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Process-Oriented Assembly System Concepts - The MarkIV Approach -

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Abstract

The Assembly Systems Unit at the Royal Institute of Technology-IVF has developed several Flexible Automatic Assembly (FAA) cell solutions over the years. Current industrial trends, however, clearly point out that the basic notions of flexibility must be extended and be enhanced without increasing the complexity. The key lies in the creation of modular assembly systems with interfaces based on open standards. It must be possible to adopt equipment from different suppliers to the system. To reach these objectives, the research group has established a development project of both suppliers, users and universities on a European level, called SHARC: Standardised Hybrid Assembly with Reactive Capacity. This project runs parallel to, and in conjunction with, the national Hyper Flexible Automatic Assembly (HFAA) project. These projects will attempt to create a system concept which will be easily adapted to a very large range of products, variants, and their associated volume fluctuations. The paper will also describe and discuss our engineering platform, the Mark IV application.

keywords: modularity, stepwise automation, flexible.

1 INTRODUCTION

The Assembly Systems Unit at the Royal Institute of Technology-IVF has developed and demonstrated several innovative *flexible automatic assembly* (FAA) cell solutions over the years, including the Mark II [1], MarkIIF [2] and Mark III [3]. These FAA cells were developed according to the following requirements:

- enable stepwise automation.
- co-existence of manual and automatic operations.
- handle a large product/variant flora.
- allow for different feeding solutions.
- have as large a capacity span as possible.
- integrate manufacturing operations.
- apply an easy, low-cost programming solution.

These FAA cell solutions fulfilled these requirements and were also further developed into what came to be termed a standard assembly machine [3]. Although award winning[1], neither of these solutions reached wide-spread industrial application. This led our team to a revision of the factors influencing this lack of response. The industrial perspective pointed out that the ever-increasing demands for *extreme capacity flexibility* and *stepwise expandability* pose certain constraints on the *fixed* cell concept and line-type assembly approach. Theoretically speaking, the assembly process in itself has not been sufficiently structured and standardised. The fact that industry has denoted a lack of assembly process knowledge (primarily) and inadequate equipment has led to solutions which are not capable of handling product and process modifications. The applied and proposed system solutions have simply been product-specific, resulting in solutions which are neither easily expandable nor truly flexible.

The backbone of any nation's industry consists of small to medium-sized companies. These companies are often sub-contractors to major corporations. Since the market demands fast time-to-market responses, short product life-cycles, and ever-increasing customer-oriented product variants, these small to medium-sized enterprises (SMEs) will inevitably be obliged to comply with the requirements. In production terms, this implies:

- production volumes must ramp up and down quickly in response to the demand (capacity fluctuations).
- short product lifespans (frequent system re-configurations).
- high, ever increasing, number of product variants.
- Just-In-Time delivery.

These problems obviously underline the need for capacity flexibility and stepwise expandability. Furthermore, these problems are accentuated by two ever-present constraints afflicting SMEs:

- low investment possibilities.
- low competence levels in automatic assembly.

2 STANDARDISATION

Our research group intends to consolidate the view that the key to truly flexible, affordable and easy-to-use FAA systems lies in the creation of a set of standard, simple, assembly process-oriented components (see fig.1). Research in this direction has begun [4], and also delivered solutions on the market. However, this has mainly focussed on the standardisation of high-volume manual assembly lines.

[1] *1996 JARA award.*

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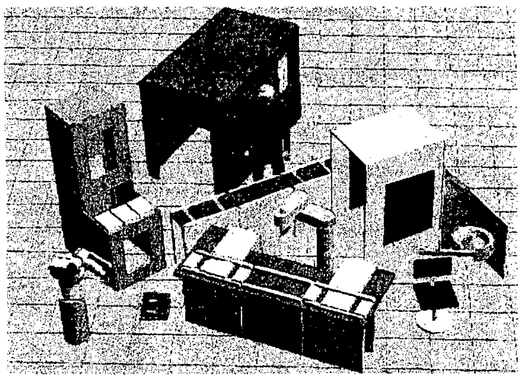

Fig. 1- Standard assembly system components.

In terms of automatic assembly, the European market has seen several robot units emerge as standard assembly units. This type of solution emanates from electronic industry [5] and may be well suited for a given size, shape and weight of components, but their costs, degrees of freedom, and the range of parts they can handle pose limitations to the general use of them. It also relates to a common scenario within automatic assembly, in which the process is assumed to revolve about robots. This is natural for robot manufacturers, but end-users, and especially SMEs, must consider that the robot is only one component of an automatic assembly system and should ideally be replaced according to the changing requirements. The industrial robot (IRb) solution must therefore be kept cheap and the assembly system solution open to alternative choices.

