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Closed loop scheduling and control of One-of-a-Kind Production

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Abstract

In this paper, a closed loop cybernetic system is proposed for real-time scheduling and control of production in an automatic shop floor or on an automatic production line for One-of-a-Kind Production. By a concept of the so-called Product Production Structure, the designs and production processes of different types of products can be formulated into a set of data. These data can be 'read' by the control system and thereby the control system makes schedule of as well as real-time controls the production of the products. In this manner, the control system gains enough robustness to cope with the great diversity of product types (or kinds) in One-of-a-Kind Production. By the simulation module and experience time estimates of production processes, the control system is designed as an estimator to be able to make the production schedule before starting a production of a product or a batch of products with different types. By its closed loop, the control system is also designed to be able to real-time control the production and update the production schedule according to states of a shop floor or a production line during the production.

Keywords

CIM, cybernetic modelling, One-of-a-Kind Production, real-time scheduling and control

1 INTRODUCTION

The main contents in this paper report a production scheduling and control system developed in the ongoing research project under the title of "Cybernetic Modelling and Control in One-of-a-Kind Production (CMCOKP)". This research project is one of the 7 research projects in the main research program, namely IPS (Integrated Production Systems) II Research Program. The IPS II is a research program under the Danish Technical Research Council aimed at developing new approaches to industrial integration and strengthening research cooperation between several Danish academic research organisations and Danish industry.

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According to the definitions made by Trostmann et al. (1993), a OKP (One-of-a-Kind Production) industry can be characterised as:

- the design of its product changes with almost every new order, and
- almost every one of its customer orders contains one and only one specimen.

The physical examples of OKP industries can be easily found in present heavy industries, e.g. a boiler manufacturing company or a shipyard.

In OKP industries, two main problems are identified in the following from the production control point of view:

- The structure (or design) of the product may change particularly much and frequently.
- Corresponding with changes of the product structure, the shop floor layout or production system configuration may change particularly much and frequently.

Because of these two problems, the control systems for automatic control of OKP (One-of-a-Kind Production) normally need much higher flexibility than the control systems for automatic control of mass production and even batch production. From a view point of control system structure, the higher flexibility of a control system is normally in conflict with its robustness. However, the reliability and feasibility of a control system depends very much on the robustness of the control system. This conflict has made the great difficulties to implement an automatic scheduling and control system in OKP industries, such as shipyards.

To resolve the problems for automatic control of shop floors in OKP industries is the main goal of the CMCOKP research project. The CMCOKP has been carried out co-operatively by the Department of Production of Aalborg University, the Control Engineering Institute of Technical University of Denmark and the Odense Steel Shipyard Ltd. in Denmark.

To develop and implement technologies and concepts for the design of automatic shop floor control systems in One-of-a-Kind Production industries by linking the industrial objectives with these technologies and concepts, a ship web welding assembly line at the Odense Steel Shipyard Ltd. is chosen as a pilot shop floor to running the CMCOKP research project. This ship web welding assembly line is named B13 line at the Odense Steel Shipyard Ltd.

2 PRODUCTION SCENARIO OF THE B13 LINE AND PRODUCT PRODUCTION STRUCTURE OF A CASE WEB

2.1 Descriptions of the B13 line and a case web

At the Odense Steel Shipyard Ltd., a ship body (or ship tank) is welded by hierarchically decomposing it into Blocks, Sub-blocks, Webs and metal plate cutting parts (i.e. base plates, brackets, flat bars, etc., see examples in Figure 1 (a)). The B13 line is one of the shop floors in the shipyard to weld different types of webs. One example of such webs to be welded on the B13 line is shown in Figure 1 (a).

As shown in Figure 1 (a), the case web consists of a base plate (BP2), three types of stiffeners, i.e. a large bracket '34STR', three large flat-bars 'S28', 'S32' and 'S37', and two small flat-bars 'S27' and 'S30'. There are a lot of different types of webs to be welded on the B13 line. Each of those webs generally consists of a base plate with different size and plan geometric model and a number of different stiffeners.

