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Tolerance Design and Adjustment of Complex Customized Product Based on Cloud Manufacturing

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Abstract

A local and temporal separated manufacturing becomes possible, which can enhance the economic efficiency of the production. Complex products such as spacecraft, large CNC Machine, large compressor face challenges in their development process. The cloud manufacturing which is based on the development of cloud computing and Internet of Things system makes the collaborative manufacturing process of complex customized product become rapid intelligent efficient and of low-energy consumption. Cloud Manufacturing is a new manufacturing pattern which organizes the manufacturing resource to provide customers with all kinds of manufacturing services as needed. Customers who have taken part in this kind of manufacturing process could integrate the resource anytime anywhere according to the product requirement. Different from the traditional manufacturing pattern, Cloud manufacturing is multi-selective dynamic and the process may be across the stage. With more resources in the manufacturing process involved, cost of the manufacturing may be increased, so the cloud manufacturing is more suitable for small batch manufacture process of large and complex manufacturing process of customized products.
In this article, we put forward a dynamic tolerance design and management framework of complex customized product based on cloud manufacturing. When the product comes into the manufacturing process, the dimension might be overflown of the acceptable zone which had been designed in the engineering phase, therefore we introduce a dynamic control that at every stage of the manufacturing we re-organize the resource based on the real-time information of the manufacturing cloud (in other word, ability of the manufacturing service) and the performance of former service. To ensure the function of the product expressed integrality and assembly process carried out smoothly, we could obtain the target optimal solution of dynamic allocation process of the tolerance on the follow-up process according to the minimum goal of the cost time and quality loss in dynamic adjustment and process stability.

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Key words: cloud manufacturing, quality loss, manufacturing cost, dynamic tolerance adjustment

1. Introduction

In the 21st century, the development of manufacturing industry had been promoted by high-technology. The concept of Cloud Manufacturing had been known by the academics in the recently years with the rising of cloud computing. The proposing of cloud manufacturing service mode [1-2] introduced the information technology into the traditional manufacturing area. Therefore, in the internet resource environment, the resource is integrated efficiently to solve the problem of new product development in manufacturing industry, to achieve the goal of appreciation and synergies. A new solution to develop

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innovation and competitiveness of manufacturing enterprise has been put forward.[3] Many studies at home and abroad have focused on the integration of cloud manufacturing and traditional manufacturing.

In the integration of cloud-computing [4] IOT [5] service-oriented-computingintelligence-science and e-manufacturing, a project of task allocation according to the workflow`s demand was proposed in the literature[6]by analysis on the characteristic and requirement of cloud manufacturing service mode, discussing the framing

and engine of workflow; literature [7] analyzed the cloud-servitization target of manufacturing resource and process requirements based on NC-processing, designed the cloud service platform which could provide the information of NC-processing products to the users with the integrated service of basic data application tools and service management; literature [8] applied the ontology to the manufacturing service systems based on the product manufacturing life cycle, describing the service and subjects which provide the service as well as the semantic attribute and data attribute of service based on the great expressing ability of ontology; literature [9] provided a optimization target system of eight target variables including time of service, quality of service, cost of service, availability, composability, reliability, maintainability and sustainability to build an optimal-target model according to the characteristic of uncertainty, coarseness, variety and dynamics in the combinations of cloud manufacturing resource based on the development of new products; literature [10] built a service-oriented cloud platform to solve the problems that the existing cloud platform provides the solution instead of supporting the combination of service; literature [11] proposed a market mechanism of configuration services based on cloud computing, but this kind of mechanism could only satisfy the demand of flow-processing users.

As the dynamics of the cloud manufacturing, it is meaningful when the manufacturing process is under the dynamic control. The dynamic control and allocation of tolerance has been discussed in the literature [12]. The actual points in feasible domain were picked to determine the dimension and tolerance of the rest processing; literature [13] proposed a concept of dynamic dimension design to solve the over proof problems in the products of small-batch according to changing the processing path or changing the dimensions for the problem that the processing dimensions were overflown of the acceptable zone; the system control was adopted to control the machining precision by allocation the tolerance after on-line monitoring of dimension in literature [14]; allocation plan and scope application were analyzed systematically in literature [15] and a new model of dynamic tolerance adjustment was proposed to solve the over-proof problems because of insufficient processing capacity.

