Conflict Coordination Based on the Transformation Bridge for Collaborative Product Performance Optimization

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Abstract. To quickly coordinate conflicts in product performance design, a transformation bridge method was proposed. Specifically, the design problems of performance conflicts were analyzed in terms of the quantification and collaboration. Based on the analysis, the mathematical models for conflict resolution and correlation function were developed. Thus the relationship between performance and design variables could be identified, and then used for searching similar cases from a repository. In addition, a core solution was developed by identifying the correlation among performance, combining the collaborative resolution method and case-based reasoning. The transformation bridge method was leveraging the extensibility of the basic-elements. Furthermore, the method for obtaining revised solutions was developed based on extension theory in particular the transformation operator and the cyclic transformation based on performance constraints, as the core of the approach to product performance optimization. The viability is evaluated in a case of screw air compressor design.

Keywords: cooperative design, case based-reasoning, extension theory, conflict resolution, fuzzy matter-element, retrieval.

1 Introduction

Production design holds the key to the development of the manufacturing industry [1]. In the context of modern design, customers' requirements for a product are to a large extent fulfilled by the performance it can achieve, raising the need of study performance-driven design [2]. As performance improvement for modern products becomes increasingly demanding, it is hard to meet this requirement by simply adjusting some design parameters as it may adversely affect other performance factors. Many methods

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have recently been performed by researchers from all over the world to address design conflicts. For example, Lee [3] developed a ship design system in which Case-Based Reasoning (CBR) was applied to conflict resolution by effectively utilizing similar experiences in the past. Wang [4] developed a conflict resolution module in the Pro/E CAD system based on the CBR method through analyzing the reasons of conflicts in smart CAPP. Resolution methods based on rules and CBR can effectively and quickly resolve some conflict problems which are common and involve low degree of coupling [5]. They, however, cannot deal with the conflict problems that involve coupled correlation in the design process [6]. To solve this problem, Zhou etc. [7] developed an interactive consultation conflict resolution method and Beheshtietc [8] established a consultation mechanism by applying multi-objective genetic algorithm to the application of conflicts. These methods, though, are not effective in terms of product design time. Conflict resolution based on TRIZ theory has been proposed as the main solution in product design [9, 10], but the methods proposed tend to focus on specific problems and thus generalization becomes a challenge.

Performance-driven product design has typical features of multiple-input-multiple-output tightly coupled performance, requiring collaborative performance optimization as a core solution and conflict coordination as a key enabling method. Hence, it raises the need of researching the complexity of the mapping between product performance and product structure, the uncertainty of changes in design variables and the viability of transforming solutions to address conflicts. Transforming bridge is a technique for researching how to transform conflict problems into solvable ones in the extension theory [11], which aims to achieve conflict resolution in the design process by establishing extension model, affair-element analysis and extension transformation.

2 Collaborative Product Performance Optimization Based on Similarity Matching

To achieve product performance optimization, it is firstly necessary to develop a formalized model for product performance based on the meta-model of product requirements. Product performance design unit is such a model that aims to meet customer's performance requirements by adjusting the properties of its key parameters and the constraints imposed on them. It is based on matter-element representation [11] and can be used to describe the correlation between product structure and product performance as well as to construct a case base for existing design solutions. The formalized model of product performance can be expressed using the following formula Mark case O_m as an object (matter), c_m as its properties and v_m as the values of c_m ($v_m = c_m(O_m)$), then the model of performance requirements can be described as $P=[O,c,v]$ and the product performance model can be described as a multi-dimensional matter-element model as follows.

$$PC = \begin{bmatrix} CaseName, & ID\_Confidence, & v_1 \\ & ID\_Class, & v_2 \\ & PE\_Performances, & v_3 \\ & PE\_Modules, & v_4 \\ & PE\_Functions, & v_5 \\ & \vdots & \vdots \end{bmatrix}$$

ID_Confidence: the product element; *ID_Class*: the product class element; *PE_Performances*: the product performance set element; *PE_Modules*: the number of module *PE_Functions*: the product function element.

Based on this formalized model, similar cases can be retrieved by matching the *ID_Class* and the values of performance factors against those required by a designer. The measure for evaluating similarity can be obtained by using the extension distance [12]: $sim(v(P),Y)=1-|d(v,Y)|$. If the interval about the value of a performance factor in the case base is $v(P)=[y_1,y_2]$, then the left side-distance and right side-distance are shown as follows.

$$d_l(v(p),Y)=\begin{cases} y_1-v(p), v(p)\le\frac{y_1+y_2}{2} \\ v(p)-\frac{y_1+y_2}{2}, v(p)>\frac{y_1+y_2}{2} \end{cases}, \quad d(v(p),Y)=\begin{cases} \frac{y_1+y_2}{2}-v(p), v(p)<\frac{y_1+y_2}{2} \\ v(p)-y_2, v(p)\ge\frac{y_1+y_2}{2} \end{cases}$$

After retrieving some cases by evaluating similarity using the above distance-based measures, these cases can be quickly used as a reference for new solutions. In terms of the performance requirements met by them, the cases can be divided into two classes: (1) those successfully meeting performance requirements with $sim_i>0$; (2) those requirement further optimization with $sim_i<0$.

