An Approach to Evolutionary Design Using Design Parameters and Goals

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Design goals are the required functions of the design elements needed to realize the design specifications of a product. In this study, it is assumed that the design goals can be explicitly expressed by the design parameters, and accordingly the mechanical design process is the assignment of proper design goals and their realization through the evolutionary refinement of the design parameters. Thus an integrated design system is proposed to assign the design goals and refine the values of the design parameters. In the design system, a genetic engine that utilizes a genetic algorithm is installed, which leads to an evolutionary design.

Keywords: Design parameter, Design goal, Evolutionary design, Re-design, Genetic algorithm

1. INTRODUCTION

A mechanical design process can be assumed to be a process specifying the design goals and refining the design elements needed to realize the specified goals. Design goals are required functions of the design elements and act as *FR* in axiomatic design [1], *response* in Taguchi method [2] or *customer's requirement* in QFD [3]. Design parameters refine the design elements and play a similar role to *DP* in axiomatic design and *factor* in the Taguchi method. In this study, the importance of design goals and parameters is highlighted and a design process based on them is proposed. The proposed system supports the process of assigning design goals and refining design parameters.

In mechanical design, designers usually specify a few major design parameters in the early design stage and then more specific design parameters in the detailed design stage. They may establish too many or few design constraints to design parameters in the design process. Genetic algorithms can handle this kind of design problems by satisfying given constraints. Also relations among the design parameters and the evolutionary process can be monitored if the design parameters are modeled as genes. So, a genetic algorithm has been utilized as an optimization tool in this study. In the algorithm, the design parameters specified by the designer are modeled as genes and the design goals specified by the designer are treated as an evaluation function. This process can refine the values of the design parameters and simulate the iterative design process, and enable an evolutionary design.

2. DESIGN PARAMETER REPRESENTATION

The concept of EO (element object) [4, 5] incorporating various design information is introduced to represent a design element. The EO representation [6] is simply expressed as shown in Fig. 1. In Fig. 1, *DesignParameter* manages the information of a design parameter and *Goal* manages that of a design goal.

There are other managers in the proposed design system to aid a design, such as *EvolutionManager* and *DesignProcessManager*. The *DesignProcessManager* guides the general design process and manages some necessary information such as the design history, the creation/deletion of EOs and the evolution of EOs. The *EvolutionManager* enables the evolutionary design process.

The *DesignParameter* in Fig. 1 manages the information of a design parameter and has the following data types to treat most data appearing in engineering problems.

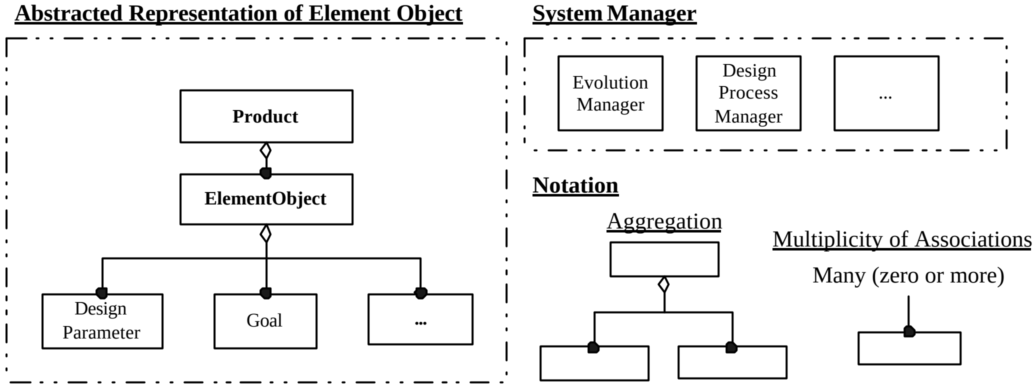


Fig. 1. Simple representation of element object

3. DESIGN GOAL REPRESENTATION

Design goals are explicitly expressed by the design parameters. The *Goal* in Fig. 1 contains the design goal and has such attributes as G*oalName*, *ObjectiveFn*, *TargetValue*, *Weight* and *Result* as shown in Table 1. *GoalName* represents the name of an objective function in *Goal*, and *ObjectiveFn* is the objective function represented by the parameters in *DesignParameters*. *TargetValue* is the desired value of the objective function, *Weight* means the importance of each objective function, and *Result* is the calculated value of the objective function.

