APPLICATION OF ARTIFICIAL NEURAL NETWORKS IN TRIBOLOGY – PREDICTION AND CLASSIFICATION MODELS

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Abstract

The influence of load and rotational speed on wear and moment of friction is presented in this paper. The tests were carried out under both constant and increasing load and at wide range of rotational speed. During the tests moment of friction, oil temperature and weather conditions were registered. On the basis of obtained results neural models for prediction of wear, moment of friction and friction classifiers were created. The different kinds of artificial neural networks and different training algorithms were applied in order to obtain the best generalisation and quality of created models. All researches showed that artificial neural networks are useful as prediction and classification models. Because of too small teaching data models were limited only to two inputs – load and rotational speed and one output – wear, moment of friction or state. The best models achieved very good precision – testing error lower than 5%. It was also proved, that various types of networks have different usefulness for different applications. MLP networks turned out to be the best wear models, GRNN networks gave the best results as models of moment of friction and RBF networks were proved to be the best classifiers. To obtain model which will give better characterization of processes proceeded in tribological pairs, much more experiments to increase teaching data have to be conducted.

Keywords: *tribology, boundary friction, lubricity, modelling of tribological processes, artificial neural networks*

1. Introduction

The lack of coherent and not verified theory of boundary friction results in considerable problems in modelling of tribological processes. Although respective friction models and mechanisms of particular kinds of wearing are rather well known, we are not able to predict values of definite tribological quantities. What is more, friction and wear models which are currently used are unfortunately imperfect [1]. Nonlinear nature of friction processes forces researching of non-analytical methods of modelling. Due to their unique properties, the artificial neural networks (ANNs) are considered as one of the newest and most promising computer methods of modelling of tribological processes [2]. They are the tool created on the basis of knowledge about biological neural system. Their dynamical development was possible only with simultaneous progress in computer science [3].

In the article ANNs were proved to be very useful for modelling of tribological processes. The authors obtained good quality models of wear for constant load, models of moment of friction under increasing load and friction classifiers – models which discriminate two states: “lubrication” and “seizure” for both load and rotational speed.

2. Test stand and research method

In order to obtain good quality models a lot of teaching data is required. The tests were carried out under constant and increasing load, and at wide range of rotational speed. Researches were undertaken on four-ball tester T-02 - the apparatus commonly used for estimating greases and oils lubricating abilities. Basic parameters which characterize the tribological pair are [4]:

- contact (Fig.1): concentrated, point, created by the surfaces of four balls,
- motion: sliding (constant rubbing speed which equivalents 50 to 1500 rpm of upper ball),
- load: changing from 0 to 7848N (800kG) – may increase constantly with speed 408.8N/s,
- lubrication: oil bath lubrication (about 8ml of grease or oil).

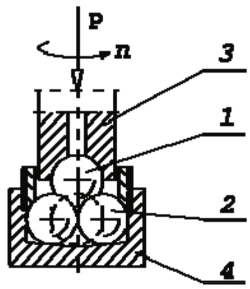

Fig. 1. Scheme of tribological pair: 1 – upper ball, 2 – lower balls, 3 – spindle, 4 – lower balls' grip

Researches on four-ball tester were undertaken with our own method, based on PN-76/C-04147 standard (with only one lubricant – Antykol TS120 oil). Parameters of method [5, 6]:

- time (t): 60s (for constant load) or determined by seizure or welding of balls,
- load (P): from 500 to 6000N (for constant load) or increasing fluently from 0 to seizure or welding,
- rotational speed (n): from 100 to 2000 r. p. m.

During researches were registered:

- motion resistance (moment of friction),
- temperature of lubricant,
- weather conditions: temperature, atmospheric pressure, air humidity.

At the end of every run diameters of wear traces was measured.

3. Research results

Selected results of researches are shown in figures below. Analysing the results it can be concluded that when load increase, diameter of wear traces also increase. What is important, this is not linear dependence.

