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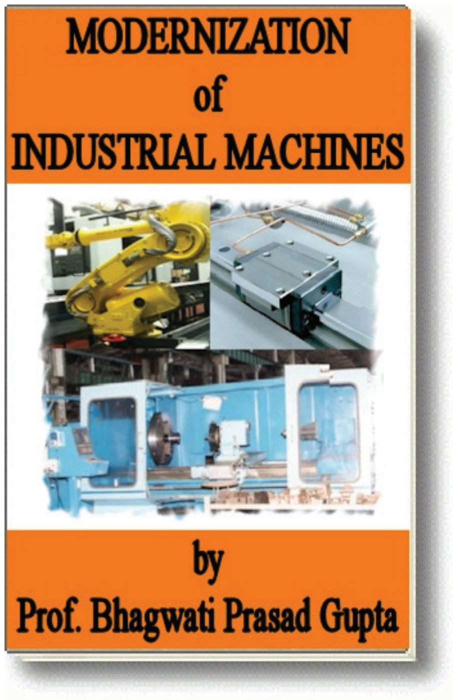
Modernization of Industrial Machines

By Prof. Bhagwati Prasad Gupta



This sample includes the detailed table of contents, the preface, some sample pages from eBook and the author bio.

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PREFACE

In a competitive environment, the growth of a business depends upon well-developed industries. The industry operations must be efficient requiring the use of well-maintained and state-of-the-art machines and equipment.

On an average, for an engineering industry, 15 years can be safely considered as the useful working life for a medium and heavy machine. Moreover, during this period, technology of the product and process are very likely to also change. Replacement of old plants and machinery is an expensive proposition. The life of a machine can be extended to a great extent by reconditioning before it is discarded as useless scrap. But the problem is what to do with the vast number of old conventional machines existing in good working condition but not meeting the new technological requirements.

Retrofitting and modernization is the only solution. This is what I have experienced while working in maintenance of plants and machines rebuilding field in engineering industries for more than 35 years. In this book, effort has been made to compile, in brief, the experience and the relevant information in the machine modernization area gathered during this period.

The modernization of a machine means an introduction of changes into the design of machines which improve their performance and capacity and prolong their service life. But before initiating the modernization effort, one needs to study the operating cycle of the machine in order to be aware of the technical behavior of the machines. Modernization of equipment is one of the principal trends in comprehensive mechanization and automation of production processes. It permits conversion of obsolete machines into semiautomatic and completely automatic machines with low expenditure in terms of labor, time and money. The first and second chapters of this book have been written to cover these topics explaining the modernization trends and guidelines. The first two chapters form the basis for the subsequent chapters.

Operational regime varies depending on the material of the job, tooling and technology followed. Chapter 3 discusses different parameters including cutting speed, feed, cutting forces involved and power required for improving the operational regime and the drives required for ensuring the same from the machine have been explained in chapter 4. Selection of drives is the most important consideration for any modernization. An overview of different options have been given for motors and drives, including servo-drives, and their selection criteria for various technological needs.

A drive can serve its purpose only when the desired motion, providing appropriate torque and speed, is available. This may mean a change of speed with a corresponding change in torque, a change in output direction or position, or more commonly, a combination of the above. So, there is a need for proper selection of rotary motion transmission devices. But, for feed mechanism usually a linear motion is required. Since devices used in old conventional machines are not very efficient, modernizing linear motion mechanism is therefore essential. In order to couple the transmission devices with the drive, suitable clutches and couplings are required. Details for such transmission devices and selection of clutches and couplings for precision applications are given in Chapters 5, 6 and 7, respectively.

By improving the drives and transmission devices, speeds and feeds can be increased and appropriately regulated. But without smooth rotary motion of the spindle and linear motion of slides on guide-ways, desired results cannot be achieved. Improvements in spindle assembly have been described in chapter 8. This chapter describes not only the methods for the restoration of old spindle, but also the standard (readily available) spindle and different types of bearings including substitution by other types of bearings. Modernization of housing guides and slide-ways have been explained in chapter 9. This chapter explains not only about the restoration of different types of conventional guide-ways but also different types of low-friction slide-ways for retrofitting during modernization of the machines. Chapter 10,'Improving lubrication system', gives the complete details of lubrication arrangements both for rotary as well as sliding motion units.

In order to equip the machines with the latest features available in the modern machines, it is necessary to be aware of the systems, devices and facilities that can be applied during the modernization. Chapter 11, 'Modernization with hydraulic and pneumatic system', includes the details of different types of hydraulic and pneumatic circuits and the components involved in them. It also provides a brief explanation of electro-hydraulic system like proportional valve and servo-valves which enable machines to perform complicated operations. A machine can be made versatile if it can be equipped with features that enable it to perform the subsequent operations also in the same setting without the need of taking the work-piece on the other type of machine. An example is key-way cutting on the shaft after turning on lathe machine in the same settings. Similarly, performance can be improved if time for the auxiliary operations can be reduced by providing self-cantering arrangements, multi-tool turrets, multi-position job setting as in pallet changer, provision of auto tool changer, on job digital measuring devices like DRO, etc. This is the topic of chapter 12, 'Retrofitting with additional features and attachments'. Performance of a machine can be further improved by incorporating copying attachments. Other arrangements including protective coverings and fitting of chip conveyors have also been discussed in this chapter.