A study on combination of cloud manufacturing and dynamic tolerance control was put forward in this paper to achieve the manufacturing principle of sensitivity,serviceability, intelligence and green manufacture by adjusting the tolerance of features which have relationship with the over-proof feature based on assembly dimension chain in the machining process of complex products.

2. Overview of Cloud Manufacturing and Complex Mechanical Product Process

Cloud manufacturing (CM) is a new service-oriented networked manufacturing mode, which combines cloud computing, IOT and other technology to virtualize the manufacturing resource. Cloud manufacturing organize the manufacturing resource according to the needs of users to supply all kinds of manufacturing services. The broad topic of cloud manufacturing runs through the product lifecycle, including the Aaas (argumentation as a service), Daas(design as a service),Faas(fabrication as a service), Eaas(experiment as a service), Simaas(simulation as a service), Maas(management as a service), Inaas(integration as a service). Users could dynamically add or delete resource whenever and wherever possible as required. Therefore the foundation of CM is manufacturing resource, the core of CM is service, the feature is dynamism and the aim is high efficiency and low consumption. CM service has the following characteristics: 1, dynamically building the resource on demand; 2, interoperability; 3, synergy; 4, heterogeneity; 5, quick responsiveness; 6, intelligent manufacturing in the whole life cycle.[16]

But the process above could not apply to all kinds of manufacturing process. When it came into the mass production, the process made no sense. Therefore the dynamics of CM works well in the manufacturing process of complex mechanical products. Complex product has the complexity in the customers` requirement, construction, technique, manufacturing process, management process, such as spacecraft, large CNC Machine, large compressor.[17] One product mentioned above consists of thousands of parts or components or subsystems, which involved in different areas. So the complex products have distinct feature in large scale, high cost, complex system, high technique, and they have long project cycle.

Comparing these two kinds of product it is more to be considered in the process of manufacturing or management and more difficult to control the process. One system has to cooperate with the others to avoid conflicts when analyze from the aspect of space, what`s more the coordinate between various resources is also required when it comes to time, the system defects that occurred during the system design stage can only be discovered after the products being manufactured and cause a large scale of scrap and rework, which is a waste of resource and time. All those problems discussed above cannot be solved by traditional manufacturing. "Private cloud" manufacturing platform for the group enterprise could solve the problems above, because of the CM`s manufacturing resource properties.

3. Problem Description

Since the complex product of which, the cost is high, the life cycle is long, the function is complicated, different from the commodity product many components of complex product are customized, the process has less demand for interchangeability. The dynamic adjustment of tolerance is meaningful in the manufacturing process of the complex product.

In the processing stage, CM judge whether the statue is out of control. Once the process was out of control, CM search the dimension chain to adjust the tolerance of the rest process according to real-time information on the CM platform.

3.1. Dynamic control of Tolerance

Complex mechanical products is a compound structure composed of many components assembled in accordance with certain relationships in order to achieve specific functions. There are complex nonlinear dynamic interactions which would be spread downstream by the part under manufacturing among the tolerances of the assembly. The dimensions and tolerances of all the parts depend on working allowance and precision of the machining process as well as the processing capability. On one condition that the over-tolerance of a part occurred, the rest processing of manufacturing and assembly would besignificant influenced, which would even cause scrap or rework. The aim of dynamic adjustment based on CM resource is to find the relevant feature or part in the dimension chain rapidly and allot the tolerance of the rest processing according to the information in the CM platform in the real-time and andthe rest can be done in the same manner until the optimal solution is obtained.

In the CM platform, the more procedures we adjust, the more time and cost it would take in the additionallogistics service. Therefore, no more than 2 procedures are adjusted in this condition. optimize the result of the cost manufacturing time and quality loss.

We assume these condition in the dynamic allocation of tolerance process: ①real-time information of machine tool is given; ②detection result of every procedure in the manufacturing of the key feature is given; ③process route is invariable. The key features of complex product in this paper has the following characteristics: high cost; high technique; significant influence in the final function.

