A Hybrid Genetic Algorithm – Sequential Quadratic Programing Approach for Canting Keel Optimization in Transverse Stability of Small Boat Design

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Abstract. The transverse stability is one of the most important characteristics of the ship in survivability. This factor can be influenced by wind, moving cargoes and passengers. In order to avoid maritime accidents due to parametric rolling, several ways are considered in the practical situation such as active and passive anti rolling method. The canting keel is a practical tool for the enhancement of ship stability. In the early ship design stage, this problem is considered to be multimodal objective problem. In the present research, a hybrid optimization technique, genetic algorithm – sequential quadratic programing (GA-SQP) is developed to determine the appropriate parametric values of design of canting keel.

Keywords: genetic algorithm, SQP, canting keel, ant rolling.

1 Introduction

According to classical ship stability, a ship assumed to be in an equilibrium state if the sum of weight and buoyancy is balanced. According to Archimedes theory, a floating body displaces volume water equal to its own weight. The center of gravity (CG) is unchanged unless weight changes or moves. Raising the CG reduces the stability while lowering the CG improves the stability. However, the freeboard is reduced by adding ballast for lowering the CG. In this case, the problem of down-flooding occurs at smaller heel angle. Next, there is the center of buoyancy (CB), which is the geometric center of the immersed hull. It moves as the vessel heels. The Fig. 1 shows that when a boat is upright, the CG is above the CB, it is stable. If the

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boat is heeled by some external forces (eg: waves, wind), CG and CB no longer act along the same vertical line and moment can be up-righting or overturning heeling. As a result, the ship is stable or unstable.

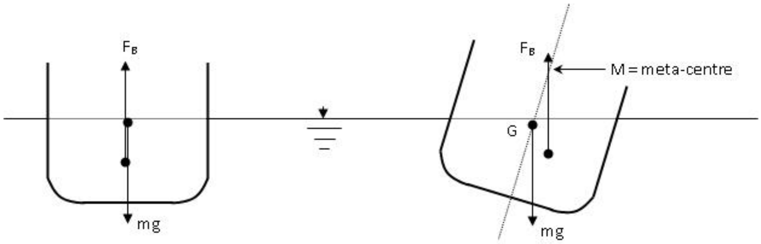

Fig. 1. Forces acting on a ship floating at the upright position

When a ship is inclined, the restoring moment is appeared due to the change of the geometry of the ship. The restoring moment should be equal to the heeling moment to ensure that the ship is in the equilibrium state. The general transverse stability was estimated mainly based on meta center at a small roll angle. In 1757, the relationship between the meta centric height (GM) and roll period of ships was founded by Bernoulli. Next in 1939, Rahola analyzed the still water level arm curves that are acceptable according to the experts' opinion[1,2]. Basically, the stability of ship is considered by using righting arm GZ curve, as shown in Fig. 2. If the righting arm GZ is large, a ship will return the equilibrium state immediately. The objective of the present work is to obtain genetic algorithm and SQP technique to determine the canting keel to generate the restoring moment effectively.

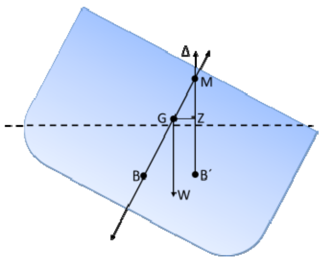

Fig. 2. Righting arm GZ

2 Hybrid GA-SQP Optimization for Canting Keel Design

For a range of small boats, canting keel has been used to increase transverse stability. This is achieved by small increasing in weight of the keel bulb (Fig. 3). As for a fixed keel, a restoring moment is based on the keel length and weight of canting keel. Obviously, these variables should be as large as possible to increase the restoring moment under a number of design load conditions. However, it leads to some limitations of ship design requirement such as longer keel, heavier weight, and greater drag. They also tend to be less maneuverable. A swing canting keel can be suitable in these cases.

