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Design and Analysis of Titanium Caliper Disc Brake

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***Abstract* - The following work studies a conceptual design of a disc brake system. Disc brakes offer higher performance braking, simpler design, lighter weight, and better resistance to water interference than drum brakes. The aim of this conceptual design was to increase the strength of the caliper, without increasing the weight of the caliper by a large amount and reducing the thermal deformation at high operating temperatures. Since titanium is difficult to machine the mono block design of conventional machined caliper was not used in this work but an attempt was made to build a brake caliper with different parts and assembled together to make a single unit. Also titanium parts used were machined from plates with no complicated shapes to save on machining costs in future. Since titanium has higher mass density care was taken while designing the new brake system to keep the weight increase to minimum. The existing brake caliper was analyzed for given load conditions with new material suggested. The results were studied for displacements and stresses along with thermal effects. The new modular caliper was analyzed for pressure and tangential load sand the results were studied for displacements/deformation and stresses with temperature effects.**

***Index Terms* - Titanium caliper, Disc brake, thermal deformation, stress, thermal effects.**

I. INTRODUCTION

Automotive industry is one of the growing industries with variation in models. In the competitive business the automotive companies have to take care of market demand. The customer choice is changes from day by day. Therefore as per customer choice vehicle must be upgrade is needed. Now a day people prefer the sport vehicles. And they look forward for high performance as well as better control on vehicle on safety point of view. In today's growing automotive market the competition for better performance vehicle is growing a lot. The racing fans involved will surely know the importance of a good brake system not only for safety but also for staying competitive. As we are aware of the fact that races are won over split of a second therefore the capacity of the brake system to slow down quickly at turns or corners is very important. The brakes designed for the purpose of racing need to have very high braking efficiency. The wear and tear of the pads or the cost is not of great concern to the manufacturer of the racing car brakes.

Initially the automobiles employed drum brakes in the cars. The main focus of this thesis is not for the passenger car technology but it concentrates on the automotive racing industry, NASCAR, the Nation Association of Stock Car Racing. NASCAR is a racing league similar to other racing leagues like Formula 1. The words "Stock Car" are complete purpose built race cars whose only similarity to the production vehicles replicate in exterior side profile. Major vehicle systems are designed for their specific racing purposes. The chassis used by the racing car is full tube frame while that used on commercial vehicles is made of single body frame. Another difference is the drive train; race versions have eight cylinder engines with rear wheel drive whereas commercial vehicles are four or six cylinder engines with front wheel drive. Motivation of project is conceptual design for a disc brake caliper and efficient working of brake system depends on how the brake behaves at high temperatures. Thus the aim of the research work will be to reduce the thermal deformation in the brake caliper. Since titanium is hard to machine, Fix caliper will be developed as an assembly instead of single block design.

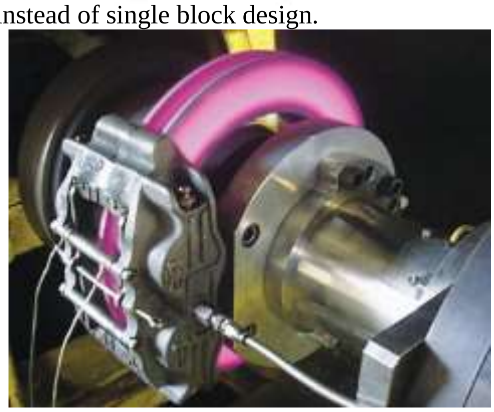

Figure 1: NASSCAR Disc brake system

Disc brake means the advance braking system use in sport as well as sport utility vehicle (SUV). The Disc brake is mainly classified into three types as disc brake, Fix caliper disc brake and floating caliper disc brake. The project uses the caliper disc brake e.g. as shown in Figure 1.1. The disc brake exists with Indian vehicles Tata manza, Tata Safari, Bolero and Mahindra Quanto. The advantages of disc brake are compact in size and deliver high performances.

II. LITERATURE REVIEW

Various researchers work regarding the design of disc brake system are discussed below,

PIOTR GRZES [15] The aim of this paper was to investigate the temperature fields of the solid disc brake during short, emergency braking. In this paper transient thermal analysis of disc brakes in single brake application was performed. To obtain the numerical simulation parabolic heat conduction equation for two dimensional model was used. The results show that both evolution of rotating speed of disc and contact pressure with specific material properties intensely effect disc brake temperature fields in the domain of time.

ABD RAHIM ABU-BAKAR, HUAJIANG OUYANG [16] This paper studies the contact pressure distribution of a solid disc brake as a result of structural modifications. Before modifications are simulated, four different models of different degrees of complexity for contact analysis are investigated. It is shown that the contact pressure distributions obtained from these four models are quite different. This suggests that one should be careful in modeling disc brakes in order to obtain correct contact pressure distributions. This work could help design engineers to obtain a more uniform pressure distribution and subsequently satisfy customers' needs by making pad life longer.

M. NOUBY, D. MATHIVANAN, K. SRINIVASAN [17] proposes an approach to investigate the influencing factors of the brake pad on the disc brake squeal by integrating finite element simulations with statistical regression techniques. Complex Eigen value analysis (CEA) has been widely used to predict unstable frequencies in brake systems models. The finite element model is correlated with experimental modal test. The 'input output' relationship between the brake squeal and the brake pad geometry is constructed reduction in cycle time for the plastic part. for possible prediction of the squeal using various geometrical configurations of the disc brake. Influences of the various factors namely; Young's modulus of back plate, back plate thickness, chamfer, distance between two slots, slot width and angle of slot are investigated using design of experiments (DOE) technique. A mathematical prediction model has been developed based on the most influencing factors and the validation simulation experiments proved its adequacy.

P. LIU A, H. ZHENG A, C.CAI A, Y.Y. WANG A, C. LUA,K.H. ANG B, G.R. LIU [18] An attempt is made to investigate the effects of system parameters, such as the hydraulic pressure, the rotational velocity of the disc, the friction coefficient of the contact interactions between the pads and the disc, the stiffness of the disc, and the stiffness of the back plates of the pads, on the disc squeal. The simulation results show that significant pad bending vibration may be responsible for the disc brake squeal. The squeal can be reduced by decreasing the friction coefficient, increasing the stiffness of the disc, using damping material on the back plates of the pads, and modifying the shape of the brake pads.