Operations on a machine can be performed only through its control system. This means the performance of a machine can be improved to the best possible level by modernization of the control system. Controls can be manual or automatic depending upon the frequency of changing operations required. Chapter 13 discusses almost all types of popular controls applied in the industrial equipment including PLC, NC and CNC. Chapter14 exclusively focusses on CNC retrofitting and the steps followed by the author on the shop floor while modernizing the old conventional machines.

Automation in manufacturing operations is the ultimate objective of modernization. All operations need to be performed and controlled through an automatic control mechanism. Programmable automation is achieved by incorporating CNC system, Robotics, and PLC. Effort has been made in this direction in chapter 15 concluding with flexible manufacturing system (FMS). By installing FMS in a manufacturing industry, automation can be increased to such an extent that the dependence on operators can be reduced and so, reliability of the operations can be improved to a great extent.

This book has been written keeping in mind the requirements of engineers, managers and investors with technical background and working in an engineering industry. Technical students seeking employment in an engineering industry will also find this book useful. After going through the text, a lot of ideas will be generated to modernize machines and save capital by reducing fresh investment in new expensive equipment. I welcome feedback and suggestions from the readers.

Bhagwati Prasad Gupta

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such as design, degree of mechanization and automation, the cutting tools used, the mode of cutting, the number of principal operating members etc.

1.3 FAILURE OF MACHINES

Product quality, productivity and cost depend on the condition of the machine. Failure may occur in the course of operation. Main causes of machine failure are given below:

- mishandling or overloading specific mechanisms and assemblies;

- maladjustment of a particular assembly or mechanism;

- failure of certain mechanisms and impairment of accuracy due to wear of individual components and parts.

By taking proper care, chances of mishandling and maladjustment can be prevented and working life of the machine could be prolonged. The effect of wear on components and mechanisms is of permanent nature. By making technical improvements, rate of wear can be reduced, but it is difficult to avert. Wearing process of machine components could be categorized into three stages.

1.3.1 WEARING PROCESS OF MACHINES

In the first stage, the process of wear is characterized by the initial work of joint, and may be termed as running-in period for the mating members. In this stage, the amount and rate of wear depend on the surface condition of the mating parts. The better is the surface finish of the rubbing portion of the parts machined and fitted to the joint service conditions, the less their initial wear will be.

The joints performs normally in the second stage. The amount of wear depend on the duration of the joint operation.

Next comes the third stage when the rate of wear is high and the increase of clearances in joints are severe. The joints, at this stage, starts operating with unacceptable noise and rattle. As wear is building up, the normal operation of the mechanism is upset and eventually it fails.

At this stage, it is necessary to compensate for the wear, to restore the joints to their normal condition, and the mechanism to its original capability of performing the job it has been designed for. If the machine has been allowed to be operated for a considerable period in the third stage with a high rate of wear, repairs involve reconditioningn or renovation requiring considerable material and labour input.

1.4 USEFUL WORKING LIFE OF MACHINE

In order to identify the machine for reconditioning, it is essential to sort list based on use full working life. Normally after 10years of useful life, replacement of a machine may be considered necessary. Depending upon the severity of working condition and in built design of the equipment, the period may be less or more. To a great extent following formulas can be applied for identifying machines to be considered for replacement.

Improving performance characteristics by adding operational features
Enhancing service life of machine
Reducing auxiliary time.
Increasing automation

2.4.1 METHODS FOR INCREASING SPEED AND POWER OF A MACHINE

For increasing speed and power of a machine, its different units and sub-assemblies need to be modified.Activities required to be performed for the same are tabulated below.

Table 2.1: Modification activities for increasing speed/power of a machine

S.No.	Description	Speed	Power
1	Changing Kinematic drive of primary motion	*	*
2	Mounting single speed drive	*	*
3	Mounting new speed gear box	*	*
4	Modification of spindle bearings	*	-
5	Modification of system of lubrication	*	*
6	Installing electric motor of higher capacity	-	*
7	Strengthening weak links of primary motion	*	*
8	Changing kinematics of feed drive	*	*
9	Strengthening weak links of feed drive	*	*
10	Improving lubrication system of feed drive	*	*
11	Changing material and improving heat treatment of fast wearing components	*	-
12	Replacing fast wearing bronze bushes by synthetic bushes or rolling bearings	*	-
13	Providing synthetic/antifriction guideways	*	-

2.4.1.1 Limitations in Increasing Speed And Power

Allowable Increase In Power P2/P1 With The Increase In Speed

$$\frac{Modified\ speed}{Original\ speed} = \frac{Modified\ power\ rating}{Original\ power\ rating}$$

i) For shaft, unhardened gears, slow speed worm drive, belt drive etc.

5.5.1.1 Standard Two Speed planetary Gearbox for Ram Assembly

The integration of the gearbox inside of the ram provides a complete, light-weight spindle-drive system that can be displaced independent of the column. The low weight and minimum dimensions of this ram enables rapid acceleration of the z-axis, resulting in minimum chip-to-chip tool change times. This solution provides a productive, high-performance spindle.

