Thermoelastic Stress Analysis, a Promising Method for the Experimental Stress Analysis of Dynamically Loaded Components

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1 INTRODUCTION

The thermoelastic stress analysis (THESA) is a relatively new experimental method to determine the stresses at structures under time dependent loading. Using the thermoelastic effect it enables contactless investigation of the state of stress at the surface of a real structure. The attainable resolution of the investigated area is high. Therefore, it is possible to detect stress concentrations due to discontinuities of construction as well as to defects like cracks or corrosion.

The paper describes the fundamentals of the method as well as technical equipment and performance of tests. The broad field of application is represented by three examples which are part of investigations at the university of Darmstadt (Wölfel and Feickert 1990) and at WÖLFEL Consulting Engineers (Wölfel et al. 1987, 1988):

- A comparison of THESA and Finite-Element (FE) results demonstrates the efficiency of the method.

- Detection of defect is shown by a laboratory test at a specimen with notch.

- Tests at a process unit of a reprocessing plant for spent nuclear fuel elements demonstrate the application at real structures.

Results of the investigations are discussed briefly.

2 FUNDAMENTALS AND PROPERTIES OF THESA

The method uses the thermoelastic effect, which means that the variation of temperature ΔT is proportional to the variation of the sum of principle stresses $\Delta I_1 = \sigma_x + \sigma_y$:

$$\Delta T = -K T_0 \cdot \Delta I_1 \quad (T_0 = \text{mean temperature, } K = \text{thermoelastic constant})$$

This relation holds for homogeneous solid bodies of linear elastic material with small strains and under adiabatic isentropic conditions.

SMiRT 11 Transactions Vol. F (August 1991) Tokyo, Japan, © 1991

The temperature variations due to the variations of elastic stresses are very small, for example 10^{-3} Kelvin due to 1 N/mm^2 variation of ΔI_1 for steel. Therefore, the exploitation of the effect (Thomson 1853) just became possible in the early eighties when the test facility was established combining a highly sensitive infra-red detector with the modern possibilities of signal processing.

Fig. 1 shows the signal flow for the used measurement system SPATE (Mountain and Webber, 1978). The test specimen is excited periodically with a load frequency high enough (> 1 Hz) to approach adiabatic conditions. The variations of temperature are measured with an infra-red camera scanning the predefined surface area dot by dot up to 256 by 256. The output signal of the infra-red camera is adjusted to a reference signal by a phase correlator. The output signals of the phase correlator are digitalised and computed according to a calibration procedure which relates the measured temperatures with $\sigma_x + \sigma_y$. The general state of stress especially shear stress ist not comprehended.

The stress pattern is stored and displayed or evaluated using additional software.

THESA instrumentation together with a test specimen of the nuclear industry is shown in Fig. 2.

3 COMPARISON OF THESA AND FINITE-ELEMENT RESULTS

To check the efficiency and accuracy of THESA, a clamped plate with central cut out is investigated by THESA as well as by FE-calculations (Fig. 3). Resolution of the measurement and mesh of FE-model are very fine. Strain gauges (SG) are used to calibrate the measurements.

Calculated first two eigenfrequencies of the plate are 51,5 Hz and 123,5 Hz (measured 49 Hz and 117 Hz). The plate is loaded sinusoidal (80 Hz) normal to the surface with an amplitude of P_0 = 10 N.

Fig. 4 shows the measured and calculated stress sum distributation of the whole plate. Plots of the stress sum along lines 1 and 4 (Fig. 5) show very good agreement of measurement and calculation. The differences are mainly less than 1 N/mm^2 which is the resolution limit for steel.

4 DETECTION OF DEFECT

The sensitivity of THESA for detection of defects is checked by testing a clamped flat bar with notch (Fig. 6). Plots of the measured stress sum along a section show characteristic stress distributions at side of notch (decrease-increase-decrease) and back of notch (increase only). These characteristics were also scanned in the investigations of real cracks and corrosion.

5 TESTS AT A NUCLEAR PROCESS UNIT

THESA used at components of a nuclear reprocessing plant showed the simple applicability of the method at real structures. It is possible to optimise the proof concept for a great amount of process units by combing FE calculations, THESA and strain gauge measurements. One of the measurement results (Fig. 8) shows the area with stress concentrations of a vessel surface near fastening. The measurement results agree globally well with FE calculations. Locally they give hints for FE-mesh refinements.