In the CM platform, if procedure i of one key task is out of control, system adjust the tolerance of the rest relevant features for economic purpose. Algorithm are as follows: find the n relevant procedures in the composition loop by searching the dimension chain, adjust the procedure based on the purpose of less procedure adjustment.

We use N as the number of the processes to be adjusted here. At first we let N=1, we only change the tolerance of one process while keep the tolerance of the other n-1 processes of the total n processes that related to the over proof procedure stable, and one solution which is the optimal value that meet a certain objective function and their constrains will be obtained, then change the tolerance of another one process and do the same way as above to obtain a corresponding optimal value, by that analogy we will obtain not more n solutions in the end, compared the solutions obtained above we can get the global optimal solution and complete the dynamic regulation of tolerance under the condition of N=1.

4. Dynamic Tolerance Allocation Model Based on CM

Objective function of dynamic tolerance allocation based on CM is cost and time and quality loss of adjustment, variable is tolerance adjustment quantity of the rest procedures, which is constrained by the function tolerance in the closed link, processing capacity and economical manufacturing precision.

4.1. Objective Function

$$\{min\ (U^T C + C_0)\} \quad (1)$$

$$\{min\ (U^T t + t_0)\} \quad (2)$$

$$\{minQ_L\} \quad (3)$$

N——the number of adjustment procedure;

U——n-dimensional column vector, coefficient matrix of adjustment cost function;

C——n-dimensional column vector, matrix of adjustment cost function according to the adjustment scheme;

t——n-dimensional column vector, matrix of adjustment time function according to the adjustment scheme;

C_0——n-dimensional column vector, the function of cost introduced in the additionallogistics service;

t_0——n-dimensional column vector, the function of time introduced in the additionallogistics service;

Q_L——n-dimensional column vector, the quality loss of tolerance after the adjustment.

When N=1,

$$U = (\mu_{ij}\lambda_j)^T ;\ C = \left(C'(T_j, T_t)\right)^T ;\ t = \Delta t_j; \tag{4}$$

Which $C'(T_j, T_t) = \omega_j[C(T_j - T_t) - C(T_j)]$;

The expand Taguchi function of quality loss is $Q_L = \sum A(x-m)^2$ for the multi-feature of quality, which A presents coefficient of quality loss and m presents the target value of dimension x.

When $N = 1$,

$$Q_L = A_j(x_j - m_j)^2 + A_i(x_i - m_i)^2 \tag{5}$$

T_j——the tolerance of the procedure j in the static allocation;

T_t——the adjustment quantity of tolerance in the procedure j;

μ_{ij} —— correlation coefficient of dimension, $\mu_{ij} = 1$ on the condition that procedure j has relationship with the procedure i;

λ_j——coefficient of processing state;

In the real manufacturing context, demand of completion time and total cost and manufacturing quality has the different weight of index for these three aspects have the relationship of interaction as well as restriction. Therefore, the result couldn`t be optimal for every objectives function at the same time. The classical weighted summation is introduced to transform the optimal problem of multi-objectives into the single objective, that:

$$minZ = \omega_1 \frac{t(e)}{t_0} + \omega_2 \frac{C(e)}{C_0} + \omega_3 \frac{Q_L(e)}{Q_{L0}} \tag{6}$$

ω_1, ω_2 and ω_3 present the weighted coefficients of time, cost and quality, $\omega_1 + \omega_2 + \omega_3 = 1$; $t_0 C_0 Q_{L0}$presents the deliver time cost and quality loss before adjustment.

4.2Constraint Conditions

In the constraint conditions, more than tolerance or precision conditions are discussed, such as availabilitycomposabilityreliability etc. So the tolerance capacity and precision are taken as the optimizing conditions after the conditions of availabilitycomposabilityreliability are introduced in this model as the filter conditions.

