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LEBLOND PRECISION LATHE SAFETY MODIFICATIONS FOR HE MACHINING

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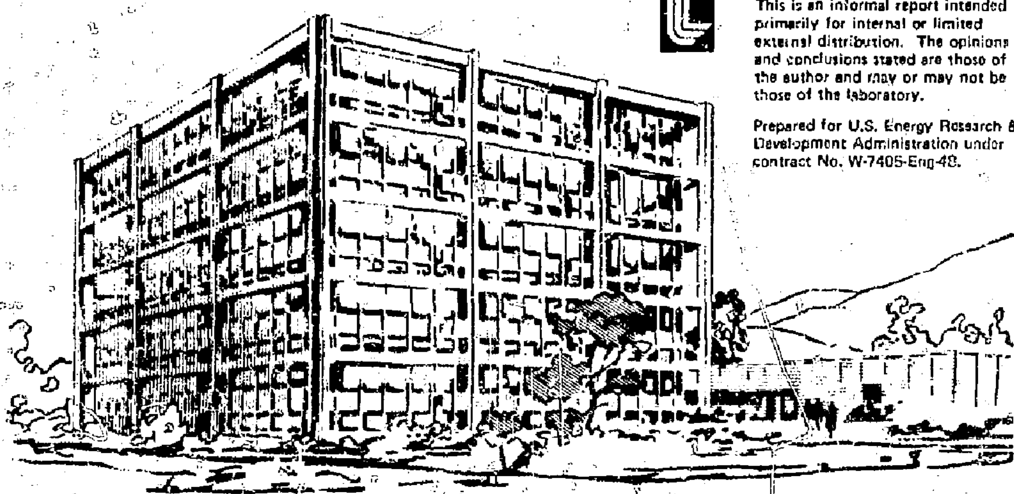

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LEBLOND PRECISION LATHE

SAFETY MODIFICATIONS FOR HE MACHINING

INTRODUCTION

In high explosives machining the three major concerns are safety, reliability, and ease of operation. With these three concerns as our main goals, LLL's EE and ME departments worked together to modify a LeBlond precision lathe for high explosives machining. The result is a unique, remote-controlled lathe which has extensive mechanical and electronics modifications. The lathe has been operating safely and successfully at Site 300's HE Test Facility since April 1978.

HE TEST FACILITY OVERVIEW

High explosives machining is an important part of the nuclear explosive design effort at LLL. To properly support the Laboratory's critical hydrodiagnostics testing, an HE machining facility must be maintained at Site 300.

In recent years this facility has experienced difficulty in completing the ever-increasing number of jobs within the required time. In fact, the facility's productivity has decreased 30 percent compared to 10 years ago. One of the reasons for this decrease is the current use of remote-controlled machine tools. Because the machine is remote-controlled and requires a lengthy set-up procedure, each job takes more time to complete compared to the time involved using the older, locally-controlled machines.

However, what the newer machines lose in time they gain in other ways. With computer-numerically-controlled (CNC) machine tools, the operator can program an entire job using computer generated tapes. The programming shortens downtime, improves accuracy, and reduces interference problems. Independent, self-contained CNC machine tool systems also competely eliminate all interference with other machining operations and, most importantly, provide maximum safety for personnel.

Safety is the name of the game. At the facility there are accepted area process handling and machining guidelines that must be followed during the HE machining process to derive maximum safety. Our overall machining procedure attempts to follow these guidelines as closely as possible.

METHODOLOGY OF MACHINE TOOL RETROFIT

The methodology we used in retrofitting the lathe can be summarized as follows: the machine must have the required modifications; the machine must be safe and reliable; and the operator must be comfortable with the control system. These considerations dictated every step in our design and implementation of the lathe's modifications.

Required Modifications

In this joint EE/ME project, our first consideration was to modify a commercial machine tool such that all actual machining requirements would be satisfied. In turn, these machining requirements partially dictated the extent of the required modifications. Since time and money did not permit us to buy a commercial control system modified to suit our needs, we purchased a standard machine tool control and modified the system both mechanically and electronically here at LLL.

