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Performance Analysis of High Speed Tool Wear Detection System based on DC Two Terminal Methods

Amine GOUARIR, Syuhei KUROKAWA, Mitsuaki MURATA, Fujiwara HIROAKI

Abstract— **This study presents performance analysis of in-process tool wear detection system which uses the tool-work thermo-electromotive force (E.M.F) by the measurement circuit system as a signal-gauge in face milling. Depending on the width of tool flank wear, the cutting edge signal increases according to the variations of the electrical resistance due the increase of the contact area between tool-work and workpice. In this experiment, different milling conditions are presented such as indexable inserts with a variation of tools wear, chip breaker and water-soluble cutting fluid which has not been evaluated until now. Thus, the objective of this research is to evaluate the performance of this high speed tool wear detection system.**

Keywords: In-process monitoring, Electric contact resistance, Signal processing, Water-soluble cutting fluid, Chip breaker**.**

I. INTRODUCTION

Nowadays the cutting tool wear is well-recognized as affecting the tool life and the surface quality of the finished product. Moreover various approach has been carried out on tool wear detection. The in-process tool wear monitoring is commonly realized fixing an independent sensor such as dynamometer whose detection of the cutting wear is based on I-kaz method and regression model [1,2,3].

In fact all those method contain a weak point like the variation of the sensitivity depending on the milling machine configuration [4]. However, the method of tool wear monitoring in the meanwhile of the cutting process or the in-process tool wear monitoring is still indispensable in the case when the cutting time is successively long such as the finish cutting process of metal molds [5].

Moreover, for in-process detection of tool wear on finishing in intermittent cutting, a definitive method has not been established yet thus in this experiment we focused on the analysis and development of the relation between the progress of tool flank wear and variation in tool-work contact resistance at the contact area, In fact there is a correlation between the change in electrical contact resistance and flank wear of the tool which has been confirmed in authors' previous studies[6]. Furthermore, sufficient research has not been achieved regarding the impact and the influence of cutting fluid and chip breaker.

In the manufacturing process, it's well-known that cutting tool wear affects the surface quality of the finished product [7]. Thus when tool wear is over a certain criteria, the tool fails due to the temperature rise caused by large friction force and also the excessive stresses [8].This is one of the reasons why coolant in other words cutting fluid can always be used to improve the condition and the quality of the milling operations [9].

In fact, this paper demonstrates the influence of coating films, water-soluble cutting fluid and chip breaker by detecting the electrical contact resistance through the developed high speed tool wear detection system based on DC Two Terminal Method [10,11].

II. METHODOLOGY

A. Experimental Setup and Procedure

The material chosen for the machining test was a S45C JIS carbon steel which is a medium strength steel, suitable for shafts and other applications excelling in machinability. Indeed a different kind of indexable insert have been chosen also to carry out the milling operation of this experiment as shown in the table 1.

In this measurement system, the principle of detecting electric resistance value by DC two terminal method is based on Ohms law with constant current in the circuit thus, the results are calculated by measuring the voltage drop at the end of each resistance.

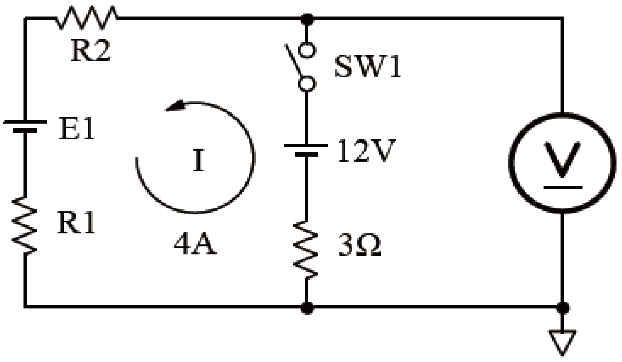

Figure 1. Equivalent circuit of the experimental system

Figure 1 illustrates the equivalent circuit of this experiment. R1 represents the tool-works electrical contact resistance and R2 is distinct resistance of measurement circuit

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and E1 is the electromotive force (E.M.F) caused by the contact between the work-piece and the tool. The circuit generates a constant current of 4A through 12V DC activating power supply and the resistance of 3 Ohm. The current of 4A can be activated through the analog switch SW1.

