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Full Length Research Paper

On-line drill wear monitoring in high speed machining of jute fiber-reinforced composites using virtual instrumentation

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Many challenges in machining need to be overcome in replacing fiber reinforced composites. In this work, jute fiber reinforced bioepoxy resin laminates were manufactured, drilled and inspected. The drilling operations were performed on jute fiber reinforced composites by high speed steel (HSS) drill bits. Drill wear state prediction allows the determination of the hole quality as well as tool replacement at proper time, during the drilling process in high speed machining (HSM). The effective drill wear model has been established to predict the drill wear states based on the relationship between the cutting current signals and the various cutting parameters (cutting speed, feed, drill diameter), using the standard data acquisition software Laboratory Virtual Instrumentation Engineering Workbench (LabVIEW) in the application of virtual instrumentation (VI). The established drill wear model was used for the continuous monitoring of the cutting tool status, and to exhibit the drill wear states as a percentage of the maximum permissible wear. Meanwhile, it facilitates defective tool replacement at the proper time in an automated manufacturing environment.

Key words: Jute fiber reinforced composites, drill wear monitoring, cutting current signals, high speed machining (HSM), virtual instrumentation (VI).

INTRODUCTION

Natural fibers have important advantages such as low density, appropriate stiffness, good mechanical properties, high disposability and renewability. Moreover, they are recyclable and biodegradable. Over the last decade, composites of polymers reinforced with natural fibers have received increased attention. Natural fiber, such as jute, possesses good reinforcing capability when properly compounded with polymers.

Drilling is a frequently practiced machining process in modern industry, owing to the need for component assembly in composite structures. High speed machining (HSM) has become one of the leading methods in the improvement of machining productivity. The term HSM covers high spindle speeds, high feed rates as well as high acceleration and deceleration rates. Furthermore, HSM does not imply only working with high speeds, but also with high levels of precision and accuracy. The development of an on-line drill wear monitoring system for HSM processes has been well recognized in industry, due to the ever-increasing demand for product quality and productivity improvement.

Wambua et al. (2003) compared the mechanical properties of different natural fiber composites. In most cases, the specific properties of the natural fiber composites were found to compare favorably with those of glass fiber composites. Palanikumar and Paulo Davim (2006) discussed the development of a mathematical model to predict the tool wear on the machining of glass fiber reinforced plastic (GFRP) composites using a statistical analysis to study the main and interaction effects of the machining parameters, namely, cutting

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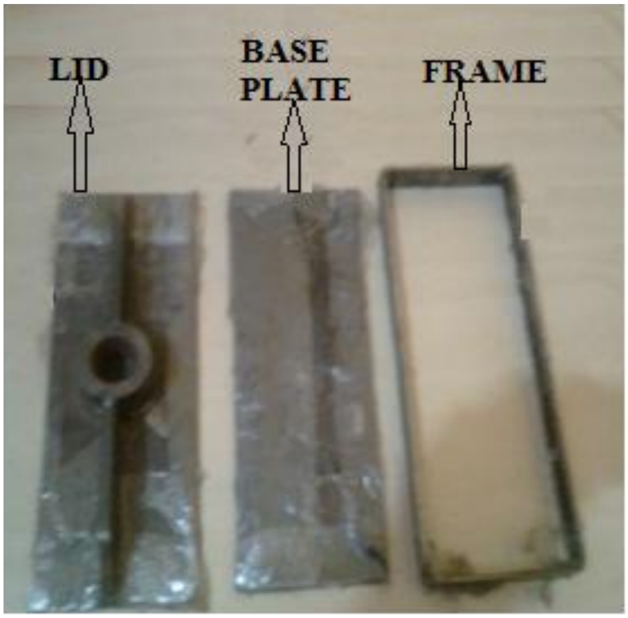

Figure 1. The selected pattern with the size of 120 x 80 x 12 mm. The pattern consists of three parts: the base plate, frame and lid. The base plate is a very thin plate which is placed inside the frame. The lid is placed on the top of the frame. The main purpose of the lid is to evenly distribute the load on the mixture, which is filled in the pattern.

speed, work piece (fibre orientation) angle, depth of cut and feed rate. Zampaloni et al. (2007) discussed the manufacturing problems and solutions of roselle natural fiber reinforced polypropylene composites.

Lin and Chen (2005) conducted a tool wear study of the effects of cutting speed and other cutting parameters on drilling characteristics, including cutting forces and tool wear, when drilling carbon fiber-reinforced composite materials at HSM. Tsao and Hocheng (2007) experimented the approach of thrust force and surface roughness produced by a candlestick drill, using the regression analysis and Radial Basis Function Network (RBFN). Xiaoli (1999) explained the method for on-line wear state monitoring and tool replacement decision-making, using a spindle motor and feed motor current signals in drilling. The models on the relationship between the current signals and the cutting parameters were established under partial experimental design and regression analysis. A fuzzy classification method was used to classify the tool wear states.

Xiaoli et al. (2005) provided a new tool breakage monitoring method for the machining center, using the current signal of the linear motor. New techniques were proposed by Ertunc and Oysu (2004) for real time identification of the tool wear status, based on the cutting force and torque measurements from the dynamometer during drilling, by using the Hidden Markov Models (HMM), phase plane method, transient time method and mechanistic approach. Li and Tso (1999) provided an on-line tool breakage detection of small diameter drills by monitoring the AC servo motor current. Li et al. (2000) presented a hybrid learning method to map the relationship between the features of cutting vibration and the tool wear condition. A neural network model with fuzzy logic was used to describe the relationship between the characteristics of vibration and the tool wear condition.

