POLİTEKNİK DERGİSİ

JOURNAL of POLYTECHNIC

ISSN: 1302-0900 (PRINT), ISSN: 2147-9429 (ONLINE)
URL: http://dergipark.org.tr/politeknik

Determination of stress concentration factor (Kt) for a crankshaft under bending loading: An artificial neural networks approach

Eğilme kuvveti altındaki bir krank mili için gerilme yığılma faktörünün (Kt) belirlenmesi: bir yapay sinir ağı yaklaşımı

Yazar(lar) (Author(s)): *Ihsan TOKTAS[1], Murat Tolga OZKAN[2], Fulya ERDEMIR [3],Nurullah YUKSEL [4]*

ORCID[1]: 0000-0002-4371-1836

ORCID[2]: 0000-0001-7260-5082

ORCID[3]: 0000-0002-1383-6857

ORCID[4]: 0000-0003-4593-6892

Bu makaleye şu şekilde atıfta bulunabilirsiniz(To cite to this article): Toktas I., Ozkan M. T., Erdemir F. and Yuksel N., "Determination of stress concentration factor (Kt) for a crankshaft under bending loading: an artificial neural networks approach", ***Politeknik Dergisi***, 23(3): 813-819, (2020).

Erişim linki (To link to this article): http://dergipark.org.tr/politeknik/archive

DOI: 10.2339/politeknik.683270

Determination of Stress Concentration Factor (Kt) for a Crankshaft Under Bending Loading: An Artificial Neural Networks Approach

Highlights

- *Stress concentration factor (Kt)*
- *Cranck shaft*
- *Artificial neural networks (ANN)*
- *Bending Loading*

Graphical Abstract

In this study contains stress concentration factor (Kt) for crankshafts under bending loading. Experimental results collected and an ANN model was developed.

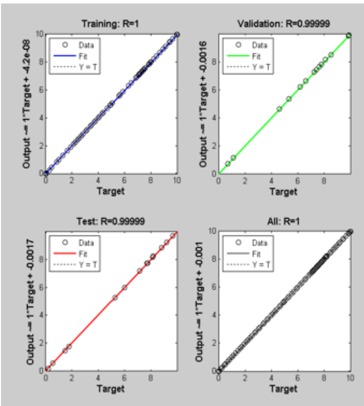


Figure. 3

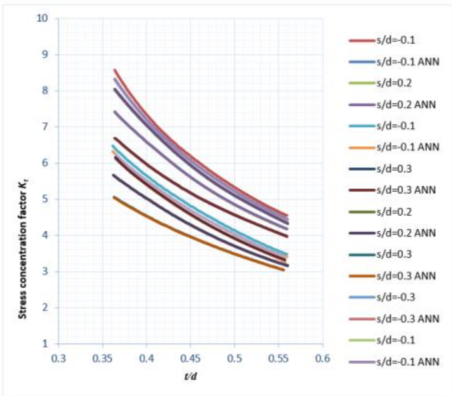


Figure . 5

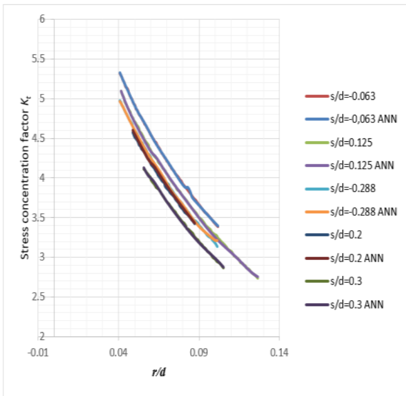


Figure. 6

Aim

This study is the determination of stress concentration factor (Kt) with artificial intelligence technique for crancshaft.

Design & Methodology

Experimental results were digitized and an ANN model was developed for the related problem.

Originality

In the study, a new method has been presented for the precise and direct determination of the stress concentration factor (Kt), which has been obtained by experimental studies before, without any digitization, determined by the graphic reading technique.

Findings

It is provided to determine the stress stress factor (Kt) easily for circular or square cross section springs.

