A Precision Improvement of Casting Process for Golf Head Manufacturing by Petri Net

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Abstract: - The precision casting and production of titanium alloy golf head is a complex and low production efficient industry in Taiwan. Due to the increasing global competition, high energy cost and explosive manpower growth, the golf head casting industry seek new approaches in the production processes and manufacturing techniques to improve productivity efficiency. This paper proposes a modeling tool based on the Petri net formalism to improve shop floor control of casting. The manufacturing golf head functions involving workflow processes and operations, scheduling, dispatching and monitoring are integrated and mapped by the Petri net model. The realistic data from industry are applied to the model and the results are sound. The overall manufacturing performance of the work cell can be estimated and improved cyclically to better performance.

Key-Words: -Petri Net, Modeling, Deadlock, Casting

1 Introduction

Taiwan has been the main producer of titanium alloy golf head in the world for several decades. E-Learning most often means an approach to facilitate and enhance learning through the use of devices based on computer and communications technology [1]. The whole supply chain of manufacturing is mature in this country. The production of the golf head significantly depends on manpower and it offers a large number of employment opportunities. This kind of manpower crowded industry, in traditional production line throughput is emphatically determined to facility layout. After the equipments are set up completely, and if there is no big difference between their product categories, then the production processes are fixed invariable. This may cause the production procedure to be redundant or may not operate continuously. If the production lines are partial with half-finished product in waiting, the efficiency will be dropped resulting in an increased cost. Since the labor production cost in Taiwan is constantly increasing, most industries are being transferred to mainland China and Vietnam. The present research has proposed a method to improve the production performance and processing continuity by Petri net theories. To avoid the deadlock of production line and to reduce redundant processing, the full production cycle time can be shortened.

The concept of Petri net is suggested by Carl Adam Petri [2]. The original purpose is used to express and discuss the communication of computer signals. A control system is a device or set of devices to manage, command, direct or regulate the behavior of other devices or systems [3]. Petri net is a graphical and mathematical modeling tool applicable to many systems. They are a promising tool for describing and studying information processing systems that are characterized as being concurrent, and/or stochastic. As a graphical tool, Petri nets can be used as a visual-communication aid similar to flow charts, block diagrams, and networks [4]. The application Petri net for a manufacturing system is essential to prevent the incidence of system deadlock which could possibly occur due to the concurrent and asynchronous nature of activities [5]. It consists of several types of machines, computers, robots, and automated guided vehicles and is designed to produce a great variety of products. Such a functional disorder of neural network is due to the excitability of individual elements of neural network and these results in altered properties of voltage sensitive ionic channels [6]. FMS consists of both the sophisticated manufacturing equipment and the advanced computer and information technology to impact flexibility to the manufacturing operations, thereby effectively meeting the changing needs of customers. Computation speed is sometimes another essential criterion [7]. The available FMS production type is very much like golf head manufacturing. Nicholas and Gonzalo used Petri nets for error recovery in the manufacturing system control for a multi-agent system representing various levels of control in a reconfigurable architecture [8]. Mieczystaw and Wtodzimesz proposed a system solution for the integration of process planning and control in the flexible manufacturing based on Petri net formalism [9]. Mark and Alan introduced Petri net as a tool for modeling, analysis, simulation and control of laboratory automation system. The present contribution focuses on the formal mathematical techniques for analyzing Petri net models, and methods for simulating and controlling laboratory automation. Petri nets inherit with a token reachability set. It is a sequential flow of a set of tokens to simulate the dynamic and concurrent activities of systems. As a mathematical tool, it is possible to set up state equations, algebraic equations, and other mathematical models governing the behavior of systems. Petri nets can be used by both practitioners and theoreticians. Thus, they provide a powerful medium of communication between them: practitioners can learn from theoreticians how to make their models more methodical, and theoreticians can learn from practitioners how to make their models more realistic. Therefore, Petri net is a graphical and mathematical modeling tool. Petri nets are a promising tool for describing and studying manufacturing processing systems that are characterized as being concurrent, asynchronous, distributed, parallel, nondeterministic, and/or stochastic. And then a process takes its mutable checkpoint only if the probability that it will get the checkpoint request in the current initiation is height [10].

