SPLIT JOURNAL BEARINGS DESIGN OPTIMIZATION USING MULTI OBJECTIVE GENETIC ALGORITHM

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ABSTRACT
This paper deals with objective of minimization of oil flow, minimization of temperature rise and minimization of power loss of heavily loaded journal bearings. The case study of sugarcane mills heavily loaded journal bearing is considered for design optimization. Design variables like length to diameter ratio, lubricant viscosity, clearance, eccentricity ratio and journal speed are considered for design optimization. Hybrid solution scheme of journal bearings is used for constructing multi objective function. In the design of journal bearings l/d ratio, clearance, viscosity of lubricant, speed and eccentricity ratio are considered as designed variables. A genetic algorithm with pareto optimality concept is used to eliminate difficulty of selecting weighting factor for multi objective optimization problem. Pareto optimal set gives superior design vectors. Results of pareto optimal front are tabulated and explained graphically in the paper. Design optimization results shows that optimum range clearance falls in between 208 microns to 269 microns and bounds for clearance is 200 microns to 300 microns. This justifies that larger clearance for cane mill journal bearings will reduce frictional power losses but will increase the oil flow rate. Viscosity of oil shows variation from 0.038 Pa-s to 0.040 Pa-s. A lower value of viscosity of oil is given preference for design considering minimum oil flow rate and minimum temperature rise. Other design variables like length to diameter ratio speed and eccentricity does not show any variations from lower bound to upper bound. Obtained results of optimization are the recommendations for selecting design variables of heavily loaded journal bearings of sugar cane mills.

KEY WORDS: Journal Bearing, Multi Objective Optimization, Genetic Algorithm, Pareto Optimality.

INTRODUCTION

Journal bearings are used in rotating machineries of industrial applications due to their large load carrying capacities, less wear and better damping characteristics. In the design of journal bearing nonlinear second order Reynolds equation is solved [1]. Different techniques are used in solving Reynolds equation like finite bearing approximations, infinite bearing approximations, finite difference methods, etc. [2-5]. Results of short bearing approximations are suitable for smaller eccentricity ratios and smaller length to diameter ratio, whereas results of long bearing approximations are suitable of larger eccentricity ratio and length to diameter ratio. In the present paper journal bearing design table provided by the hybrid approach [6] of solving Reynolds equation is used for multi objective optimization problem of heavily loaded journal bearing. Performance of journal bearing depends on variables like viscosity of oil, radial clearance, length to diameter ratio and supply pressure.

The optimization problem of journal bearing is related to three tasks, namely to obtain a precise function for the evaluation of journal bearing performance, develop optimization objectives along with design variable constraints and select rapidly converging optimization technique to obtain global minima or maxima for defined objectives. Multi-objective optimization of bearings can be viewed as a minimization of temperature increase and side leakage [7, 8]. Optimization of high-speed, short journal bearings ($0.2 < \lambda < 0.6$) using weighting and scaling factors to combine the two objective functions into one multi-objective function was achieved [7-10]. However, this has the disadvantage that the designer must have prior knowledge about the relative importance of each objective. Optimization of journal bearing by minimizing the leakage and power loss, considering them as two 'independent axioms' was done [11, 12]. An alternative approach to multi-objective optimization, namely Pareto optimal fronts was used [13, 14]. This approach uses *a* posterior articulation of the weights in that the designer initially generates a number of non-inferior (a set of equally efficient) solutions from which a final decision is made on any one solution. Aggregate several performances using a scaling and weighting strategy was adopted [17]. The scaling and weighting factors are arbitrarily chosen, which determine the generation of a single objective space in which the solution is found in terms of the optimization process and the objective design, a genetic algorithm was used to minimize oil consumption and power loss, which are conflicting, aims [18]. Hence, the optimal choice of parameters for the design of journal bearings is a multivariable and multi objective problem.

The present work deals with objective of minimization of oil flow, minimization of temperature rise and minimization of power loss of heavily loaded journal bearings. The case study of sugarcane mills heavily loaded journal bearing was considered for design optimization. Design variables like length to diameter ratio, lubricant viscosity, clearance, eccentricity ratio and journal speed are considered for design optimization. Hybrid solution scheme of journal bearings is used for constructing multi objective function. In the design of journal bearings length to diameter ratio, clearance, viscosity of lubricant, speed and eccentricity ratio are considered as designed variables.

