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Design optimization of a hollow shaft through MATLAB and simulation using ANSYS

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Abstract. Non-Traditional Optimization methods are successfully used in solving many engineering problems. Shaft is one of important element of machines and it is used to transmit power from a machine which produces power to a machine which absorbs power. In this paper, ten non-traditional optimization methods that are ALO, GWO, DA, FPA, FA, WOA, CSO, PSO, BA and GSA are used to find minimum weight of hollow shaft to get global optimal solution. The problem has two design variables and two inequality constraints. The comparative results show that the Particle Swarm Optimization outperforms other methods and the results are validated using ANSYS.

Keywords: ANSYS; hollow shaft; Non-Traditional Optimization; weight minimization

1. Introduction

In machine element, shaft is commonly used for power transmission from one to another place and is mostly has circular cross-section which may be hollow or solid. In order to transfer power different members like pulleys etc., are mounted on it. Shafts are usually subjected to torsion, axial force and bending moment or all the three. The two mostly used shafts are Machine and Transmission shafts. Transmission Shafts transmit power between the machine absorbing power and source. Integral part of the machine itself is Machine shafts. Shafts can be subjected to combinations of torsional loads, bending and axial which may fluctuate or vary with time (Khurmi and Gupta 2005). Chavan *et al. (*2017) has conducted Optimization of composite shaft with TLBO. Rejula Mercy and Elizabeth Amudhini Stephen (2018), Yildiz *et al.* (2019) have conducted study on recent Non-traditional Methods. Elizabeth Amudhini Stephen *et al.* (2018) solved the speed reducer problem to obtain global optimum solutions and the best method was found by comparing the results with nine other optimization methods. The publications (Thamaraikannan and Thirunavukkarasu 2014, Marde, *et al.* 2019) are considered also with hollow shaft in which Teaching-learning based optimization and Cohort Intelligence is investigated. Lot of meta-heuristics methods are developed, in which mostly particle swam optimization have been proven to outperform

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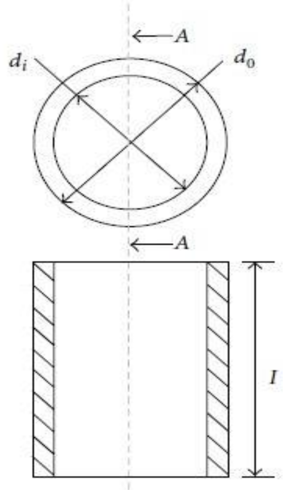

Fig. 1 Hollow shaft

their other methods in terms of speed and consistency (Kennedy and Eberhart 1995). Hollow Shaft diagram is given in the Fig. 1.

The objective of this paper is to minimize the weight of the hollow shaft which is organized as follows. In Section 2 Mathematical formulation, Section 3 comparative results, Section 4 simulation for validating optimized results, section 5 conclusion from simulation. The final conclusion is summarized in Section 6.

2. Mathematical formulation

The objective function W_s is to weight minimization of hollow shaft subject to the constraints of the outer diameter of hollow shaft $d_0=x_1$ and ratio of inner to outer diameter $k=x_2$. (Thamaraikannan and Thirunavukkarasu 2014)

Minimize $W_s=0.326 \quad x_1^2(1-x_2^2)$

subject to constraint:

$$x_1^4(1-x_2^4)\text{ -1736.93 } \geq 0 \tag{1}$$

$$x_1^3(2\times10^5)(1-x_2)^{2.5}\text{ - }0.4793 \leq 0 \tag{2}$$

and $x_1, x_2 \geq 0$

The ranges of variables are:

$$7 \leq x_1 \leq 25,$$
$$0.7 \leq x_2 \leq 0.97$$

where

x_1 is outer diameter of hollow shaft

x_2 is ratio of inner diameter to outer diameter

Table 1 Comparative results of 10 non-traditional optimization methods

Trial No.	ALO	GWO	DA	FA	FPA	WOA	CSO	BA	PSO	GSA
x_1, cm	8.5	8	8.02	9	8.43	7.835	8	7.9	7	8.5
x_2, cm	0.94236	0.9654	0.94976	0.9685	0.94637	0.958104	0.947575	0.94879	0.9699	0.9611
Time, seconds	0.785255	0.7589	0.772395	0.777175	0.777785	0.775248	0.7578	0.78361	0.7543	0.779699
Weight, kg	2.351465	2.2587	2.29165	2.3252	2.478255	2.37421	2.2356	2.405925	2.2253	2.412085