RAJENDRA POHANE, R. G. CHOUDHARI [19] FEM model is prepared for contact analysis. A three dimensional finite element model of the brake pad and the disc is developed to calculate static structural analysis, and transient state analysis. The comparison is made between the solid and ventilated disc keeping the same material properties and constraints and using general purpose finite element analysis. This paper discusses how general purpose finite element analysis software can be used to analyze the equivalent (von-misses) stresses& the thermal stresses at disc to pad interface.

H MAZIDI, S.JALALIFAR, J. CHAKHOO [20] In this study, the heat conduction problems of the disc brake components (Pad and Rotor) are modeled mathematically and is solved numerically using finite difference method. In the discretization of time dependent equations the implicit method is taken into account. In the derivation of heat equations, parameters such as the duration of braking, vehicle velocity, Geometries and the dimensions of the brake components, Materials of the disc brake rotor and the PAD and contact pressure distribution have been taken into account.

V.M.M.THILAK, R.KRISHNARAJ, DR.M.SAKTHIVEL, K.KANTHAVEL, DEEPAN MARUDACHALAM M.G, R.PALANI[21] In this work, an attempt has been made to investigate the suitable hybrid composite material which is lighter than cast iron and has good Young's modulus, Yield strength and density properties. Aluminum base metal matrix composite and High Strength Glass Fiber composites have a promising friction and wear behavior as a Disk brake rotor. The transient thermo elastic analysis of Disc brakes in repeated brake applications has been performed and the results were compared. The suitable material for the braking operation is S2 glass fiber and all the values obtained from the analysis are less than their allowable values.

PRASHANT CHAVAN, AMOL APTE[22] Gives simplified yet almost equally accurate modeling and analysis method for thermo-mechanical analysis using brake fade test simulation as an example. This methodology is based on use of ABAQUS Axisymmetric analysis technique modified to represent effect of discrete bolting, bolt preloads, and contacts within various components of the assembly.

Q CAO1, M I FRISWELL, H OUYANG, J E MOTTERSHEAD1 AND S JAMES[23] This paper presents a numerical method for the calculation of the unstable frequencies of a car disc brake and the analysis procedure. The stationary components of the disc brake are modeled using finite elements and the disc as a thin plate. This approach facilitates the modelling of the disc brake squeal as a moving load problem. Some uncertain system parameters of the stationary components and the disc are tuned to fit experimental results. A linear, complex-valued, asymmetric eigen value formulation is derived for disc brake squeal. Predicted unstable frequencies are compared with experimentally established squeal frequencies of a realistic car disc brake.

S. P. JUNG, T. W. PARK, J. H. LEE, W. H. KIM, AND W.S CHUNG[24] A simple finite element model of a disc and two pads was created, and TEI phenomenon was implemented by rotating the disc with a constant rotational speed of 1400 rpm. The intermediate processor using the staggered approach was used to connect results of two other analysis domains: mechanical and thermal analysis. By exchanging calculation results such as temperature distribution, contact power and nodal position at every time step, solutions of fully coupled thermo-mechanical system could be obtained. Contact pressure distribution of the pad surface was varied according to the rotational direction of the disc. DTV and temperature of the disc were calculated and tendency was verified by earlier studies.

HUAJIANG OUYANG, WAYNE NACK, YONGBIN YUAN,FRANK CHEN [25] covers two major approaches used in the automotive industry, the complex eigenvalue analysis and the transient analysis. The advantages and limitations of each approach are examined. This review can help analysts to choose right methods and make decisions on new areas of method development. It points out some outstanding issues in modelling and analysis of disc brake squeal and proposes new research topics. It is found that the complex eigenvalue analysis is still the approach favored by the automotive industry and the transient analysis is gaining increasing popularity.

HAO XING [26] A disc brake system for passenger car Is modelled and analyzed using both approaches i.e. the transient analysis and complex modal analysis. Complex modal analysis is employed to extract natural frequencies and a transient analysis is carried out to study the thermal effects during braking. The effect of friction in complex modal analysis is investigated.

A SÖDERBERG, U SELLGREN, S ANDERSSON [27] This paper presents an approach to simulating wear on both contact surfaces at the pad-to-rotor interface in disc brakes using general purpose finite element software. It represents a first step toward a method of simulating the brake pressure needed to effectively clean the rotor of unwanted oxide layers. Two simulation cases are presented. The first addresses running-in wear under constant load and corresponds to repeated brake applications at the same constant brake load. The second studies what will happen if a lower load is applied after the contact surfaces have been run-in at a higher load level. This lower load is applied to wear off an oxide layer after a sequence of repeated stop braking at higher load levels.

ABD RAHIM ABU-BAKAR, HUAJIANG OUYANG [28] The detailed and refined finite element model of a real disc brake considers the surface roughness of brake pads and allows the investigation into the contact pressure distribution affected by the surface roughness and wear. It also includes transient analysis of heat transfer and its influence on the contact pressure distribution. The focus is on the numerical analysis using the finite element method. The simulation results are supported with measured data in order to verify predictions. An improved numerical methodology is presented by considering three-validation stages, namely, modal analysis at component and assembly levels and verification of contact analysis. Prior to that, a realistic surface roughness of the brake pad at macroscopic level is considered in the finite element model instead of assuming a smooth and perfect surface that has been largely adopted by most previous researchers. These two aspects have brought about significant improvement to the validation as well as analysis. Wear and thermal effects are other distinct aspects of disc brakes that influence contact pressure distributions and squeal generation in a disc brake assembly and they are also included in the current investigation. Transient analysis of disc brake vibration using a large FE model that includes thermal effects is carried out.

