Laboratory versus industrial cutting force sensor in tool condition monitoring system

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Abstract. Research works concerning the utilisation of cutting force measures in tool condition monitoring usually present results and deliberations based on laboratory sensors. These sensors are too fragile to be used in industrial practice. Industrial sensors employed on the factory floor are less accurate, and this must be taken into account when creating a tool condition monitoring strategy. Another drawback of most of these works is that constant cutting parameters are used for the entire tool life. This does not reflect industrial practice where the same tool is used at different feeds and depths of cut in sequential passes. This paper presents a comparison of signals originating from laboratory and industrial cutting force sensors. The usability of the sensor output was studied during a laboratory simulation of industrial cutting conditions. Instead of building mathematical models for the correlation between tool wear and cutting force, an FFBP artificial neural network was used to find which combination of input data would provide an acceptable estimation of tool wear. The results obtained proved that cross talk between channels has an important influence on cutting force measurements, however this input configuration can be used for a tool condition monitoring system.

1. Introduction
Increasing use of tool and process monitoring systems is one of the most significant developments in the manufacturing environment [1]. Sensors most commonly used in such systems measure cutting force components or quantities related to cutting force [2][3]. They are relatively easy to install on existing or new machines and work well in harsh machine tool environments. In most reported research works however, laboratory cutting force sensors are used, despite the fact that they cannot be used in factory floor practice. It is therefore important to compare the applicability of cutting force measurements obtained using a laboratory sensor with those from a high quality industrial sensor.

2. Experimental setup
The experiments have been conducted on a conventional lathe; TUD - 50. A CSRPR 2525 toolholder, equipped with a TiN/AL2O3/TiCN coated sintered carbide insert SNUN 120408 was used in the tests. Since the inserts applied in our experiments had a soft, cobalt-enriched layer of substrate under the coating, their tool life had a tendency to end suddenly after this coating wore out. Tests were carried out until a tool failure occurred. To simulate factory floor conditions, six sets of cutting parameters were selected and applied in sequence. Each set was 30 seconds in duration.

In the first experiment cutting forces were measured using a Kistler 9263 laboratory dynamometer. In the second one, an industrial KISTLER 9601A2 [4] installed in a one-tool toolholder was used (Figure.1).
In the first tests (designated LS1) ten cycles were performed, until sudden rise of the flank wear VB occurred, reaching approximately 0.5 mm. In the second test (LS2), failure of the coating resulted in chipping of the cutting edge at the end of 9-th cycle. Flank wear was about 0.35 mm at this point. The tool life criterion for these inserts was therefore established at VB = 0.3 mm.

Figure 2 presents the cutting force components; main $F_c$ and feed $F_f$, versus the tool wear obtained in the test using the laboratory and industrial force sensor. Note the weak dependence of main cutting force on the tool wear. It is a function of the cutting parameters only.

\[ F_c = (a_p, f) \] \hfill (1)

This suggests that the cutting force measurement is useless for tool wear estimation. On the other hand, the feed force is independent of feed rate, being effected only by the depth of cut and the tool wear.

\[ F_f = F_f (a_p, VB) \] \hfill (2)

Therefore, in order to use feed force measurement to obtain information about tool wear, the depth of cut must be identified. This identification can be done directly or, using the weak dependence of cutting force on tool wear:
The feed force/tool wear relationship is close to that obtained for the laboratory force sensor. Despite the fact that a weak reliance of the cutting force on tool wear was shown in experiments LS1 and LS2, in this case the signal of this force seems to be quite strongly dependant on the wear. This is due to cross talk of the industrial sensor, i.e. the influence of feed force on the cutting force signal. Results obtained indicate that the signal from an industrial force sensor cannot be used in the same way as that received from a laboratory sensor. The tool wear estimation can be made using only formula (3) but not formula (4).

The above remarks are based only on visual evaluation of results presented in Figure 2. To explore this problem more thoroughly, particular forms of correlation between tool wear, cutting parameters and cutting forces should be established and investigated. Another, more efficient way is to make use of an artificial neural network for investigation of the feasibility of various configurations of network inputs.

3. Neural network configuration

A comparison of laboratory and industrial cutting force sensors was performed using an artificial neural network system developed in Warsaw University of Technology. It is a classical Feed Forward Back Propagation based on Rumelhart’s generalised delta rule and cumulative weight adjustment (after each iteration).

There are three parameters which have to be set by operator; number and type of inputs, number of neurones (cells) in the hidden layer and number of iterations during the neural network training. The number of neurones in the hidden layer was set as double the number in the input. The number of iterations applied in all tests was 200,000. The inputs are the subject of this investigation. At first glance it is obvious that out of 11 possible input configurations, only six (1, 2, 4, 5, 8 and 11) are worth further investigation.

Experiments LS1 and IS1 were used for training, while for testing of obtained networks experiments LS1 and IS2 were employed.

4. Comparison of neural networks performance

The most important parameter of the neural network performance evaluation is root mean square error. Table 1 contains values of this parameter. Figure 3 is a more legible presentation of this information from an engineering point of view; tool wear courses versus cutting time obtained experimentally (thick lines) in all tests and evaluated by neural networks are shown. Results that are visibly worse than others are marked with points in Figure 3 and by bold font in Table 1.

Table 1. Root mean square errors of examined neural networks.

| Net No | Inputs | Laboratory sensor | Industrial sensor |
|--------|--------|--------------------|-------------------|
|        | f a_p F_f F_c | LS1 | LS2 | IS1 | IS2 |
| 1      | × × × × × | 0.012 | 0.030 | 0.020 | 0.031 |
| 2      | × × × × × | 0.012 | 0.030 | 0.020 | 0.041 |
| 4      | × × × × × | 0.015 | 0.029 | 0.021 | **0.085** |
| 5      | × × × × | 0.013 | 0.029 | 0.020 | 0.029 |
| 8      | × × | 0.019 | 0.033 | 0.022 | 0.038 |
| 11     | × × | **0.028** | **0.039** | **0.025** | **0.114** |
Figure 3. Comparison of measured tool wear (thick lines) with estimated by neural networks in all tests.

5. Conclusions

Note that the conclusions presented below cannot be applied generally to any set of cutting conditions. They concern the usability of an industrial force sensor in comparison to a laboratory sensor.

The feed force value provides useful information about tool wear. Because this force is also dependent on uncut chip thickness parameters \( a_p \) and \( f \), these cutting parameters should be available to the monitoring system as well.

As the depth of cut has a much greater influence on the feed force than the feed rate, its value is replaceable by the cutting force value, but only if \( F_c \) is not disturbed by cross talk between channels.

The feed rate only slightly influences the feed force, so it is easily replaceable by \( F_c \). Cross talk between channels does not disturb this information.

In the case of the laboratory cutting force sensor, one of the three inputs: \( f, a_p \) or \( F_c \) can be disregarded without affecting the performance of the monitoring system. If cross talk between channels is present, only the feed value may be omitted.

Tool wear monitoring without information about uncut chip cross section is possible only if there is no cross talk between channels.

References

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