CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Optimization is the ongoing activity as evidenced by optimization studies of design a component that were carried out over the last century. During this time, improvements in analytical approaches to optimization by mathematical programming have continued to become more powerful and when coupled with the speed of modern computers, they handle optimization of very complex engineering applications. In pursuit of never ending improvements, optimization of gearbox design will play a key role in the future engineering research.

This literature covers a wide range of gear design optimization problems and engineering application with respect to various Metaheuristic Algorithms.

2.2 GEAR DRIVE AND GEAR BOX DESIGN OPTIMIZATION

Carroll and Johnson (1984) offered minimum pinion diameter design approach for the spur gears and also explained by examples with a Fortran program. This code is applicable to spur gear with standard tooth system only. The authors also conclude that this approach can be extended for helical and bevel gears.

Prayoonrat and Walton (1988) described a practical approach to gear train design and optimization. An algorithm is presented to design and optimize multi-spindle gear trains of non-speed change type. The objective of this work is to optimize gear trains on the basis of minimum overall center distance, minimum
overall size, minimum gear volume and maximum contact or overlap ratios. In this paper, two-stage optimization is carried out with direct search method to remove unacceptable solutions and tried a heuristic approach called iterative constrained refinement method.

Huseyin and Mustafa (1993) developed an interactive and highly user-oriented computer program for multi speed gearboxes. Basic principles of obtaining kinematic arrangement diagram are discussed and a model for the arrangement of gears and their shafts are suggested in this work. An algorithm is developed for the design of all the gears in gearboxes.

Hunglin and Hsu-pin (1994), in this work the input parameters considered are operating horse power, gear ratio, operating speed of pinion, elastic modulus, surface strength and bending limits for materials, the design variables are number of pinion teeth , face width, diametrical pitch, pressure angle. He adopted modified iterative Tchebycheff for optimal gear design and four objectives are listed and optimized simultaneously, under given set of constraints. Objective functions are minimizing size, weight of meshing gear set, minimizing tooth deflection and maximizing life of gear sets.

Savage et al (1994) analyzed the single mesh spur gear reduction in design optimization of system life, system volume, system weight including gears, support shafts and four bearings by using “A modified feasible direction search algorithm”. The result exposed the optimal configurations of the bearings.

Innocenti (1996) proposed a new approach for efficiency evaluation of one-multi-degree of freedom gear trains. The procedure has been developed for two degree of freedom gear trains. It is based on the determination of a vector whose
components are the torques delivered to the shafts of the gear train. In this work a
general approach for evaluating the mechanical efficiency of gear train with an
arbitrary number of degrees of freedom has been presented.

Hsin-I and Lung-Wen (1996) devised a methodology for the speed ratio
analysis of epicyclical type transmission mechanisms. A practical method for
designing gears in multispeed gearboxes has been developed and automated with
an interactive and highly user-oriented computer program.

Shinn-Liang et al (1997) contributed towards the optimization of gear train
and mainly concentrated on kinematic optimization of a modified helical gear
train. A mathematical model of modified helical gear train is developed by
considering center distance variation and axial misalignment. A multiple
optimization method is applied to reduce the level of modified helical gear train
kinematic errors and investigate optimal gear tooth modifications.

Ramamurthi et al (1997) developed methodology for fixing the leading
dimensions of a two stage gearbox to transmit a specific horse power for a given
input speed and reduction.

Yokota et al (1998) developed a solution method for optimal weight design
problem of gear using Genetic algorithms. In this work, the authors formulated an
optimal weight design problem of gear with constraints of bending strength of
gear, torsional strength of shafts and gear dimensions. This mathematical model
has been solved by using improved Genetic algorithm.

BorishAbersek (2000) presented the expert system for dimension
optimization and manufacture of gears and gearing. The optimum dimensions of
gears are determined by using genetic algorithm. After the completion of calculations and optimization of gears or gear pairs, the gears are manufactured by optimized values.

David F. Thompson et al (2000) describes generalized optimal design formulation with multiple objectives and its procedures. The methodology is applied to the design of two-stage and three-stage spur gear reduction units, subject to identical loading conditions and design criteria. The approach serves to extend traditional design procedures by demonstrating the tradeoff between surface fatigue life and minimum volume using a basic multi objective optimization procedure. This information allows the designer to judge overall trends.

Tae Hyong and Joung (2000) proposed a genetic algorithm based gear design system to optimize design of gear trains. This paper was applied for the geometrical volume minimization problem of the two-stage gear train and the simple planetary gear train to show that genetic algorithm was better than the conventional algorithms for solving the problems that have continuous, discrete, and integer variables.

