Optimal design of multiple disc clutch brake using hybrid meta-heuristic algorithm

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***Abstract*— In mechanical design, metaheuristic algorithm were used to find optimal design of mechanical element but in some case this methods cannot reach the optimal solution so engineer tries to surpass those limitation by developing new algorithm or modified the older one by making combination between the metaheuristic algorithm that are already exist. This process is called hybridization. Nowadays, Hybrid algorithms play a prominent role to solve real-life optimization problem and applications in the industry.**

In this work, we proposed a new hybrid algorithm combine two metaheuristic algorithm: the differential evolution and particle swarm optimization algorithms. The algorithm was tested on well knowing mechanical design problem and the results are compared to other optimization algorithm from literature.

Keywords—differential evolution, particle swarm, Hybridization, Multiple disc clutch brake, meta-heuristic

I. INTRODUCTION

Design can be represented as a process of taking of optimal decisions during solving design problem. Design optimization is still till this date an active field of research, which explores the best parameter values of a given problem under the specified conditions. Machine Design or Mechanical Design can be defined as the process by which resources or energy is converted into useful mechanical forms as per the needs of the human beings. In similar way all the components of the car, including engine, have to be designed so that they optimally meet all the functional requirements at lowest possible cost. Clutches and brake are one of the most useful elements of the car that is widely used by engineering to transmit power from one rotating device to a second non-rotating device. Clutches are power transmission device which permit the connection and disconnection of shafts at our will without stopping the driving machine. They are commonly found on automobile and some machine tools [1].

Over the last decades, the design optimization of multiple clutch get the attention of many engineers where numerous studies have been investigated using different optimization algorithm. Naunheimer and Bertha [2] point out the effect of design parameters on the friction clutch design. Also, they present different types of design for the clutch plate for commercial vehicles and passenger cars.

Optimization of shape and design parameters of the rigid clutch disc using FEM have been presented by Oday and al. [3] in order to improve the vibrational characteristics of the system and hence the absorption of shocks that occur during clutch engagement. Z.L. Zhou and al. [4] introduced an optimization method based on improved genetic algorithm which has been dedicate to minimize the volume of Dongfanghong-LA3004 tractor shifting clutch and so to improve the performance of the clutch and transmission system. Osyczka [5] developed a multicreteria design optimization methods based on evolutionary algorithms to optimize multiple clutch break design and minimize the stopping time the problem was treated as multiobjectifs problem with sixteen constraint.

Despite the wide use and the effectiveness of metaheuristics algorithms to solve engineering design and in our case to optimize multiple clutch break design; in some cases finding optimal solution which satisfy all the imposed condition become difficult.

To improve the results concerning the search for optima, the hybridization approach has been introduced. Hybridization between the two big metaheuristic approaches: evolution algorithm and swarm intelligence is used to improve the performance of those algorithms to solve the multiple clutch brake problem. Some hybrid versions of DE and PSO include Swagatam Das et al. [6] in which he propose a hybrid version of DEPSO algorithm addressed to solve continuous problem. José Garcia et al. [7] applied the DE mechanism in order to adjust the velocity of the particle in the PSO algorithm. Another version of DEPSO is presented by Xiaobing et al. [8] in which the population was generated either by DE or PSO mechanism according to the algorithm parameters.

In this paper aim is to find the optimum design of a multiple disc clutch brake through a new technique which combine the advantages of differential evolution and particle swarm optimization algorithm by integrating the PSO mechanism in the DE algorithm. The performance of the algorithm was investigated and tested on the design of a multiple disc clutch brake and results were compared to previous studies.

The organization of the remaining paper is as follows. In Sections 2 the basic of DEPSO is briefly explained in detail. In Section 3, detail of the design are introduced .Simulation results, comparisons and the discussion are provided in Section 4. Finally, we conclude the paper in Section 5.