Fig. 3. Canting keel system

Our design goal is to minimize keel length, keel bulb weight and rotating angle of keel. Conventional optimization techniques, called steepest descent method, such as gradient-based method, Levenberg-Marquardt method (Rao1999), have been used for a long time[3].

2.1 Sequential Quadratic Programming (SQP)

SQP techniques are used for optimization problems whose objective function and constraints must be continuous and differentiable. A nonlinear programing problem has a form:

$$\min \quad \begin{cases} f(x) \; subject \; to \\ \quad b(x) \geq 0 \end{cases} \tag{1}$$

Our objective function is obtained by approximating the Lagrangian function with m constraints and Lagrange multiplier variableλ.

$$L(x, \lambda) = f(x) + \sum_{i=1}^{m} \lambda_i b_i(x) \tag{2}$$

In our canting keel design, the objective functions are f_{weight}, f_{length}, f_{angle}. All of objective functions should be minimized as far as possible.

$$f(x) = \left[keel\_length(x) * keel\_weight(x) * \tan\left(keel\_angle(x)\right) - \text{unbalanced}\, weigth * \text{ level arm}\right]^2 \tag{3}$$

where keel_weight and keel_length are the weight and length of the canting keel, keel_angle is the rolling angle of the canting keel to provide a better stable for a boat. These values should be as small as possible.

Next, the constraints of canting keel are limited as size of canting keel.

$$keel\_length(x) \leq limitationoflength \tag{4}$$

SQP is fast when the number of objective functions is not too large[4]. However, SQP would get trapped in local minimums in some cases.

2.2 Genetic Algorithm

Evolutionary algorithms, such as GA, however, have been recognized to be possible to solve multi-objective problems[5]. The GAs were invented by John Holland at the University of Michigan in the 1960s and popularized by his student, Goldberg (1989). Holland presented GA as a mechanism of natural adaptation and imported to computer systems. His GA is a method for moving one population (strings or bits) to a new population by using a kind of "natural selection" together with crossover and mutation processes. Today, the researchers use the term "GA" to describe something far from Holland's conception. Instead of using bits in crossover and mutation process, a real coded GAs was introduced for some applications[6,7,8]. The general multi-objective problem is written in Eq (3).

2.2.1 Encoding for Initial Population

The standard GA method use a bit pattern (each gene has a value equal 0: knot-put out or 1: knot-put in). In our present work, GA with individuals using a real value is composed. A set of values in this chromosome is exchanged during the GA mechanism to generate a new chromosome in the next generation. Three major elements such as keel weight, keel length and angle encoded are illustrated in Fig. 4 to form chromosomes.

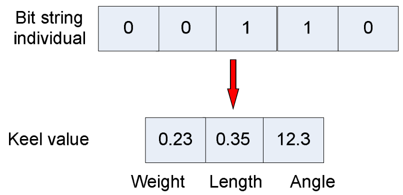

Fig. 4. Real coded individual

2.2.2 Reproduction Process

The steady-state selection is not a particular method (Whitley and Kauth 1988). Each individual in population has a fitness value. First, the individuals are sorted from lowest to highest fitness values. The main idea of this selection is that the good 80% individuals in population (good group) are selected to produce and the rest (bad group) are discarded. Also, in the good group, a few best individuals will be retained at each generation by elitism method. It is recommended that the number of elite individuals is 5% of the number of individuals in a good group. In addition, the bad group in current population will be replaced by the individuals that are executed by the crossover and mutation processes in the good group of current population. A replacement/deletion strategy is more practical than other methods because some characters of good individuals can be lost if they are not selected to produce or if they are destroyed by crossover or mutation processes.

2.2.3 Crossover Process

Crossover is explorative. The encoded design variables are arranged in a dimensional form as a "string" (individual). The individuals divide a string into sub-strings (weight, length, keel) and swap the sub-strings to create new individuals using the crossover process (see Fig. 5). After that, the next population will be generated.

