Advance Physics Letter

Design Optimization of Helical gears using Genetic Algorithm: A review

[1]Surendra Kumar Sahu, [2]C.P.Dewangan, [3]Chitrasen Patel

[1]M.Tech Student, [2]Associate Professor, [3]M.Tech Student
Department of Mechanical Engineering, Institute of Technology
Guru Ghasidas Vishwavidyalaya (A Central University), Bilaspur, Chhattisgarh, India
Email: [1]sahusk15sept@gmail.com, [2]cpdewangan@yahoo.com, [3]cspateledu@gmail.com

Abstract : Helical gears have been used for a wide range of engineering and technological applicationsespecially in automobiles,shipbuilding, aircraft and marine applications.The rapid increasing demand for high speed ratio, highly efficient cum light weight engines, with quite power transmission has led to the need for optimization of helical gears being used till today. For optimization of any engineering design initially problem function is formulated then variable parameters are decided which would minimize or maximize the objective function so as to give an optimal system performance.In this review paper,an attempt has been done to collect results and observations of previous researchers who have worked on helical gear design, optimization and genetic algorithm. Based on these observations it can be postulated that the dimensional optimization of beam strength of a helical gear can be efficiently performed by genetic algorithm (GA). GA is a non-traditional effective optimization technique which works optimization on the basic Darwinian concept- survival of the fittest. GA can solve optimization problems using its heuristic structures.

Keywords: Helical gear design, Lewis Equation, optimization, evolutionary algorithm, genetic algorithm.

I. INTRODUCTION

1.1 Helical Gears

Helical gears are similar to spur gears except that their teeth are cut at an angle to the hole (axis) rather than straight and parallel to the axis like they are in the teeth of a spur gear. Helical gears are manufactured as both right and left-handed gears. The teeth of a left-handed helical gear, lean to the left when the gear is placed on a flat surface. The teeth of a right-handed helical gear, lean to the right when placed on a flat surface. In spur gears Fig.1.1(a), the teeth are parallel to the axis whereas in helical gears Fig.1.1(b) the teeth are inclined to the axis. Both the gears are transmitting power between two parallel shafts. [19] At any time, the load on helical gears is distributed over several teeth, resulting in reduced wear. When two helical gears are engaged as, the helix angle has to be the same on each gear, but one gear must have a right-hand helix and the other a left-hand helix. In helical gear the line contact is diagonal across the face of the tooth.

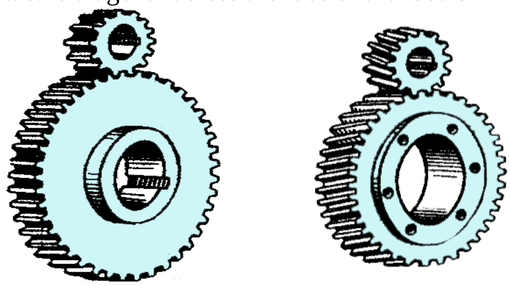

Fig.1.1 (a) spur gear Fig.1.1.(b) helical gear

Hence gradual engagement of the teeth and the smooth transfer of load from one tooth to another occur.[19] Helical gears are capable of providing smoother and quieter operations at the same time transmit heavy loads. They are useful for high speed and high power applications, quiet at high speeds. Helical gears operate with less noise and vibration than spur gears. At any time, the load on helical gears is distributed over several teeth, resulting in reduced wear. Due to their angular cut, teeth meshing results in thrust loads along the gear shaft. This action requires thrust bearings to absorb the thrust load and maintain gear alignment. They are widely used in automobile industries in manufacturing of vehicles and marine ships [20].

1.2 Design of Helical gears

The involute profile of a helical gear tooth is generated by a plane, which is cut with a skewed angle. The plane is then rolled off from a cylinder, which is illustrated in Fig 1.2. The other half of the tooth is generated by rolling of a plane in the opposite direction such that the two planes will intersect each other and thus create a complete helical gear tooth.