In automated manufacturing systems, drill wear detection plays a critical role in dictating the dimensional accuracy of the workpiece and guaranteeing an automatic cutting process. It is therefore essential to develop a simple, reliable and cost-effective on-line drill wear detection methodology for jute fiber reinforced composites in HSM. In order to accomplish the above objective, the following works were carried out. a) As per the American Society for Testing and Materials (ASTM) standard, jute fiber reinforced composite laminates were manufactured. b) A new on-line drill wear detection method was developed, based on the cutting current signal of the spindle motor using virtual instrumentation (VI). c) The drill wear model was developed based on cutting current signals and various cutting parameters with the aid of Laboratory Virtual Instrumentation Engineering Workbench (LabVIEW). d) Based on the model, cutting current signals were acquired, using the current sensor (current transformer) and the status of the wear was analyzed, using various cutting parameters. e) The defective tool replacement at the proper time was facilitated, based on drill the wear states in HSM of jute fiber reinforced composites.

MATERIALS AND METHODS

Chemical treatment

In this project, discontinuous natural fiber was used to fabricate the jute fiber reinforced composites. The fibers were cleaned normally in clean running water and dried. A solution was made of 80% NaOH and 20% distilled water in a glass beaker. After adequate drying of the fibers in normal shading for 2 to 3 h, the fibers were taken and soaked in the prepared solution. Soaking was carried out for different time intervals depending on the strength of the fiber required. In this study, the fibers were soaked in the solution for three hours. The fibers were then taken out and washed in running water, and dried for another 2 h. Chemical treatment with NaOH removes the moisture content from the fibers, thereby increasing its strength. This treatment clears all the impurities in the fiber material and also stabilizes the molecular orientation. The fibers are then taken for the next fabrication process.

Manufacturing jute fiber reinforced composites

The pattern was designed as per the ASTM standard. The pattern shown in Figure 1, used for the jute fiber reinforced composite material, is a rectangular mild steel plate with a dimension of 120 × 80 × 12 mm assembled with a top plate, side plate and a base plate. A glass beaker and a glass rod or a stirrer was taken and cleaned well with running water and warm water. The resin (Grade 3554A) and a hardener (3554B) were added in the ratio of 1:4 and the mixture was stirred for nearly 15 min (Mylsamy and Rajendran, 2011).

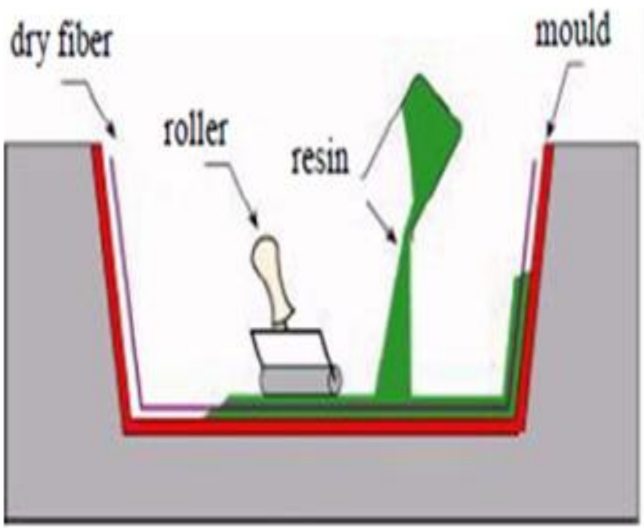

Figure 2. Hand lay-up moulding process. In this project, the hand-layup technique was used to fabricate the jute fiber reinforced composites. The base plate was fixed inside the frame and the releasing agent was applied over the plain sheet fixed on the base plate. Then, the resin and the fibers (unidirectional) were evenly layered in the mould, successively thrice.

Figure 3. The jute fiber reinforced composite laminate derived from the various manufacturing processes, such as chemical treatment, mixing and moulding, with the hand-layup process.

The reason behind this stirring was to create a homogeneous mixture of resin and accelerator molecules. After the mixing was over, the fibers were added and the stirring process was continued for the next 45 min. The ratio of fiber and resin was found to be 35:65. Then, the mixture was poured into the pattern and the roller was rolled on the mould for uniform settlement and the process was continuously done till the height of the mould reached 12 mm as shown in Figure 2. The lid was fixed on top of the frame to distribute the load evenly on the mould, and to allow the solidification for nearly 3 to 4 h. The setup was kept at room temperature for 24 h; then, the mould was taken out from the pattern. Finally, the jute fiber reinforced composite was fabricated, as shown in Figure 3. The process was repeated and necessary numbers of specimens were manufactured for the drill wear analysis in HSM.

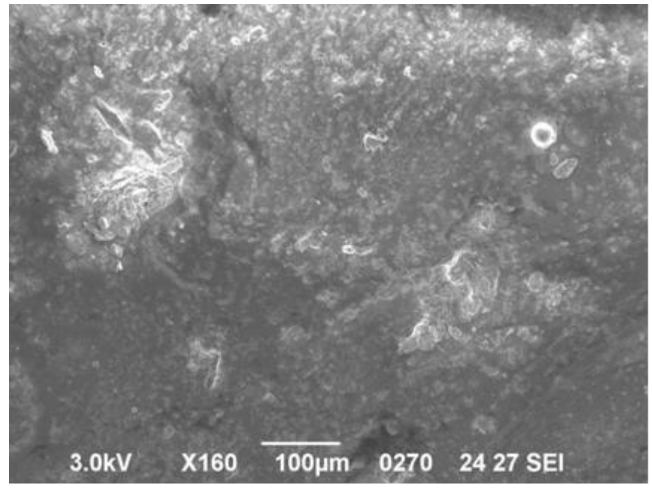

Figure 4. The SEM image of the jute fiber reinforced composite laminate examined for surface irregularities or fracture areas. SEM was employed in studying the morphological characteristics of the structure.