III. ANALYSIS OF CONVENTIONAL DISC BRAKE SYSTEM

Introduction

3.1 Existing Brake Caliper

The Figure 3-1 shows a typical NASCAR brake system [2]

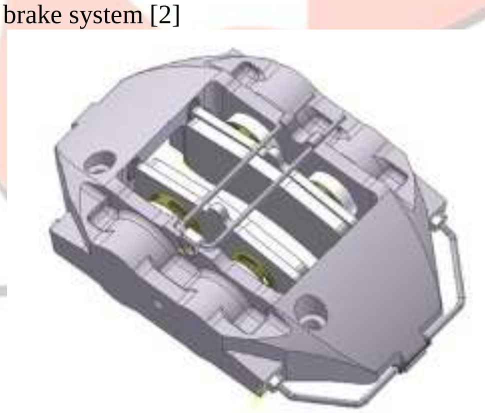

Figure 3-1: Conventional Brake Caliper

It can be observed that the major difference in the passenger car brake system and this system is that the caliper has multiple pistons on both sides of rotor. These four pistons are for applying uniform pressure to the rotor from the brake pads to increases the braking efficiency at high speeds. There is also difference in the material being used the commercial design use cast iron for brake components while the material used by NASCAR brakes is aluminum, this is used to reduce the weight of the system and improves heat transfer out of the caliper. The caliper is like a C-clamp which squeezes the pads onto the rotor to stop the rotor for braking action. The pistons are actuated by hydraulic force of brake oil which is pushed against the pistons back, when the brakes are applied. As discussed in section 1.3 the motion of piston is very less as the rotor is nearly touching the brake pads all the times. The brake pads are glued to the baking plate against which the piston pressure acts. Titanium inserts are used in between the backing plate and piston to isolate the tremendous heat produced during braking action from caliper body. One end of caliper is bolted to the suspension system. Different types of friction pads are used depending upon the utility and application of brakes. The manufacturer generally provides a card for the selection of pads. The most important physical property of brake pads is they should be non-fading.

3.2 Material Selection for Brake Caliper

The selection of material for design of any component is important. The material selected needs to be compatible with the working environment of the product. The brake caliper currently in NASCAR uses material 6061- T651 [2]. This material has good corrosion resistance and weld ability. The author in his thesis compares the different types of material for use in brake caliper in terms of cost, machining process used, thermal coefficient of expansion, tensile strength and young's modulus.

Al 2219- T 87 has a lower coefficient of thermal expansion, higher modulus of elasticity, higher strength and good machinability as compared to 6061 alloy. The cost is more but as the brake caliper is for racing cars the cost factor is not as great concern at it would be in passenger cars. Based on the information and the comparison provided aluminum alloy 2219 – T 87 will be used for design and analysis of the brake caliper. Al 2219 is readily wieldable and is useful for application in a temperature range of-450 to 600 degree F [3]. It also has high fracture toughness and T8 temper has high resistance to stress corrosion cracking. The other material used prominently in the new caliper is titanium. Titanium is difficult to machine or weld but they perform well in high temperature application [4].

3.3 Brake Pad Material [2] [1]

Brake pads material is very important for safe and consistent working of a vehicle braking system. Brake pad material is generally classified into two categories asbestos and metallic. Asbestos dust is proved to be a cancer causing agent therefore federal regulations prohibited their use in the 90s. Metallic brake pad materials are classified as low metallic and semi-metallic. All pad material begins to disintegrate at the friction surface due to high heat generation process between the rotor and pad. Due to non uniform pressure distribution between the pad and rotor, pad surface temperature will be non uniform and the areas of higher temperature will have low friction level than that of the lower temperatures. An exact analytical value of coefficient of friction between rotor and brake pads is difficult to set [1]. SAE J661 procedure is used to determine the friction coefficient for hot and cold surfaces. Disc brake pads should have certain amount of porosity to minimize the effect of water on coefficient of friction. Important Characteristics of brake pads are friction coefficient, wear rate, thermal conductivity and strength and durability [7]. These porous contents should not store contaminating agents like salts and wear particles [8]. Materials like aluminum boron carbide are found to be best suited for automobile brake pad application [9]. It has high toughness and thermal conductivity relative to other ceramics with better thermal shock absorbing capacity.

3.4 Thermal Study of Brake Caliper

During braking action the kinetic energy and the potential energy of the vehicle is converted to thermal energy through friction between the brake pads and the rotor [1] [2]. This temperature rise depends on various conditions such as frequency of brake application. Overheating of brakes can cause brake fading. The heat developed is dissipated to the cool air flowing over the brake by means of convection [12]. This convection factor was considered for thermal analysis [13]. Race cars travel at much higher speed than normal passenger cars. The kinetic energy goes up as the square of the speed. Kinetic energy is expressed as Where, m is the mass of an object and v is its speed. Going at twice the speed means four times the kinetic energy because velocity gets squared .This large amount of KE gets converted into large amount of heat energy .This tremendous amount of heat can damage the brake components [14].This heat can affect the hydraulic fluid which operates the pistons in the brakes. Therefore proper measures need to be taken for isolating the heat from some parts of the brake caliper such as pistons [1]. Ti inserts were inserted between piston and the backing plate to isolate the heat from the pistons. The author was able to perform thermal analysis to study the temperature distribution on existing caliper. The surface temperature of pads was known but the convection environment for caliper was not known. The temperature rise in the caliper body was studied from the analysis it could be seen that the rise in the caliper body was not more than 4000F. This value of temperature will be used based on the authors work to evaluate the thermal stresses in this thesis. The analysis results are shown in the figure 2-2, which shows the temperature isolation of the caliper body due to titanium inserts.

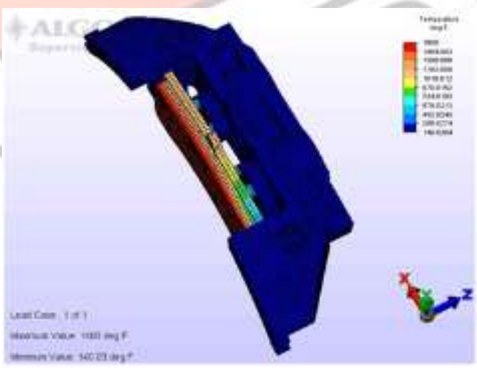

Figure 3-2: Temperature Isolation Using Ti Inserts

Figure 3-3 shows the temperature distribution through the brake caliper body. It shows that the temperature is not more than 350 0 F in any part of the caliper body. Considering a repetitive braking action this temperature was used during stress analysis in the existing Figure 2-3 shows the temperature distribution through the brake caliper body. It shows that the temperature is not more than 350 0 F in any part of the caliper body. Considering a repetitive braking action this temperature was used during stress analysis in the existing