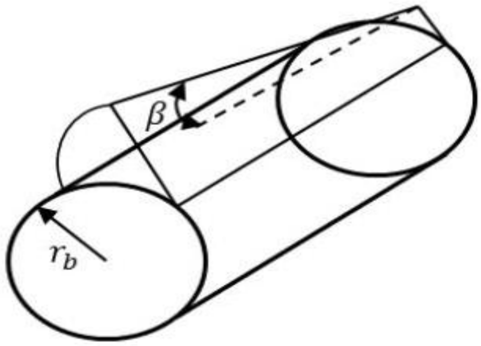

Fig.1.2 Generation of helical gear tooth profile

Steps involved in design of helical gears:

a) Gear design starts with material selection. Proper material selection is very important.
b) Find out the minimum central distance based on the surface compression stress.
c) Minimum normal module is also determined.
d) Determine the Horsepower based on Lewis formula same as spur gear design except the inclusion of helix angle.

$HP_{helical} = HP_{spur}$ * cos(Helix Angle)

e) Calculate the design horse powersame as spur gear.
f) Select the gear / pinion with horse power capacity equal to or more than design horse power.

1.2.1 Based onDedendum strength

Since a helical gear very commonly has a tendency to fail by the base of the root due to inadequate bending strength, it is appreciable to design it based on its beam strength.
Lewis formula is generally employed for flexural stress or beam strength on dedendum.[22]

$$W= F_s \cdot b \cdot m \cdot (y')$$

Where,
F_s: Flexural stress (allowable contact stress) on dedendum (kgf /mm^2)
m: Module (mm)
b: Face width (cm)
(y´): Tooth form modulus (see table 1)
W: Pitch circumferential tangent load (kgf)

The tooth form modulus is selected by standard gear specifications as shown in table 1. In this review it has been added just to provide information about how the tooth modulus form factor is chosen, while gear design. [22]

1.3 Genetic Algorithm

Genetic Algorithms are adaptive heuristic search algorithms based on the evolutionary ideas of natural selection and genetics. Genetic algorithms are a part of evolutionary computing, a rapidly growing area of artificial intelligence. GAs are inspired by Darwin's theory about evolution- "Survival of the fittest."GAs represent an intelligent exploitation of a random search used to solve optimization problems. GAs, although randomized, exploit historical information to direct the search into the region of better performance within the search space. In nature the competition among individuals for scanty resources results in the fittest individuals dominating over the weaker ones**.**

1.4 The MATLAB GA Toolbox [4]

Whilst there exist many good public-domain genetic algorithm packages, such as GENESYS andGENITOR , none of these provide an environment that is immediately compatible with existing tools in the control domain. The MATLAB Genetic Algorithm Toolbox aims to make GAs accessible to the control engineer within the framework of an existing CACSDpackage. This allows the retention of existing modelling and simulation tools for building objective functions and allows the user to make direct comparisons between genetic methods and traditional procedures.

Table 1: Tooth form modulus of gear [22]

Pressure angle 20° standard gear						Pressure angle 14.5° standard gear					
Teeth numberz	y(y´)		z	y(y´)		Teeth numberz	y(y´)		z	y(y´)	
12	0.277	0.415	60	0.433	0.713	12	0.237	0.355	60	0.365	0.603
13	0.292	0.443	75	0.443	0.735	13	0.249	0.377	75	0.369	0.613
14	0.308	0.468	100	0.454	0.757	14	0.261	0.399	100	0.374	0.622
15	0.319	0.490	150	0.464	0.779	15	0.270	0.415	150	0.378	0.635
			300	0.474	0.801				300	0.385	0.650
16	0.325	0.503	Rack	0.484	0.823	16	0.279	0.430	Rack	0.390	0.660
17	0.330	0.512				17	0.288	0.446			
18	0.335	0.522				18	0.293	0.459			
19	0.340	0.534				19	0.299	0.471			
20	0.346	0.543				20	0.305	0.481			
21	0.352	0.553				21	0.311	0.490			
22	0.354	0.559				22	0.313	0.496			
24	0.359	0.572				24	0.318	0.509			
26	0.367	0.587				26	0.327	0.522			
28	0.372	0.597				28	0.332	0.534			
30	0.377	0.606				30	0.334	0.540			
34	0.388	0.628				34	0.342	0.553			
38	0.400	0.650				38	0.347	0.565			
43	0.411	0.672				43	0.352	0.575			
50	0.422	0.694				50	0.357	0.587			

