International Trends in Manufacturing Technology

Programmable Assembly

Trends in Manufacturing Technology

PROGRAMMABLE ASSEMBLY

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IFS (Publications) Ltd., UK

Springer-Verlag
Berlin Heidelberg New York Tokyo
1984

British Library Cataloguing Publication Data

Programmable Assembly. — (International trends in manufacturing technology)
1. Assembling machines — Automatic control
I. Heginbotham, Wilfred II. Series
670.42'7 TJ1317

ISBN 0-903608-65-0 IFS (Publications) Ltd.
ISBN 3-540-13479-4 Springer-Verlag Berlin Heidelberg New York Tokyo
ISBN 0-387-13479-4 New York Heidelberg Berlin Tokyo

Typesetting by Fleetlines Typesetters, Southend-on-Sea, UK
Printed and bound by Butler and Tanner Ltd., Frome, UK

International Trends in Manufacturing Technology

The advent of microprocessor controls and robotics is rapidly changing the face of manufacturing throughout the world. Large and small companies alike are adopting these new methods to improve the efficiency of their operations. Researchers are constantly probing to provide even more advanced technologies suitable for application to manufacturing. In response to these advances IFS (Publications) Ltd, is to publish a series of books on topics that highlight the developments taking place in manufacturing technology. The series aims to be informative and educational.

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This, the second in the series – Programmable Assembly – is under the editorship of Professor Wilfred Heginbotham. The series editors are: Jack Hollingum, John Mortimer, Brian Rooks and Michael Innes.

Finally, I express my gratitude to the authors whose works appear in this publication.

John Mortimer,
Managing Director,
IFS (Publications) Ltd.

Acknowledgements

IFS (Publications) Ltd. wishes to express its acknowledgement and appreciation to the following publishers/organisations for supplying some of the articles reprinted within this book.

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Bedford MK42 7BT
England

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PREFACE

When one thinks of the assembly problem there is a natural tendency to place undue emphasis on the assembly machine, its mechanisms and its immediate surroundings. A better appreciation of the potential effectiveness of automatic assembly is obtained if one considers the elements of the industrial handling process as a whole. This comprises many functions which are peripheral to, and just as important as, the functions performed by assembly machinery. In other words, the overall marshalling and control of component parts in industry is vital at all levels and is a vital prerequisite to success. The consideration of assemblies as a separate individual activity can lead to wrong conclusions. In order to appreciate all the interactions, the problem can be divided up as follows:

- *Economics*
  Choice of the correct system and appropriate architecture. This implies the optimal selection of the level of sophistication which is required to obtain sensible financial payback. The level of sophistication (and, therefore, cost) required will depend mainly on the cost of labour, interest rates and the versatility required to cater for a particular batch production situation.

- *Parts control – coarse and fine*
  Coarse – basic design, scheduling, inventory, ordering, stores control, goods and parts received, general production control and 'in-process' handling.
  Fine – parts feeding, bowl feeders, magazines, pallets and conveyors of all types, and placement.

- *Inspection – explicit and implicit*
  Explicit – is the component the correct one? Are all the features present? (holes, screw threads, etc.)
  Implicit – will the parts go together as expected in view of the tolerances which are attainable and the general implications of component quality.

- *Mechanisms*
  Motions to bring the component parts together using placement devices and the need to use jigs and fixtures for high quantities or 'soft' tooling involving microprocessor control and sensory interaction for lower batches.

- *Communication – direct and global*
  Direct – machines requiring frequent changes to deal with smaller batches require easy reprogramming and instructional facilities. A 'black box' approach with built-in microprocessor interfacing to enable shopfloor workers

to change functions by simple procedural means based on properly designed software. Diagnostic capabilities are also necessary to encourage fast responses to malfunctions.

Global – the days of the 'free-standing' isolated control system are numbered and interfacing facilities between individual control centres must be available to enable a move to be made towards complete factory integration.

The evolution of assembly machine technology follows from the development of 'hard' dedicated machinery, up to the more versatile systems which are currently available. Typical machines as developed in the mid-1960s were in-line or rotary transfer machines and such technologies in the right context are just as effective today. Such equipment is mechanically actuated and built around modular elements comprising a main chassis, a set of placement devices and feeders. However, even though these elements of modularity exist it is not practicable on economic grounds to alter such hard automation in order to respond to product changes; i.e. one can consider the problems by a numerical yardstick as follows:

Let P = cost of the standard modular elements of the system, and Ps = cost of adapting the standard system to do a particular job, then a 'versatility index' can be expressed quite simply as $I = P/Ps$.