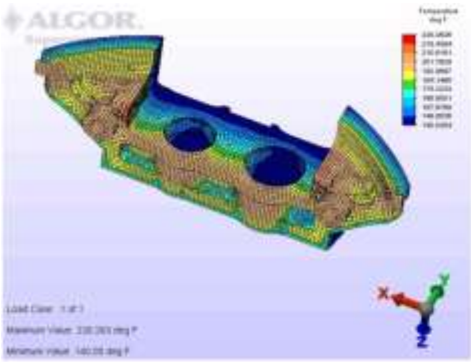

Figure 3-3: Temperature distribution in existing caliper

3.5 Structural Analysis of Conventional Brake Caliper using Al 6061 [2]

The author conducted the analysis for the conventional brake caliper using Al 6061 material. The caliper was loaded with tangential loading and pressure loading. This is described in section 3.1. As seen from figure 3-4 the maximum stress induced in the caliper is 24288 lbf/in2. The maximum displacement in Z direction as shown in figure 2-5 is 0.047 inch. Depending on this model the brake caliper was analyzed for a new material Al 2219 as suggested in section 2.2. The detailed analysis results will be discussed in section 3.1.

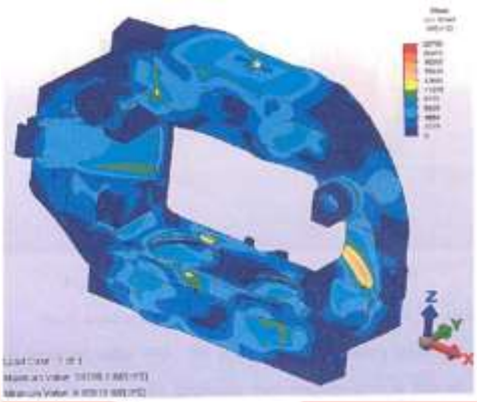

Figure 3-4: Stresses in existing caliper with Al 6061 material [2]

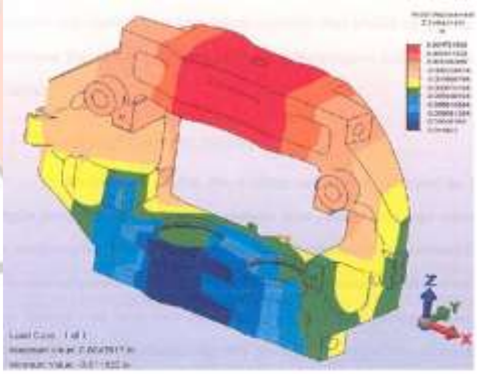

Figure 3-5: Displacement in Z-direction in existing caliper with Al 6061 material [2]

IV. CONCEPTUAL DISC BRAKE DESIGN

4.1 Introduction

The new brake caliper used the base of conventional brake caliper . The main objective of the design was to increase the strength of the caliper without increasing the weight of the caliper by a large amount, taking displacement and stress into account and also making a brake caliper with an assembly instead of a single block manufacturing. This concept of is proposed in the new design. Al 2219 and Titanium is used for the new caliper design.

4.2 Design Concept

This conceptual design was based on making a brake caliper stronger with the use of titanium. Since titanium is difficult to machine an attempt was made to keep the titanium parts as simple as possible, avoiding complex geometry, so that they can be manufactured using water jet cutting. Since titanium has a higher density than Aluminium the weight of the titanium caliper would be more than that of Aluminium counterpart. Keeping this in mind unwanted material use was eliminated during designing this caliper so that the weight of the caliper is kept to its minimum. Especially in race vehicles where the races are won over a fraction of second, weight to power ratio is very critical and always better means and methods need to be devised to control it. In NASCAR league there are weight restrictions for all the vehicles, the weight of the all racing cars must meet the uniform weight requirements. Keeping the weight increase of brake caliper within a limit can be better justified if we study its effect on the unsprang mass of the vehicle. The sprung mass is the mass of the vehicle supported on the suspension system, while the unsprang mass is defined as the mass between the road and the suspension system (springs). The mass of the wheel and components that are supported directly by the wheel, and considered to move with the wheel, but not carried by the suspension system is considered to be unsprang mass. The brake caliper assembly is attached to the steering knuckle and the suspension of the vehicle, therefore it adds to the unsprang mass of the vehicle. The mass of caliper acts against the suspension. Therefore the increase in unsprang weight affects the handling and stability of the vehicle. Increase in unsprang mass causes increase in force acting on the suspension and chassis thus reducing the tire grip on the road. Whenever the vehicle encounters a bump on a road or vertical acceleration, the acceleration is applied to the wheel assembly. If this resulting force is large enough then it causes loss of contact between road and tire resulting in loss of traction. So an attempt of keeping the weight increase to its minimum was made while designing the new system .The next objective of this thesis was to try to build the caliper in an assembly pattern instead of a single block design. The existing brake caliper is shown in figure 4-1.

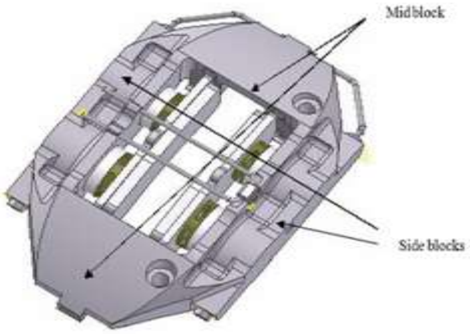

Figure 4-1: Conventional brake caliper

Figure 4-2 shows the new modular caliper. The assembly consists of two different side blocks housing the pistons. The material for side blocks is Al 2219. The Side plates supporting the side blocks are made of titanium. The left part and the right part of the caliper are assembled together using titanium stoppers. The Z-shaped stoppers were used specifically to increase the assembly resistance against loading due to rotation of the rotor.

