Inter-enterprise Multi-processes Quality Dynamic Control Method Based on Processing Network

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Abstract. During the course of inter-enterprise processing network quality control, for judging and analyzing the others process quality influence of the abnormal process quality, especially key process quality influence, and servicing whole the multi-processes quality control course, the inter-enterprise multi-processes quality control method based on processing network by means of inter-enterprise quality control model based on fractal network is proposed. In the method, multi-processes processing network is constructed by process mapping, the key process can be figured out based on the analysis of processing network sensitivity. To the key process, depending on multi-processes cost function based on cost influence coefficient among processes, the method can establish the comprehensive optimizing object function including cost and error propagation. Depending on the optimum solution of the object function solved by genetic algorithm, the key process can correct to regulate and distribute the control parameters to decrease accumulative error, to avoid false alarm and misstatements originated from the abnormal process. This application course of method could be applied with a multi-processes manufacturing example.

Keywords: Multi-Processes, Quality Control, Inter-Enterprise, Processing Network.

1 Introduction

To the complexity of product structure, the transformation of multi-processes quality control course from sample procedure to complex structure, and the degree of process relation among enterprises is more and more close, so that error propagation scope among processes extend from interior enterprise to exterior enterprise. The error propagation among processes should be created and will accumulated, especially some processes may be creating false alarm and misstatements owing to an abnormal process. Consequently, some measures should be adopted to assure the key process and others quality, decrease the error propagation among processes, and rationally distribute tolerance among processes be means of some rules to gain whole optimization in the quality and cost aspects.

In order to complete the quality dynamic control multi-processes, a lot of studiers had researched on the field at home and abroad. For example, Yang M. [1], Kano M. [2], Bayazita O.[3], and Lopez-ortega O.[4] researched inter-enterprise quality

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management system to gain product quality control. Liu D. [5], Sun H. [6] can adjust control parameters to dynamically control among processes. Dey S. [7], Wang H. [8], Choongyeun C. [9], and Loose J. [10] researched state space method to describe and solve error propagation. For dynamically adapting to the influence of the abnormal process, assuring the key process quality, and servicing for the whole multi-processes quality control course, depending on inter-enterprise quality control model based on fractal networks[11], the inter-enterprise multi-processes dynamically quality control method based on processing network is proposed. The method can build a multi-processes dynamically quality control processing network by means of process mapping. Based on the analysis of processing network performance to figure out the key process, and research the key process error influences propagated by the abnormal process. Depending on cost influence originated from among processes, the comprehensive optimizing object function including cost and error propagation can be established. Owing to the solution the object function, the key process can correct to regulate and distribute the control parameters to decrease accumulative error, to avoid false alarm and misstatements.

2 Multi-processes Dynamic Quality Control's Processing Network

2.1 The Construct of Multi-processes Processing Network

According to the fractal characteristic of inter-enterprise quality control function, based on fractal and complex networks theory, inter-enterprise quality control task execution units can be constructed as network nodes by the encapsulation of object-oriented technology. The constraint relationships among nodes are established based on hierarchical structure among enterprises and the relationship of product configuration. Based on network nodes and constraint relationships, combined with some quality control methods and supporting technologies, inter-enterprise quality control fractal networks model is established[11].

NR is constraint relation among nodes in the model.

$$NR = \left\{ \begin{matrix} MR \\ CR \end{matrix} \right\} \Bigg|_{k=0,1} = \left\{ \begin{matrix} 0 \\ 0,\ 1,\ 2 \end{matrix} \right\}_{k=0} = \left\{ \begin{matrix} 1,-1 \\ 0,\ 1,\ 2 \end{matrix} \right\}_{k=1} \tag{1}$$

where:

① MR is the management constraint of upper layer nodes to lower layer ones. $MR = 1$ represents there is management constraint between upper layer nodes and lower layer nodes. $MR = 0$ represents there isn't management constraint between upper layer nodes and lower layer nodes. $MR = -1$ represents lower layer nodes be used as backup selection or reference to upper layer nodes.

② CR is coordination constraint relation among nodes at the same layer. $CR = 0$ represents there is rejection coordination constraint relation, $CR = 1$ represents there is competition coordination constraint relation, $CR = 2$ represents there is necessity coordination constraint relation.

③ $k=0$ represents quality control function need no reconfiguration, $k=1$ represents quality control function need reconfiguration.