Indeed, it is essential and necessary to understand the relationship between tool flank wear width and tool-work contact resistance. The width of tool flank wear was measured at every constant cutting operation time, and the relation between actual tool flank wear width and tool-work contact resistance was also compared. In figure 2 we can see clearly the relation between tool flank wear width and tool-work contact resistance in different depth of cut. In this operation the cutting speed *V* was fixed at 138 m/min and the feed rate *f* at 0.10 mm/edge.

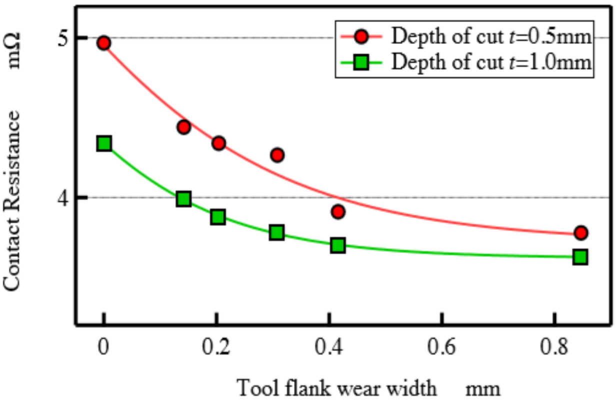

Figure 2. Relationship between tool flank wear width and tool-work contact resistance.

In addition the values of the electric contact resistance shown in Fig.2 include also the specific resistance R2 of the measurement circuit shown in Fig. 1. This figure illustrates a very good correlation between tool flank wear width and tool-work contact resistance. It seems that when the depth of cut *t* gets smaller, the change in the contact resistance according to the progress of tool flank wear becomes larger. It has already been found that tool-work electric contact resistance is not affected by the cutting speed, however, it is strongly affected by the depth of cut. The influence of the depth of cut can be evaluated by Holm's theory reported in our previous research [1].

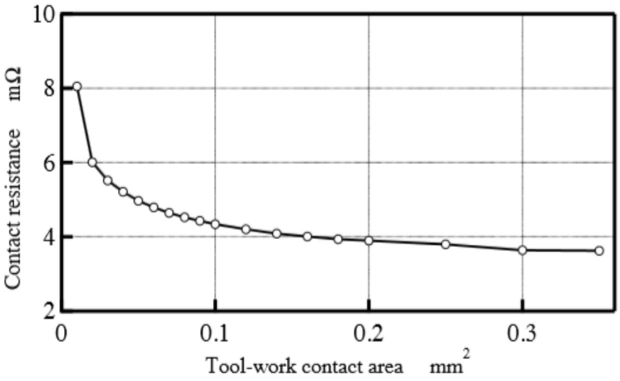

Figure 3. Relationship between tool-work contact area contact resistance in new cutting edge

However, it's difficult to measure the actual contact area of flank face in each cutting condition. Therefore, the tool-work contact area is shown by the product of the depth of cut and the feed rate. The values of the electric contact resistance shown in Fig.3 include the specific resistance R2 of the measurement circuit.

It is proved that the tool-work contact resistance decreases when the tool-work contact area increases as shown in Fig.3. Moreover, the contact resistance is not proportional to the contact area. Specifically, when the contact area gets small the inclination of contact resistance curve gets large. This result reveal that the new measurement system can also detect the contact resistance in the finish cutting process even if a small depth of cut [1,7].

B. *The first part of the experiment*

The goal of the first step is to observe the result of milling operation with a different kind of cutting tool. Table 1 below contains the characteristic and the composition of each cutting tool used in the first part of the experiment. In fact four kind of indexable inserts with a different coating have been chosen in order to analyze their conductivity regarding in-process measurement method. In fact some of them contain a different coating thickness.

The E.M.F is obtained by subtracting the standard value from the voltage drop waveform. In order to extract from the electrical contact resistance waveforms, it is necessary to calculate the average value of the thermal electromotive force.