Silva and Valette introduce Computer science/Petri nets specialists to the basic system level issues brought up by the development of Flexible Manufacturing and how Petri nets are used to aid the production engineers in their work [5]. Narahari [11] presents an approach for modeling and analyzing flexible manufacturing systems (FMSs) using Petri nets. The author builds a Petri net model (PNM) of the given FMS in a bottom-up fashion and then analyzes important qualitative aspects of FMS behavior. D'Souza and Khator report on the control of deadlocks in an automated manufacturing system by Petri Net. Deadlock detection and avoidance were performed off-line and the system was reconfigured by re-allocating the buffer capacity at the critical workstations [12]. Tchako et al present a dynamic and distributed structure for flexible manufacturing cells (FMC) derived from artificial intelligent technique for distributed problem-solving [13]. Section 1 of this paper uses the Petri net model to construct a golf head casting factory simulation model. With about fifteen years of practical experience, we construct a Petri net as the actual production situation as possible and study its series properties.

Section 2 introduces Petri net theory with special emphasis on the casting factory properties. Section 3 explains the precision casting processes for golf head manufacturing. The 4th section constructs a Petri net model to simulate casting golf head sceneries. Using the model, a series of studies on net properties, state probability for every work cell, and product throughput and system improvement are conducted. The conclusion is made in the last section.

2 Petri net theory

The Petri Net theory, its composition element, characteristics and trigger rule are described in this section. For system integration investigation, we combine Time Petri net and ordinary Petri net to design operations and events of the cast factory. Firstly, we introduce the function of the Petri Net simulation analysis and its firing mechanism. Petri Net is different from the figure graph simulation tool, because it can utilize network to express the dynamic behavior of complex system and it can carry on the analysis and verification of the systematic procedure by rigorous mathematical theory. By obtaining the related system structure and the dynamic behavior information, it can be used to avoid systematic discontinuity such as deadlock or abrupt delay events. Today, Petri net has been widely applied to simulate manufacturing production systems. Utilizing all production system conditions, it also can be set up for graphical representations using Petri net modeling. Furthermore system imitation and analysis can also be studied. Petri net is a convenient tool to depict the basic dynamic behavior of a system by its states and events. Therefore the study has used the Petri Net modeling to describe the dynamic system of a casting factory with the objective of improving production throughput and performance through detecting production bottleneck, decreasing production cycle time, controlling capacity overflow and avoiding conflicts.

2.1 Composition and defining of Petri Net

Ordinary Petri net can be differentiated for static state diagram and dynamic state behavior; the static may use a graph to express, mainly by the place nodes of round pattern, transition nodes of rectangular pattern and the arcs of direction (shown in Fig1). The dynamic Petri net is shown while a transition fires then the token can move from the former places to next step places, therefore it can be used to simulate a dynamic structure of system (as in Fig.2).

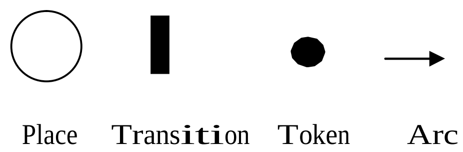

Fig.1 Basic Petri Net Composition

As in Fig.1, Place is used for expressing each kind of state in the system, and transition as straight lines or bars, and Arcs are used to connect place node and transforms node. Arc can divide into input nodes and output nodes. Input node shows that the Arc direction is to enter place, and the output node shows that the Arc direction is to leave place.

In Petri net, between place and transition have input and output arc to connect place and transition and express event flow direction. In the circle of each place, it uses token to express the existence and quantity of event, nearby the arc with number to represent the weight of arc (as shown in Fig.2). When a group tokens move and a series transitions fire, they are express a system occur a series events.

2.2 Time Petri Net

In the automated production process, time is a very important parameter. Ordinary Petri net picture have not definition of included time, but for needing time to express, dynamic system time describes and assessment of systematic efficiency, so need the concept of time.