To the complex and dynamic multi-processes association relation, taking the product machining processes in the manufacturing cell nodes of the model as object, the network process nodes having autonomy and cooperation ability can be built by means of mapping. The constraint relation among manufacturing cell nodes is mapped as the association relations among processes. If S_t is association relations matrix among processes, there is $NR \to S_t$.

$$NR \to S_t = \begin{Bmatrix} 0, 1, -1 \\ 0, 1, 2 \end{Bmatrix}_{k=0,1} \to \begin{bmatrix} 1 & 0 & \dots & \lambda_1 & \lambda_1 \\ 0 & 1 & \dots & \lambda_1 & 0 \\ \dots & \dots & \dots & \dots & \\ \lambda_1 & \lambda_1 & \dots & 1 & 0 \\ \lambda_1 & 0 & \dots & 0 & 1 \end{bmatrix}_{N \times N} \tag{2}$$

where, λ_1 $(0 \le \lambda_1 \le 1)$ can express the connection relation dense degree(strong and weak) among processes nodes. The value of λ_1 can be determined by means of machining task, manufacturing resources, machining demand, cost factors, and so on. The range of λ_1 includes:

$$\lambda_1 = \begin{cases} 1, i = j,, \text{The self-connection relation among processes nodes(The maxmum degree).} \\ \lambda_1, \text{There is the direct connection relation among processes nodes} \\ \lambda_2, \text{There is the indirect connection relation among processes nodes.} \\ \lambda_3, \text{There is the bypassingconnection relation among processes nodes.} \\ 0, i \ne j, \text{There is't the connection relation among processes nodes(The minmum degree)} \end{cases} \tag{3}$$

Depending on the process nodes mapped by machining processes in the manufacturing cell nodes, and association relations among process nodes mapped by constraint relation among manufacturing cell nodes, The structure of inter-enterprise multi-processes processing network including machining process, process nodes, and equipment is established, and it can be described as Fig. 1.

In the structure, by the one-to-many mapping, the nodes of processing network could be mapped as manufacturing resources. That is the nodes of processing network can further correspond to equipment nodes in inter-enterprise quality control fractal networks model.

2.2 The Key Process Determination Based on the Sensitivity of Multi-processes Processing Network

The key process plays a key role in course of multi-processes quality control, so that it needs to be figured out and accurately control. In multi-processes quality dynamic control network, the sensitivity of multi-processes processing network can represent the key process and key machining path. The sensitivity of node represents the node's the influence degree to whole network operation. In multi-processes processing network, the sensitivity of process node can represent the process's the node is the key process to whole processing. Based on [12-13], the sensitivity of process node in multi-processes processing network S_k can be defined as followings:

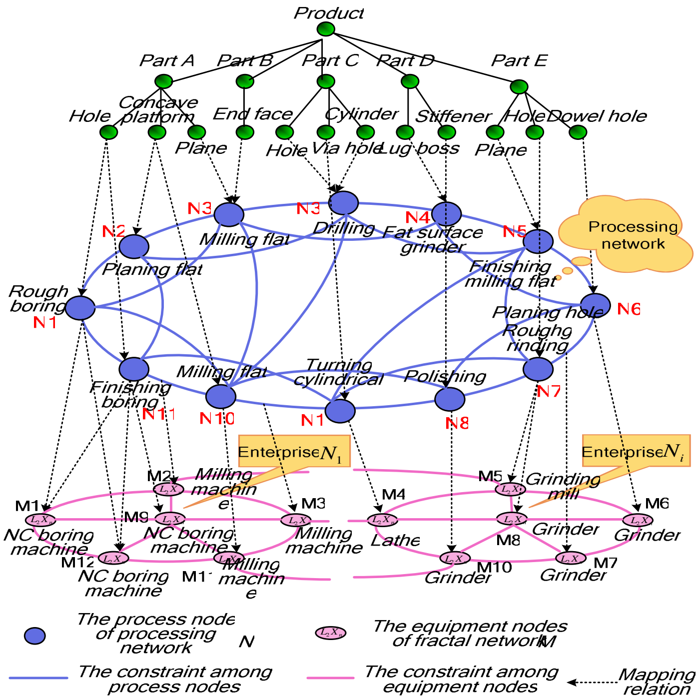

Fig. 1. The construct of inter-enterprise multi-processes processing network

$$S_k = \sup \frac{\left\| w\sigma^2_{out} \right\|_2}{\left\| \sigma^2_{in} \right\|} = \left\| w \cdot \left[\gamma^2(k) \right] \right\|_2 \tag{4}$$

where: w expresses the important degree of key quality's feature error, and it is weight coefficient. σ^2_{out} expresses the node key quality feature output. σ^2_{in} expresses the node key quality feature input. $\gamma^2(k)$ expresses relation matrix among nodes S_k can be defined as followings:

By the sensitivity of network path and process node, the key process and key machining path can be determined for multi-processes quality dynamic control.