Conclusion

Stress concentration factor (Kt) for crancshaft under bending loading is provided to be defined easily and quickly, without being dependent on any table or equation

Declaration of Ethical Standards

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Eğilme Kuvveti Altındaki Bir Krank Mili İçin Gerilme Yığılma Faktörünün (Kt) Belirlenmesi: Bir Yapay Sinir Ağı Yaklaşımı

Araştırma Makalesi / Research Article

Ihsan TOKTAS[1], Murat Tolga OZKAN[2], Fulya ERDEMIR[3*], Nurullah YUKSEL[3]

[1]Mühendislik ve Doğa Bilimleri Fakültesi, Makine Mühendisliği Bölümü, Yıldırım Beyazıt Üniversitesi, Ankara, Türkiye

[2]Teknoloji Fakültesi, Endüstriyel Tasarım Mühendisliği Bölümü, Gazi Üniversitesi, Ankara, Türkiye

[3*]Fen Bilimleri Enstitüsü, Gazi Üniversitesi, Ankara,Türkiye

(Geliş/Received : 01.02.2020 ; Kabul/Accepted : 09.02.2020)

ÖZ

Krank milleri özellikle motorlarda kullanılır. Krank milleri genellikle eğilme ve burulma gerilmelerinden etkilenir. Bu yükleme durumları motor ve parçalarının tasarımı için önemlidir. Krank mili tasarımı, tasarım deneyimi ve mühendislik hesaplamaları gerektirir. Mühendislik hesaplaması yapıldığında, stres konsantrasyon faktörü devreye girer. Bu faktörler genellikle stres konsantrasyon faktörü grafiklerinden elde edilir. Grafiklerdeki gerçek stres konsantrasyon faktörünün okunması, yanlış değerlerden elde edilmesiyle sonuçlanabilir. Bu çalışma eski çalışmaların bir güncelleme çalışmasıdır. Yeni bilgisayar teknikleri kullanılarak stres konsantrasyon faktörü değerleri sayısal değerlere dönüştürülmüştür. Stres konsantrasyon faktörü değerleri bir veritabanında toplanmıştır. Yapay Sinir Ağı (YSA) Modeli veritabanı kullanılarak geliştirilmiştir. YSA modeli, zaman ekonomisi ve stres konsantrasyonu değerlerini elde etmede yüksek doğruluk sağlar.

Anahtar Kelimeler: Stres Konsantrasyon Faktörü (SKF), krank-mil tasarımı, Yapay Sinir Ağları (YSA).

Determination of Stress Concentration Factor (Kt) for a Crankshaft under Bending Loading: An Artificial Neural Networks Approach

ABSTRACT

Crankshafts are used in especially engines. Crankshafts are usually effected bending and torsional stress. These loading situations are important for design of engine and its parts. Crankshaft design requires design experience and engineering calculations. When the engineering calculation is performed, stress concentration factor is put into effect. These factors are usually obtained from Stress concentration factor Charts. Reading the real stress concentration factor from charts can be resulted in getting from false values. This study is an update work of old studies. Using the new computer techniques stress concentration factor values were converted into numerical values. Stress concentration factor values were collected in a database. Artificial Neural Network (ANN) Model was improved using the database. ANN model is gave to us time economy and high accuracy of obtaining the stress concentration values.

Keywords: Stress Concentration Factor (SCF), crankshaft design, Artificial Neural Network (ANN).

1. INTRODUCTION

Crankshaft is one of the critical components of an engine. This machine element is connected with the other components of engine. Crancksshaft carries the connecting rod(s) and pistons. In generally engines have different number of cylinders and pistons for instance 1, 2, 3, 4, 6 or 8. Crancksshafts design has eccentric shape. The crankshaft is subjected to bending and torsion during operation. The crankshaft design is performed according to bending and torsional stress. The crankshaft must be capable of withstanding the intermittent variable loads acting on them. During transfer of torque to the output shaft, the force deflects the crankshaft. This deflection occurs due to bending and twisting of the crankshaft. Bending and torsional stresses can be achieved by using material with the correct physical properties and by minimizing stress concentration. The crankshaft is put in series to all the other components of the engine in the fault crankshaft analysis and the reliability of the whole system heavily depends on the reliability of the crankshaft. The crankshaft is a geometrically relatively complex component which is often obtained by machining a forged piece of steel or cast iron. Mechanical, thermo-mechanical or thermo-chemical surface treatments, such as shot peening, rolling, nitriding or case-hardening allow to increase the surface hardness and induce beneficial compressive residual stresses at the surface that prevent crack nucleation and propagation [1]. Arai and Peterson were researched to maximum stress in the fillet of pin and journal of