2-Speed Gearboxes augment the latest spindle drive-motor technology by providing high torque at low speed. These units mount in-line between the water-cooled motor and the spindle inside of the machine tool's ram. Features include a water-cooled housing, a hollow-through bore, low-backlash, and high-quality planetary gearing to insure low vibration, quiet and cool operation.

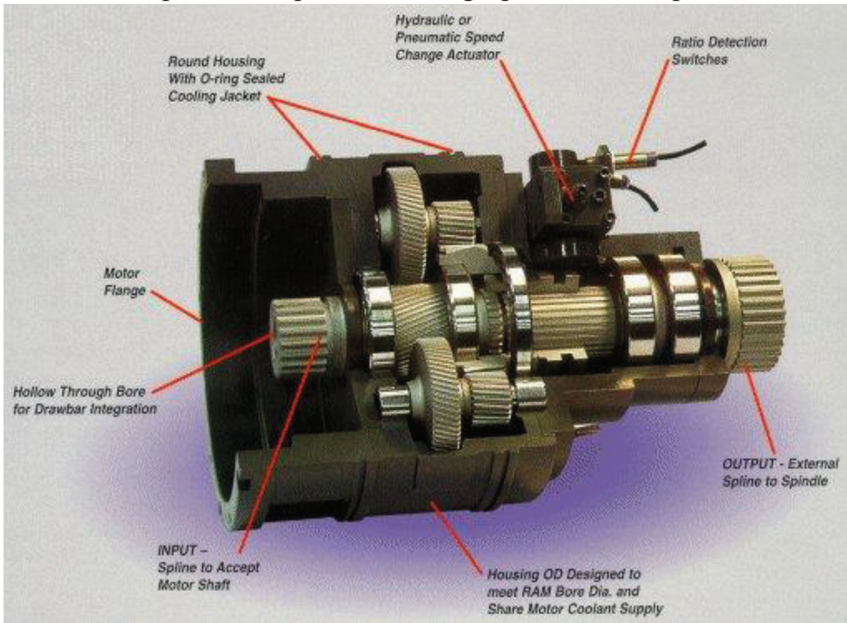

Fig. 5.7: Typical Standard 2-speed planetary gearbox

5.6 STEPLESS VARIABLE SPEED DRIVE

The use of infinitely variable speed unit has proved its worth in countless industrial applications. For best performance of machine tools requiring stepless speed changing with precise control following types of units stand unmatched.

5.6.1 PIV GEAR DRIVE

It is positive infinitely variable drive, which is coupled with a conventional induction motor to obtain step less variation of output speed. In the system an endless chain is mounted on bevel disc pairs by sliding the discs in axial direction, the distance between two discs of each pair is varied. The control system is made such that while one disc pair slides close together, the other disc pair moves away from each other. With this chain running diameter of two disc pairs could be varied. Depending upon the power transmission applications, various types of chains are used.

Ring roller chain: It consists of steel links with cradle joints joined with each other. Over these links reliable ring rolls are fastened. This type of chain is suitable for chain speed upto 25 meter per second and 37.5 K.W. power.

Rocker pressure pin chain: In this type of chain, cradle joints transmit force over the bevel disc pairs. The relative light design makes it possible to have chain speed upto 30 meter per second. Such chain can transmit power upto 27.5 K.W.

Backlash free gearing arrangement increases loading on gears causing additional power consumption and early wear of the gear profile. So where rapid and feed motions are to be transmitted through same gear train, a system has to be provided to ensure backlash-free motion during feed and with backlash motion during rapid movement. To avoid back lash in the drive two pinion (one mounted on the other) are used so that one pinion tooth face is touching one side of tooth gap in the rack and the other pinion tooth is touching the other side on the tooth gap during feed movement .To achieve the same the two pinions are given motion in the opposite direction. For rapid motion the two pinions are given the rotation in the same direction to reduce loading.

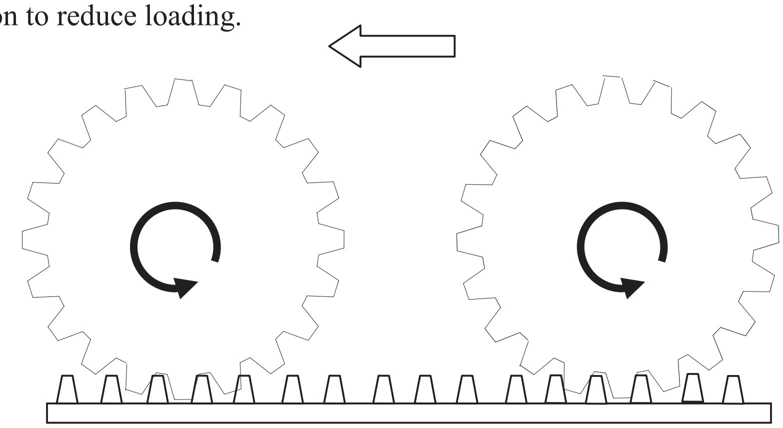

Fig. 6.2: Showing the two pinions during rapid

6.2.3.1 Preloaded Rack and Pinion Drive System

Shortening the center distance between rack and pinion is commonly accomplished by pre-loading the two mechanisms via spring compression.