(1) Condition of function tolerance

$$T_f \ll T_{f0} \tag{7}$$

T_f——the function tolerance in close link after adjustment;

T_{f0}——the function tolerance in close link in the static allocation;

(2) Condition of processing capacity

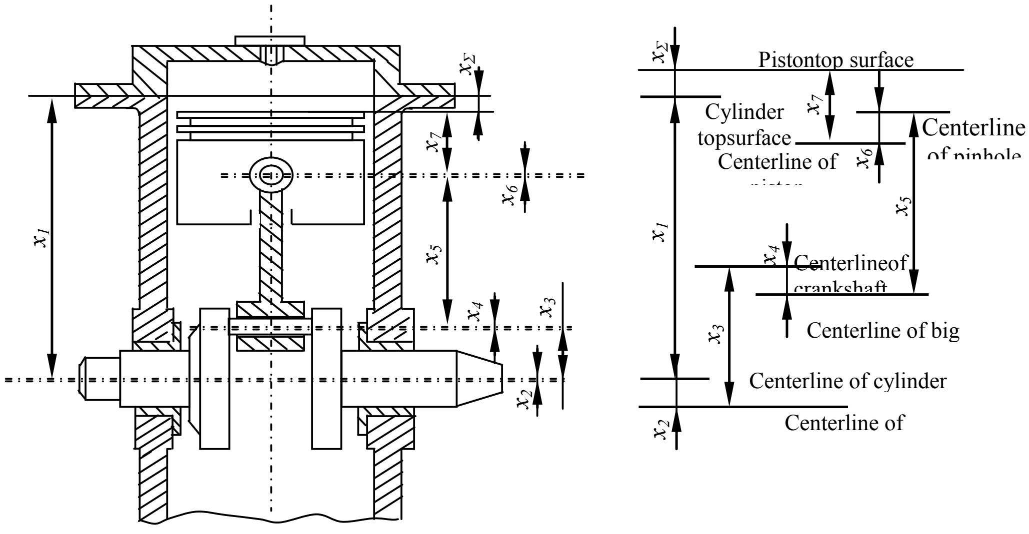
The information of processing capacity on the CM platform could be obtained by history data or experience of designers.

When N=1,the condition is shown in the Eq.(8).

$$Cps = (T_j - T_t)/6\sigma_j \gg 1 \tag{8}$$

(3) Condition of economical manufacturing precision

The condition of economical manufacturing precision must be satisfied when the tolerance of one procedure is taken into account, therefore it must be satisfied after adjustment. This condition is shown in the following formula:



(a)theassembly draft of (b) the dimensional

Fig.1.the assembly draft and dimensional chain

When N=1, the condition is shown in the Eq. (9)

$$T_{j-} \leq T_j - T_t \leq T_{j+} \quad (9)$$

T_{j-}presents the minimum deviation of procedure j while T_{j+} presents the maximum deviation.

5. Illustrative example

A simple assembly is used to illustrate the proposed method.Figure 1(a) shows the partial assembly draft oftype 390 engine's piston and cylinder.Theassembly parts and the choice of manufacturing cloud are listed in Table1 as well as the processing information in real time (supposing the X_3 is overproof and $X_{22}\,X_{62}\,X_7$ has completed the manufacturing process and been detected). The dimensional chainis shown in Fig. 1(b). Equation (10) is the objective function, subject to technical requirement by Eq. (11) and constraint of eccentricity by Eq. (12)–(14).

$$x_{\Sigma}^{(0.7)} = x_2^{(0)} + x_4^{(0)} + x_6^{(0)} + x_3^{(50)} + x_5^{(174)} + x_7^{(69)} + x_1^{(292.3)} \quad (10)$$

$$S.t. T_1^2 + T_2^2 + T_3^2 + T_4^2 + T_5^2 + T_6^2 + T_7^2 \ll 0.27^2 \quad (11)$$

$$T_{21}^2 + T_{22}^2 \leq 0.05^2 \quad (12)$$

$$T_{41}^2 + T_{42}^2 \leq 0.05^2 \quad (13)$$

$$T_{61}^2 + T_{62}^2 \leq 0.05^2 \quad (14)$$

Table 1.The assembly parts and the choice of manufacturing cloud

Name	Process dimension	Manufacturing Cloud	Detection result
X_1	292.3±0.11	3	unprocessed
X_2 X_{21}	70-0.03~70	3	unprocessed
X_{22}	70~70+0.04	2	70~70+0.04
X_3	50±0.01	3	50±0.02 (overproof)
X_4 X_{41}	57-0.02~57	2	unprocessed
X_{42}	57~57+0.04	2	unprocessed
X_5	174±0.05	3	unprocessed
X_6 X_{61}	32±0.02	3	unprocessed
X_{62}	32±0.015	2	32±0.015
X_7	69±0.06	2	unprocessed

The information of Manufacturing Cloud 1~3 is given by Table 2.