**Sorumlu Yazar (Corresponding Author)*
e-posta : erdemirfulya@gmail.com

crackshafts in bending state and studied about the parameters of crankshaft design in guided by earlier works [2-4]. Staul and Pfender et al. made use of extensometers to determine stresses in crankshafts [5, 6]. Fessler & Sood utilized the technique of photo-elasticity [7].The crankshaft is a critical component and any damage occurring to the crankshaft may put the mechanical system out of order. The numerical finite element simulation of crankshafts with multiple rods is often time consuming even quite accurate if the aim is to evaluate the stress -strain behavior at the notched area and verify the component. The development of a simplified numerical model would prove effective to reduce the time needed to reach a good approximation design of the crankshaft [8]. The design of a new crankshaft, or the upgrade of a crankshaft to higher power engines, is always a big challenge for the designer [9]. Recent years, some studies interested in crankshafts bending fatigue tests [10].In this study contains stress concentration factors (K_t) for a crankshaft in bending loading state. This study is an updating study. Graphs by obtained Peterson and Arai was converted into numerical values. The charts data converted numerical data. An ANN model was developed in new format. With using the method, interval values can be obtained without perform any interpolation etc. with high reliability.

2. MATERIAL AND METHOD

Stability conditions of machine elements against stress in terms of stress concentration were examined in general. To what extent the machine parts can be challenged depends on the strength of the product, the design of the product and the material properties. Machine parts can be found under different difficulties according to work environments. The irregular form on the machine elements such as; the channels, grooves, radius etc is varied the magnitude of the stress.FEM, photoelastic, experimental, numerical, statistical, artificial intelligence techniques, etc. were used to investigate the stress conditions of the machine element in more detail. Previously, obtained from experimental and validated data tables are already available and are used in the design. The main problem is that there are no mathematical formulas of these tables. The user only obtains these values by reading the relevant table. Value reading from table is a very tedious and error-prone process. The values obtained vary from user to user. So, a new techniques is need to read each parametric value. New computer based techniques have been begun the invetigate of the stress concentration in deeply. In the last century, computer graphical specification have been developed very impressive scale. Thus, graphical material can be converted into very sensitive numerical values. Converted numerical values were classified in an excell file according to their origin. A new ANN model was created in the sensitivity that the classical regression model can not reach. It is necessary to increase the degree of equation to improve the sensitivity of the formula in the classical regression.

When degree of equation increases, calculation becomes quite complex to obtain a result by using these equations. Usage of the ANN method, the user don't need to use any formulae and calculator. Dertermination for the Kt, A software has been created in the Matlab editor. Arai was researched about fillets of the pin and journal of a series of crankshafts in bending [2]. Design parameters were determination to optimum with using experimental techniques.

The stress concentration factor is defined (eq. 1-7) as $\sigma_{max}/\sigma_{nom}$,

where

$$\sigma_{nom} = M(d/2)/I = M/(\frac{\pi d^3}{32}) \quad (1)$$

The most important design variables are web thickness ratio t/d, fillet radius r/d, web width ratio b/d and the crank "throw" as expressed by s/d (Figure 1). These parameters are effected the stress concentration factor.

An empirical formula was developed by Arai to cover the entire range of tests [11]. By using Eq. (2-7), stress concentration factor for crankshaft in bending loading was calculated. Abrraviations hasve been defined below:

$$K_t = 4.85 \times C_1 \times C_2 \times C_3 \times C_4 \times C_5 \quad (2)$$

Where

$$C_1 = 0.420 + 0.160\sqrt{[1/(r/d) - 6.864]} \quad (3)$$

$$C_2 = 1 + 81\{0.769 - \left[0.407 - \left(\frac{s}{d}\right)\right]^2\}(\delta/r)(r/d)^2 \quad (4)$$

$$C_3 = 0.285[2.2 - (b/d)]^2 + 0.785 \quad (5)$$

$$C_4 = 0.444/(t/d)^{1.4} \quad (6)$$

$$C_5 = 1 - [(s/d) + 0.1]^2/[4(t/d) - 0.7] \quad (7)$$

M = bending moment (Nmm)
I= Moment of ineteria(mm^4)
s= eccentricity lenght (mm)
b= crank shaft witdh dimension (mm)
d = smaller diameter of circular bar; smaller width of thin flat element (mm)
t=thickness of the crank (mm)
D = larger diameter of circular bar (mm)
r= fillet radius (mm)
δ=fillet lenght (mm)
σ_{nom}= nominal stress (N/mm^2)
σ_{max}= maximum stress (N/mm^2)
K_t= Stress concentration factor
C_1,C_2,C_3,C_4,C_5= solution equation coefficient