OPTIMIZATION METHODOLGY

Real time applications of engineering involve multiple and conflicting objectives with complexities of search variables. Variables which are to be searched either has too large range or too complex constraints. An efficient optimization technique is required to deal with such complex problems. Many Genetic algorithms are used to solve multi objective optimization problem. Pareto optimality concept is popularly used for solving multi objective optimization problem.

The case study of sugarcane mills heavily loaded journal bearing is considered for design optimization. Sugar cane crushing mills consists of four rollers as shown in Fig. 1. Three squeezing rolls are arranged in triangular form.

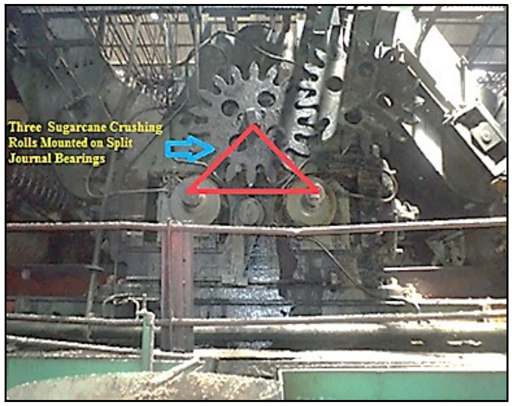

Fig. 1: Three rollers of cane mill arranged in triangular form

Sugarcane is crushed in first stage at crushing rollers and later on squeezed in three squeezing rollers for juice extraction. Squeezed sugar cane called bagasse is discharged from discharge side roller (left). To maximize sugarcane juice extraction, rolls are designed to run at very small speed 3 to 7.5 rpm. In crushing mills all rollers are mounted on split tin bronze (gun metal) bearings as shown in Fig. 2. Cane mill journal bearing under the investigation has the length of 452 mm and the journal diameter 380 mm. The bearing is made by casting process from gun metal (Cu 84%, Sn 10%, Pb 3% and Zn 3%). A centralized lubrication system is implemented for lubricating mills in tandem. Highly viscous black bituminous oil is used as lubricant. A constant supply of lubricant is done to the bearings. Oil is not recirculated back.

Fig.2: Split journal bearings of sugar cane mills

During the design of journal bearings, it is expected that journal bearing should support the load applied on it with minimum size, minimum flow rate, minimum frictonal power loss, minimum temperature rise and minimum wear. Load carrying capacity for journal bearing is evaluated by considering geometrical parameters and viscosity of lubricant used. Reynolds equation is solved for journal bearings to evaluate pressure profile of journal bearing. This pressure profile is then used to find load carrying capacity of journal bearing. Frictional power loss is evaluated from friction force and velocity of journal bearing. Wear of bearing is minimized by maximizing fluid film thickness, minimizing temperature rise and maximizing lubricating film pressure. Bearing design can be done by the hybrid approach [6].

Design variables can be constrained as per objective function. Every design variable has lower bound and upper bound in design calculations. In cane mill journal bearing optimization, lower limit of oil viscosity is kept as 0.0385 Pa-s and the upper limit as 0.085 Pa-s. Similarly, the lower bound of clearance is 200 microns and the upper bound of clearance is 300 microns. The length to diameter ratio ranges from 0.85 to 1.5. Speed has lower bound 3.5 rpm and upper bound 7.5 rpm. Eccentricity ratio has lower bound of 0.95 and upper bound 0.99.

Minimization of oil flow rate (Q) and minimization of temperature rise (ΔT) are two objectives considered in optimization of cane mill journal bearing. Minimization of temperature rise is interestingly combination of minimization of frictional power loss and maximization of flow rate of lubricant. Genetic algorithm with Pareto optimality concept is used for considering multi objective optimization problem. A computer program was developed for cane mill bearing optimization. A cane mill journal bearing of 452 mm length and lubricant density ρ_0 = 860 kg/m^3 and specific heat C_p= 4190 kJ/kgK are used in the optimization problem. Objective function is

$$\text{Objective } f(x) = \text{Minimize}(\Delta T) \text{ and Minimize}(Q) \quad (1)$$

$$\text{Where } \Delta T = \frac{\varepsilon \times \text{Frictional Force} \times U}{\rho \times C_p \times Q}$$

$$= \frac{\varepsilon}{\rho_o \times C_p} \text{ x } \frac{\text{Power loss}}{Q}$$

