C17

SECOND INTERNATIONAL METAL CUTTING CONFERENCE
第二屆國際金屬切削會議

IMCC

JOINTLY ORGANIZED BY HONG KONG POLYTECHNIC, HONG KONG
& HUAZHONG (CENTRAL CHINA) UNIVERSITY OF SCIENCE & TECHNOLOGY, CHINA
中國華中工學院及香港理工學院聯合主辦

Flexible Manufacturing Cell in an Educational Environment

BY

PT MO, PW LEUNG and PK VENUVINOD
HONG KONG POLYTECHNIC
HONG KONG

MAY 14 — MAY 18, 1985
一九八五年五月十四日至十八日

WUHAN
武　漢

SECOND INTERNATIONAL METAL CUTTING CONFERENCE

MAY 14-18, 1985, WUHAN

Flexible Manufacturing Cell in an Educational Environment

BY

PT MO, PW LEUNG and PK VENUVINOD
HONG KONG POLYTECHNIC
HONG KONG

Flexible Manufacturing Cell in an Educational Environment

Abstract

Attention is drawn to the educational benefits afforded by a flexible manufacturing cell (FMC). Details of a recently established CAD/CAM laboratory designed around such an FMC, in the Department of Production and Industrial Engineering of Hong Kong Polytechnic, are presented. Initial experience gained on the system suggests that the FMC can provide an extremely valuable infrastructure for integrated education in Manufacturing Engineering.

Introduction

While the Hong Kong industry is yet to implement the modern concepts of CAD/CAM and Flexible Manufacturing Systems (FMS) to their full potential, there has been a growing awareness that something needs to be done in this area if industry is to maintain its competitive edge in the world market.

In a recent brainstorming session, organised by the Hong Kong Government to determine needs, it was concluded that the lack of an awareness of the potential benefits of CAD/CAM among top management personnel in industry and the lack of suitably trained engineers/ technicians to implement CAD/CAM projects constituted two major blocks.

The tertiary technical education sector of Hong Kong thus has a key responsibility in the development of CAD/CAM in Hong Kong industry. This paper discusses the strategies adopted by the Department of Production and Industrial Engineering of Hong Kong Polytechnic to discharge its share of this responsibility.

Until recently, the Department has been concerned mainly with the education of technician-engineers to serve local manufacturing industries. Traditionally these industries have adopted a mixture of batch production involving low levels of automation and mass production involving high levels of hard automation; there has been no need and, hence, no incentive to grapple with the problems of education in the technology of flexible automation.

Further, the educational process (and, consequently, the laboratory infrastructure) has hitherto been organised on the traditional approach of teaching an array of subjects grouped into two separate sets, viz one concerned with manufacturing processes (such as machining, metal forming, polymer technology, metrology) and the other concerned with manufacturing systems where the individual components of a system were treated essentially as black boxes. This resulted in an array of essentially isolated laboratories which bore a tenuous inter-relationship only to the extent that each fulfilled one of the educational requirements in producing a manufacturing technician/engineer.

However, the above scenario had to be changed when, about two years back, the Department decided to apply a systematic approach to the curriculum development for a new Honours Degree Course in Manufacturing Engineering.

The first step in this systematic approach was to decide what really distinguished an 'honours' graduate from an 'ordinary' graduate or a technician-engineer in manufacturing engineering. In recognition of the needs of local industries, the Department rejected the traditional concept of 'honours' classification based on intellectual depth in specific areas. Instead, it defined an 'honours' graduate as one capable of assuming a comprehensive view of manufacturing as an <u>integrated</u> activity involving a multitude of technological and managerial decisions. To elaborate, the intended graduate had to realise that 'manufacturing' involves not only the individual production processes such as machining, forming, assembly, inspection, handling, etc. but also of the <u>integration</u> of these with the pre-production processes such as programming, estimating, process planning, scheduling or even drawing and design.

In the process of developing the curriculum necessary for the education of such a graduate, it soon became apparent that the existing array of independent laboratories provided little opportunity for the necessary integration. Meanwhile, however, faculty members had been making tentative attempts to assimilate the modern concepts of CAD/CAM and FMS. This experience brought with it the realisation that a CAD/CAM laboratory organised around a Flexible Manufacturing Cell (FMC) provides an infrastructure ideally suited to the 'integrating' function in manufacturing education while exposing students to the modern concepts of CAD/CAM. We shall discuss in the next section the anticipated educational benefits from such a laboratory.

Anticipated Educational Benefits from a FMC

A Flexible Manufacturing Cell (FMC) may be defined as a cell consisting of one or more NC machine tools, along with automated equipment for handling/transfer of workpiece/tool, all being under the control of a computer or a corresponding device, and capable of being adapted quickly to the production of any part the manufacturing requirements of which lie within a predefined range.

