Optimization methods in machine design as an advance tools for tribology

Aleksandar Marinković[*1], Tatjana Lazović[2], Miloš Sedak[3], Milana Šumarac[4]

Keywords:optimization, machine design, tribology, tool, math lab

1. Introduction

Optimization plays a significant role in process of Machine design in general and each of its components. In real world engineering problems the importance of minimum weight or energy loss are recognized in design of several machine elements, because they affect the whole system performances. Besides those it is also common to minimize an objective functions describing data such as the total volume, the life-time, wear rate or the cost of a structure. There are many optimization methods in use today and this paper presents only few samples aimed to show that it could be an advance tool for applications in machine design and tribology.

2. Optimum design of sliding bearing

Concepts and methods [1] help us to design “the best” system of journal porous metal bearing, as a typical engineering application. Developments of well known software tools for analysis and optimization are help to reach this objective.

2.1. Structural single criteria optimization

For correct operation of porous metal bearing in elasto-hydrodynamic conditions, the values of deformations are very important. In structural analysis elastic deformations and potential energy of deformation were clearly correlated, which was the reason for taking this energy as objective function:

$$\min E_{def}(\overline{\mathbf{x}}) = \min E_{def}(R,H,b,[\sigma_T]) \tag{1}$$

The main supposition in stress analysis was that deformations are only elastic, which makes constraint:

$$g_1(\overline{\mathbf{x}}) = [\sigma_T] - \sigma_i > 0 , \tag{2}$$

where $\sigma_i = \sigma_{Mises}$ is maximal stress value according to the Misses hypothesis, made for sliding bearing model in CATIA structural analysis module [2]. Admissible set of solutions D for this constrained optimization problem can be now written in the form of equation:

$$D_{\text{opt}} = \left\{ \overline{\mathbf{x}} \in R^n \mid g_1(\overline{\mathbf{x}}) > 0 \right\} . \tag{3}$$

By simulated-annealing (SA) [3], as a relative new stohastic method, folowing results are obtained by Engineering Optimizer modul in CATIA software tool.

Table 1: Variable vector and objective values

Model	Variables				Objective function
	$x_1 = R_s$	$x_2 = H$	$x_3 = b$	$x_4 = [\sigma_T]$	min E_{def}
	mm	mm	mm	N/mm^2	J
starting	15	5	20	85	0.3213
optimum	14,48	4,82	19,61	100	0.304

Optimal (minimum) objective function gives 5% reduced value of potential deformation energy compared with the sliding bearing model from start. Bearing dimensions, as variables presented in Table 1 following with results of optimization process show that optimized bearing size is a bit smaller than original.

2.2. Multi-criteria optimization

In aim to solve this optimum design problem it is necessary to define some bearing parameters and specially in case of hydrodynamic lubrication, clearance value and several tribological performances. This will be used to determinate objective function(s), variables and the functional constraints in optimum design process. In this optimization case, objective functions could be minimum mass, minimum working temperature and also minimum friction coefficient [4].

$$f_1(\overline{\mathbf{x}}) = m , \tag{4}$$

$$f_2(\overline{\mathbf{x}}) = t = \frac{W\upsilon}{kA}\mu + t_0 , \tag{5}$$

$$f_3(\overline{\mathbf{x}}) = \mu . \tag{6}$$

Bearing parameters to optimize are as follows:

$$\overline{\mathbf{x}} = \mathbf{x}\left(d, \frac{c}{r}, \frac{b}{d}, \frac{H}{d}, P, \eta, \varepsilon\right) , \tag{7}$$

and admissible set of solutions, can be presented as:

$$D_{opt} = \left\{ \overline{\mathbf{x}} \in R^n \mid g(\overline{\mathbf{x}}) > 0 \wedge h(\overline{\mathbf{x}}) = 0 \right\} . \tag{8}$$

For those optimization problems Monte Carlo method is suggested, based on interactive dialogues leading to Pareto-optimal solution, where the compromise solution for the corresponding problem is last decision of the engineer / designer, among models in Table 2:

Table 2: Pareto optimal objective functions

Model	Objective functions		
	$f_1(\overline{\mathbf{x}}) = m$	$f_2(\overline{\mathbf{x}}) = t$	$f_3(\overline{\mathbf{x}}) = \mu$
	[g]	[$^{\circ}$C]	-
198	18	36,5	0,039
610	10	38,6	0,044
686	14	36,9	0,040
1166	17	36,6	0,039

After analyze and experimental results, the final compromise solution 1166 is selected, according to (7) is:

$$\overline{\mathbf{x}} = (46{,}9; 0{,}82; 0{,}42; 0{,}35; 25; 755; 0{,}8) . \tag{9}$$

Besides above mentioned sliding and rolling bearing problems, there are several samples of single criteria or multicriteria optimization in different applications, where need to find "the best" solution for power transmissions are dominant in wide engineering praxis.

