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Research on the Calculation of Equipment Processing Status in a DFA Model-Based Flexible Manufacturing Workshop for Structural Parts

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ABSTRACT

In this paper, the flexible manufacturing workshop of structural parts is taken as the research object, and the DFA model of equipment production process is established to calculate the equipment state of CNC machining tools at any time, aiming at the problems of digitalization of workshop scheduling, state prediction of processing equipment required by intelligent production transformation and order processing progress prediction. The research process combines the two-dimensional array representation method of the workshop, the state transfer function and the remaining time matrix. Through the calculation of sample experiments, DFA model can effectively calculate the running state of each equipment in the workshop at any time, and predict the order processing progress by the number of equipment state cycles.

KEYWORDS

DFA model, Equipment state, CNC machining tools

1. INTRODUCTION

With the development of modern industrial technology, the demand for digitalization and intelligence of industrial production is getting higher and higher, and the demand for flexible manufacturing workshop with metal structural parts as the production and processing target is getting higher and higher, which also provides opportunities for enterprises to upgrade and transform their intelligent production and develop CNC machine tools [1]. As an advanced production mode, flexible manufacturing workshop can not only meet the multi-variety and small-batch production mode, but also lay the foundation for efficient and large-scale production. Modular upgrading of CNC machining tools has become the basic processing equipment for mass production of metal structural parts in flexible workshops because of its high performance and strong compatibility [2-3].

In the workshop production process, when using information technology such as equipment scheduling, it often leads to a series of problems, such as process confusion, schedule estimation and order completion time prediction [4]. Enterprises must develop a lean production model driven by technological innovation and management innovation and aimed at making full use of production resources. Only by strengthening the management level of its own production plan can the available resources of enterprises be fully planned, coordinated and adjusted to meet the practical needs of enterprises [4-5].

Regarding the equipment state calculation, Li et al. established the equipment attribute data table based on multi-objective workshop scheduling, and studied the multi-equipment state transfer in the workshop with a hybrid improved algorithm [6]. Lu et al. put forward a method of calculating the program completion rate of electrodes to monitor the machining progress in view of the problem that multiple parts arrive at the machining link at the same time [7]. And others put forward a prediction model of workshop equipment operation state combining digital twinning with k- nearest neighbor algorithm [8]. Nian et al. studied the monitoring technology of machining process of various small and medium-sized workpieces, and developed a prototype system for monitoring the production status of machining workshops based on power data [9]. Mojtaba et al. precise steps in the production process are time-consuming, which provides basic parameters for the calculation of machining progress [10]. He et al. made a systematic study on the information composition and information collection method of equipment operation state in the workshop, and gave an application integration model of equipment operation state information in the workshop [11].

In this paper, the flexible manufacturing workshop of structural parts is taken as the research object, and the two-dimensional array representation method is based on the matrix distribution of CNC machining tools in the workshop, and the two-dimensional array elements correspond to the machine tool positions. The state transition function and the remaining time matrix are introduced respectively to determine the equipment state transition process and make the equipment state zero. Combined with the state transition period, the machining progress is predicted, and finally the machining state of the equipment at any time is calculated.

2. DFA MODEL ANALYSIS

There are usually three states of NC machining machine tools in the workshop, namely, idle status, loading and unloading status and machining status. By using the two-dimensional array representation method, the equipment in the three states is set to 0, 1 and 2 respectively. Flexible manufacturing orders are characterized by large quantities and the same work procedures. The loading and unloading time and processing time of the work pieces in the same process are the same. After the workshop order enters, the equipment only switches between 1 and 2 states instead of 0. The equipment with 0 indicates that it does not participate in the processing of this order. The duration of "1" is t1, and the duration of "2" is t2. The switching process of equipment state once indicates a work piece.

Because the duration of each state has pre-determined parameters, that is, the state of NC machining machine tool will be transferred to another state for a certain period of time, at this time, deterministic finite state automata (DFA) is introduced to represent the process, and the DFA five-tuple is defined as:

$$M = (Q\ ,\ \Sigma\ ,\ \delta\ ,\ q_0\ ,\ F) \tag{1}$$

Q is a set of states, 0、1、2; Σ is the input alphabet; δ is the state transition function; q0 is the initial state; F is the set of switching states.

3. STATE TRANSITION FUNCTION

In the DFA model, the state transition function δ represents the switching rule of the DFA model in this workshop. Aiming at the state switching problem of processing equipment in this paper, it is specifically as follows: determine the initial time point T0, give the time lapse Σ=t, calculate the state of the workshop equipment at time point T0+t, and represent the stage with k, and the expression is:

$$S_{k+1} = g(\ f(T_0\ ,\ t),\ S_k\ ) \tag{2}$$

Where Sk represents the current stage state; Sk+1 indicates the state of the next stage only affected by Sk. The state switching rules described in this paper are as follows: the current state is 1 (loading and unloading), then after t1, the state becomes 2 (machining); The state is 2 (machining), so after t2, the state becomes 1 (loading and unloading); For state 0 (idle), after any time unit, the state is still 0. Then the state transfer function δ of the workshop at this time can be directly written as:

$$\begin{cases} \delta(1,\ t)=2,\ \forall t\geq 0; \\ \delta(2,\ t)=1,\ \forall t\geq 0; \\ \delta(0,\ t)=0,\ \forall t\geq 0; \end{cases} \tag{3}$$

