A FMS Dynamic Scheduling Optimization Strategy and Simulation Research

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Keywords: Emergencies, Dynamic Scheduling,FMS Dynamic Scheduling Strategy Simulation.

Abstract. According to the FMS actual production scheduling problems, this paper established a Petri nets scheduling model, And based on this model, we proposed a static scheduling algorithm combined with Petri nets reachability graph and A* heuristic graph search algorithm, Then a simulation experiment of the FMS dynamic scheduling optimization problem which has the emergency was conducted to verified the effectiveness of the dynamic scheduling strategy.

Introduction

Flexible manufacturing system (FMS) is a kind of a high level, high automation, high efficiency discrete event systems [1]. But the actual scheduling of FMS belongs to a class of NP combinatorial problems [2-3], so it is difficult to use a polynomial to solve[4]. At present, there are some methods for scheduling problems such as basic operations research methods, rules based methods, simulation based methods and artificial intelligence methods[5]. But with the increase in the number of scheduling, the calculation will become difficult. Dr. Petri proposed Petri network to provide a set of system modeling, analysis, verification, simulation, scheduling and control for the integration of the formal and graphical mathematical tools for designers[6]. The research of Petri net is mainly to construct Petri reachable graph heuristic search algorithm. But when we model the actual FMS, it will produce a large number of reachable graphs, so it is very necessary to select the appropriate scheduling algorithm to balance the workload and the optimization goal. At the same time, there are a large number of unforeseen and unavoidable uncertainties in the practical operation of the flexible manufacturing. A big gap existed between the static scheduling result and the actual scheduling due to these uncertain factors .The performance of the FMS dynamic scheduling control strategy had a great influence on the running efficiency of FMS and application benefits. Xuelei and HaoYue[7] use the enhancement of determine timed Petri nets and class A* algorithm multi-objective optimization for no consideration of such as manufacturing equipment failure problems in FMS. But these methods eventually turned into a similar breadth search algorithm, and the efficiency is not high. Therefore this paper focuses on the selective expansion of the system Petri net models reachability graph and A* heuristic search method combined the emergencies and other uncertain factors are introduced into the study on FMS scheduling problem in this paper, which can shorten the search time, improve the system flexibility, improve scheduling accuracy.

Description of the Dynamic Scheduling Problems

FMS static scheduling problem is mainly refers to the production scheduling optimization problem under the ideal environment. Once the scheduling plan is determined, the system will execute as the scheduling plan.The actual situation and the assumption of ideal production environment are not often match in the FMS running process. Because in the operation of FMS, the failure of the machine tool, urgent tasks, order cancellation and a series of uncertain factors will appear, which make the original static scheduling plan become difficult to enforce in implementation process. There will need to be done in accordance with the actual conditions of system scheduling at this time. This kind of problem is the dynamic scheduling problem[8-9]. This

paper used total completion time C_{MAX} for minimum as the scheduling performance indicators. It is established the mathematical model of the FMS dynamic scheduling optimization problem:

$$f=\min (\max C_j \quad j=1,2,\dots,n) \tag{1}$$

constraint condition

$$\begin{cases} C_i=\max(t_{ijk}^e-t_l^s),X_{ijk}=1 \\ t_{ijk}^s-t_{i(j-1)h}\geq 0,X_{ijk}=X_{i(j-1)h}=1 \\ t_{ijk}^s-t_{egk}^e\geq 0,X_{ijk}=X_{egk}=1 \end{cases} \tag{2}$$

Among them, t_s^l is the start time of l dispatch ; C_i is the last working procedure completion time of the work-piece J_i; n is the number of required work-piece scheduling in FMS; m is the number of machine tools that join this scheduling in FMS; t_{ijk} is the processing time of the process number j of the part i on the machine tool k; t_{ijk}^s is the start time of the process number j of the part i on the machine tool k; t_{ijk}^e is the finish time of the process number j of the part i on the machine tool k; X_{ijk} is logical quantity ; t_l^s is the start tine of scheduling number j.