1.2.2 Direct Gear Design of Helical gears

Direct gear design is an alternative approach to traditional gear design. Direct gear design method, separates gear geometry definition from tool selection, to achieve the best possible performance for a particular product and application. The direct design approach that is commonly used for most parts of mechanisms and machines (for example, cams, linkages, compressor or turbine blades, etc.) determines their profiles according to the operating conditions and desired performance It allows analysis of a wide range of parameters for all possible gear combinations in order to find the most suitable solution for a particular application. This optimum gear solution can exceed the limits of traditional rack generating methods of gear design [8].

II. LITERATURE REVIEW

Saul Herscovici et al.[1] in their article provided the design formulae and acceptable stress levels so that calculations of the gear tooth geometry, surface compressive and bending stresses at which the gears operate in a known application can be made accurately. Because for designers it is necessary to know the complete gear information for all gears like no.of teeth, diametral pitch, pressure angle , gear width, type of material to be selected and the type of heat treatment as well.

Work has been done by **Rodrigo Lopez Sansalvador & Juan Carlos et al.** [9] which showed a practical procedure for designing optimum helical gears. The optimization procedure was adapted to technical limitations, and it was focused on real world problems mainly. In order to emphasize the practicality of the procedure presented there, the most Common optimization techniques were also described. The objective functions which were to be optimized, limiting parameters and restrictions were needed to be defined for optimization. Finally, a graphic method was described by the author. A simple procedure for optimum gear design was presented, which was adjustable for the optimization of any combination of objective functions, and allowed the designer to impose actual restrictions. The most advantageous part of this optimization technique was that, it was not necessary to have a deep understanding of complicated optimization techniques for solving the optimization problem. Also, the procedure did not require special optimization programs. Any kind of gear design optimization problem could be solved by generating with a gear design software plots of the solution domain. The optimum point was also located easily, and it could be found visually from the plot or reviewing the data.

Takeaki Taguchiet al. [5]in there research paper,postulated with the help of genetic algorithm they had formulated OWD problem of constrained bending strength of gear, torsional strength of shafts and each gear dimension as a non-linear integer programming which was solved directly by keeping non-linear constraint. In result, the number of decision variables remained same and gave the best compromised solution. With the help of their work they also concluded that when a chromosome is not contained in a feasible region, it will include information about the infeasible region's chromosome in the evaluation function so as to improve its search efficiency.

Eckart Zitzler and Lothar Thiele [6] , compared four different Evolutionary Algorithms on a multi-objective 0/1 knapsack problem with nine varying problem settings. Apart from this, they had introduced a new evolutionary approach to multi-criteria optimization, the Strength Pareto Evolutionary Algorithm (SPEA), which is a combination of four several multi-objective EA's in a unique manner. SPEA was characterized as following :- a) Stored non-dominated solutions externally in a second, continuously updated population, b) Depending upon the number of external non-dominated points that suppress it, evaluated each individual's fitness c) Using the Pareto dominance relationship preserved population diversity, and d) In order to reduce the non-dominated set without destroying its characteristics incorporated a clustering procedure. Results obtained on two artificial problems as well as on a larger problem, the synthesis of a digital hardware–software multiprocessor system, suggested that SPEA could be applied very effectively in sampling from along the entire Pareto-optimal front and distributing the solutions thus generated over the trade-off surface.