Another rack and pinion pre-loading method is dual-pinion, which consists of two pinions engaging one rack. The pre-loaded dual pinions mesh with opposite tooth flanks on the same rack taking up the backlash between the two mechanisms.

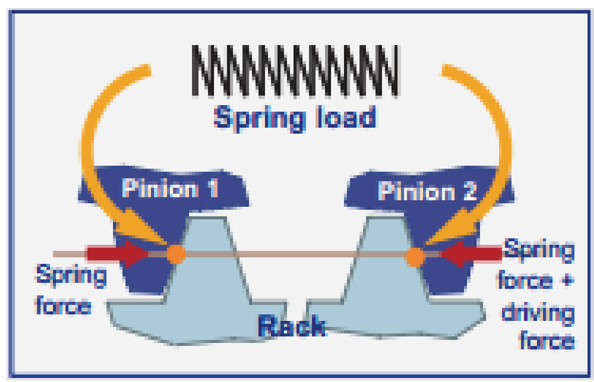

Fig. 6.3: Preloading in dual pinion rack drive

This could easily be achieved by preloading the pair of helical gears during feed drive and releasing during rapid motion.The axis backlash is eliminated by using two pinions, one to drive the axis and the other to engage the opposite tooth flank and take up the backlash. Preloading could be achieved by axially shifting the driving shaft making two helical pinions turn in opposite direction to eliminate backlash between driven gear and two meshing helical pinions.

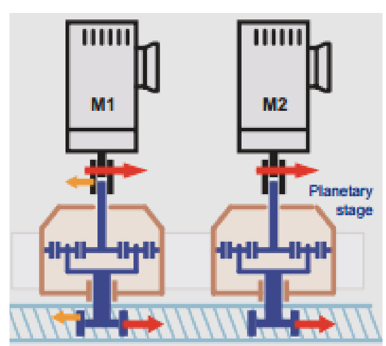

Fig. 6.4: Preloading in helical rack

Electronically preloaded systems use two motor/gearbox assemblies with dual pinions operating on the same rack in a master/slave setup. One pinion drives the axis (the "master")

Filters and strainers remove contaminants from the oil. Strainer of 100 mesh size is provided in suction-line and less than that of smaller size is provided in return line.

Standard control apparatus, standard pipe fittings and connections, and standard seals and packing should be used through out in designing hydraulic circuits. The hydraulic circuit diagram of industrial machines should be as illustrative as possible and easy to read.

11.3 CONSTRUCTIONAL FEATURE OF POWERPACK

Powerpack, generally consists of a reservoir for storing and supplying the working fluid, a strainer (usually of 140 to 150 μm size) at the pump inlet to filter out the large size particles from entering into the pump, a pump driven by a prime mover, a relief valve, a pressure gauge and a gauge damper. Depending upon the system requirement some powerpack even consist of a pressure/return line filter, oil level controls and accumulator. Fig.11.2 shows the schematic representation of powerpack.

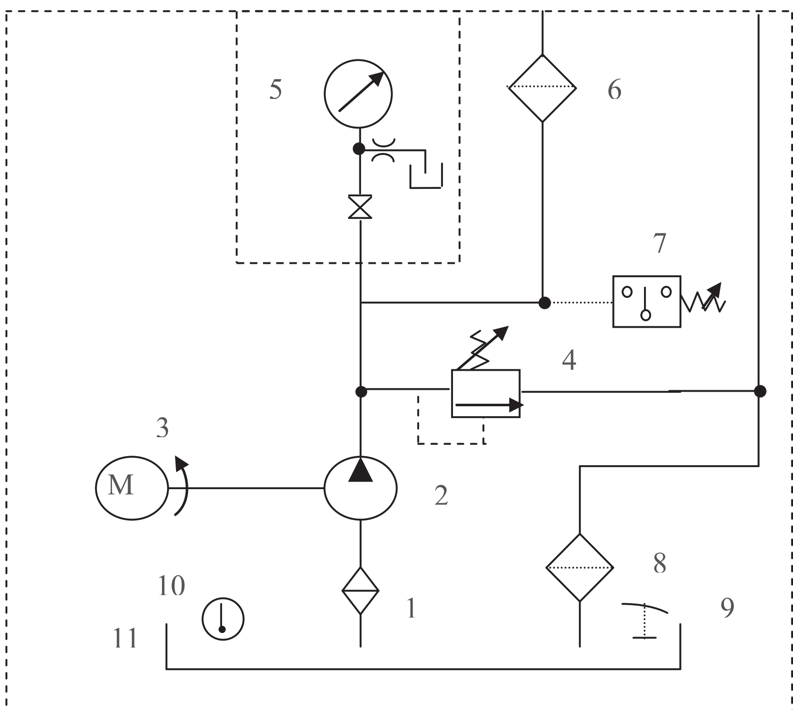

Fig.11.2 Schematic representation of hydraulic power-pack

Components of the powerpack shown in the figure are listed below.

1. Strainer

2. Pump

servo amplifier, which also receives an electrical signal fed back by a tacho-generator, potentiometer or other transducer connected to the load.