Rosic (2001) proposed an analytical and computer aided procedure for the multi criteria design of gear train transmission system. The author concluded that the multistage gear train transmission is a complex mechanical system and hence it has been decomposed. The gear train optimization was carried out through the corresponding number of stages. Marcelin (2001) applied genetic algorithm for design optimization of the gears with penalty selection methods for computer-aided design of gears. The test problem shows that genetic algorithm is a very efficient method to optimize gears.
Chong et al (2002) proposed a new and generalized design methodology to determine the basic design parameters for multi-stage gear drives analytically and systematically. The proposed design methodology automates the design process by integrating the dimensional design and the configuration design process in a formalized algorithm. The positions of gears and shafts are determined to minimize the geometrical volume of the gearbox while satisfying spatial constraints.

Gianni Caligiana (2002) proposed a fitness of the fuzzy- genetic algorithm (FGA) methodology, for the optimization of mechanical components focus to several design criterion and constraints. This approach is applied to the choice of modulus and pitch diameters of pinion or gear for a reduction spur gear train, knowing input power, pinion revolutions per minute and velocity ratio.

Deb and Sachin (2003) solved the multi-objective evolutionary algorithm for eighteen speed multi-objective gearbox design problem. In this work the use of multi-objective evolutionary algorithm named Non-dominated Sorting Genetic Algorithm (NSGA-II). It is capable of solving the original problem involving the mixed discrete and real valued parameters and more than one objective, and is capable of finding multiple non-dominated solutions in a single simulation run. The design problem involves more than one conflicting objectives of maximizing power and minimization volume of gear box.

Marcelin (2004) applied Genetic Algorithm (GA) for the design optimization of the gears and also developed a meta-model using Neural Network and GA for an integrated optimal design of mechanism. The objective function is minimization of the volume and center distance and maximization of power and efficiency.
Hong-Zhong Huang et al (2005) evaluated a multiple objectives in the optimal design of multi-stage spur gear reduction unit, such as minimizing the volume and maximizing the surface fatigue life. An interactive physical programming approach was developed and adopted. Jian-Hua Zhao et al (2005) developed the multi objective Ant Colony System (ACS) successfully to provide a solution for the reliability optimization problems of series-parallel system and also demonstrated its application to the reliability design of gearbox. The multi objective ACS algorithm offered distinct advantages to these problems compared to alternative optimization methods, and can be applied to a more diverse problem domain with respect to the type or size of the problems.

Ferenc J. Szabo (2005) presented a general way was which applied for the gears description and the optimization problem helical and profile modified gears was solved and presented. The results of this more general optimization procedure could be useful for practical gear designers in the improvement and development of gears.

Zeyveli and Gologlu (2006) developed software to automate preliminary design of gearbox with spur, helical and bevel. In the software, genetic algorithm is applied to the problem with the objective function of minimizing volume of gear trains. The objective function is constrained by bending strength, contact stress, face width, number of pinion and gear teeth. The preliminary design parameters module, number of teeth and width of teeth pinion gear pairs stages are optimized and gear ratios are determined with respect to the objective function and design constraints.

Jinliang Zhang et al (2007) used, loaded tooth contact analysis and finite element method to analyze the meshing behavior, tensile bending stress and
compressive bending stress and tooth surface contract stress. The modified pitch cone method was first presented and verified in the gear research center.

Hedlund and Lehtovaara (2008) presented a study focusing on the modeling of helical gear contact with tooth deflection. Their work introduced a mathematical model for helical gear contact analysis. Helical gear surface profiles were constructed from gear tooth geometry by simulating the hobbing process. The three-dimensional finite element model was developed for the calculation of tooth deflection including tooth bending, shearing and tooth foundation.

Sanchez Caballero, V. (2008), describes a genetic algorithm based optimization method for the design of gear transmissions was presented. For gear design, simultaneous discrete and continuous variables nonlinear related were used. A design variables coding and decoding method, as well the genetic operators of reproduction, crossover and mutation were presented. Finally, it is analyzed an example in which the developed genetic algorithm has been used, comparing the obtained results from a previous optimization.