Thus a large value for I implies good versatility, and vice versa. For the type of automation previously referred to the ratio I is in the range 0.1 – 0.2 (i.e. 80 – 90% of the installation is special purpose), hence there is no effective inter-product versatility (i.e. the ability to change the line from one product to another).

There are very many systems available today which use a higher level of modularisation usually in the form of 'free-standing' standard mechanical motions backed up by standard control system packages, be they hard wired sequential, simple memory (i.e. plugboard) or computational. None of these machines, however, can be considered to be truly 'programmable', they have a reasonable element of 'reclaimability' but could not be said to penetrate deeply into the small batch variable product production requirement because the amount of special adaption needed to adapt such devices to a particular need is still too high. However, they exhibit extensive 'inter-process versatility', i.e. they are capable of adaptation over a wide range of relatively dedicated activities such as press feeding, 'in-process' handling, machine serving and assembly. It is possible in certain application areas to achieve an 'I' of from 0.5 to 1.0.

Programmable assembly machines have, as yet, made little penetration into the everyday scene in industry; this is perhaps because the philosophy of their application is so little understood. There are generally three main approaches to programmable assembly automation:

(1) Machines architecturally designed to be capable of adaptation based on fixed structural form such as the Olivetti SIGMA, the IBM 7565 and the Bosch system. These machines have significant sensor capabilities with standard functions like 'part not placed', 'part not present', etc.

It is clear that the situation will ultimately resolve itself into 'horses for courses' and that such machines will find their niche in certain activities.

The principle by which such machines can be successfully employed is that a machine should be capable of being fooled into thinking it is handling the same things when it is not! In other words, the need for special workholder design and gripper redesign or autochanging is reduced to a minimum thus creating a large value for the factor *I*. Therefore this machinery is good for dealing with 'families' of assemblies.

(2) Design the machine architecture to suit the particular job so as to create a 'versatile' dedicated machine.

The machines in (1) and (2) are both generally successful as 'programmable dedicated machines' and there is considerable scope for the economic exploitation of technology where problems of this type can be identified. The 'programmable dedicated' concept, however, becomes even more powerful when such units are integrated together to form a complete line. By this means, the technology of mass production can be applicable to a batch production situation. Because 'station can talk to station', rapid reprogramming is possible as far as functioning is concerned. Thus, the restriction on total reprogramming of the system depends on the ease of mechanical adaptation that can be achieved which depends once more on the degree to which 'family' relationships can be established for the product.

(3) Robot arms for assembly with extensive software back-up and control.

This technology carries with it a number of question marks at this time. Not the least of these questions is that concerned with the real necessity to have a multi-axis complex arm to carry out the majority of assembly processes in industry. Of course, with the computing power of the microprocessor as it is currently available, it is possible to carry enough computing potential to control such an arm. But in the majority of cases, assembly insertion is a straight-line process and to generate an accurate straight line via a six-axis robot would seem to be an unnecessary complication. By appropriately designed software, it is relatively easy to endow the machine with a number of 'instinctive' routines which can be selected to deal with faults which are expected or anticipated.

However, having said this, if we have a continual train of potential malfunctions and the machine spends most of its time using its fault correcting functions, it is not spending its time on production. Therefore, the need for machines to be able to *interpret what is wrong* after having been sent round an interrupt loop and initiate diagnostic correction is very much a problem for the future.

This brings us to the very important subject of 'sensory' interaction in relation to assembly devices. There are around 40 'machine vision' systems worldwide and it is important to appreciate just what a vision system really achieves. On a close examination, what has really been created is a 'universal escapement' but most of the old problems of total versatility remain, i.e. problems of mechanical adaptation of grippers and other peripherals if really small batches of very different components are required to be handled.

There have also been significant developments in robot 'feel' or tactile sense over the last decade; Hitachi were the first with a commercially available system in the Hi-T-Hand Expert 2 System, which is a fully reactive feedback system for 'plug-in-the-hole' type insertion. The Draper Laboratories in the USA have a remote centre compliance (RCC) device which achieves a similar effect for relative positional errors in insertion.

A machine which adopts a particular architecture, i.e. a robot arm design which is not based on the fully articulated human arm, is the IBM 7530/40 series. This is based on the SCARA robot (selective compliance assembly robot arm) originally conceived by Professor H. Makino of Yamanashi University.