When equal current flows through the two coils, the armature of the torque motor remains centered. When current is increased in one coil and reduced in the other, the armature is shifted off from its central position in the amount proportional to the changing current. Since the valve spool is attached to the torque motor armature, the spool is also get shifted by a distance proportional to the change in current. Thus flow rate may also be adjusted by varying the current input to the torque motor and a separate flow control valve is not required.

Thus in an electro-hydraulic system, the solenoid operated direction control valve has been replaced by a servo valve. Essentially, a servo valve is a directional valve in which the solenoids are replaced by a torque motor, a device having two coils and an armature held centered by a torsion bar. With equal current flowing through the two coils, the armature remains centered, increasing the current in one coil and reducing it in the other causes the armature swing off center an amount proportional to and linear with the change in current. Since the valve spool is attached to the torque motor armature, the spool also shifts a distance proportional to the change in current. Since flow can infinitely be varied with the help of the servo valve, a flow control valve is not required. A hydraulic system so controlled is called an open loop system.

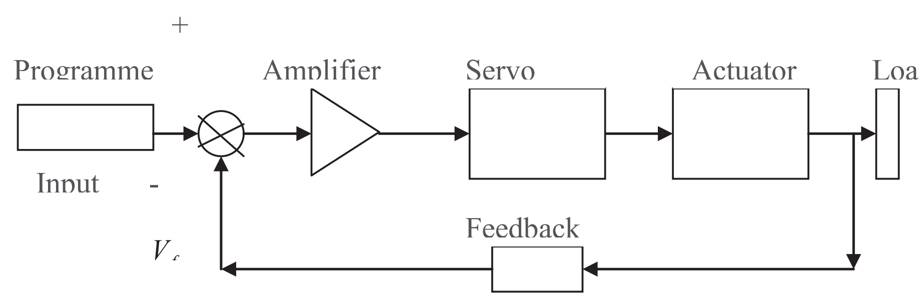

Fig. 11.6 Block diagram of closed loop servo system

In the case of closed loop system, if the actuator position is not that intended, an error signal is generated amplified and fed back into the torque motor to correct the difference. The block diagram of a closed loop electro-hydraulic system is shown in the figure 11.6. The programmer provides a reference voltage to the amplifier. This reference voltage is compared with the feedback voltage from the feedback transducer at the summing point and error is fed to the amplifier. The amplifier provides a constant output in reference to its error signal. The servo valve converts the output from the amplifier to the valve spool movement which in turn, controls the flow of oil to the actuator. The actuator may be jack or motor, responds to correct the difference and null the error. Thus with all closed loop control system, power to operate the output quantity is supplied by the external source and not by the programmer. This complete sequence takes place in very brief time span. A typical servo valve can respond at a rate of hundred cycles per second. This is one of the main reasons for the

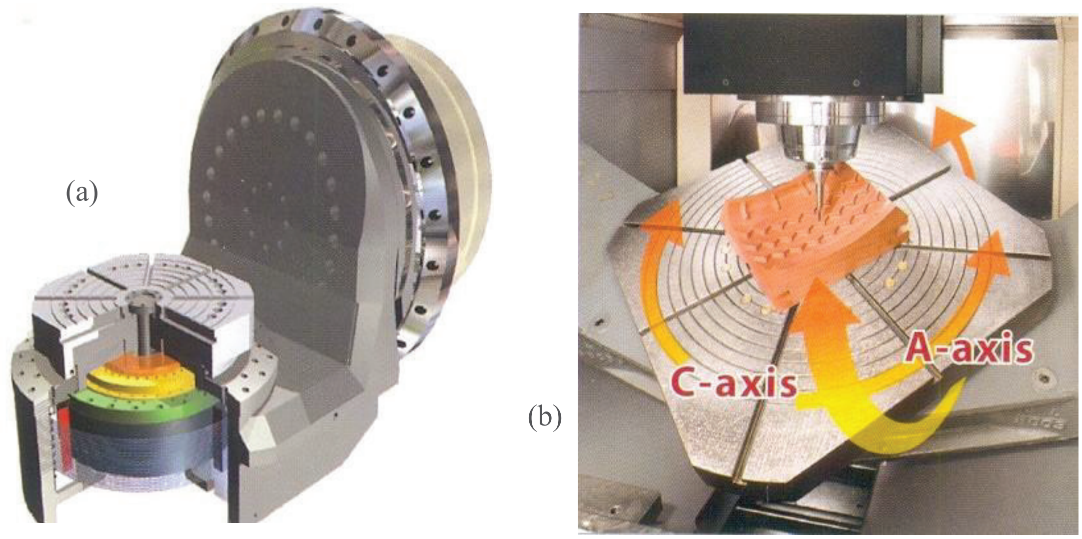

Fig.12.5:Tilting rotary table with :(a) B-axis and C-axis. (b) A- axis and C-axis

12.2.3 PROVIDING UNIVERSAL MILLING HEAD FOR ADDITIONAL AXES

Standard Universal milling heads are manufactured now a days that can be readily be fitted with the spindle quill or spindle ram of the vertical machining center. Thus 5-axis machining operation can be performed with the 3-axes machine.