The standardised solution must present concrete solutions to specific assembly problems: solutions for special tooling and/or special operations must be offered. As pointed out in some of the literature [6], this precludes a thorough study of the assembly process, the equipment, the parts design and the control system.

Note that the standardisation being mentioned here relates to the creation of assembly equipment which has been developed out of a stringent classification and structuring of the assembly process. The solution refers to an open system into which new equipment may be brought as long as it follows the delimitations and interfacing requirements. The benefits to be gained from a standardised solution are many, amongst which one may name the following:

- Shorter installation times.
- Lower investment costs and related risk factors.
- Simpler re-configurations of original layout.
- Second-hand market for equipment.

In a world in which product lifecycles are ever shorter, such an approach would render the ensuing changes in production flows and sequences far simpler and faster. The application of standard interfaces is another key factor. All in all, the time between a company's decision to invest in automatic assembly and the actual production start would definitely be greatly reduced.

Standardisation should attempt to create system components in such a way that any assembly equipment may be integrated within *any other* assembly equipment. This entails that mechanical, electrical, pneumatic, electronic and software interfaces must be standardised, be of a common format, description, etc., and allow the transport of the particular medium (software, air, etc.) without adjustments. This also entails that the physical dimensions of the particular equipment are such that the unit may be inserted into any assembly system without requiring particular modifications. Hence, standardisation must be carried out on different domains:

- mechanical interface;
- software interface;
- pneumatic interface;
- electrical interface;
- electronic interface;

Moreover, this must be done at different levels. On the higher level the communication between the assembly system and the company business system e.g. SAP must be executed by a standardised protocol. On the assembly system level the control system must communicate with the different equipment within the system, e.g. robotcells, PLCs, etc. At the equipment level, which is the most neglected, the equipment must be further standardised in many fields. The control systems of the equipment must have similar MMI (Man Machine Interface) and programming solutions independent of the function and the complexity of the actual process. Possibilities to do the programming off- line must also be supported. Different equipment, e.g. a small gantry robot, must be able to perform many different operations, e.g. soldering, gluing, riveting etc. The interface between these machines and the actual tool must be specified, both mechanical and electrical. Also between the machines and their sub equipment the interfaces must be standardised such that e.g. a feeder could be re-positioned, or changed to another, without any mechanical or control disturbances.

There are both suppliers and users of this type of equipment that have standardised parts of this, however internal company standards will not do the trick. To achieve short lead times on the delivering of equipment, which is necessary to get high capacity flexibility, it must be possible to adopt equipment from different vendors within the same assembly system.

A brilliant example of this approach is the ST.E.P, Stein Experten Pool, consisting of 17 different European companies supplying the market with assembly systems. Five of these companies and additional ten companies may assume the supplier role, depending on the focus of the process. However, due to the lack of concise and applied assembly process knowledge, equipment may still not be re-used in similar applications without major modifications.

This renders the issue complex because suppliers, software developers, equipment manufacturers, etc., including competing companies, must be brought together to establish the best approaches.

Another aspect which is not so well treated in the literature, is the impact that a standard set of assembly-oriented components may have on the design of the products. DFA, DFAA [7] and other methods aid designers in creating products based on general assembly principles. These principles are, in turn, based on human, economic, and general automation constraints. The assembly process itself, and the automatic assembly process in particular, are not treated in relation to commercially available solutions for specific assembly tasks. The creation of a standard set of assembly-oriented components, based on the assembly process itself, would definitely create a driving force for assembly-friendly design (see fig.2). Basically, the designers would know, à priori, if there are technical solutions available and which particular constraints they pose on the design. The ideal scenario would be to have a standard set of assembly components with guidelines to their specific process specifications.

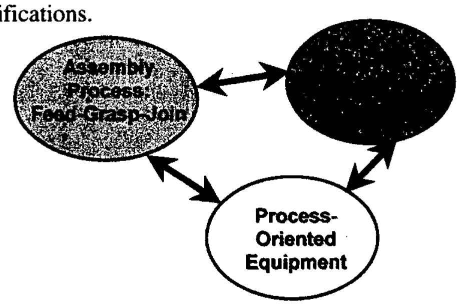

Fig.2-Design Loop with Assembly Process Knowledge.