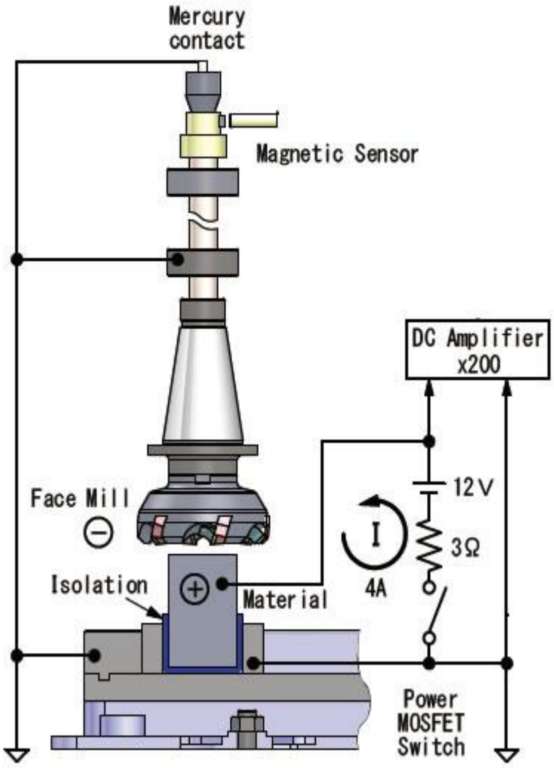

Figure 4. Experimental setup

Table 1. Specification of the cutting tools

Tool number	1	2	3	4
Base material	Cemented carbide	Cemented carbide	Cemented carbide	Cermet
Coating type	Non coating	Ti(C,N,O)	TiCN+Al_2O_3	Non coating
Coating thickness in μm	—	3	11	—
Coating process	—	PVD	CVD	—

Subsequently, as shown in Table 1 the specifications of the tools were prepared as different coating types and different tools substrate. Figure 4 shows the connection of the experimental equipment to the CNC milling machine. Firstly the electrical circuit of the resistance measurement system is connected to the milling machine, the MOSFET which is the switch of the circuit must be in the off position to avoid voltage loss.

In point of fact, measurement of the E.M.F between the work-piece and cutting tool can be carried out by measuring the voltage drop through the waveforms after 4s (which is the measurement limitation due to the capacity of the memory recorder), as mentioned before in this circuit, a constant current of 4A will be applied directly after turning on the MOSFET switch, thus the average of the E.M.F will be measured by subtraction from the voltage drop through the waveforms.

The milling operation starts in time ***t0*** before the contact of the cutting tool with work-piece as shown in Figure 5.However the MOSFT switch must turned on at time ***t1*** then after the contact and during a few second at time ***t2*** the memory recorder can record the variation of the contact resistance during maximum 4 second of milling operation.

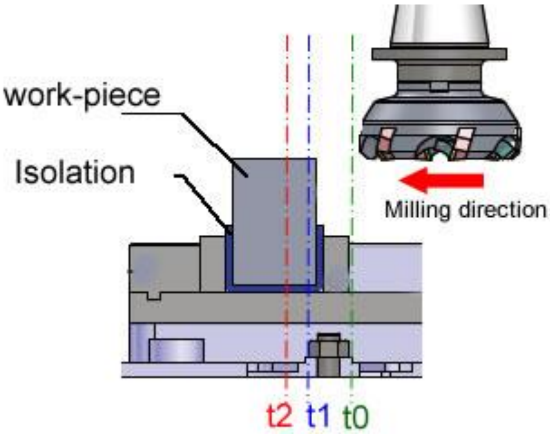

Figure 5. Methodology of measurement

Meanwhile we can observe the real time result of the milling operation on the screen of the memory recorder. Thus; every waveform will appear in each time when the contact of cutting tool with a piece-work is in progress. Figure 6 gives an example of tool flank wear width after the measurement.

In Table 2 a specification of the milling condition are presented. Some specific values have been fixed, such as, f = 0.1mm/edge and cutting speed V = 140m/min. In fact the same operation with a different cutting depth have been realized, starting by Ap = 0.1mm, 0.3mm and 0.5 mm.