Generally a design goal is expressed as multi-objective functions. In Table 1, the *Goal* has n objective functions. To solve such problems with multi-objective functions by genetic algorithms, we applied the method of specifying a value for each objective function, which was proposed by Michalewics [7]. The evaluation function in this work is expressed as below.

$$F(x) = \left(\sum_{i=0}^{n-1} w_i \times \left| f_i(x) - T_i \right|^r \right)^{\frac{1}{r}} \quad (1)$$

where,

r = generally 2 (Euclidean distance)
x = parameter value
F(x) = evaluation value for given x
w_i = weight of the i-th objective function
$f_i(x)$ = the value of the i-th objective function for given x
T_i = target value of the i-th objective function

Table 1. Attributes of *Goal*

GoalName	ObjectiveFn	Target Value	Weight	Result
GOL_0	f_0	T_0	w_0	R_0
GOL_1	f_1	T_1	w_1	R_1
…	…	…	…	…
GOL_{n-1}	f_{n-1}	T_{n-1}	w_{n-1}	R_{n-1}

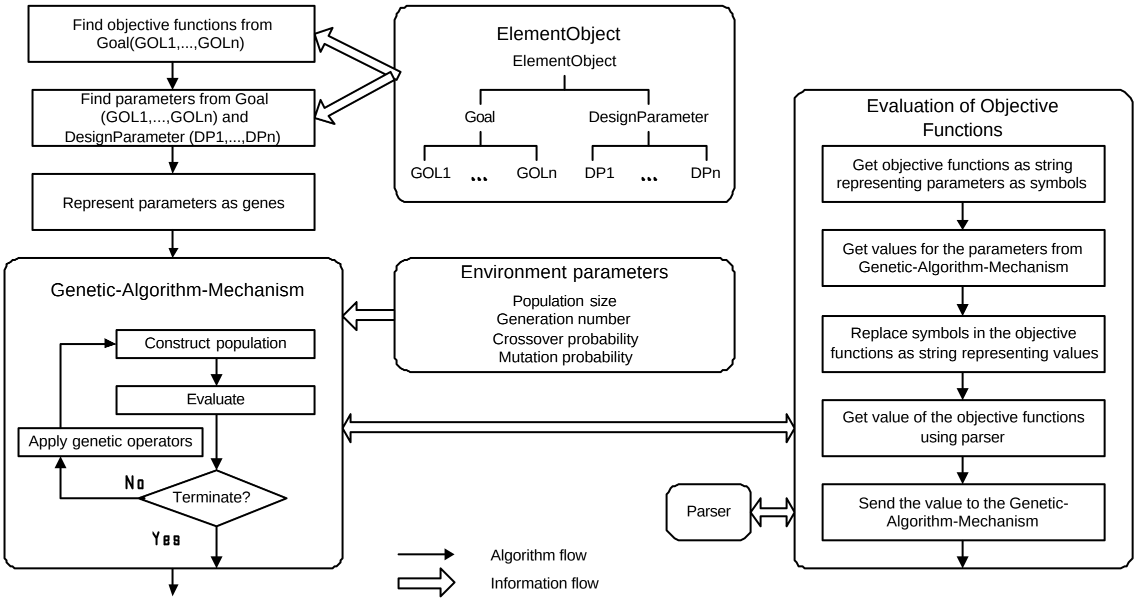


Fig. 2. Procedures for evolutionary design using genetic engine

4. EVOLUTIONARY DESIGN METHOD

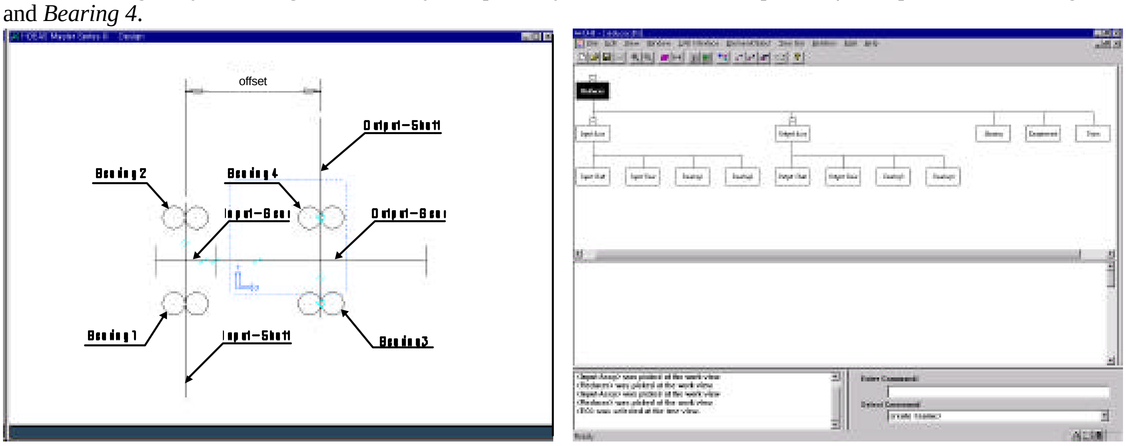
We simulate the iterative design process to improve a design using a genetic engine that solves the design goals. The improvement of a design can be regarded as the evolution of a design. Design parameters are constructed in *DesignParameter* and design goals are constructed in *Goal*. The genetic engine uses *DesignParameter* and *Goal* to optimize the design goal. Fig. 2 shows the overall procedure to optimize the design goal by using a genetic algorithm [8].

5. EXAMPLE

An integrated design system is developed to support the design process proposed in this study. A commercial solid modeler is used as a geometry processor to visualize the shape of EOs and a design information processor called DHII (Design History, Information, and Intent) is developed to handle the information in EOs. The geometry processor runs simultaneously with the design information processor. In this section, we will illustrate how the evolutionary design and re-design is performed in the proposed system with an example.