In order to express the relation between dynamic state and time in a Production system, the Petri net must be expanded so that it has the ability to demonstrate time. Every Place, Transition and Arc that time Petri net can be in the network, it may give the time which fire needs. It also contains "starts fire" event and "finishes fire" event. Therefore, timed Petri net chart is expressed with TPN = (P, T, I, O, D, F). D is used to define the operating time of every one Place, Transition and Arc, F is used to define the frequency of fire, and I represent the interval between “starts the fire time “and” finishes the fire time.

Time Petri net assumes that place has its length of time; this model may express in the Petri net system of tendency or synchronized motion. Using the Time Petri net graph event, it is used for setting up the Production schedule system of time cycle, graphing the event of time efficiency, and obtains the best execution efficiency of the whole production schedule.

Take Fig.3 as an example, the beginning state of time Petri net is stamped in P1 and P2 with their start time, and t1 may be fire need in the interval of [4, 8] and [5, 9]. Namely, it produces fire that t needs to match the intersection of time, and can change the marks of Petri net.

2.3 Efficiency analysis of Petri net

Utilizing Petri net to set up a workflow system is the basic finishing demand in the whole work, and the goal is to use each analysis method to understand the efficiency of the workflow system. Most importantly, it can perceive the existing problem in the workflow system. Therefore, this paper introduces the analysis method often used in Petri net.

2.3.1 Reachability tree

Utilize tree structure of Reachability tree model, and to drawing the transfer process of each one state of

Petri net picture. Every node in the tree structure shows the state at that time, and the Token quantity that every place has in the Petri net model. When transition by fire, Will account of the transformation of place and produce new place, namely produced new node in tree structure. As in Fig.4, its initial state has one token in and P_3 does not have a token. This state can be expressed as (1, 0, 1). After fire, T_1, P_1 and P_2 may reduce by one token, but P_2 increases by one token and this state can be expressed as (0, 1, 1). Similar, after fire through T_2, the system state transfers to (1, 0, 1) and the system returns to the original state for (1, 0, 1). It is shown in the Reachability tree (Fig.5). This method nearly may analysis all places of Petri net, but this method is too complicated for system, and the tree structure chart is too huge and difficult to analyze.