Table 2. Specification of the milling condition

Work-piece 1&2	S45C JIS carbon steel
Cutting speed V [m/min]	140
Feed rate f [mm/edge]	0.1
Depth of cut Ap[mm]	0.1,0.3,0.5
Cutting fluid	Without

In this experiment, two work-pieces are placed. The first one is related to the measurement system in order to detect the tool wear and the second is expected for changing the state of tool wears as a used tool. In the evaluation, the amount of tool wear has been used as an index by the flank wear width, the insert was used until reaching the expected value. The condition of the insert was observed by digital microscope after every milling operation. The observation of cutting tool edge conditions was recorded after every milling operation in order to collect waveforms data.

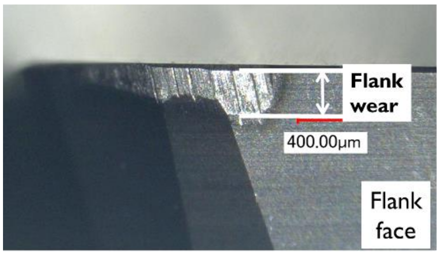

Figure 6. Tool flank wear width

C. *Result and discussion for the first part*

We can observe the result of milling operation with different depth of cut in the following order (0.1mm), (0.2mm) and (0.5mm) from Figure 7 to Figure 10. As a result, we could notice that the relation between tool flank wear width and tool-work contact resistance at the different stage of the depth of cut showed a correlation. In the graphs we can observe the output of the measurement from the tool 1 to tool 4 according to the Figure 7 to Figure 10 with reference of Table 1.

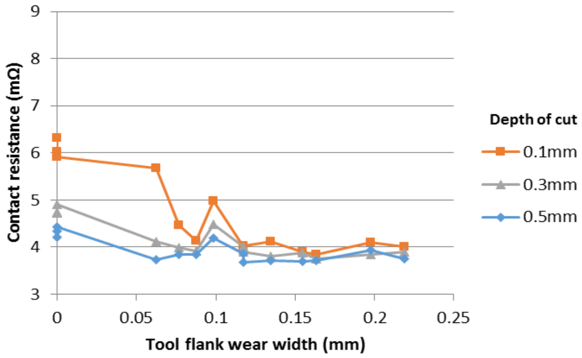

Figure 7. Relationship between tool flank wear width and tool-work contact resistance (Tool 1)

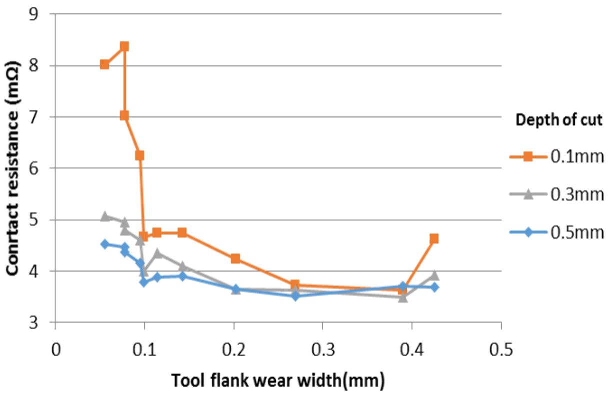

Figure 8. Relationship between tool flank wear width and tool-work contact resistance (Tool 2)

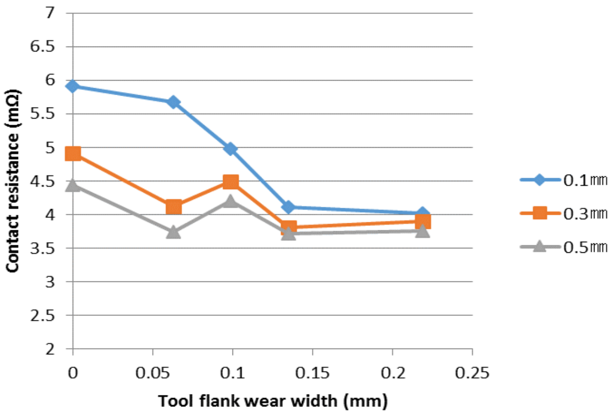

Figure 9. Relationship between tool flank wear width and tool-work contact resistance (Tool 3)

