FEATURES AND APPLICATIONS OF CNC MACHINES AND SYSTEMS

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ABSTRACT: **This paper deals with configuration and implementation of latest state of art CNC system for Automation of control activities in MAG make CNC Machining centre in 01 block of BHEL, RC Puram unit, Hyderabad. The apparatus required is Sinumerik 840D CNC system, Step 7 PLC software HMI software, electronic AC Servo Motors drivers, Position Feedback Devices. A thorough understanding of the physical configuration of CNC machining centre and its various functions are presented here. A study of CNC & PLC system, HMI, AC Servomotor, drivers and feedback elements and automation of machine functions using these devices. The introduction of CNC has radically changed the manufacturing industry implementation of latest CNC and AC Servo Motors and drivers allows reduced cycle time, higher productivity and higher level of accuracy and flexibility in the manufacturing processors. Moreover technically it has rugged and designed to withstand vibrations, temperature, humidity and noise. It has interfacing for inputs and outputs already inside the controllers which is easily programmable. Complex 3D structures are relatively easy to produce and the number of machining steps that require human action will be reduced.**
It is applied in turning Centres, Grinding machines, Punch press, wire-cut E D M, communication Industries etc. CNC and HMI systems can be updates/ upgraded by improving the software to accomplish more complex tasks. The project can be extended to automation of 5 axes machining centres. The project can be extended to automation of 5-axes machining centres.

Keywords: **Load Frequency Control (LFC), Control Strategy (PI, PID, Fuzzy Control, ADRC), Extended State Observer (ESO), Active Disturbance Rejection Control (ADRC).**

I. INTRODUCTION

Development of Computer Numerically Controlled (CNC) machines is an outstanding contribution to the manufacturing industries. It has made possible the automation of the machining processes with flexibility to handle small to medium batch quantities in part production.

Initially, the CNC technology was applied on basic metal cutting machines like lathes, milling machines, etc. Later, to increase the flexibility of the machines in handling a variety of components and to finish them in a single set-up on the same machine, CNC concept was applied to develop a CNC machining center for machining prismatic components combining operations like milling, drilling, boring and tapping. Further, the concept of multi-operations was also extended for machining cylindrical components, which led to the development of turning centers.

The introduction of NC machine tools has enabled the designer to shed some of his shackles, which inhibited him while using conventional machines. If desired, a shape can be specified which must confirm to a given mathematical formulae for example a curved profile or conic section and this shape can be

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produced with no more difficulty them for a circular arc.

I. FUNCTIONS OF A MACHINE TOOL

The purpose of a machine tool is to cut away surplus material, usually metal from the material supplied, to leave a work piece of require shape and size, produced to a high degree of accuracy and surface finish. The machine tool must possess certain capabilities in order to fulfill these requirements. It must be:

- Able to hold the work piece and the cutting tool securely.
- Endowed with sufficient power to enable the tool to cut the work piece material at economic rates.
- Capable of displacing the tool and work piece relatively to one other to produce the required work piece shape: the displacement must be controlled with a degree of precision, which will ensure desired accuracy of surface finish and size.

Ancillary functions:
In addition to the main features, the machine tool must have provision for performing ancillary functions, such as altering the spindle speed and feed rate, tool changing, etc. On a conventional machine tool, i.e. a machine tool under the direct control of an operator these functions are performed by the operator as and when he considers them to be necessary, but when the principles of automatic control are applied to the machine tools, the signal to change the speed, etc. must be written into the instructions which are supplied to the machine data.

II. FUNCTIONS OF CONTROL SYSTEM

Automatic control systems in one form or another can be applied to machine tool, in order to control the overall machine functions. The following are some of the more important functions, which can be controlled:

- Displacement of slide members
- Angular rotation of circular tables
- Stop/start of the main spindle
- Change the spindle speed
- Reverse spindle
- Change feed rate of slide members
- Rotate tool turret
- Change tool
- Cutting fluid, ON/OFF
- Lock table in position.