When one evaluates an FMC in an educational environment, the intended products are not, as in industry, the produced parts but instead the educational benefits to be derived from the facility. Obviously then the main evaluation criterion must be the educational benefit (EB) per dollar, i.e. EB/$.

It has been suggested [1] that an FMS possesses two types of flexibility, viz 'action flexibility' (i.e. the capacity for taking new actions to meet changed 'circumstances') and 'state flexibility' (i.e. the capacity to continue functioning effectively despite change). These two flexibilities are of great value in an educational environment since they afford an opportunity to introduce change and innovation. Students can undertake a series of projects (actions) to continuously refine their creative faculties - each time modifying the state of the cell in a limited way. The inherent flexibility of an FMC enables these actions to be incorporated quickly so that the student receives his reward (the satisfaction that his actions have resulted in the desired state changes) without undue delay. An FMC is thus ideally suited to the concept of active learning.

Of course, a certain amount of action flexibility is available even when one uses isolated NC machine tools or a programmable handling device (eg. a robot). However, when these individual-devices are integrated into an FMC under computer control, the resulting action flexibility can be several times higher than the sum total of the individual flexibilities offered by the devices. We believe that the marginal investment needed for this synergy (i.e. establishing a supervisory computer system) is not significant in comparison with the additional educational benefits derived so that the 'EB/$' for an FMC is far higher than that for a random array of isolated pieces of equipment.

Secondly, an FMC is in fact a manufacturing system involving a range of manufacturing functions. Given proper planning and effort it is technically feasible today to include in an FMC a variety of functions such as machining, inspection, assembly, and handling. If one then incorporates an appropriate CAD system with the FMC, one can even integrate drawing and design with all the events in manufacturing being controlled from a common graphic database. Thus, an FMC supported by CAD provides a microcosm of an industrial production system environment. Such a facility forces a student to adopt 'systems thinking' and refine his integrative abilities. No longer is it necessary to treat manufacturing systems engineering as an isolated subject dealing with networks of black boxes. The real-time data drawn from a working FMC helps open these black boxes within the context of a tangible system or network. In short, a CAD/CAM laboratory designed around the concept of FMC provides an excellent base for bringing home to the student the realisation that manufacturing is an integrated activity involving a multitude of technological and managerial decisions.

In the following sections, we describe the CAD/CAM laboratory established by the Department with the objective of realising the above benefits.

Overview of the Laboratory

The CAD/CAM Laboratory comprises two sections (see Fig. 1), one for the CAD workstations and the other for the CAM hardware (see Fig. 2).

The basic CAD facility (see Fig. 3) is made up of a Computervision Designer VX system with a colour and a monochrome work station. The software support includes packages for 2D/3D mechanical design, advanced surface design, N.C. programme generation, general purpose post-processor generation, robot simulation, programming for coordinate measuring machines, sheet metal layout and nesting and mould design. A typical application case using such a system has been described by Flohr [2] in which the company generated NC data from part drawings created on the CAD system for machining production dies.

The CAMACS (CAM Asynchronous Communication System) packages available on the system helps the Programmable Communication Unit to transfer information from the CAD system to CAM hardware using serial communication protocol.

[Currently, the CAD section is being expanded to include a Tektronics and a Vax work station to utilise other advanced software (such as GINO F, PAFEC DOGS and BOXER) available elsewhere in the institution.]

The hardware in the CAM section comprises a CNC machining centre, a CNC lathe, an NC mill/drill, an inspection station and a robot with the last four devices being currently configured as an FMC.

Basically, the above facilities have the potential of being linked together to form a computer controlled manufacturing system as outlined by Weck et al [3], and this is one of the future objectives of laboratory development.

Hardware of the Experimental Flexible Manufacturing Cell

The experimental FMC consists of a KAWASAKI-UNIMATION PUMA A760 industrial robot, an EGURO NUCPAL-10 CNC lathe with FANUC 67-B controller, a hardware programmable inspection machine SIGMASIZE 5 and a BRIDGEPORT milling/drilling NC machine with SLO-SYN controller. Supporting hardware include a small work loading station, a light beam warning system and a conveyor.

The PUMA A760 is an articulated joints type industrial robot with six degrees of freedom, each axis being driven by a d.c. servo-motor. It has a payload of 10 Kg and an arm-reach of 1.5 m. The controller is built around the 16-bit LS1-11 minicomputer. Computer mode control is achieved by programming in the VAL language.

The EGURO NUCPAL 10 is a 2-axis CNC lathe controlled by a standard FANUC 67-B controller. Full CNC operation can be selected with the edit and memory mode. NC programs can be stored in the bubble memory area by keying in manually at the control panel or transferring through a RS-232-C interface from an external tape reader.