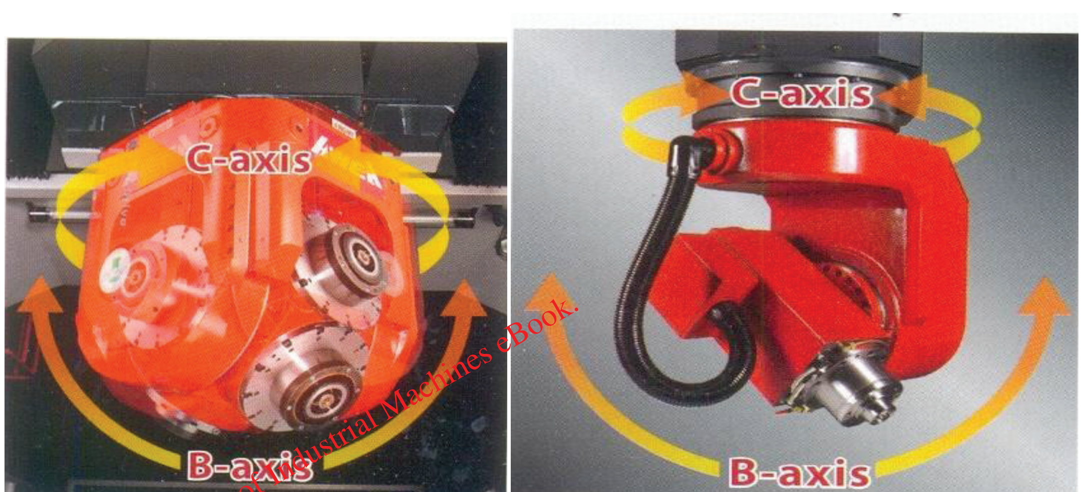

Fig. 12.6:Different types of Universal Milling Heads

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Then thrust bearing of this shaft will be subjected to an axial force proportional to the torque.Axial force may be measured by stain gauge fixed on drum.

13.4 MODERNIZATION OF ELECTRICAL CONTROL SYSTEMS

Electrical control systems are used on every equipment from simple pump controls to car washes, to complex chemical processing plants. Control circuits provide the logic for the operation of the components in the power circuit. Control circuits are typically a lower, safer voltage, such as 120 V ac or 24 V dc. Control power transformers (CPTs) and power supplies are used to transform or convert the power circuit voltage to the control circuit voltage. For every operation of a machine, there has to be an input signal that may come directly from the operator or from a sensor indicating the completion of the previous operation and preparing the system for the next operation. These input signals are further processed in a processing device and generate an output signal for starting the operation of the actuators in the specified sequence. Earlier all these functions were carried out with the help of electromagnetic contactors, relays and electronic valves. Logical control system is made responsible for the functioning of the operating system.

13.4.1 LOGIC CONTROL SYSTEMS

In order to understand the industrial logic control systems, consider the simple pneumatic system shown in Figure. The pneumatic cylinder moves in a linear dimension until it reaches the limit switch at the extended end. The cylinder is controlled with a simple two position, four-way solenoid valve as shown. The solenoid valve shown is activated by an electrical current passing through the solenoid coil. This type of simple ON/OFF programming has traditionally been done by relay control systems.

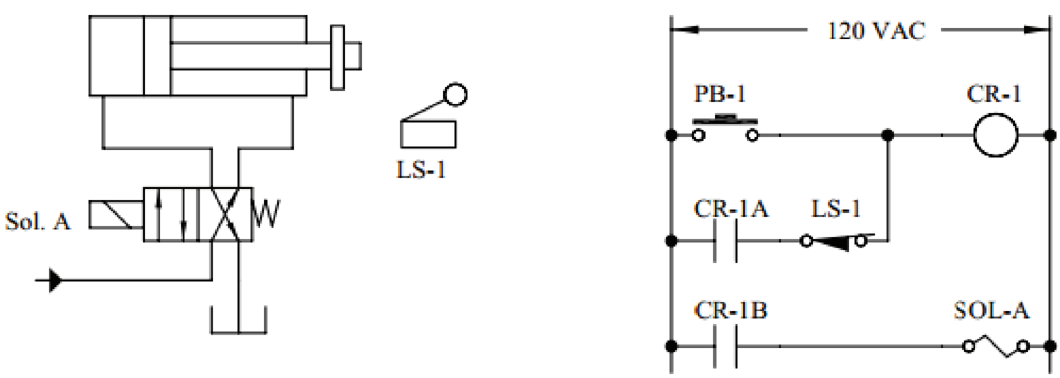

Fig.13.2: Asimple pneumatic system and its relay control ladder logic

A relay control system for the simple system of Figure LC-1 is also shown. This schematic diagram represents a type of programming frequently referred to as "ladder logic" by industrial electricians.

