GAIN SCHEDULING CONTROLLER FOR TOOL AND CUTTER GRINDING MACHINE AND ITS COMPARISON WITH FIXED GAIN CONTROLLER

1JYOTI PATKURE, 2DAGADU MORE, 3MAHESH TODKAR

1WCE Sangli , 2WCE Sangli, 3KSSPL Bangalore
Email: jtpatkure@gmail.com, dsm.wce@gmail.com, thetodkar@gmail.com

Abstract— This paper deals with closed loop control of CNC operated tool and cutter grinder machine with conventional fixed gain controller and adaptive gain scheduling controller. Reliable spindle power model is developed for the purpose of simulation and is validated. Fuzzy logic based gain scheduling control scheme for tool and cutter grinding machines is proposed in this paper. Series of simulation work with different machine parameters and disturbance condition is carried out to verify utility of the scheme. Performance of gain scheduling controller is compared with conventional fixed gain controller. From simulation result it is clear that gain scheduling controller offers better tool protection against catastrophic failure and also assures good productivity.

Keywords— Grinding, Gain scheduling controller, Fixed gain controller, Fuzzy logic

I. INTRODUCTION

Grinding is an abrasive machining process and it plays a vital role for final shaping of the components in precision manufacturing which requires high quality and accuracy of shape and dimensions. Recent advances in computer technology resulted in ever growing use of computer numerically controlled (CNC) machines for the grinding process. The great advantage of CNC based machining is its accuracy, also it reduces skill and effort requirement of machine operator. Despite of many advantages, CNC based grinding suffers by common drawback that its machining parameters are manually selected in open loop fashion. It is a common practice to choose grinding parameters conservatively according to grinding data handbook or depending upon experience and skill of the machine operator. Also CNC machine has provision of feed override knob in order to adjust the feed while running grinding operation. It is common practice by machine operator to keep on decreasing the feed with the help of feed override knob considering adverse cutting conditions. Practically such adverse cutting conditions seldom occur hence in many cases selected parameters are too conservative and not adapted to maximize the utility of the grinding machine. Such practice reduces productivity and increases the cost.

Also the grinding process is characterized with large number of uncertainties. In case of grinding the tool geometry is not well-defined like turning or milling processes. Abrasive grits are of irregular in shape and randomly distributed on the surface of the grinding wheel. In grinding process the cutting conditions are continuously varying as a result of variations in material hardness, variations in tool sharpness due to wheel wearing, variations in width and depth of cut due to vibrations. As open loop CNC machines cannot deal with such a variable cutting conditions it is necessary to control the process in the closed loop fashion. In the literature three types of control schemes are explained in order to control the machining process, viz. adaptive control with constraint (ACC), adaptive control with optimization (ACO) and geometric adaptive control (GAC). In ACC one or more machining variables are maximized under constraints in order to improve the productivity. In case of ACO, cost function is developed and optimized under practical constraints. GAC maintains surface quality and accuracy despite of tool wear and deflections. This paper deals with ACC approach; here feed is maximized under spindle power constraint.

Conventionally fixed gain controllers like proportional (P), proportional – integral (PI), proportional – integral - derivative (PID) are used to control grinding process due to its simplicity. Considering uncertainties and complexities in the grinding process, gain scheduling controller is simulated and its response is compared with the fixed gain PI controller. Ecogrind RX5+ tool and cutter grinding machine is considered for cylindrical tungsten carbide blank grinding with diamond wheel. Although results are generated only for straight flute grinding, proposed technique can be applied to any rough grinding operation in tool and cutter grinding machine.

The rest of the paper is organized as follows. Section II covers development of grinding power model. Control of grinding process with fixed gain PI controller is covered in Section III. Gain scheduling control
scheme for grinding is introduced in Section IV. Section V contains results of comparison between fixed gain and gain scheduling control scheme for grinding. In the last section conclusion about simulation results is given.

II. GRINDING POWER CONSUMPTION ESTIMATOR

To analyze the performance of tool and cutter grinder machine with fixed gain and gain scheduling controller, first it is necessary to develop a model which represents the

Table 1: Actual and calculated values of the power

<table>
<thead>
<tr>
<th>Speed (rpm)</th>
<th>Feed (mm/min)</th>
<th>Power Consumed (kW)</th>
<th>% Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>80</td>
<td>2.65</td>
<td>0.05</td>
</tr>
<tr>
<td>30</td>
<td>120</td>
<td>3.50</td>
<td>0.03</td>
</tr>
<tr>
<td>25</td>
<td>180</td>
<td>4.55</td>
<td>0.05</td>
</tr>
</tbody>
</table>

Grinding process. Grinding power model is developed and validated as follow.

Power consumed in grinding is obtained by taking product of specific grinding energy and metal removal rate (MRR). The relationship for grinding power calculation can be expressed as

\[ P = K_c \times MRR \] (1)

Where, \( P \) is spindle power, \( K_c \) is specific grinding energy and MRR is material removal rate. Specific grinding energy is energy required to remove unit volume of material. It depends upon machining variables and properties of material to be grind. Specific grinding energy is a function of material removal rate; the relation can be mathematically expressed as

\[ K_c = K \times (MRR)^v \] (2)

\( K \) and \( v \) are constants, found from experimental data. Metal removal rate depends upon feed, depth of cut and wheel, work-piece dimensions. It can be calculated using expression

\[ \text{MRR} = \text{Depth of cut} \times \text{Width of cut} \times \text{feed} \] (3)

Grinding power consumption estimator is built in Matlab Simulink. The experimental and calculated values of power consumption are represented in the table I. As percentage error between actual and calculated values of power is very less, one can assume that the power model is reliable.

