CHAPTER 2

LITERATURE REVIEW

As a first phase of this research work, various literatures relevant to this topic were studied in detail for the effective design optimization, performance analysis, thermal analysis and structural analysis of automotive disc brakes.

2.1 GENERAL LITERATURES FOR BRAKE DISC DESIGN OPTIMIZATION

Garrest N. and Vanderplaats (1979), suggests the technique of automated design using numerical optimization. Numerical optimization first involves the concept description in physical terms to give a basic understanding of the iterative procedure employed by these methods. Next, the typical engineering task is presented and converted to a form amenable to solution by numerical optimization. Basic algorithm for solving this problem is identified. The state of the art allows for the routine solution of nonlinear design problems of approximately 20 independent variables subject to 100 or more constraints. In many applications, much larger design problems may be solved. The basic approach of this study is incorporated in this design optimization work along with the following optimization procedures in the ensuing literatures.
Dixit, Beohar and Bal (2000), suggests that, stochastic signomial geometric programming is an effective tool for the optimum design of a brake disc considering random nature of design variables. This program also takes into account the probability of satisfying constraint equation, so that, the design approach is more realistic. The calculation equations in this approach are as such introduced for the design of a brake disc for a light duty passenger vehicle.

Das A.K. and Pratihar (2002) suggests that, optimization through genetic algorithm yields better results in the machine element design under certain circumstances. The same design through traditional methods has some drawbacks such as there is a chance for the solutions get trapped into local minima. The algorithm developed for one type of problem, may not be suitable to solve another type of problem. In this context, the real coded genetic algorithm proved to be a versatile design optimization algorithm for design of machine elements. The design optimization procedure adopted by these authors is as such incorporated in this work to determine the exact dimensions of a brake disc.

Hand book of statistical quality control (SP : 28 - 1985) (Source Indian standards (IS : 7300 - 1974), deals with methods of regression and correlation. This method deals with the statistical methods of regression and correlation in the case of two variables. Regression deals with situation where the variation of one variable is dependent on the variation of second variable. This technique is as such incorporated in this work to determine the inner and outer radius of the brake disc by satisfying the constraint of maximum torque transmission by the brake disc.
Dr. Hanan Ahamad Kamal and ENG, Medhat Helmy Easssa (2002) suggests that, genetic programming is an advanced branch of genetic algorithm. The main difference between genetic programming and genetic algorithm is the representation of the solution. The new way of solution representation in GP is encouraged the researchers to use it in solving designing problems where the size and shape of the solution is unknown. In this work the design dimensions of the brake disc are generated using the above optimization techniques, and their exact values are represented and used only after the classical operators (cross over, mutation etc.) of this genetic programming.

Murali M.R., Krishna and Douglas Chojeck (1998), deals with a modeling approach for the preliminary design of automotive disc brakes. In this approach, the parametric modeling is carried with the help of geometric description, design objective, formulation of objective function, sensitivity analysis, design of experiment description (DOE) and optimization procedure. Finally, the modeling approach has been enhanced through the inclusion of FEA component models. This approach can yield fruitful results at the earliest stages of design itself. The procedural steps involved in this parametric modeling approach are incorporated in this work to achieve the conflicting goals and objectives with respect to design and performance of the brake disc.

Fukano A. and Matsui H. (1986), suggests a vehicle system design procedure using high-fidelity virtual prototyping. In this approach, it is stated that, simulation has become a powerful approach for compressing product development cycles. Using the different simulation tools, each development team independently designs and simulates their specific component. While the current simulation approaches are appropriate for component design, system simulations are harder to execute and maintain. Hence, the authors presented a
new architecture for co simulation using distributed object referred as Cud's. Finally, the authors concluded that, from a user point of view this approach and its initial implementation will yield a model based iterative design approach. The easier way of attacking complex design problems through this co-simulation is incorporated in this work to the required extent.

Walter et al (1993), deals with the brake roughness - disc brake torque variation, rotor distortion and vehicle response. They suggested new methods of measurement and analysis techniques for the assessment of a disc brake design and operational aspects. These new measurement methods involved the measurement of in-stop torque variation and rotor thickness variation as well as rotor total indicated runout. From this literature, it is also observed that, the disc brake torque variation is a non-stationary function and its frequency content is a function of rotational speed. Further, the literature also giving a concluding remarks that, the rotor thickness variation increases with increasing temperature. The basic concepts from this literature is considered in this work to the required extent for the design and performance of the brake disc.