Kalyanmoy Debet al. [7], had provided a systematic comparison of various evolutionary approaches to Multi-objective optimization using six carefully selected test functions. Each test function involved a particular feature that was supposed to cause difficulty in the evolutionary optimization process, particularly in converging to the Pareto-optimal front (e.g., multimodality and deception). By analysing these different features separately, a conclusion was achieved by virtue of which it was made possible to predict the category of problems to which a certain technique was or was not well suited. However, in contrast to what was already been doubted, a hierarchy of the algorithms was obtained as indicated by the experimental results. Moreover, the resulting effects were proving that the suggested test functions provided enough complexity to compare multi-objective optimizers. Lastly, elitism was also shown as an important factor for improvement of evolutionary multi-objective search.

A research by **Alexander L. Kapelevich and Roderick E. Kleiss [12]**explained thatDirect-gear design is an alternative approach to traditional gear designing methods. Since it allows analysis of a wide range of parameters for all possible gear combinations aiming to find the most suitable solution for anspecific application. This approach of direct gear design had an advantage that this optimum gear solution could exceed the limits of traditional rack generating gear design methods.

B .Venkatesh et al. [16], carried out the structural analysis of a high speed helical gear used for marine engines. These engines are continuously subjected to large stresses and deflections which are needed to be minimized. The dimensions of the model were obtained by theoretical techniques. These stresses generated and the deflections of the helical gear tooth had been analyzed for different materials and the final results obtained were compared to check the correctness by theoretical analysis and FEM. The project mainly concentrated on reduction of gear-weight and enhancing the accuracy of gears. The same authors, in 2014 came up with another research article "Investigate the Combined Effect of gear ratio, helix angle, face width and module on beam strength and Wear tooth load of Steel alloy Helical Gear" in which the effect of gear ratio, face width, helix angle, module to obtain the optimum beam strength and wear tooth load under variable circumstances was shown. Initially the helix angle, face width, speed and module were kept constant, when the gear ratio was increased; the corresponding beam strength remained constant. Secondly keeping the helix angles, gear ratios, speed, module except face width were kept constant and for variation of face width, the beam strength increased. Similarly for helix angles, gear ratio, face width and speed kept constant, with increase in module the beam strength increased accordingly. All this calculation work was done based on the Lewis equation and Buckingham equation. Similar experiments were done for the wear tooth load of the helical gear tooth and corresponding results were obtained.

Work has been done by **Faruk Mendi et al. [14]**on the dimensional optimization of motion and force transmitting components of a gearbox by using genetic algorithm (GA). The study was aimed to get the optimum values for gearbox shaft, gear and the optimal rolling bearing. . In genetic algorithm optimization, the best-suited result out of many results is obtained within the solution space which is subjected to specific design constraints. By optimizing the dimensions of gearbox components, the design with smallest volume was obtained which could carry the system load. The results of GA optimization and analytical methods were compared whose conclusion indicated that GA can be used effectively as well as reliably in machine element design problems.

Erol Kilickap et al. [15], studied the influence of machining parameters on the surface roughness obtained in drilling of AISI 1045 and applied Genetic algorithm for determining the optimum machining conditions of cutting speed, feed rate, and cutting environment for minimizing the surface roughness.

Avanish Kumar Dubeyet al. [13] in their research articlehave developed a computer-aided genetic algorithm-based multi-objective optimization (CGAMO) methodology for simultaneous optimization of multiple quality characteristics in LTD.

Ovidiu BUIGA et al.[18]performed optimal mass minimization of a single-stage helical gear unit and optimum dimensioning of shafts, gearing and housing with genetic algorithms (GAs). The proposed optimal design with GAs yielded considerably better solutions than the traditional optimization methods. Also, the GAs provide us a better information of the trade-offs between various objectives (such as service life and mass).

III. METHODOLOGY

3.1 Optimization

Optimization is a procedure of finding and comparing feasible solutions until no better solution can be found.Evolutionary algorithms (EA's) are often well-suitedfor optimization problems involving several, often conflicting objectives[7]. It is a process that finds the best or optimal solution for a problem [5,6,18]. All optimization problems can be summarized to revolve around these three factors:

a) **An objective function**: which is to be minimized or maximized.

b) **A set of variables**: which affect the considered objective function/problem.

c) **A set of constraints**: which allow the unknowns to take on certain values but exclude others.

