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Application of Neural Networks for Finding the Relation between Stress and Operational Parameters of NPP Temelín

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ABSTRACT

Quick and sufficiently precise determination of stresses and strains measured by I&C, TMDS a CHEMIS is very important for ON-LINE assessment of continuous damage of material under operating conditions. For this reason it is advantageous to use one of the method of artificial intelligence – neural network. This paper shows even a practical example of the application of this method and, at the same time, it discusses the advantages of results got in comparison with finite element method (FEM). The approach to selection of characteristic loading used for the preparation of training data is also shown. This paper presents the results of actual calculation and analyses merits of reached coincidence for determination of tenzor of stresses by means of FEM and neural networks (NN).

KEY WORDS: diagnostic system, damage, tenzor of stresses, neural network, fatigue, material, ON-LINE, FEM.

INTRODUCTION

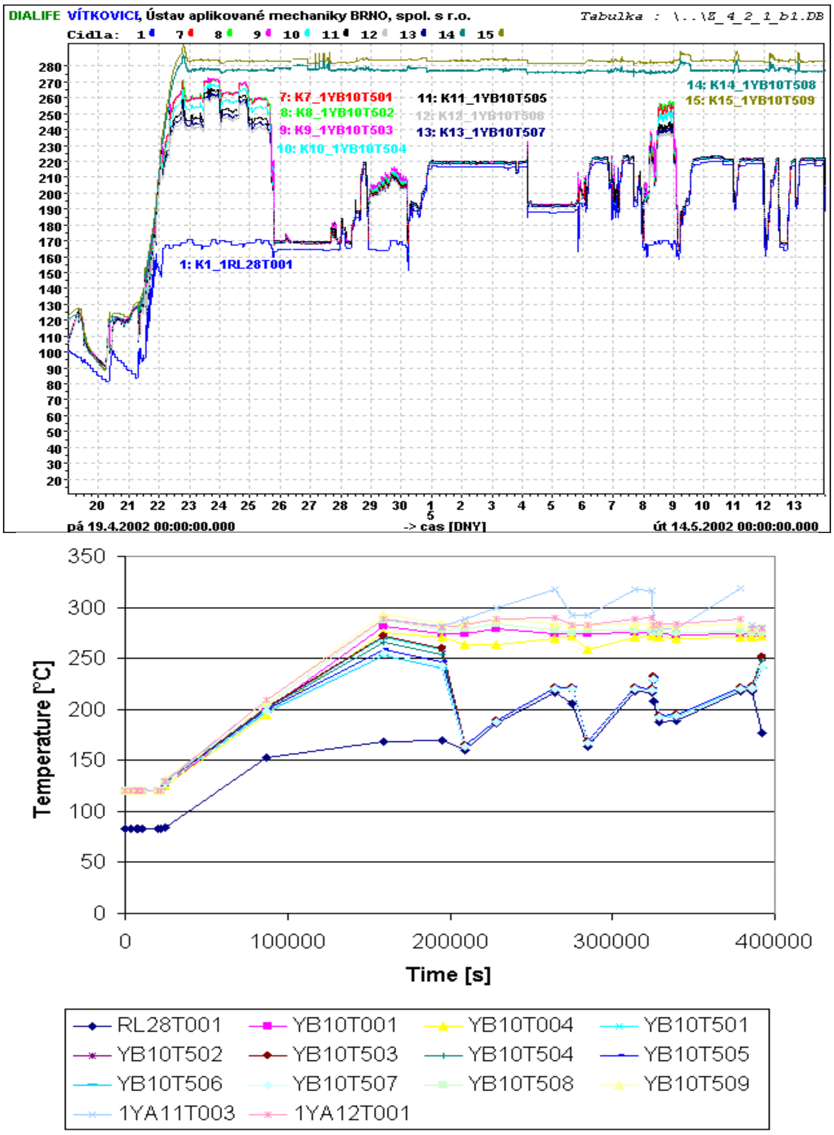
For following the development of material damage of individual components of NPP Temelín not only quick and sufficiently precise determination of stresses and strains measured by I&C, TMDS a CHEMIS is required. For this reason the method of neural network using the element of artificial intelligence has been applied. DIALIFE diagnostic system has a block structure a part of which also is a subblock of calculation of states of stress from values of operating parameters.
In principal two methods of calculation exist for the determination of state of stress from data measured.
1. Classical approach using other than real time behaviour of operating parameters measured for the calculation. This method leads to development of so-called loading blocks. In this way only an approximate model of a real time behaviour can be got. The state of stress is calculated e.g. by FEM method, however, the accuracy of the successive assessment is directly proportional to the similarity of model and real time behaviour of parameters.
2. An approach taking during the calculation of state of stress into consideration real time behaviour of operating parameters. To ensure the coincidence of calculation for the determination of the state of stress and parameters measured the calculation has to keep the same time period with which the chain of measurement reads the individual states of loading. Application of FEM for the calculation of state of stress at any time instant makes problems and not always coincides with the possibilities of computer art available. Empirical methods, that could be applied, are, no doubt, quick but they may lack an acceptable accuracy. In such case the application of neural networks seems to be effective. Their main advantage lies in speed of calculation with keeping the accuracy that can be compared with FEM. This property is utilised fully with their application for ON-LINE and/or OFF-LINE assessment in DIALIFE diagnostic system.

