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# INFLUENCE OF THE FORCE COMPONENTS ON THE PERFORMANCE OF ARTIFCIAL NEURAL NETWORKS FOR TOOL WEAR MONITORING

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***Abstract.*** *A large number of works have been presented describing the results from research with Artificial Neural Networks (ANNs) for tool wear monitoring. In these works the ANNS were "fed" with different types of information, frequently with values from measurements of force and acceleration. The correlation between these values and the tool wear state have been shown in the literature but their influence in the performance of the ANNs, and most of all, the correlation between the results from the ANNs and the tool wear were not clearly presented. In the present work the authors show the results of experiments and analysis to find out the force components that gives more contribution for the performance of the ANNs tested and trained with data from tool wear tests. These data were sampled during the turning of non-ductile steel bars, with different types of tools and several cutting conditions.*

***Keyword:*** *Tool wear monitoring, Tool monitoring, Tool wear*

## 1. INTRODUCTION

In Canabrava Filho et al (1999) and Canabrava Filho (2000), ANNs were used to predict the tool wear state due to their capacity for solving problems difficult to be modelled by mathematics and their capacity for displaying the results quickly. The other important characteristics of ANNs is to display good results when tested for conditions of a particular system that was not used in their training section. The use of the ANNs to obtain the amount of a particular type of tool wear or to detect the tool wear states (fresh or worn) are reported in Rangwala et al. (1987), Dimla et al. (1997), Das et al. (1996) and Dimla et al. (1997).

In this work, tool wear tests when turning were undertaken for data acquisition, with two types of tool and two steels. The data obtained were used to train and to test the feed forward artificial neural networks (ANNs) trained by Backpropagation method.

The best results were obtained from ANNs trained and tested with data from tests with non-ductile steels and coated tools with chipbreaker. The second best results were observed for the ANNs trained and tested with data from tool wear tests with coated tools with a plain rake face. The predictions of the ANN trained and tested with data from tool wear tests with coated tools with a plain rake face was not as accurate as the predictions form the ANN trained with tools with chipbreaker.

The ANN trained only with components of static force presented better estimations than ANN trained with only the RMS of acceleration components.

In the present work the authors show the results of experiments and analysis to find out the force components that gives the best contribution for the performance of the ANNs from Canabrava Filho (2000). A possible explanation for the superior performance from the ANNs tested for coated tools with chipbreaker compared to the ones from ANNs tested for coated tools with plain rake face is presented.

## 2. EXPERIMENTAL SET-UP.

The cutting tests for data acquisition consisted of turning operations on bars with a diameter of 100mm and a length of 600mm. The equipments used during the cutting tests were: accelerometers Bruel & Kjaer 4332 & 4334; charge amplifiers Kistler 5006 and 5001; digital tachometer ONO SOKKI HT-331; dynamometer Kistler 9263; input/output board Amplicon PC-30 PGH; lathe Dean Smith & Grace type 18 Centre Lathe, fitted with 20hp variable speed drive; personal computer Opus 486-33mhz; and surface finish measuring instrument Taylor Hobson Talysurf 10.

Table 1 - Materials, tools and cutting parameters used in the tests.

| FAMILY OF TESTS | TEST | v (m/min) | s (mm/rev) | a (mm) | TYPE OF TOOL | WORK PIECE MATERIAL |
|---|---|---|---|---|---|---|
| T | T1 | 280 | 0.30 | 2.0 | P25 CNMG432* 120408 | EN-8 (SAE 1040) hardness=180HB |
| | T2 | 190 | 0.50 | 3.0 | | |
| | T3 | 230 | 0.50 | 3.0 | | |
| | T4 | 250 | 0.37 | 1.0 | | |
| | T5 | 270 | 0.37 | 2.0 | | |
| | T6 | 250 | 0.37 | 2.0 | | |
| TT | TT1 | 290 | 0.37 | 2.0 | P/K15 CNMA432** 120408 | |
| | TT2 | 310 | 0.37 | 2.0 | | |
| | TT3 | 310 | 0.50 | 1.0 | | |
| | TT4 | 330 | 0.50 | 1.0 | | |
| Z | Z1 | 120 | 0.29 | 2.0 | P25 CNMG432* 120408 | EN-19 (SAE 4140) hardness=330HB |
| | Z2 | 180 | 0.29 | 2.0 | | |

Tool grades: * Iscar ic656 (coated TiN-TiC-TiN);** Iscar ic428 (coated tool $Al_2O_3$).
The inserts were held in a holder type PCLNR 2525-12A.

