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Impact of Computer Integrated Manufacture

. . . on Engineering Education

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Introduction

The international market is moving towards one of world price, world delivery and world quality (1). The success of a manufacturing enterprise in Hong Kong depends on its ability to respond to this movement.

The Technological choices of our competitors are rapidly changing in response to market pressures towards improving quality, shorter product life cycle periods, greater product variety with the associated smaller batch sizes, tighter delivery schedules and, at the same time, lower costs.

Increasingly, the traditional reliance on predominantly manual systems is being questioned in view of its inconsistency in terms of product quality and delivery schedules. Direct labour costs are playing smaller and smaller roles in the equations leading to the technological choice. Some have even concluded that the alternative to automation is liquidation (2).

At the same time, the trend towards smaller product life cycle periods is restricting the range of applications where hard automation is feasible. Thus, the need for flexible manufacturing systems, which can serve "a volatile market with minimum response time from order input to saleable product" (2) is steadily increasing.

Figure 1 shows, rather simplistically, the cost-volume relationships for the three broad technological alternatives (viz. manual, hard automation and flexible automation). Projections from historical data concerning labour and equipment costs related to each alternative (see broken lines in Figure 1) indicate that the range of applications where flexible automation is the rational choice is likely to grow substantially in future (3).

Nature of Flexible Automation

Flexible automation differs from the traditional hard automation techniques in its emphasis, not only on replacing human muscular activity in a programmable way, but also in replacing human mental activity concerning information processing and decision making through extensive use of digital computers and numerical techniques.

A wide spectrum of flexible automation solutions, ranging from techniques (such as CAD, CAM, CAPP

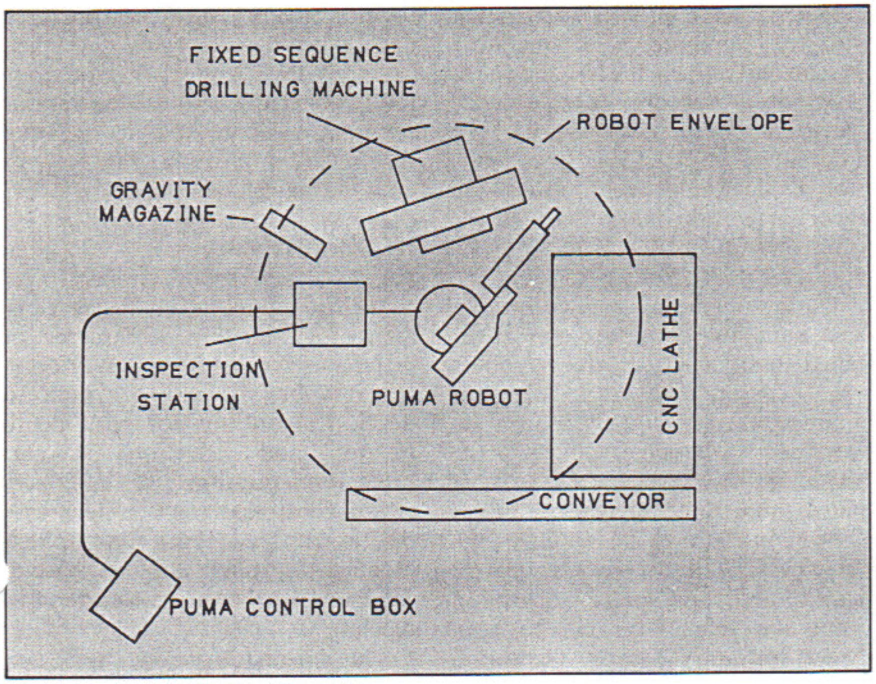

Fig. 2 An Early FMC Configuration

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 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 'system 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.

The following sections 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 one for the CAD work stations and the other for the CAM hardware.

The basic CAD facility is made up of a Computervision Designer VX system with two work stations supported by the full range of CADDS 4 software for 2D and 3D mechanical design and drafting, interactive NC programming, post processor development, robot simulation etc. This system is extensively used by students for for designing the parts, tooling, grippers, fixtures etc used in the FMC in addition to generating the NC programs, cell monitoring programs and robot programs required during the operation of the FMC.

In addition, a VAXI work station is used to access other design software such as PAFEC DOGS and BOXER and SIMSCRIPT simulation software used for determining the optimum scheduling strategies during FMC operation.

The CAM section comprises of the processing, handling and inspection equipment required for the FMC.

The processing facilities consist of a Mitsuiseiki VR3A CNC machining centre (2½ axis, 20 tool magazine, Fanuc 6M controller), an EGURO NUCPAL 10 CNC Lathe (2 axis, 4 in-line tool posts, Fanuc 6T-B Controller) and an EMCO CNC milling/drilling machine.

Handling for the FMC is performed by a PUMA A760 robot (1.5m arm reach, 10 kg pay load, six degrees of freedom, articulated joints, pneumatic gripper activation, d.c. servo control, 16 bit LSI-11 microcomputer controller, VAL version 13 programming language).