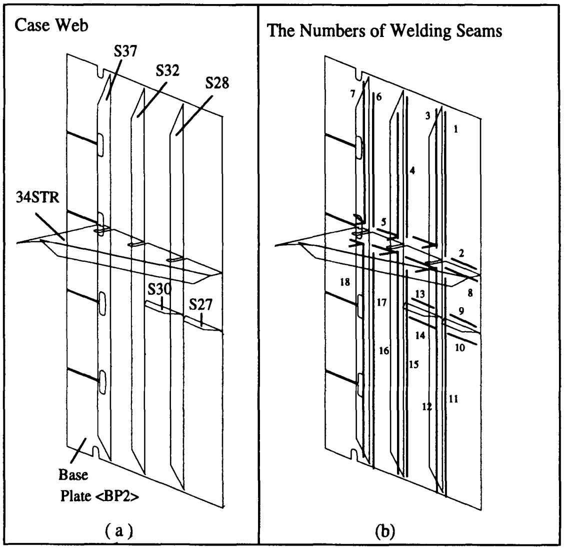

Figure 1 A case web.

At present time, the B13 line at the Odense Steel Shipyard Ltd. is a man-machine combined ship web welding assembly line. By the CMCOKP research project, a new automatic (or robotised) B13 line is going to be designed for the shipyard to remodel its present B13 line. The layout and working procedure of the automatic B13 line are quite different from the present B13 line at the shipyard.

The discussions made in this paper are focused on the new automatic B13 line. To simplify the description in the following, the term of B13 line will be simply used to refer to the automatic B13 line but not the present B13 line at the Odense Steel Shipyard Ltd.

According to the design made by Ørum-Hansen et al. (1994), the B13 line consists of an one-band conveyor and three types of robots. The space of the conveyor is subdivided into 5 even working stations. At every movement of the conveyor, the web panels (or base plates) placed on the conveyor will be transferred from one station to another station. The layout of the B13 line is scratched in Figure 2.

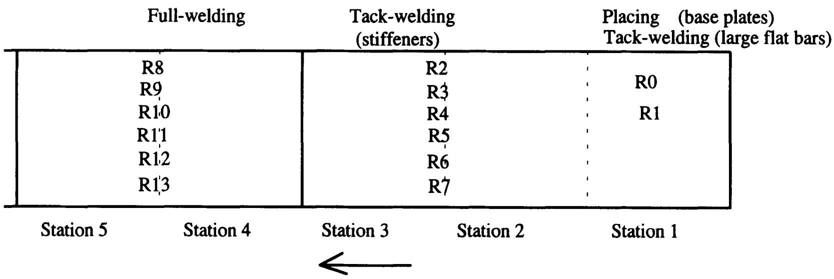

Figure 2 Layout of the B13 line.

In Station 1 of the B13 line (see Figure 2), two set-up robots are designed to place base plates of webs and then to tack-weld large flat bars (the length of the bar > 3 m). The robots work in Station 1 are shown as R0 (to place base plates, i.e. 'BP2' in Figure 1 (a)) and R1 (to tack-weld large flat bars, i.e. 'S28', 'S32' and 'S37' in Figure 1 (a)) in Figure 2. R0 and R1 always sequentially work in Station 1 by the sequence of R0→R1.

In Stations 2 and 3, maximum six tack-welding robots are designed to tack-weld stiffeners on base plates. These robots are shown as R2 through R7 in Figure 2. R2 through R7 can freely work either in Station 2 or Station 3. In the following description, this type of robots will be simply called a TR or TR's. In Station 2, the small flat-bars (i.e. 'S27' and 'S30' in Figure 1 (a)) are planned to be tack-welded, and in Station 3 the large bracket (i.e. '34STR' in Figure 1(a)) is planned to be tack-welded.