## 3. RESULTS OF THE EXPERIMENTS WITH THE ANNs FOR TOOL WEAR PREDICITON.

It was initially decided that values of 0.3 mm for mean flank wear and 0.6 mm for the maximum value of flank wear and notch wear should be used for the tool wear/life tests. However, the tools often performed unsatisfactorily before these values were reached and alternative criteria for tool life were used. For tests with EN-8 steel the formation of a crater was observed in the form of pieces of coating being chipped off the tool. Although cutting was still possible the tools were considered worn and therefore the tests were stopped. For tests with EN-19 steel chatter was quite common as wear progressed and the tests were stopped when this was observed.

Since the tool life criterion used varied between different tests the percentage of tool life used so far at any stage of the tool wear tests was chosen to be the output of the ANNs.

The evaluations of the performance of the ANNs were undertaken by means of the mean relative error (MRE) calculated by equation 1. This type of error is one of the errors suggested by Masters (1993) to be used to evaluate the error of the ANNs during their training section.

$$MRE = sum ( abs( ta(t) - o(t) / ta(t))) / no \qquad (1)$$

Where:

MRE = mean relative error;

t = the time of the measurements used in the input of an ANN;

ta(t) = the value of the target for the time of the measurements used in the input of an ANN;

o(t) = the value of the output of an ANN for the time of the measurements used in the its input;

no = number of points in the data set used to test the ANN.

The structure, the parameters used as input and the tests used in the training section of each ANN are presented in "Table 2". Different sets of data from each test were used to train and to test the ANNs. Only results from ANNs tested for T1, T2, T6, TT4 and Z2 will be presented in this work due to the shortage of space to include graphs and tables showing results from other tests.

Table 2 - Characteristics of the ANNs trained for the experiments.

| ANN | Structure of the ANN* | Input | Tests used in the training section | Num. data used to train |
|---|---|---|---|---|
| 1_4H | 6x4x1 | Fv, Fs, Fa, Av, As & Aa** | T1 &T2 | 24 |
| force | 3x2x1 | Fv, Fs & Fa | T1 & T2 | 24 |
| acc | 3x2x1 | Av, As & Aa** | T1 & T2 | 24 |
| v&s | 2x2x1 | Fv & Fs | T1 & T2 | 24 |
| s&a | 2x2x1 | Fs & Fa | T1 & T2 | 24 |
| 2 | 6x6x1 | Fv, Fs, Fa, Av, As & Aa** | T1, T2, T3, T4, T5 & T6 | 50 |
| 3 | 6x4x1 | Fv, Fs, Fa, Av, As & Aa** | TT1, TT2, TT3 & TT4 | 50 |
| 5 | 6x4x1 | Fv, Fs, Fa, Av, As & Aa** | Z1 & Z2 | 49 |
| 6 | 6x8x1 | Fv, Fs, Fa, Av, As & Aa** | T6, TT4 & Z2 | 38 |

* I (number of input neurons) x H (number of hidden neurons) x O (number of output neurons)

** Av, As & Aa are RMS components of acceleration in three cutting, feed and depth directions and Fv, Fs & Fa are components of force in three cutting, feed and depth directions.

### 3.1 Results from the ANNs trained and tested with data from different tool wear tests.

Table 3 presents the values of MRE and correlation with time calculated with the results from the ANNs used in this work.

