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C16.

ROLE OF FLEXIBLE MANUFACTURING CELL IN THE EDUCATION OF THE MODERN MANUFACTURING ENGINEER

by

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Abstract

The world wide upheaval in manufacturing through the widespread application of computers demands a new breed of manufacturing engineer capable of assuming a comprehensive view of manufacturing as an integrated activity involving a multitude of technological and managerial decisions. To meet the corresponding educational challenge, a thorough reorganisation of manufacturing education is needed in terms of curriculum development and laboratory infrastructure. It is suggested here that a CAD/CAM laboratory centred around a flexible manufacturing cell provides a cost effective base for reorganisation in the latter two areas. Experience gained in developing and running such a laboratory in Hong Kong Polytechnic is presented in some detail.

Introduction

Modern manufacture distinguishes itself by its increasing emphasis on flexible automation and extensive application of digital computers not only to relieve workers of routine mental activities but, more importantly, to integrate the diverse modules of manufacturing activity into a coherent system. Thus, there is a rapid trend towards programmable automation of not only the production processes (through the use of CNC machines) but also of the transportation (through the use of robots, AGVs, programmable conveyors etc), inspection (through vision systems, CMMs etc) and storage (through automated warehousing). Simultaneously, there is a trend towards integrating these elements into comprehensive self-adapting systems such as flexible manufacturing cells (FMC) and systems (FMS). Further, through the integration of computer aided design (CAD) with computer aided manufacture (CAM) the total integration of manufacture from design to dispatch is achieved.

This manufacturing revolution has not just been a manifestation of gradual technological evolution but also a response to a host of economic and social trends in the developed world such as the rapidly rising human expectations, increased creative innovation, rapid proliferation of number and variety of products etc. These trends were anticipated by Merchant [1] in 1973 and developments since then have confirmed their accuracy. Merchant also anticipated the directions in which manufacturing organisations/societies had to change to meet the challenge of these trends and explicitly stated the needs for flexible automation and computer integrated manufacture (CIM). He further anticipated that the trend towards "increasing complexity and rapid obsolescence of technical knowledge" needs to be met by "interdisciplinary transfer and use of world-wide knowledge" and increased industrial involvement in technological education and information transfer".

Obviously, then, educational strategies in manufacturing engineering need a through reappraisal to meet the challenges posed by modern manufacture.

To illustrate this point, consider the Hong Kong scene. Hong Kong industries traditionally 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. However, since Hong Kong is essentially an exporting economy it cannot be isolated from the technological and market trends in the developed world. There has thus been growing awareness that something needs to be done in the area of CAD/CAM if Hong Kong is to maintain its competetive 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.

Educational Requirements for Modern Manufacture

Consider now the directions in which the educational process must change to meet the needs of modern manufacturing engineers/technicians. Firstly, the education process must keep up with the knowledge explosion in manufacturing engineering. Since a distinguishing feature of modern manufacture is its 'software' component [1], it must recognise the 'mecha-tronic' nature of modern manufacture i.e. it should include instruction in the application of microprocessors, microcomputers, electronic devices and interfaces, database techniques, computerised production planning and control etc.

Secondly, the students need to be trained in systematic thinking since, *inter-alia,* today's computer (unlike human decision makers) do not tolerate fuzzy data or data evaluation criteria.

Thirdly, since the essence of modern manufacture is its emphasis on integration through computers (i.e. CIM), the education process must develop the ability to apply and integrate diverse knowledge elements in the context of the total manufacturing scene.

Manufacturing engineering education may respond to the above requirements at the levels of curriculum development and/or laboratory infrastructure. However, the present paper intends to discuss mainly the strategies concerning laboratory infrastructure. We shall base this discussion on the experience of the Department of Production and Industrial Engineering of Hong Kong Polytechnic.

The educational process (and, consequently, the laboratory infrastructure) at the Department 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 integrated 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 integration 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 supervision 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 [2] 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 (e.g. 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. In other words, 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 <u>system</u> 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, inpsection, 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 is made up of a Computervision Designer VX system with a colour and a monochrome work station supported by the full range of mechanical CADDS 4 software.

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.

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.