3 Analyzing the Conflict Problem in Collaborative Performance Optimization

Mark product performance as an object element G which represents the optimization objectives and product structure as a condition element L which represents the variables to be transformed to eliminate conflict and find optimal solutions. The conflict resolution problem for collaborative performance optimization, then, can be denoted as $CQ=G*L$ where * means a logical operator. The key issue in this problem is the correlation function $k(v(P))$ which quantifies the changes made to the problem as well as the resultant changes in performance. The deviation of the formula for this function is out of the scope of this paper and has been published elsewhere [11, 13].

Collaborative performance optimization based on the formalized model discussed above may incur three kinds of conflicts as follows:

1) Independent performance conflict which can be formally denoted as $CQ_{11}=\{CQ_{11} | G_{P_i} \uparrow L, P_i \in simP<0\}$

2) Conflict between different performance factors, which can be formally denoted as $CQ_{12}=\{CQ_{12}|(G_{P_i}\wedge G_{P_j})\uparrow L, P_i, P_j \in simP<0\}$

3) Conflict between a performance yet to be optimized and other factors that have been optimized denoted as $CQ_2=\{CQ_2|(G_{P_i}\wedge G_{P_j})\uparrow L, P_i \in simP<0, P_j \in simP>0\}$

Generally, there are three methods to solve CQ as follows.

1) Perform transformation T_G on G and mark ϕ as the threshold of the corresponding product performances, then the range of the application of this method is: $k(v(P))\in(-\phi,\phi)\in k'(v(P))$.

2) Perform transformation T_L on L, and then the range of the application of this method is $k(v(P))\in(-\infty ,\varphi)$ with the transformation result $k'(v(P))\in(-\phi,\infty)$.

3) Perform transformation $T_{CQ}=(T_G, T_L)$ on both G and L. This method will only be selected when correlation function keeps in the range $k'(v(P))\in\pm(\phi,\infty)$ in the condition of cyclic transformation.

4 Reasoning Based Transformation Bridge for Collaborative Performance Optimization

4.1 Constructing the Core Conflict Problem

The relationship between the performance of a product and its structure is not as explicit as the relationship between its function and its structure as a specific performance is resulted from several different functions. Performance design is not as explicit as functional requirements. There are generally two different situations in the mapping process from performance and structure.

1) The mapping from performance and structure is explicit. For instance, the displacement and exhaust pressure of a screw air compressor are dynamic performance of the compressor as well as noise the dynamic performance of the nose, and thus can be mapped to the parts of the noise.

2) The mapping relationship between performance and structure is complex and fuzzy. For instance the noise of a screw air compressor is the green performance of the compressor but involves many complex parts. The noise of the compressor, then, may include aerodynamic noise, mechanical noise and electromagnetic noise.

There are several rules of implication analysis as follows.

Implication rule 1: If R is achieved, then R_1 and R_2 are achieved at the same time. This is the case where R implicates $R1$ and $R2$, being denoted as $R\Rightarrow R_1\wedge R_2$

Implication rule 2: If R_1 and R_2 are achieved at the same time, then R is achieved. This is the case where R_1 and R_2 implicate R, being denoted as $R_1\wedge R_2\Rightarrow R$

Implication rule 3: If R is achieved, then R_1 or R_2 is achieved. This is the case where R implicates R_1 or R_2, being denoted as $R\Rightarrow R_1\vee R_2$

Implication rule 4: If R_1 or R_2 is achieved, then R is achieved. This is the case where R_1 or R_2 implicates R, being denoted as $R_1 \vee R_2 \Rightarrow R$

Many transformation programs for product structure can be obtained through implication analysis and the case-based reasoning method in the extension theory. This program is denoted as $A_i = \{A_{i1}, A_{i2}, A_{i3}, \ldots, A_{in}\}$ where $i = 1, 2, 3, \ldots, m$ and n denotes the transformation programs for product structure. If there are n^{th} characteristics, it contains dominating object, application object, accepting object, time, address, degree, manners and tools. Core problem of CQ can then be denoted as $KCQ = G * A_{ij}$.

4.2 Structure Transformation Reasoning Based on the Core Problem

The normal extension transformation methods, priority, weight of these methods are denoted, and then, the basic transformation can be expressed using the matrix [11].