Safety and Reliability

Our operating procedure was based on the following line of reasoning generally accepted and followed by DOE H.E. facilities. We assumed that, based on failure probabilities, two distinct failures will not occur at the same time. That is, if a failure occurred in a particular area of the control system, a failure would not occur simultaneously in the corresponding safety logic monitoring that condition. This assumption was defined as an "intrinsically safe" mode of operation.

Human Interface Considerations

Of utmost importance in any machine tool retrofit is the human interface of the operator with the control system. The operator must be very comfortable during the machining process, and be able to quickly take corrective action with a minimum amount of thought.

EXTENT OF SYSTEM MODIFICATIONS

Control System Overview

The lathe is interfaced to a General Electric Mark Century model 1050 Computer Numerical Control (CNC) specifically designed for multiaxis machine tool control. The CNC has the following major characteristics: software flexibility, dedicated microprocessors, modular design, and functional board layout. This particular CNC has one eight bit microprocessor per axis (2 each). These microprocessors interpolate motion data and generate axis command pulses. The CNC also has a 16 bit microprocessor which processes the executive program software commands and handles all of the software overhead requirements. It was not necessary to modify the GE executive software package in any way. We implemented most of the LLL electronic modifications with standard small- and medium-scale TTL chips and two Intel MCS-48 microprocessors.

Interface to the GE CNC presented no particular problems. Static control status and dynamic control conditions are monitored; positional data is stored and processed; set limits are checked; and appropriate action control commands are generated and processed by the control system.

LIST OF MODIFICATIONS

We made the following mechanical and electronic modifications on the lathe control system:

1. Remote Control Capability

   Remote and local control capability were necessary for operator safety. We placed the GE CNC in a remote control room about 90 feet from the machining room. A local control pendant was designed and interfaced to the system in the machining room. This arrangement provides the necessary machine tool operator control for part set-up in the local area, complete machining control in the remote area, and adequate operator safety.

2. Chip Thickness and Surface Feet Per Minute Calculators

   These modifications were implemented with the Intel MCS-48 microprocessor family of chips. A detailed discussion of these two important modifications begins on page 6 of this report.

3. Tool Force Monitor

   Tool force is monitored and displayed on a real time basis in both the lateral and vertical directions during the machining operation. Semiconductor strain gauges are arranged in a full bridge network which yields a high level of sensitivity. The rate at which tool force readings are made is a function of spindle RPM. When the spindle is below 60 RPM, force readings are made two times per second. If the spindle is above 60 RPM, readings are made at the rate of 2 1/2 times per spindle revolution. Tool force set limits are selected by the machine tool operator prior to the machining operation to suit particular machining conditions. If the first or lower force limit is exceeded, a feedhold (FH) command is generated with the intent of causing the force to decrease to a safe value. If the force increases until the second or higher set limit is exceeded, an emergency stop (E-stop) command is generated which initiates a safe shut down of the system.

4. Spindle RPM Limit Detector

Spindle RPM is continuously monitored and displayed on a digital readout during the machining process. For safe machining practice, it is not desirable for the spindle RPM to exceed an upper limit of 600. For this reason, two spindle RPM set limits are designed into the logic. If the spindle speed exceeds 525 RPM, a feedhold (FH) command is generated. A further increase in spindle speed to 600 RPM will cause an E-stop command to be generated.

5. Stored Part Program

Part program paper tape reading errors are responsible for a high percentage of machine tool mishaps. For this reason, it is very desirable to read and store the entire part program in memory prior to the actual machining process. After the part program is stored, the real time machining process commands are derived from memory. To accomplish this need, we purchased, as an option in the GE CNC, an additional 12K of memory for up to 120 feet of part program storage.