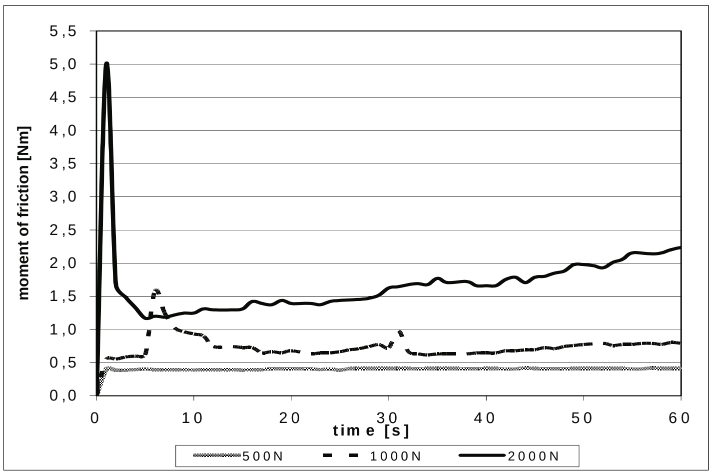

Fig. 2. Moment of friction for n = 1250 r. p. m

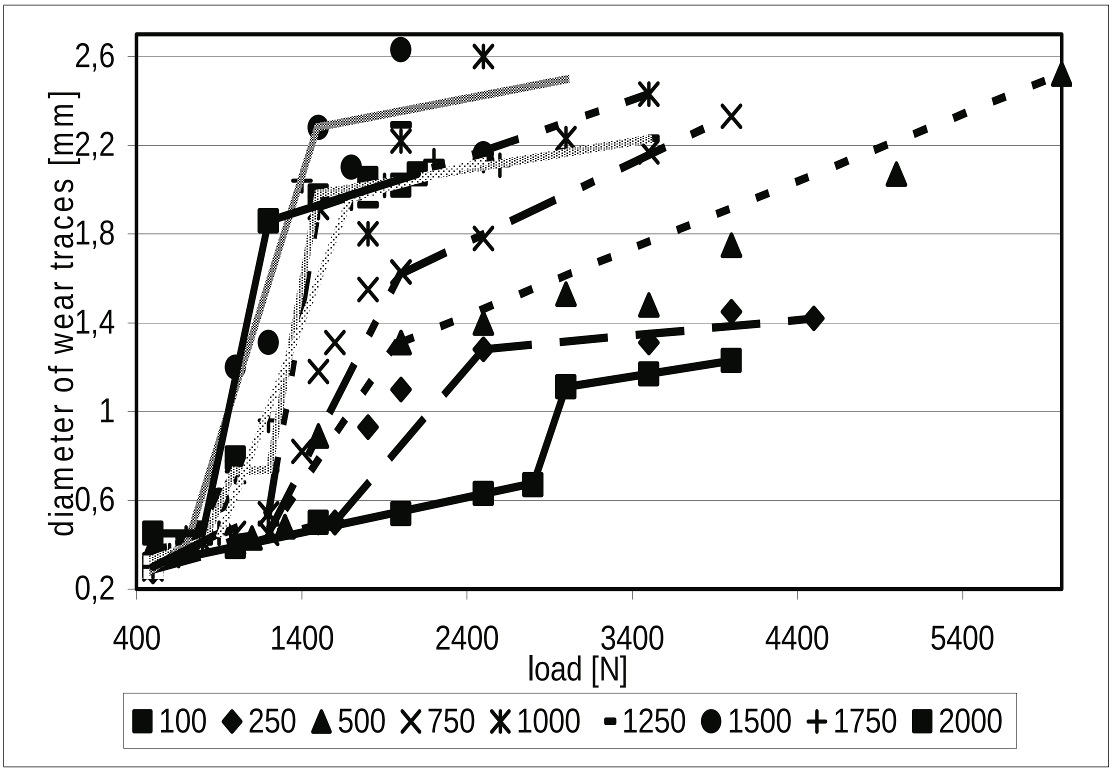

Fig. 3. Diameter of wear traces as a function of load for different rotational speeds