Therefore, Eq. 1 becomes

$$\text{Objective } f(x) = \left[\frac{\varepsilon}{\rho \times C_p}\right] \text{x Minimize} \left[\frac{\text{Power loss}}{Q}\right] + \text{Minimize } Q \quad (2)$$

Let, x is design vector consisting of five design variables x(1) = slenderness ratio (l/d), x(2) = Clearance (c) (microns), x(3) = viscosity (μ) (Pa-s), x(4) = speed (N) (rpm), x(5)= eccentricity ratio (ε)

Constraints are

$$0.85 \le l/d \le 1.5$$

$$200 \le c \le 300$$

$$0.0385 \le \mu \le 0.085$$

$$3.5 \le N \le 7.5$$

$$0.95 \le \varepsilon \le 0.99$$

The output obtained from optimization toolbox consists of table with objective function optimum values and pareto optimal values of design variables. The convergence rate of Genetic algorithm depends on probability values of crossover, mutation and stall generation. Good strings are retained and poor strings in fitness function values are rejected, therefore crossover value of 0.9 probability is selected during optimization. Diversity in population depends on mutation value.

RESULTS AND DISCUSSION

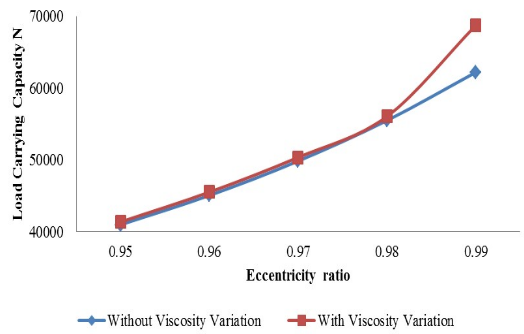

Fig.3: Load carrying capacity journal bearing with and without viscosity variation

Fig. 3 shows load carrying capacity with and without viscosity variation against eccentricity ratios. With the increase in eccentricity ratio there is increase in load carrying capacity of journal bearing.

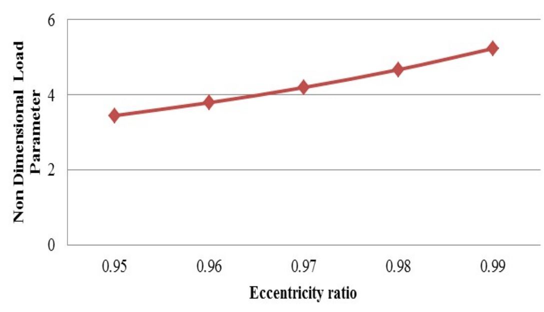

Fig.4: Load carrying capacity variation with respect to eccentricity ratio

Fig. 4 shows that non dimensional load parameter increases with increase in eccentricity ratio. Fig.5 shows that Sommerfeld number reduces with increase in eccentricity ratio; which indicates that there is increase in load carrying capacity

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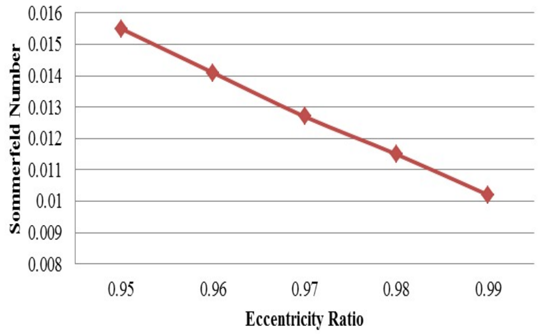