Table 2 Boundary values

	d_0 (= x_1)		k (= x_2)	
	cm	mm	cm	mm
Upper Bound	25	250	0.97	9.7
Lower Bound	7	70	0.7	7
Optimum (PSO)	7	70	0.9699	9.699

3. Comparative results

The ten non traditional methods are run for 20 trails and the average is taken and the results were compared. The Comparative results are tabulated in Table 1.

x_1=d_0 is the outer diameter of hollow shaft, cm

x_2=k is the ratio of the inner to the outer diameter, cm

4. Simulation for validating optimized results

The hollow shaft was designed according to the given dimensions. Nickle cobalt chromium alloy material was taken as the material of the shaft (Bansal 2018). The ends of the shaft were fixed and the shaft was subjected to twisting moment of 1.0×105 kg-cm. The boundary values are tabulated in Table 2.

4.1 Upper boundary results

The mesh is generated for Upper boundary geometry that given in Fig. 2 and it is seen that the mesh flow is continuous.

The total deflection under twisting moment of the hollow shaft is given in Fig. 3 and deformation is 0.021609 mm which is under the allowable maximum deflection 2 mm for a shaft of length 500 mm.

Stress under twisting moment in the hollow shaft for upper boundary geometry for is shown in Fig. 4 and is 24.28 MPa which is under the ultimate tensile strength of material i.e., 965 MPa.

4.2 Lower boundary results

The mesh is generated for Lower boundary geometry is given in Fig. 5 and it is seen that the mesh flow is continuous.

