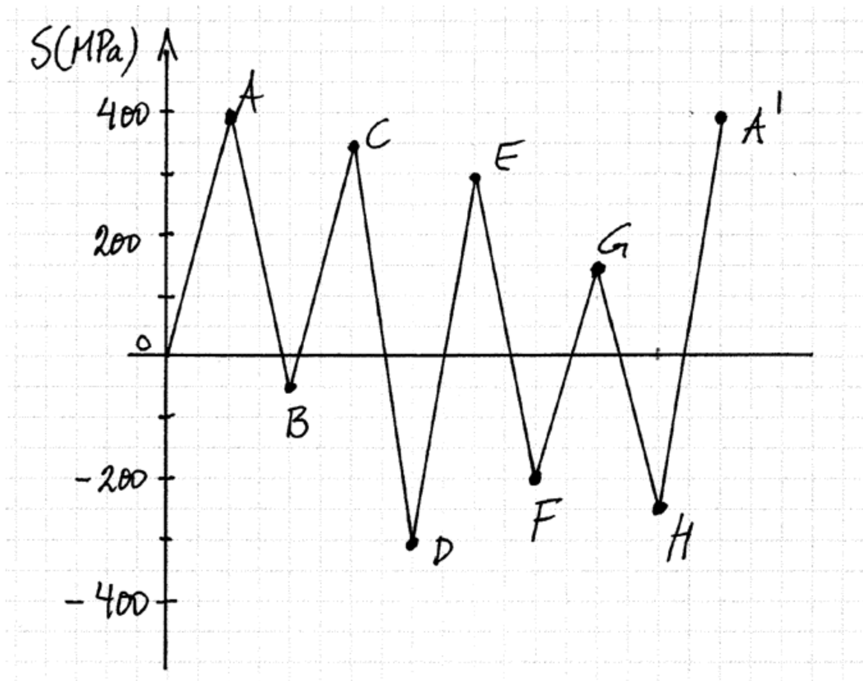
a) For welded joints, the stress range σ_r is used as stress measure in the S-N curve for a specific joint geometry. Why is only this stress measure used? Define also the joint class C for a welded joint (which corresponds to the fatigue notch factor for the weld geometry).
b) The relationship between the stress amplitude and the number of cycles to fatigue failure, the S-N curve, is given in the Figure below for a specific material. If the stress amplitude is first 400 MPa for 300 cycles, and then lowered to 300 MPa, how many cycles can be sustained at this lower amplitude before fatigue failure occurs, based on the Palmgren-Miner damage accumulation rule?



THEORETICAL PART (14 p), cont'd

Question 3 (3p)

A stress sequence measured in a material point is shown below. This stress sequence is then repeated. Note that the stress sequence ends when the line H-A' crosses the x-axis. Evaluate stress cycles with amplitudes and mid stresses for the load sequence shown using the rain flow count method.



Question 4 (3p)

A steel cylinder is rolling on a steel plate with no interfacial friction. For this case the largest Dang Van equivalent stress will occur below the surface[1]. The figure shows the evolution of the state of stress at a material point below the surface. The shear stress, τ_{xz}, on a shear plane parallel to the surface and the hydrostatic stress are plotted as a function of the normalized distance to the centre of the contact from the material point studied. In other words, the plot shows the stress evolution during a load passage, which is equal to one load cycle. The stresses are normalized by the peak contact pressure p_0.

a) Give the definition of the hydrostatic stress and explain what it means that it is a stress invariant.

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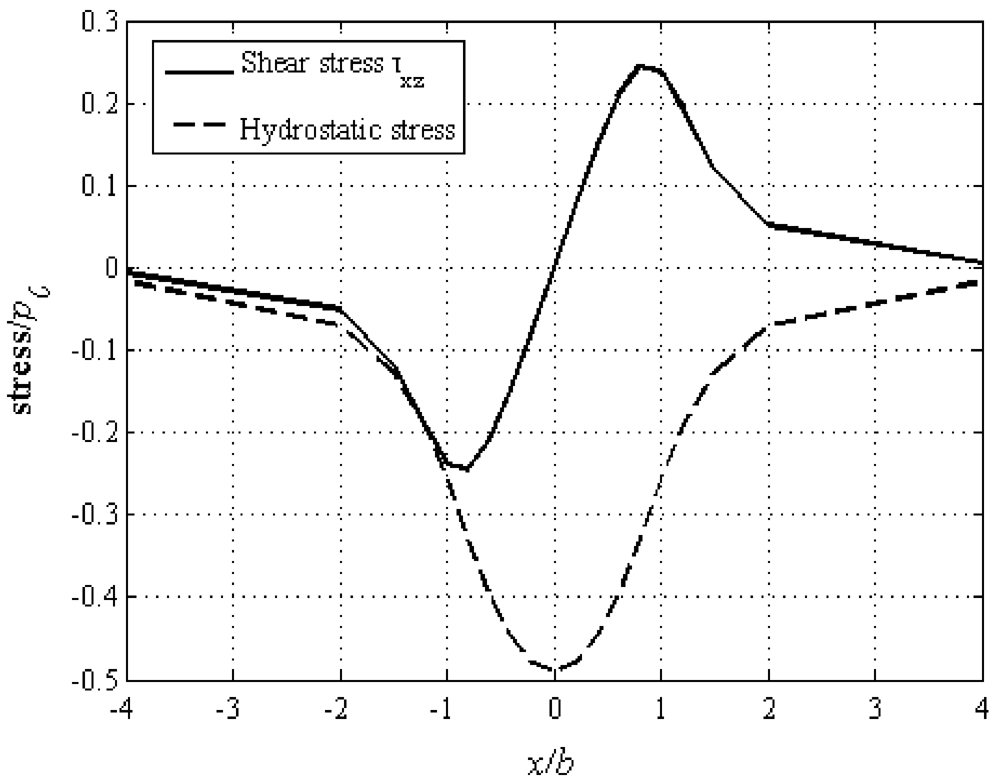
[1] The distance below the surface will depend on the size of the contact patch, *b*, but that is nothing you need to worry about here. The stress magnitudes in the task are evaluated at this critical distance.