Scanning electron microscope (SEM)

SEM is a type of electron microscope that images the sample surface by scanning it with a high-energy beam of electrons in a raster scan pattern. The electrons interact with the atoms, which makes the sample produce signals that contain information about the sample's surface topography, composition and other properties such as electrical conductivity. SEM can produce very high resolution images of a jute fiber reinforced composite sample surface, revealing details about less than 2 to 5 nm in size. Due to the very narrow electron beam, SEM micrographs have a large depth of fielding a characteristic three-dimensional appearance, useful for understanding the surface of a sample structure. Jute fiber reinforced composite specimens are sputter coated with gold, then placed in a vacuum chamber for viewing the computer monitor at up to 10,000x magnifications as shown in Figure 4. An Electron Dispersive X-Ray Thermo detector (EDX) machine was used to study the composition of the microstructure of the Jute fiber reinforced composite shown in Figure 5.

Wear in drilling operation

Drilling

The drilling operation is frequently used as a preliminary step for many operations like boring, reaming and tapping; however, the operation itself is complex and demanding. The actual cutting ability of the drill is reduced with increased wear, resulting in poor surface finish, over-sized holes, built up edges along the lips, noise etc.;

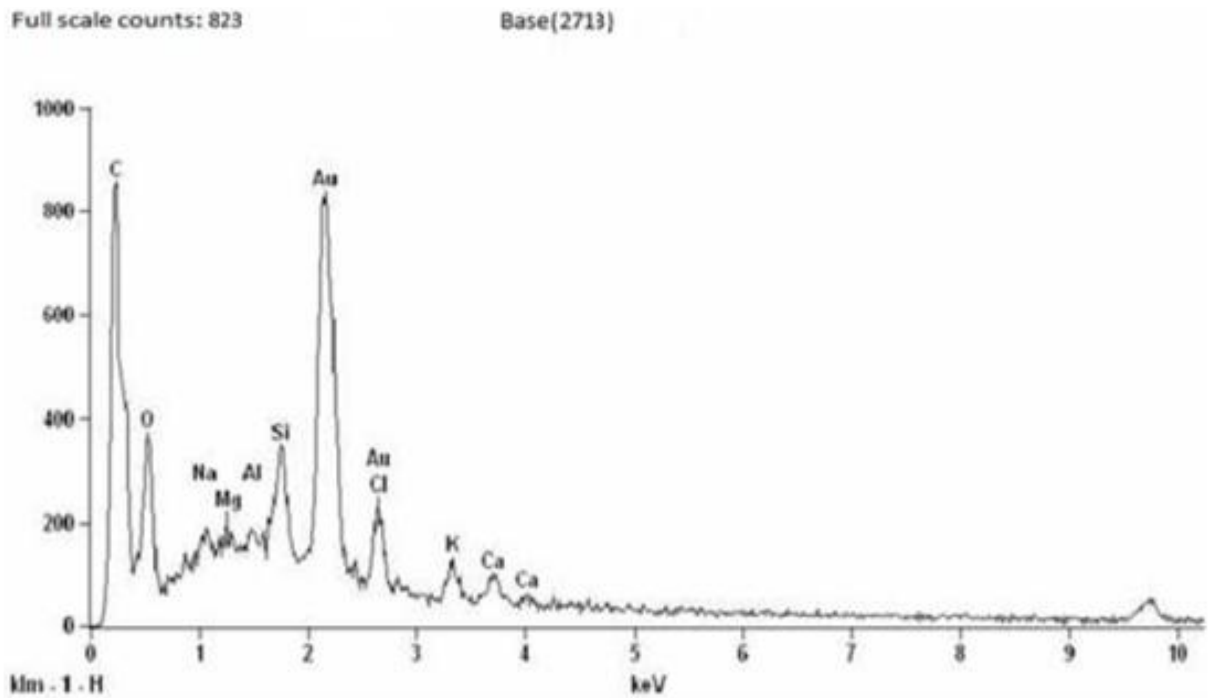

Figure 5. The EDX analysis of the jute fiber reinforced composites. It specifies various compounds present in this jute fiber natural composite laminate specimen.

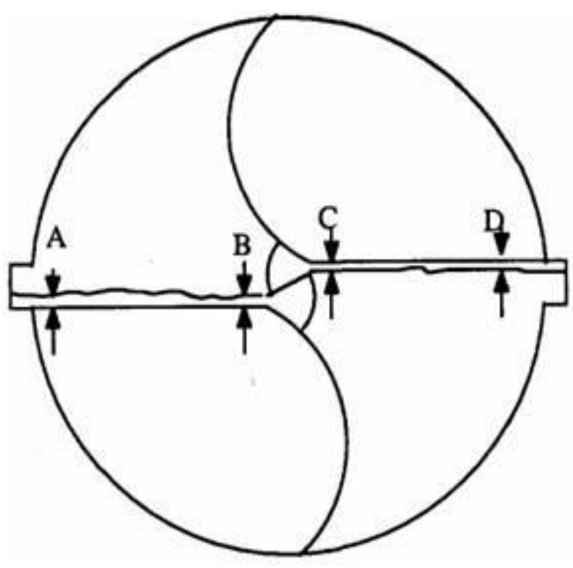

Figure 6. The measurement of flank wear. The average flank wear was computed by measuring the wear in each section, and then taking the arithmetic average, that is, average flank wear = (A+B+C+D)/4.

also, if the resharpening is delayed, more material has to be ground off. So, the online prediction of drill wear plays a very significant role in the HSM process. Monitoring of drill wear is an important issue, since wear on drill affects the quality of the hole and the tool life of the drill.

Drill wear

Drill wear is a progressive process which takes place at the outer margin of the flutes of the drill, due to the intimate contact and elevated temperatures at the tool workpiece contact. Drill wear differs from other cutting tool wears, such as turning, milling, etc. In addition, the chip flow creates significant friction between the cutter and the workpiece inside the drill hole. These frictional forces can significantly change the dynamics of the system and cause the cutter to break. Altogether, seven types of wear can be recognized: outer corner wear, flank wear (actually two types), margin wear, crater wear, chisel edge wear and chipping at the lip. Because of the adhering material, many of these wear types are difficult to measure in practice. Therefore, flank wear has been used as a measure of drill wear, since it can be easily and reliably measured. The measurement of flank wear is shown in Figure 6 (Li and Ting, 1996).