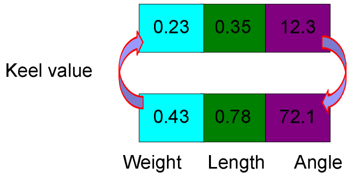

Fig. 5. Crossover mechanism

2.2.4 Mutation Process

The role of mutation is to understand how GA solves complex problems. Mutation is exploitation; it creates a small deviation on the surface. The role of mutation in GA has been considered as preventing premature convergence of the solution (see Fig. 6).

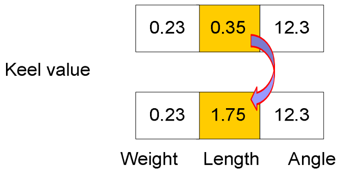

Fig. 6. Mutation mechanism

2.3 Hybrid GA-SQP

A major disadvantage of GA is the convergence speed. The hybrid GA-SQP is considered an effective optimization solver that can enhance the convergence speed. In the present study, GA is applied first to generate the initial point. Then, the calculations would shift to SQP. When objective values close to the local minimum based on our specified tolerance are achieved, our process returns to GA to escape from this local minimum. The basic structure of GA-SQP is illustrated in Fig. 7.

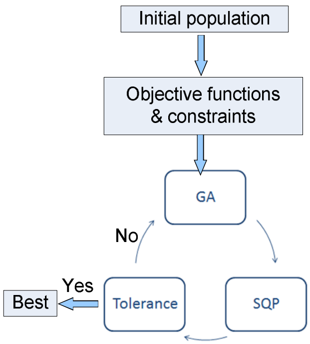

Fig. 7. Hybrid GA-SQP algorithm

3 Numerical Study

By using GA-SQP technique for canting level design, we obtained the following control variables. In order to demonstrate the results, the transverse stability of boat with and without canting keel is calculated by measuring the GZ curve. In this study, our optimization code was written in MATLAB and GZ curve is generated from MAXSURF ship design software. The small boat in our example is obtained as Fig.8 and Table 1

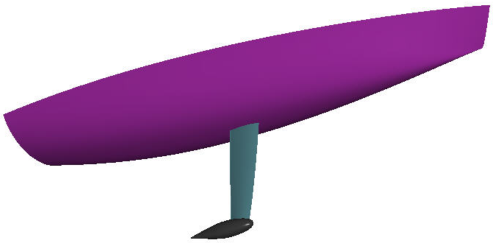

Fig. 8. Small boat with canting keel system

Table 1. Assumption of load case condition in small boat

	Weight [ton]	Long.Arm [m]	Vert.Arm [m]	Trans.Arm [m]
Full ship	6.401	6.460	1.020	0.000
Moving weight	0.5000	6.460	1.020	1.000
	6.901	LCG=6.460	VCG=1.020	TCG=0.072

As shown in Figs.9,10 and Table 2, the GZ curves were generated to demonstrate the efficiency of hybrid GA-SQP for canting keel optimization. The SQP technique reaches the local optimum very fast while the GA technique finds the optimum point slowly. Theoretically, the GZ curve generated from the SQP technique is the greatest. However, the weight of keel bulb is very large and it is not practical in design compared to the weight of full ship. The GZ curve from GA-SQP seems to achieve the global optimum in this case.

Other optimization techniques such as differential equation (DE), gradient-based methods work well and fast but there is no guarantee that an optimal solution will be reached. Simulated annealing (SA) is very slow if the objective functions are complicated. SOMA is able to solve even highly complex optimization problems [9]. The hybrid GA-SQP has been recognized to be possible simply to solve multi-objective problems while reducing the convergence speed.

