ADAPTIVE CONTROL MACHINING

INTRODUCTION

Adaptive control system is a logical extension of the CNC-mechanism. In CNC mechanism the cutting speed and feed rates are prescribed by the part programmer. The determination of these operating parameters depends on the Knowledge and experience regarding the work piece, tool materials, coolant conditions and other factors. By contrast in adaptive control machining, there is improvement in the production rate and reduction in the machining cost as a result of calculating and setting of optimal parameters during machining. This calculation is based on measurements of process variables in real time and followed by a subsequent on-line adjustments of the parameters subjected to machining constraints in order to optimize the performance of the overall system.

Adaptive control (AC) machining originated out of research in early ١٩٦٠'s sponsored by U.S Air Force. The initial adaptive control systems were based on analog devices, representing the technology at that time. Today adaptive control uses microprocessor based controls and is typically integrated with an existing CNC system.

Adaptive control possesses attributes of both feedback control and optimal control. Like a feedback system measurements are taken on certain process variables. Like an optimal system, an overall measure of performance is used. In adaptive control, this measure is called the index of performance (IP). The feature that distinguishes adaptive control from other two types is that an adaptive system is designed to operate in a time varying environment. It is not usual for a system to exist in environments that change over the course of time. An adaptive control system is designed to operate for the changing environment by monitoring its performance and altering accordingly, some aspects of its control mechanism to achieve optimal or near optimal routine. The feedback and optimal systems operate in a known or deterministic environment. If the environment changes significantly, these systems might not respond in the manner intended by the designer. On the other hand, the AC system evaluates the environment, more accurately. It evaluates its performance within the environment and makes the necessary changes in its control characteristics or if possible, to optimize its performance.

FUNCTIONS OF ADAPTIVE CONTROL

The three functions of adaptive control are:

١. Identification function.

٢. Decision function.

٣. Modification function.

IDENTIFICATION FUNCTIONS

This involves determining the current performance of the process or system. Normally, the performance quality of the system is defined by some relevant index of performance. The identification function is concerned with determining the current value of this performance measure by making use of the feedback data from the process. Since the environment will change overtime, the performance of the system will also change. Accordingly the identification is one that must proceed over time or less continuously. Identification of the system may involve a number of possible measurements activities.

DECISION FUNCTION

Once the system performance is determined, the next function is to decide how the control mechanism should be adjusted to improve process performance. The decision procedure is carried out by means of a pre-programmed logic provided by the designer. Depending upon the logic the decision may be to change one or more of the controllable process.

MODIFICATION FUNCTION

The third AC function is to implement the decision. While the decision function is a logic function, modification is concerned with a physical or mechanical change in the system. It is a hardware function rather than a software function. The modification involves changing the system parameters or variables so as to drive the process towards a more optimal state. The process is assumed to be influenced by some time varying environment. The adaptive system first identifies the current performance by taking measurements of inputs and outputs. Depending on current performance, a decision procedure is carried out to determine what changes are needed to improve system performance. Actual changes to the system are made in the modification function.

ADAPTIVE CONTROL SYSTEMS

The adaptive control of metal working process is a logic extension of numerical control and computer control. In NC process as described so far, the cutting speed and feeds are prescribed by the path programmer. The determination of these parameter depends on his knowledge and experience about the work piece and tool materials, coolant condition and other factors. The main idea of AC is the improvement of the cutting process by automatic on line determination of speed and/or cutting. The AC is basically a feedback system in which cutting speed and feed automatically adapt themselves to the actual condition of the process and are varied accordingly to the changes in the work conditions as work progresses. That is done by performing of the process output variables and calculating either a performance level or machine constrains.

In practice the AC system of machine tools can be classified into two types:

١. AC with optimization (ACO)

٢. AC with constrains (ACC)

ACO refers to systems in which the performance is optimized according to a prescribed IP, sometimes called the figure of merit. The IP is usually an economic function such as maximum production rate or minimum machining cost.

ACC are systems in which machining conditions such as spindle speed or feed rate are maximized within the prescribed limits of machines and tool constrains such as maximum torque, force or horse power. It has been shown in cases where part configuration is not simple; the NC has many economic advantages over conventional machining process. Similarly the use of AC systems is mostly justified when extremely hard materials such as titanium and stainless steel have to be machined. A further saving of time is achieved in the programming stage. In selecting feeds and speeds, the programmer must accommodate the worst cutting conditions. In AC system the correct feed and speed are automatically found and it is not necessary to spend efforts on calculations of optimum feeds and speeds. By increasing tool life simultaneously with time saving, the adaptive control system contribute to lower operating costs, which justifies the extra price of adding AC to a conventional NC machine.

DEFINITION OF AC MACHINING

For a machining operation the term AC denotes control systems that measures certain output variables and uses to control speed or feed. Some of the process variables that have been used in AC machining systems include spindle deflection or force, torque, cutting temperature

and horse power. The motivation for developing an AC system lies in buying to operate the process more efficiently. The typical measures in machining have been metal removal rate and cost per volume of metal removed.