6 CONCLUSIONS

At the available level of development the method THESA will find a broad field of application in reactor technology because of its general properties:
Development, testing, optimisation and quality control of components, verification and optimisation of calculation models, detection of defects.

Efforts for further development of THESA are focussed on separation of stress sum, evaluation of relations between defect parameters and state of stress, reduction of measurement time.

REFERENCES

Mountain, D. S., Webber, J. M. B. (1978). Stress pattern analysis by thermal emission (SPATE), Proc. Soc. Photo-Opt. Instr. Engrs., Vol. 164, pp. 189-196.

Thomson, W., (1853). On the dynamical theory of heat. Trans. Roy. Soc. Edinburgh 20, pp. 261-283.

Wölfel, H., Feickert, W. (1990). Comparison of Thermoelastic Stress Analysis and Finite-Element Results. 9fh Intern. Conf. on Exp. Mech., Copenhagen, pp. 748-757.

Wölfel, H., Kennerknecht, H., Krapf, K.G. (1987). Stress analysis of components of industrial processing plants: Combination of thermoelastic stress analysis and finite element calculations. SPIE Vol. 731, pp.122-131.

Wölfel, H., Krapf, K.-G., Richter, M. (1988). Verfahren der Thermoelastischen Spannungsanalyse zur Rißdetektion. DGZfP-Jahrestagung Siegen, pp. 274-283.

