Experimental study and model development for on-line drill wear monitoring system using Lab VIEW

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Abstract*: Description of this research paper is to study the development of on-line monitoring of drill wear model during the machining process of the AISI 1040 Steel. As an application of Virtual instrumentation, the Laboratory Virtual Instrument Engineering Workbench (LabVIEW) is a data acquisition software has been used in this work. The main purpose of using this software system in this work is to forecast the drill wear states monitoring. The focus on the relationship between spindle motor cutting current signals and other cutting parameters is considered for forecasting of drill wear states. The status of cutting tool can be continuously monitored by using the proposed method of on-line drill wear monitoring system. The wear status of the cutting tool is exhibit in terms of maximum permissible wear. In addition to these performance statuses, the proposed system can also help to replace the defective too at proper time interval.

***Index Terms*: Cutting Current Signals; LabVIEW; AISI 1040 steel; Drill Wear Monitoring.**

I. INTRODUCTION

The emerging of on-line drill wear process monitoring, it has motivated the researchers to do a lot of research work in that field. Consequently, the number of researches has started the greater number of research projects based on this monitoring system. The purpose of raised research project on this monitoring system is to focus the important futures of wear monitoring system. The focused important futures of this wear monitoring system are: 1) the influence of drill wear shows the quality of the surface finish and the dimensions of the products that can be produced 2) Today, based on conservative estimates of tool life, the tool changes can be made that leads to sudden failures and unnecessary high number of changes, because consideration of the full lifetime of tools and as a result of the loss of valuable production time. 3) Unmanned production is possible only if there is an effective method available for drill wear monitoring system and tool breakage detection. 4) As consequences of the above results, without an effective drill wear monitoring method, the possibility of automated production and quality control cannot be made really. The classification of drill wear monitoring methods is based on the two categories which are: 1. direct method and 2. indirect method. The use of the direct method is to determine the tool wear directly, these methods really measure the tool wear as such. These direct methods, however, are not effective either economically or technically, when its focus on, such as computer vision or visual inspection etc. In indirect monitoring methods, the measurement parameters identify the wear, such as force, torque, vibration, power, sound and cutting current signals [1]. Spindle motor current informs that how much power consumption of the cutting process and it advises about the dynamics of cutting. Measuring the spindle motor current is the easiest among other methods and consequently, the application of this current measurement technique can be taken into the various field work [2]. Recently, by using fuzzy logic technique, during the machining process, the favorable role of feed and spindle motor current is to forecasting the wear values, it has been reported [3]. The establishment of on feed-motor current for on-line, the development of drill wear monitoring system is to estimate the tool wear rate and, consequently, monitoring tool wear condition. The establishment of knowledge of feed cutting current, the following are determined: 1)In case the tool wear has accelerated and 2)if the tool has reached the final stages of its useful life [4].The establishment of the relationship of the cutting force and the motor current, using the current signal of the linear motor, a new tool breakage monitoring was developed in Vertical Machining Centre (VMC) the effective relationship between the cutting force and the motor current and the use of the nonlinear energy operator in this method is to capture the abrupt changes of the motor current signal, which is directly related to the tool breakage [5]. The establishment of usage, it aimed at repetitive manufacturing operations, where many signals per second might be obtained with fixed parameters such as spindle speed shape, drill bit diameter, feed, and a good statistical study can be done. Focus on the application of drilling process with different degrees of wear in the drill bit, during the drilling process, the use of the correlated wear is to find the relationships between Acoustic Emission (AE) and torque measured, and also with the degree of wear of the tool [6]. Considering the combination of principal component analysis technique and least squares support vector machines, the development of the new drill wear prediction system is applied for the micro broaching process.