Rolling Window Re-scheduling Policy

Scheduling process is complex thank to the emergencies, but the scrolling window re-scheduling method opens up provide a new idea [10] for the study of dynamic scheduling problems. Therefore, this paper proposed a method which uses rolling window re-scheduling strategy to solve the dynamic scheduling optimization problem. Rolling window re-scheduling is according to the current processing status and unexpected accidents in the system information when any one time comes by identifying multiple static scheduling time again[11-12] immediately to re-scheduling. We should first define a scrolling window (the work-pieces window) when using the scroll window re-scheduling technology. This article divided all work-pieces in the window into four parts such as: being machined work-piece set, processing work-piece set, rough set, pending scheduling the work-piece set. Three windows are defined as shown in Figure 1 at the same time for example the completion window, the scheduling of the processing window and wait for the scheduling window. Being machined work-piece set was Stored in the completion window; processing work-piece set and unprocessed work-piece set were stored in the scheduling of the processing window; pending scheduling the work-piece set was stored in the waiting for the window. When re-scheduling time came, moved being machined work-piece set out of the scheduling process window and then put pending scheduling the work-piece set into it at the same time. Finally, using scheduling algorithm for scheduling and processing work-piece in the window schedule calculation [5].
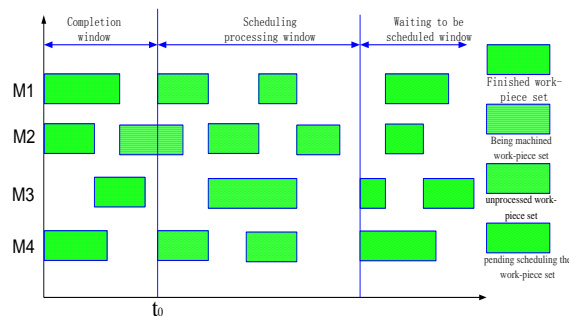

Fig.1. The diagram of the relationship between the work-piece window and the different work-piece set.

It takes different scroll re-scheduling mechanism for different FMS dynamic scheduling problem. The rolling window re-scheduling mechanism can be basically divided into three categories[13].
(1) event-driven re-scheduling

Event-driven re-scheduling is that when emergencies occur in the scheduling execution process, it is necessary to re-scheduling immediately. Re-scheduling model was shown in Figure 2. Event-driven scheduling can well be handled emergencies, but it lacks the ability to foresee and overall concept [12] for the future events. FMS system needed re-scheduling of the event-driven emergencies mainly: (a) machine failure; (b) emergency orders issued; (c) the delivery time of the orders was advanced; (d) scheduling order was canceled.
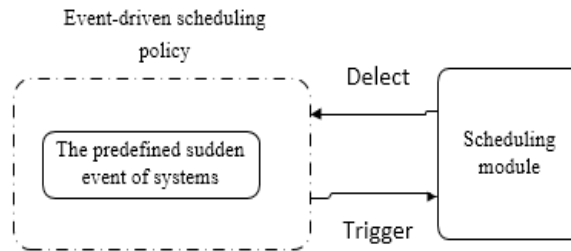

Fig.2 Event-driven scheduling policy model

(2) Periodic driver re-scheduling

Periodic driver re-scheduling is that for every production cycle the system will scheduling once again. Its re-scheduling model was shown in Figure 3. It is the most using of the scheduling strategy in the actual production scheduling. The period of the re-scheduling is the time interval between the two scheduling, which is a key indicator for periodic driver re-scheduling [14]. Under normal circumstances the re-scheduling period is a fixed value. But the demand of the outside enterprise market was changing which made the time and the number of the order arrives system also change. It leads to big differences of production load in the different scheduling cycle. This paper adopts the change cycle scheduling method [15] which cycle calculated was as follows:

$$T^* = \frac{T}{\eta}.$$
(3)