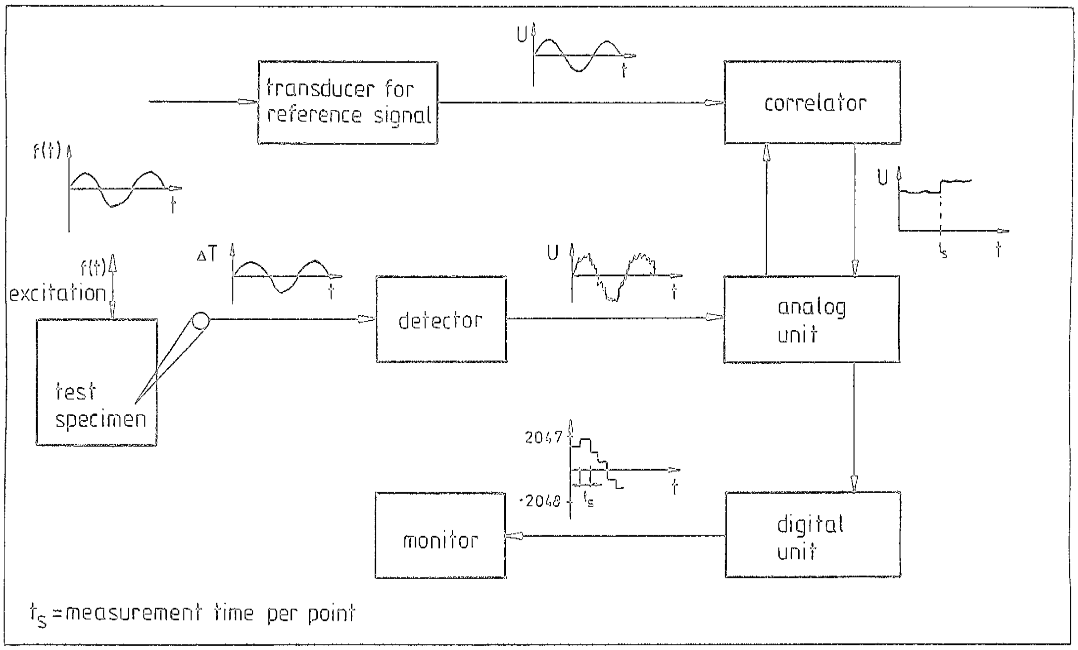


Fig. 1: Signal flow chart of the measurement system for THESA

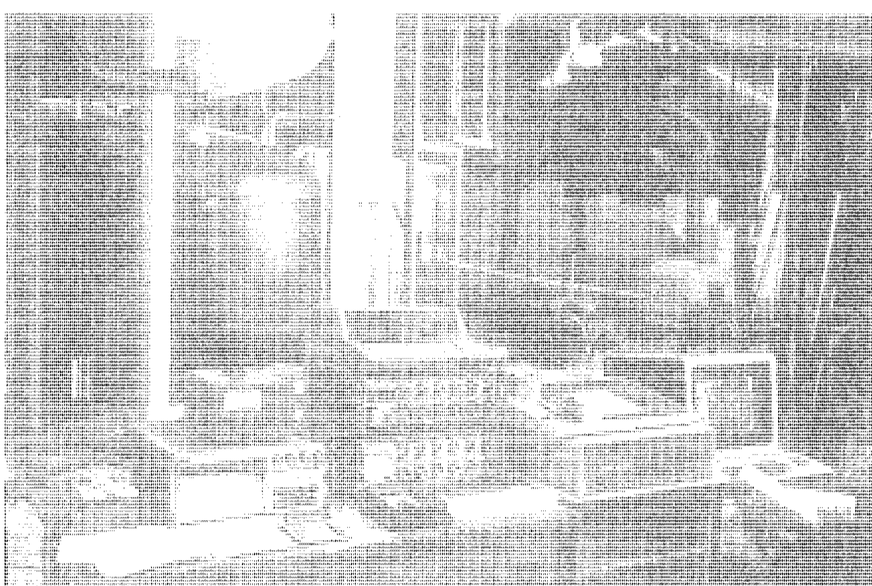


Fig. 2: THESA instrumentation with nuclear process unit as test specimen

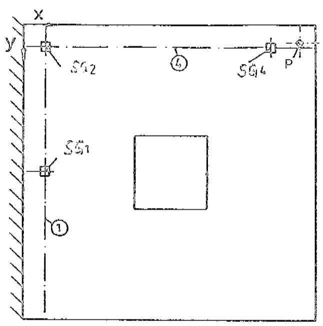
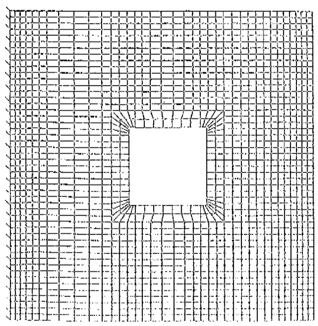


plate
(200x200x2,45 mm)
cut out (50x50xmm)