5.1 GEARBOX MODELING IN THE DESIGN SYSTEM

Fig. 3 (a) shows the skeleton model of a gearbox generated in the geometry processor and Fig. 3 (b) shows the element objects in the proposed design information processor. In this example, the gearbox called *Reducer* is divided into five EOs: *Input-Assy, Output-Assy, Housing, Requirement, and Team*. *Input-Assy, Output-Assy,* and *Housing* represent the input shaft subassembly, output shaft subassembly, and the casing of the gearbox respectively. *Requirement* and *Team* represent the information on the design requirement and the members in the team respectively. The input shaft subassembly, *Input-Assy,* is again divided into *Input-shaft, Input-Gear, Bearing 1, and Bearing 2* by the designer. Similarly, *Output-Assy* is divided into *Output-Shaft, Output-Gear, Bearing 3,* and *Bearing 4*.



(a) (b)

Fig. 3. Designing a gearbox (a) Skeleton model of a gearbox generated by geometry processor

(b) Process of designing a gearbox in the information processor

Table 2. Definition of design parameters related to the gearbox design

EO	Parameter	Value	Description	*InducedEO*	*ParameterOf-InducedEO*
Requirement	*power*	10	power[kW]	*Requirement*	*power*
	rpm	500	rpm [rpm]	*Requirement*	*rpm*
	ratio	3.5	reduction ratio	*Requirement*	*ratio*
	offset	237.5	offset	*Requirement*	*offset*
Reducer	*a*	(21)	Teeth number	*Input-Gear*	*Teeth*
	b	(74)	Teeth number	*Output-Gear*	*Teeth*
	m	5	module	*Input-Gear*	*Module*
	i	3.5	reduction ratio	*Requirement*	*ratio*
	l	237.5	offset	*Requirement*	*offset*
Input-Gear	*Module*	5	module	*Input-Gear*	*Module*
	power	10	power[kW]	*Requirement*	*power*
	rpm	500	rpm [rpm]	*Requirement*	*rpm*
	Teeth	(21)	Teeth number	*Input-Gear*	*Teeth*
Output-Gear	*Module*	5	module	*Output-Gear*	*Module*
	power	10	power[kW]	*Requirement*	*power*
	rpm	500	rpm [rpm]	*Requirement*	*rpm*
	Teeth	(21)	Teeth number	*Output-Gear*	*Teeth*