NEURAL NETWORK

Neural network (NN) itself has a mathematical structure that allows a certain „memory“ form created by internal parameters. NN structure can be imagined as an oriented graph of mutually interconnected layers – neurons. During „training“ the network internal parameters are tuned by using the known pairs – input-output – so to minimize an error between the network output and a required output (output defined in a training set). Thus a base of knowledge during the teaching process on which basis NN gains its ability to generalize its knowledge even for data it has never met before. NN can be said to be able to interpolate up to a certain level even to extrapolate the dependence of functions between input and output parameters without knowing the dependence proper. This dependence is included in training data and NN identifies it during the teaching process. The accuracy with which NN will react is already defined before starting the training when setting up the structure and during selection of patterns for the training set.

SELECTION OF TRAINING DATA

In our case I/O relation is described by pairs: measured operating parameters (states of loading) – state of stress at the investigated place of the structure. In the diagnostics of power equipment usually media pressures and temperatures even surface temperatures of material and other are input parameters.
A damage of a selected investigated place is always concentrated to places of stress. At selected places a stress analysis for whole time sequence of states of loading has to be performed. With respect to long time periods and time demands data from real states of loading have to be selected. Simplified loading models originate on the base of operational measurements done and they describe a certain characteristic behaviour of a parameter measured in operation (stratification of temperatures along the periphery, thermal shocks, etc.). Flowing medium temperature is a decisive parameter for a thermal field calculation. Temperatures on surfaces of thermocouples are used for verification of calculation. Fig. 1 shows an example of a real model and model derived from it for stress analysis. In spite of this model simplification the training data preparation is a very time consuming case.



YB10T501 through 507 [°C] … thermocouples measuring temperature of periphery at FW SG nozzle region
YB10T508 through 509 [°C]… thermocouples measuring temperature at FW SG nozzle close to SG wall
1RL28T001 [m^3/h] ………temperature of SG feed water
Fig.1 Example of time change of real operating data and those selected for the calculation

State of stress due to thermal fields does not depend only on instantaneous temperature distribution at a given moment but on history of changes in temperatures. Therefore the input vector has to contain not only an actual record of temperature but also temperatures of previous time periods, in so-called “time window”. Neural network model working with such formulated layers is marked as TDNN (Time Delay Neural Network) in literature. For the training proper, the set size is limited both from time and also functional reasons. Thus it is necessary to select a representative characterising a whole measurement set for training. A clustered analysis could be applied for the selection.

CALCULATION OF STATE OF STRESS IN THE MOST STRESSED PLACE OF FEED WATER NOZZLE OF STEAM GENERATOR

The above mentioned way of the determination of time behaviour of state of stress and successive determination of a damage level is implemented in DIALIFE diagnostic system having been developed in our Institute. In practice the neural networks are used at investigated place of equipment of nuclear power engineering and in chemical industry.
As an example of NN application for the state of stress calculation we have used the feed water nozzle of a steam generator of Temelín NPP. Fig. 2 shows the diagram of layout of thermocouples along the nozzle surface with the indication of the most stressed regions on the nozzle model.