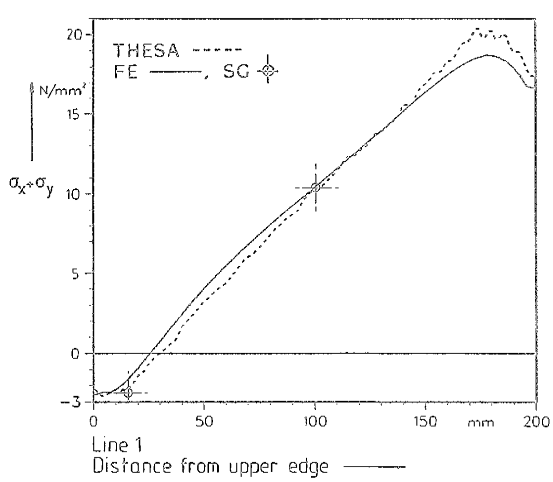
FE-model

Fig. 3: Geometry and FE-model of plate with central cut out

THESA

FE calculation

Fig. 4: Results $\sigma_1+\sigma_2$ of plate



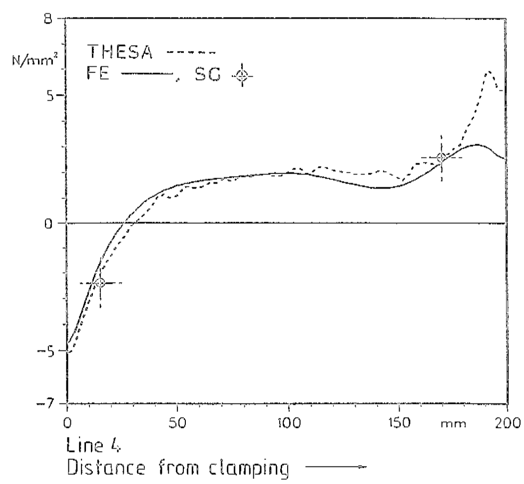


Fig. 5: Results of plate, stresses along lines 1 and 4

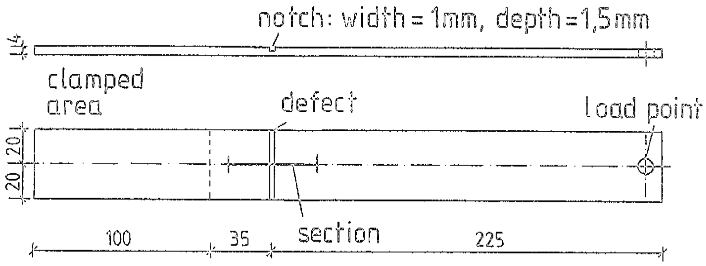


Fig. 6: Specimen with notch

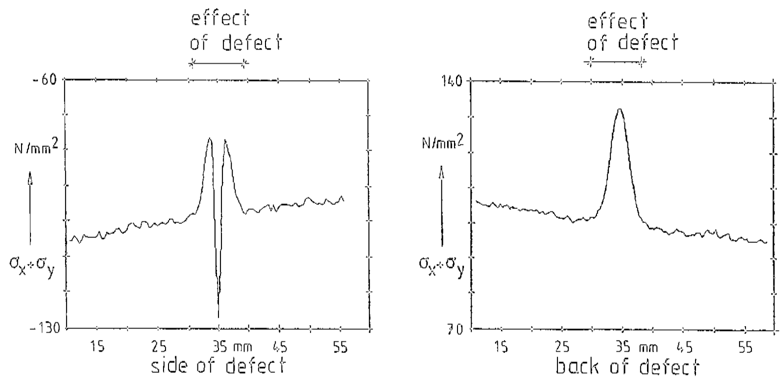


Fig. 7: Measured stresses along section

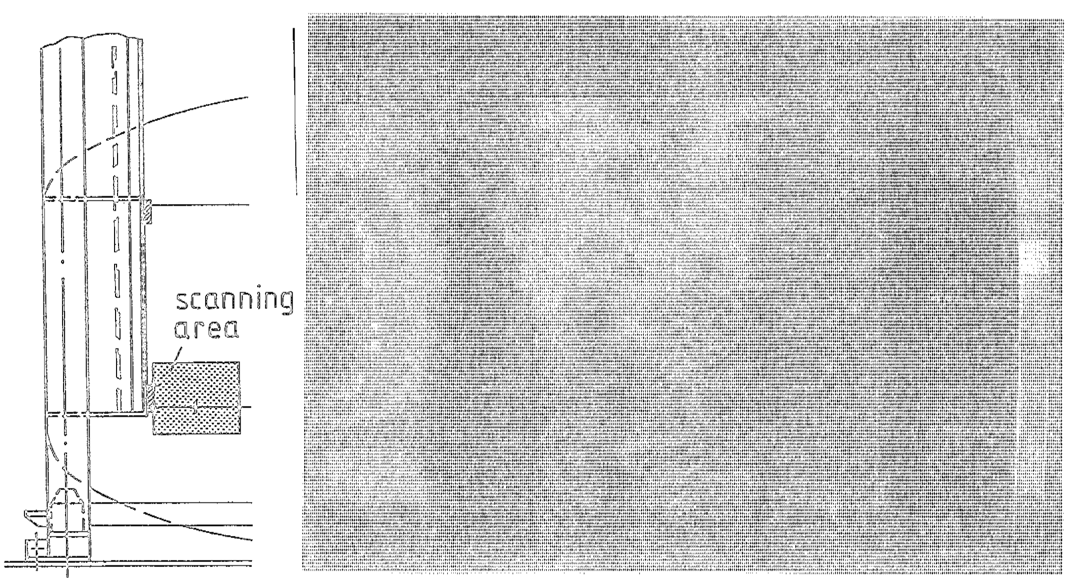


Fig. 8: Measurement $\sigma_1+\sigma_2$ of process unit (s. Fig. 2)