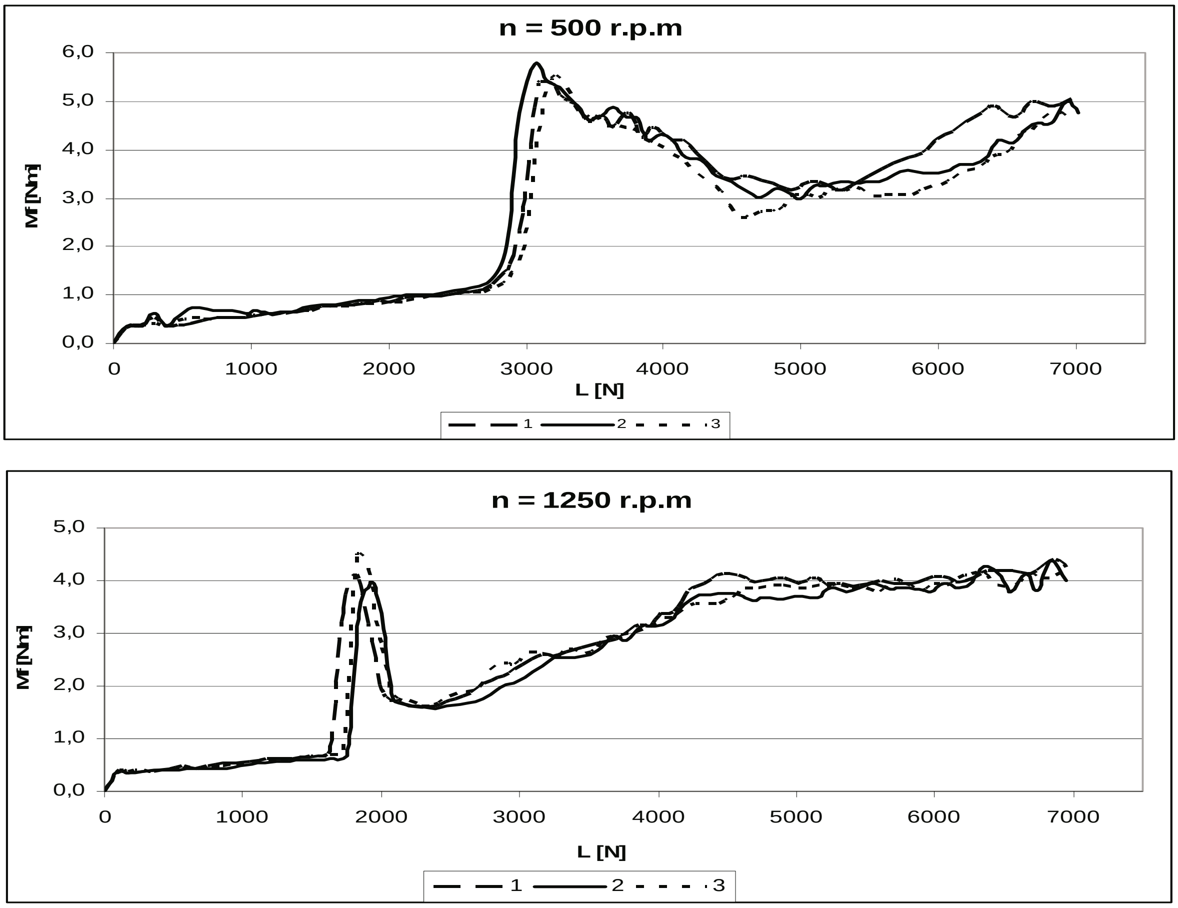

Fig. 4. Moment of friction as a function of load for selected rotational speeds (fluently increasing load)

4. Neural models

On the basis of obtained results the artificial neural networks (ANNs) were created. The ANN is an instrument developed on the ground of knowledge about structure and working of biological neural networks [3]. Their basic task is to processes and to analyze information. The ANNs were created in STATISTICA Neural Networks packet.

The ANN consists of neurons – the elements which process input signals to one output signal. To create ANN teaching process has to be conducted during which one network parameters have to be chosen. Values of these parameters depend on customary criterion of minimization errors committed by network.

Method of modelling

Data used during modelling was divided onto three groups: teaching, verifying and testing. Teaching group was built from vectors which took part in modifying network parameters, especially involved with neuron’s connection. After every period teaching errors were calculated. When teaching period ended, network was verified by second group of data – verifying group. After this period verifying errors were calculated. Then, every model was tested by third group of data – testing group – to check model's adequacy to specific object. What is important, data used for testing each model did not take part in teaching process – network simply did not “see” them before. Data used during modelling consisted of 219 occurrences.