Slide Displacement:

The main function to be performed by a control system on a machine tool is the displacement of the machine slides. Since the slides are displaced to alter the position of the tool related to the work piece and produce the component to the required dimensions, system of automatic control applied to machine tools are known as a Numerical Control Systems and the machine itself as an NC machine tool.

Conventional Nomenclature for Displacement of Slides:

Machine tool has two or more slide ways, disposed at right angles to one another, along which the slide is displaced. Each slide can be fitted with a control system. In a machine with three orthogonal slide ways the movements will be considered to take place along X, Y, and Z-axis.

Control Systems for Slides of NC Machine Tools:

In a NC machine tool, the main condition subject to control is the displacement and positioning of the slides. Machine tools have slide displacement controlled by open loop or closed-loop.

Command Signals:

The command signal for displacing the slide of a NC machine tool normally represents dimensions, or a continuous stream of successive dimensions relating to the component being machined.

III. CNC SYSTEMS

The CNC is a computer based electronic equipment that receives commands in digital form from perforated tape or other types of input, as well as positional information of certain elements of the machine. The CNC interprets certain of these digital data as requirements for new positions of the machine elements and gives appropriate commands of direction and velocity. The CNC also interprets certain other additional data as command of velocity, of discrete functions, of actions etc.

Numerical control (NC) is a method employed for controlling the motions of a machine tool slide and its auxiliary functions with an input in the form of numerical data. A computer numerical control (CNC) is a microprocessor based system to store and process the data for the

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control of slide motions and auxiliary functions of the machine tools. The CNC system is the heart and brain of a CNC machine which enable the operation of the various machine members such as a slides, spindles, etc. as per the sequence programmed into it, depending on the machining operations.

The CNC systems are constructed with an NC unit integrated with a programmable logic controller (PLC) and sometimes with an additional external PLC (non-integrated). The NC controls the spindle movement and the speeds and feeds in machining. It calculates the traversing paths of the axes as defined by the inputs. The PLC controls the peripheral actuating elements of the machine such as solenoids, relay coils, etc. Working together, the NC and PLC enable the machine tool to operate automatically.

Elements of a CNC Machine Tool:

In a CNC machine tool there are three major groups of elements

- Control and electronics
- Electric drives (electromechanical drives)
- Mechanical elements (table, Slide, tool holder, etc.)

In addition, there can be hydraulic and pneumatic systems, which are integrated with the CNC machine tool.

The primary function of the drive is to cause motion of the controlled machine tool member (spindle, slide, etc.) to conform as closely as possible to the motion commands issued by the CNC system.

In order to maintain a constant material removal rate, the spindle and the tool movements have to be coordinated such that the spindle has a constant power and the slide has a constant torque.

Input Elements:

Some of the commonly employed input elements are push-button, foot switch, proximity switch, float switch, relay contact, photo transistor switch, selector switch, pressure switch, limit switch and flow switch.

Output Elements:

Output Elements that are commonly used are:

- Indicating Lamps
- DC control relays (electromagnetic)
- Power contractors
- DC and AC solenoids
- Electromagnetic clutch and brake
- Solid state relay.

A control relay (CR) is an electromagnetic device excited through an ac or dc electric coil. The dc relays are used as interface between the CNC-PLC and the ac or dc power switching devices.

Contractors (C) are also electromagnetic devices which are excited with ac voltages (110 V or 220 V used for ON/OFF functions of induction motors, induction coils, drive power circuits, etc. Power contractors are designed to switch currents up to several hundreds of amperes at 440 V ac three-phase.

Overload (OL) Relays:

Bi-metallic thermal overload relays are very commonly used as overload protection devices for various ac motors such as hydraulic pump motor, coolant pump motor, lubrication motor, blower induction motor, or any other power ac circuit. The overload (OL) relay, when connected in series with the power circuit, will open out when the current increases beyond a preset value.

Miniature Circuit Breaker (MCB):

An MCB is a protective device, which will provide both overload and short circuit protection when connected in a circuit. Hence an MCB will replace a fuse and a bi-metallic overload relay. When an MCB trips, it is manually reset. Compact MCBs with auxiliary trip contact are used in the electrical control panel for CNC machines.