Stages of drill wear

Drill wear consists of the following stages: Initial wear stage, normal wear stage, moderate wear stage, ultimate or end wear stage and worn-out stage. Drill wear states can be classified as the function of tool life, which is obtained from the tool maker's microscope: the initial wear stage consists of the wear rate up to 0.1 mm. Normal wear stage consists of the wear rate between 0.1 to 0.2 mm. This wear stage is the initial position of the wear rate value. Hence, it will not create any damage to the tool and machine. Moderate wear stage has a wear rate value of 0.2 to 0.4 mm. In this stage, the tool has moderate wear. The ultimate wear stage is the severe stage of wear. In this stage, the wear range lies between 0.4 and 0.6 mm. It shows the exact wear matter in the output graph. In the ultimate

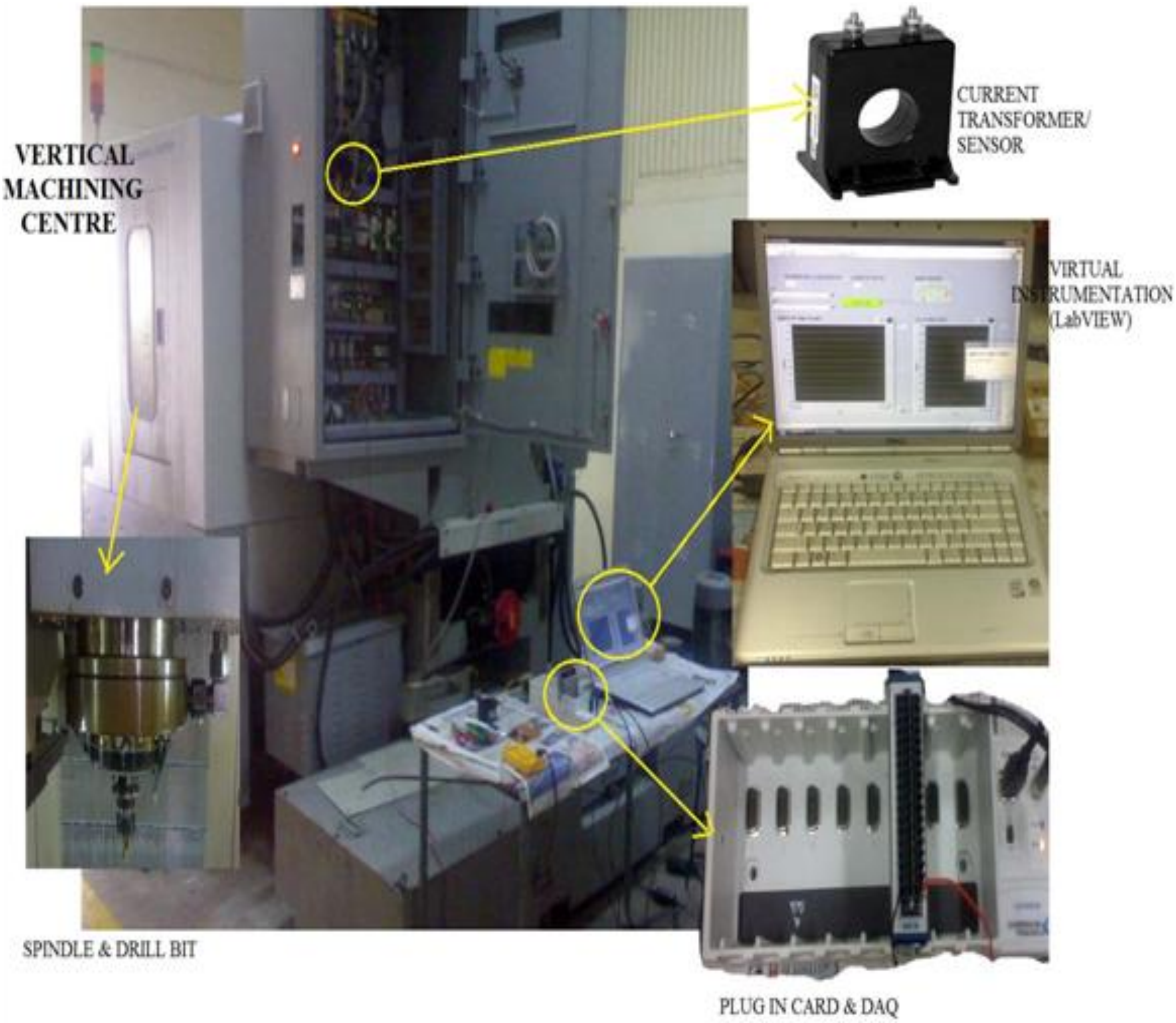

Figure 7. Experimental set-up for the on-line drill wear monitoring system. Experimental works are carried out on VMC under dry cutting conditions. A series of hardware (CT, DAQ with plug in card) and software (LabVIEW) was connected in the drill wear monitoring system in the application of VI.

wear stage, the tool has to be replaced. The final wear stage is worn-out stage.

Drill wear monitoring methods

Drill wear monitoring methods can be classified into two categories, which are direct and indirect methods. With direct methods, it is possible to determine the tool wear directly, which means that these methods really measure the tool wear as such. In spite of many attempts, direct methods, such as visual inspection or computer vision, etc. are not effective either economically or technically. In indirect monitoring methods, the wear is identified by measuring the parameters such as torque, force, vibration, sound, cutting current signals, etc. Most of the indirect approaches have been developed for fixed cutting conditions in practical applications; however, the cutting conditions are not fixed; therefore, a wear estimation strategy that operates under varying cutting conditions is much needed. So, the proposed on-line drill wear monitoring operates various cutting parameters with different drill wear states under indirect monitoring methods of the cutting current signals in a spindle motor drive.