Created neural models contained two inputs: load and rotational speed and one output signal – diameter of wear traces, moment of friction or state: “lubrication” or “seizure” dependable on the type of created model. “Lubrication” was defined a state in which boundary layer was not destroyed (low values of moment of friction, insignificant wear); “seizure” was a state in which boundary layer was destroyed (fast growth and high values of moment of friction, significant wear).

As a criterion of definite state selection, growth of moment of friction was chosen. When value of moment of friction grew up over 25% during one second, it meant that state changed from “lubrication” to “seizure.

Types of networks and teaching methods

During searching the most suitable model different types of networks were tested:

- multilayer perceptrons (MLP),
- radial basis function (RBF),
- Generalized Regression Neural Network (GRNN)

To all this types of networks different teaching algorithms are attributed:

- back propagation method (BP) – MLP,
- conjugate gradient method (CG) – MLP,
- Quasi-Newton method (QN) – MLP,
- subsample method (SS) – RBF, GRNN
- means method (KM) – RBF.

Results of modelling

Many different models were analyzed, especially at an angle of their variety, teaching methods and parameters like: teaching speed, number of teaching periods, number of layers and neurons. As a result many various models, which better or worse imitated friction process, were received. The best networks are composed in Table 1 and Table 2.

Tab. 1. Summary of the best models – wear and moment of friction models

		Type	Teach. Error	Veryf. Error	Test. Error	Deviation Quotient	Correlation
Wear	1	MLP 2:2-5-2:2	0.04	0.06	0.03	0.201	0.980
	2	MLP 2:2-5-2:2	0.04	0.05	0.04	0.183	0.983
	3	RBF 2:2-7-2:2	0.17	0.17	0.17	0.185	0.961
	4	GRNN 2:2-80-2:2	0.10	0.14	0.17	0.196	0.921
Moment of Friction	5	GRNN 2:2-540-2-1:1	0.04	0.05	0.04	0.181	0.984
	6	GRNN 2:2-540-2-1:1	0.04	0.05	0.04	0.183	0.983
	7	RBF 2:2-81-1:1	0.05	0.05	0.06	0.188	0.982
	8	MLP 2:2-9-8-1:1	0.07	0.04	0.05	0.189	0.982

Tab. 2. Summary of the best classifiers

		Type	Error			Correct Classifications [%]	
			Teach.	Ver.	Test.	„Lubrication”	„Seizure”
Classifiers	1	RBF 2:2-29-1:1	0.23	0.24	0.12	96	94
	2	RBF 2:2-29-1:1	0.23	0.24	0.15	96	93
	3	MLP 2:2-7-1:1	0.41	0.09	0.22	90	90
	4	MLP 2:2-8-1:1	0.40	0.09	0.20	85	90

Analysis of the best networks shows, that quite good models were obtained. The testing errors for prediction models were lower than 5% and correlation was higher than 0.98. The best classifiers gave testing errors about 12% and higher than 90% correct classifications.

One of the most interesting results is a fact that various types of networks turned out to have different usefulness for different applications. MLP networks turned out to be the best wear models, GRNN networks gave the best results as models of moment of friction (under fluently increasing load) and RBF networks were proved to be the best classifiers among other networks. It results from different structure, properties and method of working of those types of neural networks. Structure of the best networks is depicted on below pictures.