2.3 The Cost Influence Coefficient among Processes

The key process figured out by the sensitivity of multi-processes processing network should decrease accumulative error, avoid false alarm and misstatements, optimize operation in quality and cost aspects, and has dynamic adaptation ability by means of the cost influence among processes[14-15]. Based on the quantitative analysis of among process nodes in multi-processes processing network, the cost influence coefficient among processes can be established for cost optimizing combined with cost function. There are some quantitative indexes to multi-processes measure cost influence, and they are as followings:

(1). Time influence coefficient among process nodes t_n

Time influence coefficient among process nodes t_n can be expressed in status waiting time among nodes, namely a interval time between a process node implement task time M_j and next node implement task time M_j. Time influence coefficient among process nodes t_n can be described as:

$$t_n = (M_j - M_i) \tag{5}$$

Because a node may be has many predecessor tasks, namely there are many processes, t_n can count the status waiting time to the node in every condition.

(2). The throughput influence coefficient among process nodes u_n

The throughput among process nodes can be expressed degree in processing network. To node u_i and node u_j, $\forall(u_i, u_j) \in u$, in stable status, the throughput influence coefficient among process nodes u_n:

$$u_n = u_i / u_j = P[M(S_i)] / P[M(S_j)] \tag{6}$$

where: $P[M(S_i)]$, $P[M(S_j)]$ expresses the probabilityof node u_i throughput $M(S_i)$ and the probability of node u_j throughput $M(S_j)$ respectively. u_n describes the influence degree of process task implement probability.

(3). Resource utilization influence coefficient among process nodes r_n

Resource utilization influence coefficient among process nodes r_n is probability ratio quality task implement among process nodes by resource utilization, and it expresses manufacturing resource supply and utilization influence degree in multi-processes. In any time, $\forall t \in T$, resource utilization influence coefficient among process nodes r_n is represented as followings:

$$r_n = P[H(S_i)] / P[H(S_j)] \tag{7}$$

where: $P[H(S_i)]$, $P[H(S_j)]$ expresses the probabilityof node u_i resource utilization $H(S_i)$ and the probability of node u_j resource utilization $H(S_j)$ respectively.

For describing to the cost influence coefficient among processes, combining with resource utilization influence coefficient r_n, throughput influence coefficient u_n, and time influence coefficient t_n, multi-processes cost influence coefficient c_n can be expressed as followings:

$$c_n = w_1 r_n + w_2 u_n + w_3 t_n \tag{8}$$

where: w_1, w_2, w_3 express weight value among influence coefficient, and their value can be determined by machining process, machining feature, material, manufacturing resource, and so on. There is $w_1 + w_2 + w_3 = 1$. Multi-processes cost influence coefficient c_n can be took as a part of cost object, and the error propagation equation of multi-processes based on state space method can be took as quality object, depending on the self-organization evolution law of multi-processes processing network, multi-processes can rationally distribute control parameter , such as tolerance, process redundancy, can decrease accumulative error, and avoid false alarm and misstatements created by abnormal process.

3 The Multi-processes Quality Dynamic Control's Implementation

In the multi-processes quality dynamic control cost function $TC = f(x_1, x_2, ... x_n)$, TC is whole product cost when manufacturing factors $(x_1, x_2, ... x_n)$ are inputted. $x_i (i = 1, 2, ... n)$ is i th manufacturing factor's input quantity[16-17]. When x_i 's cost coefficient is p_i, combining with multi-processes cost influence coefficient c_n, multi-processes quality dynamic control cost function is as followings:

$$TC = c_1 p_1 x_1 + c_2 p_2 x_2 + ... c_n p_n x_n = \sum_{i=1}^{n} c_i p_i x_i \tag{9}$$