III. CONTROL OF GRINDING PROCESS WITH FIXED GAIN CONTROLLER

Fig. 1 represents conventional method to control a grinding process with fixed gain controller. Here feed is controlled under spindle power constraint. This is a typical ACC type control scheme. Here grinding power model calculates the power required to complete grinding operation with specified wheel and work-piece specifications and chosen grinding parameters. This actual spindle power value is sensed by sensor and fed back for comparison with the constraint power. The error between actual spindle power and constraint power is processed by fixed gain controller. The fixed gain controller could be Proportional (P) or Proportional-Integral (PI) or Proportional-Integral-derivative (PID) type. As PI controller assures zero steady state error, PI controller is chosen as a fixed gain controller. Hence command feed (Uc) will be

\[ Uc = k_p \times E + k_i \int E \, dt \] (4)

Where \( Uc \) is command feed. \( k_p \) and \( k_i \) are proportional and integral gain respectively and \( E \) is error

According to command feed servo system sets the feed value. The Simulink block diagram of this control scheme is given in fig. 2.

A. Control of grinding process with gain scheduling controller

B. Considering uncertainties and variable cutting conditions in grinding process, adaptive gain scheduling control technique is proposed. In this case proportional and integral gain of PI controller are not constant but are scheduled with the help of fuzzy gain block depending upon actual spindle power. Fig. 3 represents the applied control scheme.

C. Power model calculates the power required to complete grinding operation when wheel, work-piece conditions and chosen machining parameters are...
This actual power value is fed to fuzzy gain block. Crisp power value is first fuzzified in fuzzy gain block. Depending upon membership functions and rule base specified in the knowledge base, inference engine decides the corresponding values of proportional and integral gain. These gain values are fed to PI controller. Depending upon these gain values PI controller processes the error between constraint power and actual spindle power and gives corrective feed value. Fuzzy gain block is single input single output Mamdani type fuzzy logic controller. Combination of triangular and trapezoidal membership functions is used. Centroid method of defuzzification is applied.

With this control technique the grinding power is continuously monitored and accordingly gain of the PI controller is scheduled such that optimal feed override is selected. Smaller spindle load reflects lesser power consumption than constraint power, which activates higher feed value. Higher spindle load reflects higher power consumption, which triggers smaller feed value. This control scheme assures robustness during rise of feed and tool protection during fall of feed by offering different rate of rise and fall of feed. Also during air cutting, no material is removed and spindle is less loaded hence controller sets maximum feed value to reduce cycle time. The Simulink block diagram of this control scheme is represented with fig. 4.

**IV. RESULTS**

Response of tool and cutter grinding machine with fixed gain controller and with fuzzy gain scheduling controller are simulated. Their performances are analyzed on the basis of response during wheel, work-piece engagement, response to momentary and prolonged disturbance condition, simplicity and ease of implementation.

E. Wheel, work-piece engagement

In case of fixed gain controller, the response mainly depends upon selected gain values. With proportional gain $k_p= 20$ and integral gain $K_i= 50$ result obtained are as shown in fig. 5a. In this case high initial overshoot is seen. Power is about 300% of constraint power and after about 13 seconds it falls to constraint power. Such spindle loading during wheel, work-piece engagement, may damage the work-piece.

With proportional gain $k_p= 10$ and integral gain $K_i= 15$ result obtained are as shown in fig. 5b. In this case initial overshoot is avoided but actual power takes about 20 seconds to reach the constraint power value. This practice increase cycle time. Hence with fixed gain controller there is tradeoff between tool protection and productivity. In order to obtain optimized response, it is necessary to tune gain values of PI controller carefully. Also any change in machining parameter value leads to tuning of new set of gain value and it may consume more time.

With gain scheduling controller, during wheel work-piece engagement, small gain values are selected which gives small feed and power values. After complete engagement gain scheduling controller selects gain such that feed is slowly increased and actual power starts following constraint power. Refer fig 5c. This strategy protects tool against damage due to spindle loading during wheel and work-piece engagement.
a. Response of fixed gain controller with Kp=20 and Ki=50, during wheel and work-piece engagement  

b. Response of fixed gain controller with Kp=10 and Ki=15, during wheel and work-piece engagement  
c. Response of gain scheduling controller, during wheel and work-piece engagement  

F. Response  

to disturbance conditions  

Grinding process is characterized with large number of uncertainties. The disturbance conditions may occur due to vibrations, uneven work-piece hardness, wheel wear and external disturbances. During disturbance conditions actual spindle power rises above the constraint power, which may damage the work-piece, grinding wheel or machine tool. Controller is supposed to maintain the spindle power below constraint power, despite of disturbance conditions. For the purpose of simulation, momentary disturbances are modeled as saw tooth wave for limited time and prolonged disturbances are modeled as a step change.

a. Response of fixed gain control scheme to the momentary disturbance of 10 seconds  
b. Response of gain scheduling control scheme to the momentary disturbance of 10 seconds  

H. Simplicity and implementation  

Fixed gain controllers are simpler and easier to implement than adaptive gain scheduling controllers. To implement gain scheduling controller with analog technique, it is necessary to have function generator and multipliers but it can be easily implemented in computer controlled machines.

CONCLUSION

Reliable spindle power estimator for grinding process is developed in Matlab Simulink. Adaptive gain scheduling control technique and conventional fixed gain control technique are simulated for tool and cutter grinder machine. Performance of tool and cutter grinder machine is compared on the basis of simulation results. From simulation results it is clear that gain scheduling control technique offer better productivity and tool protection than conventional fixed gain control technique.

Gain scheduling control technique also deals with various uncertainties in grinding process. Hence adaptive gain scheduling control scheme is helpful to save both cost and time of the process.

REFERENCES


