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Experimental Stress Analysis

CRACK GROWTH MONITORING WITH REMOTE CONTROL

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Abstract: Cyclic loading of the CT and CCT specimens were made in our department during the project focused on pitting in rolling contact. These experiments were done to find parameters of Paris law and to verify the criteria controlling both crack propagation rate and direction. Experiments were made by means of electromagnetic testing machine AMSLER. Crack growth was monitored by camera with sensing head. Movement of camera was driven by support with 3D motion controlled by step motors. Consequently the experiments can be fully monitored online.

1. Introduction

Pitting is problem of the contact fatigue and project goaled to this problem was solved in our department during last years. This project was aimed on the gears pitting, spur gear system mainly. The postulate of solving was that pitting fundamental is propagation of fatigue crack under rolling contact condition. Simulation of the crack propagation by means of FEA and comparing with experimental data was our method of solving this problem [1]. Acceptable correspondence between experimental data and numeric simulation confirms that propagation of fatigue crack is real mechanism of pitting abrasion.

2. Theoretic background

Phenomenological theory of crack propagation used in this project is based on precondition of initial cracks are so big that mass can be modelled as isotropic continuum and second one that plastic zone on crack tip is small comparing with size of body and crack. Stress array on crack tip is decided for direction and rate of crack propagation.

2.1. Crack growth direction

Both one parameter and two-parameter criteria of crack growth direction were used. Criteria of maximum tangential stress component said, that direction of crack propagation matches maximum tangential stress component. This tangential component can be expressed from first member of Williams expansion of complex stress function [2, 3].

$$K \sin\theta_0 + K\left(3\cos\theta_0 - 1\right) = 0 \tag{1}$$

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Maximum energy release rate and J-integral maximum criteria was used too. Tangential stress component can be expressed by means of the first two members of Williams expansion

$$K_I \sin\theta_o + K_{II}(3\cos\theta_o - 1) - \frac{16T\sqrt{2\pi r_c}}{3}\sin\frac{\theta}{2}\cos\theta = 0, \tag{2}$$

where parameter r_c represents process zone size which is considered to be material constant.

2.2. Crack growth ratio

The crack growth rate in case of classic fracture mechanics can be expressed by means of Paris law

$$\frac{da}{dN} = C(\Delta K)^m, \tag{3}$$

where da/dN is crack growth rate, C and m are material constant and ΔK is amplitude of SIF. Nevertheless in some cases the measured crack growth rates are not in good agreement with the ones computed according to (3). Suppression of T-stress in (3) is supposed to be the significant source of prediction error. Modified Paris law considering constraint influence on crack growth rate can be (according to [3]) expressed as

$$\frac{da}{dN} = C\left[\lambda\left(\frac{T}{\sigma_y}\right)\Delta K\right]^m, \tag{4}$$

Where function λ is defined as

$$\lambda\left(\frac{T}{\sigma_y}\right) = 1 - 0.33\left(\frac{T}{\sigma_y}\right) + 0.66\left(\frac{T}{\sigma_y}\right)^2 - 0.445\left(\frac{T}{\sigma_y}\right)^3.$$

T represents T-stress and σ_y represents yield stress of given material.

3. Experiment

Experimental measurements are necessary to verify proposed model as well as to generalize accepted presumptions and achieved numerical results. Experiments presented in this article were carried out in the laboratories of FME CTU. They were focused on the verification of the fatigue cracks propagation direction as well as on their growth rate under mixed mode conditions. Two sets of circular CT specimens made of 18CrNiMo7-6 steel (σy = 1000 MPa after treatment) were tested. The first set was destined for the measurement of crack propagation in the plane of symmetry of specimen under the crack opening mode conditions. It was used for determination of parameters C and m in Paris law (2). CT specimens of the second set were modified (two holes near the initiation notch were drilled Fig. 4) in order to achieve mixed mode loading and curved crack shape. Electromagnetic testing machine Amsler was used to obtain cyclic loading with frequency approximately 100 Hz and with aspect ratio R = 0.06 and the same load level for all specimens. The Amsler machine is controlled by new Zwick/Roell control units and TestXpert software. The crack growth was observed with the aid of digital camera Nikon DN100 with sensing head Volpi AS 13/17. The pictures of crack tip were captured in intervals of 10^4 numbers of cycles order.

Figure 1: *Amsler 10 HFP 422 Vibrophore with installed camera and 3D table.*

Snapshots of crack tip were taken by means LuciaNet software, and this software was used for determination of crack propagation during appropriate number of cycles. Sensing head with needful focus length must be used. Only four or five pictures of required quality can be taken in one position of camera. Originally moving of camera had been made manually. Due to this manual moving measuring procedure had been slowed down and continuous presence of staff had been necessary. It had been really confusing because one measurement step had taken approximately ten minutes. Moreover, the vibrations inevitably caused by manual handling had lead to further delay.