The SIGMASIZE-5 is a hardware strappable signal processing comparator which takes in dimension-transducer inputs and produces output signals according to conditions. Both visual and electrical outputs are available in parallel. In the FMC set-up, two electrical logic output signals which indicate if the blank is within tolerance are tapped for robot motion control.

The BRIDGEPORT drilling/milling machine is an old-fashioned paraxial NC machine which can only take in data from its tape reader block-by-block. It is hard-wired to the FMC to perform drilling functions. (It is intended to replace this machine in the near future, with a Mitsui-Seiki CNC Machining Centre so as to enhance the capabilities of the cell.)

Operation of the Experimental FMC

The experimental FMC is capable of performing continuous unmanned production of one or more components designed on the CAD system (Fig. 3). The operation cycle is illustrated in the flow-chart as shown in Figure 4.

Since the robot controller has the highest level of intelligence among the FMC components, it is assigned the supervisory function. As Ranky [4] states, the simplest and the most common method of control signal communication with PUMA is through its input/output ports. In this preliminary trial, the overall supervision and decision are incorporated into a set of robot programs written in VAL, version 13. Communication with other equipment is through 12 high/low signals via 4 input and 8 output ports of the robot controller.

The FMC set-up is being constantly enhanced. Currently, a pair of grippers with a built-in optical sensor switch has been designed and installed to sense if a workpiece is present. Also, the operation cycle is being expanded to handle 4 different workpieces which are assembled to form 2 compound components.

The trial operation of the FMC has helped us to identify the major areas of development required for realising a more comprehensive flexible cell - these will now be considered.

Development Areas

Our aim is to provide practical opportunities for the students to encounter the various aspects of flexible manufacturing during the development of a moderate scale FMC.

The aims we have set for the proposed FMC are that it should be capable of:

(1) processing 25 to 100 different components without manual intervention;

(2) scheduling and controlling production automatically with the aid of the turnkey computer system; and

(3) achieving off-line programming for all FMC machine tools and the robot and system simulation from a CAD database.

This project is being executed by a team and the development is sub-divided into the following areas of activity.

(1) Database generation

The 25 to 100 components are being designed on the Computervision Designer VX system. Limitations on the components are that they are to be within the payload of the PUMA robot and within the dimensional constraints of the NC machines. The Components-Database will be generated by the CADDS IV 2-D and 3-D geometric modelling software, the Advanced Surface Design software and other supplementary software such as Drafteze and Mechanical Properties.

The NC Programs Database is generated in conjunction with the Components Database. Part programs in G codes, APT programs as well as Computervision NC software will be used so as to expose the students to various levels of NC programs generation.

The PUMA 760 Robot Programs Database will be generated in the VAL language. This database will be structured for maximum flexibility to facilitate process alternations and redefinition of location variables.

A Global Coordinates Database will provide information of all FMC component dimensions and their relative positions. This database is required in the preparation of robot programs as well as in executing grahic simulation programs such as the Computervision Robograhics software.

(2) Work Handling

The PUMA robot plays the major role in this area. Robot hand gripper and end-effector design will be an active area of development. Currently a student project is being undertaken to design an automatic fingers-changing gripper system for the handling of workpieces with different sizes and shapes. A procurement study is currently underway to add a vision system such as the UNIVISION to the PUMA robot so as to increase its flexibility and intelligence. A long term plan is to add a mobile base to the PUMA robot so as to extend its range of operation. The initial concept is a microprocessor controlled track system with positional feedback control.

The pneumatic power chuck currently installed in the CNC lathe only accepts a fixed workpiece diameter after each manual adjustment. This constraint must be removed if the manufacturing cell is to be acceptably flexible. The feasibility of refitting a programmable servo-chuck to achieve this end is being studied. A dedicated handling manipulator for loading and unloading workpieces to the CNC lathe is being considered so as to free the PUMA robot for other duties.

A universal fixture with groups of five to six small adaptable jigs is proposed for the Mitsui Seiki CNC machining centre to accommodate workpieces of different geometries for machining operations.

Supporting transfer mechanisms, indexers and conveyors are to be added as required.

(3) Tool Management

The 20-position tool magazine is adequate to the flexible employment of the CNC machining centre. This automatic tool changing capability is to be enhanced by pre-set tooling. Unfortunately, no similar facility is available on the CNC lathe which must therefore rely on block tooling. Tool changing for the lathe will be served either by the PUMA robot or by dedicated tool block changing mechanism - a final decision on this matter is yet to be taken.

(4) Inspection

Dimensional measurement by electronic comparators such as the SIGMASIZE-5 has already been successfully tried out in the FMC. An intended development is the installation of probes on the machining centre to attain on-machine inspection facility. Student projects have already been conducted in the area of coordinate measuring machine data acquisition. In the future, the anticipated vision system for the PUMA robot will play a major role in inspection and quality control in the FMC.