This system has an effective insertion 'compliance' characteristic by design and not as an 'add-on' feature. The jointed arms are constrained to move in a horizontal plane and to have a high stiffness in a direction normal to the plane of movement, coupled with a very great resistance to angular rotation. Control during insertion is achieved in a 'free' state (i.e. without actual drives energised) in a direction parallel to the plane of rotation. Thus the small forces involved (low horizontal stiffness) and no significant angular deflection enables the system to 'comply' in a horizontal direction and achieve the same effect as an RCC device. This is a good example of how intelligent mechanical design can utilise the natural characteristics of a particular piece of robot architecture.

Programmable assembly machines will become economic inside a *total systems concept* for a factory whereby instructions will be able to be accepted by the machine in response to the input from a central source concerned with product design and controlling production. A CAD/CAM terminal is the likely mode for the input of design and functional information. However, the whole integrated factory concept implies a greater discipline from engineering as a whole and it is true to say that, unless this discipline in terms of product design and manufacture to facilitate assembly and handling takes place, then the future for flexible assembly systems remains uncertain.

A rule which is generally true in terms of applying automation is that, if the machine produces more parts in a given time than its human counterpart, then it will succeed economically. Now this does not mean that a direct comparison should be made between the rate of manual working and the *rate of machine working* in terms of the cycle time to produce an assembly. The overall output over a longer period is the figure to look for. This is because that although the machine may be working on a longer cycle time than its human counterpart, but so long as it only takes a fraction of a human being to supervise it and can be left for long periods to look after itself, then its *daily production* could be significantly in excess of that which could accrue from a human workforce.

Thus the beneficial effect of increasing automaticity can be missed by one's preoccupation with comparing man and machine directly on the wrong basis. It is also true to say that machines and systems presented here, once having been 'taught' the job, give their full production rate straight away, whereas a human workforce has a learning curve and a performance which varies throughout the working period. Clearly, to achieve the advantages that programmable assembly can offer requires a whole saga of re-thinking, re-assessment and evolutionary interaction. Success will be achieved by evolution not revolution. It is hoped that this book will assist in stimulating this process.

May 1984 W. B. Heginbotham

CONTENTS

Chapter 1 – Flexible assembly systems

Chapter 2 – Assembly applications

Chapter 6 – Economics

Chapter 7 – Social aspects

Chapter 1

FLEXIBLE ASSEMBLY SYSTEMS

Units in isolation may be dedicated but when linked together can create a flexible system. This chapter examines the systems aspect. The five papers illustrate that flexibility can be achieved with a variety of basic methods – fixed indexing, free-flow pallet and linked cells.

THE USE OF MODULAR FLEXIBLE ASSEMBLY SYSTEMS AS A HALF-WAY PATH BETWEEN SPECIAL DESIGN AND ROBOTS

F. J. Riley, The Bodine Corporation, USA

First presented at the 3rd International Conference on Assembly Automation, 25–27 May 1982, Boeblingen, Stuttgart, West Germany

Abstract

Much of the media coverage of robotics contrasts their flexibility with the so called 'hard' automation of dedicated one-up specially designed assembly machines. These articles tend to ignore the existence of modular universal assembly systems capable of meeting a broad spectrum of assembly requirements. This paper proposes a viewpoint that broad advances in the use of automated rather than manual assembly will come not from robots, but from standard modular assembly systems. The choice will be an economic one and even a political one; not what is technically feasible, but what is economically practical. Standard assembly machines designed for specific products, sizes and volumes rather than for specific industries are based on broad experience in special design and pay full attention to the problems of debugging, operation and maintenance. The use of such standard systems allows the tool designer to concentrate on the real problems of product and product component design and quality.

Introduction

For the last few years those of us involved in the construction of automatic assembly systems seem to have been bombarded by press reports of the advent of the age of robots. Certainly the sales of robots have been incredible. In some areas, particularly in those of spot welding and painting, they offer definite advantages over manual techniques, not only by cost reduction but in improved quality.

These reports seem to infer that robots are also increasingly active in discrete parts assembly. One article is quoted by the next and it becomes increasingly difficult to determine the extent of the specific applications of robotic assembly.

Even more so, is it to find out if there are any economically justifiable installations of discrete parts assembly through the use of robots.