Three transformation results will be obtained due to different transformation directions. There are meeting requirements direction, not meeting requirements, and no effectiveness to the results. So the process model of conflict coordination based on transformation bridge method can be given as in

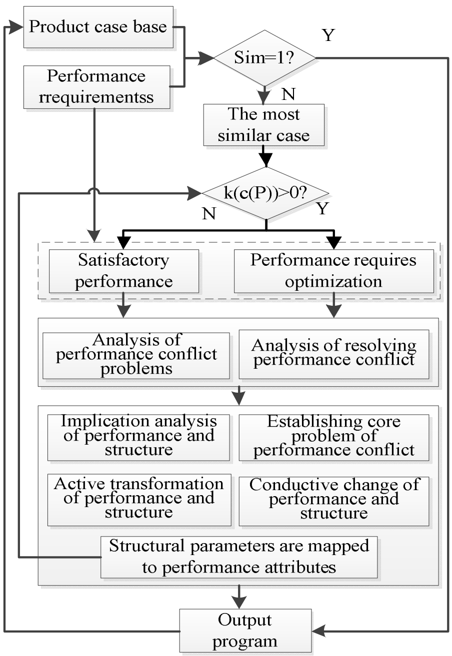


Fig. 1. Flowchart of the process of conflict resolution based on the extension theory

5 Application and Example

Air compressor is widely used in the industrial sectors oil extraction, chemical engineering, electricity generation and mechanical engineering. The structure of a screw air compressor is shown in Figure 2.

The components of the compressor are explained as follows. 1-55kw motor (10- absorber component, 11-motor vibration damper); 2-center resting; 3- coupling component; 4- nose assembly(12- absorber component, 13- host damping frame, 14- male and female rotors, 15 air filter assembly, 16- inlet valve component); 5- oil and gas separator component; 6- minimum pressure valve; 7- inner cooler; 8- thermostat valve; 9- oil filter components; 17- axial flow fan assembly.

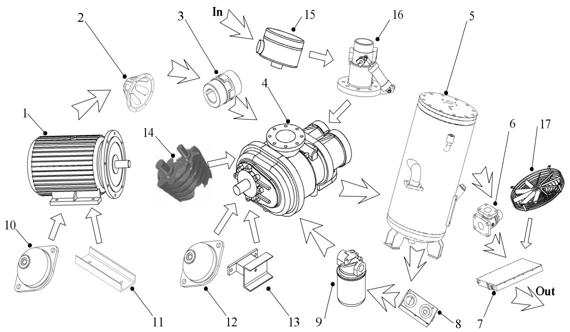


Fig. 2. Main components and schematic diagram of the screw air compressor of LG-6.7/10

Then a set of correlation functions of evaluation characteristics are established and denoted as $k_1(x)$. And the condition of transformation can be determined by judging by judging $K(P)=\bigwedge_{i=1}^{n} k(x_i)$. Take the noise performance as an example to illustrate how to calculate correlation functions. A correlation function can be constructed as the following equation with X (dB)=(50,107), X_0 (dB) =(60,70) and optimal value x_0=62 dB. So $k_4(x)$ can be established seen in [11]. The noise of a similar case retrieved from the design case base is 80dB, then the correlation degree between this case and the desired value is given as in $k_4(80)$= -0.27<0. So the case base can be calculated as $K(CQ)=k_1\wedge k_2\wedge k_3\wedge k_4\wedge k_5\wedge k_6\wedge k_7=0.075\wedge 1\wedge 0.91\wedge(-0.27)\wedge(-1)\wedge(-0.25)\wedge 1<0$. This indicates that the attributes of noise, weight and lubrication oil need to be transformed. So the conflict problem can be resolved by applying collaborative performance optimization in terms of the three attributes, as shown in the following.

$$P = G * L - \left\{ \begin{array}{l} g_4 * m_4 \Rightarrow A_1 = \begin{bmatrix} reduce & dominating\ object & noise \\ & application\ object & designer \\ & accepting\ object & LG\text{-}6.3/10 \end{bmatrix} \\ g_5 * m_5 \Rightarrow A_2 = \begin{bmatrix} lighten & dominating\ object & weight \\ & application\ object & designer \\ & accepting\ object & LG\text{-}6.3/10 \end{bmatrix} \\ g_6 * m_6 \Rightarrow A_3 = \begin{bmatrix} reduce & dominating\ object & lubrication\ oil \\ & application\ object & designer \\ & accepting\ object & LG\text{-}6.3/10 \end{bmatrix} \end{array} \right.$$

Set the effect size of the correlation function as $\phi=0.5$, $\alpha_1=1.2$, and $\alpha_2=1.1$, then it is obtained $k_5=0.83>0$ and $k_6=0.65>0$, which means weight and lubrication oil meeting customers' requirements. Comparing this with the matter-element method which can achieve noise properties requirement, the conductive contradiction path of different structures can be obtained. Through the comparison of several aerodynamic noise characteristics and the noise values, noise conflict problems are resolved by several main matter-element solution paths in this work, as shown in Table 1.