Configuration of a CNC System:

A schematic diagram of the working principle of an NC axis of a CNC Machine and the interface of a CNC control.

A CNC system basically consists of the following:

- Central processing unit (CPU)
- Servo-control unit
- Operator control panel

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- Machine control panel
- Other peripheral devices
- Programmable logic controller

Central Processing Unit (CPU):

The CPU is the heart and brain of a CNC system. It accepts the information stored in the memory as part program. This data is decoded and transformed into specific position control and velocity control signals. It also oversees the movement of the control axis or spindle and whenever this does not match with the programmed values, a corrective action is taken.

Speed Control Unit:

This unit acts in unison with the CPU for the movement of the machine axes. The CPU sends the control signals generated for the movement of the axis to the servo-control unit and the servo-control unit converts these signals into a suitable digital or analog signal to be fed to a servo-driver for machine tool axis movement. This also checks whether machine tool axis movement is at the same speed as directed by the CPU.

Servo Control Unit:

The decoded position and velocity control signals, generated by the CPU for the axis movement forms the input to the servo-control unit. This unit in turn generates suitable signals as command values. The command values are converted by the servo-drive unit which is interfaced with the axes and the spindle motors.

The servo-control unit receives the position feedback signals for the actual movement of the machine tool axes from the feedback devices (like linear scales, rotary encoders, resolvers, etc.). The velocity feedback are generally obtained through tacho generators. The feedback signals are passed on to the CPU for further processing. Thus, the servo-control unit performs the data communication between the machine tool and the CPU.

The amount of movement and the rate of movement are controlled by the CNC system.

Closed Loop System:

The closed loop system is characterized by the presence of feedback. In this system, the CNC system sends out commands for movement and the result is continuously monitored by the system through various feedback devices. There are generally two types of feedback to a CNC system-position feedback and velocity feedback.

Open Loop System:

The open loop system lacks feedback. In this system, the CNC system sends out signals for movement but does not check whether actual movement is taking place or not. Stepper motors are used for actual movement and the electronics of these stepper motors is run on digital pulses from the CNC system.

Operator Control Panel:

The operator control panel provides the user interface to facilitate a two-way communication between the user, CNC system and the machine tool. The consists of two parts:

- Video display unit
- Keyboard

Video Display Unit (VDU):

The VDU displays the status of the various parameters of the CNC system and the machine tool. It displays all current information such as:

- Complete information on the block currently being executed actual position values, set or actual difference, current feed rate, spindle speed.
- Actual position value, set or actual difference, current feed rate, spindle speed.
- Active G functions, miscellaneous functions
- Main program number, subroutine number
- Display of all entered data, user programs, user data, machine data, etc.
- Alarm messages in plain text
- Soft key designations.

Keyboard:

A keyboard is provided for the following purposes:

- Editing of part programs, tool data, machine parameters.
- Selection of different pages for viewing.
- Selection of operating modes, e.g., manual data input, jog, etc.
- Selection of feed rate override and spindle speed override
- Execution of part programs
- Execution of other tool functions

Machine Control Panel (MCP):

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It is the direct interface between the operator and the NC system, enabling the operation of the machine through the CNC system.

During program execution, the CNC controls the axis motion, spindle function or tool function on a machine tool, depending upon the part program stored in the memory. Prior to the starting of the machining process, machine should first be prepared with some specific tasks like,

- Establishing a correct reference point
- Loading the system memory with the required part program
- Loading and checking of tool offsets, zero offsets, etc.

IV. MODES OF OPERATION

- Preset mode
- Manual data input (MDI) mode
- Automatic mode
- Reference point mode
- Jog mode
- Incremental mode

(1) MANUAL DATA INPUT (MDI) Mode: This mode is used for Manual operation of functions or programs.
(2) PRESET Mode: By using this mode, we can clear the current positional readings of an axis to any desired value. JOG Mode : In JOG mode axes can be moved with the keys (+) or (-) of the axis on MCP. The feed rate depends on the selected position on the feed override - switch (0-120%).
(3) AUTOMATIC Mode: This mode is used for executing & handling existing programs, automatically by initiating program execution
(4) REFERENCE Mode: This mode is used to synchronize the physical position of the axes with CNC system.
(5) INCREMENTAL (INC) Mode: With the help of this mode we can increment the position of axes by 1 micron or 10 microns or 100 microns or 1 mm.