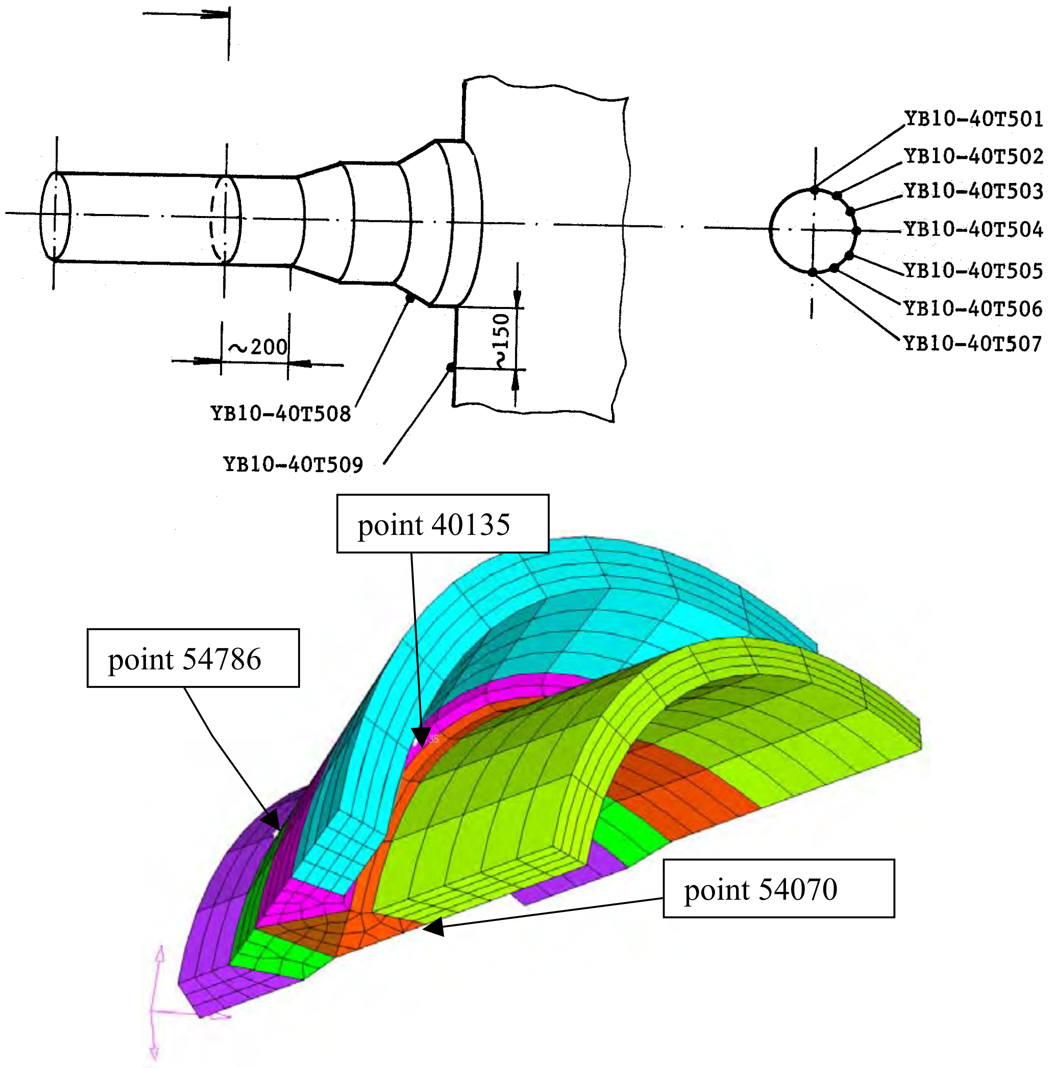


Fig.2 Diagram of Layout of Thermocouples and the Most Stressed Places of Feed Water Nozzle

The calculation of thermal fields and successive state of stress uses temperatures of thermocouples located along the piping surface, temperature, pressure and amount of flowing media. Training data were calculated on the base of a loading model by FEM system of SYSTUS program file. About 5500 training patterns – I/O – were set up from the calculated data. During the training the patterns were presented at random. After finishing the training, NN was tested in such way that a pattern set being not used in training was presented to NN. The coincidence of NN outputs with output patterns found by FEM was compared by the calculation of mean error for individual components of tenzor of stress (Table 1).

Graphs in Fig. 3 show an example of the comparison of input and output values from six components of tenzor of stress found out by adapted neural network and stress values found out by FEM. In this case the neural network was trained with 4 layers and 91 neurons. This figure shows a good coincidence of stress found out by FEM and NN.