5.2 DESIGN PARAMETER SPECIFICATION

When EOs for these components are created, design parameters are defined by the designer as in Table 2. Note that the relationship of the design parameters is also specified when they are defined. In *Requirement* of Table 2, design requirements are specified; *ratio* is the reduction ratio (3.5), *offset* is the offset distance between the input and output shaft (237.5 mm), *power* is the transfer power (10 kW), and *rpm* is the revolutionary speed of the input shaft (500 rpm). In *Reducer* of Table 2, the design parameters are chosen by the designer based on his/her design intent; *a* is the number of the teeth of the input gear, *m* is its module, *b* is the number of the teeth of the output gear, *i* is the reduction ratio, and *l* is the offset distance between the input and the output shafts. It can be noted from the column *InducedEO* that *a* was already defined when *Input-Gear* was defined. Similarly, *b* was also defined when *Output-Gear* was defined. It is assumed that EOs for *Input-Gear* and *Output-Gear* exist in the database. Otherwise, the designer would create them while he/she works on the *Requirement*. *i*, *l*, and *m* are specified as fixed values while *a* and *b* are the variables to be optimized in the evolutionary design to be followed. The choice of the design variables is also up to the designer and represents his/her design intent.

5.3 GOAL SPECIFICATION

Fig. 4 shows how design goals are defined for evolutionary design by using the design parameters established in Table 2. In this example, the following two equations are used as objective functions. Each objective function has the target value (or target parameter) and the weight factor as shown in Fig. 6.

$$i = \frac{b}{a} \tag{2}$$

$$l = \frac{m \times (a + b)}{2} \tag{3}$$

In Fig. 4, two objective functions corresponding to Eq. (2) and (3) are displayed in the upper list, the design parameters used to describe the objective functions are in the middle list, and the environment parameters for the genetic engine are in the lower list. The genetic parameters include generation number (500), population size (20), crossover probability (50%) and mutation probability (10%). If the tab Evolve is pressed, the genetic engine solves the objective functions using the data in *Fig. 6*. In this example, a and b are calculated to be 21 and 74 by the genetic engine respectively, which results in a reduction ratio of 3.5238 and an offset of 237.5. If the designer is satisfied with these values, he/she presses the tap Propagate to set the parameters and to propagate the values to the other EOs: Input-Gear and Output-Gear.

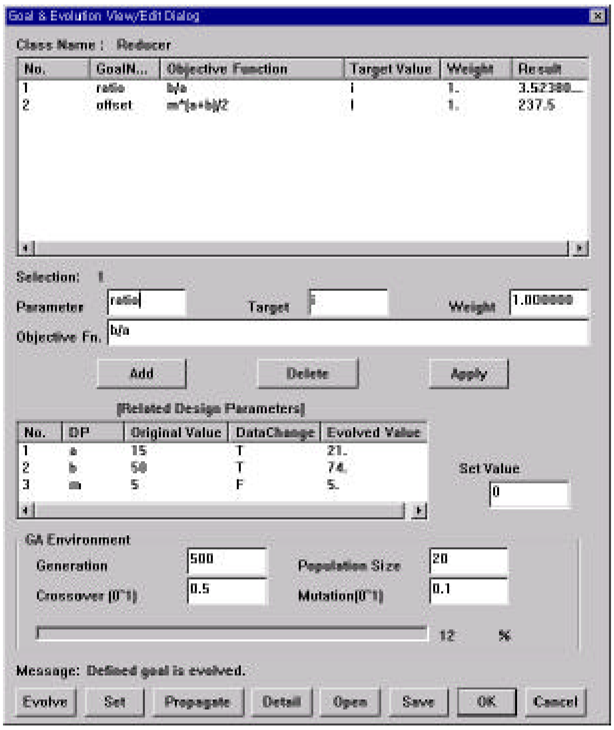


Fig. 4. Design goal constructed in *Reducer*

6. CONCLUSION

In this study, a new design process that utilizes design parameters and goals is proposed and its implementation is described. This study has solved with following problems.

- representation of design element incorporating design parameters and goals
- specification of design parameters and goals in the design system
- evolutionary design using the design parameters and goals

An integrated design system was developed to realize the proposed design process and demonstrated its applicability through a design example.

7. ACKNOWLEDGEMENTS

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