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Using the platform of PXI (PCI Extension for Instrumentation) and LabVIEW, the development of the corresponding tool wear monitoring system can be obtained. This LabVIEW has its powerful performance in data acquisition, user interface design, data management, and hardware connectivity. Because of this powerful performance, the selected LabVIEW as software platform is to improve the whole software package [7].In different machining process, MATLAB software is also used for on-line monitoring system. A two-channel strain gauge produced a strain gauge signal, it mounted at the tool holder. The ability of the system is to detect and analyse the signals relating to the deflection of the tool holder from the cutting force, and the corresponding estimation of wear displayed on the computer screen. The signal conditioning device obtains the transmission of the strain gauge signal, then moves into the data acquisition, and finally reaches to the computer system [8]. The main purpose of LabVIEW software is used for processing of micro-drilling torque analysis techniques and data acquisition. The powerful input impedance of the spindle motor as monitoring signature can be carried out, and all measured signals including amplified drilling torque, voltage and current were digitalized with 5120Hz sampling rate by a 12-bit DAQ (Data Acquisition) after a low-pass filter [9]. In CNC (Computer Numerical Control) machine tools, LabVIEW software is used for two things that are: 1) signal acquisition and 2) feature extraction purpose in process monitoring system [15]. The sensor signals from the Open CNC machine process are acquired via DAQ and then feature extraction and decision-making steps were done in LabVIEW [10]. The advanced mathematical model is used for correlating the interactive and higher-order influences of various machining parameters (surface roughness, cutting speed, feed, specific energy, machining time on metal removal rate, diameter of cut, volume fraction and flank wear) using Taguchi method [16]. A multiple regression model is used to represent relationship between input and output variables based on GA (Genetic Algorithm) [11].

In this research work, the following works are carried out:a) The On-line drill wear model is developed based on adaptive control theory under LabVIEW environment. b) On-line drill wear prediction method is developed based on the cutting current signals of the spindle motor using VI. c) Based on the on-line drill wear model, cutting current signals are acquired using current sensor and the status of the wear is analysed over a wide range of cutting condition (cutting speed, feed rate, drill diameter). d) The drilling process is carried out in VMC on AISI 1040 steel as work piece. e) Based on drill wear states and their values, at the proper time, the facilitation of the defective tool replacement can be made. The new combination of the on-line drill wear monitoring system has introduced in the present work; the integration of VMC with the spindle motor current signals using VI under LabVIEW environment.

II. Experimental Setup and Procedures

A. Experimental Setup

The use of this Proposed method: identifies the wear states from the measured process data. measures and the spindle motor cutting current signals during drilling of AISI 1040 steel. The identified wear states which are used to decide the tool replacement at the proper time. Vertical Machining Centre (VMC) had carried out the drilling experiments, using AISI 1040 steel work piece and High Speed Steel (HSS) twist drill and, varying cutting conditions that has been observed as follows: Cutting speed (800 rpm, 1000 rpm, 1200 rpm), Drill diameter (Ø8 mm, Ø10 mm, Ø12 mm) and Feed (0.10 mm/rev, 0.15 mm/rev, 0.20 mm/rev).Most of the automobile industries uses the AISI 1040 as structural components .The majority of fastener holes are used in the many automobile industries by using the drilling experiment. Since high stresses and fatigue parts are subject to continuous load, the issue of quality (diameter, form, surface finish etc.,) of holes is important one. The typical applications of AISI 1040 steel, it includes crank shafts, spindles, automobile axle beams, connecting rods, bolts, and lightly stressed gears. The permanent magnet synchronous AC servomotors drive the spindle motor in VMC directly. The Current Transformer (CT) gathers the spindle motor current signals of the VMC during experiments which is mounted on the spindle motor drive. It cannot be directly applied to the measuring instruments if the circuit has too high current. Therefore, the reduced current can be obtained by using the Current Transformer. This reduced current is accurately proportional to the current in the circuit and expediently connected to the measuring and recording instruments as well.

B. Measurement of drill wear

A universal toolmakers microscope can be used to measure the width of the wear on the flank face of the drill. Fig. 1 shows the measured wear in each section gives the average flank wear, after that, the arithmetic average can be computed. The formula for average Flank Wear is (A+B+C+D)/4 [12]. At periodic intervals, the cutting time for each drill measured the wear. The maximum wear, at a particular point, which can measure the wear mark. In drilling process, the allowable wear value of HSS tool is 0.4 mm. Hence, each tool shows the wear value until the maximum flank wear reaches 0.4 mm.