Table 1. matter-element method to reduce noise of screw air compressor

performance characteristic	matter element method	Configuration element set
aerodynamic noise A_{11}	A_{111} reduce intake noise	Inlet strainer PE1 ∧ inlet muffler PE3
	A_{114} reduce fan noise	electrical machinePE5 ∧ cooling fan PE6

The inlet noise of the screw air compressor belongs to low-middle frequency noise, for which resistance muffler is generally selected. Formula about noise reduction of resistance muffler is described. Some types of screw air compressors in the case base contain the intake muffler while some do not. The most similar case is retrieved the noise performance of which, however, does not meet the requirement. Moreover, intake muffler is not installed in this compressor because different types of air inlet have different fundamental frequency and the fundamental frequency of its inlet noise is 99HZ. Thus the muffler configuration element in the case base cannot be applied to this type and the extension transformation (the different transformations for this case are listed in Table 3) is needed with the condition matter-element of muffler structure parameters shown in the following equation.

$$l = \begin{bmatrix} expansion\ type\ silencer & material & corrosion\ resistant\ plate \\ & shape & circle \\ & the\ diameter\ of\ entrance & 60mm \\ & outlet\ diameter & 60mm \\ & expansion\ type\ diameter & 180mm \\ & expansion\ type\ length & 140mm \end{bmatrix} = \begin{bmatrix} l_1 \\ l_2 \\ l_3 \\ l_4 \\ l_5 \\ l_6 \end{bmatrix}$$

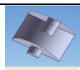
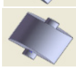
A set of transform operators is generated randomly by computer. Transformation control is done through the implication relationship between noise reduction, cost and product configuration. Then the following three groups of transformation operators $\{T_L\}$ are obtained. As a result of a series of transformations, a group of programs about product structure is obtained, as shown

$$l' = (t_{29}^{2} \wedge t_{110})l = \begin{bmatrix} \text{Expansion type silencer} & \text{Material} & \text{Glass steel\&Galvanized steel sheet} \\ & \text{Shape} & \text{Circle} \\ & \text{Entrance diameter} & 85mm \\ & \text{Exit diameter} & 85mm \\ & \text{Expansion type diameter} & 340mm \\ & \text{The first expansion chamber} & 161.5 \\ & \text{The second expansion chamber} & 58.4 \end{bmatrix}$$

At present there is no precise method for calculating noise, so the overall noise is not the result of simply adding the noises from all the sources. Assume the noise intensity in k^{th} noise, overall noise z_n can be obtained as: $z_n = log(10^{n1} + 10^{n2} + L + 10^{nk})$. Some measures will be taken to reduce noise since it exists in the compressor, then the overall actual noise, denoted as f, after noise reduction is the difference between the total noise intensity and the noise reduction z_r, i.e.: $z=z_n-z_r$.

Based on the analysis of the above transformation operators, the muffler $-P_N$ and P_N after transformation can be calculated using noise theories and the correlation degrees of the noise performance after a series of transformations can be obtained. The resultant configuration program set is shown in Table 2.

Table 2. The muffler configuration schemes after transformations

new muffler	Configuration schemes	view muffler cutaway model	$-P_N$ dB	P_N dB	$K(CQ)$
1	$T_4 \wedge T_1 \wedge T_1 \wedge T_1 \wedge T_1 \wedge T_2 \wedge T_2$		14.3	71.3	-0.058
2	$T_4 \wedge T_1 \wedge T_1 \wedge T_1 \wedge T_1 \wedge T_2 \wedge T_2 \wedge T_1 \wedge T_3$		18.1	68.5	0.088
3	$T_4 \wedge T_1 \wedge T_1 \wedge T_1 \wedge T_2$		12.1	74.2	-0.148

6 Conclusion

In this paper, a method for coordinating conflicts in collaborative performance optimization is described in detail, which is based on the extension model, affair-element analysis and extension transformation. Through developing quantitative analysis methods of correlation function and several affair-element solution programs, a method for performance optimization is developed, with which, designers can search for similar cases in the past that will be transformed by the design system automatically. As demonstrated in the application, the method is successfully used in the optimization of a screw air compressor. In our future work, I will further improve the method and develop a computer-based decision support system to help designers in complex engineering systems with complex performance requirements.

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