WHERE TO USE ADAPTIVE CONTROL

One of the principal reasons for using NC is that it reduces the non-productive time in a machining operation. This time saving is achieved by reducing such elements as work piece handling time, set up for job, tool changes and other sources of operator and machine delay.

١. Adaptive control is not suitable for every machining situation. In general, the following characteristics can be used to identify situations where adaptive control can be beneficially applied. The in-process time consumes a significant portion of the machining cycle time.

٢. There are significant sources of variability in the job for which AC can compensate.

٣. The cost of operating the machine tool is high.

٤. The typical jobs involve steels, titanium and high strength alloys.

SOURCES OF VARIABILITY

The following are the typical sources of variability in machining where AC can be most advantageously applied.

١. Variable geometry of cut in the form of changing depth or width of cut: In these cases, feed rate is usually adjusted to compensate for the variability.

٢. Variable work piece hardness and Variable machinability: When hard spots or other areas of difficulty are encountered in a work piece, either speed or feed is reduced to avoid premature failure of tool,

٣. Variable work piece rigidity: if the work piece deflect as a result of insufficient rigidity in set up, the feed rate must be reduced to maintain accuracy in the process.

٤. Tool wear: It has been observed in research that as the tool begins to dull, the cutting force increases. The adaptive controller will typically respond to tool dulling by reducing feed rate.

These are the sources of variability present themselves as time varying and for most part, unpredictable changes in the machining process

TYPES OF ADAPTIVE CONTROL

There are basically two groups of adaptive control.

a. Geometrical adaptive control.

b. Technological adaptive control.

GEOMETRICAL ADAPTIVE CONTROL

This type of adaptive control is concerned with monitoring the shape and dimension of a machined component. It relies on some in process gauging instrument to relay information with a very short time response. The index of performance of such a system is the final dimension and shape of the component. It may be said that the desired final goal of the automated machining process is that the drawing of the work piece to be machined component is the output.

TECHNOLOGICAL ADAPTIVE CONTROL SYSTEM

Under the umbrella of technological AC two distinct systems are grouped:

١. Adaptive control constraint (ACC)

٢. Adaptive control optimization (ACO)

ADAPTIVE CONTROL CONSTRAINT (ACC)

The system developed for actual production was somewhat less sophisticated than the research ACO systems. The production AC systems utilize constraint limits imposed on certain measured process variables. Accordingly, these are called adaptive control constraint (ACC) systems. The objective in this system is to manipulate feed and/ or speed so that these measured process variables are maintained at or below their constraint values.

The most useful constraints in practical ACC systems are the cutting force F, the cutting power P, and the torque T.

When the cutting force and torque are too high, the cutter may break in bending or in twist. On the other hand, for maximum productivity, the maximum allowable feeds and cutting speed must be used. The principle of ACC system is to sense the constraint variable and to adjust the cutting speed and feed according to this measurement and a programmed strategy. In a case where two constraints are used simultaneously, the system must consider the variable which to its maximum permissible value. The advantage of this ACC system is that the cutting tool is protected against catastrophic failure simultaneously with keeping highest possible feed rate. The position and speed commands are fed by the NC system to drive the machine. The resulting motion is sensed by feedback devices and sent back to the NC system to complete a servo loop.

The adaptive controller operates as a second feedback loop outside the servo loop. The signals from sensors mounted on the machine are fed into the adaptive control. The latter determines, according to programmed constraints and its strategy, the appropriate corrections in the feedrate and spindle speed and sends the results to the AC system. That means that in each segment of the work piece the programmed speed and feed are fine-tuned by the adaptive controller according to changes in the working conditions.

The adaptive controller is fed by signals of two sensors:

I. Spindle torque sensor: The spindle torque is measured by strain-gauges mounted on the machine spindle.

II. Tool vibration sensor: The tool vibration is measured by two accelerometers mounted on the machining spindle housing.

The sensor data are fed to the adaptive control unit which calculates new feed and speed to optimize metal removal rate within the limits of a set of constraints. These constraints are as follows:

١. Maximum permissible spindle speed in rpm. This limit can be imposed either by the machine capability or from metal cutting considerations.

٢. Minimum spindle speed. It takes into account limitations of the spindle drive.

٣. Maximum allowed torque. This limit is prescribed by cutter radius and length as well as by depth of cut and finish requirements.

٤. Maximum allowed chip load, in /rev. the chip load is actually the feed per tooth. The number of teeth on the cutter should fed to the control by the operator.

٥. Minimum chip load. This constraint is required to prevent slow feeds.

٦. Maximum permitted federate in rpm. This constraint takes into account the cutter radius and length, spindle material, accuracy and finish requirement.

٧. Maximum allowed vibration, measured as a percentage of the acceptable operating range. The zero point is used to indicate air gap.

٨. Impact chip load, in in/rev. This limit is the maximum cutter feed per spindle revolution that would be allowed in traveling through unprogrammed air gaps. This limits the feed of the tools when entering in to the work piece.

