FMS におけるフレキシブルなセルの割り当てと ダイナミックスケジューリングのための方法*

荒井 栄司**・Amnuay SAE-TANG***

An Approach to Flexible Cell Assignment and Dynamic Scheduling in FMS*

Eiji ARAI** and Amnuay SAE-TANG***

One of the most essential requirements in the flexible automation is to increase the product flexibility with reducing the heavy load of CAD/CAM systems. The keywords to realize the requirement seem intelligent and distributed information processing. This paper proposes the feasible solution to realize the intelligent and distributed production systems in order to increase the flexibility especially against the errors and failures of the factory floor. The flexible cell assignment to execute the given jobs and the dynamic scheduling to re-schedule quickly when required are the important functions for the factory management. The former is realized by generating flexible sets of machining features in CAD, and non-deterministic cell assignment according to the functionality/performance and real-time status of cells. The latter is realized by performing operation planning in the cell controllers with use of the real-time simulation and dynamic scheduling system. An example reveals feasibility and availability of the proposed control/management architecture of the production system.

1. Introduction

The keywords for the realization of future flexible automation systems are "intelligent" and "distributed" information processing on the factory floor where all manufacturing activities are integrated. Most of recent researches working on the next generation of manufacturing systems have concluded that the suitable flexible automation has to be autonomous and includes both intelligent and distributed processing¹⁾.

When the factory is operated soundly with no faults according to the given production schedule, the conventional process/operation planning concept is very effective. However, the actual factory has various kinds of changes such as product modification in design division, estimation errors

and facility faults in production division. In order to fit these changes in real-time, it is too hard and time-consuming to re-calculate the total process/operation plan. On the other hand, in the recent production systems, computers and controllers on the factory floor have enough power to decompose the given jobs and to generate the operation sequence according to the performance and functionality of the cell to execute the required jobs.

In order to increase the flexibility of the production system, the process planning in CAM system should be executed independently from the real-time facility information of the factories. The input to process planning system is parts and product models constructed in the product design division. The detailed functions of factory floor facilities and their real-time operating conditions should be considered within the operation planning system, not in the process planning system. The process planning itself has to be flexible so that it can offer several alternative sets of processes with precedence constraints to other machining cells when the already assigned cell can not execute the job. The flexible machining features are introduced to realize the flexible cell

* 原稿受付 1994年11月30日

** 大阪大学 工学部 Department of Welding and Production Engineering, Osaka University; 2-1 Yamadaoka, Suita city, Osaka 565, JAPAN

*** 東京都立大学 大学院 Graduate School of Tokyo Metropolitan University; 1-1 Minami-Osawa, Hachioji city, Tokyo 192-03, JAPAN

Key Words: FA, CAD/CAM, CAPP, production management, scheduling.

when unexpected errors and failures occur in the factory or cell, process plan and operation plan are not flexible enough to be adapted in the distributed production system in which the recombination of machining features is required to find alternative cells and facilities for the continuous processing of production. For this reason, it is desirable that many feasible sets of machining features are determined from the job description referring to the factory facility data and used as the process description.

The standardized cell data representing general functionality and performance of cells in the factory will be used as the resource data to determine schedules of the jobs. The rough machining time of each process can be determined from the cell data and used in the scheduling system. The result of scheduling will be used for the cell assignment. When the cell controller receives the assigned process from the assignment system, it will decompose the process into many operations by using real-time functionality and performance data of the cell. The result of operation plans depends on available facilities in the cell. The machining simulation of operations will be performed during the operation planning to estimate the actual machining time of the process. This machining time will be fed back to the scheduling system before the cell finishes the machining. This feedback is called here as the monitor forecast. Since the failures in the cell may cause the cell to change the machining operation such as using alternative tools, machining conditions and cutting paths, the estimated machining time will be different from the standard time used in the scheduling system. If the difference of them are large, the re-scheduling of the remaining processes in jobs will be done by the scheduling system. Since the scheduling method used is simple and conventional, the re-scheduling can be quickly and simply performed when needed. Moreover, the production process can be effectively performed without the interruption from the failures and errors.

The standardized cell data used for the scheduling system will be updated by the data abstraction system every time when the failures or errors occur in a cell. This will be helpful for determining more precise standard machining time of jobs so that the re-scheduling caused by the large difference between the estimated and standard machining time can be reduced.

3. Flexible machining features

A set of two models, before and after machining of a part, is used to show a job. A job can be extracted by making the difference between these two models. Fig. 2 shows an example of the two models of a part represented by 3-D geometric model and a job extracted from their geometry difference. By decomposing the job into many primitive elements and grouping them, a set of machining features can be determined. Since we use machining features to represent processes of a job, the grouped machining features can represent a set of processes in a job. To increase flexibility of the production system, many sets of machining features feasible to be used in process and operation planning system will be decomposed from the job.