(5) Assembly

In the proposed FMC, only simple assembly work will be required. Power tools incorporated with the PUMA robot will be responsible for the majority of the assembly work. Currently, a student project is being conducted to form an assembly station around the PUMA robot with five pneumatic power tools. Another student project has just been completed aimed at the development of a Remote Centre Compliance device to facilitate robot assembly. The device is capable of successful insertion even at 2.5 mm alignment error provided either the hole or the plug is chamfered. Force sensing end effectors development is another anticipated area of activity related to automatic assembly.

(6) Communication

Eventually the Computervision turnkey system will act as the overall supervisor of the system. A star network will be adopted in which all communications will route through the main node. Due to restrictions in the installation of communication interface at the turnkey mini-computer's main chassis, only one programmable communication unit is available. A microprocessor based intelligent switching device is therefore necessary to distribute system supervisor commands and messages to individual machines and to receive feedback information whenever appropriate messages are being communicated through RS-232-C ports. As far as access methods are concerned, both Time Division Multiple Access method and the Token Passing Method are under consideration.

For the slave components of the FMC namely the CNC lathe, CNC machining centre and the PUMA robot, tailored post-processors must be generated to properly interpret the input commands. Especially for the CNC machines, besides controller software modifications, hardware enhancement is also necessary for successful network communication. The general purpose post-processor writer CV POST has been found useful in writing the post-processors for the CNC lathe and the CNC machining centre.

(7) Scheduling and Supervision Control

Group Technology techniques are particularly suitable in planning the FMC since group attributes and family codes can readily be assigned to the components, tools and jigs alike. Scheduling and process planning can then be simplified.

To carry out the scheduling tasks, a supervisory system which can activate the system components at appropriate times is required. Careful design of the software and decision of the type of functions at various levels are vital to the success of the cell. Basically, the hierachical structure of distributed computer control is to be adopted so that malfunction at one part of the system should not stop the operation of the other machine tools unless the error is fatal. Moreover, the supervisor should be so constructed that it is capable of adjusting its parameters to suit changes in system requirements. In this respect, Doumeingts et al [5] have pointed out that a four level decomposition of production control system adapted to the analysis of decision centre is desirable for a multi-level hierarchical complex system. It is necessary that any new task which may be requested at any moment will be absorbed into the system re-evaluating the priorities at various decision levels before arriving at a new schedule for accommodating the new demand. The data base structures available on the Computervision system will be used for organising the database.

Educational Aspects

As mentioned earlier, the primary aim of the flexible manufacturing cell project is to provide opportunties to the students to gain experience and to enhance their knowledge by participating in the development process. Examination of the type of work to be carried out within the cell reveals that nearly all fields within the scope of production and industrial engineering are represented. Typical examples are:

- Hardware automation making use of pneumatics, hydraulics and electrical relay controls.
- Microprocessor applications in sub-system control levels.
- Measurement of system parameters with traditional as well as modern methods.
- Applications of industrial robots and their peripherals.
- Work study and ergonomics in layout planning and optimisation of machine - utilisation.
- Operations research applied to the analysis of task scheduling.
- Numerical control problems including high level programming and post-processing.

The list is never-ending and as work is completed on the system, it is inevitable and desirable that more problems will appear.

It is envisaged that a staff member responsible for an area of development within the system will sub-divide major undertakings into a set of inter-related projects, the successful execution of these being within the capability of an undergraduate student. A typical example is afforded in the area of software development. Provided the staff member has a clear and well-planned software structure, the functional programmes can be written in modules. Similarly, the intelligent switching device itself can be a student project suitable for one to two students and the communication package on the main computer (necessary to activate the device dynamically) could easily be another student project executed under the same supervisor.

Undoubtedly, it would not be possible to rely solely on undergraduate effort and personal involvement of staff members in the project is essential. This includes proposal of student projects, coordination of work, progress monitoring, equipment and materials mnagement and, most important of all, aiding students to solve problems which are beyond their unassisted capabilities.

In addition to its educational potential, the FMC project can demonstrate the capabilities of flexible manufacture to Hong Kong industry. In fact, this laboratory is the first real CAD CAM set-up in Hong Kong. Existing industrial facilities are mainly devoted to design and drafting purposes. For example, we might note that integrated circuit and printed circuit board manufacturers in Hong Kong still rely heavily on manual operations to transform computer-drafted drawings into film negatives. Although the cell can only perform metal cutting processes at the moment, it could be expanded to include coordinate measuring machines, N.C. punching etc. (relevant software to drive the computer controlled machines of the latter processes is readily available in the turnkey system).