Experimental work

Experimental set-up

Drilling experiments were carried out on the vertical machining centre (VMC), using a HSS twist drill and jute fiber reinforced composite as the workpiece. Figure 7 shows the experimental set-up for the on-line drill wear monitoring system. Table 1 shows the experimental conditions for the same on-line drill wear monitoring system. The spindle motor in VMC is directly driven by permanent magnet synchronous AC servomotors. During the experiments, the spindle motor current signals of the VMC were measured by the current transformer (CT) ***/*** current sensor which were mounted on the spindle motor drive. When the current in a circuit is too high it cannot be directly applied to the measuring instruments. So, the CT was used to produce a reduced current which can be accurately

Table 1. Experimental conditions for the on-line drill wear monitoring system. Drilling experiments were carried out on the VMC using HSS twist drill and jute fiber natural composite laminates, under various cutting parameters.

S/N	Specifications	
1	Varying cutting condition	Feed (0.15 to 0.30 mm/rev) Cutting speed (1500 to 3000 rpm) Drill diameter (Ø10 mm, Ø12 mm, Ø14 mm)
2	Work piece	Fabricated jute fiber reinforced composite laminates
3	Tool	High speed steel twist drill (HSS)
4	Sample size	400, during steady wear period of drill
5	Machine	Vertical machining centre (VMC)

proportional to the current in the circuit as well as conveniently connected to the measuring and recording instruments. The data acquisition card (DAQ) is a hardware, which converts the current signals into digital signals, and conditions, amplifies, measures, scales, processes, displays and stores the sensor signals. DAQ comes in many physical formats. A common type (National Instruments compact DAQ) NIcDAQ 9205 uses the plug-in card, which fits into the free expansion slot in the computer.

Virtual instrumentation (VI)

VI is defined as combination of hardware and software with industry-standard computer technologies to create user-defined instrumentation solutions. It specializes in developing plug-in hardware and driver software for data acquisition (DAQ). The driver software is the programming interface to the hardware and is consistent across a wide range of platforms. Application software such as LabVIEW, Measure and Component Works, Lab Windows/CVI, deliver the sophisticated display and analysis capabilities required for VI. Each VI contains three main parts: Front Panel (how the user interacts with the VI), Block Diagram (the code that controls the program), and the Icon/Connector (means of connecting one VI with the other VIs). LabVIEW is used for developing the drill wear model in the proposed on-line drill wear monitoring system. The block diagram (back panel) contains the graphical source code of the drill wear model. The front panel objects appear as terminals on the block diagram.

LabVIEW

LabVIEW is a platform and development environment for a visual programming language from National Instruments. LabVIEW is a graphical programming language that uses icons instead of lines of text, to create applications. In contrast to text-based programming languages, where instructions determine program execution, LabVIEW uses dataflow programming, where the flow of data determines the execution. LabVIEW gives the flexibility of a powerful programming language without the complexity of traditional development environments. LabVIEW is a graphical development environment with built-in functionality for simulation, data acquisition, instrument control, measurement analysis and data presentation.

Drill wear model for jute fiber reinforced composites

In order to establish the model of cutting current signals as the function of the cutting parameters and drill wear, the effects of the cutting parameters and the current signals for drill wear were first examined. A schematic diagram of the on-line drill wear monitoring system is shown in Figure 8. Cutting parameter information, that is, cutting current signals gathered by the CT are transferred to the drill wear model (LabVIEW) via DAQ. Inside the DAQ, the cutting current signals were sampled by an Analog to Digital Convertor A/D (wave form analyzer AF-550A, sample frequency 25 kHz), and given as input to a personal computer.

The drill wear model was constructed using LabVIEW, based on the cutting current signals and the various cutting parameters. Figure 9 shows the front panel of the drill wear model. The indicators on the front panel allow an operator to input data into or extract data from a running VI in the drill wear monitoring system.

The front panel displays the charts (current vs. time, voltage vs. time) based on the drilling process, wear states, current count, number of acquisition and backup files in the form of graphs and tables. Figure 10 shows the back panel of the drill wear model which holds the actual function of the drill wear model.

The function of the drill wear model consists of five stages. They are analog pre-processing, digital pre-processing, feature extraction, wear modelling and decision integration. Analog pre-processing refers to the processing of raw data for digitization. It is a stage mainly determined by the hardware used for data collection. Digital pre-processing refers to the filtering of the screen out noise and other unwanted signals contained in digitized data, and also to apply the analytical models to normalize the digitized data with regards to varying cutting parameters. Additionally, analog signal processing (both linear and non linear) is used to alleviate the processing load in the data acquisition system and the computer. The current signals are measured as the analog to digital (AD) converter output in mV, and displayed on the front panel of the on-line drill wear model. Feature extraction refers to the extraction of meaningful information from the digitized data, which is used in subsequent wear modeling stage, throughout the application. Wear modeling refers to the establishment of the dependency between the extracted features and drill wear conditions. Decision integration refers to the integration of the outputs from the drill wear model, to reach a final decision regarding the tool condition.