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 6T-B controller, a hardware programmable inspection machine SIGMASIZE 5 and a BRIDGEPORT milling/drilling NC machine with SLO-SYN controller.

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 6T-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 (scheduled to be replaced by a CNC machining centre) 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.

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.

Since the robot controller has the highest level of intelligence among the FMC components, it is assigned the supervisory function. In this 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 10 - 20 different components per set-up 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.

The development is sub-divided into the following areas of activity.

(1) Database generation

The 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 and M 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 graphic simulation programs such as the Computervision Robographics 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 by a dedicated tool block changing mechanism - several alternative designs are presently under evaluation.

(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. 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. End-effectors with power tools, force-sensing devices etc. 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 [illegible]

(6) Communication and Supervision

A star network with a dedicated supervisory switching processor (the Motorola MVME 10 system) as the main node will be adopted to provide communication link for the FMC. The database will be located in the Computervision system with data transfer performed by the CAMACS software.

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.

To optimize the scheduling and supervision tasks, preliminary simulations will be performed. Activities have already been started in applying simulation software such as the SIMSCRIPT package for optimization.

Conclusion

Despite the fact that the facility was commissioned only nine months ago, a total of 10 projects are currently being executed on the educational 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 graphic 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 multifaceted manufacturing engineering problems in a situation closely resembling that in real-life.

References

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CAD/CAM SYSTEM HARDWARE CONFIGURATION