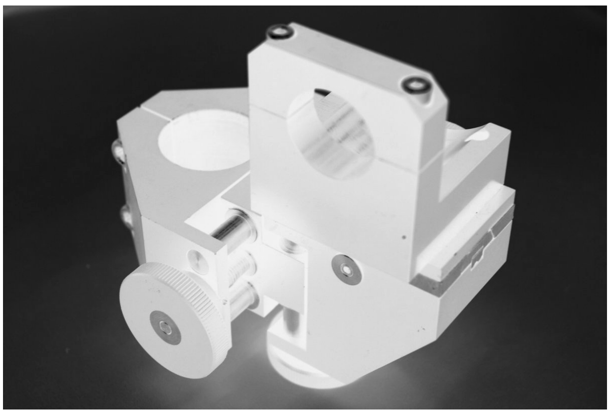

Figure 2: *Original manual 3D table*

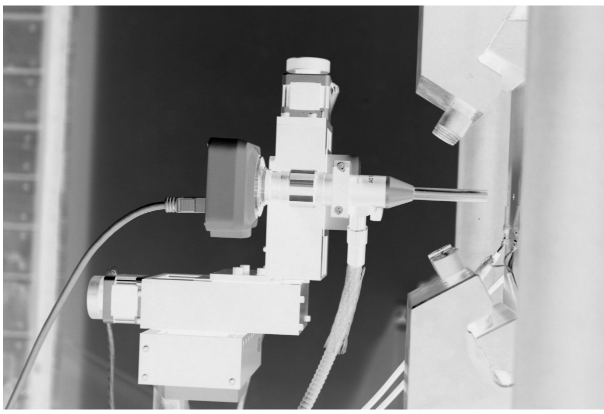

Figure 3: *New design of 3D table with installed camera and sensing head.*

4. New table design

Experience with measuring crack growth was the reason to design new 3D PC controlled table. This problem was solved in collaboration with firm “Petr Tax OPTAX s.r.o.” New table consists of three axes. Each axis is represented by step motor units controlled by programmable control unit C1x with power module 6410-001 manufactured by firm Microcon. These control units were collected together in one box. This box is connected by RS232 with computer. Control software is used for camera moving. LuciaNet software enables online specimen monitoring. Using this visual feedback one can take snapshot and/or move or focus camera. Software VLC is used for remote desktop control on measurement PC. Using software TestXpert it is possible to set and start single step of experiment, to take snapshot of crack tip in the end of each step. Usage of new table rapidly decreased vibration of camera that sped up taking snapshots of crack tip. On some loading levels is test machine is very noisy. Therefore remote control of experiment is more comfortable.

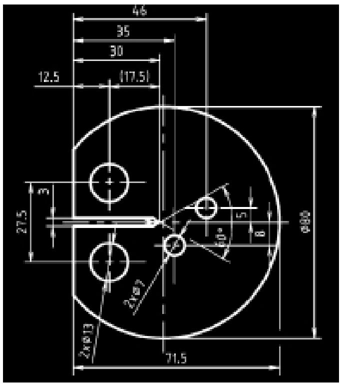

Figure 4: *Modified CT specimen*

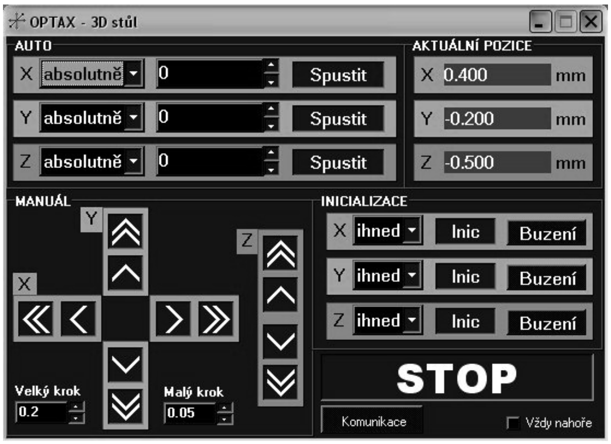

Figure 5: *3D table control software interface*

5. Conclusion

New 3D table was designed. This table enables remote monitoring and control of cyclic loading experimental research. Particularly crack growth monitoring was significantly improved and sped up. New experimental setup was utilised to indentify LFM material parameters in scope of project dealing with simulations of pitting arise. Some results of this research were published in [1].

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