Among them, T^* is the cumulative processing time of all machine tools in the system, η is the number of the re-scheduling system. It can be seen that the number of times of the system re-scheduling is directly proportional to the production load. The more the production load, the greater the number of re-scheduling; conversely, the smaller the production load, the fewer the number of re-scheduling of the system.
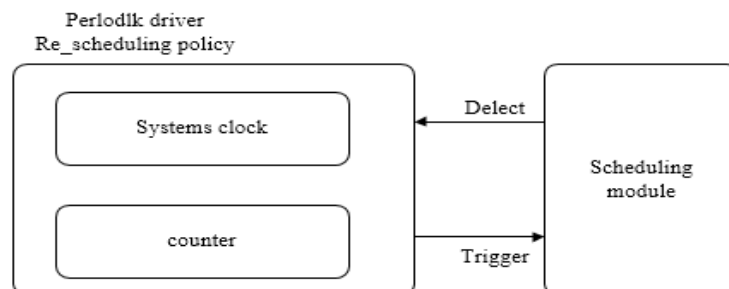

Fig.3 Periodically driven scheduling policy model

(3) Mixed-driven re-scheduling

Mixed-driven re-scheduling combines the advantage of event-driven and periodic driver re-scheduling mechanism. In normal production cycle, scheduling arrangements used the periodic

driver re-scheduling. Scheduling arrangements adopt event-driven scheduling when the machine failure accrued, emergency orders, cancellation and other emergencies in the system running.

Dynamic Scheduling Process and Simulation Analysis of the Incidents

Now the emergencies encountered in the actual production was analyzed by using the scroll window scheduling policy. For static scheduling problem, it is known that the state of the initial state of the machine was available can be used and the processing start time of each work-piece were 0 moments. However for dynamic scheduling problem, owing to the processing constraints of continuity, the machine being processed was put into the re-scheduling only in the finished process when the scheduling time t_l^s of the number of l was arrived. In this case, it is necessary to calculate the starting time of the work-piece of the re-scheduling window or pending dispatch window. For the work-piece i in re-scheduling window, the formula of the start processing time t_{ijk}^s about the first step j on machine k was as following:

$$t_{ijk}^s = \max\{\max\{t_l^s, t_{i(j-1)}^e\}, t_k^e\}. \tag{4}$$

t_k^e is the end processing operations time of the machine's last processing. For the work-piece i in the pending scheduling window, the formula of the start processing time t_{i1k}^s of first step in machine k was as following:

$$t_{i1k}^s = \max\{t_l^s, t_k^e\}. \tag{5}$$

It can be seen form the above two equations, incidents in the production process for frequent re-scheduling will be increased the calculate cost. Therefore when the emergency occurs, the first should be according to the size of the deviation between the current process and of the current scheduling schemes, the re-scheduling calculation should be decided first. It can be used Gantt charts and other tools to manually adjust the existing scheduling scheme or negligible when the deviation is small. It can be considered the dynamic re-scheduling calculation [16] when the deviation is larger. Fig 4 is the dynamic scheduling flowchart adopted in this paper.
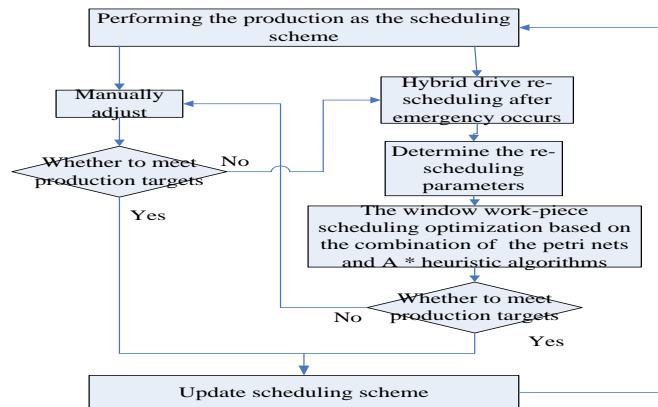

Fig.4 Dynamic scheduling flowcharts

It takes the machine failure of the emergencies often appearing the actual workshop for example to analysis its dynamic re-scheduling process and make the examples of simulation analysis.