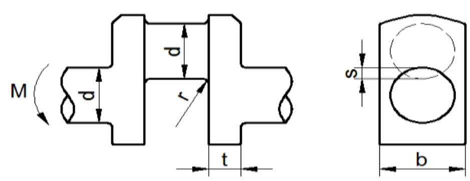


Fig. 1. Model of a crankshaft in bending loading

Table 1. Stress concentration factors K_t variable parameters for a crankshaft in bending loading

t/d	s/d	b/d	r/d	K_t
0.36	-0.1	1.33	0.0625	3
0.56	-0.3-0.1		0.1	8.5
	0.2			
	0.3			

2.1. Artificial Neural Network (ANN) Model

ANN is a subfield of Artificial Intelligence. ANN has a mathematical operational context in its back ground. ANN works with different learning algorithms. A neuron is the basic element of ANN. Neurons duties, shapes and size can be varried. Neurons activities is important. An ANN may be seen as a black box which contains hierarchical sets of neurons (e.g. processing elements) producing outputs for certain inputs. Each processing element consists of data collection, processing the data and sending the results to the relevant consequent element. The whole process may be viewed in terms of the inputs, weights, the summation function, the activation function and outputs (Figure 2) . A neural network usually consists of input layer, hidden layer(s), and output layer [12-17]. In this study contains determination of stress concentration factors (K_t) for a crankshaft in bending loading. For this aim; Peterson's stress concentration factor charts were investigated. These charts are drawn as a result of the experimental study and are not identified by a mathematical function. These charts are still used today to define the stress concentration. It is necessary to read the data in these curves when defining the stress concentration for a particular problem. Value reading from table is a very tedious and error-prone process. The values obtained vary from user to user. A numerical data bank was created for these curves. An ANN database was created using obtained from graphs data and a new ANN model was developed. The data were obtained according to study parameters (*t/d, s/d, b/d, r/d*.and K_t (Table 1)) that has 3654 lines x 4 columns. Among them, 30% data have been randomly selected and used as the test data and other 70 % data were used training are determination of the K_t for a crankshaft in bending loading.

LM (Levenberg-Marquardt) algorithm and MLP (Multi Layer Perception) were used in the developed ANN model. The parameters, that were t/d, s/d, b/d, r/d, were used as input-layer and Kt were used as output-layer of the ANNs. In the ANN model, tansig, logsig and purelin transfer functions (f) have been used and expressed as follows (Eqs 8-11):

$$NET_i = \sum w_{ij}.x_j + w_{bi} \quad (8)$$

$$a = \text{tansig}\ (n) = \frac{2}{(1+e^{-2n})} - 1 \quad (9)$$

$$a = \text{logsig}\ (n) = \frac{1}{(1+e^{-n})} \quad (10)$$

$$a = \text{purelin}\ (n) \quad (11)$$

n: Number of processing elements in the previous layer.where NET is the weighted sum of the input.

An ANN model was developed using Matlab NN tool. For this aim a new ANN code has been prepared and developed.

