Generalized Extremal Optimization for Solving Complex Optimal Design Problems

Fabiano Luis de Sousa[1], Valeri Vlassov[1], and Fernando Manuel Ramos[2]

[1] Instituto Nacional de Pesquisas Espaciais – INPE/DMC – Av. dos Astronautas, 1758
12227-010 São José dos Campos,SP – Brazil
{fabiano,vlassov}@dem.inpe.br
[2] Instituto Nacional de Pesquisas Espaciais – INPE/LAC – Av. dos Astronautas, 1758
12227-010 São José dos Campos,SP – Brazil
fernando@lac.inpe.br

Recently, Boettcher and Percus [1] proposed a new optimization method, called Extremal Optimization (EO), inspired by a simplified model of natural selection developed to show the emergence of Self-Organized Criticality (SOC) in ecosystems [2]. Although having been successfully applied to hard problems in combinatorial optimization, a drawback of the EO is that for each new optimization problem assessed, a new way to define the fitness of the design variables has to be created [2]. Moreover, to our knowledge it has been applied so far to combinatorial problems with no implementation to continuous functions.

In order to make the EO easily applicable to a broad class of design optimization problems, Sousa and Ramos [3,4] have proposed a generalization of the EO that was named the Generalized Extremal Optimization (GEO) method. It is of easy implementation, does not make use of derivatives and can be applied to unconstrained or constrained problems, non-convex or disjoint design spaces, with any combination of continuous, discrete or integer variables. It is a global search meta-heuristic, as the Genetic Algorithm (GA) and the Simulated Annealing (SA), but with the *a priori* advantage of having only one free parameter to adjust. Having been already tested on a set of test functions, commonly used to assess the performance of stochastic algorithms, the GEO proved to be competitive to the GA and the SA, or variations of these algorithms [3,4].

The GEO method was devised to be applied to complex optimization problems, such as the optimal design of a heat pipe (HP). This problem has difficulties such as an objective function that presents design variables with strong non-linear interactions, subject to multiple constraints, being considered unsuitable to be solved by traditional gradient based optimization methods [5]. To illustrate the efficacy of the GEO on dealing with such kind of problems, we used it to optimize a HP for a space application with the goal of minimizing the HP's total mass, given a desirable heat transfer rate and boundary conditions on the condenser. The HP uses a mesh type wick and is made of Stainless Steel. A total of 18 constraints were taken into account, which included operational, dimensional and structural ones. Temperature dependent fluid properties were considered and the calculations were done for steady state conditions, with three fluids being considered as working fluids: ethanol, methanol and ammonia. Several runs were performed under different values of heat transfer

E. Cantú-Paz et al. (Eds.): GECCO 2003, LNCS 2723, pp. 375–376, 2003.

rate and temperature at the condenser. Integral optimal characteristics were obtained, which are presented in Figure 1.

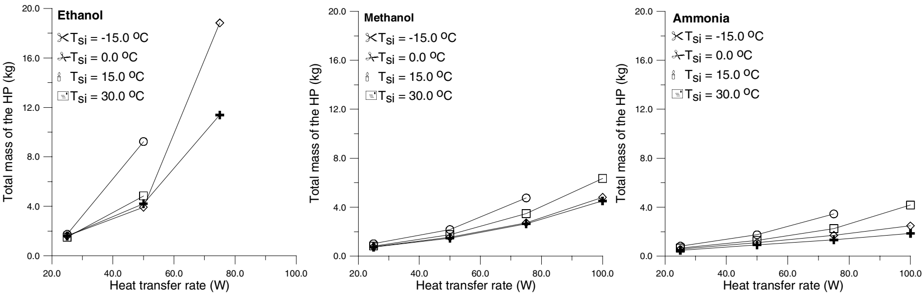

Fig. 1. Minimum HP mass found for ethanol, methanol and ammonia, at different operational conditions.

It can be seen from these results, that for moderate heat transfer rates (up to 50 W), the ammonia and methanol HPs display similar results in terms of optimal mass, while for high heat transfer rates (as for Q = 100 W), the HP filled with ammonia shows considerably better performance. In practice, this means that for applications which require the transport of moderate heat flow rates, cheaper methanol HPs can be used, whereas at higher heat transport rates, the ammonia HP should be utilized. It can be also seen, that the higher the heat to be transferred, the higher the HP total mass. Although this is an expected result, the apparent non-linearity of the HP mass with Q (more pronounced as the temperature on the external surface of the condenser T_{si} is increased), means that for some applications there is a theoretical possibility that the use of two HPs of a given heat transfer capability can yield a better performance, in terms of mass optimization, than the use of an single HP with double capability. This non-linearity of the optimal characteristics has an important significance in design practice and, thus, should be further investigated. These results highlight the potential of the GEO to be used as a design tool. In fact, it can be said that the GEO method is a good candidate to be incorporated to the designer's tools suitcase.

References

1. Boettcher, S. and Percus, A. G.: Optimization with Extremal Dynamics, Physical Review Letters, Vol. 86 (2001) 5211–5214.
2. Bak, P. and Sneppen, K., "Punctuated Equilibrium and Criticality in a Simple Model of Evolution", *Physical Review Letters*, Vol. 71, Number 24, pp. 4083–4086, 1993.
3. Sousa, F.L. and Ramos, F.M.: Function Optimization Using Extremal Dynamics. Proceedings of the 4th International Conference on Inverse Problems in Engineering, Rio de Janeiro, Brazil, (2002).
4. Sousa, F.L., Ramos, F.M., Paglione, P. and Girardi, R.M.: A New Stochastic Algorithm for Design Optimization. Accepted for publication in the AIAA Journal.
5. Rajesh, V.G. and Ravindran K.P.: Optimum Heat Pipe Design: A Nonlinear Programming Approach. International Communications in Heat and Mass Transfer, Vol. 24, No. 3, (1997) 371–380.