The constraints should be experimental determined from prior cutting tests are manually preset by the machine operators to the required values prior to the starts of the machine operator

to the required values prior to the starts of the machine process. The setting of the constraints defines the permitted operating range for the ACC systems.

ADAPTIVE CONTROL OPTIMIZATION (ACO)

The ACO Systems for N/C machine tools is a control system that optimizes performance index subjects to various constraints. It is basically a sophisticated closed loop control system, which automatically works in optimum conditions, even in the presences of work piece and tools materials variations.

The block diagram of the entire system is show in Fig.٦. The system consists of a Keller-type profiler milling machine, Dyna Path N/C system, sensor units and adaptive controller. The sensor measures the torque, temperature and vibration. These measurements are used by the adaptive controller to obtain feed and speed values for obtaining optimum cutting conditions. The input of the adaptive controller is the data reduction Subsystem (DRS). This unit is fed by the online measurement as well as by the actual feed and speed and a set of constraints. The optimization strategy used by the optimization computer unit (OCU) is based upon the gradient method, which is also called the steepest ascent method; each step of this strategy begins with an exploration of the region of the actual point to determine a local gradient. In this case, the control space consists of two variables. Feed (s) and speed (v). An exploration step $=٠.٠٠٠١$ ipr is made and followed by a second exploration step of $= ١٠$ rpm. Basing up in the calculations in the above steps, the local gradient and the operating point is then moved a single step in the direction of this gradient. The cycle of steps is repeated until the maximum value of is reached.

ADAPTIVE CONTROL MACHINING SYSTEM (ACC SYSTEM)

Typical applications of adaptive control machining are in profile or contour milling jobs on an NC machine tool. Feed is used as the controlled variable and cutter force and horsepower are used as the measured variable. It is common to attach an adaptive controller to an NC machine tool. Numerical control machine are a natural starting point for AC for two reasons. First NC machine tools often possess the required sero motors on the table axes to accept automatic control. Second, the usual finds to machining jobs for which NC is used possess the sources of variability that makes AC feasible. The adaptive control retrofit package consists of a combination of hardware components are:

١. Sensor mounted on the spindle to measure the cutter deflection (force)

٢. Sensor to measure spindle motor current. This is used to provide an indication of power consumption.

٣. Control unit and display panel to operate the system

٤. Interface hardware to connect the AC system to the existing NC or CNC control unit.

The software in the AC packages consists of a mach inability program which can be called as an APT MACRO statements. Program in the part. The inputs to the program include cutting parameters such as cutter size and geometry, work material hardness. Size of cut and machine tool characteristics. From calculations based on these parameters, the outputs from the program are feed mates, spindle speeds, and cutter force limits for each section of the cut. The objective in these computations is to determine cutting conditions which will maximize metal removal rates. The NC part programmer which ordinarily has to specify feeds and speeds for the machining job. With adaptive control, these conditions are computed by the mach inability program based on the input data supplied by the part programmer. In machining, the AC system operates at the forces value calculated for the particular cutter and machine tool spindle. Maximum production rates are obtained by running the machine at the highest feed rate consistent with this force level. Since force is dependent on such factor of the control action is to maximize metal removal rates within the limitations imposed by existing cutting conditions. When the force increases due to increased work piece hardness of depth or width of cut, the feed rate is reduced to compensate. When the force decreases, owing to decrease in the foregoing variables or air gaps in the part, feed rate is increased to maximize the rates of metal removal. If the actual cutter force is below this threshold level, the controller assumes that the cutter is passing through an air gap when an air gap is sensed, the feed rate is doubled or tripled to minimize the time wasted traveling across the air gap. When the cutter reengages metal on the other side of the gap, the feed reverts back to the cutter force mode of control. More than one process variable may be measured in an adaptive control machining, System. Originally attempts were made to employ three measures signals in some system: temperature, torque and vibration. Currently, some system has used both cutter load and horsepower generated at the machine motor. This purpose of the power sensor is to protect the motor from overload when the metal removal rate is constrained by spindle horsepower rather than spindle force.

BENEFITS

A number of potential benefits accrue to the user of an AC machine tool. AC has been successfully applied in such machining processes as drilling, milling, tapping, grinding, boring. Following are some of the benefits gained from AC.

١. Increased production rates. Productivity improvement was the motivation force behind the development of AC machining online adjustments to allow for variations in work geometry, material and tool wear provide the machine with the capability to achieve the highest metal removal rates that are consistent with existing cutting conditions.

٢. Increased tool life. In addition to higher production rates, AC will generally provide a more efficient and uniform use of the cutter throughout its tool life.

٣. Greater part protection. Instead of setting cutter force constraint limit on type basis of maximum allowable cutter and spindle deflection, the force limit can be established on the basis of work size tolerance.

٤. Less operator intervention. The advent of AC machining has transferred control over the process even further out of the hands of the machine operator and into the hands of management via part programmer.

CONCLUSION

For a machining operation adaptive control is the best method for controlling the process. AC systems are best suited for applications like work pieces with variable geometry of cut in the form of changing depth and width of cut, air gaps etc. It has a number of advantages but the disadvantages are high cost and not suitable for all machining operation.

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