Electrical current passing through the coil of the relay (the "control relay") closes one of these sets of contacts (CR-1B) which allows current to flow through the pneumatic valve solenoid, SOL-A. Another set of contacts, CR-1A in Figure LC-1, is used to "hold" the contacts closed

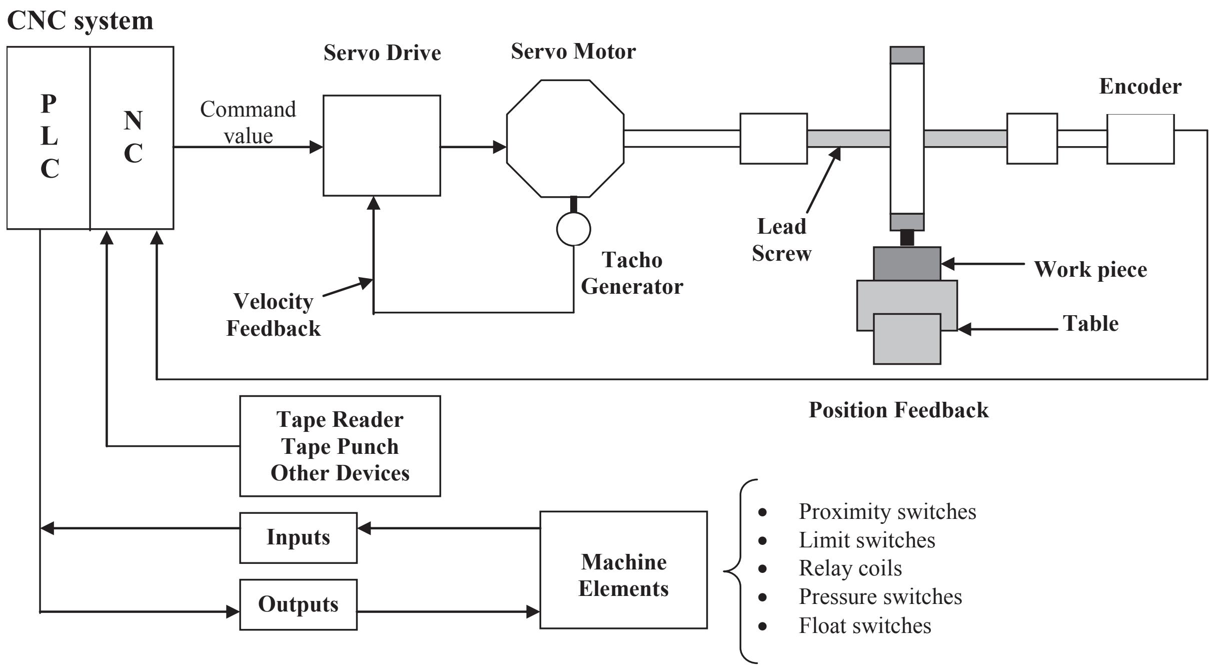

Fig.14.2: Schematic diagram of a CNC

Structure of a CNC system basically consists of the following:

1. Central processing unit (CPU)
2. Speed control/Servo-control unit
3. Operator control panel
4. Machine control panel
5. Other peripheral device
6. Programmable logic controller (PLC)

14.4.1 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 whenever this does not match the programmed values, a corrective action is taken.

All the compensations required for machine accuracy (like lead screw pitch error, tool wear out, backlash, etc.) are calculated by the CPU depending upon the corresponding inputs made available to the system. The same will be taken care of during the generation of control signals for the axis movement. Also, some safety checks are built into the system through this unit and the CPU unit will provide continuous necessary corrective actions. Whenever the situation goes beyond control of the CPU, it takes the final action of shutting down the system in turn the machine.

14.4.2 SPEED CONTROL UNIT AND SERVO-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

15.1.2 AMPLIFIERS

Electrical, Electronics, hydraulic, pneumatic amplifiers and mechanical lever, wedge eccentric etc. comes under this category.

15.1.3 OPERATIVE-MEMBERS OR ACTUATOR

An actuator accepts energy and produces movement (action). The energy supplied to an actuator might be electrical or mechanical .

Servomotors are used to transform input command signal into mechanical motion. Following types of motors can be employed to act as Servomotor.

- AC electric motor-induction motors with a cage rotor and two stator windings (control windings and excitor windings).
- D.C. Electric motor.
- Stepper motor.
- Hydraulic servomotors.
- Pneumatic motors.
- Clutches such as electro magnetic particle clutches are also some times used in the operating system.

15.2 TRAVEL TRANSDUCERS

Travel transducers can be mechanical, hydraulic or pneumatic, electrical, electromechanical or electronic type. A few commonly used transducers are given below:

15.2.1 MECHANICAL TRANSDUCERS

These are essentially cams and stops. Cams are connected to a shaft through mechanical linkage and machine slide moves corresponding to the shape of the cam. Stops having a face of hardened steel & are fixed on stationary component like bed or frame of the machine .The moving comes to a halt after coming in contact with the stop due to increase in resisting force faced by feed mechanism or by switching the clutches of the feed mechanism. Single position and multiposition stops are usually fitted with a micrometer and an indicator to permit fine adjustment of stop motion upto 0005 mm.

15.2.2 ELECTROMECHANICAL TRANSDUCERS

Electromechanical transducers are devices intended to make or break electric circuits controlling start and stop functions and speed of its movable components. These are primarily contact limit switches, microswitches, pressure switches, etc.

Contact Limit switches: Pushrods of the switch exist in several modifications to permit both the translational and swinging motions .It is generally desirable to have a high speed during make of contact to minimize the duration of an arc or flash over and slower speed during break of a contact to minimize transients particularly for DC and inductive circuits.

Micro switch: The micro switch senses the position or displacement of any part. It is used for level measurement by sensing the displacement of float. It can be used counting, position sensing in machine tools and automation.