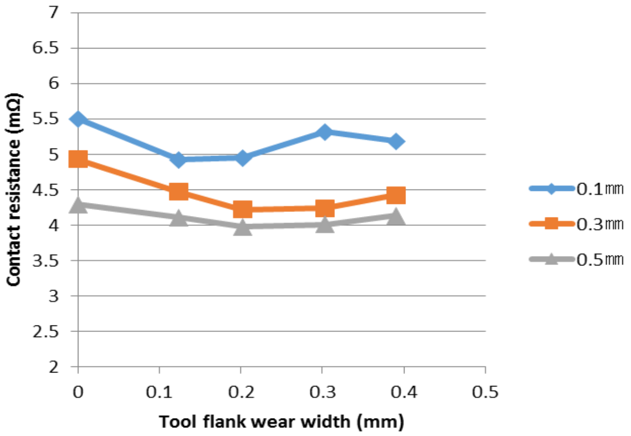

Figure 10. Relationship between tool flank wear width and tool-work contact resistance (Tool 4)

The results show that in every milling operation the contact resistance increases when the contact area decreases for each tool. However, we can notice that even if correlation exists in every operation, there also some differences between each tool. For example, in case of non-coated tools if we observe and compare tool 1 in Figure 7, tungsten carbide is easier in measurement than cermet tool 4 in Figure 10. In the case of coated tools, we can notice that cemented carbide Ti(C,N,O) PVD and cemented carbide TiCN+Al_2O_3 CVD are both easier in measurement, because the fluctuations are clearly identifiable in every depth of cut.

D. The second part of the experiment

In order to analyze the effect of chip breaker and cutting fluid in the measurement system, the same operation of milling has been carried out as the first test. In this case, the chip breaker is examined. This operation also was carried out under the same conditions as the previous part which mean that milling operation has been done also in three different depth of cut such as; first 0.1mm then 0.3mm and finally 0.5mm. The results can be observed in Figures 11.

Table 3. Specification of the cutting tools

Tool number	1	2	3
Base material	Cermet	Cermet	Cemented carbide
Chip breaker	—	With	—

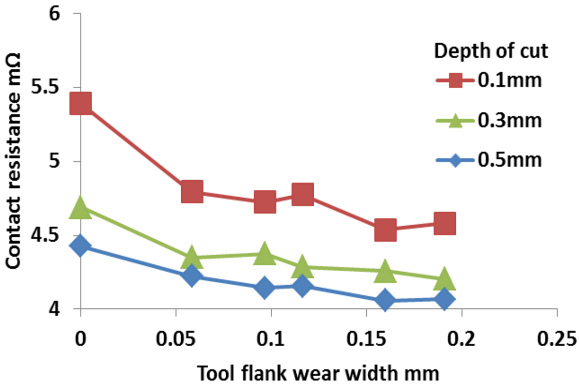

Figure 11. Relationship between tool flank wear width and tool-work contact resistance (with chip breaker)

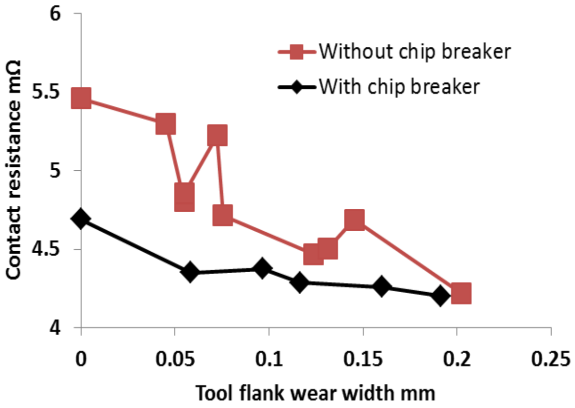

Figure 12. Relationship between tool flank wear width and tool-work contact resistance *Ap*=0.3

To compare the difference between operation with chip breaker and without chip breaker, three kind of indexable inserts have been used. Table 3 illustrates the specification of each tool. The result of tool 1 and tool 3 has been measured in the first step of the experiment. The comparison was carried out with the new result of tool 2.