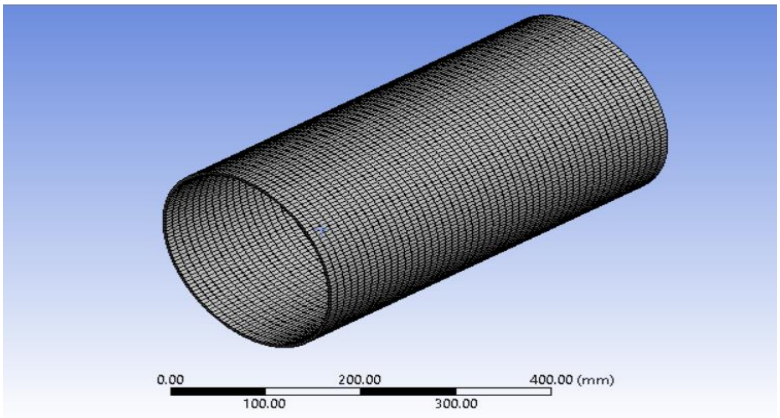

Fig. 2 The meshing of the Upper boundary geometry

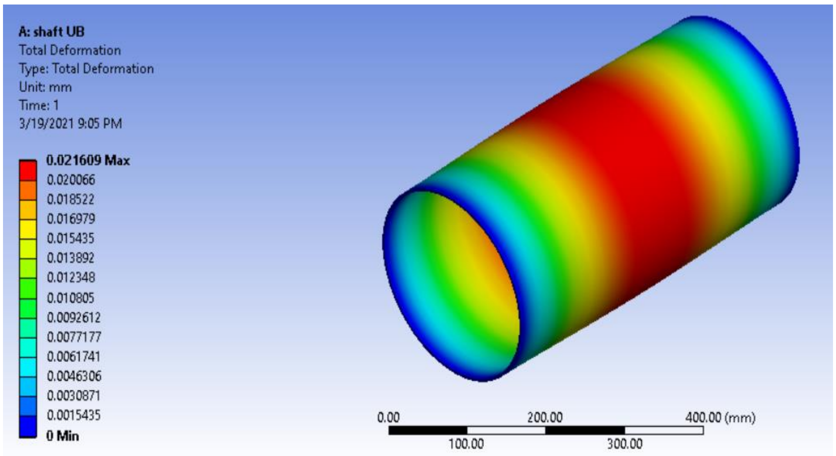

Fig. 3 Deflection under twisting moment

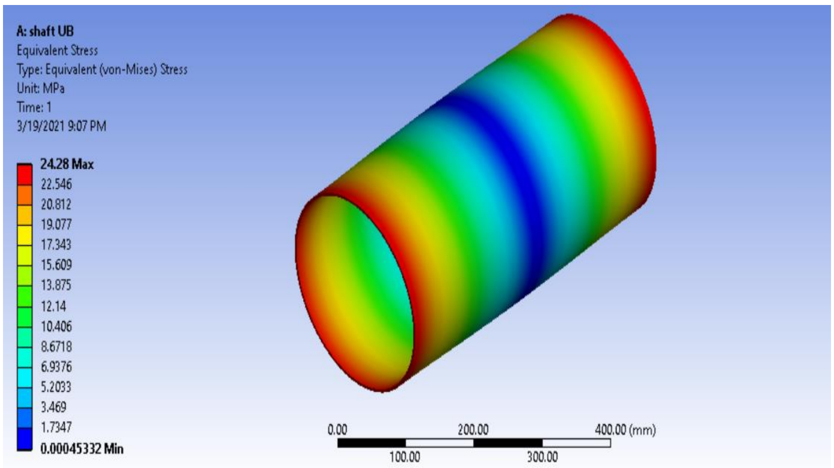

Fig. 4 Stress under twisting moment

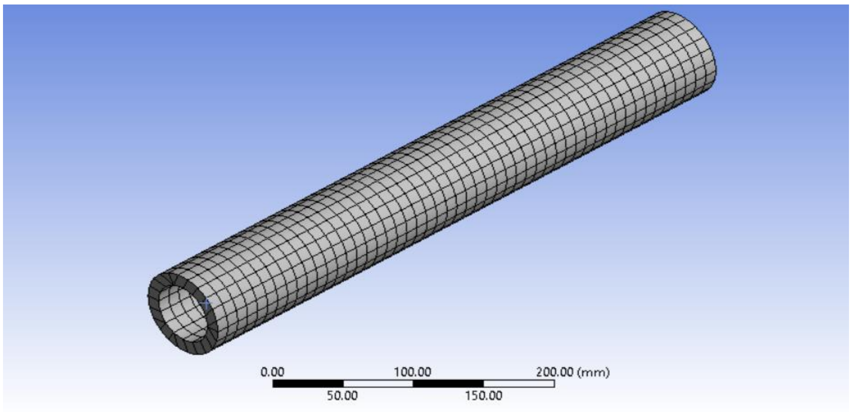

Fig. 5 The meshing of the lower boundary geometry

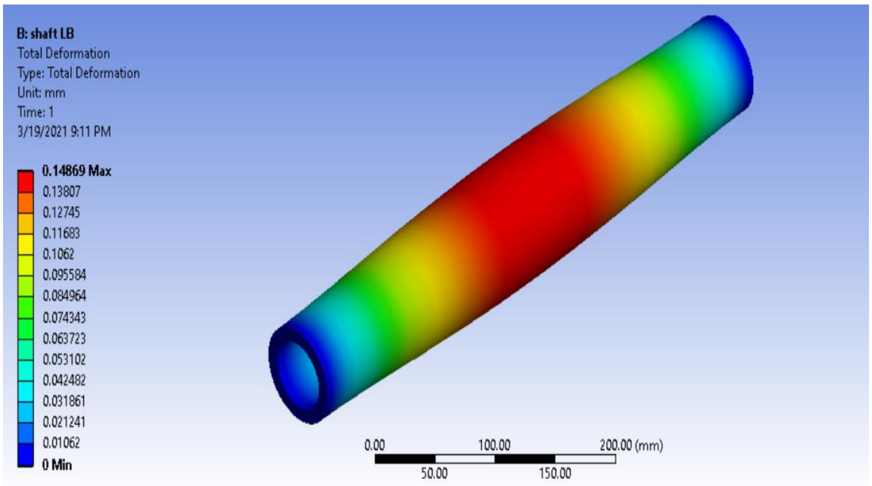

Fig. 6 Deflection under twisting moment

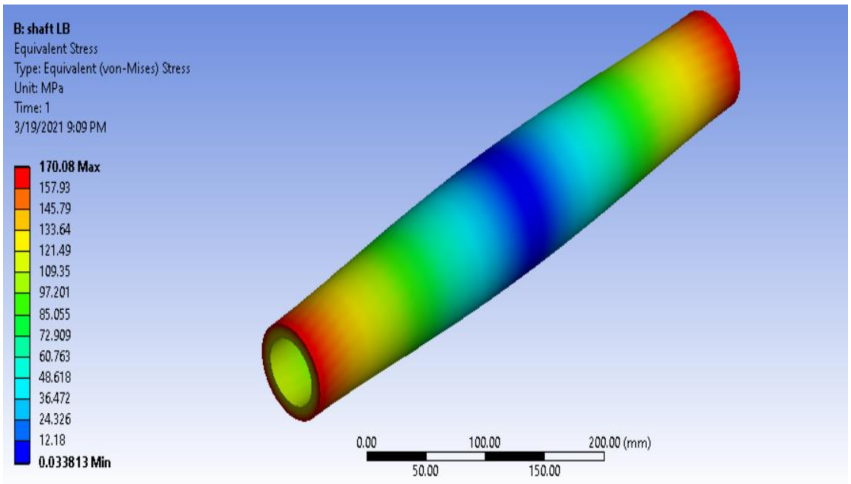

Fig. 7 Stress under twisting moment

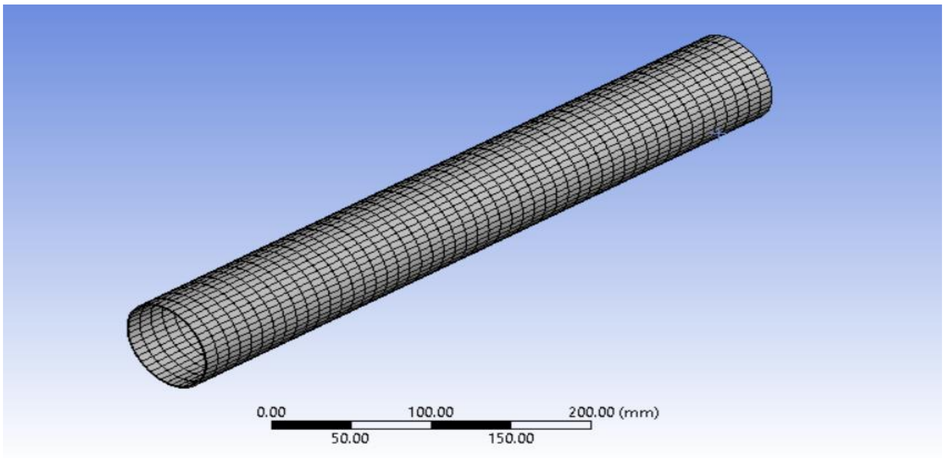

Fig. 8 The meshing of the optimum boundary geometry

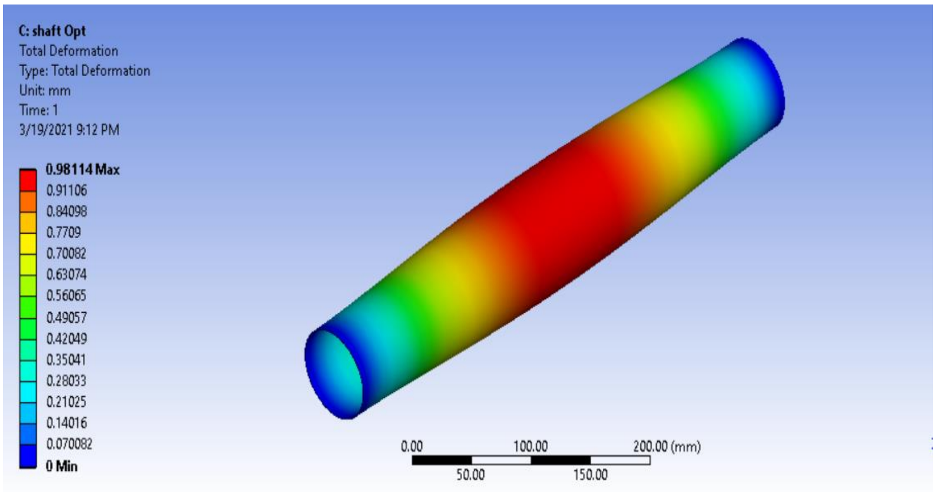

Fig. 9 Deflection under twisting moment

The total deflection under twisting moment of the hollow shaft is given in Fig. 6 is 0.14869 mm which is under the allowable maximum deflection of 2 mm for a shaft of length 500 mm.

The stress developed in the hollow shaft for lower boundary geometry for twisting moment is shown in Fig. 7 is 170 MPa which is under the ultimate tensile strength of material i.e., 965 MPa.

4.3 Optimal boundary results

The mesh is generated for optimum boundary geometry is given in Fig. 8 it is evident that the mesh flow is progressive without any discontinuity.

The total deformation of the hollow shaft for optimum boundary geometry for twisting moment is given in Fig. 9 is 0.98114 mm which is under the allowable maximum deflection 2 mm for a shaft of length 500 mm.