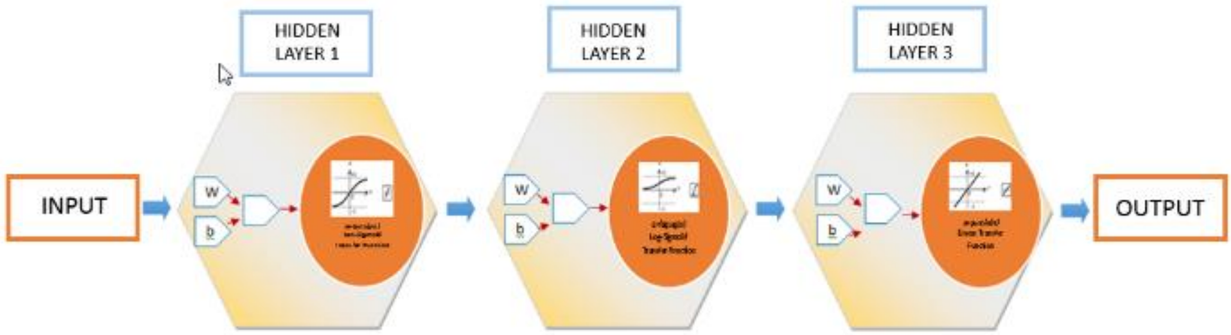
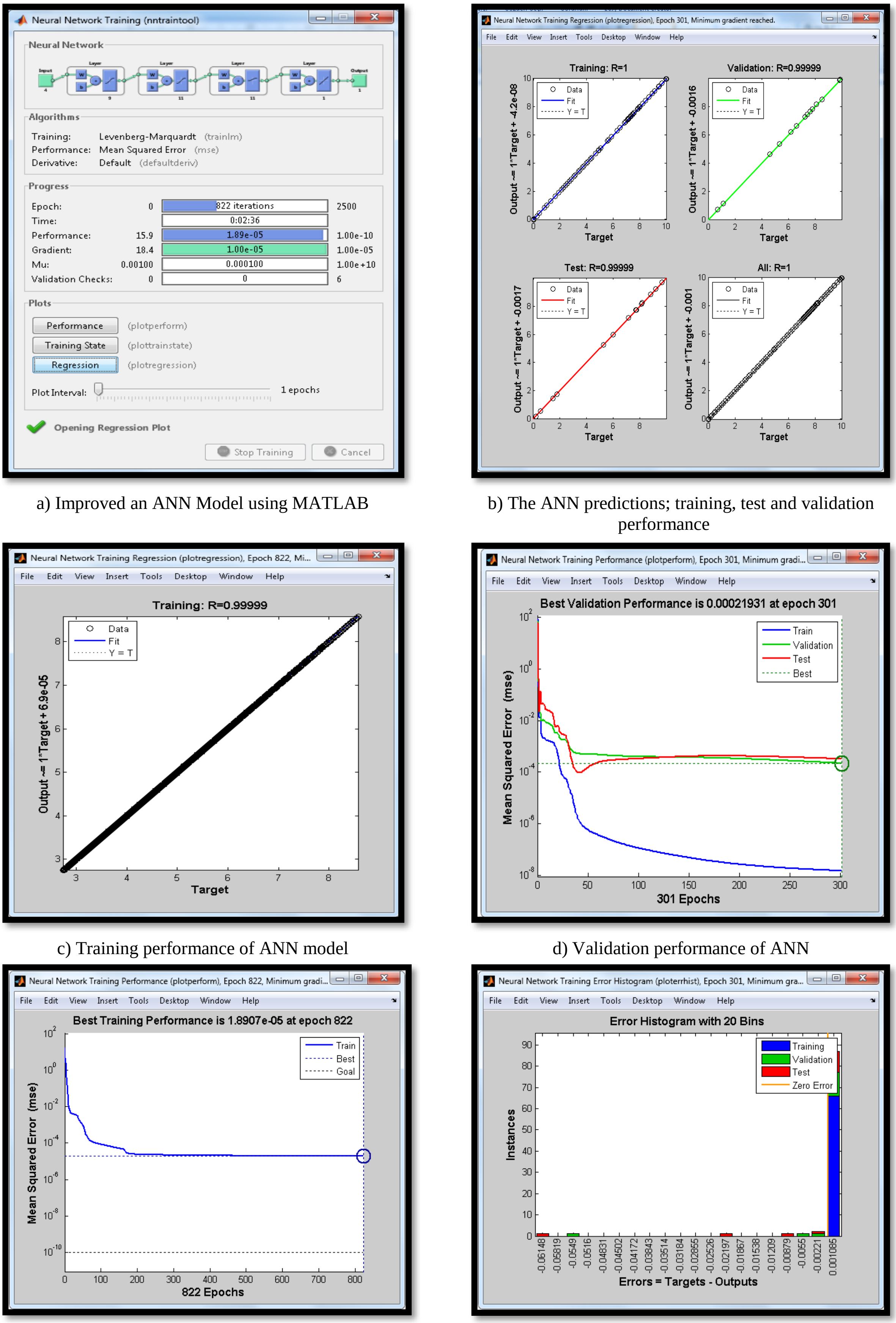


Fig. 2. Basic artificial neural network model



a) Improved an ANN Model using MATLAB

b) The ANN predictions; training, test and validation performance

c) Training performance of ANN model

d) Validation performance of ANN

e) Training performance of ANN

f) Error Histogram of ANN

Fig. 3. Developing ANN model

Figure 3a shows Improved an ANN Model using MATLAB. Figure 3b shows The ANN predictions; training, test and validation performance. Figure 3c shows training performance of ANN model and Figure 3d shows Validation performance of ANN. Figure 3e shows Training performance of ANN and Figure 3f shows Error Histogram of ANN and These figures have been getting from prepared Matlab code. Training ANN model results were compared with the statistically (Table 2).

Table 2. Statistical Performance of training ANN model

Absolute Fraction of Variance (R^2)	Root Mean Square Error (RMSE)	Mean Error Percentage (MEP %)
0.999869	0.139119	0.610405

The back propagation learning algorithm has been used with Scaled Conjugate Gradient (SCG) learning algorithm and Levenberg-Marquardt (LM) learning algorithm versions at the training and testing stages of the Networks. The number of hidden layers and the number of neurons for each hidden layer were determined. Then, the number of iterations were entered by the user, and the training starts. The training continues either to the end of the iterations or reaching the target level of errors.