2.2 GENERAL LITERATURES FOR BRAKE DISC DESIGN PERFORMANCE

Performance of a disc brake depends on many factors involved in the design and operation. To review, understand and to design an efficient brake disc, the following literatures have been studied.
Limpert (1975) gives an elaborate technical text on brake design and safety. In this text, the fundamentals, functions, design, performance and safety aspects of automotive braking systems are very elaborately discussed with suitable examples. In this work, all the fundamentals related to design, performance and safety are followed from this design book.

SAE recommended practice (SAE J880a) (1985), recommends the stipulated performance requirements for motor cycles and motor driven vehicles. The recommended parameters and their values are either taken as the input data for this work or the performance parameters obtained as results and compared.

Klaus, Andreas Schindler and Manfred Wallrich (1987), deals with the comparison of the braking performance achieved by average drivers in vehicles. The test procedures and the type of results obtained in their work is considered for comparison of some of the theoretical and actual test results obtained in this work.

Rudalf Limpert, Franco E Gamero and Ron Boyer (1974), discussed in detail about the brake balance for straight and curved braking. The authors discussed about the stopping distance, brake force and braking dynamics. The basic concepts related to the above performance parameters were considered for the analysis of performance of the designed brake disc in this work.

Pigozzi G. and Ceretto E. (1992), deals with analysis, design and testing of two-way proportioning for improved braking in a turn. The authors discussed in detail about the optimizing the braking performance, stable
stopping distance, general braking efficiency and experimental procedures to obtain them. The concepts and results postulated in this literature is considered for the calculation and comparison of results obtained in this work.

Erwin R. D. and Winkler C.B. (1987), deals with the influence of braking efficiency on the probability of wheel lockup. This literature gives an idea about the braking efficiency values to avoid the wheel lockup. It also suggests that, as braking efficiency falls below 80%, the frequency of occurrence of lockup on wet surfaces begins to rise rapidly, in a generally exponential manner and using cars with braking efficiency levels as low as 50%, drivers would experience lockup very frequently. Based on this conclusions, the braking efficiency calculations and values are taken care off in this work for efficient operation of the braking system.

Mark A. Flick, Richard W. Radlinski, and Russel L. Kirkbride (1987), deals with the effect of aftermarket linings on braking efficiency. Even though the study is on brake linings, it gives an idea about the braking efficiency values with respect to friction material. It also provide the information's about the torque versus pressure data, brake effectiveness, braking efficiency under laden condition for different peak tire/road friction values. From this literature, the frictional coefficient values are taken care off in this work to the workable limits.

2.3 GENERAL LITERATURES FOR THERMAL LOADING OF BRAKE DISC

Since the friction is involved in the braking operation, the frictional energy is transformed into heat energy and subsequently the heat energy is
dissipated through the system components, which in turn affects the brake system performance. To understand the nature and extent of these thermal phenomena, the following literatures were reviewed and the concepts derived from them are used in this investigation.

Limpert R. (1975), gives an elaborate technical text on thermal aspects of disc brake for different design and operating conditions. It also discuss about the fundamentals, functions, design and performance of the disc brake system for varied thermal loading conditions are very elaborately discussed with suitable examples. This literature also discussed about the fundamentals of conductive, convective and radiative heat transfers from the disc brake system. From this literature, all the fundamentals related to thermal design, performance, heat transfer and metallurgical limitations were studied and incorporated in this work.

David C. Sheridan, James A. Kutchey and Farzad Samie (1988), suggests an approach to the thermal modeling of disc brakes. This literature deals with four different modeling approaches for the thermal analyses of disc brakes. The models ranging from a simple lumped-parameter model to a complex three dimensional model. The lumped parameter (zero dimensional model) rotor model predicts transient bulk rotor temperature, while a one-dimensional model provides peak surface as well as bulk temperature. The steady state two-dimensional model of the entire brake system predicts plateau temperatures during a multi-stop driving schedule. Finally, a complex three-dimensional transient model can be used to obtain detailed local rotor temperature distribution for any stopping sequence. The fundamentals
pertaining to conductive and convective heat transfers and the thermal network modeling concept was reviewed from this literature and they were incorporated.

Limpert R. (1972), deals with the thermal performance of automotive disc brakes. The author discussed in detail about the heat flux and the temperature evolved in the brake disc with necessary examples and illustrations. From this literature, the basic concepts pertaining to brake disc temperature, heat flux and the factors associated with the improved thermal performance were considered and incorporated in this work.

Reinhard Eisengraber, Jaroslaw Grochowicz, Matthias Schuster, Klaus Augsburg and Lars Koch (1999), deals with the different methods for the determination of the friction temperature of disc brakes. These methods are purely an experimental one, but, the concepts and the results are so encouraging to know about the temperature history of the disc brakes. This information is highly helpful for the comparison of results from this integrated investigation.