Pressure switch: The pressure switch senses if desired the pressure is reached or not. It is available in different pressure ranges, from vacuum to very high pressures.

2) Processing operations e.g. spot welding, arc welding, spray painting, machining
3) Assembly and inspection process
4) Programmable manipulators that follow specified path working better than humans with respect to hostile environments for long hours with consistency in operations.

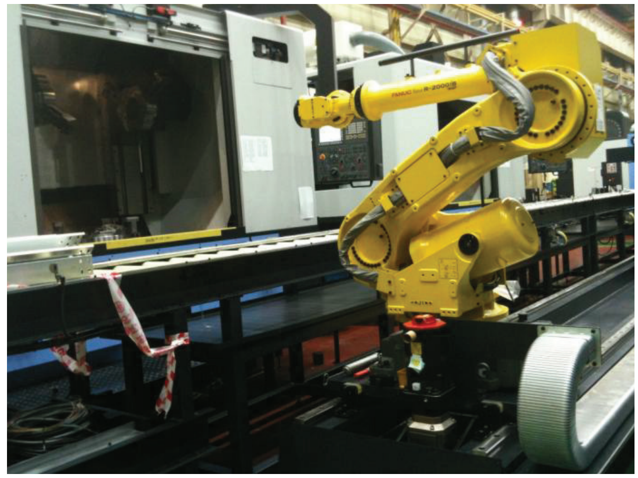

Fig.15.1: Robot operating in a humanless factory

15.5 FLEXIBLE MANUFACTURING SYSTEM (FMS)

Conventional manufacturing systems have been marked by one of two distinct features:

- The capability of producing a variety of different product types, but at a high cost (e.g., job shops).
- The capability of producing large volumes of a product at a lower cost, but very inflexible in terms of the product types which can be produced (e.g., transfer lines).

An FMS is designed to provide both of these features. Flexibility in manufacturing means the ability to deal with slightly or greatly mixed parts, to allow variation in parts assembly and variations in process sequence, change the production volume and change the design of certain product being manufactured. A flexible manufacturing system (FMS) makes it possible to automate production with machine tools and thus enable unmanned production and increase the production capacity and utilization rate of the machine tools. An FMS is a “reprogrammable” manufacturing system capable of producing a variety of products automatically.

A Flexible Manufacturing System (FMS) is a production system consisting of a set of numerically controlled machines connected through an automated transportation system. Each process in FMS is controlled by a dedicated computer (FMS cell computer).

15.5.1 OPERATION PRINCIPLE OF THE FMS

Machining cycles are based on job sequences assigned. A job sequence defines the loading jobs, machining jobs, and unloading jobs for a machining cycle, as well as the order the jobs are performed in. The specific fixture to be used for clamping the part and the part ID after the machining cycle are also specified in the job sequence. The operator can create and edit job sequences and save them as master data. The job sequences of a part comprise the operation plan for the part.

About the Author:

Bhagwati Prasad Gupta, a Professor in Deptt.of Mechanical Engineering at Inderprastha Engineering College near Delhi, has spent more than 35 years in the field of maintenance, and has been exposed to various industries in India, Russia, Germany and Switzerland. As General Manager (Facility Rebuilding Division) in Bharat Heavy Electricals Ltd, he has been responsible for Machine-rebuilding and Modernization of the plants and machinery. He has organized several training workshops, made presentations at seminars and published papers on various topics of Operation and Maintenance of Machine-tools and Equipment in different technical journals. His book on "*Machinist Handbook on Precision Machining and Equipment Maintenance*" was published in electronic format by Feed Forward Publications and is available on website *www.FeedForward.com.au*.

His other book *"Industrial Hydraulic Systems and Circuits"* is available on website http://www.feedforward.com.au/hydraulic_control_system.htm. His third book *on "Industrial Maintenance"* was published by S. Chand & Co. New Delhi. He is Fellow of Institution of Engineers and Member of All India Management Association. As consultant, recently, he visited machine-tool manufacturing industries in Taiwan and South Korea for technical discussions on latest trend followed in designing and manufacturing of industrial machines.

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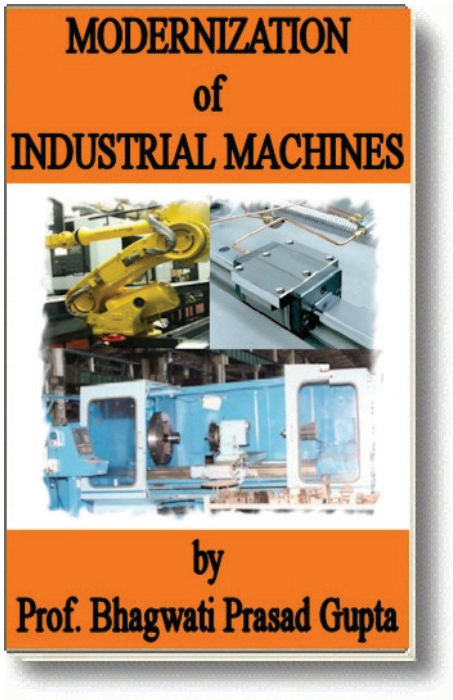

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