II. BASIC OF DEPSO ALGORITHM

The powerful performance of any metaheuristics algorithm is measured by its capability to balance between the exploration and exploitation process. In the beginning of the search, the algorithm needs to explore the search space then during the search the need of the exploration process is reduces while the need of the exposition process increases. From this point and in order to improve the performance of DE and PSO a new hybrid algorithm call DEPSO is introduced in this section in which DE algorithm is used to explore the search space and maintain the diversity of the population while the PSO is used to update the best solution at each iteration. The combination of this two advantage reduce the possibility to drop in local minimum.

PSO is a population based optimization tool, which could be implemented and applied easily to solve various function optimization problems, or the problems that can be transformed to function optimization problems. As an algorithm, the main strength of PSO is its fast convergence, which compares favorably with many global optimization algorithms [9].

At each iteration, the position and the velocity of particle are updated using the flowing equation:

$$x_i^{(t+1)}=x_i^{(t)}+v_i^{(t+1)} \tag{1}$$

$$v_i^{(t+1)}= v_i^{(t)}+c_1r_{i1}\ (pbest_i^{(t)}- x_i^{(t)}) + c_2r_{i2}\ (gbest- x_i^{(t)}) \tag{2}$$

Where i=1,…, population size, c_1,c_2 are two acceleration constants called cognitive and social parameters, r_1,r_2 are random vector $\in$ [0,1].best local position (pbest) and the overall (global) best position (gbest).

The DE algorithm has shown better performance than many other evolutionary algorithms (EAs) in terms of convergence speed and robustness over several real-world problems, it has many attractive characteristics, such as compact structure, ease to use, good convergence and robustness [10]. DE employs mutation and crossover operators in order to generate a trail vectors, then the selection operator starts to select the individuals in new generation t+1 [11].We present in details the overall process in the pseudo code of the Hybrid DE and PSO (DEPSO) algorithm.

In the DEPSO algorithm the DE algorithm is applied first to generate new solution and the PSO mechanism is integrated in the phase of selection and activate only when the solution found by DE algorithm didn't reach the optimal solution or satisfy the condition.

The pseudo code of the Hybrid differential evolution and particle swarm optimization (DEPSO) algorithm is:

Algorithm: DEPSO

Input: the initial values of control parameters: NP, G_{max}, Var, Cr ,F,c_1 and c_2

Step1: / / Initialization

For i =1 to NP population size do

Generate an initial population X_{ij}

Evaluate the initial population using penalty function to handle constraints

Step2: // Generation Loop

For g=1 to G_{max} do

For j=1 to Var (dimension) do

Generate the trial vector // r_1, r_2, r_3 are Selected randomly such us that $r_1 \neq r_2 \neq r_3$

$V_{i,j}^{g+1}=X_{r1}^{g}+F(X_{r2}^{g}- X_{r3}^{g})$

Select $j_{rand} \in$ Var

If (rand () < CR or j = jrand) // rand () denotes a uniformly distributed random
number between 0 and 1//

$U_{i,j}^{g+1}= V_{i,j}^{g+1}$

Else

$U_{i,j}^{g+1}= X_{i,j}^{g}$
End if

Evaluate the trial vector using penalty function to handle constraints
If $f(U_{i,j}^{g+1})< f(X_{i,j}^{g})$ then

$X_{i,j}^{g+1}= U_{i,j}^{g+1}$

Else
PSO activated
Find a new particle using PSO mechanism equation (1)

End if
End for
End for.

Output: the best individual with the smallest objective function value in the population.

A. *Parameter Settings*

The parameters of the DEPSO algorithm have been summarized with their assigned values in TABLE I.