3. Optimum design of multispeed gearbox

Among different gear transmissions, very significant place is reserved by planetary transmitters, which are used in many branches of industry regarding to their properties and several advantages. This kind of power transmission unit can handle larger torque loads relative to its compact size than any other gear combination in other standard transmissions. Besides they serve longer time and produce less noise under similar operating conditions. An essential step in design of every power transmission systems is its dynamic analysis. Natural frequencies and vibration modes of every transmission component provides important information for tuning resonances away from operating speeds, minimizing response and optimizing the structural design.

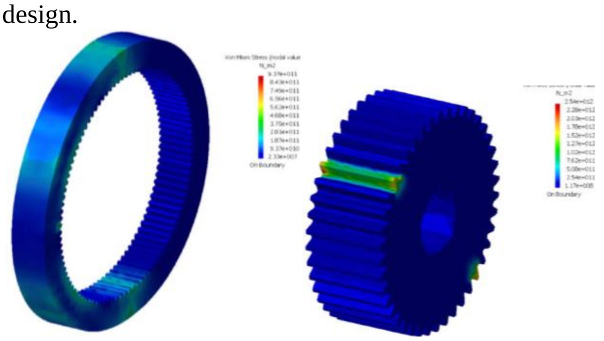

Figure 1: The first mode for internal and planet gear

Based on Von Mises Stress values, the mode of vibration for central and planet gear is predominantly bending in nature. While bending mode of vibration is observed in the first mode, the second mode of vibration exhibit a coupling between bending and torsion.

Using this dynamic analyze of planetary gears, it is possible to make several approaches in optimum design of this transmissions. Here will be presented an approach in optimum design of internal gear targeting its minimum weight.

$$\min m(\bar{x}) = \min m(x_1, x_2, \ldots x_n) \tag{10}$$

The variable vector includes gear dimensions, where constrains are strength safety factor and train components natural frequencies. Admissible set of solutions *D* for this constrained optimization problem can be also written in form of equation:

$$D_{\text{opt}} = \left\{ \bar{x} \in R^n \mid \frac{[\sigma_F]}{[\sigma_F]} - S_F > 0 \wedge \omega_1 - \omega_z^* > 0 \right\}. \tag{11}$$

This complex structural optimization problem was solving using modulus for single criteria optimization in CATIA V5 and results of internal gear optimization shows that its mass could be reduced from m = 9,2 kg to optimal m = 3,3 kg, respecting constrains in form of gear strength and its natural frequencies (11). This results are advantageous and have practical importance, because they are enough to describe vibration behaviour of the planetary transmission structure, where structural analysis results are excellent base for redesign aimed to find an optimal solutions for transmissions concerning requested characteristics where the best solution for gearing design should be a high reliability and efficiency of gearbox [5].

4. Conclusion

This paper is a brief review of wider investigations carried out with the aim to apply powerful optimisation methods in solving wide range of tribology problems. Multi-criteria optimization models very well reflects the design process in which usually several conflicting objectives have to be satisfied. All relevant parameters that effect the sensitivity of the constraints should be identified. The procedure developed in this paper is advantageous because of using Math Lab tools the results could be very practical for engineering application in design of machine elements, such are sliding / rolling bearings, gearings, transmissions etc.

5. Acknowledgement

This work has been performed within the projects TR-35021 and TR-35011. Those projects are supported by the Republic of Serbia, Ministry of Science and Technological Development, which financial help is gratefully acknowledged.

6. References

[1] Arora J.S.: "*Introduction to optimum design*", McGraw – Hill, New York, USA , 1989.

[2] Marinković A., Rosić B., Petropoulos V.: *Analysis and optimization of dynamically loaded porous metal sliding bearings under conditions of elasto-hydrodynamic lubrication*; Engineering Computations, Emerald, ISSN 0264-4401, Volume 24, Number 3, pp. 255-268, 2007.

[3] Kirkpatrick, S., Gerlatt, C.D. Jr., Vecchi, M.P.: *Optimization by* Simulated *Annealing*, Science No. 220, pp. 671-680, 1983.

[4] Marinković A., Rosić B., Pauschitz A.: *Multicriteria* optimization *as a Tool for Tribology (on sliding bearing example)*; Tribology Colloquium, Volume II, pp.905-910, Stuttgart / Ostfildern, Germany, 2004.

[5] Marinković A., Rosić B: *Gears simulation with optimization possibilities*, Proceedings of OETG International Tribology Symposium - "Reliability Engineering", Proceedings pp. 55-62, St. Pölten, Austria, Nov. 2007.

[6] Rosić B., Marinković A., Urošević D.: Dynamic parameters analysis of planetary transmission structure, 2nd International Conference "Power Transmission 06", Proceedings pp.159-162. Novi Sad, Serbia, April 2006.

[*] Corresponding author: amarinkovic@mas.bg.ac.rs

[1] University of Belgrade, Mechanical Engineering Faculty, Belgrade, Serbia; amarinkovic@mas.bg.ac.rs

[2] University of Belgrade, Mechanical Engineering Faculty, Belgrade, Serbia; tlazovic@mas.bg.ac.rs

[3] University of Belgrade, Mechanical Engineering Faculty, Belgrade, Serbia; msedak@mas.bg.ac.rs

[4] University of Belgrade, Mechanical Engineering Faculty, Belgrade, Serbia; msumarac@outlook.com