Spindle also can be controlled by using MCP. It can be rotated Clockwise or Anticlockwise with specified speed by using the pushbuttons on MCP.

V. DESIGN OF MODERN CNC MACHINES

The design & construction of computer numerically controlled (CNC) machines differs greatly from that of conventional machine tools.

Important parts and aspects of CNC machine's to be considered in their designing:

(a) MACHINE structure
(b) Guide ways
(c) Feed drives
(d) Spindle & spindle bearings
(e) Controllers, software & operator interface
(f) Measuring instruments
(g) Gauging
(h) Tool monitoring

(a) Machine Structure

The Machine structure is the load carrying & supporting member of the Machine tool. All the motors, drive mechanism & other functional assemblies of machines tools are aligned to each other & rigidly fixed to the Machine structure. The Machine structure is subjected to static of dynamic forces & it is, therefore, essential that the structure does not deform or vibrate beyond the permissible limits under the action of these forces.

(b) Guide ways

Guide ways are used in Machine tools to:

i) Control the directions or lines of action of the carriage or the table on which a tool or a work piece is held.
ii) To absorb all the static & dynamic forces.

(c) Feed Drives

On a CNC Machine the function of feed drives is to cause motion of the slides as per the motion commands. Since the degree of accuracy requirement is high, the feed drive should have high efficiency & response. The fed drive consists of (a) servomotor (b) Mechanical transmission system.

(d) Spindle / Spindle Bearings

Material removal using single point or multi point work piece requires rotational speeds of the order of 30-6000 rpm and even higher. All work or tool carrying spindles rotating at these speeds are subjected torsional and radial deflections. They are also subjected to thrust forces depending on the nature of the metal cutting operation being performed. To intorsional strain on

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the spindles they are designed to be as stiff as possible with a minimum over hang. Also, the final drive to the spindle should be located as near as possible the bearings.

(e) Gauging

Gauging on a Machine tool is basically used for work piece inspection, for defining tool off-sets & for tool breaking detection.

(f) Tool monitoring systems

A tool monitoring system monitors the tools wear & tool breakage.

(g) Controls, Software & User Interface

CNC controls are the heart of the CNC MACHINEs. The early CNC controls were developed for simple applications in turning, machining centres & grinding.

The new generation computer numerical controls allow simulations control of more axes, interpolate positions faster, and use more data points for precise control. These processors perform multi tasks run one programming & simulating a second – which maximizes the Machine use.

(h) Measuring systems

On all CNC Machine, an electronic measuring system is employed on each controlled axis to monitor the movement & to compare the position of the slide & the spindle with the desired position.

Measuring systems are used on CNC Machines for:
(i) Monitoring the positioning of a slide on a slide way.
(ii) Orienting the spindle table & measuring the speed of the spindle.

Turning Centre Developments

Historically, the CNC technology was applied on turning machines with a conventional horizontal bed configuration having two servo axes – are for the saddle and the other for cross slide – and with an index able tool turret. Over a period of time the concept of slant bed configuration was adopted for higher rigidity, better chip disposal and easy access for loading and unloading of components together with disc type turret to accommodate move number of tools.

Advantages of CNC Machines

CNC machines offer the following advantages in manufacturing:

- Higher flexibility
- Increased productivity
- Consistent quantity
- Reduced scrap rate
- Reliable operation
- Reduced non-productive time
- Reduced manpower
- Shorter cycle time
- Higher accuracy
- Reduced lead time
- Just-in-time (JIT) manufacture
- Automatic material handling
- Lesser floor space
- Increased operational safety
- Machining of advanced materials

Interfacing Machine Elements To CNC/PLC

Interconnecting the individual elements of both the machine and the CNC system using cables and connectors is called interfacing.