For decreasing multi-processes manufacturing cost, combining with the minimum of error propagation.among processes, and completing cooperation and optimizing quality control, the comprehensive optimization object function is established as followings:

$$obj(f) = \min(y) + \min(TC) = \min(Cx_0 + v) + \min(\sum_{i=1}^{n} c_i p_i x_i) \tag{10}$$

$$\text{Constraint condition:} \quad TC = f(x_1, x_2, ... x_n) \tag{11}$$

$$\sum \delta_{id} \le \Delta X \tag{12}$$

$$\delta_{ij\min} \le \delta_{ij} \le \delta_{ij\max} \tag{13}$$

$$\delta_{ij} + \delta_{i,j-1} \le Z_{0j} - Z_{0j\min} \tag{14}$$

$$\delta_{id} = \delta_{im_i} \tag{15}$$

where: Formula(11) describes manufacturing cost constraint. Formula (12) describes tolerance constraint in the assembly process. i th part tolerance δ_{id} should less than assembly tolerance ΔX . Formula (13) describes the processing ability constraint among processes. ith part's j th process real tolerance should less than maximum allowable tolerance $\delta_{ij\max}$, and should more than minimum allowable tolerance $\delta_{ij\min}$. Formula (14) describes process redundancy constraint. δ_{ij}, $\delta_{i,j-1}$ are ith part's j th and $j-1$ th process tolerance. Z_{0j} is j th process nominal process redundancy. $Z_{0j_{\min}}$ is j th process minimum allowable process redundancy. Formula (15) describes the last process tolerance δ_{in} should meet the demand of drawing regulations design tolerance δ_d .

Genetic algorithm has giant advantage to solving combined optimization problems in a large searching space[18-19]. Therefore, the multi-objective optimization genetic algorithm is adopted to realize comprehensive optimization object function among processes, depending on some constraint conditions. According to the result by means of genetic algorithm, key process' some control parameters can be obtained. The key process can correct to regulate and distribute the control parameters to decrease accumulative error, to avoid false alarm and misstatements from the abnormal process in controlled status for optimizing and dynamically control. The implementation of multi-processes quality control can be expressed in Fig. 2.

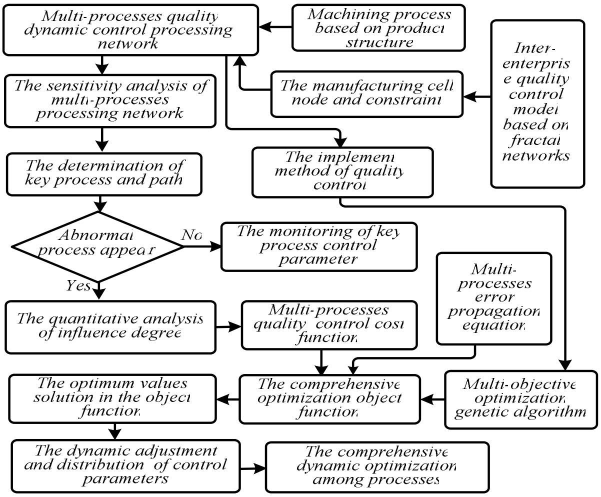

Fig. 2. The implementation procedure of multi-processes quality dynamic control

4 Example

The air-cylinder jacket is a critical part of engine, and it can be manufactured by more method and new material as high technology development. However, the processing course change more complex and involve more enterprise. The processing course can be expressed a network structure relation more than a flow structure relation. When the abnormal process is appeared in complex air-cylinder jackets machining correlation processes, other processes, especially key process, should decrease accumulative error, to avoid false alarm and misstatements, and carry out the quality and cost comprehensive optimization in controlled status. Taking Japan Daihatsu DL air-cylinder jackets processing quality dynamic control as example, the implementation of multi-processes quality dynamic control could be applied. Based on Japan Daihatsu DL air-cylinder jackets structure characteristics and commonprocessrule[20], assuming that rough boring inner hole is a abnormal process owing to some reasons such as machine wear or disoperation, depending on the process production technology of Tianxiang Electromechanical Industry General Corporation(Hengyang , China), the Japan daihatsu DL engine air-cylinder jackets's machining process and path can be established. The machining processes are described in Table 1.

Table 1. Japan Daihatsu DL engine air-cylinder jackets's machining processes[20]