Table 3 – Values of MRE and correlation calculated with the results from ANNs.

| ANN | Mean Relative Error (MRE) | | | Correlation with time | | |
|---|---|---|---|---|---|---|
| | T6 | TT4 | Z2 | T6 | TT4 | Z2 |
| 2 | 0.186 | - | - | - | - | - |
| 3 | - | 0.281 | - | - | 0.855 | - |
| 5 | - | - | 0.081 | - | - | 0.982 |
| 6 | 0.124 | 0.283 | 0.259 | 0.976 | 0.849 | 0.917 |

Superior results were found for ANNs trained with data from each family individually, but taking into account that ANN 6 was trained with data from tests with different tools, different materials and different cutting conditions its performance was satisfactory.

### 3.2 Influence of the types of measurements used as input for the ANNs on its behaviour.

Table 4 presents the values of the MRE and the correlation with time calculated for the results from experiments carried out to verify the influence of the components of force and RMS acceleration in the performance of the ANNs.

Table 4 - Values of the MRE and the correlation calculated for the results from the ANNs.

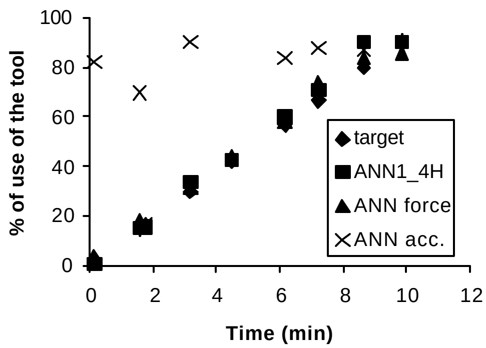
| ANN | Average Error in the Test Section* | | Correlation with time | |
|---|---|---|---|---|
| | T1 | T2 | T1 | T2 |
| 1_4H | 0.122 | 0.077 | 0.974 | 0.994 |
| force | 0.085 | 0.078 | 0.988 | 0.994 |
| acc. | 0.397 | 0.860 | 0.735 | 0.451 |
| v&s | 0.215 | 0.730 | 0.932 | 0.985 |
| s&a | 0.085 | 0.162 | 0.989 | 0.978 |

The values of MRE and correlation with time show the superior performance of the ANN trained only with the components of force compared with the performance of the ANN trained only with the RMS of the components of acceleration. Figure 1 (a) presents the graphs plotted with the results from this experiment for data from “T2” test.

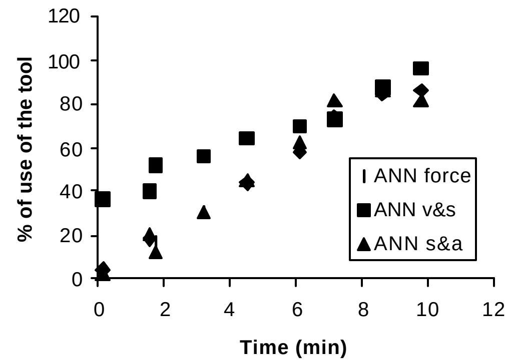
Once the ANN “fed” with values of the components of the force displayed the better performance, an experiment was undertaken to find out which force components had the greater influence on the ANNs behaviour. In this experiment the cutting and feed force, that form the plan perpendicular to the tool, and the feed and depth force, that form the plan parallel to the tool, were used to train the “ANN v&s” and “ANN s&a” respectively.

The MRE calculated for the “ANN s&a” for both tests are far smaller than the ones calculated for the “ANN v&s”. The superior performance of the “ANN s&a” can be explained by changes in the values of the feed and depth of cut force caused by the wear of the surfaces that form the grooves of the rake face of the tools during the tool wear tests. Figure 1 (b) presents the graphs plotted with the results from this experiment for data from “T2” test.

These results show the capacity of the ANNs trained with values of force and acceleration to find out and to use the information that gives the best contribution for their performance.




(a)




(b)

Figure 1 – (a) Graphs of percentage of use of the tool against time for the “ANN force”, “ANN acc.” and ANN1_4H. (b) Same graphs for the “ANNforce ”, “ANN v&s” and “ANN s&a”. Both figures were plotted with data from “T2” test.

