# Notch optimization under multiaxial loading

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***ABSTRACT.*** *Shape optimization of components subjected to multiaxial fatigue is considered. In these cases the application of static optimization algorithms, generally based on Von Mises stress, is no more applicable. In this paper an optimization routine for multiaxial fatigue is developed on the basis of the CAO technique proposed by Mattheck. According to a criterion for fatigue strength estimation of notched specimens made of ductile materials and subjected to mutiaxial fatigue: Liu-Zenner. Abaqus 6.8-1is used as the commercial software to develop finite element simulation and Python 2.4and Matlab2007 are used as the subroutine programs.*

## INTRODUCTION

Fatigue failure is the most experienced failure in many fields such as automobile and aerospace industry. It is possible to avoid fatigue failures by simple over dimensioning the dangerous notches which afflict the components, but the global weight and the performances of the components will results worst. Another, more attractive way to improve the fatigue behaviour of machine element is the definition of procedures able to lead toward the optimum design of notched parts. In the present study, computer aided optimization (CAO) [1] is used as an optimization method to increase the fatigue life in notched components.Previously, Peng et al[2] have tried to optimize the notches based on other method for uniaxial loading, Wilczynski[3] has tried to optimize the shape under multi axial fatigue loading for crack propogation.

The present approach is composed of five steps. Roughly speaking, it is based on simulating the stress field in the notch zone namely “Growth Zone” with temperature and decreases the elastic module in that zone simultaneously. Abaqus 6.8-1[4] is used as commercial software to apply this method. In the original CAO method which is developed by Mattheck [1], the Von-Mises stress is the criterion for calculating the stress concentration factors and also the stress which should be transformed to temperature. Liu-Zenner is the chosen criterion [2] due to the fact that based on the litreture [6, 7] the fatigue prediction of this method in different types of loading is reasonable. Liu-Zenner is an integral criterion based on the average value of the shear and normal stress acting on each material plain; thus the exact definition of shear stress on each plane is required. In this paper, Papadopoulos definition [8] of the amplitude and mean value of the shear stress acting on the plane is used. This definition is almost free from any ambiguity because they are based on the construction of a unique minimum-circumscribed circle to the load path described by the shear stress on the critical plane. As it is mentioned, in order to apply the criterion, it is necessary to calculate the integrals over the planes in Liu-Zenner method. Thus the space, obviously, should be divided into several planes. This division should be implementable on numerical software. The Webber [9] method which deals with the way to obtain a homogeneous distribution of planes having almost the same area and also the determination of the smallest circle surrounding the loading path is implemented. At the end, an example based on the developed method is represented. Results obtained from the numerical examples indicate that distribution of the Liu-Zenner [5] calculated stress on the notch area in comparison with the original shapes is significantly imporved leading to decrease and even in some cases to avoid stress concentration on the notch.

## OPTIMIZATION PROCEDURE

The paper is based on a method introduced by Mattheck [1] which is derived from the natural phenomenon of adaptive growth in trees. The CAO method [1] is briefly described in the following steps. The flowchart is also illustrated in Figure 1.

1. A finite element model of the structure representing the desired appearance of the component is produced by Abaqus 6.8 [3].Fatigue loading is applied by introducing the stress amplitude and phases of the harmonic function; consequently, the history of stress tensor through the time will be obtained on each node.
2. Based on the FEM results the Liu-Zenner [5] stress for each node will be calculated by using Python 2.4 [10]. The strength of the specimen could be estimated based on the calculated fatigue limit.
3. The computed stresses are then substituted by a virtual temperature distribution. In this way the points which showed previously highest mechanical stresses would be the hottest points in the component. Moreover, the modulus of the elasticity in the upper layer is set to only 1/400 of the initial value. Thus there would be a fictitious soft layer with particularly high temperature at original overloaded zones and rather cold layers in the unloaded region. Before applying and changing the stress field into temperature field, it should be noted that without considering the ambient temperature the notched area will always be increased.
4. In the next FEM computation which considers just the thermal loads, the previous mechanical load (tension) is set to zero. Moreover, only the soft upper layer will have a thermal expansion factors $\alpha>0$. During this computational stage with only thermal loading, the 'pudding-soft' upper layer expands corresponding to its temperature distribution, and that is the Growth Zone which previously experienced the highest loads (in computation step 2) at this stage tolerates the highest

temperature and expands most clearly, i.e. it grows more. All the prodcedure is controlled by Matlab 2007 [11].

5. The structure already improved by growth in computation step 4 is already shape-optimized to some extents, and occasionally one such growth cycle is sufficient. This is checked by again setting the E-modules of the soft layer at the value of the basic material and starting at step 2 with a new FEM computation under purely mechanical loading, which will deliver a more homogeneous stress distribution with greatly reduced notched stresses. The computation loops 2-5 are run through repeatedly, till the stress concentration factor stops changing due to fact that construction conditions forbid further growth.

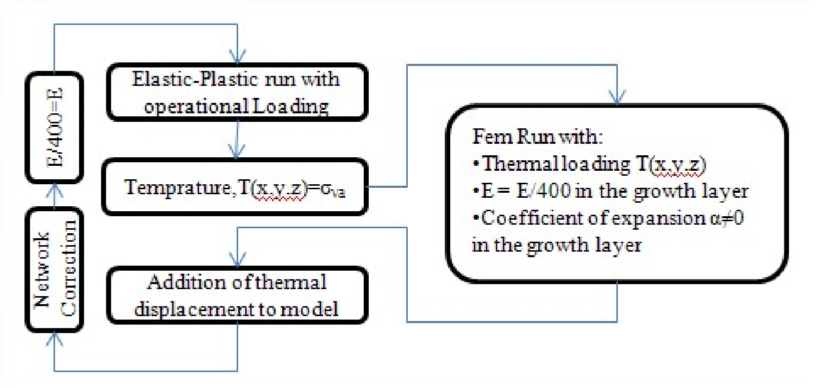


Figure 1: Flowchart of proposed CAO method

## MULTI AXIAL FATIGUE CRITERIA

Finding fatigue limit under multi axial loading has been one of the most controversial issues in the last century; due to the fact that, without omitting and simplifying the problem condition, most of the structures in real life, which are under the cyclic load, suffer from the multi axial fatigue damages. There are many different criteria from different categories which have been proposed to find the fatigue limits. The Liu-Zenner is the chosen criterion which is described briefly in the following part.

### *Liu-Zenner criterion [2]*

The Liu-Zenner [5] multi-axial criteria of integral approach and of the critical plane approach can be derived as special cases from the general fatigue criteria. Based on the literature [6, 7] the estimated life time according to this criterion shows appropriate results in different loading condition. The Liu-Zenner multi-axial criteria of integral approach and of the critical plane approach can be derived as special cases from the general fatigue criterion. The Eqs (2) and (3) are based on Figure 2. In the following equations The $\sigma_{\upsilon a,\sigma}$ and $\sigma_{\upsilon a,\tau}$, stress amplitudes, are calculated in each cutting plane from the time function of the stress components.