NO.	*Process name*	*Type*	*Equipment*	*Fixture*	*Tool*
P1	centrifugal casting		centrifugal casting machine		
P2	cutting	QD-01	self-made trimming machine	three flap sleeve fixture	special cutter
P3	rough boring cylindrical	Ck620	self-made NC lathe	three flap sleeve fixture	cylindrical turning tool
P4	rough boring inner hole	TK716	vertical NC boring machine	jackets vertical fixture	rough boring tool
P5	rough turning cylindrical	Ck620	NC lathe	plasticssleeve fixture	cylindrical turning tool
P6	rouht turning reference	Ck618	self-made NC lathe	three flap sleeve fixture	cylindrical turning tool
P7	half refined reamers inner hole	TK716	vertical NC boring machine	jackets vertical fixture	half rough boring tool
P8	finish turning reference	CK762	multi-tools NC lathe	plasticssleeve fixture	gear turning tool
P9	refined reamers inner hole	T716	vertical NC boring machine	jackets vertical fixture	gold boring tool
P10	turning reference	Ck618	self-made NC lathe	three flap sleeve fixture	arcturning tool
P11	finish turning cylindrical	Ck620	NC lathe	plasticssleeve fixture	cylindrical turning tool
P12	finish boring inner hole	TK716	vertical NC boring machine	jackets vertical fixture	gold boring tool
P13	rough grinding inner hole	M4215	vertical grinding machine	three flap sleeve fixture	diamond whet-slate
P14	turning water sealing groove	CK620	NC lathe	three flap sleeve fixture	groove turning tool
P15	turning support shoulder	CK620	NC lathe	three flap sleeve fixture	end-face tool
P16	finish grinding inner hole	M4215	vertical grinding machine	four vertical post fixture	finish grinding whet-slate
P17	milling cylindrical	M131	cylindrical grinder	three flap sleeve fixture	whet-slate
P18	polishing inner hole	M4215	vertical grinding machine	four vertical post fixture	polishing grinding wheel

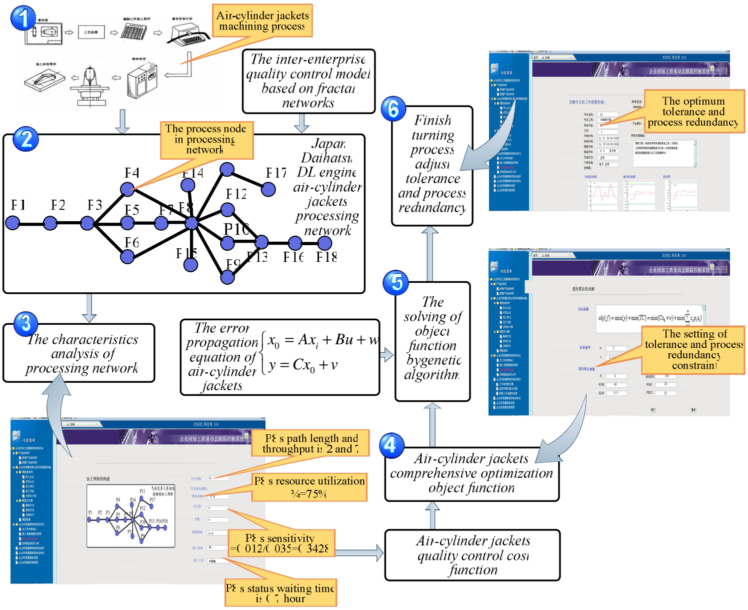

Fig. 3. The Daihatsu DL engine air-cylinder jackets quality dynamic control's implementation

The implementation procedure of Japan Daihatsu DL engine air-cylinder jackets quality dynamic control can be described in Fig. 3.

The implementation procedure includes: (1)Owing to the structural characteristics of the engine, machining path can be constructed assuming machining processes in Table 1. (2)Depending on air-cylinder jackets's machining processes and path, the air-cylinder jackets processing network can be established by mapping. (3). The finish turning reference process can be determined by the maximum sensitivity processing network. The air-cylinder jackets quality control cost function can be counted when cost influence coefficient among processes is combined. (4)The error propagation equation of air-cylinder jackets processing network can be built by means of state space method. The comprehensive optimization object function is established by error propagation equation and quality dynamic control cost function. (5)The object function can be counted by multi- objective optimization genetic algorithm. (6)The finish turning reference process can regulate tolerance and process redundancy depended on optimum tolerance and process redundancy.

5 Conclusion

The inter-enterprise multi-processes dynamically quality control method based on processing network can figure out the key process by means of the sensitivity of multi-processes processing network, can express the cost influence coefficient among processes. Depending on multi-processes quality dynamic control cost function by cost influence coefficient, and the error propagation of multi-processes by state space method, the comprehensive optimization object function is established. Owing to genetic algorithm, the optimum values in the object function can be obtained. Consequently, based on the optimum values, the key process can correct to regulate and distribute the control parameters to decrease accumulative error, to avoid false alarm and misstatements originated from the abnormal process, to implement the quality and cost comprehensive optimization, and to assure quality operation in controlled status for optimizing and dynamically control.

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