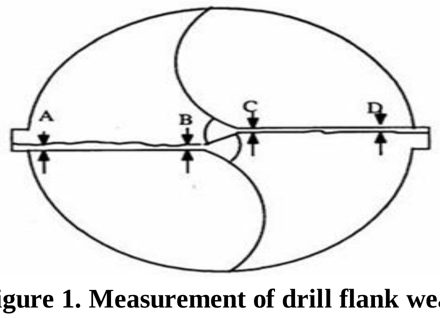

Figure 1. Measurement of drill flank wear

III. VIRTUAL INSTRUMENTATION (VI)

The definition of VI is the combination of hardware and software with industry-standard computer technologies,

which is used to generate the user-defined instrumentation solutions. For DAQ, the focus of the virtual instrumentation is to develop the plug-in hardware and driver software. The driver software which is the programming interface to the hardware. It is consistent across a wide range of platforms. Application software, for example, the Measure and Component Works, Lab Windows/CVI, LabVIEW, which deliver the sophisticated display and analysis capabilities, it is essential for VI. The three main parts of each VI, which are Block Diagram (The code that controls the program), the Icon/Connector (Means of connecting one VI with the other VIs) and Front Panel (How the user interacts with the VI)[13].

A. LabVIEW

LabVIEW, which is a graphical programming language, it uses icons instead of lines of text, which is used to create applications. In text-based programming languages, the instructions determine the program execution, whereas LabVIEW uses dataflow programming that determines the execution. Without the complexity of traditional development environments, the LabVIEW gives the flexibility of a powerful programming language. It is a graphical development environment which has built-in functions that can be used for simulation, data acquisition, instrument control, measurement analysis, and data presentation [14]. In the proposed on-line process monitoring system, the use of LabVIEW is to develop the on-line drill wear model.

IV. DILL WEAR MODEL

A. Development of drill wear model

The effects of the varying cutting parameters such as cutting speed, feed, and drill diameter and the current signals for drill wear which examines the establishment of the drill wear model of cutting current signals as the function of the cutting parameters and drill wear. In LabVIEW environment, the construction of the drill wear model is based on adaptive control theory. The Current Transformer (CT) gathers the cutting parameter information that can be transferred to the drill wear model (LabVIEW) via DAQ. The Analog to Digital Convertor A/D (wave form analyser AF-550A,sample frequency 25 kHz) had sampled the cutting current signals inside the DAQ, which is taken as the input to a personal computer. The proposed method which is based on adaptive control theory, firstly it tends to separate the effect of different variables were involved in the process (inputs as well as different wear states) by relying on a process model. Secondly, this method tends to be more dependent on on-line testing by using on-line determination of equation parameters. The tool life can be divided into three states that has been characterized by three different flank wear. The three flank wears are normal wear, moderate wear and ultimate or severe wear. During the ultimate tool wear state, the sudden rise of wear rate has been observed here as an indication of the need for tool replacement. The wear curve is usually not smooth and also fluctuates due to many factors affect tool wear. During the moderate state, the wear amount, w, is expressed as the sum of two parts for practical tool monitoring. The first part is the determinable linear increase w_1t, which is superimposed onto the second, w_0:

$$w = w_0 + w_1 t \tag{1}$$

During normal phase, w (mm) is the flank wear value and w_0 (mm) is the initial flank wear. In the second phase, w_1 (mm/min) is the flank wear rate in the second phase and ‘t’ (min) is the cutting time. The main objective of monitoring is to focus on the rise in the wear rate w_1 associated with the final stage of the accelerated tool wear in ultimate wear state with the purpose of a tool replacement decision. This proposed work can be achieved indirectly by monitoring the spindle motor current, ‘I’ and this current is related to the tool wear, w. During drilling, the relationship of spindle motor cutting current and flank wear under varying cutting conditions which is shown as follows:

$$\Delta I = k_0 w + C_0 \tag{2}$$

Generally, $\Delta I = I - I_0$, where I_0 is the ‘air cutting current’ and I is the magnitude of the measured total current that is consumed when there is no cutting load. Note that Eq. (2) holds in the second state, which is called as the moderate flank wear state. Hence, the dependence of the spindle motor cutting current on flank wear can be modelled in this specific context as a linear function:

$$\Delta I = \Delta I_0 + kw \tag{3}$$

where drill diameter d,k is a parameter dependent on cutting conditions such as cutting speed v,ΔI_0 is the spindle motor cutting current arising under identical cutting conditions but with an un-worn cutting tool (i.e. when w = 0) and feed rate f. Combining Eqs. (1) and (3), we obtain

$$\Delta I = \Delta I_0 + kw_0 + kw_1 t \tag{4}$$

Differentiating the terms in Eq. (4), we can express the change in spindle motor cutting current, ΔI’, as

$$\Delta I' = kw_1 \Delta t \tag{5}$$

Thus we can obtain the wear value w_1

$$w_1 = \Delta I'/k\,\Delta t \tag{6}$$

In principle from Eq. (6), the noticeable change in the calculated wear rate w1 should indicate that the tool is in its ultimate stage wear and that should be replaced. The use of current sensor measures the spindle motor cutting current which is converted into digital signals by using DAQ. The adjusting values of speed and feed values can be taken as per the work piece material that can provide the constant value of k. The purpose of reducing the fluctuations in the signal, the low pass filter takes the processed digital signals. The use of peak-peak signal measurement is to calculate the spindle motor cutting current parameter ΔI. The calculation of cutting time parameter Δt would be done by using the pulse duration of the signal for each drill.

The estimation of drill wear value would be taken by using the parameters ΔI', Δt and k which are shown in the below relation.

$$w = (1/k)\,(\Delta I'/\Delta t) \quad (7)$$

The utilization of this equation (7) is to develop a new online drill wear model in the LabVIEW environment. During machining, the measurement of the on-line process signals (e.g. cutting current signals) can be taken by this method. Also, this method identifies the process features from the measured process data. The use of the identified process features is to determine the initial cutting conditions. The storage of these initial conditions in the drill wear model can be used to identify the next process.

B. Tool replacement control

The process of obtaining a basis for the replacement of the tools at the proper time is one of the main objectives in the drill wear state. The estimation of drill wear stage can be done by using the knowledge of the current signals and various cutting parameters based on the model. With linear incremental relationship, as the drill wear increases, the cutting current can be increased. During the steady state wear period, in the AISI 1040 steel, the sample holes of X, Y, Z can be taken. As drill wear process is on-line, the time variables can be mentioned in the drill wear model. The alert has to be shown while the drill wear state is 'moderate'. In the same way, the tool has to be replaced while the status is 'ultimate'. The repeated process of system works would be taken in anticipation of the process reaches the ultimate stage and then the manual replaced the tool because of avoiding the worn-out condition. The establishment of the cutting current signals and the varying cutting parameters, in online drill wear process monitoring system, the AISI 1040 steel's tool replacement can be made well.