6. Tool Set Station

During machine tool set up, it is critical that the tool be properly centered on the pole or axis of the part. We designed and installed an electronic tool set station on the machine that allows the machine tool operator (MTO) to quickly and accurately reference the tool to both small and large parts.

7. Safe Distance Limit Switches

Limit switches were added to protect the MTO from a runaway condition while the MTO is exposed to HE in a "live" machine. During the setup procedure, the MTO references the tool to the part at the tool set station and then backs the machine slides away from the part to capture the tool behind the limit switches. The MTO mechanically "arms" the switches and then loads the HE in the machine. It is now safe to leave the room and go to the remote control station. The system is placed in the remote control mode and the switches are electronically "disarmed". It is the responsibility of the MTO to follow the reverse procedure after the machining operation is completed and the HE part is unloaded.

8. Auxillary Axes Positional Encoders

Redundant encoders are coupled to the leadscrew of each axis and also the spindle. The axes encoders measure the absolute position of the tool while the spindle encoder signal is used to calculate spindle RPM. The MTO can refer to the encoder derived display and compare the GE CNC "commanded" position with the displayed "absolute" position. The encoder signals are also used for various safety functions.

9. Purge of Electrical Cabinets

HE dust and chips inside electrical cabinets could cause an explosion if there is an electrical discharge. To guard against this situation, all electrical cabinets in the machining room are purged with a positive air-pressure which prevents HE dust and chips from entering the enclosures.

10. Vacuum and Coolant Flow Monitors

Vacuum and coolant flow are monitored in an effort to maintain overall safe operating conditions. If an unsafe condition develops in the vacuum or coolant flow, appropriate safety action begins automatically.

MICROPROCESSOR IMPLEMENTED MODIFICATIONS

The chip thickness calculator and surface feet per minute calculator are each implemented with an Intel MCS-48 microprocessor and associated TTL logic. All logic is wired on a small universal Augat card interfaced to the GE model 1050 CNC system. (see Figures 1 and 3).

We chose the Intel MCS-48 microprocessor for these particular modifications for several reasons. Although simple arithmetic calculations must be made that may be considered an over-kill for the MCS-48, the MCS-48 instruction set is simple to use and is very powerful. In addition, the I/O ports are conveniently suited for interfacing to the CNC system logic. The cost in dollars and time looked very attractive, especially since many similar modifications on this CNC as well as other machine tool control systems could be easily implemented with the same MCS-48 family.

Chip Thickness Calculator (CTC)

The CTC is designed to continuously calculate the real time value of chip thickness during the actual machining cycle. Chip thickness is the thickness per spindle revolution of the material that is being removed from the part. In other words, it is the distance that the tool travels tangential to the part in one spindle revolution (Figure 1).

The CTC microprocessor is programmed to do the following: determine system status; make the actual calculations; compare the results of these calculations to preset limits; and process an action command if the calculations exceed the preset limits. The program software was written in assembly language and consists of about 300 instructions.

The process of calculating the actual chip thickness is made five times per spindle revolution. Even at the highest spindle speed of 525 RPM there is plenty of time for the processor to rest between actual process cycle times.

CTC Process Cycle

Each CTC process cycle takes one fifth of a spindle revolution to complete. There are three phases to the machining process cycle (Figure 2):

- The status phase
- The calculation phase
- The action phase

The status phase begins after the GE CNC system is turned on and the CTC processor is reset and initialized. The processor goes into a loop state until the CTC process cycle flip-flop is set. Before the calculation phase can begin, a chip thickness value of 0.015, 0.035, or 0.86 inch per revolution must be stored in RAM memory, and all other conditions are met (AUTO ON, SPINDLE ON, and NORMAL MODE).

In the calculation phase, the actual value of chip thickness is calculated as shown in Figure 2. Delta x and delta z represent the actual distance the tool travels in one calculation phase (one fifth of a spindle revolution). The square root of the sum of the squares is computed in software and represents the tangential distance along the normal programmed path that the tool travels in one process cycle.