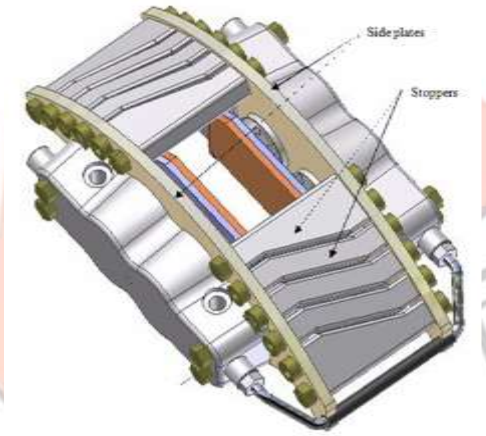

Figure 4-2: Modular brake caliper assembly

The other option for the stopper was using straight stoppers parallel to each other, connecting the two side titanium plates. The unique Z shape was selected for maximum strength, as this shape allows maximum material per stopper and increases the overall stiffness of the structure. Since the caliper is fixed to the vehicle through the clamping holes on the left hand side, the right side of the caliper has a tendency to move fractionally in the direction of rotor motion on application of brake as seen in figure 4-3. The stopper shape also resists this motion.

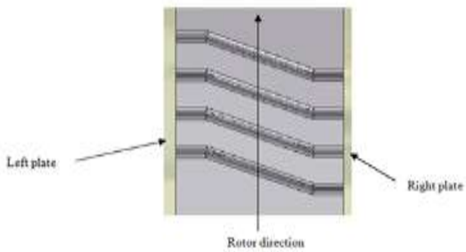

Figure 4-3: Stoppers used to connect side plates

4.2 Modular Caliper Assembly

The detailed assembly of the modular brake caliper is shown in figure 4-4.

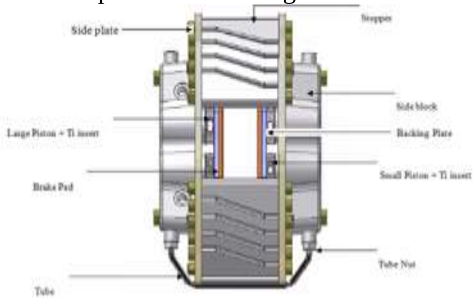

Figure 4-4: Detailed modular brake caliper assembly

The two side blocks that enclose piston cylinders are attached to the side plates using titanium nut bolts. The left hand side housing is bolted from two holes to suspension assembly. The four pistons two on each side push the brake pads on to the rotor when the brake is applied. The tube is fixed to the caliper leading edge with the help of tube nuts and a sleeve to guide it. The tube is useful for circulation of brake fluid in side the cylinder bores. Figure 4-5 shows the internal structure of brake caliper. Here we can see the pistons/seal arrangement and the holes provided for brake fluid to pass in the piston cylinders.

Figure 4-5: Internal structure of modular brake caliper assembly

Effective braking requires the pads to be pressed against the rotor as uniformly as possible [1]. Uniform pressure between the pad and rotor results in uniform pad wear, brake temperature and more stable friction coefficient between pad/rotor. In racing cars especially at high speeds non uniform pressure wears the brake pads unevenly. Pad wear is more at the leading end, where the rotor enters the caliper, than the trailing end where the rotor exits as shown in figure 4-6.

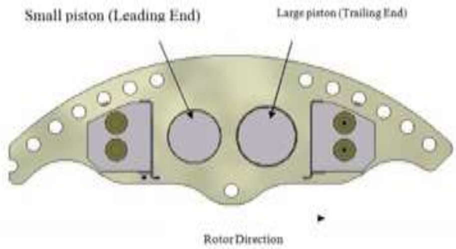

Figure 4-6: Leading-Trailing end in modular brake caliper

This is caused by higher pressure between the pad and rotor at the leading end than the trailing end. This is caused by the lever arm between pad drag force and abutments force. This results in tapered pad wear. For reducing the tapered wear two different sized pistons are used, with the smaller piston located at the leading end and the larger piston located at the trailing end. The brake pads are mounted on the backing plate as a sub-assembly. This subassembly is connected to the pistons with titanium inserts in between them .The pistons and backing plate are separated by the titanium inserts as for temperature isolation which will be discussed in section 5.1. The two side plates are bolted with stoppers in between them with the help of titanium bolts. The rotor rotates with a very small clearance with the brake pads. The brake pads are pushed onto the rotor surface when the brakes are applied. Four abutments plates are fixed on left and right end to support the brake pad and backing plate assembly. These plates are made of sheet metal steel. The abutments plates are fixed to the caliper body on four pad blocks using screws. The pad blocks are bolted to the side plates. The total arrangement is such that the pad-backing plate assembly can slide forward and backward between the left-right abutments plates. The figure 4-7, shows the half section of the caliper showing the two abutment plates on right and left side.

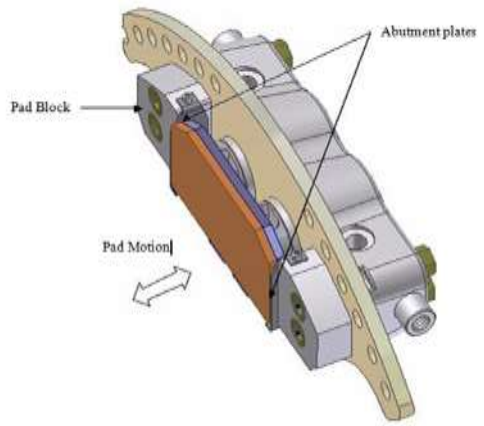

Figure 4-7: Details of abutment plates and pad-backing plate assembly

The pistons are also made of Aluminium. The exploded view of the whole brake assembly is shown in figure 4-8. Here all the parts can be seen and a general idea of the assembly procedure can be understood.

Figure 4-8: Exploded view of the modular caliper assembly

The assembly view of the caliper and vented rotor is shown in figure 4-9. The Slotted rotor is used for cooling purposes. The detailed drawing views of each part used in caliper assembly are shown AppendixB.