TABLE I. PARAMETER SETTING

Parameter	Definition	Value
NP_{DE}	Population size	50
NP_{PSO}		30
G_{max}	maximum number of generations	500
Var	Problem dimension	5
Cr	crossover control parameter	0.8
F	Mutation scale factor	0.2
c_1	Acceleration constant for cognition part	2
c_2	Acceleration constant for social part	2

To show the efficacy of the algorithm on constrained problem one of the well knowing benchmark in mechanical system is the multiple clutch brake design. The major problem of constrained problem is how to deal with violation of constraint. Deb's heuristic constraint handling method [12] based on penalty function is used in this problem. In this technique a penalty factor is added to the objective function value of each infeasible individual to limit constraint violations .the method based on transforming a constrained optimization problem into an unconstrained problem. The new objective function is given as follows:

$$f(x) = \{ f(x) \quad \text{if } x \in \text{feasible region}$$

$$f(x) + \text{penalty}(x) \quad x \notin \text{feasible region}\} \qquad (3)$$

Where

penalty(x) = {0 if no constraints is violated, 1 otherwise }

The detail of benchmark are given in the next section.

III. BENCHMARK PROBLEM AND RESULTS

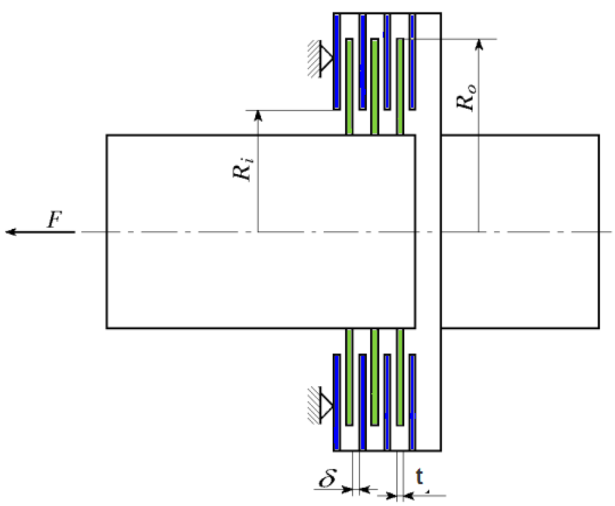

Fig. 1. Multiple disc clutch brake schema

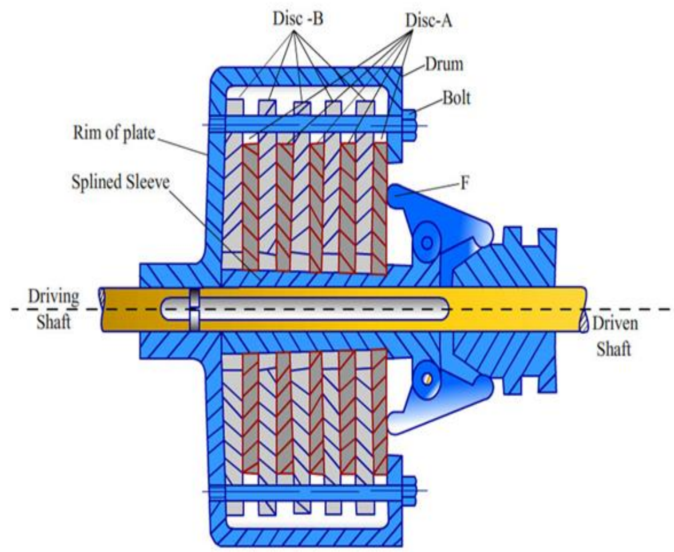

Fig. 2. Multiple disc clutch brake design

A. Optimization of a Multiple Disc Clutch Brake

Fig.1.and Fig 2 shows a multiple disc clutch brake. The objective is to minimize the mass of the multiple disc clutch brake with five discrete variables: inner radius R_i, outer radius R_o, thickness of discs t, actuating force F and number of friction surfaces Z [13].