V. Results and Discussion

A. Tool replacement control

Concerning the cutting current signals and various cutting parameters, the series of experiments could be taken out. The beginning of the experiments can be taken along with the establishment of the on-line drill wear model through new drills. This continuation of experiments would be taken until the drills reach the maximum wear. During the steady state wear period, the results of experiment scan be taken, including various cutting speed, feed and drill diameter. For each drill hole, the details of the extracted features (cutting current signal and various process parameters) and drill wear states can be recorded. With three different drill diameters (8 mm, 10 mm and 12 mm), on the AISI 1040 steel workpiece, the performance of the drilling operations can be carried out. With regular intervals, the sample drill hole ranges (1 - 150, 151 - 300, 301 - 440) could be selected based on varying cutting parameters. Based on different drill diameters, the parameters feed rate and cutting speed can be changed as per the selected drill hole ranges. During the steady state (over 440 drill hole scan be executed in this study) wear period, the experimental results can be taken effectively including various cutting speed, feed and drill diameter. The obtained results can be carried out by the way of drill wear model for the selected drill hole ranges with 8 mm, 10 mm and 12 mm diameters are listed in Figure. 2, Figure. 3 and Figure. 4. During machining, in drilling process, the possibility of monitoring the current signals can be taken out, and the expectation of the result shows that the cutting current increases when the tool gradually wears. In online process monitoring system, as per the drill wear states, the normal condition of the wear state stands in the place of initial sample hole ranges, 1 - 150 for 8 mm, 10 mm and 12 mm diameters. In the next hole range 151 - 300, the normal wear state remains up to the drill hole number 210 for 12 mm diameter, 214 for 10 mm diameter,217 for 8 mm diameter, although the changes of the feed rate and cutting speed could be happened. The consideration of the moderate wear state, it starts in the drill hole number 218 for 8 mm diameter, 215 for 10 mm diameter and 211 for 12 mm diameter and it is continued up to the drill hole number 435, 431 and 427 for 8 mm diameter, 10 mm diameter and 12 mm diameter respectively. In the final sample hole range 301 ÷ 440, the feed rate and the cutting speed can be increased and the wear stage can be changed from moderate state to ultimate state at the drill hole number427 for 12 mm diameter, hole number 436 for 8 mm diameter and hole number 432 for 10 mm diameter. The warning message can be raised when the drill wear value reaches the ultimate critical condition (0.4 mm and above) through the drill wear model based on the on-line drill wear process monitoring system. The final decision of regarding tool condition and tool replacement can be carried out instantly as per the warning message. Considering the all selected drill diameters, the observation of the experiment is that the cutting current and drill wear increases linearly during the feed rate and cutting speed increases. This experimental shows that the effect of drill wear and cutting current consumption for different feed rates and cutting speeds for selected drill diameters (8 mm, 10 mm, and 12 mm). The observed function of drill, at various cutting condition, the noticed curves shows the variation of cutting current signals. For each condition, with particular drill diameters, the drilling process scan be carried out with each case until the drill wear reaches the ultimate wear state. From the observed diagram, it shows that a linear trend was followed by the cutting current signals until reaching the ultimate wear state.

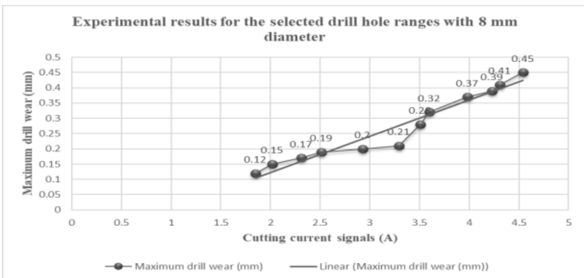

Figure 2. Experimental results for the selected drill hole ranges with 8 mm diameter

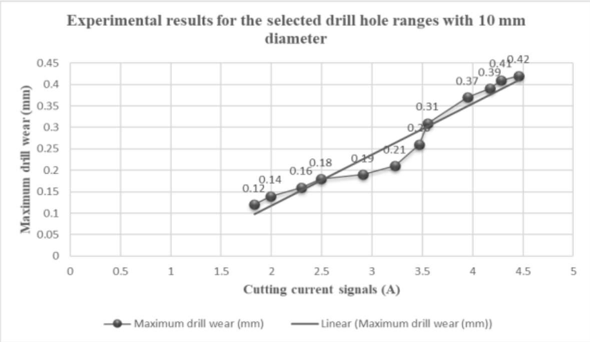

Figure 3. Experimental results for the selected drill hole ranges with 10 mm diameter

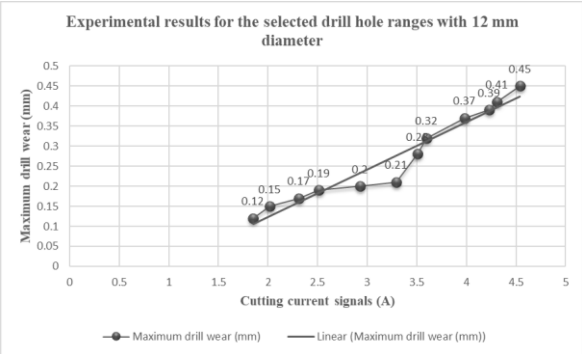

Figure 4. Experimental results for the selected drill hole ranges with 12 mm diameter