The standardisation of components and its ensuing modularisation also lead to optimised production flow solutions. One will no longer be obliged to run a line-type system and flows optimised in relation to specific objectives will be possible (mass customisation, mixed model production etc).

3 Hyper Flexible Automatic Assembly

The HFAA project was initiated in order to meet the future assembly demands being posed by industry in general. The predominant assembly solutions adopted today tend to be product-specific, generally manual, and mainly line-type. This scenario must definitely be modified. In order to do so, a structured approach to the assembly process itself lies at the core of the project.

The project is being carried out by the following research institutes:

- The Royal Institute of Technology (KTH)
- Linköping Institute of Technology (LiTH)
- The Swedish Inst. of Prod. Eng. Research (IVF)

The HFAA project is being partially financed by PROPER (Programme for Production Engineering Research) and industry. The HFAA project will deal with four distinct project areas:

1. Analysis of the assembly process and its interactions with product design and assembly equipment.
2. Analysis of mini-assembly requirements and its requirements in terms of specific equipment.
3. Study of assembly factories concerned with mixed-model production and mass customisation.
4. Development of a standardised, modular, hybrid assembly system concept.

The final objective is to create a modular, HFAA system *concept* which consists of standardised assembly system components. Particular emphasis will be placed on the analysis and standardisation of the assembly process [6]. The actual system, the Mark IV detailed in this paper, is only to be considered as an engineering platform for the evaluation of a given set of ideas/concepts.

4 The SHARC/EC (Standardised Hybrid Assembly with Reactive Capacity) Project

The SHARC project (CRAF-1999-7 "SHARC") focuses on the development of a commercially available, modular, HFAA concept based on a set of standardised, low-cost, process-oriented components. The SHARC project is in the process of being acknowledged by the European Commission and consists of end-users, system suppliers, software system developers and R&D institutes. The partners are:

- MCA OY (system supplier and project coordinator).
- ACS GMbH (generic robot controller platform).
- Autic AB (software development).
- CRS Robotics Nordics AB (robot supplier).
- Easy Living AB (SME/end-user).
- Delft University of Technology (R&D).
- IVF Stockholm (R&D).
- KTH (R&D)

This research group intends to apply the HFAA results in a true industrial application. The final objective is to create a commercially available modular, HFAA system concept [10]. The SHARC project technical objectives are encompassed by what the HFAA concept will be expected to exhibit.

The standard requirements of automatic change-overs, automatic materials handling, and automatic assembly are obviously included. The HFAA/SHARC solution also intends to adopt earlier research results such as the sub-batch principle[1]. Note that the development work includes both hardware and software aspects.

5 The Mark IV installation

The new Mark IV system being built intends to allow the user to go from single manual assembly stations to serially coupled FAA cells and, in time, a full-scale robot assembly system. The system will be built for products that are produced by Easy-Living AB (see fig.3).

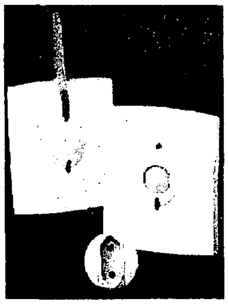

Fig.3-The Products

Since the creation of standard components lies at the heart of the project, the intention is to create a system concept which will be easily adapted to a large range of products, variants, and their volume fluctuations.

The intended HFAA concept is to support the idea of an initial, purely manual assembly approach. This setup should consequently be able to be upgraded into a single-robot cell setup, a mixed manual-FAA cell setup and/or a fully automated assembly line. In other words, its stepwise automation must be carried out in a structured, standardised manner and with modular, process-oriented components. This approach does not only intend to produce an adequate *investment* schedule for the user, but the stepwise automation also refers to the fact that the *operators* gradually acquire the *competence* required to use and maintain an automatic assembly system. This is a very important aspect for SMEs! Small companies MUST acquire in-house competence at an adequate pace. They are seldom in a position in which they may relate back to the system vendor for support. In fact, such forms of support are often the main reason for which FAA solutions have failed in the past [8].

6 Capacity vs. Stepwise Automation

The Mark IV installation, as well as the HFAA project, support the idea of building systems with over-capacity. An added bonus with the standardised set of assembly components is that the modules should be relatively cheap, fast and reliable to add into an existing system in order to attain new production goals.

The benefits of attaining over-capacity are various.