RESULTS AND DISCUSSION

A series of experiments was carried out between the cutting current signals and various cutting parameters. The experimental results were taken during the steady state wear period (sample drill holes were bored over the jute fiber reinforced composites). Table 2 shows the

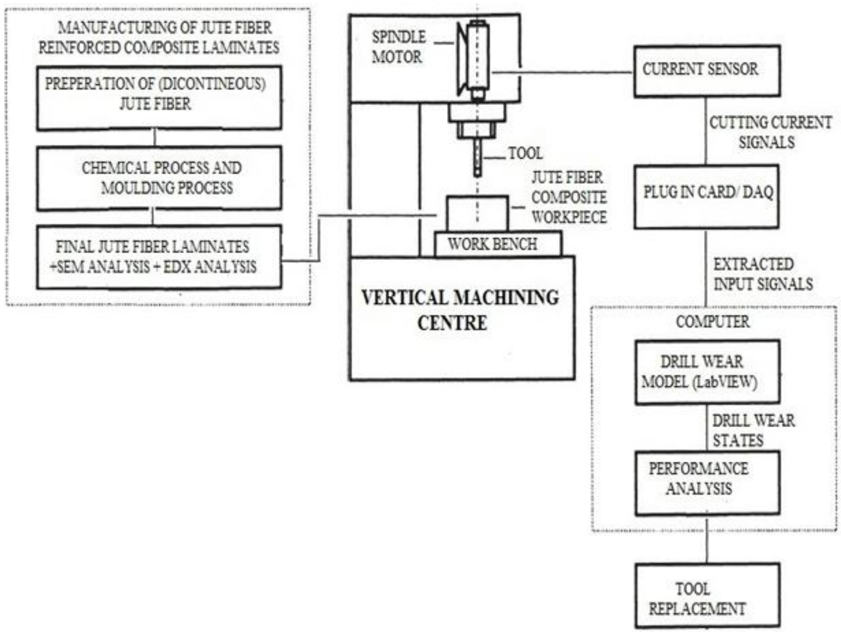

Figure 8. The schematic diagram of the on-line drill wear monitoring system, which provides the flow of the experimental work for the manufacturing of the jute fiber natural composite laminates, drill wear state monitoring through the cutting current signals and tool replacement control.

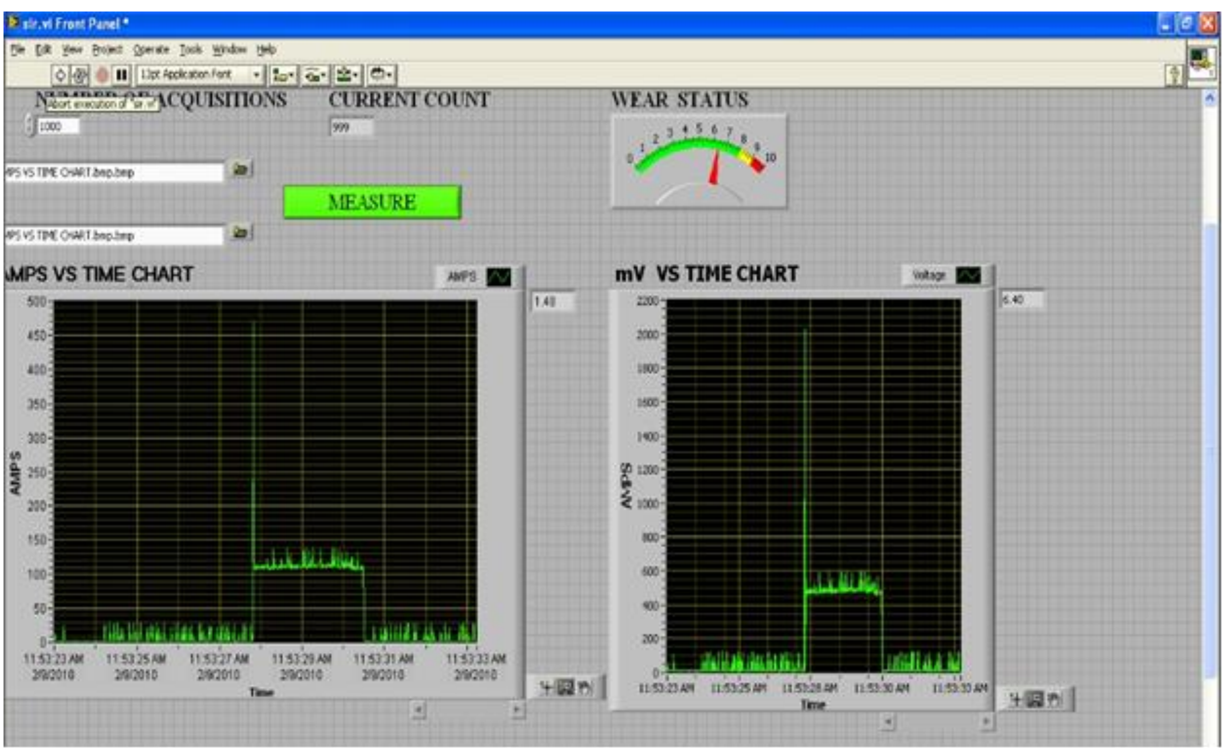

Figure 9. The front panel of the dill wear model, which is used to interact with the user when the program is running. Users can control the program, change the inputs, and update data in real time. Controls are used for inputs- adjusting a slide control to set an alarm value, turning a switch on or off, or stopping a program. Indicators are used as outputs. Every front panel control or indicator has a corresponding terminal on the block diagram. When VI is run, values from the controls flow through the block diagram, where the functions reside, and the results are passed into other functions or indicators.