In the workshop layout representation method based on two-dimensional array in this paper, the state transition function δ can be directly written as a matrix:

$$P_\delta=\begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix} \tag{4}$$

4. TIME MATRIX CALCULATION

In order to calculate the equipment state after time t and predict the order progress at any time, it is necessary to determine the input value σ, and then input the experimental preset value, that is,① the current workshop processing equipment state q0;② The preset loading and unloading time t1=30s and processing time t2=45s;③ elapsed time t=360s. Taking a local device with a length * width of 3*3 as an example, the current state of the preset input value is:

$$\mathrm{q}_0=\begin{bmatrix} 1 & 1 & 2 \\ 2 & 1 & 2 \\ 1 & 2 & 1 \end{bmatrix} \tag{5}$$

The sequence of t1 and t2 only represents the initial state of the current equipment, and t1+t2 represents the switching period of the state "1-2", so the time matrix is expressed as follows:

$$T_0=\begin{bmatrix} t_1+t_2 & t_1+t_2 & t_2+t_1 \\ t_2+t_1 & t_1+t_2 & t_2+t_1 \\ t_1+t_2 & t_2+t_1 & t_1+t_2 \end{bmatrix}=\begin{bmatrix} 75 & 75 & 75 \\ 75 & 75 & 75 \\ 75 & 75 & 75 \end{bmatrix} \tag{6}$$

By calculating t/T0, we can calculate the "1-2" switching times c of each element in the matrix, and the calculation formula is:

$$C=\frac{\mathrm{t}}{t_1+t_2}=\frac{360}{75}=4.8\ ;\ \{C\}=C-[C]=4.8-4=0.8 \tag{7}$$

{C} indicates the fractional part of the result that is less than one period, and {C} is converted into seconds of 0.8*75=60s and classified and discussed:① "Time remaining" < t1, and the state remains unchanged;② t1 < "remaining time" < t2, state 1 becomes 2, and state 2 remains unchanged;③ t2 < "remaining time" < t1+t2, state 1 becomes 2, and state 2 becomes 1. In addition, in actual production, the state of 1 or 2 may have existed for a certain time, and there are differences among machine tools, so the number of switching cycles directly substituted into "1-2" will produce errors, and it is necessary to introduce the residual time matrix to zero the original equipment, so that the equipment can be represented as just converted to the current state. If the state 1 of equipment X21 in q0 lasts for 15s, the residual time is t01=30-15=15s. The state 2 of another device X11 lasts for 20s, so the remaining time is t02=45-20=25s. The time matrix that returns to zero after introducing the remaining time matrix is expressed as:

$$T_0 = \begin{bmatrix} t_1 + t_2 - 20 & t_1 + t_2 & t_2 + t_1 \\ t_2 + t_1 - 15 & t_1 + t_2 & t_2 + t_1 \\ t_1 + t_2 & t_2 + t_1 & t_1 + t_2 \end{bmatrix} = \begin{bmatrix} 55 & 75 & 75 \\ 60 & 75 & 75 \\ 75 & 75 & 75 \end{bmatrix} \quad (8)$$

At this time, t/T0 is calculated for X11 and X21 respectively, where X11 is (360-15)/75=4.6, and {C} is converted into 0.6 * 75 = 45s; X21 value is (360-20)/75≈4.53, and {C} is converted into 0.53*75≈40s. After classified discussion, the workshop equipment state matrix is as follows:

$$\mathrm{F} = \begin{bmatrix} 1 & 2 & 1 \\ 2 & 2 & 1 \\ 2 & 1 & 2 \end{bmatrix} \quad (9)$$

When calculating the machining progress, [C]=4, that is, the number of "1-2" switches is 4 times, which indicates that each machine tool has machined 4 workpieces in time t.

5. PSEUDO-CODE OF CALCULATION PROCESS

By introducing the residual time matrix to "zero" the elements in the matrix, the new state after subtracting the residual time matrix is calculated, so that the time matrix is calculated when the duration of the machine tool state is 0, and then the processing progress of the subsequent order is calculated. After the parameter t is input, the calculation of the order processing progress and the running state of the workshop processing equipment can be expressed by the following pseudo code:

```
function F(Xij， {C})
for i in range(Length):
for j in range(Width):
If t<= remaining time matrix [i][j]:
New state matrix [i][j]= state matrix q0[i][j]
else:
Remaining time C=t- remaining time matrix [i][j]
Number of state changes =
Remaining time C//[ State 1 duration+State 2 duration] [State matrix q0[i][j]]
The remaining time c is decimal {C}
New state matrix [i][j]={C}F(Xij, {C})
```

6. CONCLUSION

In this paper, aiming at the problems such as the state prediction of processing equipment and the prediction of order processing progress required by the digitalization and intelligent production transformation of flexible manufacturing workshop of mechanical parts, based on the processing order of metal structural parts, the calculation of workshop processing state without other interference factors is studied from the aspects of DFA model establishment, state transfer function, time matrix calculation and remaining time matrix introduction, etc., by preset loading and unloading and processing duration, With 3*3 local layout samples of equipment, after adding the input value t, the switching state of machine tool equipment after the pre-input time t has passed from any time can be calculated and the growth of machining progress can be predicted by the above calculation methods.

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