The stress developed in the hollow shaft for optimum boundary geometry for twisting moment

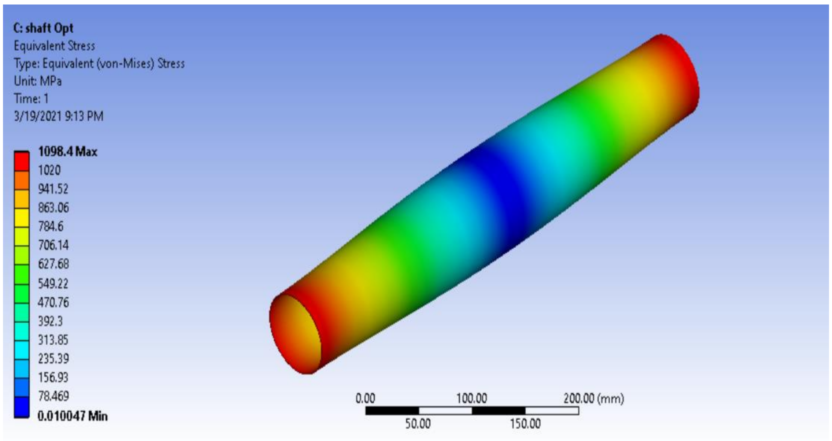

Fig. 10 Stress under twisting moment

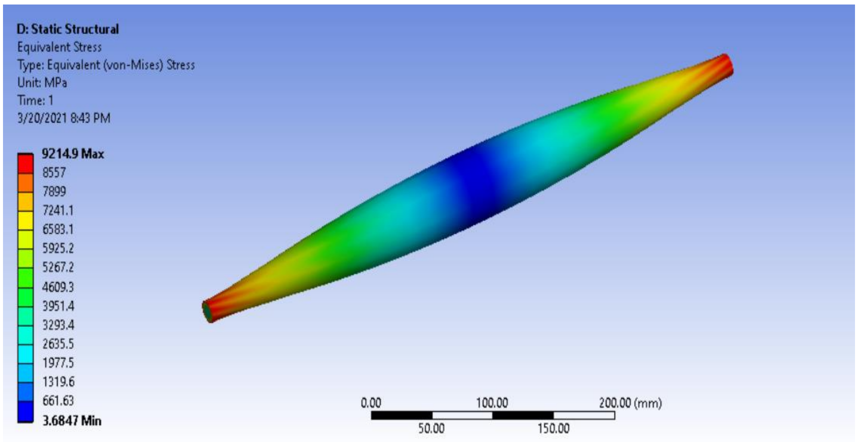

Fig. 11 Stress under twisting moment for a solid shaft of weight 0.09318 Kg

is shown in Fig. 10. Stress developed in the hollow shaft is 1098.4 MPa which is more the ultimate tensile strength of material i.e., 965 MPa. (Christu Nesam David and Elizabeth Amudhini Stephen 2018)

However, the weight of the shaft is 0.9318 Kg for the optimum value geometry which is very low as compared to 11.487 Kg and 8.015 Kg for upper boundary geometry and lower boundary geometry respectively.

Furthermore, for the same weight solid shaft in Fig. 11 show that the stress value is very high as compared to the hollow shaft at the optimal values.

5. Conclusion from simulation

The hollow shaft problem has been simulated for different geometry that is Upper boundary, Lower boundary and optimum boundary. Lower boundary and upper boundary geometry leads to failure of the model. The simulation was repeated with optimized boundary condition. The weight of the hollow shaft for the optimum value geometry which is very low compared to lower boundary and upper boundary geometry respectively.

6. Conclusions

Design Optimization of a Hollow Shaft with two design variables i) x_1 is outer diameter of hollow shaft ii) x_2 is ratio of inner to outer diameter. The objective was to minimize weight of the Hollow Shaft.

We have used MATLAB to solve the Hollow Shaft problem. Ten non- traditional Optimization methods were used to solve the problem and concluded that Particle Swarm Optimization method gives the minimum weight compared to other methods in terms of simplicity and minimum run time. Hence Particle Swarm Optimization Method would be the best method.

To validate the results, simulation of the design was carried out using ANSYS. The weight of the hollow shaft is 0.9318 Kg for the optimum value geometry which is very low as compared to 11.487 Kg and 8.015 Kg for upper boundary geometry and lower boundary geometry respectively.

Therefore, the optimum value derived from Particle Swarm Optimization was used. It was evident that the total deflection and stress are well within the limit, with minimum cost of manufacturing. PSO can be used for solving other optimization problems.

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