THEORETICAL PART (14 p), cont'd

b) Determine the maximum Dang Van stress σ_{EQDV} for the studied material point and shear plane. Express σ_{EQDV} as a function of the peak contact pressure p_0. The material parameter in the Dang Van criterion is $c_{\mathrm{DV}} = 1/3$.

Hint: A state of plane strain exists, which for instance means that τ_{xy} and τ_{yz} are zero.



PROBLEM PART (36 p)

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

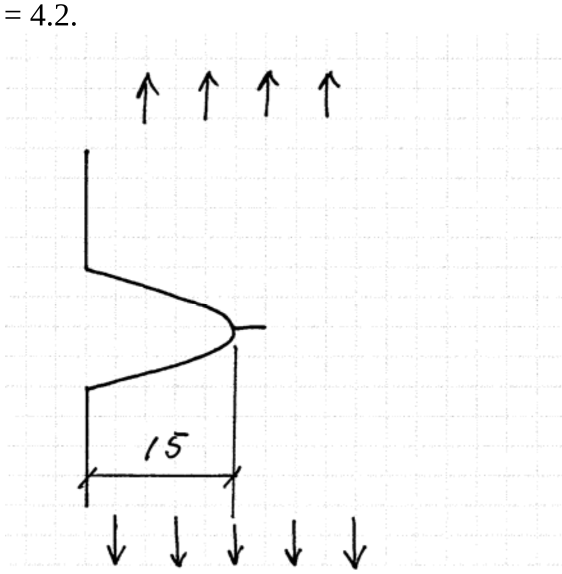
Question 5 (12p)

A high strength steel is to be used as a material for leaf springs in a ground transportation vehicle. During service, cyclic bending is expected to result in a zero-to-tension load, ie the stress ratio $R = 0$. The alloy has an ultimate tensile strength of $\sigma_u = 1500$ MPa. Shot peening of the product prior to the assembly will introduce a surface residual stress $\sigma = -550$ MPa. The beneficial effect of this residual stress may be accounted for. The surface finish of the final product will correspond to a surface finish factor $m_s = 0.4$. The critical point in the leaf spring studied has a stress concentration factor $k_t = 2.2$ and a notch sensitivity $q = 0.86$. Size effects may be neglected ($m_d = 1$)

Determine the maximal nominal stress amplitude that can be allowed on the surface of the leaf spring if it shall be designed for an infinite life?

Question 6 (12p)

At the root of a deep edge notch in a large plate made of AISI 4340A steel, cracks may initiate and grow. How many cycles of a nominal stress varying between 50 and 150 MPa may be allowed, if cracks larger than 1 mm can be detected and if the stress intensity factor may not be larger than $0.5*K_{IC}$? The notch as a depth of 15 mm and a stress concentration factor $k_t = 4.2$.



PROBLEM PART (36 p), cont'd

Question 7 (12p)

A solid axle with a circular cross-section is mounted in a hauler. The axle has a diameter of 40 mm and is made of steel with ultimate tensile strength $\sigma_{\mathrm{UTS}} = 500$ MPa and the fatigue limits in alternating and pulsating bending $\sigma_{\mathrm{FLB}} = \pm 240$ MPa and $\sigma_{\mathrm{FLBP}} = 200 \pm 200$ MPa. The surface of the axle is machined.
The axle transmits a power of 15 kW at 100 rotations per minute. The power is applied in alternating sequences (due to back-and-forth movements of the vehicle).

a) Evaluate the material parameters in the Crossland criterion. Account for surface roughness and loaded volume (size effect).
b) Due to misalignment the axle may be subjected to rotating bending. Estimate the maximum allowed magnitude of the normal stress amplitude due to rotating bending if a safety factor of 1.5 against fatigue initiation should be obtained based on the Crossland criterion. Presume bending and torsion to be in-phase.

Hint: The torsional moment, T [Nm], is related to the transmitted power, P [Watt], and the rotational speed, n [rotations/minute] as $P = T(2\pi n/60)$.