- The assembly system is no longer designed on the basis of a given product family.
- The assembly system will denote few difficulties in ramping-up to higher volumes.
- It is easier to predict time-to-market figures .
- De-coupling a robot during ramp-down phases is simpler and faster than laying off operators (and economic flexibility: sell the robot or keep it for future ramp-ups).
- It offers the possibility for alternative scenarios: maintain level of automation during ramp-downs, but lower the number of operations/machine. This leads to lower maintenance costs!

To date, assembly systems are probably the only technical solutions being built with stringent capacity limitations. Most manufacturing equipment is designed or purchased on the basis that they deliver more than what is immediately necessary (machining centres, material handling systems, etc.). This is not, however, the ruling dogma in the application of assembly systems! Most assembly system users simply *assume* that extra capacity is possible. The problems that ensue are obvious and well detailed in industry: low capacity flexibility, difficulties in building more capacity into existing solutions, long production halts, high investment risk factors, etc. It is therefore of importance to change such attitudes. Assembly systems should be built with high capacity levels. They should also be built in such a way that this capacity is not unreasonably expensive.

The standardisation of the components may, and should, lead to a reduction in costs. The difficulty lies in creating robustness into this standardisation. One must recall that high flexibility may be generally regarded as the capacity of any given system to absorb changes and disturbances at the lowest possible cost. Flexibility is consequently proportional to the robustness of the system in question.

In order to achieve robust, standardised solutions, the HFAA project, and the Mark IV installation, are conducting the research in close collaboration with SMEs and assembly system vendors.

7 The Mark IV Layout

The Mark IV layout is an industrial application of some of the results obtained within the HFAA project [9] The Mark IV system is built up of three assembly cells: two robotic assembly cells and one manual packing cell with quality assurance functions. The assembly cells all consist of standard product flow, material flow and IRb modules.

The system will be built in three separate stages: one cell will be built at a time. This decision was taken to alleviate the investment load on Easy-Living and also to enable the company to acquire the necessary knowledge, to run and maintain the system, at a gradual pace. This approach will also enable the team to evaluate the stepwise upgradeability of the solution.

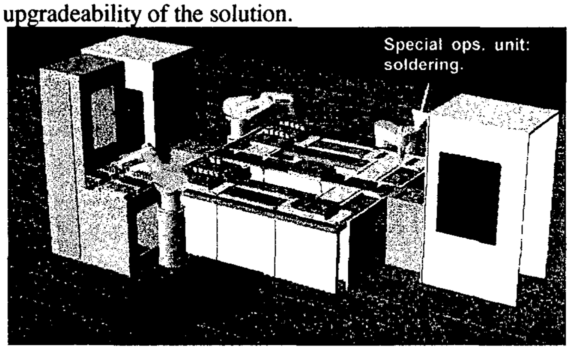

Fig.4 - The Mark IV - Cell1 Layout

The Mark IV - Cell1 layout will assemble all of the products but at a considerably lower annual volume (see fig.4). This cell is obviously more susceptible to balancing problems but the aim is not primarily focused on high performance but rather on introducing technology to a small company in a gradual manner. Once the economical and strategic prerequisites exist, the next cell will be integrated.

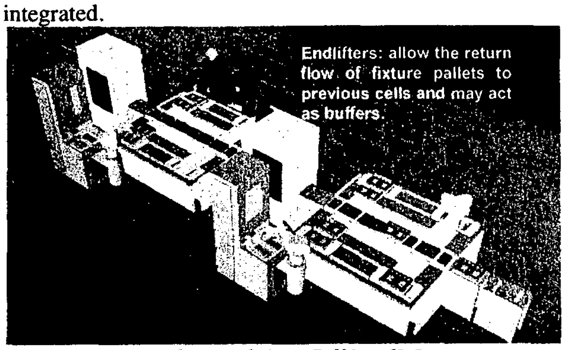

Fig.5 - The Mark IV - Cell1and2 Layout

The introduction of the second cell will require minor investments since the assembly machines are already operational (see fig.5). This layout is almost fully functional and will allow higher annual volumes and optimised material flow. The only operations missing are packaging and testing which are to be incorporated in the final stage: cell3 (see fig.6).

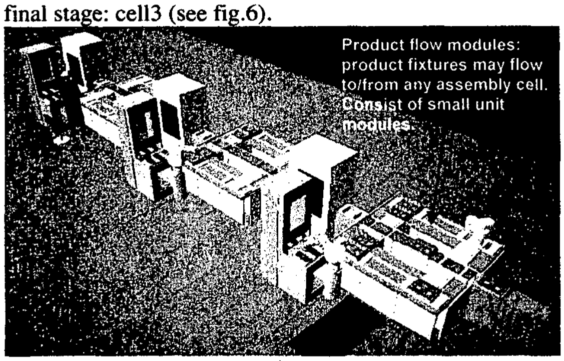

Fig.6 - The Complete Mark IV layout for Easy-LivingAB.