Fig. 5: Sommerfeld number variation with respect to eccentricity ratio

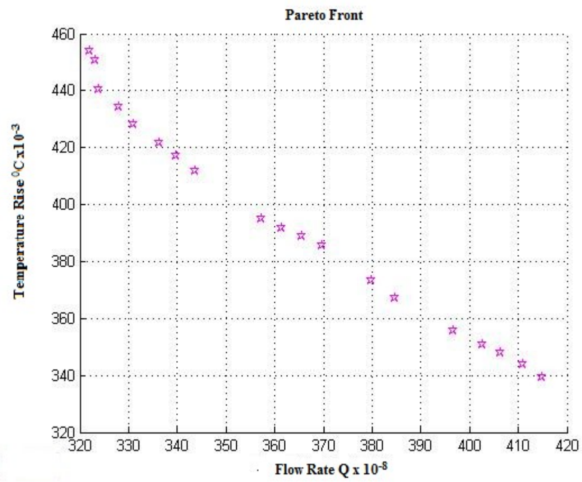

Fig.6: Pareto optimal front for oil lubricated cane mill bearings

Fig. 6 shows the pareto optimal front for objectives flow rate and temperature rise. Non dominated sorted design variables are recognized by Pareto optimality front. This method gives multiple values of design variables, which gives optimum values for objective functions. Wide range for design variables should be used otherwise for narrow range tight tolerance will be obtained. This will lead to increase in manufacturing cost of bearing.

Results in Table 1 (APPENDIX 1) shows that optimum range clearance falls in between 208 microns to 269 microns and bounds for clearance is 200 microns to 300 microns. This justifies that larger clearance for cane mill journal bearings will reduce frictional power loss but will increase the oil flow rate. Viscosity of oil shows variation from 0.038 Pa-s to 0.040 Pa-s. Therefore, high viscosity of oil will increase frictional power loss but low viscosity will increase oil flow rate. A lower value of viscosity of oil is given preference for design considering minimum oil flow rate and minimum temperature rise. Other design variables like length to diameter ratio, speed and eccentricity does not show any variations from lower bound to upper bound. Therefore, in optimum design these variables can be considered insignificant when oil flow rate and temperature rise are given consideration for design. Table 1 suggests lower value of viscosity. The multi objective optimization is done and a set of pareto optimal front is obtained as reported in Table 1. Table includes objective function values for optimized design vectors.

CONCLUSIONS

- Hybrid solution approach is used for formulating multi objective optimization problem of sugar cane mill journal bearing with objectives of minimum oil flow rate and minimum temperature rise.
- Optimum range clearance falls in between 208 microns to 269 microns and bounds for clearance is 200 microns to 300 microns. Viscosity of oil shows variation from 0.038 Pa-s to 0.040 Pa-s.
- A lower value of viscosity of oil is given preference for design considering minimum oil flow rate and minimum temperature rise.
- Other design variables like length to diameter ratio, speed and eccentricity does not show any variations from lower bound to upper bound.

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APPENDIX I

Table 1 Objective function values with optimized design parameters for oil luricated cane mill bearings

Index	Flow Rate Q x 10^{-6}	Temperature Rise °C	Journal Dia. (d) m	Clearance microns	Viscosity Pa-s	Speed rpm	Eccentricity Ratio
4	4.1491	0.33951	0.3000	268.74	0.0386	3.5134	0.950009
9	4.1085	0.34393	0.3000	266.05	0.0387	3.5130	0.950071
1	4.0634	0.34814	0.3005	262.33	0.0386	3.5133	0.950167
10	4.0256	0.35103	0.3002	260.42	0.0387	3.5133	0.950073
7	3.9660	0.35562	0.3001	256.75	0.0386	3.5132	0.950051
8	3.8471	0.36747	0.3002	248.86	0.0387	3.5132	0.950081
20	3.7987	0.37356	0.3001	245.83	0.0388	3.5131	0.950067
13	3.6954	0.38568	0.3009	237.92	0.0388	3.5137	0.950088
16	3.6558	0.38882	0.3002	236.51	0.0389	3.5131	0.950081
3	3.6145	0.39170	0.3002	233.88	0.0387	3.5129	0.950078
14	3.5799	0.39501	0.3001	231.33	0.0387	3.5131	0.950046
6	3.4370	0.41205	0.3000	222.57	0.0388	3.5130	0.950052
11	3.3909	0.41725	0.3002	219.75	0.0388	3.5130	0.950073
19	3.3621	0.42181	0.3002	217.51	0.0388	3.5128	0.950072
5	3.3093	0.42823	0.3002	214.06	0.0387	3.5128	0.950128
15	3.2785	0.43448	0.3002	212.09	0.0390	3.5128	0.95008
18	3.2385	0.44041	0.3002	209.60	0.0390	3.5123	0.950079
17	3.2309	0.45059	0.3001	209.18	0.0399	3.5129	0.950095
2	3.2192	0.45405	0.3001	208.47	0.0400	3.5123	0.950078
12	3.2192	0.45405	0.3001	208.47	0.0400	3.5123	0.950078