In the action phase, the microprocessor compares the calculated value of chip thickness to the programmed limit and then takes appropriate action. If the calculated value is less than the programmed limit, both the feed hold flip-flop and process cycle flip-flop are cleared and the program begins the next process cycle. If the calculated value is equal to or greater than the programmed limit, a FH command is generated. In a FH state, the CNC command pulses to the x and z axes are terminated giving the control system a chance to clear the fault. After five more process cycles another calculation is made. If the condition still persists after these five additional process cycles the fault is genuine and could be dangerous. The processor then generates an E-Stop command to the GE CNC which shuts down the system, aborting the machining cycle.

After shutdown, the operator looks at the fault-display panel to determine the problem. The operator then decides on the necessary steps required to correct the problem and restart the machining process.

SURFACE FEET PER MINUTE CALCULATOR (SFMC)

The SFMC is designed to calculate the real time value of surface feet per minute (SFM) on a continuous basis during the machining cycle. SFM is defined as the velocity of the tool relative to the part and is a direct function of the tool radius and spindle RPM.

Surface Feet Per Minute Calculator Overview

The SFM microprocessor (Figure 3) is programmed to do the following: determine system status; calculate SFM once per spindle revolution; compare the calculated value of SFM to a preset limit; and process an action command if the calculation exceeds the limit.

SFMC Process Cycle

The SFMC process cycle takes one spindle revolution to complete. As with the CTC, there are three phases to each process cycle:

- the status phase
- the calculation phase
- the action phase

The status phase begins after the GE CNC system is turned on and the SFM processor is reset and initialized (Figure 4). In the status phase the processor then goes into a loop state until the SFM process cycle flip-flop is set. Before the calculation phase can begin all status conditions (AUTO MODE, SPINDLE ON, NORMAL MODE) must be met.

In the calculation phase, data to compute the spindle RPM is input to the processor. After the spindle RPM is calculated, it is multiplied by the tool radius. This result is representatives of the real time calculated value of SFM.

In the action phase, the processor compares the real time calculated value of SFM to a set limit of 210 feet per minute and takes appropriate action in the following circumstances. If the calculated value is less than the set limit, both the feed hold flip-flop and SFM process cycle flip-flop are cleared and the processor begins the next process cycle. If the calculated value is equal to or greater than the set limit, a FH command is generated. In the FH state, the CNC stops generating command pulses to the x and z axes. The processor then checks the TIMER flip-flop. If the TIMER is not set, the processor sets it and waits for 1.2 seconds. If the TIMER flip-flop is set, two SFM calculations in a row have violated the set limit and the processor will then generate an E-Stop command causing an orderly shut down phase to occurred.

As with any condition that causes the system to be turned off, the operator must now look at the fault display panel to determine the problem and decide what steps must be taken to correct the problem and restart the machining process.

CONCLUSIONS

The HE machining process will always have its inherent dangers. At LLL, we seek to minimize these dangers by making this process as safe and reliable as possible. This purpose is reflected in the LeBlond lathe retrofit implemented by LLL's EE and ME departments. The lathe CNC design and modifications were based on modern principles of safe HE machining including the protection of personnel in adjacent work areas.

The lathe control system became operational at the Site 300 HE Test Facility in April 1978. At that time we started an operational "shake down" phase familiarizing the machine tool operators with the overall control system. HE parts were machined on a two shift basis for several weeks reducing the backlog of parts considerably. The facility has since returned to one shift with the machine tool control system performing as we expected. We are very pleased to report that the operators feel very comfortable with our modifications and the overall control system.

Based on the sucess of this machine tool system, a Bostomatic mill converted into a mill/lathe has been modified using safety features first incorporated on the LeBlond lathe. The lathe and mill/lathe are the first in a series of eight machine tools which are to be modified for HE machining. As with the LeBlond lathe, all systems will be modified to meet LLL's prerequisite requirements of machine safety and reliability.