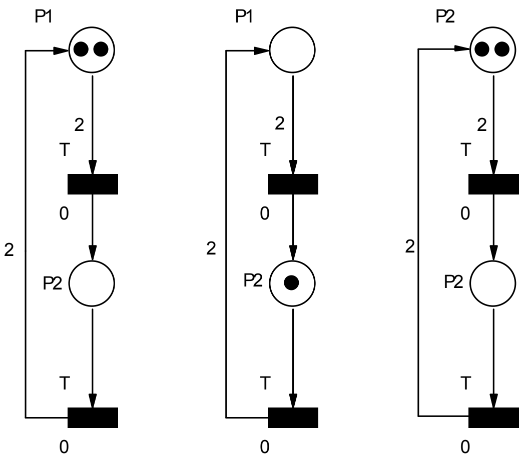

Fig.2 Petri Net fire state diagram

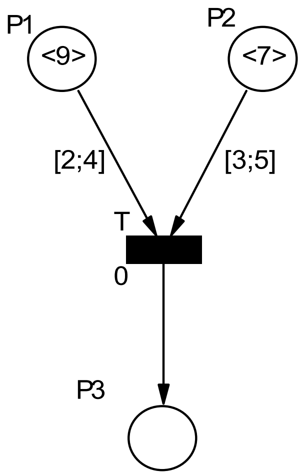

Fig.3 Timed Petri net

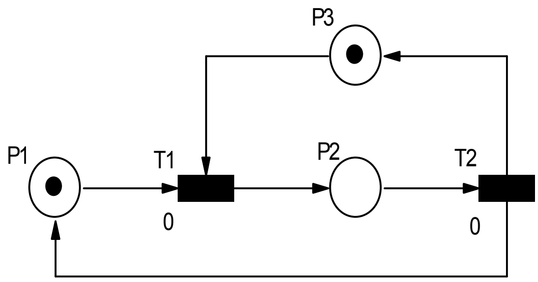

Fig.4 Simple Petri net picture

$$m_0 = (\ 1\ 0\ 1\ )^{T}$$

$$\downarrow$$

$$m_1 = (\ 0\ 1\ 0\ )^{T}$$

$$\downarrow$$

$$m_2 = (\ 1\ 0\ 1\ )^{T}$$

Fig.5 Reachability tree representation

2.3.2 Matrix equation

The matrix equation method is used to express Petri net in the form of a matrix, through the inherited incident matrix to express its properties and construct its Reachability tree to trace each event condition. However, the deadlock is only created when mutual exclusion, hold, wait, no preemption and circular wait all happen together. If one of the main elements can be prevented, the deadlock will not happen [14]. The matrix equation method can be utilized to express and forecast series system situations to avoid any accidents occur.

Define 1: Input matrix, output matrix

Petri net picture N = (P, T, D^-_{ij}, D^+_{ij}), D^-_{ij} is the input matrix, D^+_{ij} is the output matrix, D^-_{ij} = I (t_i, p_j), D^+_{ij} = 0 (t_i, p_j), $D_{ij} = D^-_{ij} + D^+_{ij}$ is the related matrix.

Define 2: Matrix fire condition

Petri net picture N = (P, T, D^-_{ij}, D^+_{ij}), When Transition $t_i \in T$, Also all $p_i \in P$ make $M(p_j) \geq e[j]$ □ D^- , j = 1,2,3,⋯,m . Then token M can be started, so T can fire, among them e[j] is the non- negative unit vector.

Define 3: New token produced after fire

t_i is produced new token M after fire:

$$M = M_0 + O - I$$
$$= M_0 + D$$
$$D = (O-I) \,□\, t_{ij}$$

Based on the Petri net in Fig. 6, the system matrix is shown in table 1. Among, them D^- expresses the input matrix of the system and D^+ expresses the output matrix of the system. (For example, t_1 inputs to both P_1 and P_4, therefore the t_1 input matrix is indicated by (1, 0, 0, 1). The t_1 output has P_2, therefore the t_1 input matrix is indicated by (0, 1, 0, 0). In t_2, the t_2 output has P_2. The t_2 output has P_3 and P_4, therefore the t_2 output matrix is indicated by (0, 0, 1, 1).

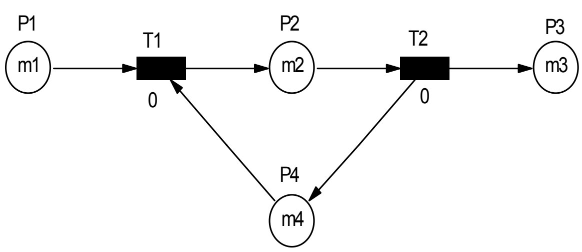

Fig.6 Petri net matrix

Table 1 System matrix Comparison

I	P_1	P_2	P_3	P_4	D^-
t_1	1	0	0	1	
t_2	0	1	0	0	
0	P_1	P_2	P_3	P_4	D^+
t_1	0	1	0	0	
t_2	0	0	1	1	

$$\text{Input matrix } D^- = \begin{bmatrix} 1 & 0 \\ 0 & 1 \\ 0 & 0 \\ 1 & 0 \end{bmatrix}$$

$$\text{Output matrix } D^+ = \begin{bmatrix} 0 & 0 \\ 1 & 0 \\ 0 & 1 \\ 0 & 1 \end{bmatrix}$$

Relationship Matrix $D=D^+-D^-$

$$D = \begin{bmatrix} -1 & 0 \\ 1 & -1 \\ 0 & 1 \\ -1 & 1 \end{bmatrix}$$

When t_1 fires,

$$M_{t1} = \begin{bmatrix} 1 \\ 0 \\ 0 \\ 1 \end{bmatrix} + \begin{bmatrix} -1 & 0 \\ 1 & -1 \\ 0 & 1 \\ -1 & 1 \end{bmatrix} \begin{bmatrix} 1 \\ 0 \end{bmatrix}$$
$$= \begin{bmatrix} 1 \\ 0 \\ 0 \\ 1 \end{bmatrix} + \begin{bmatrix} -1 \\ 1 \\ 0 \\ -1 \end{bmatrix} = \begin{bmatrix} 0 \\ 1 \\ 0 \\ 0 \end{bmatrix}$$