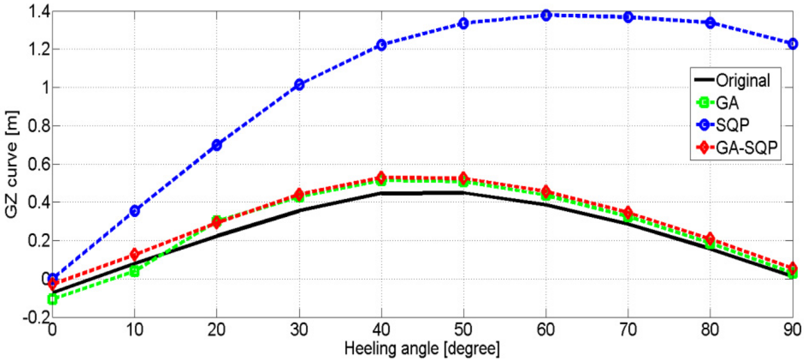

Fig. 9. GZ stability curve using optimization techniques

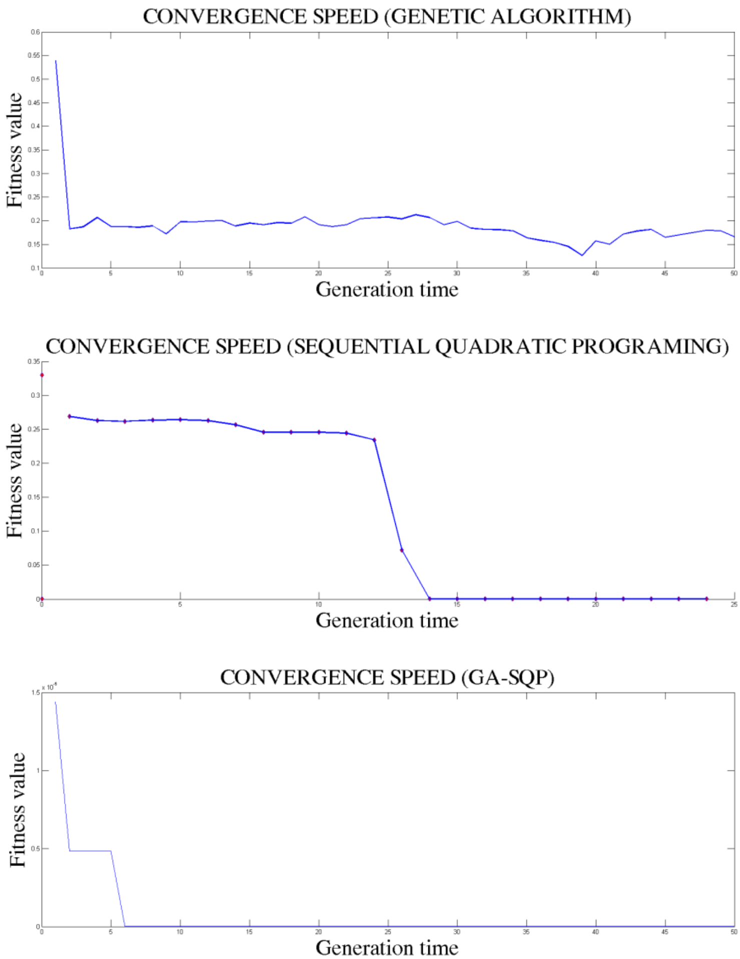

Fig. 10. Convergence of objective value (a) GA technique, (b) SQP technique, (c) GA-SQP

Table 2. Design variables using optimization techniques

	Keel bulb [ton]	Keel angle [degree]	Keel length [m]	Objective value
GA	0.1300	82.3000	3.8810	0.0000
SQP	5.0508	2.8062	2.0223	0.0000
GA-SQP	0.2450	82.3795	2.0589	0.0000

4 Conclusion

The presented hybrid GA-SQP technique represents the best performance in GZ stability calculation. The accuracy of modeling is dependent on the generation time of the process. This procedure is able to shift to the SQP technique to get the process faster and shift back to the GA techinique to find other better solutions until the convergent solution is guaranteed within the required precision. For future research, the emphasis should be on performing an experiment of controllable canting keel system.

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