3.2Various Methods of Optimization [7]:

a) Single- variable optimization algorithms

b) Multi-variable optimization algorithms

c) Constrained optimization algorithms

d) Specialised optimization algorithms

e) Single and multi-objective optimization algorithms

f) Non-traditional optimization algorithms**.**

IV. OPTIMIZATION USING GENETIC ALGORITHM

An algorithm is a set of instructions that is repeated to solve a given optimization problem.A geneticalgorithm conceptually follows steps inspired by the evolutionary biological processes of nature[17,3,13] .Genetic Algorithms follow the idea of survival of the fittestgiven by Charles Darwin. Better and better solutions evolve from previous generations until a near optimal solution is obtained.A genetic algorithm is an iterative procedure that represents its candidate solutions as strings of genes called chromosomes.

4.1 General Structure of a Genetic Algorithm:

1. A genetic representation of potential solutions to the problem.
2. A way to create a population (an initial set of potential solutions).
3. An evaluation function rating solutions in terms of their fitness.
4. Genetic operators that alter the genetic composition of offspring (Crossover, mutation, selection, etc.).
5. Parameter values that genetic algorithm uses (population size, probabilities of applying genetic operators, etc.).

Generalized steps of optimization using genetic algorithm

Step 1 :Determine the number of chromosomes, generation, and mutation rate and crossover rate value.

Step 2: Generate chromosome-chromosome number of the population, and the initialization value of the genes chromosome-chromosome with a random value

Step 3: Process steps 4-7 until the number of generations is met.

Step 4: Evaluation of fitness value of chromosomes by calculating objective function.

Step 5: Chromosomes selection.

Step 6: Crossover.

Step 7: Mutation.

Step 8: New Chromosomes (Offspring).

Step 9: Solution (Best Chromosomes).

This can be shown with the help of a simplified flowchart also as given below:

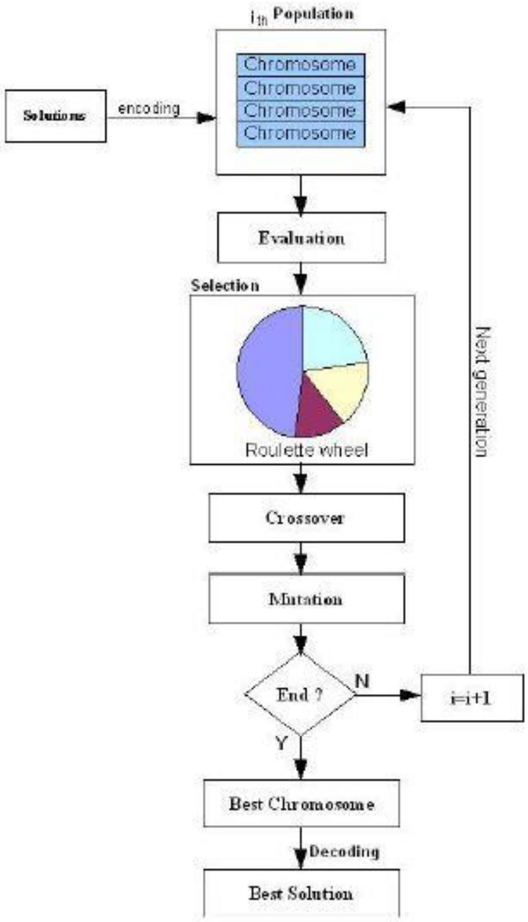

Fig.3 Generalized steps of optimization using genetic algorithm

Genetic Algorithms are a type of machine learningfor representing and solving complex problems.They provide a set of efficient, domain-independent search heuristics for a broad spectrum of applications.A genetic algorithm interprets information that enables it to reject inferior solutions and accumulate good ones, and thus it learns about its universe.