Fig. 2 Removal area determined from blank and finished part

Fig. 3 shows a flow diagram of the machining features decomposition from a job. First, the removal area (job) is determined by making the difference between the blank material and the finished part. Sets of machining features are extracted from the removal area. Not only one set of fixed machining features but possible sets are extracted. For instance, the removal area that is composed of the planar faces can be decomposed by the cutting planes that are generated referring to the kinds of concave and convex edges. Fig. 4 shows an 2-D example of the decomposition.

Machining features are recomposed from the decomposed elements. The recomposition of feasible machining features is executed with taking following conditions into consideration.

- (1) chain of dimension and datum elements.
- (2) accuracies and tolerances of the dimension

Fig. 3 Process description extraction in CAD from job description

Fig. 4 An example of the decomposed element from the removal area

and

(3) machining know-how independent of the specified machining facilities.

The precedence constraints among machining features are derived from geometric interference

detected from the geometric modeling system and additional attributes such as surface roughness⁴⁾. With taking the precedence constraints into consideration, machining features in each set are grouped. Each of them is recognized as a process description.

The extraction of several sets of machining features from the same removal area is useful for the flexible cell assignment. As shown in Fig. 5, one cell may machine all removal area, on the contrary, several cells may cooperate to machine the same area. Taking the errors and failures in the cells into account, the flexible cell assignment according to the flexible machining features is effective for dynamic scheduling or in the distributed flexible production system.

From the sets of machining features, production scheduling is required to assign only one suitable set of machining features to one cell. Production functionality, performance, time, cost etc. of each cell are considered in the scheduling system to define the objective function for the scheduling. The data of each cell used in the scheduling system are the standardized data in the factory database instead of the real-time data in the cell database.

A process description is a set of grouped machining features. One job description may be developed to generate several process descriptions by extracting flexible machining features.

Fig. 5 Flexible cell assignment by flexible feature sets

4. Operation planning in machining cell

Operation plan depends on facilities in each cell. It can be determined from the assigned process by using the real-time facility data of the cell. The assigned process description (grouped features)

may be developed differently when it is assigned to different cells according to the ability and functionality of the cell. To determine the operation, the cell controller is required to do the basic functions such :

- (1) recognize structure and functionality including ability and capacity of the cell.
- (2) recognize details of the assigned process.
- (3) communicate and collaborate with other cells to complete the assigned process when the ability of the cell is not enough to execute the process.
- (4) generate the optimal operation plan from real-time ability and functionality data of the cell.

Moreover, the cell controller has to possess the real-time simulation and the control command generating functions. The first function is used to estimate the actual machining time of the assigned process while the latter function is used to generate NC commands to control the facilities in the cell. The results from these two functions depend on the real-time ability and functionality data of the cell. Setup time, tool changing time, and other cutting preparing time are added to the machining time. These times are evaluated exactly by using the real-time facility data in the cell.

Through the real-time simulation, if it is detected that the cell can not absolutely complete the assigned process or the machining time is much longer than the standard time used in the scheduling system, re-grouping of process or re-scheduling (re-assignment) will be performed dynamically. Especially, when it is detected that the unmachinability of the assigned process is caused from errors and failures in the cell, such information will be fed back to the scheduling system to re-generate the process and find the re-schedule of the new process immediately. The new process plan can be determined from many feasible sets of machining features determined in CAD. The suitable process will be selected to replace the previous one by considering from its standard machining time.

When operation plan is generated, the control commands will be generated in order to control facilities in the cell to execute the operation plan. This control commands are effected directly by the real-time facility data such as tools, jigs, and fixtures^{5), 6)}.

Production scheduling is the core system in the automated factory¹⁾. To be able to respond quickly with the change in the production system, the re-scheduling should be easily and quickly

determined. Scheduling methods based on the simple heuristic rules⁷⁾ such as SPT (Shortest Processing Time), LPT (Longest Processing Time), DDATE (Earliest Due Date), etc. should be used because they are not time-consuming when comparing with other mathematical scheduling methods⁸⁾. Moreover, data such as machining time used as the input data of the scheduling system should be only approximated value. The use of precise data will also cause the scheduling system to be complex, costly and time-consuming.

From this reason, the simple scheduling method based on SPT heuristic rule is used to generate the schedule of jobs here. The data such as machining time is approximately determined from process plans, not from operation plans, with referring to the standard facility data in the factory floor.

5. Case study

A case study is introduced in order to make clear the effectiveness of the cell assignment and dynamic scheduling with the real-time simulation.

Fig. 6 is a typical FMS where the master production schedule is generated by the simple scheduling method (SPT rule) like shown in Fig. 7. The machining time is estimated through the standardized machining time in the factory database.

When the machining process is assigned to the cell, the cell controller develops the operation plan using its real-time simulation function like Fig. 8 where the machining time is estimated in detail such as shown in Fig. 9.