As children we were entertained by reading fairy tales and other folklore. I remember specifically the tale of the emperor who walked into his court stark naked and asked his courtiers how they liked his new clothes. Each member of the court outdid the others in praising the beauty and the fit of the clothing until a small child spoke out and said the emperor was naked.

It seems we have a close similarity here to the present top management enthusiasm for the use of robots in assembly, and the ensuing staff level lip service to the future role of robots in assembly. This paper is intended to be one small voice questioning the substance of these claims. To be successful in this attempt, the topic of automatic assembly must be made clear.

What is automatic assembly?

Automatic assembly may be interpreted as the mechanised placement of individual discrete components into a specific spatial relationship to form an end item with some specified function. This automatic progressive placement of one component after another may include the orientation of components from bulk storage, the retrieval of oriented components from storage, the fabrication of components on the assembly line, the monitoring of the physical placement of each component, the joining of the components to form the assembly and inspection for functionality of the assembled product. An increasingly important requirement for product documentation such as serialisation or date coding may be included among the operations of an assembly system.

While we stand in awe at some of the larger car assembly lines having a high degree of mechanisation, the vast bulk of all assembly work is done on products or subassemblies of relatively small size. One does not assemble a car from discrete components, but rather from a series of major subassemblies which in themselves are made up of smaller assemblies. The vast bulk of assembly labour lies in the preparation of relatively small subassemblies.

Many widely used products are in themselves quite small, for example switches, circuit breakers, writing instruments and toys.

If mechanised assembly is to aid in the increase of productivity necessary to maintain a good standard of living expected in the industrial world and desired by the Third World, it must assemble products on a competitive basis to that of hand assembly. Harsh as it may sound to some academic ears, mechanised assembly has a socially useful role only if it is economically justifiable.

The great fallacy of proposed robotic assembly is not its failure to face up to the problems of debugging and start-up; not its failure to recognise that most assembly problems are parts feeding rather than parts transfer; not in its proponent's failure to include quality audits as part of assembly; but basically because *robotic assembly probably is not cost efficient.*

Let us put this into a simple context, contrasting so called 'hard' automation at its present state with proposed robotic assembly.

A comparison of technologies

The Bodine Corporation builds many complex assembly systems. These machines produce assemblies at a rate of 30 to 65 assemblies per minute. These assemblies generally have from six to 15 components. Machine prices range from $300,000 to $650,000 (US) for a fully debugged system with full documentation installed on a customer's floor. At the present time, in addition to many smaller rotary machines, the American plant ships approximately 35 machines of this size yearly.

For purposes of comparison take a most typical example of a 12 part assembly produced at a rate of 55 assemblies per minute with a typical machine price of $500,000 (US). Over half of the machines to be produced this year would fall within ±10% of these figures. The licensees in England and in Japan would normally be somewhat lower in price for comparable machines to those made in the USA.

Looking now to the world leaders in the use of robots. We are told that there are approximately 14,500 true robots in use in Japan (December 1981) of which 30% are involved in assembly. If this figure is accurate it would mean 4350 assembly robots in operation. Assume that each of these robots is capable of assembling a 12 part assembly in one minute while joining it and functionally testing it as part of the assembly process. Also assume that these robotic systems were placed on the production floor in operation with all necessary tooling, feeders and so on, for $35,000 (US) average price. This is a generous assumption.

Comparing this assumed total Japanese use of assembly robots with the production of assembly machines by the Bodine Corporation alone in the last 27 months, we have:

Robots:

	4350	robots
	×12	pieces/min/robot
	52,200	components assembled/min (gross)

Automatic assembly machines:

	12	pieces/assembly
	×55	cycles/min
	660	pieces/min/machine (gross)
then,	52,200	
	÷660	
	≃79	assembly machines required to assemble same number of parts as 4350 robots in one minute

Cost comparison:

4350 robots	@ $35,000	= $152,250,000
79 assembly machines	@ $500,000	= $39,500,000

Therefore the potential capital reduction through use of so called 'hard' automation is $112,750,000 (US).

Adjusting the assumptions in favour of robots to any reasonable level and downgrade the performance of so called 'hard' assembly to any reasonable level, will not significantly change the results. *Robots will not be as cost effective as mechanised assembly for most types of production suitable for automatic assembly.*

Robot supporters may call 'foul'. They will say that the flexibility of the robot and the rapid changes in the market place have been ignored and that a 'hard' dedicated machine useful only for high volume production of a specific product has been compared with the flexibility of the programmable robot.