The results in the second part of the experiment shown in Figure 11 have correlation also with the chip breaker, however in Figure 12, we can notice that although the correlation exists, there are also some differences between each tool with and without chip breaker. If we compare tool 1 and tool 3 without chip breaker, we can observe that cermet and cemented carbide without chip breaker are both easier in measurement than cermet with chip breaker.

E. *The third part of the experiment*

In this part of experiment, the test was designed to evaluate the effect of cutting fluid, as shown in Table 4. Water-soluble cutting fluid has been used to check the availability of the measurement system.

Table 4. Milling condition

Work material	S45C
Cutting speed *V* [m/min]	140
Feed rate *f* [mm/edge]	0.1
Depth of cut *Ap*[mm]	0.1,0.3,0.5
Cutting fluid	water-soluble

The result shown in Figure 13 demonstrates that the presence of cutting fluid has less difference in the in-process measurement system. We could understand also that the high speed of the milling operation does not allow the cutting fluid to attend around the cutting edge which means that there are always conductivity between cutting edge and work piece.

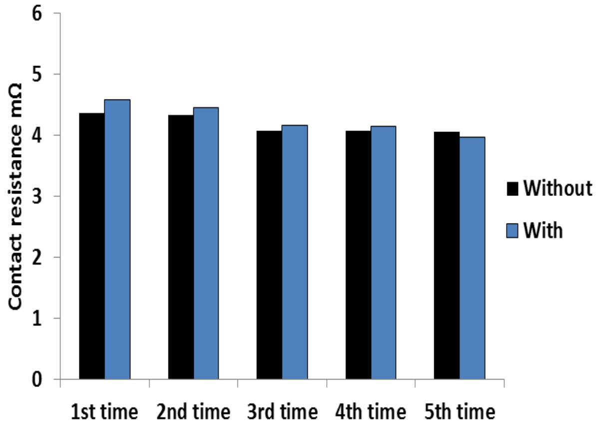

Figure 13. Tool flank wear width and tool-work contact resistance in condition with coolant and without

However, the presence of the cutting fluid seems to have higher value of contact resistance than milling in dry condition, but in this situation, we used water-soluble oil. The conductivity of cutting fluid may have an important effect of variation, thus the result may be different in the case of water-insoluble cutting fluid.

III. CONCLUSIONS

1) A correlation has been obtained between the electrical contact resistance value and tool wear with and without chip breaker.

2) According to the result of the experiment, the variation result of contact resistance between the tool and work piece shows that, whatever the nature of the tool shape or cutting fluid, there are always correlation in the results of measurements and the signal of the contact resistance can be always detected.

As a conclusion; we can say that the present High Speed Tool Wear Detection System based on DC Two Terminal Methods is effective as in-process detection tool wear system with the presence or the absence of water-soluble cutting fluid and also with and without chip breaker.

IV. ISSUES FOR FURTHER STUDY

The given experimentation setup generates electrical contact resistance waveform signals that contain necessary information by measuring the average value of the thermal electromotive force concerning whether cutting is taking place or not, as well as for whether a worn tool or new tool is used for cutting.

These waveform signals also have a relatively unexplained variability of noise, especially when the depth of cut is smaller. However, further study is necessary to determine the exact reason of this noise during the cutting progress and improve the quality of the signal by isolating the measurement system or developing specific filter. Moreover to reach the mentioned objectives, it’s very important to improve the connection between the tool and the wok-piece by replacing the contact mercury into other sensors more safely and effectively.

There is also an isolation film placed on the work table under the work-piece to avoid the current loss. The cutting operation with coolant makes the system unavailable. However, further study is necessary to develop a compact and robust system enough for industrial use, by replacing the actual isolation by other sensors specifically designed for the measurement of the cutting operation with coolant.

The support of the mercury contact unit was designed specifically for OKK Toshiba CNC Milling machine used in this experiment. Further study is necessary to develop a wireless connection system in order to make this measurement system universally applicable in any kind of milling machine.

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