Extreme care should be taken during interfacing. Proper grounding in electrical installation is most essential. This reduces the effects of interference and guards against electronic shocks to personnel. It is also essential to properly protect the electronics equipment.

Axes of the Machine

X : longitudinal slide
Y : grinding wheel-head vertical
Z : grinding wheel-head horizontal (Transverse)
V : dressing axis vertical
W : coolant flow axis vertical

Hand held unit (HHU)

This can be held by the operator in hands. It is used to take various manual movements of the axes.

Hydraulic power pack

It consists of hydraulic oil, hydraulic motor and hydraulic pump to send the pressurized oil to various parts of the machine for carrying out different hydraulic functions like Job Fixture clamp and unclamp etc.

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Coolant system

In the present machine, the Coolant system consists of Coolant flow system and Coolant Filtration system. The whole system is of KNOLL make.

Various functions in the machine

The functions include Coolant ON/OFF, Door Open & Door Close, Hydraulics ON/OFF, Job Fixture Clamp/Unclamp etc. Controls for all these functions are located on Machine Operator Panel which is above the CRT display unit.

CNC Part Program

- The instructions for carrying out movements of all axes combined with relevant Auxiliary functions (like spindle rotation, coolant on/off etc.) are written sequentially & logically in a language called "G-CODE & M-CODE PROGRAMMING".

- The set of instructions is called "PART PROGRAM".

- The Part Program language offers

1. User variables
2. Predefined user variables
3. System variables
4. Indirect programming
5. Arithmetic & Angular functions
6. Relational & Logical operations
7. Program Jumps & Branches
8. Program Coordination
9. Sequential statements

Measuring Systems for CNC machine tools

The measuring systems for CNC machine tools give the position of the machine tool. They are of two types:

- Rotary encoders
- Linear encoders

Rotary encoders:
The built-on optoelectronic rotary encoders measure paths, angles of rotation, or speeds of machines. They can be used in conjunction with numerical controllers, programmable logic controllers, drives and position displays.

Measuring Principles:

Encoders with optical scanning incorporate measuring standards of periodic structures known as graduations.

These graduations are applied to a carrier substrate of glass or steel. The scale substrate for large measuring lengths is a steel tape. These precision graduations are manufactured in various photolithographic processes. Graduations can be fabricated from:

- Extremely hard chromium lines on glass
- Matte-etched lines on gold-plated steel tape
- Three-dimensional grid structures on glass or steel substrates.

Absolute Measuring Method:
With the absolute measuring method, the position value is available from the encoder immediately upon switch-on and can be called at any time by the subsequent electronics. There is no need to move the axes to find the reference position. The absolute position information is read from the scale graduation, which is formed from a serial absolute code structure as shown in Fig. 1.

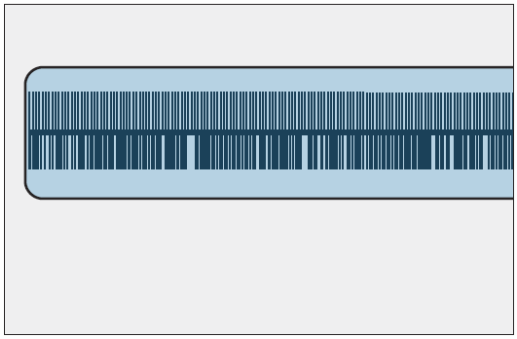

Figure1: Graduation Scale

Incremental Measuring Method:

With the incremental measuring method, the graduation consists of a periodic grating structure. The position information is obtained by counting the individual increments (measuring steps) from some point of origin. Since an absolute reference is required to ascertain positions, the scales or scale tapes are provided with an additional track that bears a reference mark. The absolute position on the scale, established by the reference mark, therefore the reference mark must be scanned to establish an absolute reference.