Model FMC

Apart from the full scale flexible manufacturing cell established to generate opportunities for real applications, a model FMC with two small educational robots (reach 0.3 m) and several microprocessors has been assembled to supplement facilities in the laboratory. There are two main reasons for such a back-up:

(1) The industrial robot in the full scale FMC is potentially dangerous although the highest level of safety precaution has been taken to operate it. (A panic circuit has been connected with the aid of a beam sensor unit. A metal fencing will also be constructed to enclose a special floor area for its work envelope. Whenever it is working, at least one trained person will be present at the controller alert to the need for emergency action)

    In contrast, the educational robots are small light weight machines which cannot cause injury to operating personnel.

(2) Since there are many students in the Department (more than 160 full time students at each level), one FMC will not be able to provide sufficient facilities for everyone in the class but it is not considered worthwhile, to invest in another FMC.

The model FMC will be enhanced by:

(1) Improvement of the control system of the educational robots.

(2) Purchase of bench type CNC machines (lathe and milling centre).

(3) Development of component software.

(4) Establishment of communication and supervisory software.

The configuration of the model FMC does not have to be the same as that of the full scale counterpart. For instance, a bus-structured local area network can be adopted instead of the star network in the full scale system. The idea is to provide a safe and relatively inexpensive set up to investigate common problems of flexible manufacturing.

Conclusion

Despite the fact that the facility was commissioned only six months ago, a total of 10 projects are currently being executed on the full scale and on the model FMC. The number is expected to grow in the future. With the aid of the turnkey system, much software development work is obviated, in particular the NC part programming and robot off-line programming can be performed interactively on the grahic workstations once the part models are created.

From our experience in executing the current projects, students show great interest in their work and obtain invaluable experience through extensive sessions. The fact that a flexible manufacturing cell draws on knowledge in more than one field of expertise in manufacturing engineering implies more people of a wide variety of interests can be accommodated under the project objective. Through project presentation and group discussions, experience is shared and efforts can be coordinated. An FMC offers an educational institution the opportunity of solving of multifaceted manufacturing engineering problems in a situation closely resembling that in real-life.

References

1. Mandelbaum, M., "Flexibility in decision making: an exploration and unification," PhD Thesis, Department of Industrial Engineering, University of Toronto, 1978.

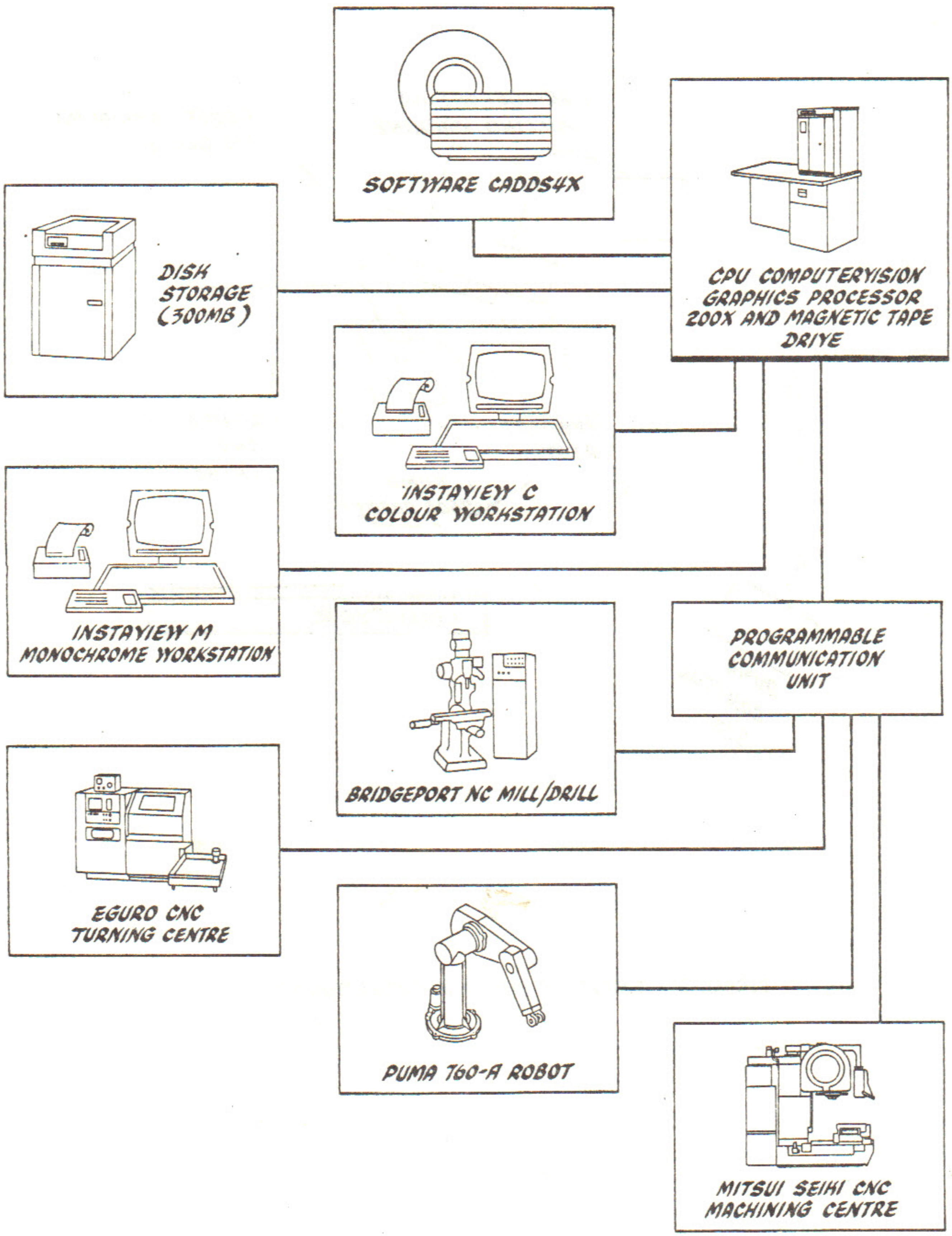
2. Flohr, D., "Generating numerical control data," The CAD/CAM Handbook, Computervision Corporation, pp 149-158, 1980.