Inspection facilities include a SIGMASIZE — 5 hardware strappable signal processing comparator which takes in dimension — transducer inputs and produces output signals according to conditions. In addition, a vision system based on an OCULUS card on IBM PC is under development for checking part dimensions, orientation and position. The system may also be interfaced with the robot to provide vision guidance during part presentation to the cell.

Configuration of the FMC

The development of the FMC is being directed towards a facility that can process a random mix of 10 to 20 distinct parts belonging to a common family without manual intervention. Manual assistance however is still needed while resetting the cell for changing over from one family to another. For this purpose, a part family is defined as a group of parts that can be processed using a common set of tools/grippers/fixtures.

Families may consist of exclusively turned parts (T), turned parts with limited prismatic features (TP) and exclusively prismatic parts (P).

A working configuration of the cell for two T-parts (with or without a secondary drilling operation) has already been developed and tested etc.) which merely 'aid' the human operators by relieving them of a large number of routine information processing tasks to strategies (such as FMC, FMS and CIM) which aim at taking over the supervisory and real time decision making roles of human operators and managers are available today. The major benefits accruing from the latter strategies have been identified (4, 5) as:

- upto 80% reduction in work in progress
- improved productivity through increased equipment utilisation
- unmanned operation i.e. possible third shift
- improved flexibility i.e. smaller batch sizes
- upto 90% reduction in manufacturing lead times.

Flexible automation techniques available today cover all phases of manufacturing activity viz. operation (○), transportation and handling (⇨), inspection (□) and storage (▽). Depending on the local circumstances, each of these phases can be progressively automated so that flexible automation becomes a self-sustaining evolutionary process (6). It is not imperative to imitate the complex FMSs developed by some of the Japanese and American giant corporations.

Further, it must be noted that Computer Integrated Manufacture (CIM) need not necessarily involve automation in the sense of replacement of human muscular activity. It is possible to visualise a CIM environment where only the information processing and real time information integration tasks are delegated to computers while the physical activities are still executed by human operators. Substantial gains in resource utilisation and lead times are still possible at this level of automation.

Need for a New Breed of Manufacturing Engineers

Notwithstanding the above eulogisation of flexible automation, its adoption round the world has not been as wide spread as anticipated initially. In this context, it has been suggested recently that "CIM is here only in potential and requirement and nowhere in reality due to the absence of people of the right calibre" (7). At a brain-storming session conducted in 1985 by the Industries Department of Hong Kong Government, it was concluded that the lack of awareness of the potential benefits of CAD/CAM among top management and the lack of suitably trained engineers/technicians to implement CAD/CAM projects constitued two major blocks.

It is increasingly being realised that there is an urgent need to develop a new breed of manufacturing engineers who is capable of viewing manufacturing as an integrated activity involving a multitude of technological and managerial decisions. "Manufacturing engineers are now beginning to be required to be responsible for engineering the total system of planning, including the design of the product, the planning of its production and the actual execution of its production" (8). Thus, the International Institution for Production Engineering Research (CIRP) has recently (1985) suggested a redefinition of the manufacturing engineer as "a total, comprehensive engineer, ..., working to an all embracing job description" (9).

The tertiary education sector of Hong Kong thus has a key responsibility in the development of this new breed of manufacturing engineers needed for the implementation of CIM in Hong Kong. This paper is an update of a recent paper (10) discussing some of the strategies adopted by the Department of Production and Industrial Engineering of Hong Kong Polytechnic in discharging 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.

