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Review Paper

Monitoring and Control of Machining Process: A Review

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Abstract

Detection and control of machining parameters such as cutting force, torque, vibration, tool condition, and surface finish is essential for faultless machining in manufacturing systems. This study presents a review on regular and enhanced methods used for monitoring and control of metal cutting processes. The difference between the various available methods, structures and the corresponding equipments are identified and evaluated.

Keywords: Machining processes, Monitoring, Control.

Introduction

Machining process is shape transformation processes in which metal is removed from a work-piece in the form of chips to produce a part with specific quality and specifications[1]. Machining process is widely used in global manufacturing industries. Machining is a complex process which depends on several phenomena and small variation in any one of them can affect the desired resultsn[2,3]. Hence it is important to investigate and regulate these variables (i.e., cutting force, vibration, acoustic emission, torque, surface finish, etc) while machining[4]. Process monitoring is the manipulation of sensed measurements (e.g., vision, force, temperature) to determine the state of the processes and Process control is the regulation of input variables (process input variables are feed, speed, depth-of-cut)[5].

In-process sensing and control techniques can be viewed as a key component for the next generation of quality control. In current industrial scenario, excellence is ensured in the product engineering cycle at two distinct stages. At first stage, different statistical methods are applied for designing to ensure good quality product[6]. At the second stage statistical process control (SPC) methods are applied during inspection stage, to check the quality of the manufactured product[7]. However, real-time sensing and control will bring in a third level of quality assertion, which can be implemented during machining (i.e. in-process). This compliments statistical and SPC method, and reduces the requirement of costly post-process inspection[8].

However, there have been many improvements in the field of machining process control and development, started with the introduction of automation in the form of numerically controlled (NC) machine tools, after that due to significant evolution in the field of computers the computer numerically controlled (CNC) systems led to research interest in implementing a higher level process control. In these systems servo-control functions were implemented using on-board computers rather than hard-wired digital circuits. These process control systems are commonly referred as "adaptive control" (AC) systems in the manufacturing community[9-11]. Adaptive Control has been classified[12] into three main categories: [I] ACC Adaptive Control with Constraints, [II] ACO Adaptive Control with Optimization, [III] GAC Geometry Adaptive Control. In ACC systems the material removal rate is maximized through safeguarding the cutting forces at the highest possible rate, by not putting the tool into danger of breakage. The ACO systems deals with adjusting cutting variables (such as surface roughness, power consumed, operation time, cutting forces, cost and even more) for the maximization of material removal rate. However, a major problem in this system was absence of on-line measurement of tool wear estimation. Even today reliable methods for tool wear estimation do not exist in an industrial environment[13-15]. Lots of analysis, synthesis, and development work have been done in the field of adaptive controls used for monitoring and control machining process parameters[16,17]. This paper presents a review on work done in the field of monitoring and control of machining processes.

Monitoring of Machining processes

For the purpose of surveillance of machining process several monitoring techniques have been used. In all this methods different process parameters (e.g., force, power, acoustic emission, and feed motor current) are measured and compared on-line with estimated value[18,19]. The machining monitoring techniques can be broadly categorized into two methods, the first direct monitoring methods and second Indirect monitoring methods[5]. Direct monitoring methods are more accurate[20], but are limited up to laboratorial research work only, due to several practical limitations. On the converse, the indirect monitoring methods are less accurate and more appropriate at heavy manufacturing environment.

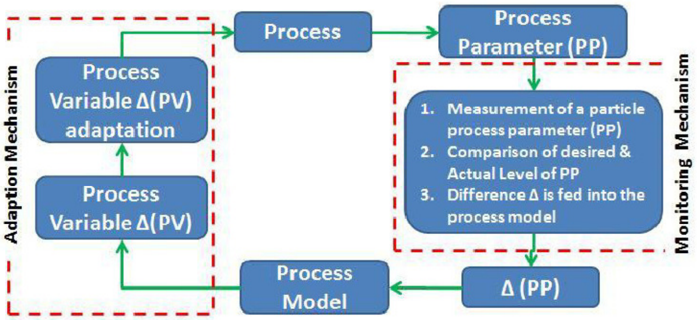

Figure-1
Process – Monitor – Control Loop[4]

Monitoring of Machine tool: Monitoring and control of machine tool is necessary for automated manufacturing. For preventing the machine damages due to lack of discretion of processes, monitoring is very much essential. Due to monitoring the damages can be prevented by stopping the process or by adjusting the process input variables. Lots of work has been done in the area of detection of chatter, tool wear and tool breakage. In the following section these approaches are discussed one by one.

Tool Wear Assessment: The quality of surface is directly influenced by flank wear[21]. Flank wear effect the distribution of heights and slopes of the surface and it alters the lubrication retention capability and some other tribological properties also [22-24]. Tool wear assessment is important to plan tool changes and to control tool life for manipulation of the cutting input parameters and to avoid scrape. Tool wear estimation methods can be broadly categorized into two types, first as direct method and second the indirect method[25]. Direct methods measure tool wear in terms of loss of material or worn out surface through optical methods[26,27]. In heavy manufacturing environment direct methods are less suitable and are not utilized in the field of in-process manufacturing. Within the indirect methods, flank wear is determined by linking it to different measured variable as temperature, vibration, work piece size change, cutting force, or acoustic emissions[28-32]. For the purpose of surface roughness measurement some more methods of non-contact type have also been utilized[33,34]. And for more sensitive measurement of tool wear, cutting force and Acoustic emission (AE) are being utilized and they are more reliable. Various studies have been done to correlate flank wear with the cutting force and similarly with the acoustic emission[35]. The functional analysis of AE signals and their statistical analysis have helped in defining the flank wear more clearly[36,37].