In Stations 4 and 5, maximum six full-welding robots are designed to completely weld stiffeners on base plates of webs. The welding seams for the case web shown in Figure 1 (a) are identified and coded in Figure 1 (b). These robots are shown as R8 through R13 in Figure 2. R8 through R13 can freely work either in Station 4 or Station 5. In the following description, this type of robots will be simply called an FR or FR's. In Station 4, welding seams '1', '2', '4', '6', '9', '10', '11', '13', '14', '15' and '17' for welding the case web are planned to be carried out. In Station 5, the rest of welding seams for welding the case web are planned to be completed.

The design and control of the three different types of robots, i.e. set-up robots R0 and R1, tack-welding robots R2 through R7 and full-welding robots R8 through R13 mentioned above are described by Ørum-Hansen et al. (1994).

2.2 Product Production Structure of the case web

The concept of Product Production Structure was firstly proposed by Drs Nielsen and Holm (1990). The Product Production Structure of a product is an joined logic illustration of the product design (or product decomposition) and production (or process planning). A Product Production Structure consists of three types of legends: circles, boxes and arrow lines. A circle on the Product Production Structure represents a product state. By the product states, particular the product states which mean the parts of the product, the design of the product is illustrated. A box on the Product Production Structure represents a process. The arrow lines on the Product Production Structure indicate the sequence of the processes by which the product is produced.

The Product Production Structure for the case web described in Section 2.1 is drawn in Figure 3. In Figure 3, the boxes are processes or operations and the circles are product states. The rectangles T1 through T5 mean six working stations of the B13 line.

To get the clear illustration in Figure 3, most of the intermediate product states are omitted. Only the final product state (circle 'xxxep'), the components (circles in rectangles T1, T2 and T3) of the case web and the welding seams (circles in rectangles T4 and T5) are shown in Figure 3.

To read the boxes in connection with their associated circles and the descriptions made in Section 2.1, the meanings of the operations shown in Figure 3 can be derived.

According to the Product Production Structure of the case web and the time estimate of each of the operations, a set of structured data can be formulated and stored in a data base.

For example, operation T11 in Figure 3 can be stored as 'T11=S1_10:0_bp2' in the data base. This data means T11 is carried out in station 1 (as 'S1'), normally takes 10 minutes (as

'10'), it is a set-up operation (as '0') and it operates on the base plate 'bp2'. By reading such data of all the operations for producing webs on the B13 line, the control system of the B13 line can make the production schedule for and control the production on the B13 line. The control system of the B13 line is described in the following section.

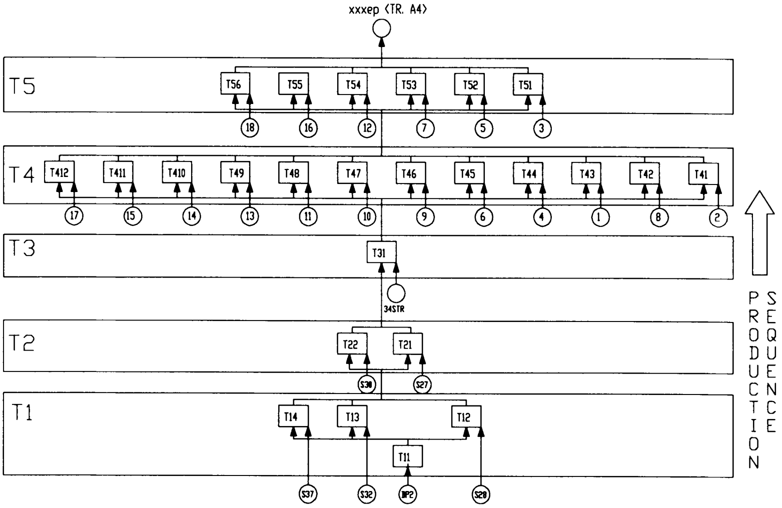

Figure 3 Product Production Structure of the case web.

3 CLOSED LOOP SCHEDULING AND CONTROL SYSTEM

At the Odense Steel Shipyard Ltd., a three-level (simply from the top to the bottom called A, B and C levels in the shipyard) hierarchical system has been used to schedule and control its production above the shop floor level. To simplify the description, this control system is named Factory Control System in this paper. The inputs to the B13 line control system are the outputs from the sub-control systems on the C level of the Factory Control System. An output from the Factory Control System to the B13 line control system is a batch of webs (normally with different types) to be welded on the B13 line in a certain time period T (e.g. a week or a month). It is simply called a C-schedule in the shipyard.