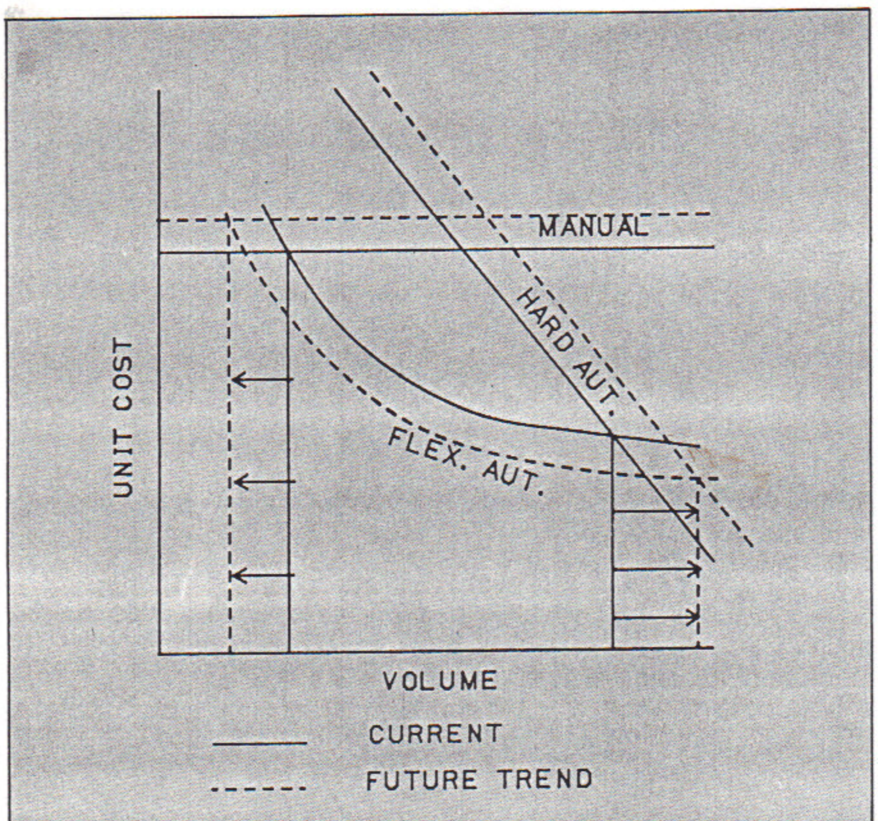

Fig. 1 Economic Comparison of Automation Alternatives

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 (11), 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 computers (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. In effect, a shift "from knowledge-based education to skill and capability based education" is needed (10).

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 based 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, over two years back, the Department decided to apply a systematic approach to the curriculum development for 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, CIM 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 CIM. The anticipated educational benefits from such a laboratory are discussed in the next section.

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 or 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 (12) 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 (see Figure 2). The fixed sequence drilling machine was used for the secondary drilling operation. In this set up, the robot picked up blanks (one at a time) from a gravity magazine, transported them to the SIGMASIZE — 5 station for checking end orientation and then transported them to the CNC lathe and drilling machine in the required sequence for processing before unloading the finished parts on a conveyor. The robot controller acted as the cell supervisor and initiated all control signals, via a relay system acted as the cell supervisor and initiated all control signals, via a relay system developed in house, for triggering the chuck, pneumatic vice etc at the appropriate times.

The cell is presently being reconfigured progressively to process larger daily orders including T, TP and P parts — by drafting the CNC machining centre and the CNC milling machine into the cell. The cell control algorithm will interpret the daily order and request the next part to be presented on a screen situated at the manually operated part presentation station.

The reconfigured cell is found to be too complex to be supervised by the robot controller. Consequently a separate cell supervision unit has been developed in house.

The Cell Supervisor Unit

Figure 3 shows the structure of the Cell Supervisor Unit built around a Motorola 68000 microprocessor (with 32K ROM and 512K RAM). The modular nature of the unit is designed to permit easy expansion and modification to meet future needs.

The 68000 assembly language based driver program (currently 13k long) has been developed with the aid of the VME/10 software development system. The driver program will be progressively refined to take into account the optimum priority rules for cell scheduling determined from simulation studies using SIMSCRIPT.

The driver program is downloaded via RS232 transmission protocol into the RAM area. Once executed, this program will log into the Computervision operating System and retrieve the NC and robot programs appropriate to the particular daily order from the Computervision CAD system's storage device. These program are then buffered in the RAM area for subsequent distribution to the CNC machines during cell operation.

During operation, part processing and handling programs are distributed to the CNC machines/robots via separate RS232 links at appropriate moments. The separate Interface Adapter Units (LAM) linked to each machine's control panel (note only the VR3A link is shown in Figure 3) simulate the activities of the machine control panels and also detect operation status like cycle off/on. This has been found necessary because the cell is essentially a retrofit of CNC machines designed for manual operation. (Such adapters would not be necessary if the machine tool builders designed the CNC machines keeping FMC requirements in view). The RS232 links and the LAUs together enable full DNC (direct numerical control) of the cell such as to respond to real time decision making requirement during cell operation.

Development Areas

The basic facilities to achieve some degree of unmanned operation of the cell have been described above. However, the cell needs developments in several directions to achieve a high degree of efficiency and reliability. Indeed, the provision of a range of realistic and progressively sophisticated development objectives is the main purpose of building this FMC.

Some of the presently planned and on-going development activities are briefly described below.

(1) Database Generation:
A representative component database is being created by students on the CAD system using the 2D/3D and advanced surface design software. The software for NC program data base is already available on the CAD system. Post processors for the three CNC machines are being developed using CV POST. Work is in progress to hierarchically organise the various program modules so as to facilitate easy retrieval by the Cell Supervisor Unit during cell operation.

(2) Work Handling:
An automatic robot gripper/finger changing system is under development for handling workpieces of different sizes and shapes. Work is in progress on the vision system to develop algorithms for part identification and detection of part orientation/position. A microprocessor controlled track system with positional feed back control is planned to provide a mobile base to the PUMA robot so as to extend its reach.

The pneumatic power chuck currently installed in the CNC lathe accepts only a fixed workpiece diameter after each manual adjustment. To remove this constraint, a novel design of flexible chuck is under prototype development stage.

A universal fixture with groups of five or six small adaptable fixture units is being developed by students for the machining centre.

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

(3) Tool Management
The 20-position tool magazine is adequate for 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-

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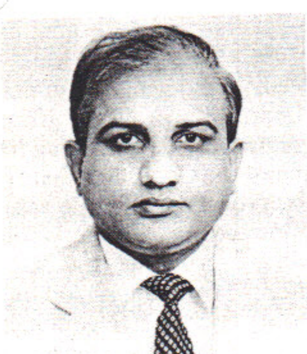

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