The further information is assumed that Cloud 1 has the longest distance among these clouds while the time and cost of material flow is longest and most expensive. The distance of Cloud 3 is the shortest.

Table 2 The information of manufacturing cloud 1~3

	Machining method 1			Machining method 2			Machining method 3		
	σ	T_+	T_-	σ	T_+	T_-	σ	T_+	T_-
x_{41}	3.1	19	13	4.9	30	19	62	30	13
x_{42}	4.9	46	19	7.5	46	30	12.1	74	46
x_{61}	4.1	25	16	6.4	39	25	10.1	62	39
x_{62}	2.6	16	11	4.1	25	16	5.2	39	16
x_5	6.2	40	25	7.5	100	63	10.3	160	63
x_7	4.8	120	74	7.8	190	120	12.3	190	74
x_{21}	3.1	19	13	4.1	30	19	6.2	46	30
x_{22}	4.9	30	19	6.2	46	30	7.5	74	46
x_3	6.4	39	16	7.3	39	25	10.2	62	25
x_1	21	130	81	29.1	210	81	40.5	320	200

*the unit of σ is 10^{-3}

According the current research, the manufacturing cost could be calculated and the adjustment result of every featureand every cloud is shown in Table 4.$X_1X_3X_5X_7$are the locating features, $X_{21}X_{22}X_{41}$arethe ex-circles and $X_{42}X_{61}X_{62}$ arethe inner-holes. In the dimension chain, $X_{22}X_3X_{62}$ have been machined, and $X_{21}X_{22}X_{41}X_{42}X_{61}X_{62}$ have no relationship with the overproof-feature X_3.

As the total cost includes the manufacturing cost and the cost of material flow, a coefficient is introduced in the cost model to cover it which is shown in Eq. (15). The total increment of cost is shown in Eq. (16).

$$\mathrm{C} = (1 + \mathrm{k}) \cdot \mathrm{C(T)} \quad (15)$$

$$\Delta\mathrm{C} = (1 + \mathrm{k}) \cdot \mathrm{C(T)} - \mathrm{C(T)}_0 \quad (16)$$

Which k has relationship with the distance among these clouds. We assume that $k_{12} = 0.09; k_{13} = 0.07$; $k_{23} = 0.04; k_{11} = k_{22} = k_{33} = 0$ when the material transported as a matter of fact.

According to the Eq. (10)-(17) and constraint condition of cloud 1-3 above, we could obtain the manufacturing cost of the optimal result in each feature adjustment. The result is shown in Table 3.

To illustrate the model which is proposed in this paper, we suppose different A in $Q_L = A\sigma^2$ of Cloud 1-3 to indicate the quality loss. It is shown in the table 4.

Since the manufacturing cost chosen above has included the time cost, in the objective function (2) the manufacturing time item should be elided. According to the value of k discussed in the preceding part of text, the model has been simplified with the same coefficient k as table 5 below, which time coefficient=$\frac{t(e)}{t_0}$.

Table 3.TheΔ cost of the optimal result in each feature adjustment

Component link		Cost		
		Cloud 1	Cloud 2	Cloud 3
T_4	T_{41}	7.940776989	-	7.576521164
	T_{42}	6.007139174	5.511136857	-
T_6	T_{61}	-	5.731582331	-
	T_{62}	-	-	-
T_5		-	1.720644319	1.654465691
T_7		1.651218445	-	1.57547448
T_2	T_{21}	-	5.287349296	5.498843268
	T_{22}	-	-	-
T_3		-	-	-
T_1		-	1.2795744	-

Table 4.The quality loss of each cloud

Component link		Quality loss		
		Cloud 1	Cloud 2	Cloud 3
T_4	T_{41}	0.587700031	0.22408533	0.029483968
	T_{42}	1.468332751	0.52498125	0.112298328
T_6	T_{61}	1.028016391	0.38227968	0.078242964
	T_{62}	-	-	-
T_5		2.350800122	0.52498125	0.081372376
T_7		-	-	–
T_2	T_{21}	0.587700031	0.15688773	0.029483968
	T_{22}	-	-	-
T_3		-	-	-
T_1		26.96937705	7.90327773	1.25809256