When t_2 fires,

$$M_{t2} = \begin{bmatrix} 0 \\ 1 \\ 0 \\ 0 \end{bmatrix} + \begin{bmatrix} -1 & 0 \\ 1 & -1 \\ 0 & 1 \\ -1 & 1 \end{bmatrix} \begin{bmatrix} 1 \\ 0 \end{bmatrix}$$

$$= \begin{bmatrix} 0 \\ 1 \\ 0 \\ 0 \end{bmatrix} + \begin{bmatrix} 0 \\ -1 \\ 1 \\ -1 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 1 \\ 1 \end{bmatrix}$$

3 Precision casting process

Casting is a process of melting the metal material at high temperature and then mould, it to an appropriate shape. In "the precision casting method", a smooth surface with precise size can be obtained. Precision casting is also called investment casting and dewaxing method. The main characteristics are described in the following.

(a) Make models by proper consumption material.

(b) Spread the refractory material.

(c) Melt the metal, pour it in the mold, and then cool it slowly.

(d) Break the molding shell, remove the casting from sprue, and then take the casting out.

Mold manufacture

First produce the sample model of the same size as model. The size of master mold must be added swelling and shrinking tolerance of the materials in manufacturing processes. Then use electroforming technology will be used to make wax-shooting moulds of the aluminum material using a wax injecting machine.

Wax- Shooting

Utilize the wax injecting machine to inject the melted wax in the mould, and take the wax mould out of the mould after cooling. One must pay attention to relevant wax-shooting condition parameters such as metal mold temperature, wax temperature, pressure, leaves of the mold time, and the wax pattern temperature.

Repair model

Any defect of the wax model will be found directly, only with perfect wax model and the perfect casting part can be produced. Defective wax mould will certainly produce bad casting, and it is required to inspect for Air Bubble, Non-Fills, Warped Pattern, Sink, Flush, Mark, and Rough Surface.

Composing tree

Weld the wax mould on a runner mold and assemble it into a wax tree. If the interval of the wax model is too small, the models will not be able to heat evenly causing the casting to have the flaw. It is important to leave the wax model in the Composing tree unharmed. Fig. 7 depicts the completion status of composing tree.

Fig.7 Completion status of composing tree

Dipping and Stuccoing

As in Fig.8, first wax tree is dipped in ceramic slurry, later stuccoing is use refractory grain sifted onto coated wax tree, and the general shell mold materials mainly include binder, fire-proof material, and a mixture of the slurry. First colloidal silica is used while mixing the barrel followed by adding 90% of the fire-resistant powder. The slurry stickiness, temperature, and adhere to the condition need to be controlled. Dipping and stuccoing are repeated several times to obtain desired shell mold, and reach the suitable hardness.

Fig.8 Coating forms the shell mould

Dewax

Dewax method use heating to melt the shell mold wax such as the autoclave dewaxing method. Other methods utilize solvents to melt out of wax, high temperature burning, microwave dewax and liquid heating etc.

Casting

Utilizing furnace to melt out of metal liquid, later pour it into in the mould. Then wait to cool, break the shell mould and take out the casting, as shown in Fig. 9. The smelting process must avoid metal oxidation and the pollution.

Fig. 9 Break the shell mould

After the casting is completed, the casting must use a Cast Shocking Remover to remove the shell mould, and then utilize a Cast Cutting Machine to cut off and remove sprue and gate. Then use a blast machine to remove the residual refractory material.

4 Construction and Analysis of the Precision Casting Process

The golf head is mainly cast from titanium alloy material, and needs to adopt the v-casting. The Vacuum Furnace equipment is expensive, so effective utilization could reduce the cost.

4.1 Set up picture

Design a Petri Net picture of each work station cast as in Fig. 10. The main composition machine equipment has a sintering furnace, preheating oven, vacuum furnace, cast shocking remover, abrasive cutter, and sand blast the examination. The main processing flow is as follows : Sintering → Pre-Heating → Ingredient → Vacuum casting → Break the shell mould→ removing the Runner →Sifted onto refractory grain, and inspections. Form table two and form table three define the place and transition.