Figure 4-9: Modular caliper and rotor assembly

V. ANALYSIS OF NEW MODULAR CALIPER

5.1 Thermal Study of Modular Brake Caliper

As described in section 2.2 the thermal analysis of modular brake caliper was performed. To reduce the analysis time half model was analyzed. The model used for thermal analysis is shown in figure 5-1

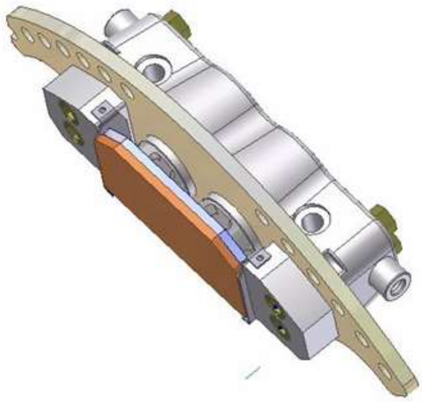

Figure 5-1: Half -Modular brake caliper used in thermal analysis

The parts included into the model were the side block, side plate, pad blocks, abutments plates, and pistons, titanium inserts, backing plate, brake pad and nut- bolts. The stoppers were eliminated to reduce analysis time (Figures 4-4 & 4-7). This model was transferred to ALGOR for analysis. A very fine absolute mesh.07 was used to obtain accurate results .The meshed model is shown in figure 5-2 size of

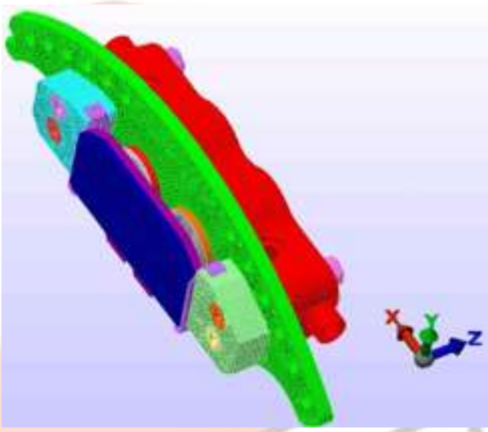

Figure 5-2: Meshed model for thermal analysis for modular caliper

The design parameters used were mass density, specific heat and thermal conductivity. The surface pad temperature was known to be 600 0 F [2]. The temperature of inside diameter of the caliper body (the lower part of the caliper) was assumed to be 200 0 F. The emperature of outside diameter of the caliper body (the upper part of the caliper) was assumed to be 140 0 F. The results of the thermal nalysis can be seen in figure 5-3. It can be seen that how well the titanium inserts play a role of temperature isolator. They insulate the heat eveloped at the pad surface from the rest of the caliper body parts effectively as shown in figure 5-4.The temperature of 1600 0 F is reduced o around 300 0 F at the pistons and beyond.

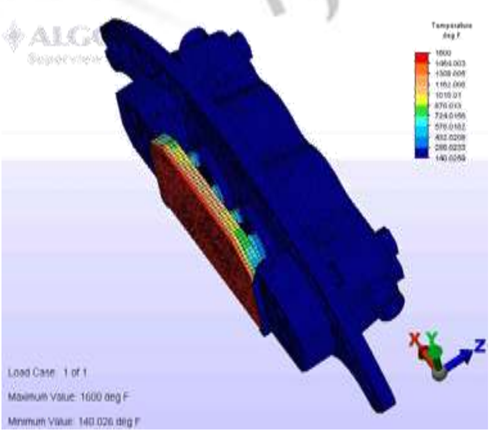

Figure 5-3: Temperature analysis results Temperature distribution in Ti inserts

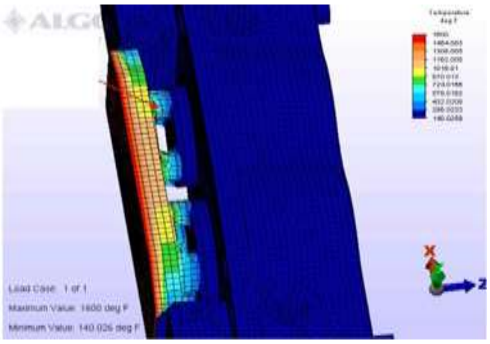

Figure 5-4: Temperature isolation by titanium insert

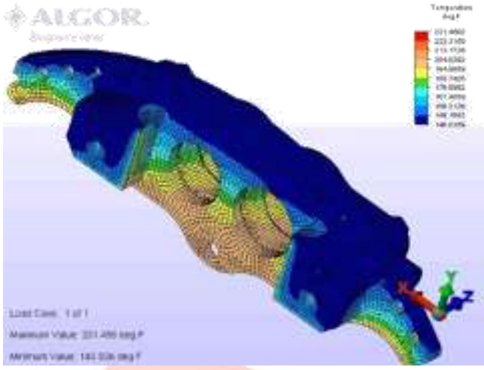

Figure 5-5: Temperature distribution in modular caliper

As seen from the figure 5-5, the temperature rise in the body was not more than 300 0 F. This temperature will be used as maximum temperature condition while determining thermal stresses in the caliper.

5.2 Structural Study of Modular Brake Caliper

The important aim of this study was to find out displacement in the new caliper. The new design proposed was analyzed using ALGOR software for displacements and stresses. The model used for analysis is shown in figure 5-6.

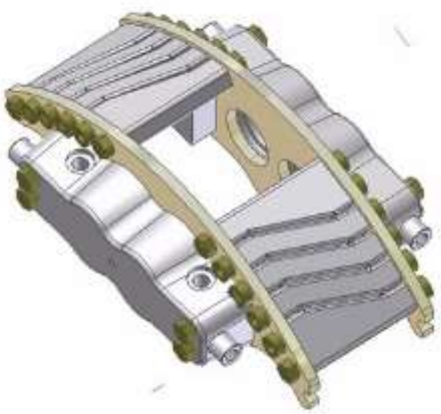

Figure 5-6: Modular brake caliper model used for FEA

Since the primary objective of the analysis was the structural analysis of the caliper main body, the only caliper parts taken into consideration were the two side blocks, the stoppers, nut bolts, Side plates and pad plates (see figures 4-4 and 4-7). The model was meshed with an absolute mesh size of 0.07. The meshed model is shown in figure 5-7.