Rui Li (2008) introduces an adaptive genetic algorithm (GA) introduced to solve the multi-objective optimization design of the reducer. An adaptive GA based on a fuzzy controller was introduced; aiming at the characteristic of multi-objective, multi parameter, multi-constraint was used for a multi-objective optimization model of the helical gear reducer. Finally, a numerical example was illustrated to show the advantages of this approach and the effectiveness of an adaptive genetic algorithm used in optimized design. Salgado and Aionso (2008) designed the planetary gear trains used in the mechanical spindle speeders and is optimized by minimizing the volume and the kinetic energy of these boxes. These results can be of great significance for spindle speeder manufactures.
Bernd-Robert Hohn et al (2009) discussed causes of power loss in gearboxes used as torque and speed converters. He proposed different methods are discussed for power loss reduction in a gearbox. A bearing system can be optimized when using more efficient systems than cross loading arrangements with high preload. Low loss gears can contribute substantially to load dependent power loss reduction in the gear mesh.

Dolen M (2009) investigates the optimal design of a four-stage gear train using genetic algorithms. Five different genetic encoding methods, which integrate various heuristic search techniques, are projected to deal with the most vital constraints of the problem. The fitness criterion used by all genetic algorithms includes a merit function for minimizing the size of the gearbox. The results showed enhancement in the design value over earlier approaches without confidence on the designer’s interaction to avoid geometric constraint violations and make easy the convergence.

Zhang Xiao-qin et al (2010) proposed Visual Basic programming mixed with MATLAB for automatic optimization design for gear reduces. Genetic algorithm and genetic toolbox of MATLAB was used when calculating, with the advantages of simple programming, good reliability and high efficiency. Savsani et al (2010) presented two advanced optimization algorithms known as Particle Swarm Optimization (PSO) and Simulated Annealing (SA) to find the optimal combination of design parameters for minimum weight of a simple and multi-stage spur gear trains. The results of the proposed algorithms are compared with the benchmark results. It is observed that the proposed algorithms offer better gear design solutions.
Vipin and Chauhan (2010) discussed, minimizing the surface fatigue life factor and volume of gear box with classical SQP algorithm and other non-traditional NSGA-II with other geometric conditions. Mohammadpour et al (2010) discussed an optimal design for gears considering gear transmission error, size and lubrication parameters and using Grey Relational Analysis Technique. A new approach has been used so as to calculate the transmission error in involutes spur gears to urge outputs within the shortest time with a high accuracy.

Hong-chen Wang and Zhen-yuZou (2011) developed an optimization algorithm by simulated annealing to find the optimal combination of design parameters for minimum weight of gears in simple and multi-stage spur gear trains. Xiaoqin Zhang (2011) proposed integer serial number encoding genetic algorithm, which effectively dealt with continuous and discrete variable optimization problem. It reduces the code length of the string to improve the encoding and decoding efficiency, no invalid solution or duplicate solutions. A bevel gear optimization design mathematical model was illustrated with automatic optimization design.

Gang  He et al (2011) optimized a two-stage cylindrical helical gear reducer with volume and the center gear distance was adopted as objective functions separately. The particle swarm optimization method was used to improve the design quality of two stage gearbox. Wang Hong-chen and Zhen-yu (2011) presented an advanced optimization algorithm as simulated annealing (SA) to find the optimal combination of design parameters for minimum weight of gears. For the application on an example a simple and multi-stage spur gear trains are considered. The results of the proposed algorithms offer better design solutions with the benchmark results.
Juan Carlos Herrera-Lozada et al (2011) presented a new algorithm, namely, a micro artificial immune system (Micro-AIS) based on the Clonal Selection Theory for solving numerical optimization problems. He proposed new cloning operator. For the maturation stage, two simple and fast mutation operators were used. He validated with set of test functions taken from the specialized literature and compared.

Seok-chul Hwang et al (2011) analyzed the contact stresses between spur gear teeth using a plane model and validated the Hertz stress and AGMA contact stress with the finite element contact stress. Yogesh C Hamand (2011) calculated the stress for a pair of gears using the Lewis formula, Hertz equation, and AGMA standards and compared the result with FEA. Finite element method can simulate contact stress in a pair of mating gears. The results of Ignacio GonzalazPerar (2011) showed that contact stress was highest at higher points on the involutes and lower fora single pair of teeth.

Massimiliano Pau et al (2012) investigated the calculation of the tooth bending strength and surface durability of normal and high contact ratios were sufficient for preliminary designs or standardized purposes. The stresses calculated using these simple equations derived from the linear theory of elasticity and Hertzian contact model were not in good agreement with experimental results.