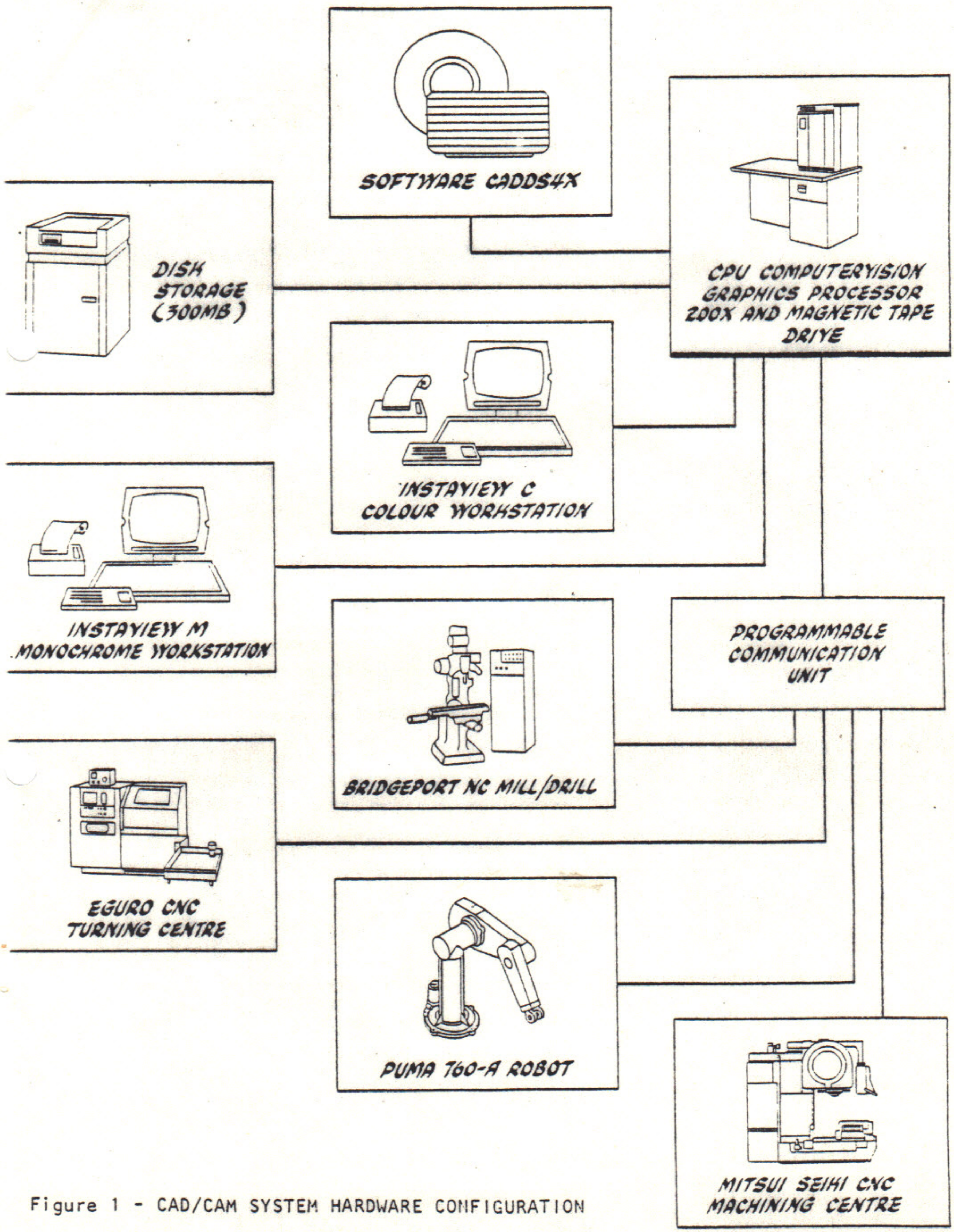

Figure 1 - CAD/CAM SYSTEM HARDWARE CONFIGURATION

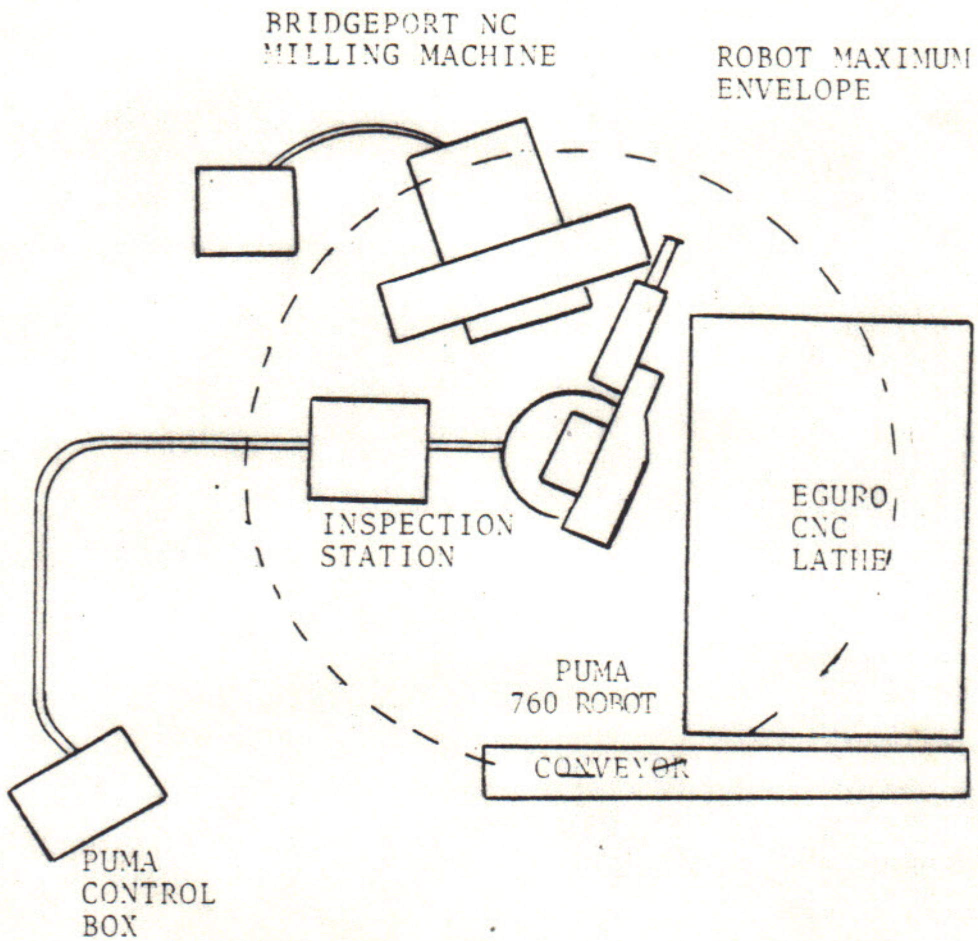

Figure 2 - LAYOUT OF FLEXIBLE MANUFACTURING CELL