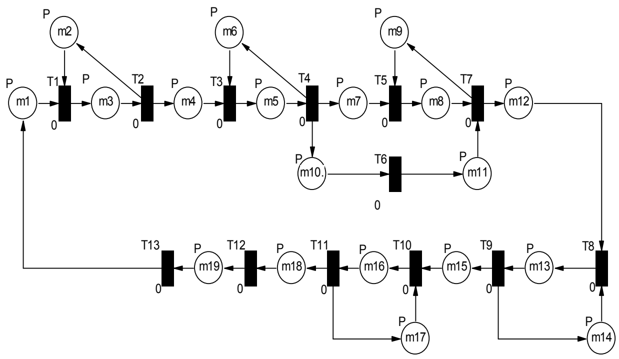

Fig.10 Petri Net picture of each work station

4.2 Carry out efficiency

Figure 11 shows the casting of each workstation system that belongs to the Petri Net group chart. The Reachability Graph of this system is shown in Fig. 12. Utilize Petri Net to design the process, and sketch its Reachability tree and mathematics matrix to compute and analyze casting system properties. Furthermore, we can use Markov Chain theory to analyze system's performance. It is defined as in Fig. 11.

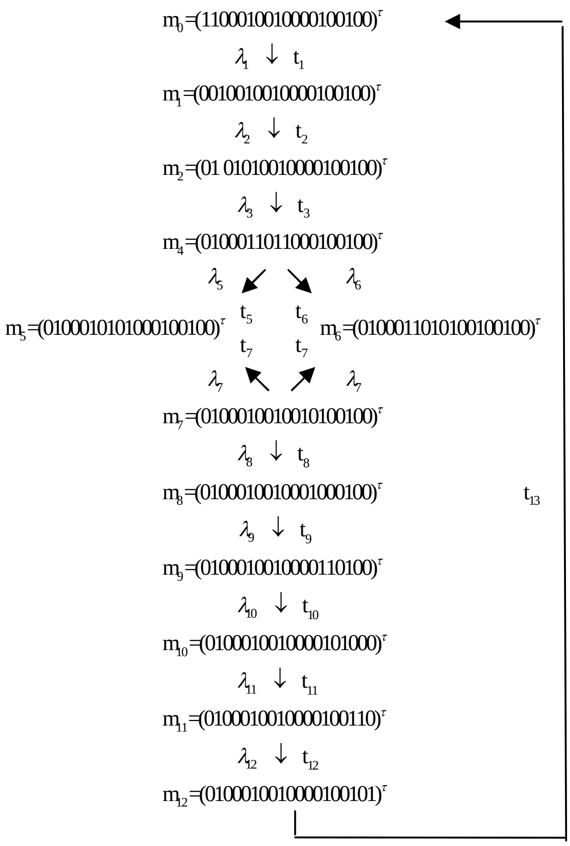

Fig.11 Reachability Group Chart

$$
\begin{matrix} \pi_0 & \pi_1 & \pi_2 & \pi_3 & \pi_4 & \pi_5 & \pi_6 & \pi_7 & \pi_8 & \pi_9 & \pi_{10} & \pi_{11} & \pi_{12} \end{matrix} \; x
$$

$$
\begin{pmatrix}
-\lambda_1 & -\lambda_1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & -\lambda_2 & -\lambda_2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & -\lambda_3 & -\lambda_3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & -\lambda_4 & -\lambda_4 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & -(\lambda_5+\lambda_6) & -\lambda_5 & -\lambda_6 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & -\lambda_7 & 0 & -\lambda_7 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & -\lambda_7 & -\lambda_7 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & -\lambda_8 & -\lambda_8 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -\lambda_9 & -\lambda_9 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -\lambda_{10} & -\lambda_{10} & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -\lambda_{11} & -\lambda_{11} & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -\lambda_{12} & -\lambda_{12} \\
\lambda_{13} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -\lambda_{13}
\end{pmatrix} = 0
$$