Takaharu Ldogaki, Hisashi Kawai, Hiroshi Harada and Hideo Lnoue (1987), dealt with the measurement system of transient temperature distribution on the brake disc rotor. The authors devised a transient temperature distribution measuring system. In this system, the electromagnetic wave length principle along with radiation concept is used to measure the transient temperature. They have presented the real time temperature distribution in the brake disc with appropriate examples. This literature is helpful in deciding about the emissivity of material surface for radiation heat transfer calculations and to compare the instantaneous temperature of the brake disc.
Yoshio Jimbo et al (1990), deals in detail about the development of high thermal conductivity cast iron for brake disc rotor. This literature gives an idea about the new material for brake disc. The authors analyzed the non-steady state thermal conductivity and thermal stress of the material which they have developed. They have presented the resulting temperature of their analysis through finite element methods. The basic concepts and the results presented in this paper is highly useful in comparing the maximum thermal stresses and material behaviour of the designed brake disc.

Field House and Steel (2003), deals with study of brake noise and the influence of centre of pressure at the disc / pad interface, the coefficient of friction and caliper mounting geometry. The authors have experimentally verified the temperature rise due to interface pressure and the effect of offset on temperature rise. The concepts and results from this literature is helpful for this work to decide about the disc/pad interface pressure and the resulting thermal characteristics of designed brake disc.

2.4 GENERAL LITERATURES FOR BRAKE DISC MATERIALS AND THEIR PROPERTIES

There are two types of disc materials used by the automotive industry today. The first, used for family sized vehicles, operates on the principle of small diameter, high strength discs with sufficient inherent strength to resist any tendency towards the formation of thermal cracking, and distortion, at high operating temperatures. These discs whilst having good strength properties have relatively low thermal conductivity. The second one is that, of large, weaker, low strength discs with high thermal conductivity, has been applied more
commonly, to the larger high powered type of vehicle where space constraints are not so critical, and as a consequence, a larger diameter thicker disc can be employed. To take care of the above aspects in this work, the following literatures were reviewed to get the exact details regarding the materials used for brake disc.

Macnaughtan and Krosnar (1998), discussed in detail about the cast-iron a brake disc material for the future. This literature gives an elaborate understanding of brake disc requirements, suitability of cast iron for the brake disc, types of cast irons used for the brake disc, material composition and their properties. This review enables us to choose right choice of cast iron material for the brake disc designed in this integrated work.

Graham L. Donne and Peter M. Watson (1981), discussed about the effect of cast iron disc brake metallurgy on friction and wear characteristics. The author presented the noticeable differences between the friction and wear characteristics of the four gray cast irons. The basic concept of friction and wear characteristics of suitable grade of cast iron has been taken from this literature and incorporated in this work.

Fash J.W. Dalka T.M. and Karthik R. (1998), deals with the influence of brake system properties on motor cycle braking. This literature gives an elaborate idea about the material for brake discs and pads. The authors also suggested the various treatments applied to brake disc/pad combinations. The concepts and the experimental results presented in this literature has been used for the comparison of designed brake disc performance.
Horst Metzler (1990), deals with the brake rotor - friction partner of brake linings. This literature gives an elaborate idea about the earlier material and the recent materials for brake discs. It also suggests, various manufacturing methodologies for the enhanced strength of the brake disc. The properties of recent materials have been adopted from this literature for the design of brake disc in this work. To find the suitability of alternate material for brake disc literatures pertaining to alternate materials for brake disc the following literatures has been reviewed and incorporated in this work.

Naoki Odani, Masaaki Kobayashi and Konji Kakihara, (1999), deals with the effect of transferred film $\mu$ behaviour of disc brake pad in humidity environment. This literature deals with brake pad performance in a wide variety of working conditions. It also compares the asbestos and non-asbestos braking pads under different humidity conditions. This literature is helpful for this work to decide about the frictional coefficient between the brake disc and the pad.

Masaaki Kobayashi and Naoki Odani (1997), deals with study on stabilization friction coefficient of disc brake pads in cold condition. The authors relating the stability of the frictional coefficient with brake squeal in cold conditions. The have summarizes that, the $\Delta \mu$ was more easily affected by the relative humidity environment than by the temperature environment. The effect on $\Delta \mu$ increased when a film, composed of the transition elements of the friction material containing much oxygen element was formed on the disc sliding surface, and there was little wear powder on the sliding boundary. Also, they have concluded that, the $\Delta \mu$ was caused by the pad moisture absorption. These concepts were taken care off in this work to decide about the pad material and its performance.
Junichiro Yambe, Masami Takagi and Toshharu Matsui (2003), dealt in detail about the development of disc brake rotors for heavy and medium-duty trucks with high thermal fatigue strength. The authors discussed about a new method developed to evaluate thermal fatigue by simulating high-speed braking test using an actual disc brake rotor. Thermal fatigue strength is confirmed to be improved with increasing graphite number in the microstructure. They also confirmed that, the graphite number increases in proportion to the amount of nickel added, and that the inoculation of cerium, a rare earth element, produces an effect similar to that of adding nickel. Based on this approach, a new, low cost material for disc brake rotors for heavy and medium-duty trucks is developed using both cerium and nickel. This literature is helpful for this work to decide about the material composition and properties for the brake disc.