The Process of Dynamic Scheduling about Machine Fault .The machine failure has many types. The machine failures which occurred in FMS system scheduling process usually do not consider the specific circumstances of the failure, while it is divided into two categories according to the severity of the failure or the time required to repair the fault. That is big machine fault and small machine glitch.

$$t_m \geq N_1, \forall m, N_1 > 0. \tag{6}$$

$$\sum_{i=1}^{n} \sum_{h=k}^{l} t_{ih} \geq N_2, \forall i, h, 1 \leq k \leq l, N_2 > 0. \tag{7}$$

t_m is the repair time for the fault machine; N1,N2 is the known positive; l is the number of processes for the parts i; k is start processing operations of the work-piece i on the machine which it was repaired completion; t_{ih} is the processing time of the process number h for the part i, which is for the remaining parts. Eq. (6) is a discriminate condition to distinguish the big machine failure from small fault, which meet the Eq. (6). is the major machine failure, or machine glitches. Eq. (7) is used to distinguish the remaining processing time after the machine troubleshooting. If meet the Eq. (7), the remaining processing time required is longer, otherwise, the remaining processing time is shorter. The specific measures for machine fault as follows:

If a machine happened a major failure where the system has the same type machine and the remained processing time in the system was not very long, the fault machine can be directly exited from the scheduling; If there is a major fault machine and has not the same type machine for instead, or the system residual processing time is very long, hence the fault machine after repaired should be returned to the system for scheduling. For machine glitches, the repair time is relatively short.

If use large machine failure scheduling mechanism, it will not only affect the normal work of other machine tools but also make processing capacity of the faulty equipment can't be brought into full play. Therefore, if a glitch in the machine tool equipment, you can wait until it repaired back to the system and make the remaining tasks of scheduling order reasonable delay.

Dynamic Scheduling Simulation instance of machine failure . In order to fully test the FMS system dynamic scheduling process, the experimental simulation was done. The system has six machine tool and it was divided into three categories: M1 machine as the type I; M2, M3 machine as type II; M4, M5, M6, machine tools as type III. There are 5 artifacts need to be processed in the system. The processing time of each working procedure and the type of the machine and other relevant information were shown in table 1:

Tab 1.　The work-piece machining information table

Work-piece	process	Processing time	Machine Type	priority level	The earliest commencement time	The lateness commencement time
J1	1	4	III	1	0	24
	2	5	I			
	3	3	II			
J2	1	3	II	1	0	24
	2	4	III			
	3	2	I			
J3	1	4	I	1	0	24
	2	6	II			
	3	4	III			
J4	1	5	I	1	0	24
	2	4	III			
	3	7	II			
J5	1	3	III	1	0	24
	2	5	II			
	3	4	I			

The Petri net model of the FMS static scheduling can be established and used the algorithm combined A* heuristic scheduling algorithm with Petri nets reach-ability graph to obtain the static scheduling optimization solution by analyzing the example of static scheduling. Hence the static

scheduling Gantt chart of this algorithm (as shown in figure 5) was got and the minimum make-span was 20.
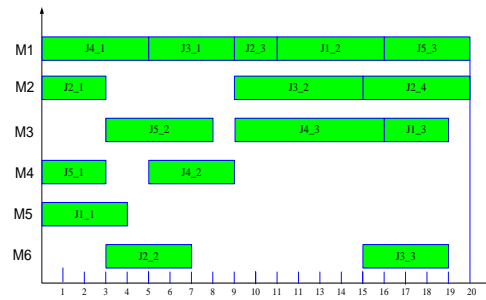

Fig.5 Static scheduling Gantt chart

Assumed the machine M5 happened major fault in the t=2 of on the basis of the FMS static scheduling algorithm. And assumed that it required a longer time to repair machine M5 while the remaining processing time is not very long, the machine M5 exit this scheduling. At this time, the associated delay time of P_{115} can be set to a larger value in the Petri net model of the library which in order to make it keep the maintenance state in the schedule. Because the first step of the work-piece J_1 has replaceable machine tools, the work-piece J_1 was removed from the machine M5 and re-engage the scheduling. The work-pieces J_2, J_4 and J_5 are in the processing state at the re-scheduling time t=2 and the machining process can't be interrupted in re-scheduling in accordance with the rules. In other words, each machine should be released after completed the current machining operation. It can be seen that the release time of the machine M1, M2, M4 is 3, 1, 1 from the static scheduling Gantt chart 5 respectively. It can be known that the symbol of Petri net model was identified in re-scheduling time t = 2 by the static scheduling Petri net model:

$m_{t=2}(p_{411})=1$ $m_{t=2}(p_{212})=1$ $m_{t=2}(p_{541})=1$ $m_{t=2}(p_{115})=1$
$m_{t=2}(p_3)=1$ $m_{t=2}(p_{3\_s})=1$ $m_{t=2}$(The rest of the library)=0

The excitation sequence obtained by using the method combined A* heuristic search algorithm with rolling window re-scheduling policy: T411(s) T212(s) T514(s) T116(s) T212(e) T514(e) T523(s) T411(e) T311(s) T424(s) T116(e) T226(s) T523(e) T311(e) T424(e) T226(e) T121(s) T322(s) T433(s) T121(e) T231(s) T322(e) T336(s) T231(e) T433(e) T531(s) T242(s) T133(s) T133(e) T336(e) T531(e) T242(e).Thus it can be seen, re-scheduling program Gantt chart is as shown in figure 6.
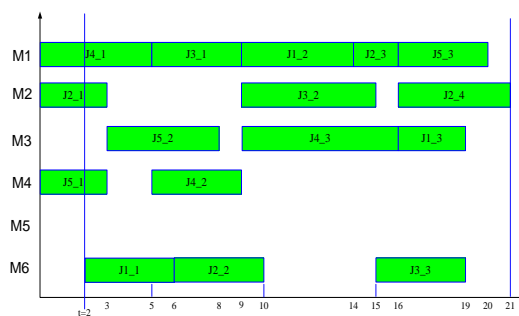

Fig.6 Scheduling Gantt chart of resources M5 break down and quit

Supposed machine tools M3 occurred malfunctions at t=2, which can be repaired in a short period of time, then the scheduling staff decided not to conduct dynamic re-scheduling while the processing step of corresponding work-piece on the fault machine was proceeded for awaiting processing. Assumed the machine tools M3 was completed repaired at t=4 and then put it into production. The second step of the work-piece $J5$ which was processing on machine M3 at t=3 was delayed to Start processing at t=4 (M3 was completion repaired) according to the previously described and static scheduling scheme. Other processing programs were not changed. Re-scheduling scheme shown in figure 7.
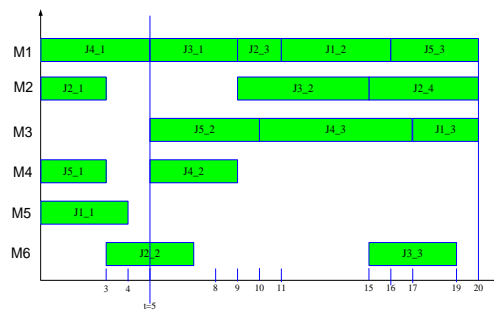
Fig.7 Re-Scheduling Gantt chart when resources M3 failure and repaired

It can be seen from the contrast of figure 3.2 and figure 3.3 that the longest completion time of machine M5 exiting scheduling system was a unit more than the make-span minimum of the static scheduling systems, which happens to be the release time of machine M2. It can be found from the contrast of figure 5 and figure 6 that the system re-scheduling after M3 breaks down and repaired was received the same make-span minimum as the static scheduling system. It shows that the processing program after the failure was received reasonable optimization by using the rolling window scheduling strategy.

Conclusion

It proposed a rolling window re-scheduling policy which was based on event-driven and cycle-driven for the FMS dynamic scheduling problems in the actual production environment. The strategy used minimum total completion time as the scheduling performance indicators. Then the excitation sequence obtained by using the method combined A* heuristic search algorithm with rolling window re-scheduling policy. Further, the Gantt chart obtained by the excitation sequence. It is established the mathematical model of the FMS dynamic scheduling optimization problem. This paper mainly takes the big machine fault and small machine glitch in the actual production workshop for example to analysis the common emergencies and simulates dynamic scheduling. The scheduling Gantt chart which was got through simulation compare with the Gantt chart of static scheduling system The result shows that the dynamic scheduling policy is feasible.

Acknowledgement

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