ACKNOWLEDGEMENTS

As the person with Electronics Engineering responsibility for this project, I would like to thank the following people for their contributions: Robert Donaldson, Project Leader; Jerry Chrislock, Overall Project Coordinator; and Ronald Casterson, Electronics Systems Engineer. The personnel of the following groups also contributed much time and effort to this project: Computer Aided Manufacturing, Machine Tool Development, Machine Tool Repair, and H.E. Machinist.

GLOSSARY

CT	Chip Thickness
CTC	Chip Thickness Calculator
CTV	Chip Thickness Value
CNC	Computer Numerical Control
E-Stop	Emergency Stop
FH	Feed Hold
f/f	Flip Flop
GE	General Electric
HE	High Explosive
MTO	Machine Tool Operator
PC	Process Cycle
QA	Quality Assurance
RPM	Revolutions Per Minute
SDLS	Safe Distance Limit Switches
SFM	Surface Feet Per Minute
SFMC	Surface Feet Per Minute Calculator
TTL	Transistor Transistor Logic

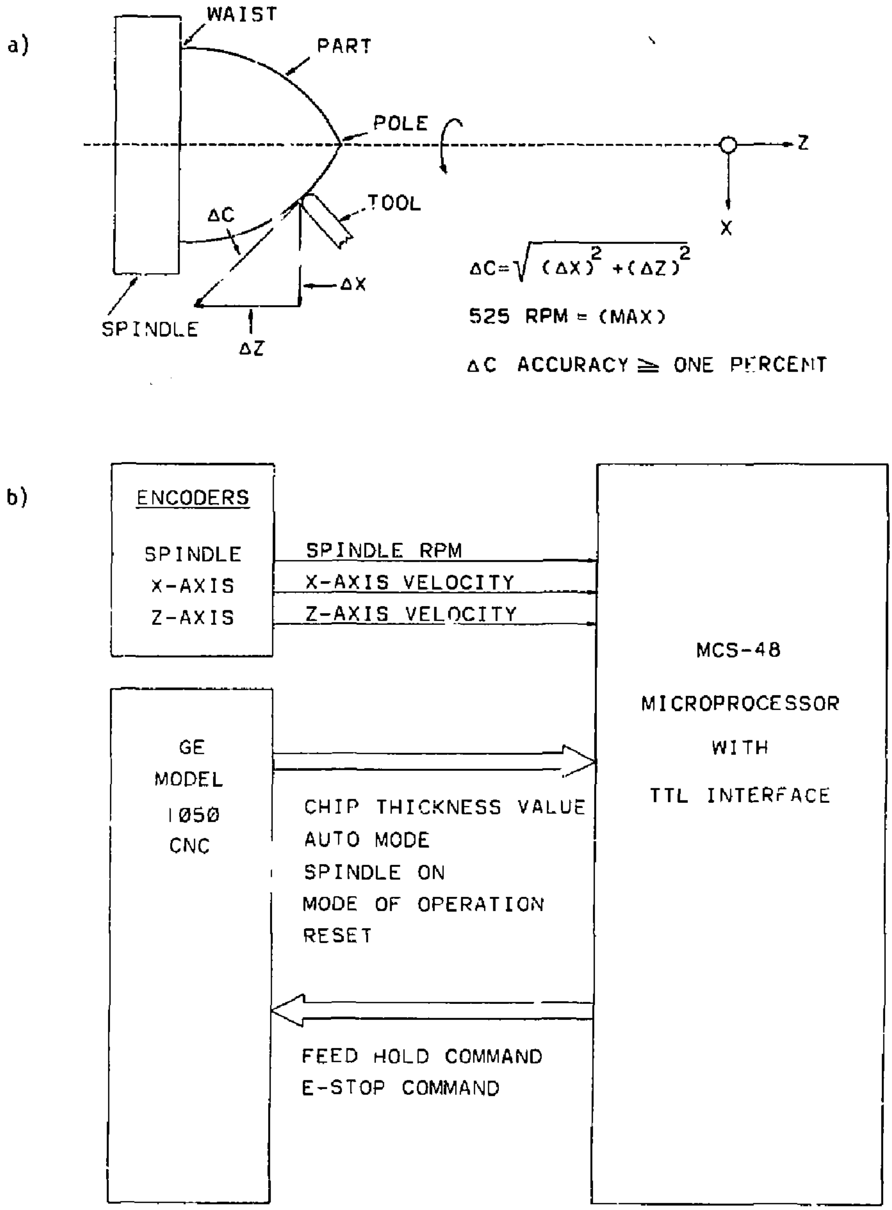

FIGURE 1. CHIP THICKNESS CALCULATOR

a) TOP VIEW OF LATHE AND CHIP THICKNESS EQUATION

b) SYSTEM BLOCK DIAGRAM