VI. BLOCK DIAGRAM OF A CNC SYSTEM

The block diagram of a typical CNC system is shown in the Fig. 2. The microprocessor along with associated hardware does the function of

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data storage, motion path calculation, command generation etc. The intelligence needed for the execution of these functions is in the form of a series of instructions to the microprocessor and is called "executive program", which resides in memory. The output interface has provision for connecting external peripheral devices needed for data transfer. The operator's control panel and CRT is used as a media by which the operator communicates with the system. The axis interface does the function of command generation and feedback signal processing. The peripheral to machine interface (PMI) does the machine oriented functions like spindle speed decoding, tool functions and miscellaneous functions like coolant switching and lubrication control, interfacing with the push buttons, limit switches, pressure switches, float switches, proximity switches etc.

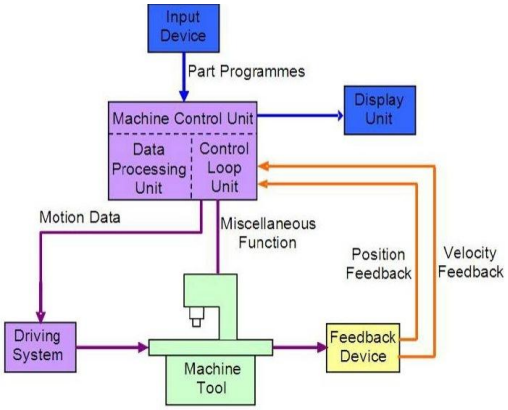

Figure2: Block Diagram of CNC Machine

Open Loop Control System:
In this system the machine slides are commanded and moved to a position but the information of the actual movement of the slide is not feedback to control system. There is no check on the actual position reached with reference to the desired position as directed by the command. The feed drive used is a stepper motor or electro hydraulic stepper motor. When a single pulse is given to these motors, they move through discrete angles thus achieving the desired position. The disadvantage of this type of system is that there is no check on the final position reached.

VII. ADVANTAGES OF CNC MACHINES

1. CNC machines can be used continuously 24 hours a day, 365 days a year and only need to be switched off for occasional maintenance.

2. CNC machines are programmed with a design which can then be manufactured hundreds or even thousands of times. Each manufactured product will be exactly the same.

3. Less skilled/trained people can operate CNCs unlike manual lathes / milling machines etc.. which need skilled engineers.

4. CNC machines can be updated by improving the software used to drive the machines

5. Training in the use of CNCs is available through the use of 'virtual software'. This is software that allows the operator to practice using the CNC machine on the screen of a computer. The software is similar to a computer game.

6. CNC machines can be programmed by advanced design software such as Pro/DESKTOP®, enabling the manufacture of products that cannot be made by manual machines, even those used by skilled designers / engineers.

7. Modern design software allows the designer to simulate the manufacture of his/her idea. There is no need to make a prototype or a model. This saves time and money.

8. One person can supervise many CNC machines as once they are programmed they can usually be left to work by themselves. Sometimes only the cutting tools need replacing occasionally.

9. A skilled engineer can make the same component many times. However, if each component is carefully studied, each one will vary slightly. A CNC machine will manufacture each component as an exact match.

VIII. APPLICATIONS

The applications of CNC include both for machine tool as well as non-machine tool areas.
In the machine tool category, CNC is widely used for lathe, drill press, milling machine, grinding unit, laser, sheet-metal press working machine, tube bending machine etc. Highly automated machine tools such as turning center and machining center which change the cutting tools automatically under CNC control have been developed. In the non-machine tool category, CNC applications include welding machines (arc and resistance), coordinate measuring machine, electronic assembly, tape

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laying and filament winding machines for composites etc.

IX. Conclusion

The PLC Program developed in the previous pages is transferred into the RAM Memory of the PLC of HINUMERIK 2000 T CNC System by using the following tools:

i) Windows based STEP 5 Software
ii) PLC Programmer / PC
iii) Communication cable between programmer / PC and PLC

After transferring the logic into the CNC, the status of Inputs and Outputs are diagnosed on CNC by simulating various inputs.
Relays and contactors are interfaced to the output ports of output modules and the live actuation of output devices has been observed.

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