3. TESTING THE ACCURACY OF ANN MODELLING

In order to understand an ANN modelling is making good predictions, the test data which has never been presented to the network is used and the results are checked at this stage. The statistical methods of R2, RMSE and MEP values have been used for making comparisons [11-16]. The same data obtained from the regression analysis is used to determine the mentioned values.

These values are determined by the following Eqs (12-14):

$$RMSE = \left((1/p) \sum_j \left| t_j - o_j \right|^2 \right)^{1/2} \quad (12)$$

$$R^2 = 1 - \left(\frac{\sum_j (t_j - o_j)^2}{\sum_j (o_j)^2} \right) \quad (13)$$

$$MEP = \frac{\sum_j \left(\frac{t_j - o_j}{t_j} \times 100 \right)}{p} \quad (14)$$

Using the trial error method, the structure of the network (i.e. the number of neurons and hidden layers) is altered and the training operation is repeated. To be able to get accurate results we have used three hidden layers. Number of neuron in the hidden layer were changed (e.g. from 5 to 150) to determine the best network architecture.

4. RESULTS AND DISCUSSION

In this study, we have composed the chart data and network predicted output results t/d, s/d, b/d, r/d and Kt for the stress concentration factor parameters for statistical error analysing methods. As presented in Table 2, the statistical error levels for both training and testing data sets are evaluated. As the table illustrates the network with three hidden layers of [3+9+11+11+1] neurons at each layer has provided the best results (Figure 4). ANN model has been illustrated Figure 4. In this model, it is consist of 4 input layer(s) and with processing element at 3 hidden layer(s) and finally 1 output layer. In terms of the statistical error analysis methods, using Levenberg-Marquardt (LM) learning algorithm technique for Output.

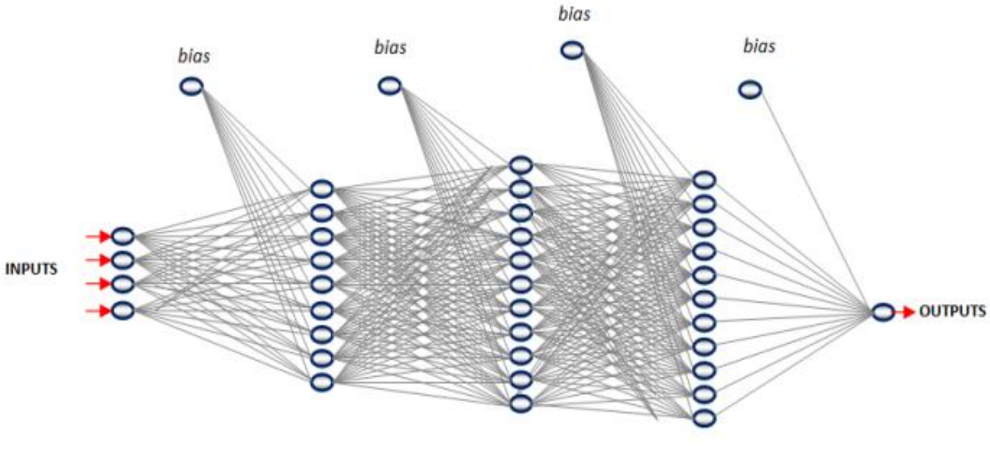


Fig. 4. ANN architecture with [3+9+11+11+1] processing elements at four hidden layers

Figure 5 shows K_t values was determined according to t/d, s/d. Figure 5 shows comparison of emprical values (chart values) and ANN model values. Figure 6 shows K_t values was determined according to s/d, r/d. Figure 6 shows comparison of emprical values (chart values) and ANN model values. Both ANN models results and emprical values were compatibled with graphical data.