The problem can be stated as:

Minimize

$$f\,(R_i,\, R_o,\, t,\, F,\, Z)=\pi\,(R_o^2 - R_i^2)\; t\,(Z+1)\rho \qquad (4)$$

The first design constraint considered in this study is imposed on the outer and the inner radii which must be smaller than specified minimum

$$g_1(x)=\Delta_R+R_i-R_o\leq 0 \qquad (5)$$

for the second constraint, the length of the brake must not be greater than the specified maximum

$$g_2(x)=(Z+1)(t+\delta)-I_{max}\leq 0 \qquad (6)$$

The pressure constraint has the form

$$g_3(x)=P_{rz}+P_{max}\leq 0 \qquad (7)$$

The temperature constraint has the form

$$g_4(x)=P_{rz}\, v_{sr}+P_{max}\, v_{sr\,max}\leq 0 \qquad (8)$$

The relative speed of the slip constraint has the form

$$g_5(x)=v_{sr} - v_{sr\ max} \leq 0 \quad (9)$$

The stoping time constraint is

$$g_6(x)=T-T_{max} \leq 0 \quad (10)$$

the generated torque must be greater than the input torque safety

$$g_7(x)= SM_S - M_h \leq 0 \quad (11)$$

The stopping time must not be less than 0

$$g_8(x)= -T \leq 0 \quad (12)$$

Where:

Braking torque M_h is

$$M_h= (2/3)\ \mu FZ\ [(R_o^3 - R_i^3)/90(R_o^2 - R_i^2)] \quad (13)$$

Real pressure P_{rz} is

$$P_{rz=}F/\ \pi\ (R_o^2 - R_i^2) \quad (14)$$

The mean relative speed of the slipstick v_{sr} is

$$v_{sr}=2\ \pi\ n\ (R_o^3 - R_i^3)\ /90(R_o^2 - R_i^2) \quad (15)$$

The stopping time

$$T=I_z\ \pi\ n/30(M_h+M_f) \quad (16)$$

B. Numerical Example

This problem is considerate as a discrete programming problem. Data for the optimization process were as follows:

Discrete values of the decision variables

- R_i={60,61,62,…,80}mm
- R_o={90,91,92,…,110} mm
- t={1,1.5,2,2.5,3}mm
- F={600,610,620,…,1000} N
- Z={2,3,4,5,6,7,8,9}

Parameters for the brake

TABLE II. PARAMETER FOR THE BRAKE

Parameter	Definition	Value
Δ_r	minimum difference between radii [mm]	20
t_{max}	maximum disc thickness [mm]	3
t_{min}	minimum disc thickness [mm]	1.5
I_{max}	maximum length [mm]	30
Z_{max}	Mutation scale factor	10
$v_{sr\ max}$	maximum relative speed of the slipstick [m/s]	10
M	coefficient of friction	0.5
M_s	Static input torque [Nm]	40
M_f	Frictional resistance torque [Nm]	3
N	Input speed [rpm]	250
P_{max}	Maximum allowable pressure on the disc[MPa]	1
I_z	moment of inertia of the working machine [kg mm2]	55
F_{max}	maximum actuating force [N]	1000
T_{max}	maximum stopping time [s]	15
S	factor of safety	1.5
$R_{i\ min}$	minimum inner radius [mm]	55
$R_{o\ max}$	maximum outer radius [mm]	110
ρ	density of material [kg/mm3]	0.0000078

IV. RESULTS AND DISCUSSION

The general performance of the proposed DEPSO algorithm has been investigated by testing it on multiple clutch design problem. This problem is a minimization problem that contain five design variable which are all discrete and subject to eight constraints.

Values for the objective function, design variables and constraints reached by DEPSO algorithm in addition of results for other algorithms including NSGA-II [14], TLBO [15], and AMDE [16] algorithm are reported in TABLE III.

The best, average (mean), worst, standard deviation (SD) of the function values for the multiple clutch design problem are reported in TABLE IV.

