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Optimum design of rotor-bearing system stability performance comparing an evolutionary algorithm versus a conventional method

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Abstract

The main intent of this paper is to formulate, demonstrate, and validate a practical means of implementing an evolutionary optimization technique in a rotor-bearing system. The optimum design of a flexible rotor supported on three-lobe bearings is studied for the optimal performance considering system stability along with other design criteria such as fluid film thickness, power loss, film temperature, and film pressure using the genetic algorithm and the method of feasible directions. The results for different operating speed values obtained and presented in this study are to provide a comparison of these two methods, and to show the potential of the genetic algorithm in optimization of rotor-bearing systems. The genetic algorithm obtained reasonably good results for the objective function and comparable to the method of feasible directions. Thus, the genetic algorithm provides the designer an alternative design optimization approach for rotor-bearing systems.

Keywords: Genetic algorithm; Method of feasible directions; Rotor-bearing system; Optimization

1. Introduction

Today's availability of remarkably powerful personal digital computers has permitted more and more detailed analytical models of the basic physics associated with the rotor-bearing system. Many different numerical optimization techniques have been developed and used for design optimization of rotor-bearing systems in Refs. [1–3]. Most of these techniques are based on gradient methods. These methods are reasonable effective for well-behaved objective functions. This is because of the gradient of function helps to guide the direction of the search. However, when the continuity and existence of derivatives of the function are not presented, gradient methods lack robustness and trap in local optima. The development of faster computer has given chance for more robust and efficient optimization methods. One of these robust methods is the genetic algorithm, which has gained recognition as a general problem solving technique in many applications [4]. The genetic algorithm is a guided random search technique. Its parameter search procedures is based on the idea of natural selection and genetics [4]. It uses objective function information instead of derivatives as in gradient-based methods. Numerical search techniques are good at exploitation but not exploration of the parameter space. They focus on area around the current design point, using local gradient calculations to move to a better design. Since there is no exploration for all regions of parameter space, they can easily be trapped in local optima [5]. The genetic algorithm is a class of general purposes algorithm that can make a remarkable balance between exploration and exploitation of the search space [5,6]. The genetic algorithm is new to the field of the rotor-bearing system analysis, and in current literature there is limited work in the area of the rotor-bearing system using the genetic algorithm. The studies by Saruhan et al. [7,8] focus on the use of the genetic algorithm in developing a global objective optimization for fixed pad journal bearing and tilting pad journal bearing, respectively.

2. Optimization procedures

The complexity and time consuming nature of the design process of the rotor-bearing system warranted the

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Nomenclature

$a(i)$	decimal value of string
f_p	film pressure constraint
f_q	lubricant flow constraint
f_t	film temperature constraint
f_u	orbital displacement constraint
g_j, g_k	constraints
l	chromosome length
$NCON$	number of constraints
NDV	number of design variables
NIC	number of inequality constraints
P	penalty function
χ_1	pad arc length
χ_2	pad groove arc length
W	resultant
Θ_W	resultant angle from x-axis
L_G	gravity load
r_b	bearing radius
r_j	penalty coefficients
r_p	radius of curvature of pad
r_s	journal radius
$x(i)$	variables vector
ε	precision
β_i	growth factor
ω_i	damped natural frequency
π	constant: 3.14159…
n_p	number of lobs
Q_s	total amount of lubricant expelled from the sides of bearing
α_c	ratio of chamfer flow to total supplied lubricant flow
γ_i	lubricant inlet density
p_i	system lubricant pressure
δ_g	clearance space between lubricant groove and orifice diameter

development of new methodologies which would simplify and speed up the design process. In this paper, the method of feasible directions and the genetic algorithm applied to the optimum design of the rotor-bearing system performance. The method of feasible directions is a numerical search method which starts with an initial guess and proceeds iteratively searching through the feasible region for an optimal solution. The method of feasible directions was first developed by Zoutendijk [9] and then modified by Vanderplaats [10] for more efficient and robust. The method of feasible direction is based on observation that a search direction, S_i, is found such that a small move along it would produce an improvement in the objective function value without violating the active constraints:

$$X_{i+1} = X_i + \alpha S_i, \tag{1}$$

where i represents the iteration number, S the direction of movement, the scalar quantity α defines the distance of movement (search quantity) that must move along direction, and X_{i+1} the final point obtained at the end of ith iteration. The choice of S_i depends on the position of point X_i. The algorithm is formulated in the following form:

$$\text{Maximize}\, f(X), \tag{2}$$

$$\text{Subject to}\; g_j(X) < 0, \tag{3}$$

$$g_j(X) = 0 \quad j = 1, \ldots\ldots, NC\ (\text{number of constraint}), \tag{4}$$

where f and g_j are objective and constraint functions, and X is an n-vector of design variables. Mathematically, the usability and feasibility requirement for the search direction vector, S, can be expressed as follows:

$$\nabla f(X_i)\, S \leqslant 0 \text{ usability}, \tag{5}$$

$$\nabla g_j(X_i)\, S \leqslant 0 \text{ feasibility}, \tag{6}$$

where $\nabla f(X_i)$ is the gradient of the objective and $\nabla g_j(X_i)$ is the gradient of the jth active constraint computed at point X_i. Reader can refer to detailed information about this technique by Vanderplaats [10]. The algorithm outlined in Fig. 1 utilizes the method of feasible directions in order to find optimum design parameters that meet the specific design criteria.

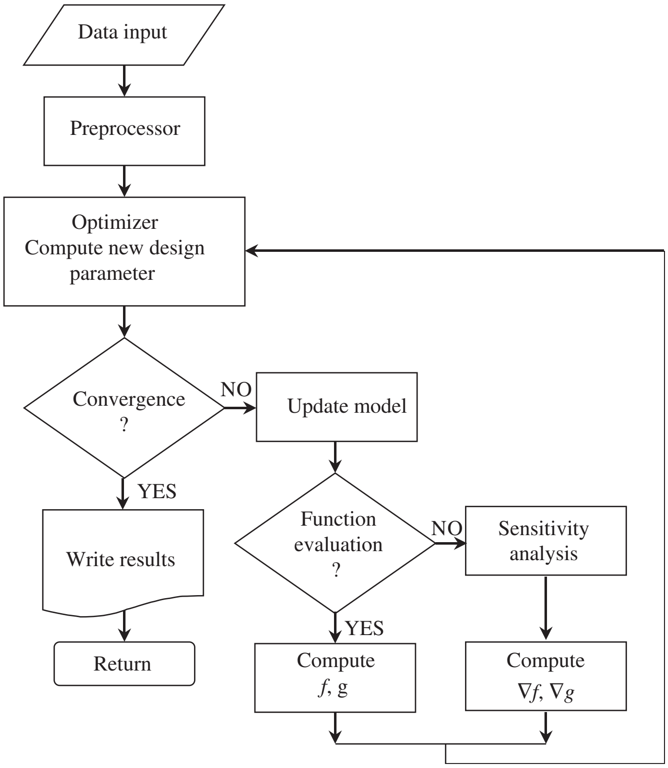

Fig. 1. Constrained optimization algorithm.