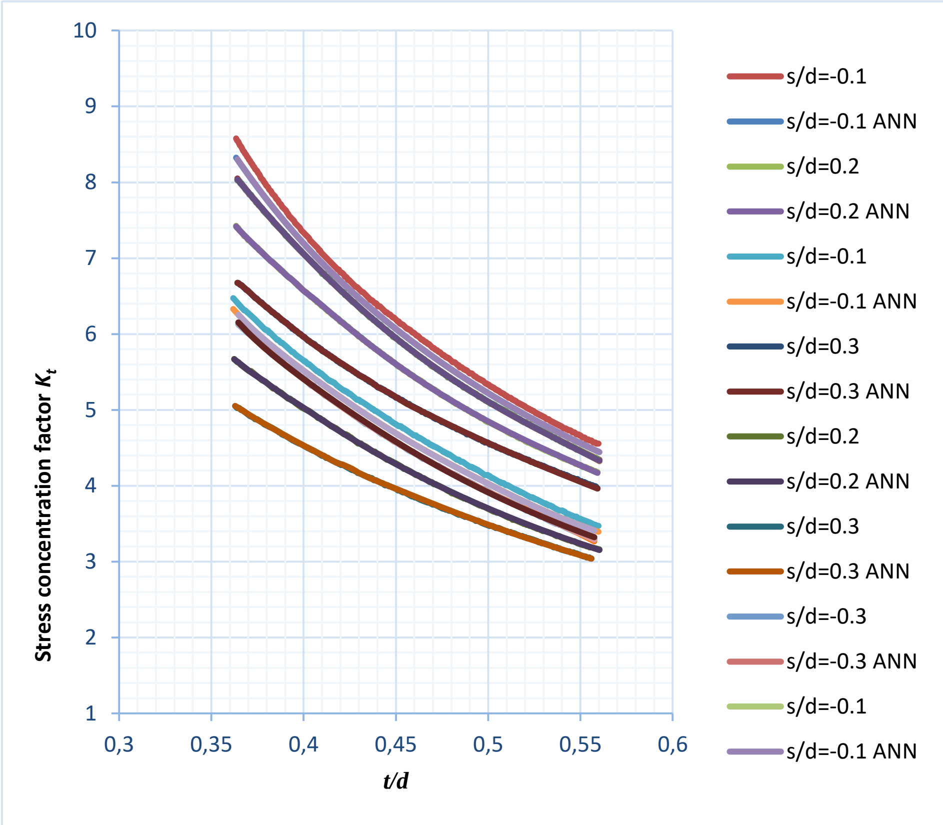


Fig. 5. Stress concentration factors Kt for a crankshaft in bending loading

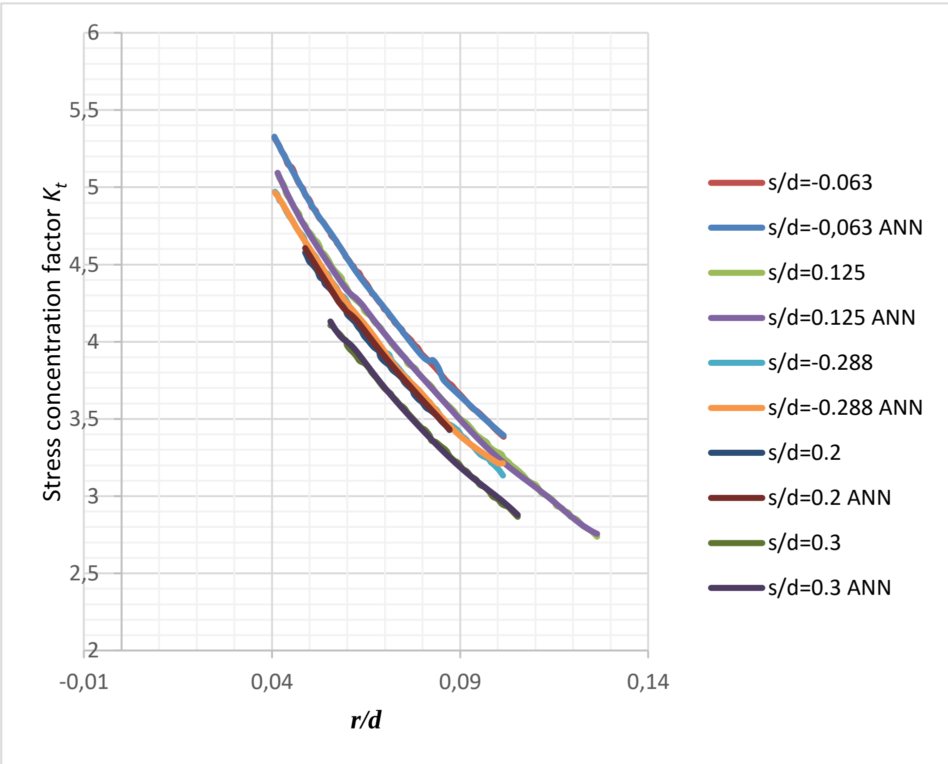


Fig. 6. Stress concentration factors Kt for a crankshaft in bending loading

5. CONCLUSION

In this study contains stress concentration factor determination using Peterson's Stress Concentration Factor charts and ANN modelling. Peterson's graphs have been accepted as scientifically valid, but a mathematical equation has not yet been transformed. Peterson's charts were drawn as a result of the experimental study and were not identified by a mathematical function. The values in these graphs can be defined only with the result of experimental studies. It is easier and more practical to determine these values using auxiliary software instead of using formulas. These charts are still used today to define the stress concentration factor. It is necessary to read the data in these curves when defining the stress concentration for a particular problem. These curves have been converted into numerical values with the help of highly sensitive computer software. An ANN database was created using these data. A new ANN model was developed using Matlab software. Different ANN models were tried and the best model was determined To determine the stress concentration factor according to diffrent bending loading states in design of crankshaft was explored. The ANN model was provided high accuracy for prediction of stress concentration factor (K_t). This model has R2=0.999869, MEP%=0.610405 and RMS=0.139119. User can be read fault value that getting from chart. Using the ANN model these faults were eliminated. Easy and economical method was improved using An ANN model. This model was effective and usefull method. This method can be used with more reliability.

DECLARATION OF ETHICAL STANDARDS

The authors of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

REFERENCES

[1] Chien W.Y.; Pan J.; Close D. and Ho S. "Fatigue analysis of crankshaft sections under bending with consideration of residual stresses", ***Int. J. Fatigue***, 27: 1-19, (2005).

[2] Arai J," The bending stress concentration factor of solid crankshaft", ***Bulletin of JSME,*** 8: 322, (1965).

[3] Peterson R. E, "Fatigue of shafts having keyways", ***Proc. ASTM.*** 32(2): 413, (1932).

[4] Peterson R. E, "Methods of correlating data from fatigue tests of stress concentration specimens", ***Stephen Timoshenko Anniversary Volume, Macmillan, New York.*** pp**.**179, (1938).