B. Testing and validation of drill wear states

In the testing and validation phase, in the varying cutting condition, the online drill wear model measured the drill wear values. For performance analysis, the 9 sample drill wear values could be taken. The tool maker's microscope measured the drill values by applying the same varying cutting conditions. Figure. 5 shows the performance of the online drill wear monitoring, in which the drill wear values are plotted in opposition to the measured drill wear values from tool maker microscope. In the Table. 1 comparison of estimated drill wear for AISI 1040 steel and actual or measured drill wear. The performance showed that the developed online drill wear model measured the drill wear values which are 95% to 98% same as measured drill wear values from tool maker's microscope.

Table 1 Comparison of measured (actual) drill wear and estimated drill wear for AISI 1040 steel

Drill size (mm)	Cutting speed (rev / min)	Feed (mm / rev)	Cutting current signals	Drill wear: tool wear model (mm)	Drill wear: digital tool maker's microscope (mm)	Drill wear states
8	800	0.10	2.47	0.16	0.15	Normal
	1000	0.15	3.51	0.30	0.29	Moderate
	1200	0.20	4.23	0.41	0.40	Ultimate
10	800	0.10	2.49	0.18	0.17	Normal
	1000	0.15	3.55	0.31	0.32	Moderate
	1200	0.20	4.28	0.41	0.41	Ultimate
12	800	0.10	2.51	0.19	0.18	Normal
	1000	0.15	3.60	0.32	0.31	Moderate
	1200	0.20	4.31	0.41	0.42	Ultimate

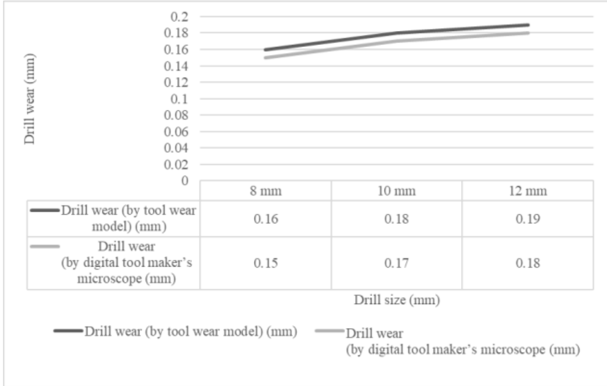

Figure 5. Comparison of measured (actual) drill wear and estimated drill wear for AISI 1018 steel

VI. CONCLUSION

In LabVIEW environment, the application of VI over a wide range of varying cutting conditions, the cutting current signals are correlated with drill wear. Based on the spindle motor current signals, the important effects of drill wear and cutting condition scan be considered. The necessary conditions of the drill wear status and the cutting parameters can be considered while the replacement of the tool carried out. In tool changing, the cutting current signals also act as a dynamic improvement. The essential of the efficient drill wear status and the prediction of the combination tool, for any specific operation, the above demonstration of on-line drill wear model which helps to study the performance of LabVIEW. The performance of different wear states of the AISI 1040 steel has been demonstrated effectively, with the purpose of the replacement of defective tool can be carried out at the proper time. From the performance analysis, this experimental shows that the drill wear values are predicted by the drill wear model. Also, in comparison with practical drill wear measurement, the drill wear model provides the alert more accurately. The developed online drill wear model measured the drill wear values which are 95-98% same as the measured drill wear values from the tool maker's microscope. From the results of Experiments, by practically, the monitoring system can be effectively employed because it is having the qualities of simple, reliable and cost-effective. This model can be used efficiently in the manufacturing industries by studying the efficient process of this model and there placement of the tool control and the drill wear status at regular intervals can be done without human intervention which increases the productivity and safety aspects, future advancements still made using LabVIEW.

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