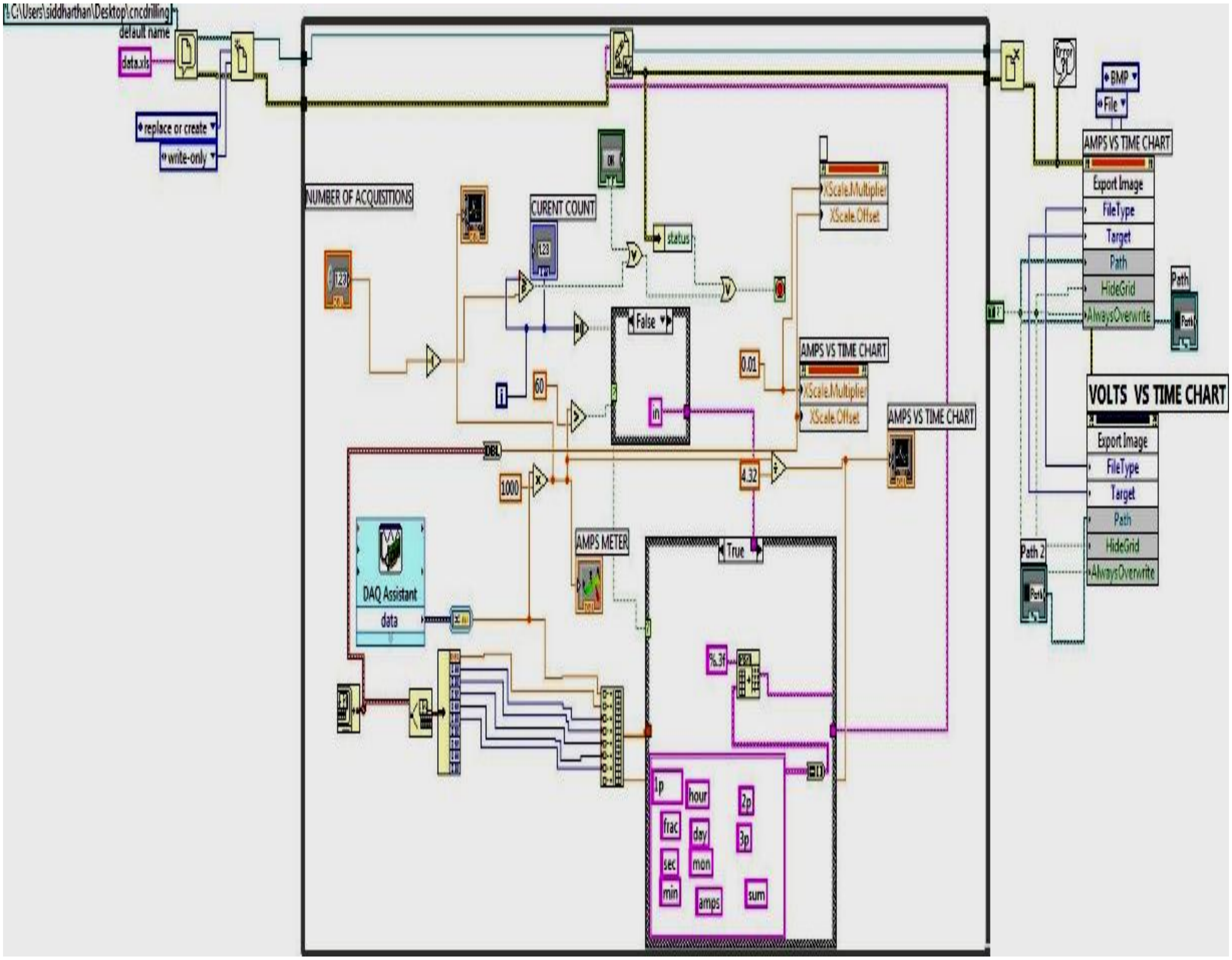

Figure 10. The block diagram of the drill wear model. It contains the functions and structures from the built-in LabVIEW VI libraries. Wires are connected to each of the nodes in the block diagram, including the control terminals, indicator terminals, functions and structures. An icon is a graphical representation of a VI. It contains text, images or a combination of both.

Table 2. Experimental results of the jute fiber reinforced composite laminates. Based on the relationship between the cutting current signals and drill wear states the tool replacement control was identified. The mode of control is specified as ‘in’ when the wear stage is upto moderate. When the wear stage crosses the moderate stage it is specified as ‘out’. Based on the decision on the wear stages, the tool has to be replaced immediately.

Power (w)	Fraction	Seconds	Minutes	Hours	Days	Mon(Fn)	Current (A)	Drill wear (mm)	Mode of control
0.026	0.32	51	24	12	9	2	2.37	0.21	In
0.031	0.56	53	24	12	9	2	2.51	0.26	In
0.037	0.72	57	24	12	9	2	3.11	0.31	In
0.041	0.62	01	24	12	9	2	3.45	0.35	In
0.046	0.68	05	24	12	9	2	4.09	0.39	In
0.052	0.44	09	25	12	9	2	4.31	0.44	Out
0.058	0.47	14	25	12	9	2	4.64	0.49	Out
0.064	0.52	15	25	12	9	2	5.29	0.54	Out
0.071	0.68	19	25	12	9	2	5.63	0.58	Out