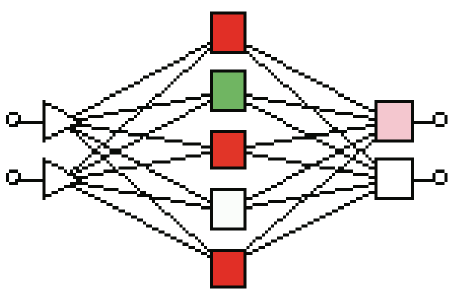

Fig. 5. Scheme of MLP network

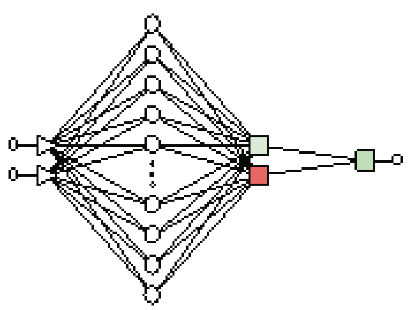

Fig.6. Scheme of GRNN network

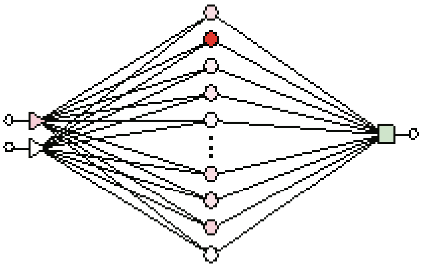

Fig.7. Scheme of RBF network

Results generated by networks were compared with data obtained experimentally. Chosen comparisons are depicted on below graphs.