Gueva, Sinatora, Guesser and Tschiptschin (2003), dealt in detail about the wear resistance of cast irons used in brake disc rotors. The authors discussed about the wear resistance of three different types of gray cast iron (gray iron grade 250, high-carbon gray iron and titanium alloyed gray iron), used in the brake rotors and compared them with the results obtained with a compact graphite iron (CGI). These type of results and comparisons were studied in detail and the appropriate material for the brake disc was chosen in this work.

Denholm (1998), discussed in detail about the aluminium metal matrix composites rotors and drums. This literature gives the material properties of aluminium metal matrix composites, factors for the effective design of rotor based on this material and also its performance and thermal characteristics. Based on this review, aluminium metal matrix composite material is chosen as one of the alternate material for brake disc in this investigation.
Electrovac (power cooling subtracts) version 1.0/THS (2001) gives the basic properties for aluminium - silicon carbide metal matrix composites. This literature basically deals with manufacture of base plates using this metal matrix composite. It also gives the specifications and design rules and manufacturing standards. This silicon carbide based metal matrix composite is chosen as one of the alternate material for the brake disc in this investigation.

2.5 GENERAL LITERATURES FOR STRUCTURAL AND THERMAL ANALYSIS OF BRAKE DISC USING FINITE ELEMENT METHOD

The finite element method of structural and thermal analysis is widely applied to analyze the automotive components. To incorporate this analysis in this work, the following literatures were reviewed and incorporated.

Kao, Richmond and Douarre (1998), deals with the thermo-mechanical instability in braking and brake disc thermal judder. The authors analyzed the above characteristics through finite element study and compared with the experimental findings. This literature also gives an elaborate idea about the phenomena modeling, dynamic aspects and thermomechanical model formulation. The concepts and the techniques from this literature are as such used in this work for the thermomechanical modeling and analysis.

Thomas Valvano and Kwangjin Lee (2000), deals with an analytical method for the prediction of thermal distortion of a brake rotor. It suggests that, the severe thermal distortion of a brake rotor can affect important brake system
characteristics such as the system response and brake judder propensity. The authors formulated and developed a thermal stress and distortion analysis procedure using finite element methods. The basic concepts and the above procedure from this literature is incorporated in this integrated investigations.

Sanjay K. Mahajan, Yu-Kan Hu. and Kevin Zhang (1999), dealt in detail about the vehicle disc brake squeal simulations and experiences. The authors used finite element model of the brake system. The components were modeled using solid elements and the complexity of the system assembly varied depending upon the analysis method. They have used the NASTRAN software for the complex eigenvalue determination. Even though this literature is associated with the brake squeal, it is highly useful for modeling and structural analysis of the designed brake disc in this work.

Yu-Kan, Sanjay K. Mahajan and Kevin Zhang (1999) , suggests a method of brake squeal doe using nonlinear transient analysis. This literature gives an elaborate idea about the brake squeal determination through finite element modeling. It also discusses about the nonlinear friction, DOE factors and squeal intensity factor. Even though this literature is basically pertaining to brake squeal, the finite element modeling approach described here is used for the finite element analysis of the brake disc designed in this work using ANSYS software.

Wayne V. Nack (1999), dealt in detail about the brake squeal analysis by finite elements. This literature suggests a model for brake squeal analysis using nonlinear dynamics, coulomb friction, variable friction coefficient, stability index, convective mass matrix etc. and the analysis was carried out
using NASTRAN software. The concepts given in this literature is highly useful in modeling the convective heat transfer and thermal stress analysis of the brake disc designed in this work through finite element analysis.

Ouyang, Cao and Mottershead (2003), dealt in detail about the vibration and squeal of a disc brake. The authors analyzed the above characteristics through finite modeling and experimental verifications. In their investigations, the authors, considered the dynamics of the whole system and established the squeal and vibration frequencies. The concepts used in this literature for finite element modeling is incorporated to the required extent in this work for the finite element analysis the designed brake disc.