## 4. Analysis of the influence of the feed and depth components of the force in the performance of the ANNs.

The values of force in the three components of the cutting force displayed a trend of continuous increase during the tests with EN-8 and EN-19 steels and an excellent correlation with the tool wear, except for the depth force at the late stage of the “Z2” test. In this case, while the cutting and feed forces had a tendency to increase, the values of the depth force remained almost the same. The trend of increase of the forces components during the tool wear tests was expected based on results reported in papers from other authors such as Lister (1993), Oraby (1991) and Yellowley (1993).

The changes on the surface of the rake face caused during the tool wear tests, were not quantified and therefore the influence of these wears can only be inferred by the analysis of the feed and depth components of force.

This analysis is based on the modification of the angle (θ) between the force resultant of the feed force and the depth force, and the feed force during the tool wear tests.

Figure 2 (a) shows that this angle increased in a linear fashion during the T6 test. This indicates changes on the rake face (probably wear on the backwall of the groove) and the formation of the notch during this tool wear test. The chips formed during the tests of the “T” family were well broken (up and side curl) and their formation was very stable. The changes of the rake surface caused by the different types of wear during these tests were very smooth, which results in the continuous changes in the feed and depth forces and the increase of the angle between the resultant and the feed force.

Figure 2 (b) shows that for “TT4” test the values of this angle (θ) displayed a linear trend but with great scatter around the line. This trend was observed also for other tests of the “TT family”.

The chips formed during these tests were not similar to the ones formed during the tests of the “T family” and their forms changed during the tests. The tool wear tests of the “TT family” produce different types of chips in the same test. During these tests the formation of spiral, short spiral and well broken chips was observed. These chips were produced by side curl hitting the workpiece and the tool, moving vertically near the flank of the tool. The "TT4" tests mainly produced chips formed by short spirals with one to one and a half turns.

The chip formation in the tests of the "TT family" was more dependent on the cutting conditions and the type of the material than the geometry of the tool. The differences in the chip formation in the same test due to the lack of chipbreakers, can be reflected in the scatter of the values of the (θ) during the tests of the "TT family". Therefore, although the values of feed and the depth of cut forces obtained during these tests increased, they do not provide as good information for the ANNs as the ones obtained during the tests with the "T family".