3. Weck, W., Zenner, K., and Tuechelmann, Y., "New development of data processing in computer-controlled manufacturing systems (DNC, FMS)", Fourth Int. IFIP/IFC conf. on Programming Research and Operations Logistics in Advanced Manufacturing Technology, Michigan, 1979.

4. Ranky, P.G., "The design and operation of FMS," IFS (Publications) Ltd., pp 257-265, 1983.

5. Doumeingts, G., Brevil, D., Grislain, G., and Pun, L., "Decision-aid and predicates in production control," Fourth Int IFIP/IFAC Conf. on Programming Research and Operations Logistics in Advanced Manufacturing Technology, Michigan, 1979.

CAD/CAM SYSTEM HARDWARE CONFIGURATION



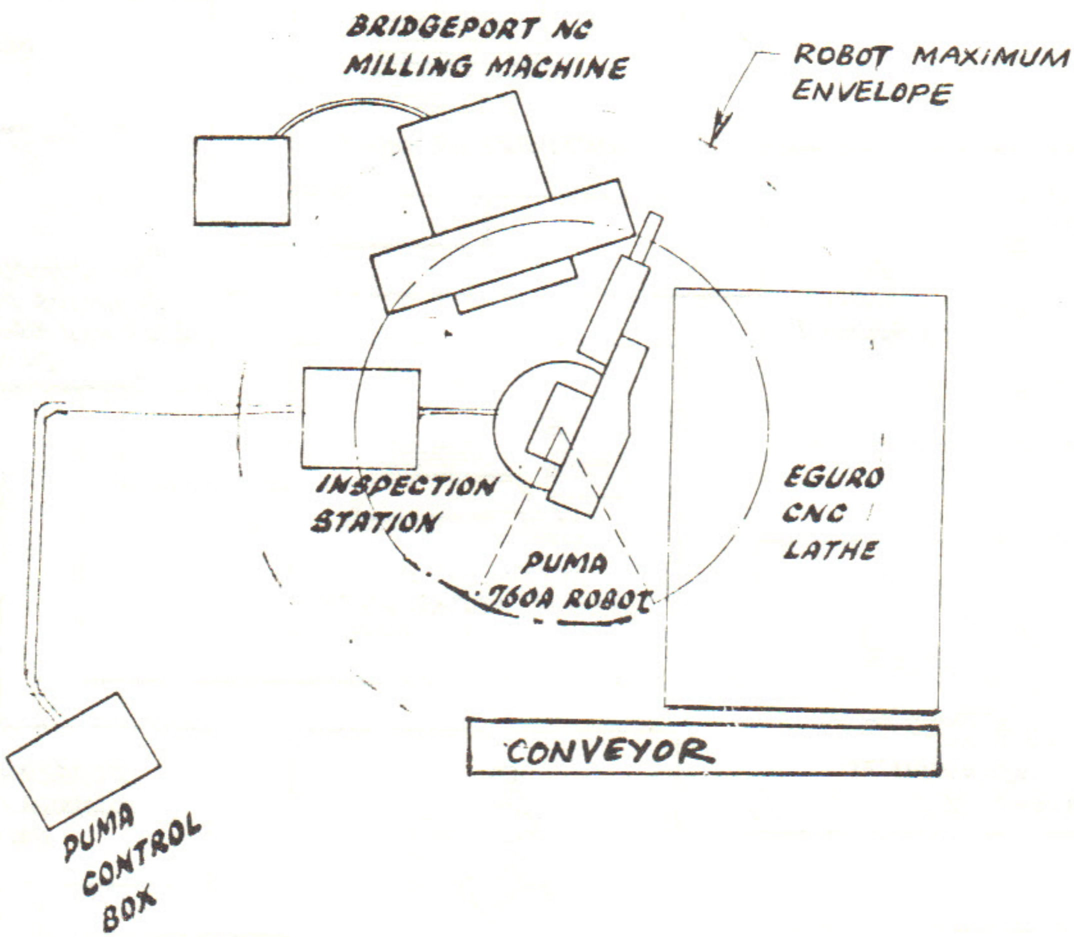
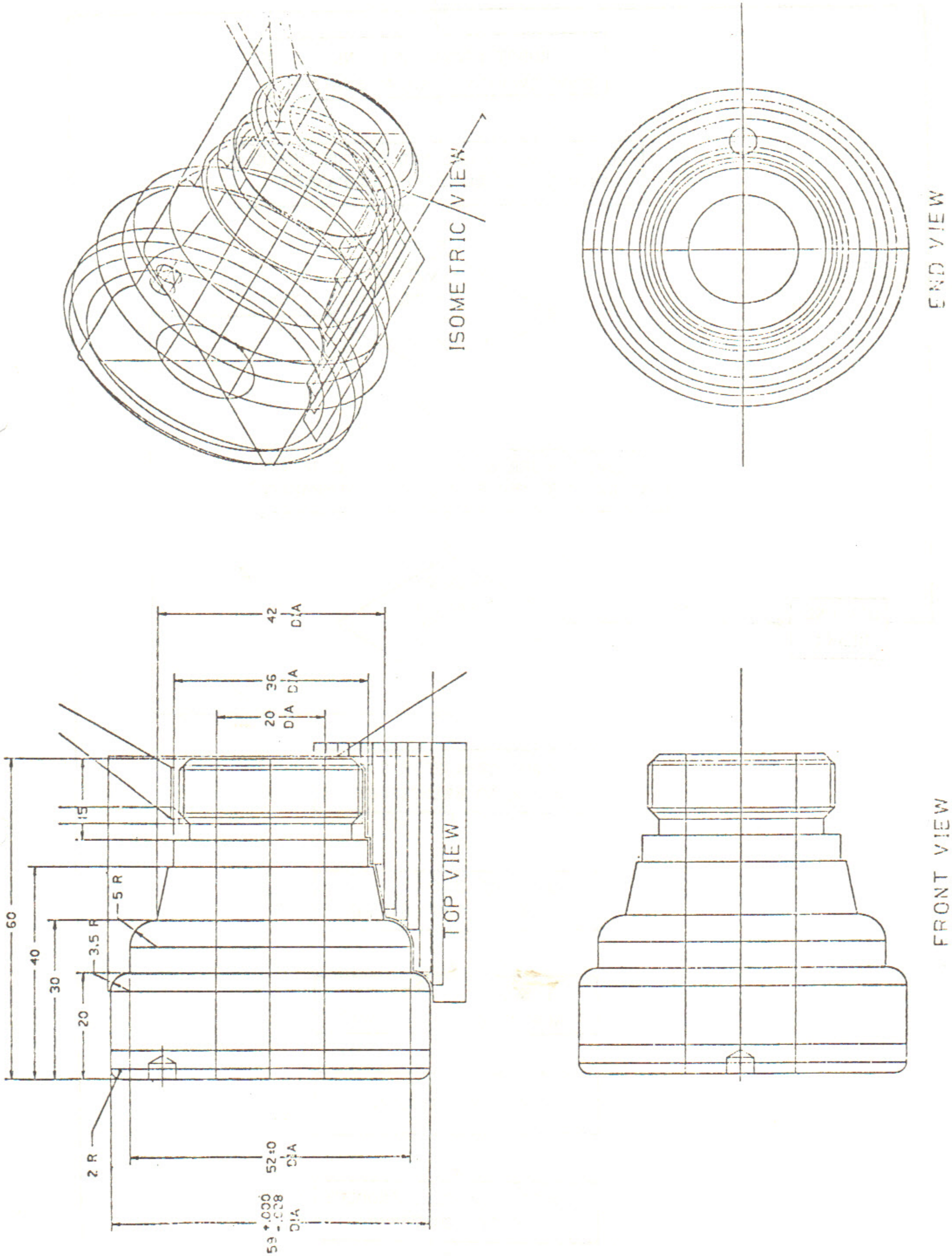
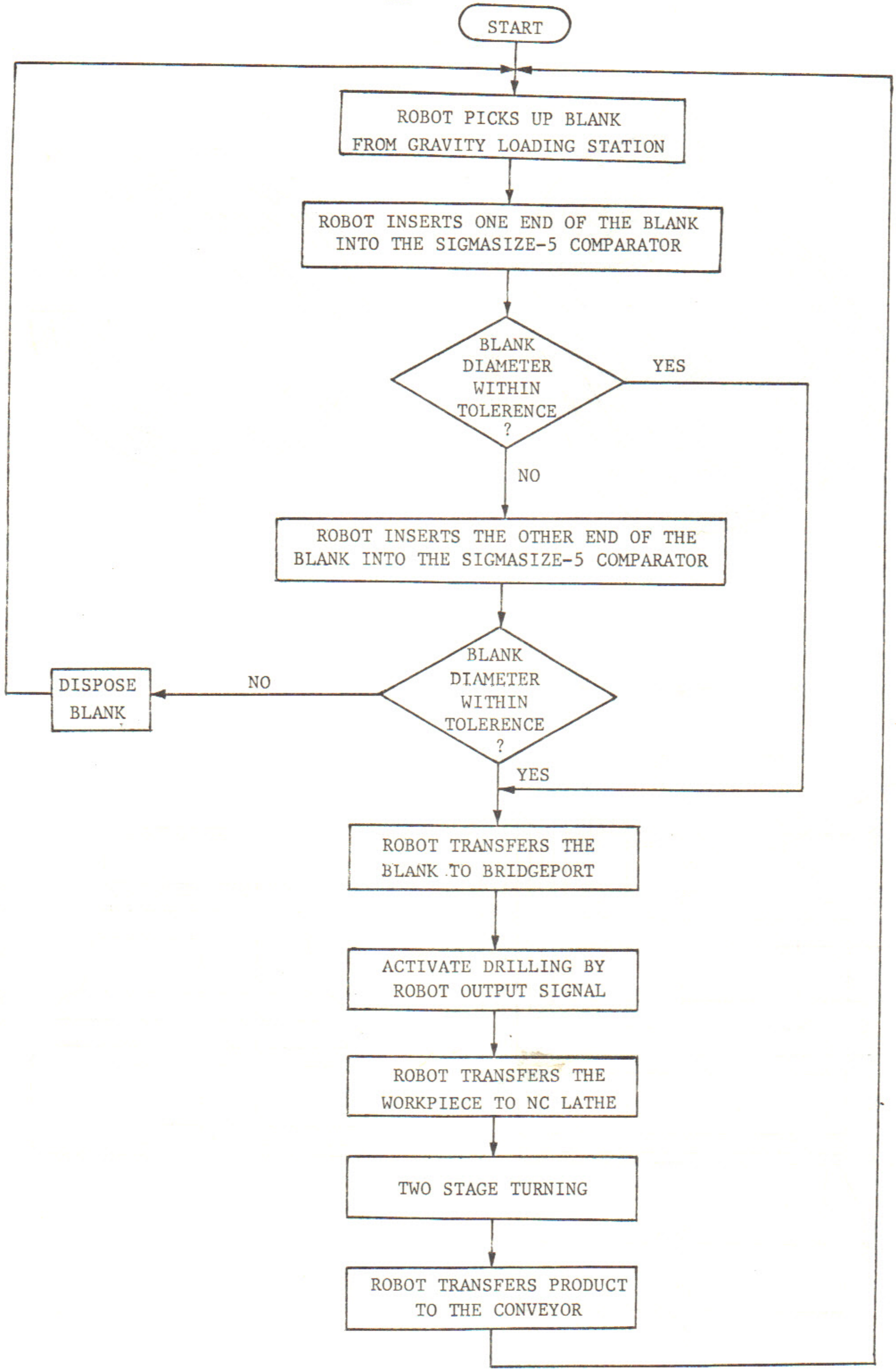


FIGURE 2 - LAYOUT OF FLEXIBLE MANUFACTURING CELL


ISOMETRIC VIEW
END VIEW
TOP VIEW
FRONT VIEW
42 DIA
36 DIA
20 DIA
60
40
30
20
15
5 R
3.5 R
2 R
52.0 DIA
59 +.000 -.028 DIA


START
ROBOT PICKS UP BLANK FROM GRAVITY LOADING STATION
ROBOT INSERTS ONE END OF THE BLANK INTO THE SIGMASIZE-5 COMPARATOR
BLANK DIAMETER WITHIN TOLERENCE ?
YES
NO
ROBOT INSERTS THE OTHER END OF THE BLANK INTO THE SIGMASIZE-5 COMPARATOR
BLANK DIAMETER WITHIN TOLERENCE ?
NO
DISPOSE BLANK
YES
ROBOT TRANSFERS THE BLANK TO BRIDGEPORT
ACTIVATE DRILLING BY ROBOT OUTPUT SIGNAL
ROBOT TRANSFERS THE WORKPIECE TO NC LATHE
TWO STAGE TURNING
ROBOT TRANSFERS PRODUCT TO THE CONVEYOR