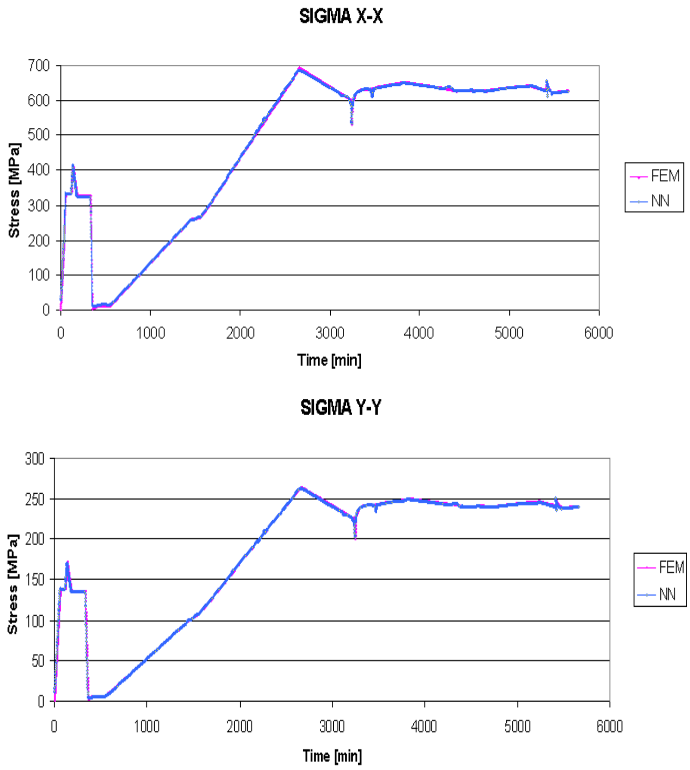


Fig.3 Comparison of Stress Components of FEM and NN

Table 1. Comparison of Got Accuracy of Calculation

Point 54786	σ_x [MPa]	σ_y [MPa]	σ_z [MPa]	τ_{xy} [MPa]	τ_{yz} [MPa]	τ_{xz} [MPa]
max. $\Delta\sigma$(MKP-NS)	30	21	15	24	11	7
abs. error [MPa]	1,56	0,43	0,56	0,46	0,30	0,06
relat. error [%]	2,2	0,84	2,1	0,7	1,1	1,2

σ - stress [MPa]
abs. error – absolute error [MPa], relat. error – relative error [%]

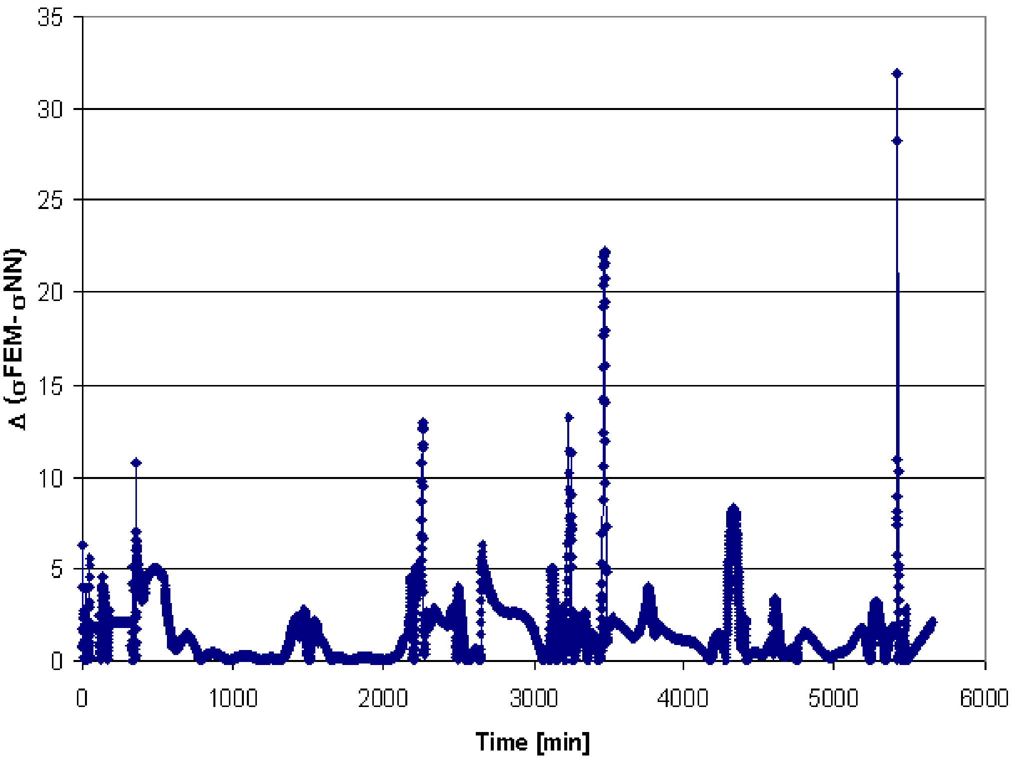


Fig.4 Time Behaviour of Difference between Stress Found out by FEM and that found out by NN for point 54786

CONCLUSION

The above example and also others show that the application of neural networks can surely interpolate even a function hidden in training data with the accuracy comparable with FEM but incomparably quicker. As opposed to FEM the neural network does not calculate the state of stress over the whole body volume but only in the most stressed points. Influences of shape, material and clamping are included in training data having been got from FEM calculation.

Stress and strain analysis done for adaptation to NN is no doubt time demanding but it affords a tool being able to calculate the state of stress in a real time over unlimited time interval simultaneously even for several places. For this reason this approach suits for ON-LINE or OFF-LINE assessment of components and is implemented in DIALIFE diagnostic system.

REFERENCES

1. Kosko, B., Neural Networks And Fuzzy Systems, Prentice Hall Inc. Englewood Cliffs, 1992.
2. Swingler, K., Applying Neural Networks, A Practical Guide, Academic Press, London, 1996.
3. Vincour, D., Pochmann, K., Application Of Dialife Systém On Dukovany Nuclear Power Plant, 5. International Colloquium CAPE'99, Wilderness / South Africa, April 1999.