OvidiuBuiga and OvidiuPopa (2012) presented an optimal design mass minimization problem of a single-stage helical gear unit, complete with the sizing of shafts, gearing and housing using genetic algorithms. It could be observed that the proposed optimal design with genetic algorithms had the potential to yield considerably better solutions than the traditional heuristics. At the same time,
genetic algorithms offered a better understanding of the trade-offs between various objectives such as service life and mass.

YallamtiMurali and Seshiah (2012) evaluated the optimization of spur gear set. Objective functions are its center distance, weight and tooth deflections and the decision variables such as module, face width and number of teeth on pinion, and subjected to constraints namely bending stress, contact stress. Solutions for the non-traditional methods could be obtained by computerizing algorithms “C” language. The results were calculated by using “C” language for three materials namely Cast Iron, C-45 and Alloy steel.

NenadMarjanovic et al (2012) presented a characteristics and problems of optimization of gear trains with spur gears. It provides a description for selection of the optimal concept, based on selection matrix, selection of optimal materials, optimal gear ratio and optimal positions of shaft axes. He also presented the definition of mathematical model, with an example of optimization of gear trains with spur gears, using original software. Using an approach like this for the optimization of gear trains with spur gears gives results that can be applied in real applications.

Kumar Singh et al (2012) optimized internal spur gear with minimization function of center distance using GA. Prabhakaran and Ramachandran (2013) was studied about importance of gear material change in spur and helical gear. He compared the bending Stress of a Spur and Helical Gears by adopting different gear materials by FEA.
Chang Wei Wu et al (2013), a multi-objective optimization model of the gear train is established with minimum quality and minimum center distance of the gear using particle swarm optimization algorithm.

Mogaland Wakchaure (2013) attempted to optimize worm and worm wheel with multiple objectives such as to minimize volume, center distance between worm and worm wheel and deflection of worm. The variables considered are gear ratios, face width, pitch circle diameters of worm and worm wheel. Xueyi Li et al (2013) presented an optimization mathematical model for designing two-stage cylindrical gear reducer was firstly constructed based upon the drive principles and design criteria of cylindrical gear transmission. Few techniques were adopted for calculating the key performance parameters, such as profile factor and dynamic load coefficient. The results were revised with the corresponding boundary a constraint dynamically during the optimization process. It was implemented by mixed programming.

Sanghvi et al (2014) discussed a two stage helical gear train to optimize volume and load carrying capacity. Three different methodologies MATLAB optimization toolbox, genetic algorithm and multi objective optimization (NSGA-II) technique are used to solve the problem. In the first two methods, volume is minimized in the first step and then the load carrying capacities of both shafts are calculated. In the third method, the problem is treated as a multi objective problem. For the optimization purpose, face width, module, and number of teeth are taken as design variables. Constraints are imposed on bending strength, surface fatigue strength, and interference. From the results, NSGA-II shows more superior results than obtained by other methods in terms of both objectives.
Said Golabi et al (2014) proposed the general form of objective function and design constraints for the volume or weight of a gearbox has been considered. By selecting different values for the input power, gear ratio and hardness of gears, the practical graphs from the results of the optimization are presented. From the graphs, all the necessary parameters of the gearbox such as number of stages, modules, face width of gears, and shaft diameter can be derived. The results are compared with benchmark works. Ketan Tamboli et al (2014) computed a helical gear pair of a heavy duty gear reducer was considered. The formulation of the constrained non-linear multi-variable optimization problem with derived objective function and constraints is presented to minimization of volume of gear reducer. The solution is attempted using Particle Swarm Optimization (PSO).

Ovidiu Buiga and Lucian Tudose (2014) discussed a optimal design of helical gear train with minimization of the complete speed reducer mass. The results obtained by using GA shows significant improvement over the results obtained by traditional design. This paper also presents, study about the trade-off between the mass and the service life.

Padmanabhan et al (2015) proposed a new Modified Artificial Immune Algorithm to solve Gear design problem. In order to generate a superior population of initial solutions, a two new cloning operator was introduced. Then, to mutation process, two phased mutation process adapted to make a good enhancement in potential solution. The optimized results were obtained by new immune algorithm shows considerable reduction in weight in compared with trail method for both gear materials and also shows better results over power and center distance.

Paes et al (2015) proposed the operation of a genetic algorithm to design and optimize geometric parameters of a transmission two stage gears. He proposed
fitness function is a weighted average of significant presentation factors on gears design such as total drive weight, tooth contact stress, bending stress and total space occupied by the assembly. The second fitness considered as the center distance and the tooth contact stress and bending stress. The weights of the average are customized in numerous simulations. He concludes the influence of these weights on algorithm presentation to position out the optimal transmission design.