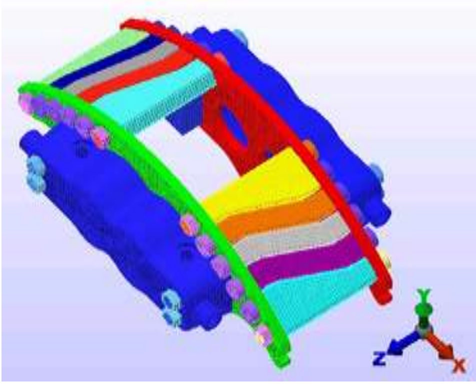

Figure 5-7: Meshed modular brake caliper model

Fixed boundary conditions were used for the mounting holes representing the caliper body fixed with the vehicle body. The loads acting on the caliper structure were of two types the pressure loading acting on inside the cylinder and the tangential force loading acting on the trailing pad blocks. When the brakes are applied the brake pad pushes onto the rotating rotor, the pad along with the backing plate are pushed in a tangential direction which results in the tangential loading. A pressure loading of 1500 psi was used [2]. The tangential force was calculated

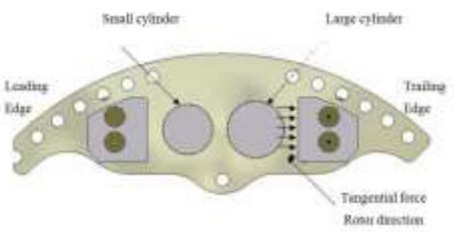

Figure 5-8: Pad loading with trailing edge in modular caliper

Force = Pressure x Area of each cylinder x coefficient of friction

Force exerted due to the larger Piston

$F = P \text{ x } \pi/4 \text{ x } (Dlarge)\ 2 \text{ x } \mu$ (1)

$F = 1500 \text{ x } \pi/4 \text{ x } (1.337)\ 2 \text{ x } 0.4 = 842.371$ lb

Force due to smaller Piston

$f = P \text{ x } \pi/4 \text{ x } (Dsmall)\ 2 \text{ x } \mu$ (2)

$f = 1500 \text{ x } \pi/4 \text{ x } (1.181)\ 2 \text{ x } 0.4 = 657.26$ lb

Total tangential force = F + f = 842.371 + 657.26 =1499.6 lb (3)

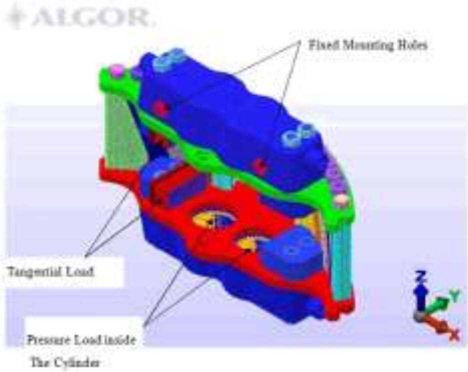

Figure 5-9: FEM model with loads and constraints in modular caliper

Using the above information the static stress analysis is performed to evaluate displacement and von misses stresses. The FEM model is shown in figure 5-9. The design parameters used for two materials Titanium and Al 2219 are shown in Table 5-1 [3] [4].

TABLE 5-1: Physical Properties of Aluminum and Titanium

Sr. no.	**Physical Properties of Aluminum and Titanium**		
	Physical Properties	***Al 2219***	***Titanium***
1	Mass Density (lbf .s2/in/in3)	2.688 x 10-4	4.21 x 10-4
2	Modulus of Elasticity (lbf /in2)	10.7 x 106	16.825 x 106
3	Poisson's Ratio	0.33	0.34
4	Thermal coefficient of Expansion(1/oF)	12.5 x 10-6	4.9444 x 106

The Brake caliper will be analyzed for cold and hot working conditions. The important results of this analysis were the displacement in X (longitudinal direction) and Z (axial direction).

5.3 Structural Analysis of Modular Brake Caliper

The overall displacement of the caliper is shown in figure 5-10. The maximum displacement in the brake caliper is 0.039 inches. The displacement on the left hand side is zero because of the fact that the caliper is fixed with the steering knuckle (vehicle body) through the mounting holes. The maximum displacement occurs around the trailing edge area which is not fixed with the vehicle body.

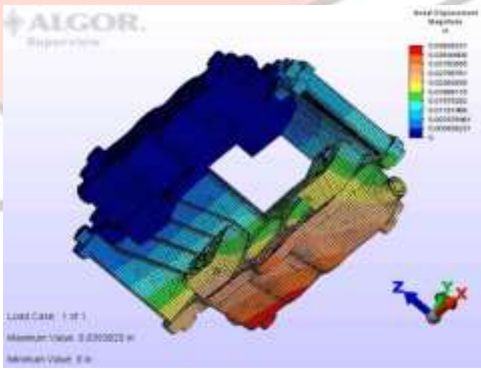

Figure 5-10: Overall displacement in the modular caliper

The overall deformation of the caliper at the exaggerated scale factor 5 is shown in figure 5-11. The unreformed shape of caliper is shown in a transparent form while the deformed shape is shown in solid form.

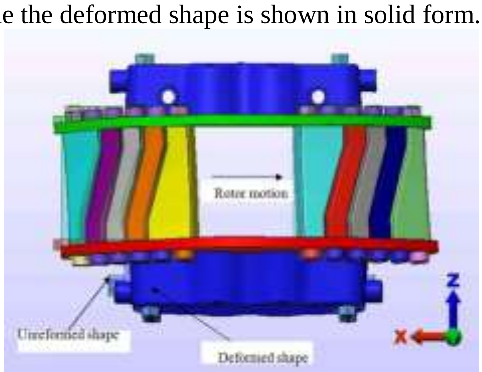

Figure 5-11: Displaced model of the modular brake caliper

The maximum Z –direction displacement corresponds to the loading in axial direction is shown in figure 5-12. The maximum displacement is 0.004 inch in z direction. The maximum displacement in negative Z direction is 0.02 inch.

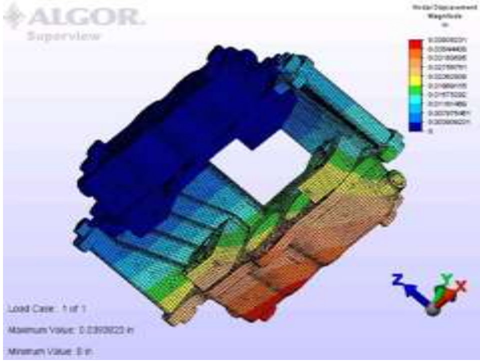

Figure 5-12: Nodal displacement in Z direction of the modular brake caliper

The maximum X –direction displacement corresponds to the loading in axial direction is shown in figure 5-13. The maximum displacement is 0.001 inch in X direction. The maximum displacement in negative X direction is 0.01 inch.