Fig.12 Reachability Graph

$$-\lambda_1\pi_0 + \lambda_{13}\pi_{12} = 0 \qquad \lambda_1\pi_0 + \lambda_2\pi_1 = 0$$
$$\lambda_2\pi_1 + \lambda_3\pi_2 = 0 \qquad \lambda_3\pi_2 + \lambda_4\pi_3 = 0$$
$$\lambda_5\pi_4 + \lambda_7\pi_5 = 0 \qquad \lambda_6\pi_4 + \lambda_7\pi_6 = 0$$
$$\lambda_8\pi_7 + \lambda_9\pi_8 = 0 \qquad \lambda_9\pi_8 + \lambda_{10}\pi_9 = 0$$
$$\lambda_{10}\pi_9 + \lambda_{11}\pi_{10} = 0 \qquad \lambda_{11}\pi_{10} + \lambda_{12}\pi_{11} = 0$$
$$\lambda_{12}\pi_{11} + \lambda_{13}\pi_{12} = 0$$
$$\lambda_4\pi_3 - (\lambda_5 + \lambda_6) = 0$$
$$\lambda_7\pi_5 + \lambda_7\pi_6 - \lambda_8\pi_7 = 0$$
$$\Sigma\pi_i = 1$$

When

λ_2=820 λ_2=820
λ_4=810 λ_4=810
λ_6=805 λ_6=805
λ_8=800 λ_8=800
λ_{10}=800 λ_{10}=800
λ_{12}=790

Obtains by the above equation

π_0=0.0853 π_1=0.0853
π_2=0.08635 π_3=0.08635
π_4=0.0434 π_5=0.04425
π_6=0.04425 π_7=0.0885
π_8=0.0885 π_9=0.0885
π_{10}=0.08906 π_{11}=0.089629
π_{12}=0.089629

As shown above, an analytical method of Petri Net gets the efficiency of every work station, can be used for reference of working efficiency evaluation and improve in future.

Table 2 Place of Petri net defined for casting the work station

m1	The shell mold arrives	m11	The material arrives
m2	Sintering Furnace	m12	casting finishing
m3	Prepares Sintering	m13	Removing the Runner
m4	Sintering Finishing	m14	Cast Cutting Machine
m5	Prepares Preheating	m15	Finish Cutting
m6	Preheating Oven	m16	Prepares sand Blast
m7	Preheating Finishing	m17	Blasting Machine
m8	Preparation Casting	m18	Sand Blast Finishing
m9	Casting Furnace	m19	Inspection Finishing
m10	Prepare Materials		

Table 3 Transition of Petri net defined for casting the work station

T1	The shell model puts in Sintering Furnace	T8	Tree bunch puts in Cast Cutting Machine
T2	Shell mould sintering time	T9	Removing the Runner time
T3	The shell model puts in Preheating Oven	T10	Casting puts in Blasting machine into
T4	Time of preheating of shell mould	T11	The casting puts in Blasting machine
T5	The shell model puts Vacuum Furnace	T12	Check-Out Time
T6	The material putting in place	T13	The packing produces goods
T7	Cast time		

5 Conclusion

Golf heads are the diverse massive production industry with multi-level manufacturing procedures. While the all production processes are fixed invariable by one kind of production pattern that may make the system regulation conceal some problems and induce processes not smoothly, then causes the working inefficiency. Petri Net can be used for finding the unsmooth fault and avoids it before it really happens. It not only is a kind of graphical construct tool that is easy to use and understand, but also has powerful system analysis capability. Petri Net can be built by Reachability tree chart to analyze and estimate their system working efficiency.

Furthermore, by building the diverse golf production flow chart, Petri net's firing simulation function can be used to find out which part in which shop has problem, and then solve it. Meanwhile, it can estimate the production efficiency from every department to find and improve their defects cyclically. By Petri net model, integrated production activity planning and control, and oriented cellular optimal manufacturing are possible. The Petri net model, being still in development, can assist engineers in solving problems of long-term production plan and control the flow of products at any shop flow. The simulation function of token flow can contribute to improve the entire productivity of the manufacturing system.

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