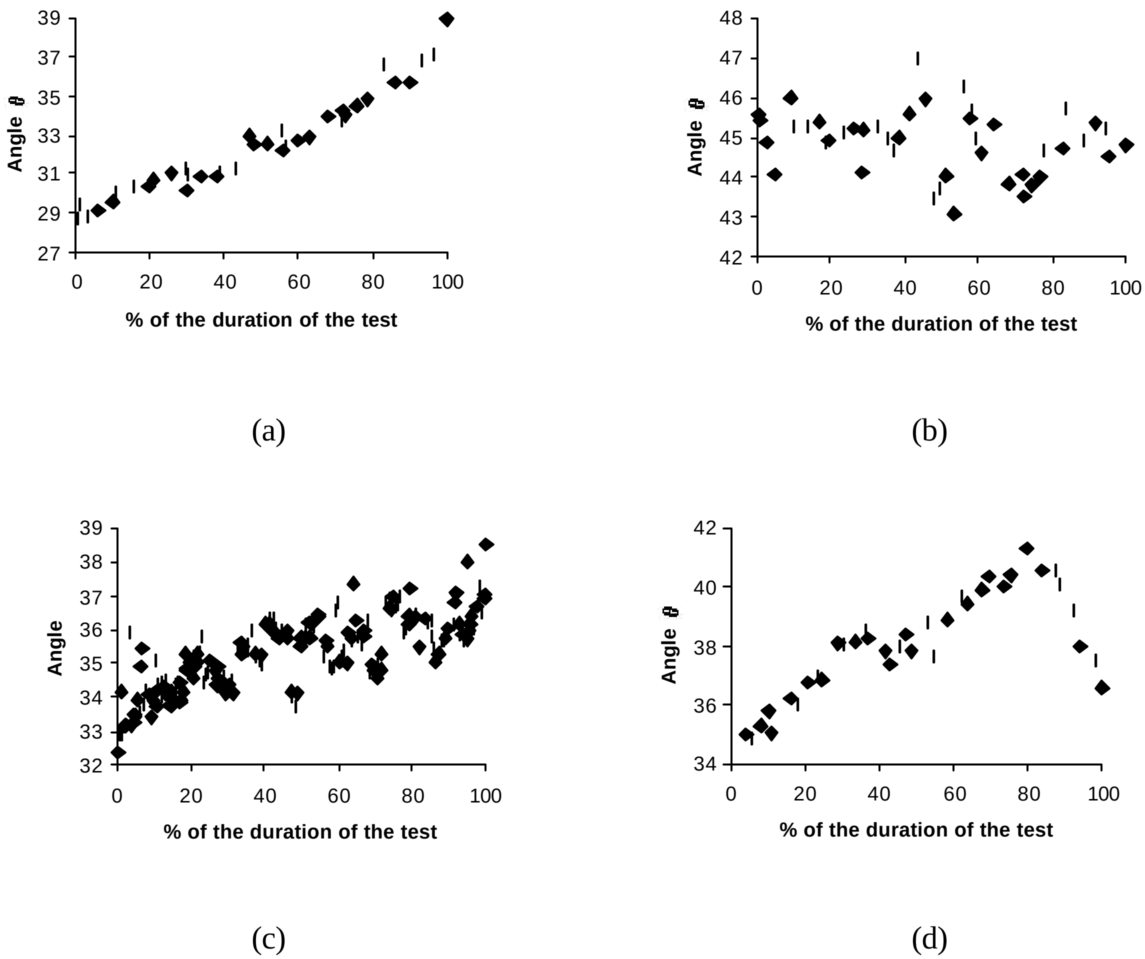
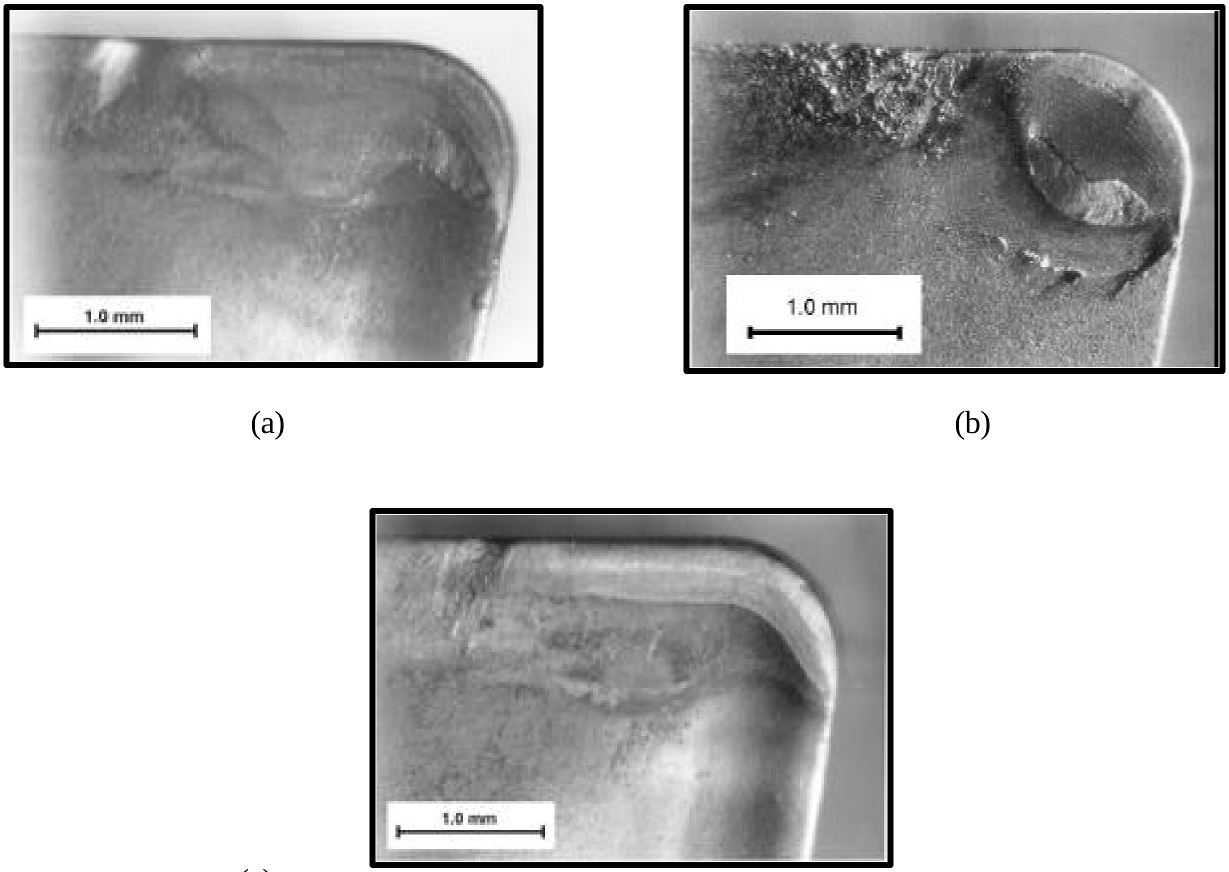