In this particular application the assembly cells have been serially linked but it is important to note that the product flow need not be serial and can assume any sequence required.

The robots are conventional CRS F3 robots. The number of feeders has been virtually eliminated by the use of vision. The vision system will be integrated to the material flow module and will operate in parallel with the robot. Should the need of feeders arise, these may be placed beside the robot in setup jigs.

Note that some of the equipment has been simplified for this particular application and that further work to achieve standard modules will be driven much further.

8 CONCLUSIONS

The HFAA and SHARC projects are obviously directed to small-to-medium sized products. This form of focus is required in order to ensure the attainment of the intended results. A potential widening of the targeted product sizes is envisaged and contacts have been taken with Ericsson, ABB, and other companies. The VOLUX project [12], which ran under Woxén financing, has treated the problem of assembly of large products in large volumes. This project was carried out at our department and the results have been input to the HFAA project.

The methods used within the project include DFA2 [7] and Modular Function Deployment (MFD [13]). DFA2 is used to assist the customer in forming automatic assembly-friendly products and in deriving which assembly equipment is necessary. The method is therefore used in forming a distinct classification of the equipment required in small-to-medium sized product applications. MFD has been tested for the selection of required modules for the HFAA concept. Other methods such as Axiomatic Design [14] have not been considered at this stage of events. Axiomatic design focuses on the development of final solutions and does not offer the possibility to investigate on the true source of problem causes. Once a clear-cut classification of the assembly process is derived, the Axiomatic Design principles may be applied to structure the functionality requirements for the desired modules.

Albeit the absence of adequate automatic assembly solutions, the market for robot handling systems is forecasted to have an average annual growth of 5.3% up to the year 2005 ((see fig.7 [11]). The report also states that this market is predicted to experience *high growth* in revenues, *especially if advances are made in software and its compatibility with modular-type equipment*[11]. This is precisely the type of equipment and software that the HFAA/SHARC project is intending to develop.

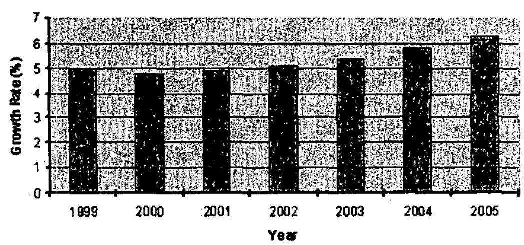

Fig.7- Robot Systems Market Growth Rate (predicted [11])

The HFAA/SHARC concept allows the user to start from purely manual assembly stations consisting of product and material flow modules. The user may then gradually replace manual stations with robot stations once the product volumes and/or economic situation enable it.

The project is concentrating on the standard interfaces between robots and the superior control system, rather than the creation of "standard robot modules". The belief is that true *long-term* flexibility may only be achieved by leaving the robot solution open for changes. It should be possible to introduce other types of robots according to the changing needs, and at a low cost. Hence the focus on the interfacing.

The intention with the project is to create a series of several alternative component solutions according to the specific product or task (process-related). Many simple, strictly task-oriented components with standard interfaces are better than few, very flexible but extremely expensive solutions. In other words, the automatic assembly system itself will inevitably reach a given complexity level, such that the components within it should not contribute to raise it even further. The users' acquisition of knowledge and competence must also be enabled in an adequate manner. Simple and effective in-house maintenance must also become part of the flexibility equation. For SMEs and large companies alike, the ideal scenario is attained when *any further enhancement in flexibility only leads to a reduction in overall costs*[10]. The stepwise flexibility enhancements must therefore be very well targeted, standard, cheap and robust. Note that the the flexibility must be well exploited. One must underline that it is the assembly system as a whole that should be hyper flexible, not its individual components.

The HFAA project was initiated in 1999 and will run for four years. The SHARC project is expected to start in April 2001. The Mark IV installation should be viewed as an engineering and testing platform for some of the results obtained by the HFAA/SHARC project.

Note that the HFAA/SHARC system is not intended for micro-assembly and that certain limitations are placed on the maximum size and weight of the parts to be assembled (further work is being conducted).

ACKNOWLEDGEMENTS

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