[5] Staul G, "Der Einfluβ der form auf di Spannungen in Kurbelwellen", ***Konstruction***, 10: 2, (1958).

[6] Pfender M, Amedick E. and Sonntag, "Einfluβ der Formgebung auf die soannungsverteilung in kurbelkropfungen", ***M.T.Z.***, 27: 225, (1966).

[7] Fessler H. and Sood, V. K, "Stress distribution in some diesel engine crankshaft, Trans", ***ASME Diesel and engine Power Division conference, Toronto, Paper,*** 71: 1, (1971).

[8] Baragetti S, "Design Criteria for High Power Engines Crankshafts the Open", ***Mechanical Engineering Journal,*** 9: 271-281, (2015).

[9] Bargis E. Garro A. And Vullo V, "Crankshaft design and evaluation -Part 1 -Critical analysis and experimental evaluation of current methods, Part 2 -A modern design method: modal analysis -Part 3 -Modern design method: direct integration", ***In: The international conference on reliability, stress analysis and failure prevention, Century 2 emerging technology conferences, San Francisco, California,*** (1980).

[10] Choi K.S. and Pan J. "Simulations of stress distributions in crankshaft sections under fillet rolling and bending fatigue tests", ***Int. J. Fatigue***, 31: 544-557, (2009).

[11] Pilkey, W. D, "Formulas for Stress, Strain, and Structural Matrices", ***2nd ed.,Wiley, New York,.*** (2005).

[12] Ozkan M. T.; Toktas I, "Determination of the stress concentration factor (K_t) in a rectangular plate with a hole under tensile stress using different methods", ***Materials Testing,*** 58(10): 839-847, (2016).

[13] Ozkan M. T, "Surface roughness during the turning process of a 50CrV4 (SAE6150) steel and ANN based modeling", ***Materials Testing***, 57(10): 889-896, (2015).

[14] Ozkan M. T.; Ulas H. B.; Bilgin M, "Experimental Design and Artificial Neural Network Model For Turning 50crv4 (Sae 6150) Alloy Using Coated Carbide/Cermet Cuting Tools", ***Materiali In Tehnologije / Materials and Technology,*** 48(2): 227-236, (2014).

[15] Ozkan M.T., Erdemir F., "Determination of stress concentration factors for shafts under tension", ***Materials Testing***, 62(4): 413-421, (2020).

[16] Ozkan M. T," Experimental and artificial neural network study of heat formation values of drilling&boring operations on Al 7075 T6 workpiece", ***Indian Journal of Engineering & Materials Science,*** 20(4): 259-268, (2014).

[17] Ozkan M. T, "Notch sensitivity factor calculationin the design of shafts using artificial neural network system", ***Education Science and Technology Part A: Energy Science and Research,*** 30(1): 621-630, (2012).