The cell controller feeds the estimated machining time back to the scheduling system before starting the machining operation. If the difference between the two machining time is large, then the scheduling system will re-schedule the remained machining processes dynamically.

6. Conclusion

The keywords of the future factories seem to be distributed and intelligent. In machining, the role of CAD/CAM and distributed cell systems will be changed greatly. CAD system intends to expand the functionality to some CAM areas that is realized with product oriented data. Distributed cell system includes also some CAM functionality that requires the real-time facility data. CAM system is deeply connected with production scheduling in which the grouping of production process and the assignment to cells are executed from both product oriented and production facility oriented data.

Fig. 6 Typical flexible manufacturing system

MAKINO_V11_E.CHART

2/17 (WED)

```

8:00 <----- ON DUTY -----> 12:00 12:45 <----- ON DUTY -----> 18:45 17:00 <----- ON DUTY -----> 12:45
      1-----2-----3-----4-----5-----6-----7-----8-----9-----10-----11-----12
1234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890
MCN01 -----
MCN02 -----
MCN03 -----
VEH01 0-00100000-0-1000-0-10-0-0-1-100000-0-10-0-0-0-1000-0-00-100000-00-0-0-0-0-0010000
SS01 -----
SS02 -----
OPE01 -----
OPE02 -----

```

[illegible]

2/18 (THU)

[illegible]

Fig. 7 Typical time chart of production scheduling

Fig. 8 Real-time simulation for operation planning in the cell

Machining area : $-113.000 \leq x \leq 113.000$
 : $-72.000 \leq y \leq 73.000$
 : $0.289 \leq z \leq 45.289$
 Fast feed speed : 10000.000 mm/min 0.486 m
 00:00:02
 Cutting speed : 114.000 mm/40.967 m
 05:59:21
 Total block : 5684 block
 Total byte : 86904 byte
 Tape length : 220.736 m
 Tape volume : 1 Vol.
 Machining time : 5h 59min 24s

Fig. 9 Evaluated machining time through real-time simulation in the cell

Two functions are essential to increase the flexibility and to reduce the heavy load of CAD/CAM/production planning systems, those are pre-processing to prepare the candidates of machining features in CAD and flexible cell assignment in CAM system. Flexible machining features extraction is realized to generate the candidates, that improves the process planning and scheduling processing more flexible.

For the accuracy in CAM system, it is preferable to utilize the real-time facility data. However, the CAM system has too heavy duty in both

computation time and required memory to reflect the real-time data, and is executed by using the macro simulation referring to the standardized facility data etc.. The detailed simulation is executed in the distributed cell controller for the operation planning with use of the real-time facility data. The cell controller can forecast the machining result such as finishing time in advance according to the real-time simulation.

When the estimated machining time of the assigned process is fed back from the cell to the CAM/scheduling system, it is possible to re-

schedule quickly even by the conventional scheduling methods. In other words, the dynamic scheduling function will be realized with use of the monitor forecast according to the real-time simulation.

References

- 1) P. G. Ranky : Intelligent Planning and Dynamic Scheduling of Flexible Manufacturing Cells and Systems ; Proc. of the 1992 Japan-U. S. A. Symposium on Flexible Automation, pp. 415~422 (1992)
- 2) I. Hatono, K. Tachibana, M. Umano and H. Tamura : Distributed Real-time Scheduling for Flexible Manufacturing ; Proc. of the 1994 Japan-U. S. A. Symposium on Flexible Automation, pp. 803~810 (1994)
- 3) J. Peklenik : Development of the Part Spectrum Database for Computer Integrated Manufacturing System ; Annals of the CIRP, Vol. 39, No. 1, pp. 471~474 (1990)
- 4) K. Iwata et al. : A Proposal of Knowledge Base Structure for Integrated Process Planning System ; Prep. of the CIRP Int. Seminar, pp. 4B: 1~4B: 13 (1990)
- 5) K. G. Adams and S. H. Huang : RTX : A Real-Time Operation System Environment for CNC Machine Tool Control ; Prep. of 7th IFAC/IFIP/IFORS/IMACS/ISPE Symposium on Information Control Problems in Manufacturing Technology, Vol. 1, pp. 59~64 (1992)
- 6) K. Iriguchi et al. : Realtime Tool Path Generation for 5-Axis Control Machining ; Proc. of the IMACS/SICE Int. Symposium '92, pp. 95~100 (1992)
- 7) J. H. Blackstone, Jr., D. T. Phillips and G. L. Hogg : A State-of-the-Art Survey of Dispatching Rules for Manufacturing Job Shop Operations ; International Journal of Production Research, Vol. 20, No. 1, pp. 77~88 (1982)
- 8) D. J. Hoitomt, P. B. Luh and K. R. Pattipati : A Practical Approach to Job-Shop Scheduling Problems ; IEEE Transactions on Robotics and Automation, Vol. 9, No. 1, pp. 1~13 (1993)