GA Provides efficient, effective techniques for optimization and machine learning applications. If these new solutions, or offspring, are better solutions than the parent solutions, the system will keep these as more optimal solutions and they will become parents[9]. This is repeated until some condition (for example number of populations or improvement of the best solution) is satisfied.A necessary component for applying GA to constrained optimization is how to handle constraints because genetic operators used to manipulate the chromosomes often yield infeasible offspring.

4.2Common terms used in Genetic Algorithm:

1. **Population:** a set of individuals each representing a possible solution to a given problem.
2. **Gene**: a solution to problem represented as a set of parameters, these parameters known as genes.
3. **Chromosome**:genes joined together to form a string of values called chromosome.
4. **Fitness score(value)[11]**:every chromosome has fitness score can be inferred from the chromosome itself by using fitness function.
5. **A fitness function[11]:** is a particular type of objective function that prescribes the optimality of a solution (that is, a chromosome) in a genetic algorithm so that that particular chromosome may be ranked against all the other chromosomes.

4.3 Basic Genetic Algorithm Operators:[10]

4.3.1Selection:

Selection replicates the most successful solutions found in a population at a rate proportional to their relative quality .Selection is the stage of a genetic algorithm in which individual genomes are chosen from a population for later breeding (recombination or crossover). Genetic algorithms produce new generations of improved solutions by selecting parents with higher fitness ratings or by giving such parents a greater probability of being contributors and by using random selection.

4.3.2Recombination(Crossover):

It decomposes two distinct solutions and then randomly mixestheirparts to form novel solutions.Crossover means choosing a random position in the string (say, after 2 digits) and exchanging the segments either to the right or to the left of this point with another string partitioned similarly to produce two new off spring.

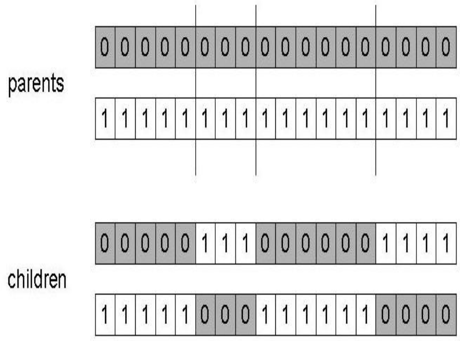

Fig.4 Two point cross- over

4.3.3Mutation:

It randomly perturbs a candidate solution. It produces a sudden change in the chromosome at any gene, the reason for which is unknown.

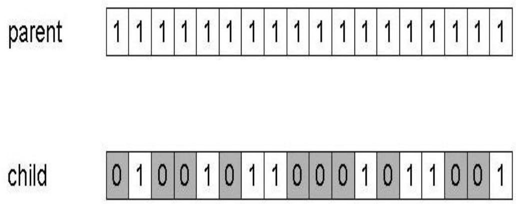

Fig.5 Mutation

Mutation is the occasional introduction of new features in to the solution strings of the population pool to maintain diversity in the population. The mutation probability is generally kept low for steady convergence. A high value of mutation probability would search here and there like a random search technique.[10]

V. CONCLUSION:

The beam strength of helical gears is an important criterion for its designing as it also decides the force and power to be transmitted. If optimization of various influencing factors like contact ratio, gear ratio, helix angle, face width, module, pressure angle is done considering their combined effects then it will certainly enhance the effectiveness and performance of the helical gear. GA can also solve the objective functions and constraints that are not stated as explicit function of design variables that are hard to be solved by classical methods. Since genetic algorithm method of optimization is easy, effective and time-saving,it must be used by the researchers to optimize various engineering designs. Also we can conclude that the use of GA Toolbox given in MATLAB is easy to use as well as effective for such design optimization problems.

REFERENCES:

[1] Herscovici S. (1985): Spur and helical gear design, Power engineering and manufacturing Ltd.

[2] Sansalvador L.R. and Carlos J. (1993) ,Centre de Investigacia y assistencia technica Practical Optimization of Helical Gears Using Computer Software, ,May-June issue, gear technology, pp. 16-21.