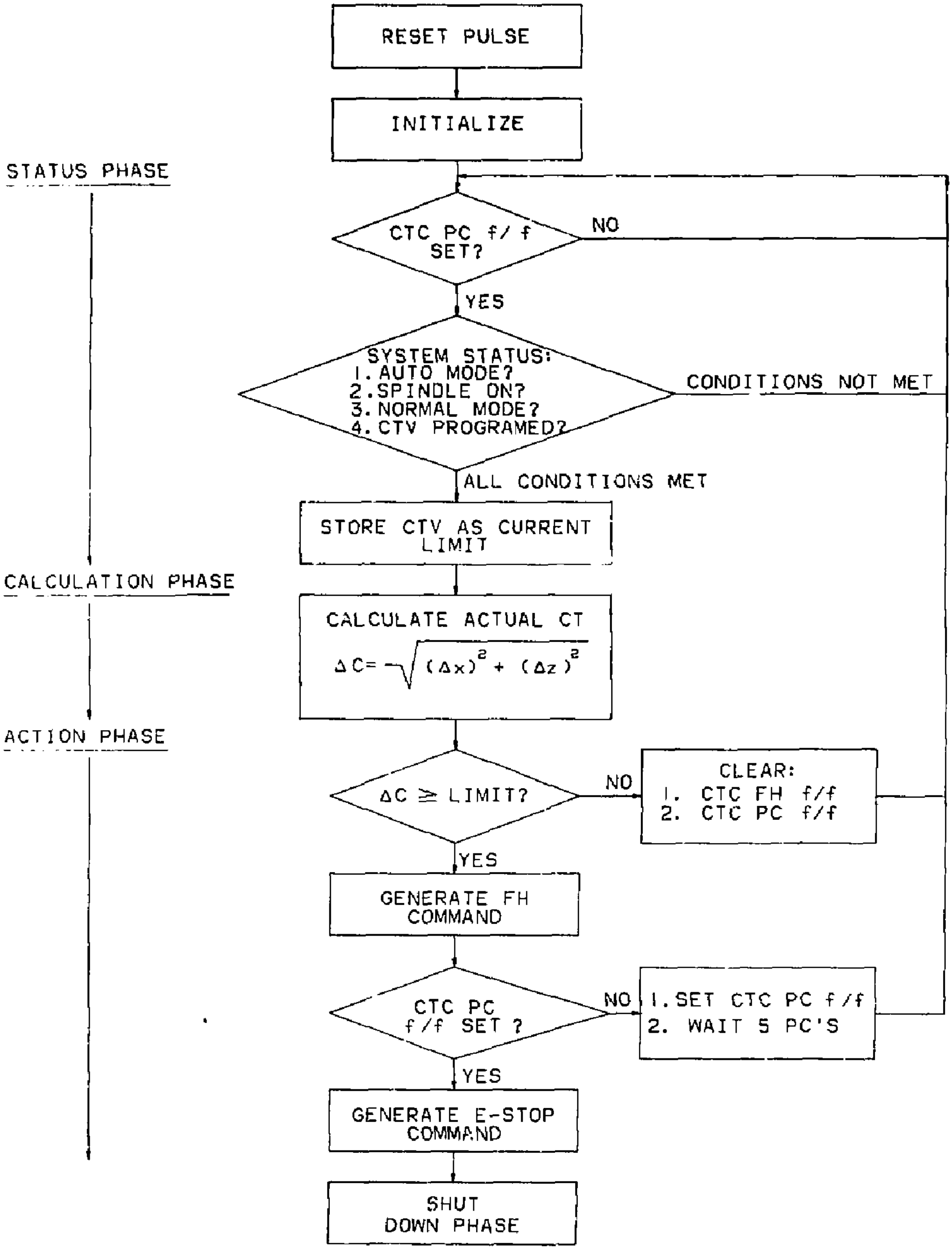

FIGURE 2. CHIP THICKNESS CALCULATOR PROCESS CYCLE

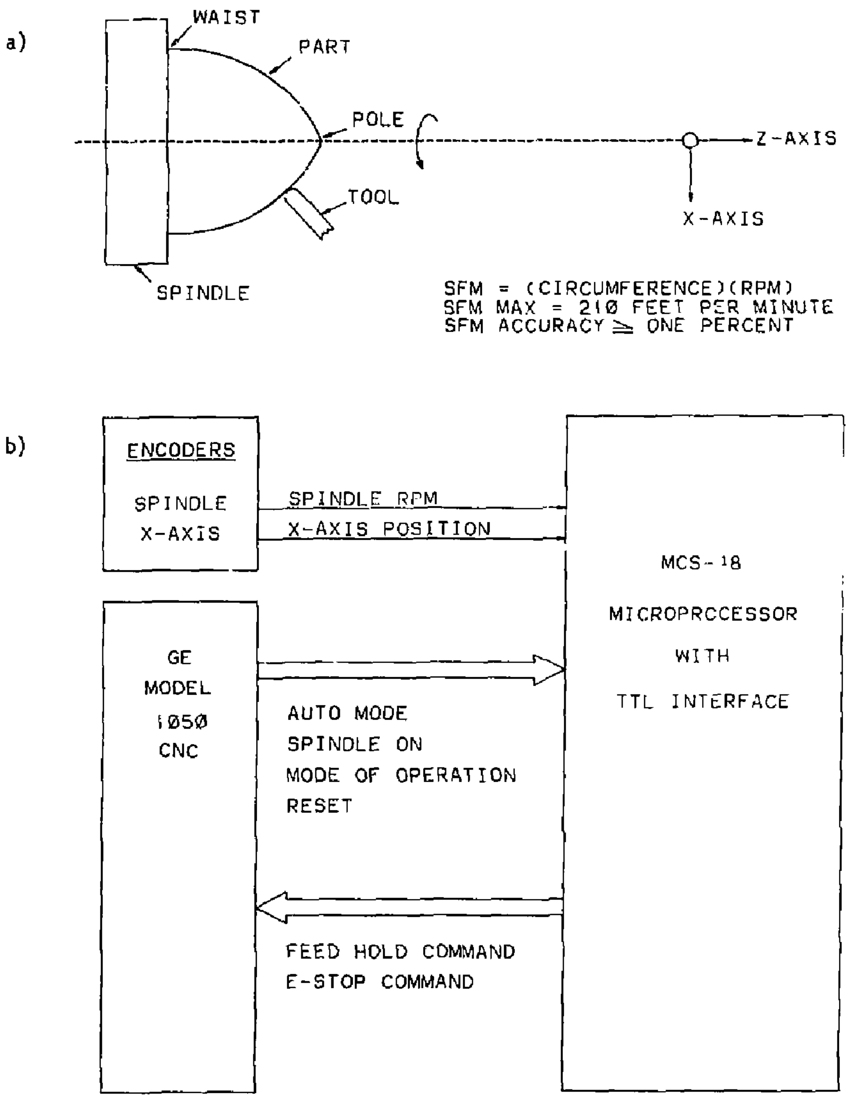

FIGURE 3. SURFACE FEET PER MINUTE CALCULATOR

a) TOP VIEW OF LATHE AND SURFACE FEET PER MINUTE EQUATION

b) SYSTEM BLOCK DIAGRAM

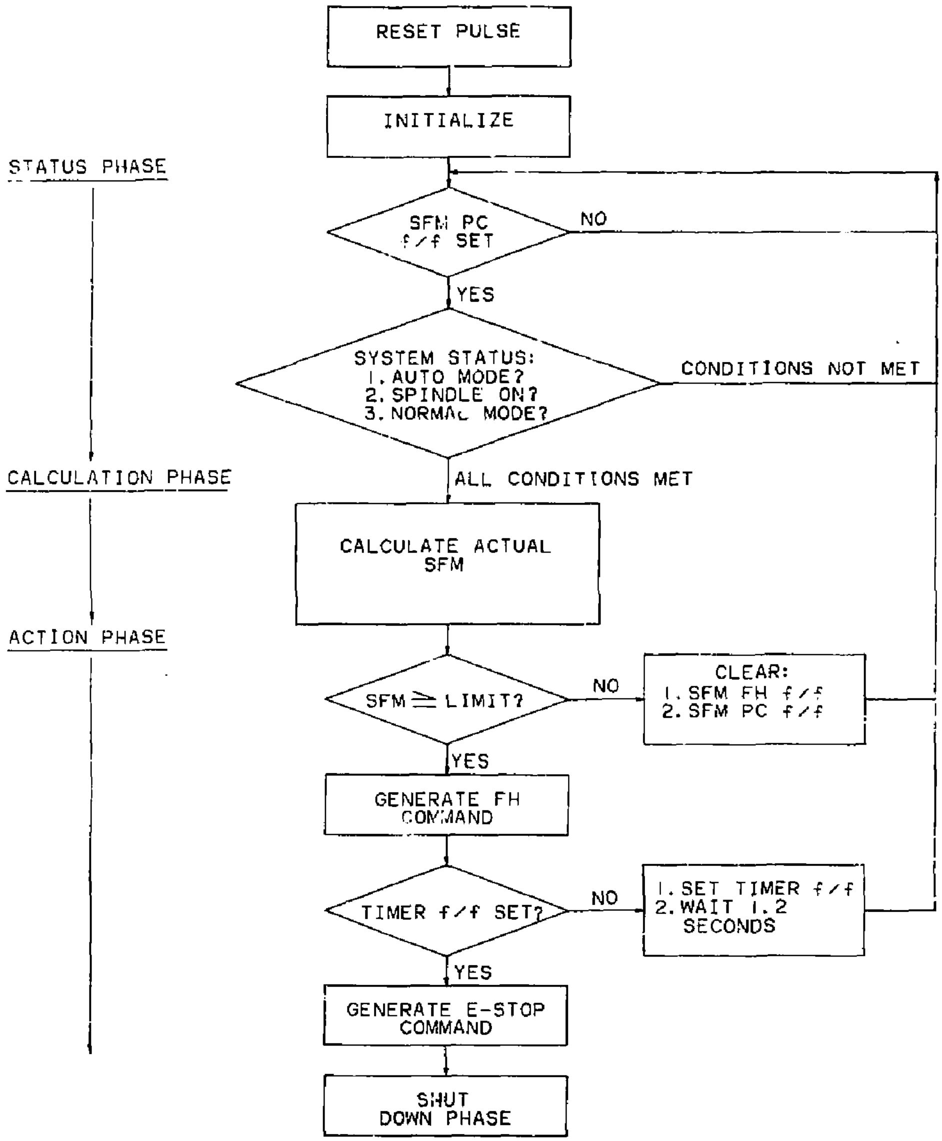

FIGURE 4. SURFACE FEET PER MINUTE CALCULATOR PROCESS CYCLE