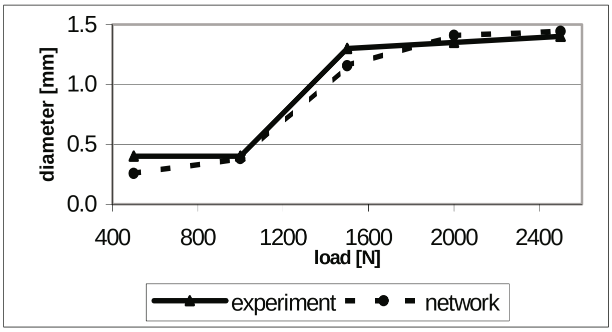

Fig. 8. Diameter of wear traces as a function of load for n = 500 rpm

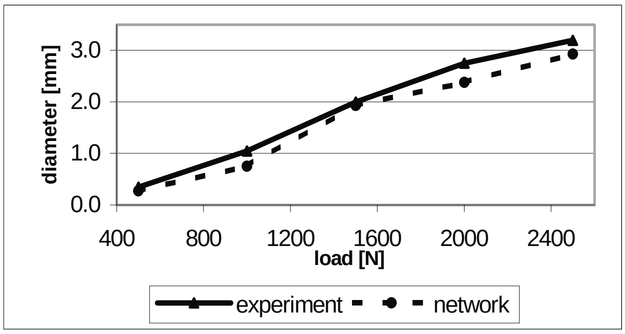

Fig. 9. Diameter of wear traces as a function of load for n = 1000 rpm

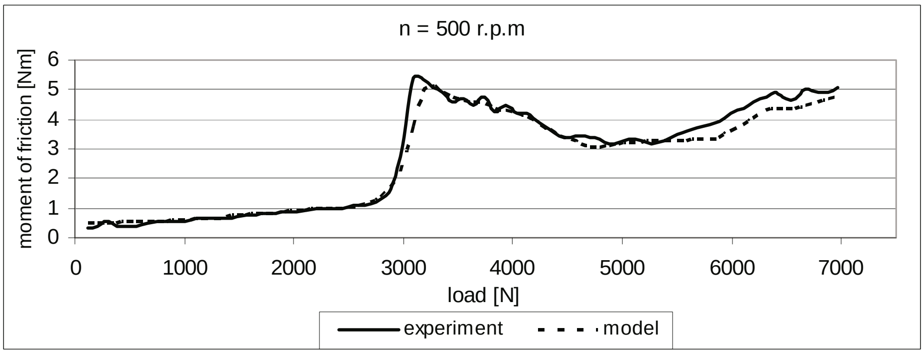

Fig. 10. Moment of friction as a function of load for 500 rpm

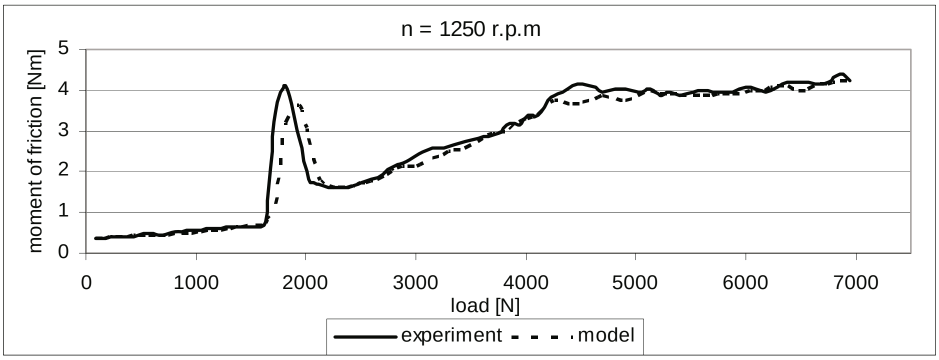

Fig. 11. Moment of friction as a function of load for 1250 rpm

The networks imitate results of experiment in a proper way – character of curves, maximum values of wear and moment of friction, points of sudden growth of diameter and moment of friction are similar.

To estimate the quality of neural classifiers Receiver Operating Characteristic curve – ROC curve was created (Fig. 12). It sums up classifier efficiency – perfect classifiers give the curve which adjoins to the left and top edge of chart, with area under the curve about 1.0. For random classifications field under the ROC curve equals about 0.5 (classifier with field less than 0.5 could be improved by classes inversion).

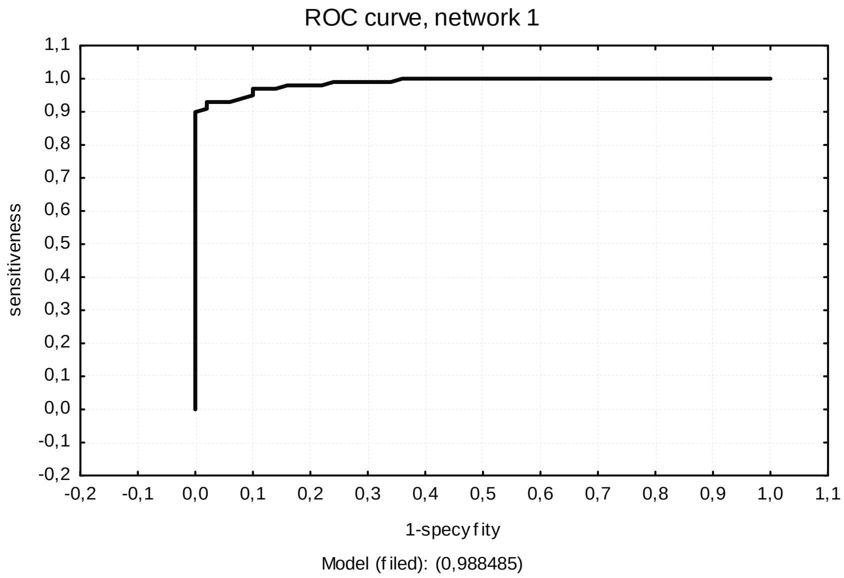

Fig. 12. Receiver Operating Characteristic curve for chosen model

Another useful ability of ANNs is analysis of input's sensitiveness – especially important and useful, when network contains many input parameters. In this analysis network computes quotient of error committed by network without particular input and error committed with this input. This analysis shows us which inputs influence final result the most.

Table 3. Analysis of inputs sensitiveness

		rotational speed	load
wear	quotient	3.20	5.02
	rank	2	1
moment of friction	quotient	5.13	4.88
	rank	1	2
classifier	quotient	2.16	3.26
	rank	2	1

If the quotient value is bigger, then the considered input is more influential in final result. When the quotient is lower than one, we receive better model when we skip this input. If the quotient is very big and we skip this input – model will be worst than before skipping [3].

5. Conclusion

All researches showed that artificial neural networks are very useful as a prediction and classification models. The best networks achieved very good precision – testing error lower than

5% and correlation was higher than 0.98 for prediction models. The best classifiers gave testing errors about 12% and higher than 90% correct classifications. It was also proved, that various types of networks have different usefulness for different applications. MLP networks turned out to be the best wear models, GRNN networks gave the best results as models of moment of friction and RBF networks were proved to be the best classifiers. That fact results from different structure, properties and method of working of those types of neural networks. We have to remember that model was tested only for definite values of load and rotational speed. What is more, only one type of lubricant was used and weather conditions were not taken into account during modelling. To obtain model which will give us better characterization of processes proceeded in tribological pairs, much more experiments to increase teaching data have to be conducted.

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