[3] Christopher R. Houcks and Jeffery A. Joines (1994): A genetic Algorithm for function optimization: A Matlab implementation.

[4] Chipperfield A. J and Fleming P. J. (1995): The MATLAB Genetic Algorithm Toolbox, IEE Colloquium on Applied Control Techniques, Digest No. 1995/014.

[5] Yokota T., Taguchi T. and Gen M (1998): A solution method for optimal weight design problem of the gear using genetic algorithms, Elsevier Science Ltd, Great Britain,Vol.35, Issue 3-4, pp.523-526

[6] Zitzler E. and Thiele L.(1999): Multi objective Evolutionary Algorithms-A Comparative Case Study and the Strength Pareto Approach, IEEE Transactions on evolutionary computation, vol. 3, no. 4, pp.257-271

[7] Deb K.M., Zitzler E. and Thiele L. (2000): Comparison of Multi objective Evolutionary Algorithms: Empirical Results, Massachusetts Institute of Technology Evolutionary Computation, vol. 8(2), pp.173-195.

[8] Kapelevich A. and Kleiss R.E. (2002):Direct Gear Design for Spur and Helical Involute Gears, gear technology publications , September issue,pp.29-35

[9] Holst T.L. and Pulliam T.H.(2003):Evaluation of genetic algorithm concepts using model problems : multi-objective optimization, National Aeronautics and Space Administration Ames Research Centre Moffett Field, California

[10] Popov A. (2003): Genetic algorithms for optimization-Application in controller design problems., TU Sofia, Hamburg, pp. 3-21.

[11] Farzad A. Sadjadi (2004): Comparison of fitness scaling functions in genetic algorithms with applications to optical processing, Proceedings of SPIE, Vol. 5557, pp. 356-364.

[12] Kapelevich A. and McNamara M.(2005) Direct Gear Design for Automotive Applications: SAE International Journal, pp.1-9

[13] Kumar S., Dubey A.K. and Pandey A.K.(2009): Computer-Aided Genetic Algorithm Based Multi-Objective Optimization of Laser Trepan Drilling, International journal of precision engineering and manufacturing, vol. 14, no. 7, pp. 1119-1125

[14] Mendi F., Baskal T., Boran K. and Boran F.E.(2010): Optimization of module, shaft diameter and rolling bearing for spur gear through genetic algorithm, Elsevier, Expert systems with applications, vol.37, pp. 8058-8064.

[15] Kilickap E., Huseyinoglu M. and Yardimeden A.(2010): Optimization of drilling parameters on surface roughness in drilling of AISI 1045 using response surface methodology and genetic algorithm, Springer-Verlag London Limited

[16] Venkatesh B. Kamala V. and Prasad A.M.K. (2010): Design, Modelling and Manufacturing of Helical Gear,International journal of applied engineering research, Dindigul, vol. 1,Issue.1,pp. 103-114

[17] Guo C.(2011): A Programming of Genetic Algorithm in Matlab7.0, Modern Applied Science, Vol. 5, No. 1; February 2011, pp. 230-235

[18] Buiga O. and Popa O.(2012): Optimal mass design of a single-stage helical gear unit with genetic algorithms, Proceedings of the Romanian academy, series a, volume 13, number 3/2012, pp. 243–250

[19] Mayuram M.M and Gopinath K.(2012): NPTEL Lecture on helical gears, module 2, Machine design-II, IIT Madras.

[20] Meenakshi C., Kumar A., Kumar H., Kumar M. and Obed Iqubal (2014): Design of Helical Gear Using MATLAB, Middle-East Journal of Scientific Research IDOSI Publication 20 (3), pp.405-406.

[21] Venkatesh B., Prabhakar S.V .,Vattikuti and Reddy M. (2014): Investigate the Combined Effect of gear ratio, helix angle, face width and module on beam strength and Wear tooth load of Steel alloy Helical Gear, International Journal of Current Engineering and Technology, Special issue 2, pp.692-695.

[22] PSG Design databook, PSG College of Technology, Coimbatore.

◈◈◈