Tool Breakage Assessment: The prediction of tool breakage is very much essential in automated machining to avoid damage to the machine tool or work piece and to reduce downtime due to wrong alarms. With the objective of this, some tool breakage diagnosis systems have been developed to spot failures quickly and prevent any kind of damages. There are several parameters through which tool breakage can be indicated[38]. These parameters such as cutting force, AE signals, spindle and feed motor current and vibration have been utilized to predict or estimate the tool breakage[39-44]. On line tool breakage detection have been done in milling operation[45-46]. In spite of significant efforts, consistent and robust signatures of tool breakage have not yet been found. Spectrum analysis and pattern identification techniques have been utilized to evaluate the cutting state in the form of chatter and chip formation[47]. To predict tool breakage acoustic emission signals have also been analyzed and these signals have been utilized in categorizing chip formation and tool breakage[48]. In all these spectrum-based tool breakage detection techniques the large amount of computational tasks are associated for obtaining the spectrum. Instead of single-sensor-based approach a multi-sensor approach[49] for spectrum pattern classification was given using artificial neural networks which was able to give the tool breakage patterns. However, these neural networks prepared require excessive training. Another pattern classification method the multi-valued influence matrix (MVIM) method[50] requires less training compare to ANN and has a fixed structure and provides robust detection of tool breakages. For the purpose of online tool breakage assessment unsupervised neural networks have also been utilized with the application of multiple sensors [51].

Chatter Prediction: Chatter prediction is much more important rather its investigation because presence of chatter during machining may damage machine tool and can reduce dimensional accuracy as well as surface finish of the work piece. Chatter can be defined as self-excited vibration of machine tool, which may result in unstable cutting process. Therefore, it is required to detect machine tool chatter rapidly and initiate corrective actions before damage arise. The prediction of chatter is done by monitoring several variables such as cutting force signal, or the emitted sound from the machine. Mainly two major difficulties occur while monitoring chatter is to place the sensors on to the machine tools and the poor frequency response by the transducers[52]. In most of the chatter detection approaches analysis of frequency is performed at the locations where the vibrations are more prominent.

Cutting Force Monitoring: For the purpose of monitoring machining process there are number of systems which utilize force or torque signals. In the following section the review work in cutting force and torque monitoring is presented.

External Sensors: The sensors used for cutting force monitoring can be categories into two classes as external sensors and internal sensors. External sensor can be defined as devices which are mounted on the machine tool to measure cutting force or torque while machining[53]. Wide ranges of different force sensors are available commercially.

Force Sensors: The dynamometers based on piezoelectric effect are most widely used sensors for the purpose of cutting force measurement in industries[54]. Details about different type of dynamometers with their specification is widely available on web[55]. These dynamometers are applicable in micro machining, via non rotating tools or miniature rotating tool[56]. And these dynamometers are costly hence applied to limited area of machining monitoring [57].

Torque Sensors: Along with piezoelectric dynamometers[58] strain gauges had also been used to estimate cutting torque. Magnetostrictive torque sensor[59] was developed for monitoring torque in spindle while machining. Some difficulties occur while integrating these sensors in spindles due to heat in the spindle motor. Due to the less space availability installation of torque or force sensors within the spindles become difficult. Hence sensors are integrated into a tool holder for measuring torque. Strain gauges can be integrated into a tool holder to compute axial, radial forces and torque[60].

Internal Sensors: In numerically-controlled machines different parameters like motion, cutting torque or force is calculated from a motor’s armature current. Therefore no extra sensors are needed so this way this approach of force sensing is cheap at the price. For tool breakage detection[61,62] servo motor current was utilized to estimate cutting force. Tool breakages have also been detected by monitoring the spindle motor current[63]. In many CNC machines, spindle load is displayed on a screen. While analyzing cutting force the dynamic analysis of the moving mass is important. Cutting force can be measured in multi-axis NC machine also[64]. In the feed drives cutting force detection while cutting is also possible[65,66]. Various Algorithms like domain analysis, statistic analysis, artificial neural network, wavelet analysis, and complexity analysis has been applied for fault diagnosis and machining process analysis[67-71.]

Processes Control

Process control is the next step to process monitoring, where the controllers correct the anomalies between the measured and desired values. Due to arrival of open-architecture controllers it became possible to execute control systems in machine tools[72]. Machine tool control is usually accomplished at two levels: (I) servo-control to execute the motion command, or (II) supervisory control to repeatedly regulate the process variables for regulating the process[73].

Conclusion

On the basis of review work conclusions drawn are as follows:

Despite of so many research work and developments only few techniques of monitoring and control are actually utilized in manufacturing environment, because most of the monitoring systems developed are specific to isolated platform, and cannot be integrated with other solutions to provide an effective control for maintaining optimal process performance.

Due to in-process sensing and control, now quality can be assured while operation itself. Where as in the conventional product engineering cycle the quality could be maintain during the design or inspection stage only.

Most of the control systems are expensive because they use costly devices and techniques hence are limited to laboratories for research purpose.

Implementation of monitoring and control systems in production can be done either by retrofitting the existing machine tools or it is incorporated into new machine tools. In the process of retrofitting machine tool, the problem of production downtime is associated therefore it is less justified method for implementing monitoring and control system in manufacturing.

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