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Intelligent adaptive control and monitoring of band sawing using a neural-fuzzy system

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ABSTRACT

In bandsaw machines, it is desired to feed the bandsaw blade into the workpiece with an appropriate feeding force in order to perform an efficient cutting operation. This can be accomplished by controlling the feed rate and thrust force by accurately detecting the cutting resistance against the bandsaw blade during cutting operation. In this study, a neural-fuzzy-based force model for controlling band sawing process was established. Cutting parameters were continuously updated by a secondary neural network, to compensate the effect of environmental disturbances. Required feed rate and cutting speed were adjusted by developed fuzzy logic controller. Results of cutting experiments using several steel specimens show that the developed neural-fuzzy system performs well in real time in controlling cutting speed and feed rate during band sawing. A material identification system was developed by using the measured cutting forces. Materials were identified at the beginning of the cutting operation and cutting force model was updated by using the detected material type. Consequently, cutting speed and feed rate were adjusted by using the updated model. The new methodology is found to be easily integrable to existing production systems.

1. Introduction

In band sawing, the power rating of the machine limits the thickness and hardness of the metal to be cut. In band sawing process, metal removal is accomplished by forcing a multi-toothed tool against the workpiece. The depth of cut in sawing cannot be preset like other metal cutting processes and control can only be exercised over the thrust load applied between the blade and workpiece material. The amount of metal removed by each tooth is dependent primarily on how well the blade transmits the applied pressure to the workpiece and also on the penetration ability of the cutting teeth. Machining forces generated during sawing process are therefore found to have greater significance than in other chip removal processes. It has been found that thrust and cutting loads per tooth per unit thickness reduced with an increase in cutting speed. A reduction in the thrust force will cause a reduction in the depth of cut taken by the engaged teeth. An increase in the feed rate causes a substantial increase in both cutting and thrust loads per tooth. Geometry of the workpiece does also have a considerable influence on cutting performance. In band sawing, the thrust load is normally constant along the workpiece breadth. When sawing round sections the width of the workpiece changes within the cut, the cutwidth increases as the blade moves towards the centre and decreases as the cut is being finished. Band saw machines that operate on a pressure feed principle maintain a constant chip load per tooth as described while the blade saws through varying sections.

Artificial intelligence (AI) methods are widely used in solution of complex engineering problems. Some of the most commonly used AI techniques are neural networks (NN), fuzzy

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Nomenclature

D	diameter
e	output error
f	feed rate
f_i	instantaneous feed rate
F_{out}	process output
F_{meas}	measured force
F_{ref}	reference force
G	material group no
H	hardness
I	integral of error
IAM_1	intelligent adaptive module
L	instantaneous height
MRR	material removal rate
PI	performance index
TWR	tool wear rate
y_{proc}	plant output
y_{ref}	reference model output
v_i	instantaneous cutting speed

logics (FL), expert systems (ES) and models using hybrids of these.

Artificial intelligence methods are used in every stage of manufacturing. Machining is one of the basic manufacturing methods used in the industry. Manufacturers must minimize cost and process time, and additionally the product must comply with the required dimensions and quality criteria for a better competition.

Increasing the productivity of metal cutting machine tools is a principal concern for manufacturing industry. In traditional machining systems, cutting parameters are usually selected prior to machining according to machining handbooks or the user's experience. The selected machining parameters are usually conservative to avoid machining failure. To ensure the quality of machining products, to reduce the machining costs and increase the machining efficiency, it is necessary to adjust the machining parameters in real-time and to optimize machining process at that time. Adaptive control of the machining process is preferable to solve above problems.

Since band sawing process is non-linear and time-varying, it is difficult for traditional identification methods to provide an accurate model. Adaptive control methods provide on-line adjustment of the operating conditions. Therefore, parameter adaptive control techniques for machining processes were developed to adjust the feed rate automatically to maintain a constant cutting force. Applications of these techniques successfully increased both the metal removal rate and tool life.

In this paper, an intelligent neural-fuzzy adaptive control scheme is proposed for band sawing process. The proposed adaptive control system can be applied effectively in various cutting situations.

2. Literature survey

There are a lot of works existing in the literature on monitoring and controlling of the machining operation.

Groover pointed out that conventional control theory could be inefficient and unstable due to disturbing variations in the machining conditions. It is stated that fixed cutting forces would be a useful approach for increasing tool life and material removal rate (Groover, 1987).

The conventional PID feedback control system has been used in controlling machining processes by numerous researchers (Masory and Koren, 1980, 1985; Lauderbaugh and Ulsoy, 1989; Koren, 1988). The main problem with the fixed gain Adaptive Control Constraint (ACC) system is the one that produce poor performance and may become unstable during the time-varying machining process. The use of various forms of adaptive control in an ACC system has been examined by adjusting the gain of the controller.

Model reference adaptive control-based ACC systems (MRAC) have been developed by some researchers (Masory and Koren, 1980, 1985; Lauderbaugh and Ulsoy, 1989). These studies found that MRAC perform control duties better than fixed gain controllers. A typical MRAC incorporates the parameter estimation of the cutting process.

Recently, many studies have been devoted to the theory of fuzzy control and its application to machining processes. Tarng et al. developed a fuzzy logic-based controller (FLC) for adaptive control of turning operations. The developed FLC can adjust feed rate on-line so as to reduce machining time and maintain constant force (Tarng and Cheng, 1993; Tarng and Wang, 1993).

In the experimental studies of Zhang and Khanchustambham (1993), it is shown that process optimization is possible by online monitoring and controlling of the machining process. This eliminates the effect of disturbances caused by operator.

An online monitoring system was designed by Ordonez et al. (1997) by using artificial intelligence based on sensors. Signals which were taken from sensors are used in AI decision making during the cutting process. The real time signals obtained through force transducers and estimated cutting forces obtained by using NN were compared. Consequently, estimated model was implemented to surface roughness, tool wear and geometric tolerances. Feed forward and back propagation algorithms were used as architecture and training algorithm of NN model, respectively. Direct and indirect adaptive fuzzy techniques and simulations of conventional controls were compared.

An adaptive control approach was suggested by Rodolfo et al. (1998) for maintaining the cutting force constant, in the milling process. The constant force feed rate was investigated without delay time.

Tsai et al. (1999) observed that, surface roughness can experimentally be determined by one or more quantitative measurements. Estimated surface roughness model was based on relative vibrations between the tool and the work piece. Estimated surface roughness was improved by using signals that are taken from vibration and proximity sensors. System accuracy was observed as 96–99%.

An adaptive controller with optimization was designed based on two kinds of NN by Liu and Wang (1999) for milling process. A modified back propagation NN was proposed adjusting its learning rate and adding dynamic factor in the learning process, and was used for the online modeling