Figure 2 – Graphs of angle θ versus % of the duration of the test for tests "T6" (a), "TT4"(b), "Z1" (c) and "Z2"(d).

The graphs of the figure 2 (c) and 2 (d) show the values of the angles (θ) that were calculated with data from the Z1 test displayed greater scatter than the ones that were calculated with data from the Z2 test. No apparent reason was found for this different behaviour of the angle (θ) since the tests were undertaken with the same feed rate and same depth of cut, and therefore the chips were formed on the same region of the rake face of the tool.

The values of the angle (θ) calculated with data from Z2 increased up to 80% of the duration of the test and decreased during the last 20%. This change of trend observed in the graph is probably due to the deformation of the nose of the tool, which was evident from the cracks parallel to the nose that were observed on the rake face, during the last part of the test.

Although no deformation of the nose of the tool used for the Z1 test was noticed, cracks observed on its rake face, indicates that if the Z1 test had been longer than nose deformation would occur.




(a) (b)

(c)

Figure 3 – Photographs of the tools at the end of the tool wear tests. (a) “T6” test, (b) “TT4” test and (c) “Z2” test.

In figure 3 (a) the wear on this face, the notch wear and a small area without coating near the nose can be observed.

In figure 3 (b) the severe wear in the area near to the region, without coating, where the chip leaves the rake face can be observed. Unlike the tests with tools with chipbreaker, during the tests with plain rake face tools the formed notch was not wide, probably due to the side curl formation of the chip.

In figure 3 (c) the notch formed by the side of the swarf, of the same as that observed in the tests with EN-8 steel can be observed. Cracks parallel to the main cutting edge and to the nose were also observed. This is an evidence of the deformation of the tool at the late stages of the tool wear test.

## 4. CONCLUSIONS.

1) The ANNs trained to display the percentage of life used so far at any stage of the tool wear tests proved to be adequate when turning non-ductile steels, especially for the tools with chipbreakers.

2) The results of the experiments show the capacity of the ANNs trained with values of force and acceleration to find out and to use the information that gives the best contribution for their performance.
3) The results from the ANN fed only with the components of the force displayed better predictions than the one only fed with the values of the RMS of the components of the acceleration.
4) The ANN trained and tested using feed and depth of cut component of the force as input displayed superior results than the one that used cutting and depth of cut components of the force.
5) The predictions from the ANN trained with data from tests with tools with a planar rake face was not as accurate as the predictions from the ANN trained with data from tests with tools with chip breaker.
6) Superior results were found for ANNs trained with data from each "family" individually, but satisfactory results were obtained from the ANN trained with data from tests of different families, undertaken with different tools, different materials and different cutting conditions.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