TABLE III. PARAMETER AND OBJECTIVE VALUES OF THE BEST SOLUTIONS OBTAINED FOR SPEED REDUCER PROBLEM

algorithm	ABC	NSGA-II	TLBO	AMDE	DEPSO
Design variable					
$\mathbf{r_i}$	70	70	70	70	**70**
$\mathbf{r_o}$	90	90	90	90	**90**
T	1	1.5	1	1	**1**
F	988	1000	810	810	**867**
Z	3	3	3	3	**3**
Constraint					
$\mathbf{g_1}$	0	NA	NA	NA	**0**
$\mathbf{g_2}$	-24	NA	NA	NA	**-24**
$\mathbf{g_3}$	-0,90172	NA	NA	NA	**-0.91376**
$\mathbf{g_4}$	-9,996	NA	NA	NA	**-9.997**
$\mathbf{g_5}$	-9,9649	NA	NA	NA	**-9.9649**
$\mathbf{g_6}$	-3,2147	NA	NA	NA	**-1.6158**
$\mathbf{g_7}$	-59,1775	NA	NA	NA	**-44.582**
$\mathbf{g_8}$	-11,7852	NA	NA	NA	**-13.384**
Objective function					
fmin	0.31366	0.4704	0.31365661	0.31365661	**0.31365661**

TABLE IV. STATISTICAL RESULTS OBTAINED BY DEPSO MULTIPLE CLUTCH BRAKE DESIGN PROBLEM

Statistical	Best	Mean	Worst	SD
DEPSO	0.31365661	0.31365661	0.31365661	2.2316E-16
AMDE	0.31365661	0.31365661	0.31365661	2E-016
TLBO	0.313657	0.3271662	0.392071	NA
NSGA-II	NA	NA	NA	NA
ABC	NA	NA	NA	NA

The solution given by DEPSO algorithm for the proposed problem shows that the proposed algorithm can obtain the optimal or near optimal solution when compared with ABC, TLBO, AMDE algorithms while it's better than the solution founded by NSGA-II

However, it is observed from the statistical results TABLE IV. that DEPSO outperforms TLBO for the best, the mean, and the worst solutions while it's gives a similar result for AMDE. Hence, DEPSO is effective to solve the multiple disc clutch brake design problem.

In addition the developed algorithm offered a small standard deviation value (2.2316E-16) which confirms the robustness of the DEPSO algorithm to solve this problem

The simulation results of the best solution show that the algorithm can achieve the optimal solution for the given problem. As shown in Fig. 3, the performance of the DEPSO is better than the ABC algorithm on the testing suite in terms of the optimization parameters results. DEPSO converges to the global optimum very quickly. So, it is demonstrated that DEPSO is effective and has efficient ability in global search.

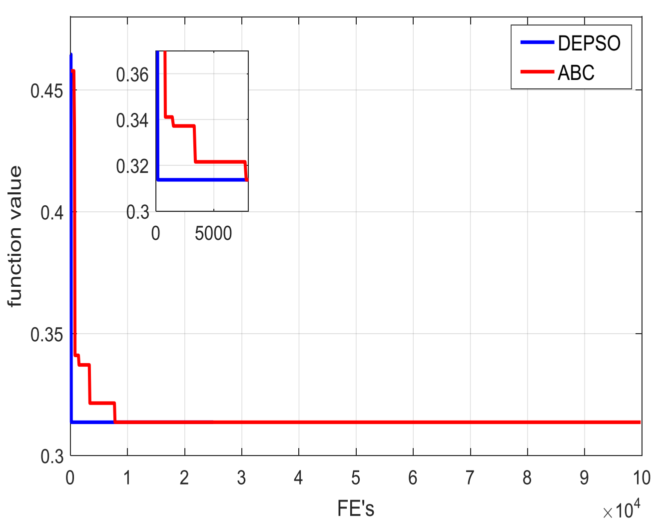

Fig. 3. Evolution of best mean results obtained by DEPSO for multiple clutch brake design

V. CONCLUSION

In the paper, new hybrid optimization methods based on the combination between two metaheuristic algorithms are presented. The main aims of these methods are to overcome the inability of certain metaheuristic algorithms to solve engineering design or to find the optimal solution that lead us to search for new algorithm or make hybridization to the existing one.

This method can be very useful in the design of constrained optimization problems with discrete variable.

The example presented in this paper is a multiple clutch brake design with five design variable and eight constraint. Numerical results show the efficiency of the DEPSO algorithm to find the optimal solution.

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