2.3 METAHEURISTIC ALGORITHMS ON ENGINEERING APPLICATIONS

Non-Traditional techniques comprises of a variety of methods including optimization paradigms that are based on metaheuristic algorithms such as biological genetics and natural selections. While these methods provide many uniqueness that make it the method of choice for the researchers in their various engineering application.

The emergence of Genetic Algorithm, Artificial immune algorithm, Ant Colony Optimization, Particle Swarm Optimization and Sheep Flocks Heredity Model Algorithm has attracted many researchers available in the different disciplines to apply in their own fields.

Askon P et al (2003) evaluated an optimal machining parameters for continuous profile machining were determined with respect to the minimum production cost, subject to cutting force, power constraint and tool tip temperature as constraints. This machining optimization problem was resolved by an evolutionary mechanism such as simulated annealing (SA) and genetic algorithm (GA). The optimized results from GA and SA are compared.
Vijayakumar et al (2003) presented cutting optimization model for multi-pass turning operations. Ant Colony Optimization (ACO) has been applied to solve the machining optimization problem. The results of the proposed approach are compared with results of simulated annealing and genetic algorithm.

Jerald J et al (2005) approached with non-traditional techniques like genetic algorithm (GA), simulated annealing (SA) algorithm, Memetic Algorithm (MA) and Particle Swarm Algorithm (PSA) to optimize the different scheduling mechanisms. Minimizing the idle time of the machine and minimizing the total penalty cost were considered as multiobjective function. The results of the different optimization algorithms were compared.

Chandrasekaran M et al (2006) developed a makespan minimization optimization for the job shop scheduling of different size problems. Artificial immune system algorithm (AIS) was used for finding optimal makespan values of different size problems. The artificial immune system algorithm is tested with 130 benchmark problems. The results show that the AIS algorithm is an efficient and effective algorithm which gives better results than the traditional approaches.


Afshari and Sajedi (2012) introduced two new mutation methods, namely Shift Change method and Inverse method in Job-shop scheduling and a vaccination method, to achieve more than one optimal solution concurrently and release from
local optimum. Yunfang et al (2012) proposed a general framework of Multi-Objective Immune Algorithms, which reviews a uniform outline of this kind of algorithms and gives a description of its principles, mainly used operators and processing methods. Gopinath et al (2012) developed artificial immune algorithm based hybrid algorithm to optimize the scheduling problem. The hybrid algorithm is used for finding optimal make span, mean flow time, mean tardiness values of different size problems.

Ramya G and M. Chandrasekaran (2013) proposed a Shuffled Frog Leaping Algorithm and Sheep Flock Heredity Model Algorithm for minimizing the maximum completion time based on job scheduling and minimization of labor costs based on employee workload.

From the above literatures, researcher findings focused on, Gear drive optimization was carried out with single objective functions. Many researches deal single objective or multi objectives problems separately either with gear pair or gearbox. Gear Material’s impact on design not carried out. Design and error reduction in parameters of gears and gearboxes were the main focus by researchers rather than dealing with optimization problems.

2.4 LIMITATIONS OF THE EXISTING RESEARCH

Based on the above literature review, the following limitations were identified and need attention:

- In the past, research work on gear pairs and gearboxes carried out separately by researchers.
• Gear design optimization is limited to single objective functions. Many researches did not deal multi objectives.

• Design optimization problems were mainly solved using classical techniques, which finds difficulty in constrained search space.

2.5 NEED FOR FURTHER RESEARCH

The current state of research indicates the potential scope of research in the gear pair and gearbox optimization. Based on the literature review, the following issues are emphasized.

• There is a need to develop a comprehensive optimization models from gear pairs to gearboxes, as a complete design approach.

• Optimization of desirable parameters has to be incorporated.

• Multi objective optimization for obtaining best possible gear trains is to be implemented.

• Design optimization of machine tool gearbox needs focus for obtaining sleek and efficient models.

• Need to develop a robust optimization tool, based on metaheuristic computation, which should be more flexible than the classical methods.

2.6 SUMMARY

In this chapter, an effort has been made to review the literature on design of gears and gearbox problems and various optimization techniques. The chapter also
summarizes the current state of the art and the limitations. The limitations reviewed are taken care of the present research work. In next chapter, different types of optimization techniques are discussed.