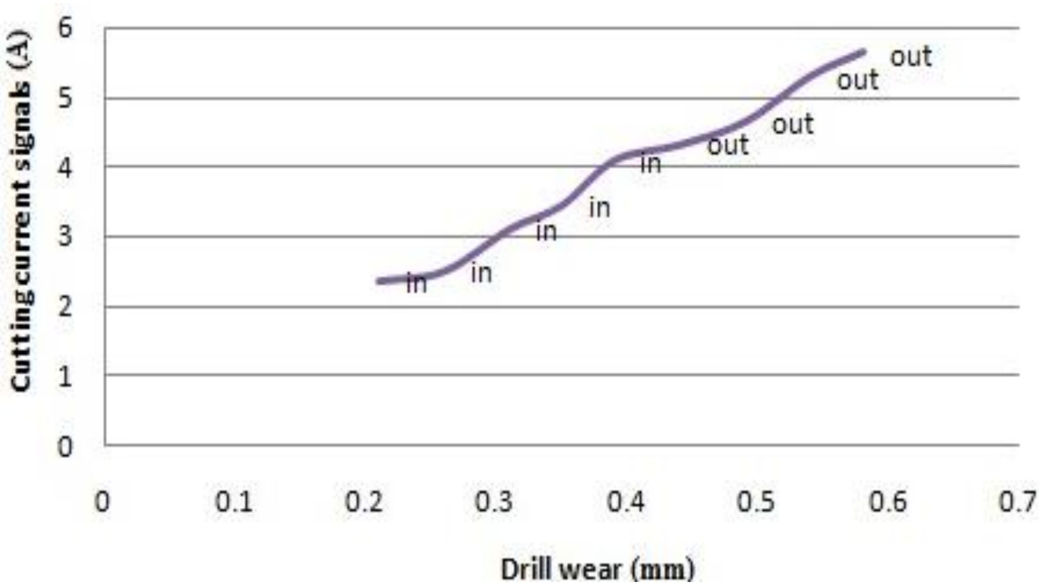

Figure 11. The relationship between the drill wear and the cutting current signals; it's associated with the friction between the tool and the workpiece. It is expected that the cutting current fluctuates when the tool gradually wears. It is generally known that the cutting forces increase through current signals as the tool wear increases. This is due to the increase of friction between the tool and the work piece. The mode of control is specified as 'in' when the wear stage is upto 'moderate'. When the wear stage crosses 'moderate' it is specified as 'out'. Based on the mode of control, the tool has to be replaced at the proper time.

results obtained from the front panel of the drill wear model and it shows the drill wear states for the jute fiber reinforced composites. The time variables are mentioned in the table since the drill wear model is for on-line. The drill wear is associated with the friction between the tool and the work piece. It is generally observed, that the current amplitude increases as the drill wear increases, with an almost linear incremental relationship, as shown in Figure 11. In drilling, it is possible to monitor the current signals during HSM, and it is expected that the cutting current fluctuates when the tool gradually wears.

Examining these results, the following conclusions can be made: The drill wear is exhibited on the front panel of the on-line drill wear model in the form of cutting current signals. The drill wear stage is monitored and estimated in the on-line basis using LabVIEW, through the cutting current signals. So, the new method for on-line drill wear stage monitoring using VI is very effective and simple for hole making industries, for composite materials, especially jute fiber reinforced composites.

Tool replacement control

One of the main objectives of detecting the drill wear stage is to obtain a basis for the replacement of the tools. Based on the model, the drill wear stage can be estimated from the knowledge of the various cutting parameters and the cutting current signals. The drill wear status is displayed in the front panel according to the drill wear, as shown in Figure 12. When the drill wear status is 'moderate', the alert has to be made, and when the status is 'ultimate', the tool has to be replaced. According to the wear status obtained, the decision on tool replacement can be made.

Conclusion

The different proportions of the jute fiber reinforced composite laminates were successfully manufactured and the quality of the drill in the composites was analyzed. The models regarding the relationship between the cutting current signals and drill wear for different drill wear stages were established through an experimental study using LabVIEW in the application of VI. The effects of drill wear under various cutting parameters were analyzed. The control of tool replacement requires the recognition of the drill wear stage, associated with the various cutting parameters and cutting current signals. In the proposed on-line drill wear state monitoring, the different wear stages of the jute fabric reinforced composites were exhibited effectively, so that the defective tool can be replaced at the proper time in the automated manufacturing environment. It was found that the proposed monitoring system provides a convenient way to estimate the drill wear accurately, using the cutting current signals. The experimental results show

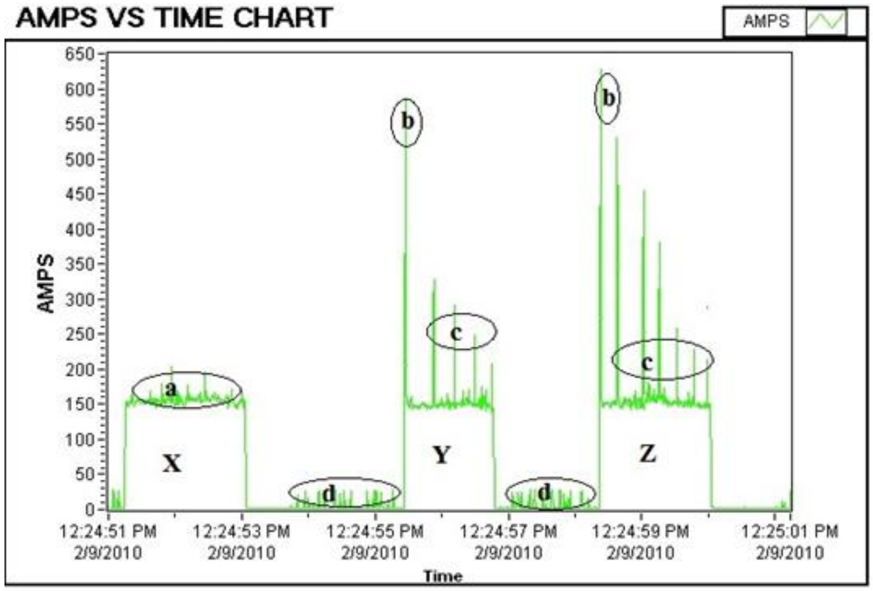

Figure 12. The effect of the drill wear on the sample by the spindle motor drive cutting current. The cutting current increases as the drill wear increases with linear incremental relationship. The sample holes (X, Y and Z) are taken during the steady state wear period of the jute fiber natural composite laminates. 'a' indicates minimal wear on the already drilled hole; it also specifies some fluctuations of current signals and machine vibrations during HSM. 'b' indicates the initial thrust on the newly drilled hole, and the rest of the peaks in 'Y' indicate the moderate wear stages. 'd' indicates the spindle rotation without producing any hole. 'c' indicates the maximum wear rise on the system, so that the tool has to be replaced immediately.

that the monitoring system can be effectively employed in practice. In future, the different proportions of the natural fiber composites can be taken for manufacturing natural composites, and the image processing can be used for analyzing the drill wear, based on image pattern matching, using LabVIEW.

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