According to a C-schedule, the control system of the B13 line needs to further decompose webs into basic metal plate cutting parts and schedule as well as control the production of these webs on the B13 line.

The overall control structure of the B13 line control system is shown in Figure 4.

As shown in Figure 4, by equations (1), (2) and (3), the B13 line control system will firstly determine how many robots are needed to be configured on the B13 line according to a C-schedule, i.e. a batch of webs (as input path '***tasks***' shown in Figure 4) to be welded in a certain time period (viz. T in Figure 4).

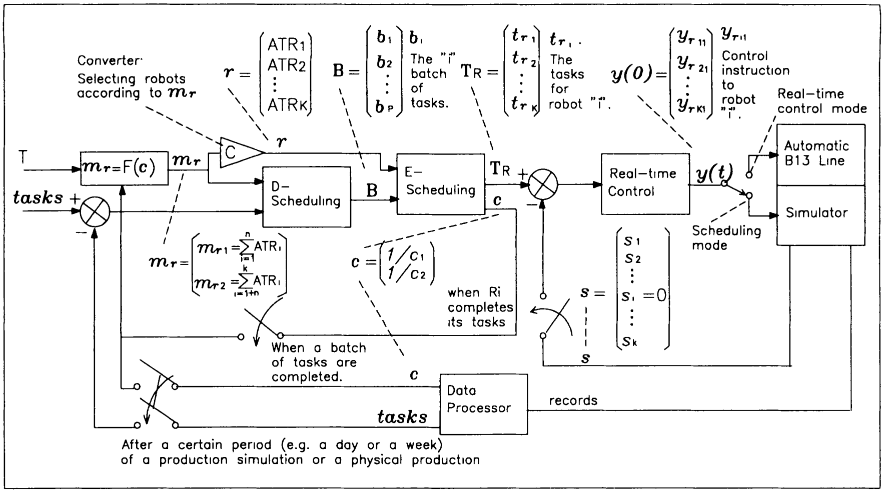

Figure 4 The control system of the B13 line.

$$mr = \begin{bmatrix} mr_1 \\ mr_2 \end{bmatrix} = F(c) = \begin{bmatrix} \sum_{i=1}^{h} T1i \Big/ T & 0 \\ 0 & \sum_{i=1}^{m} T2i \Big/ T \end{bmatrix} \begin{bmatrix} \frac{1}{c_1} \\ \frac{1}{c_2} \end{bmatrix} \tag{1}$$

T_{1i}: a time estimate of a tack-welding operation.
T_{2i}: a time estimate of a full-welding operation.

$$c_1 = (\frac{1}{n} \sum_{i=1}^{n} \text{working time of TRi/(working time of TRi + waiting time of TRi)} \tag{2}$$

$$c_2 = (\frac{1}{k-n} \sum_{j=n+1}^{k} \text{working time of FRj/(working time of FRj + waiting time of FRj)} \tag{3}$$

As stated in Section 2.1, robots R0 and R1 always sequentially work in Station 1. Hence by equations (1), (2) and (3), only the numbers of tack-welding robots (TR's) in Stations 2 and 3 and full-welding robots (FR's) in Stations 4 and 5 (see Figure 2) are calculated. It should point out here that m_{r1} (or m_{r2}) may be not equal to the number of TR's (or FR's) since ATR_i (see Figure 4) may be not equal to 1. This is because the robots (TR's or FR's) may work with different speeds. If a robot works with the average speed, its ATR equals 1. Otherwise, the ATR may be more than 1 (faster than the average speed) or less than 1 (slower than the average speed).

According to m_{r1} and m_{r2}, the Converter (as C triangle shown in Figure 4) will determine the number of TR's (viz. 'n') and the number of FR's (viz. 'k–n') by selecting proper TR's among R2 through R7 and FR's among R8 through R13. Then the D-scheduling module in Figure 4 will consequently determine the sequence and the lead time for producing each of the webs in the C-schedule.