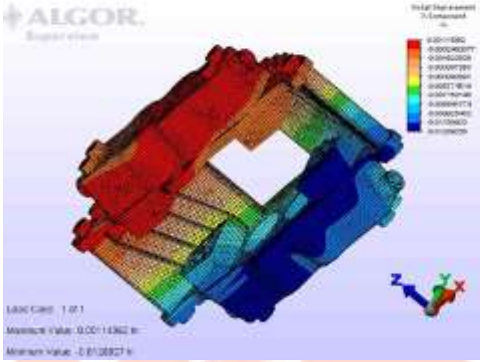

Figure 5-13: Nodal displacement in X direction of the modular brake caliper

5.4 Structural Analysis of Modular Caliper with Thermal Effects

As the brake is operated it gets heated with repetitive braking, therefore the thermal -stress analysis was performed. The new analysis was performed similar to the one in section 5.1. The same boundary conditions and loads were applied to the new design. This analysis of brake caliper was performed at a nodal temperature of 300 0 F. Figure 5-14 shows the stress levels in the caliper. The artificial high stresses around the mounting holes are eliminated as described in section 3.2.

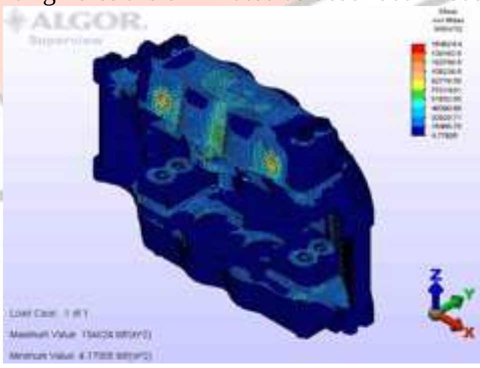

Figure 5-14: Stress in modular brake caliper including thermal effects

Since the side blocks are made of aluminum it will be expanding in high temperature environment. The caliper is mounted through the mounting holes on to a rigid suspension system, therefore as the caliper heats up high thermal stress and displacement will be induced at the areas near the mounting holes. The overall displacement of the caliper is shown in figure 5-15. The maximum displacement in the brake caliper is 0.05 inches. The displacement on the left hand side(mounting holes side) is zero because of the fact that the caliper is fixed with the steering knuckle (vehicle body) through the mounting holes. The maximum displacement occurs around the trailing edge area which is not fixed with the vehicle body.

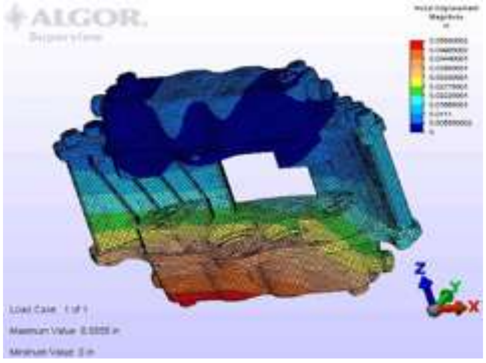

Figure 5-15: Displacement in the modular brake caliper including thermal effects

The maximum Z –direction displacement corresponds to the loading in axial direction is shown in figure 5-16. The maximum displacement is 0.006 inch in z direction. The maximum displacement in negative Z direction is 0.04 inch.

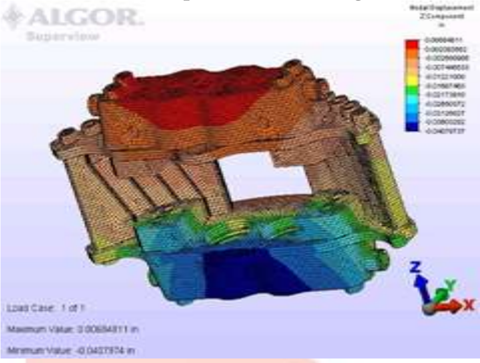

Figure 5-16: Z Displacement in the modular brake caliper including thermal

The maximum X –direction displacement corresponds to the loading in axial direction is shown in figure 5-17. The maximum displacement is 0.007 inch in X direction .The maximum displacement in negative X direction is 0.02 inch.

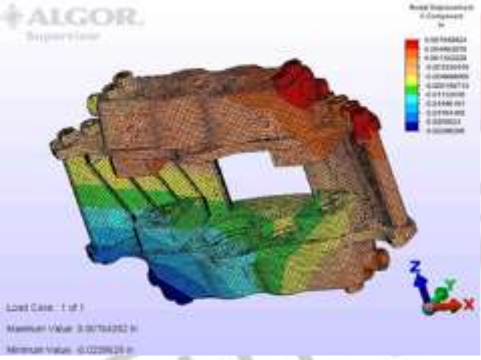

Figure 5-17: X Displacement in the modular brake caliper including thermal

VI. CONLUCION

The detail review of the thesis will lead one to understand that essentially a new conceptual caliper design was proposed to decrease the thermal deformation at high temperatures. The modular caliper is an assembly unit made up of simple and easy to manufacture parts. The machining cost will be reduced as compared with the monoblock unit. As seen in section 2.1 the suggested material for brake caliper was Al 2219. The existing caliper was analyzed with a new material Al 2219-T87 for Stress and displacement. The Existing caliper was first analyzed at cold working conditions without taking into account the effects of thermal expansion. The stresses and displacements were noted (section 3.1). The maximum stress was lower for Al 2219 than the Al 6061 brake caliper. This result coupled with the discussion in 2.1 confirmed the use of Al 2219 for the new brake caliper. The existing brake was analyzed at 300 0F. The caliper showed high thermal stresses and displacement as compared with the previous case (section 3.2). This is due to the thermal expansion of caliper body.

The modular design was analyzed without considering the effects of thermal expansion (section 5.3). This is done to study the amount of deformation due to tangential force and pressure loading. These results were used to study the increase in deformation in the caliper at high temperatures. The modular brake was then analyzed using a nodal temperature of 300 0F. The displacement increased as compared with the previous case. This is due to the thermal expansion of the individual parts in the assembly. Since race cars brakes always operate at high temperature the thermal deformation /displacement results are important. The thermal displacement in the modular caliper is lower than the conventional caliper by 8.56 % (section 5.4). This is shown in table 6-1.

VII. ACKNOWLEDGMENT

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