Table 5.Thetimecoefficient of each cloud in each feature adjustment

Component link		Time coefficient		
		Cloud 1	Cloud 2	Cloud 3
T_4	T_{41}	1.09	-	1.04
	T_{42}	1.09	1	-
T_6	T_{61}	-	1.04	-
	T_{62}	-	-	-
T_5		-	1.04	1
T_7		1.09	-	1.04
T_2	T_{21}	-	1.04	1
	T_{22}	-	-	-
T_3		-	-	-
T_1		-	1.04	-

According to $minZ = \omega_1 \frac{t(e)}{t_0} + \omega_2 \frac{C(e)}{C_0} + \omega_3 \frac{Q_L(e)}{Q_{L0}}$, table 4-5 could be add together as a matrix by dividing the C_0 and $Q_{L0}$with the table 6 as a matrix.C_0andQ_{L0} could be calculate by the information in Table 1.

When the users of CM platform focus on different constraint, a different result would be get, such as the time constraint condition, the cost constraint condition, the quality loss constraint condition. The ωon the time constraint condition given by the simulation example is that $\omega_t = 0.5, \omega_C = 0.25, \omega_{QL} = 0.25$ .The ω on the cost constraint condition given by the simulation example is that $\omega_C = 0.5, \omega_t = 0.25, \omega_{QL} = 0.25$.The ω on quality loss constraint condition given by the simulation example is that $\omega_{QL} = 0.5, \omega_t = 0.25, \omega_C = 0.25$. And the result of them is different.

The optimum proposal on this occasion focused on time is to adjust the feature x_{41} to Cloud 3 to complete the rest manufacturing task keeping the others immovable according to Table 6.

The optimum proposal focused on cost is to adjust the feature x_7 to Cloud 3 to complete the rest manufacturing task keeping the others immovable according to Table 7.

The optimum proposal focused on quality is to adjust the feature x_{41} to Cloud 3 to complete the rest manufacturing task keeping the others immovable according to Table 8.

Table 6.Theoptimal result focused on time.

	Cloud 1	Cloud 2	Cloud 3
x_{41}	1.505624544	-	0.81378065
x_{42}	1.523828602	1.006511521	-
x_{61}	-	2.008222639	-
x_{62}	-	-	-
x_5	-	2.393646252	1.000719827
x_7	1.438225853	-	0.831439074
x_{21}	-	2.115520152	1.025849759
x_{22}	-	-	-
x_3	-	-	-
x_1	-	2.350488131	-

Table 7.Theoptimal result focused on cost.

	Cloud 1	Cloud 2	Cloud 3
x_{41}	1.538083643	-	0.844750799
x_{42}	1.53092616	1.013023043	-
x_{61}	-	2.014994621	-
x_{62}	-	-	-
x_5	-	2.394394871	1.001439653
x_7	1.438590919	-	0.831787394
x_{21}	-	2.120760305	1.051699519
x_{22}	-	-	-
x_3	-	-	-
x_1	-	2.350488131	-

Table 8.Theoptimal result focused on quality.

	Cloud 1	Cloud 2	Cloud 3
x_{41}	1.888789989	-	0.55659115
x_{42}	1.950559647	1.006511521	-
x_{61}	-	2.969673296	-
x_{62}	-	-	-
x_5	-	3.746543884	1.000719827
x_7	1.786086639	-	0.622529827
x_{21}	-	3.185800151	1.025849759
x_{22}	-	-	-
x_3	-	-	-
x_1	-	3.660976262	-

6. Conclusion

An integrated tolerance design and management model is presented in this paper to expound the application area and processing of Cloud Manufacturing making full use of the dynamics and efficiency which is different from the traditional manufacture model. We can select the componenttolerance and the suitable manufacturing cloud withhigher quality less cost and time. The Illustrative example shows that when the users of CM platform have different emphasis on the objective function, a different result is concluded by this model. It is flexible and makes the designed results more practical and effective.

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