The E-scheduling module in Figure 4 assigns and controls operations to each of the robots which are installed on the B13 in a certain production period. As mentioned in Section 2.1, the B13 line is designed as a five-station production line linked by an one-band conveyor. This design implies that each of the robots on the B13 line should be assigned the proper amount of tasks so that it has same working time as the others in order to gain a higher overall working efficiency. According to this criterion, the E-scheduling module assigns tasks for each of the robots by the following algorithms:

```
y=1; x=0; Number_of_robots=k;
Repeat
      Time_quota_of_robot_[y]=(∑T1i (or∑T2i)/MR1 (or MR2))·ATRy;
      Repeat
      x=x+1;
      to assign Operation_[x] to Robot_[y];
      Until ∑Time_estimate_of_operation_[x] >= Time_quota_of_robot_[y];
y=y+1;
Until y>k;
```

After a schedule has been made by the E-scheduling module according to the above mentioned algorithms, waiting times between robots are irrevocably generated. By equations (2) and (3), c_1 and c_2 will be updated. To catch the production period (i.e. T) set by a C-schedule, m_{r1} and m_{r2} will be updated by equation (1). According to the new m_{r1} and m_{r2}, the D- and E-scheduling modules will generate new schedules and then the new c_1 and c_2 will be calculated by equations (2) and (3) again. In this manner, the control system will be recursively running until the desirable production schedules are approached. These production schedules include a time phased table for the production of webs on the B13 line, a time phased table for all kinds of operations associated with the carrying out robots, the number of the TR's and the number of the FR's in a certain production period. To start this closed loop, c_1 and c_2 are initially set as 1.

The Real-time Control module in Figure 4 is a dispatching and monitoring module. According to the schedule made by the E-scheduling module, it dispatches operation control instructions either to the Simulator in Figure 4 if the control system is working on the off-line scheduling mode or to the robots on the B13 line if the control system is working on a real-time control mode.

After a scheduling procedure (the system links with the Simulator) or a production procedure (the system links with the B13 line), according to the 'records' the Data Processor in Figure 4 will statistically estimate executing times for the same or the same kind of operations and feeds back these estimates to the scheduling modules (as '***tasks***' feedback path shown in Figure 4) as well as calculate c_1 and c_2. According to the new time estimates and new c_1 and c_2, the control system will recursively approach new schedules (if the system works on an off-line scheduling mode) or update the existing production schedule (if the system works on the real-time control mode).

4 CONCLUSIONS

According to the discussions made in this paper, it can be concluded that

- The control system proposed in this paper has system configuration flexibility.

- By applying the concept of Product Production Structure, the control system gains enough robustness to be able to cope with a wider product type domain in One-of-a-Kind Production.
- By the scheduling algorithms presented in this paper and a recursively approaching procedure conducted by the control system, the just in time production schedules can be achieved by the control system.

Although the control system structure, algorithms and concepts presented in this paper are developed particularly for shop floor control in One-of-a-Kind Production, they may also be references for the design and development of shop floor control systems in other industries.

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6 AUTHORS' BIOGRAPHIES

Yiliu Tu is a post-doctoral research fellow at the Department of Production, Aalborg University, Denmark. He received a B.Sc. in Electronic Engineering and an M.Sc. in Mechanical Engineering both from Huazhong University of Science and Technology in China. In 1993, he received his Ph.D. from Aalborg University of Denmark. His present main research interest is real-time scheduling and control of automatic shop floors in One-of-a-Kind Production. He is a senior member of SME and CASA/SME.

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Ulla Brandt Rasmussen received her M.Sc. in Production Engineering in 1992 at the Department of Production, Aalborg University, Denmark. Since August 1992 she is a Ph.D. candidate within the area of dynamics of shop-floor control. Her special research interests are real-time control of automatic shop-floor systems within the area of One-of-a-Kind Production, and the application of Coloured Petri Nets for shop-floor control systems.