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Characterizations of Mechanical properties of Disc brake for Automated Hand Brake System

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***Abstract*—**As nowadays human life is getting busy and complicated due to their work and development. With the emergence in technology, every step that is taken to reduce human effort is taken into account. By introducing the concept of sensors many automobiles functions that we have to do manually is now controlled by sensors. On the same platform normal steering place taken by power steering to reduce human effort. So, taken into consideration above said innovation. The disc brakes failed repeatedly during extreme braking conditions that ultimately reduced the efficiency and performance of the rotor. Static analysis is performed on the disk rotor to validate the ductility and thermal analysis is performed to determine the heat flow acting on the disk. The distribution of the temperature around the disk rotor is also analyzed. Three emerging materials are stainless steel, cast iron and carbon-carbon composite, are compared with each other to verify maximum deformation, tension and temperature. The disk brake is modeled in solid edge and analysis is performed in ANSYS for design and constructs automatic handbrake system. As conventional handbrake system is hydraulic or pneumatic method which involves human interference like pulling or pushing the lever. Sometimes due to negligence we forget to apply handbrake system. This may lead to rolling of vehicle in case of slopes in parking area. So, with this project we reduce human intervention in applying handbrake and thus reduce unnecessary accidents. Also, as I say automatic hand brake system so removal of brake lever will provide more space is driving cabin. The hand brake engagement and disengagement is done with the help of IR sensor and rack & pinion method.

***Keywords*—** Automatic hand brake, Hydraulic system, Solenoid, Disc brake, IR sensor etc

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I. INTRODUCTION

Nowadays, the condition of increasing road traffic makes the handling of vehicles more difficult. The present scenario demands an exploration of new vehicle handling mechanism, which in turn forces us to find out an alternative way instead of current system or a modified steering mechanism for better handling. While the vehicle enters a congested or narrow area there would be no one who doesn't wish for, if they would be able to reduce the turning radius of their vehicle or if they could move the whole vehicle sideways without turning the vehicle.

One of the most important safety features in an automobile is brake. The brakes function to slow and stop the rotation of the wheel. To stop the wheel, braking pads are forced mechanically against the rotor or disc on both surfaces. They are compulsory for the safe operation of all vehicles. In short, brakes transform the kinetic energy of the car into heat energy, thus slowing its speed. Brake fade is the reduction in stopping power that can occur after repeated or sustained application of brakes, especially in high load or high speed conditions. Brake fade can be a factor in any vehicle that utilizes a friction braking system including automobiles, trucks, motorcycles, airplanes, and even bicycles. Brake fade is caused by a build-up of heat in the braking surfaces and the subsequent changes and reactions in the brake system components and can be experienced with both drum brakes and disk brakes. Loss of stopping power, or fade, can be caused by friction fade, mechanical fade, or fluid fade. Brake fade can be significantly reduced by appropriate equipment and materials design and Selection, as well as good cooling. It is more prevalent in drum brakes due to their configuration. Disc brakes are much more resistant to break fade because the heat can be vented away from the rotor and pads more easily, and became a standard feature in front brakes for most vehicles.

A typical automobile consists of two types of brakes, one for retarding the speed of vehicle while it is in motion and other is to hold the vehicle in its place when standing still or parked. The latter is mostly important when the vehicle is parked on slope. It is important to disengage the handbrake before starting the vehicle from rest position. Due to operator errors the conventional handbrake system remained engaged even when the vehicle was moving due to manual operation of the hand lever through which the handbrake is operated. This

led the brakes to become ineffective and eventually they failed to serve their purpose. To overcome all the limitation of the conventional system we proposed the new automatic handbrake engagement and release system. Study takes into account several safety issues and permutations with the hand brake which are listed below as problem statements.

The development and use of disc brakes began in England. in the 1890s. The first automotive caliper disc brake was patented by Frederick William Lanchester in his Birmingham, British factory in 1902 and successfully used in Lanchester automobiles. The disc brake is a wheel brake that slows the rotation of the wheel by the friction caused by the thrust of the brake pads against a Brake disc with a set of stirrups. The brake disc (or rotor in American English) is usually cast iron, but may In some cases, they consist of compounds such as reinforced carbon. Composites with carbon or ceramic matrix. This is connected to the Wheel and / or axis. To stop the wheel, the friction material in the shape of brake pads, mounted on a device called brake. Clamp, is forced mechanically, hydraulically, pneumatically or electromagnetically against both sides of the disk. Friction causes the disk and the fixed wheel to slow down or stop. The breaks turn the movement into heat, and if the brakes get too hot, they become less effective, a phenomenon known as braking the brakes.

A drum brake is a brake that uses friction caused by a set of shoes or pads that press outward against a rotating cylinder-shaped part called a brake drum. The term drum brake usually means a brake in which shoes press on the inner surface of the drum. When shoes press on the outside of the drum, it is usually called a clasp brake. Where the drum is pinched between two shoes, similar to a conventional disc brake, it is sometimes called a pinch drum brake, though such brakes are relatively rare. A related type called a band brake uses a flexible belt or "band" wrapping around the outside of a drum. The modern automobile drum brake was first used in a car made by Maybach in 1900, although the principle was only later patented in 1902 by Louis Renault. He used woven asbestos lining for the drum brake lining, as no alternative dissipated heat like the asbestos lining, though Maybach had used a less sophisticated drum brake. In the first drum brakes, levers and rods or cables operated the shoes mechanically. From the mid-1930s, oil pressure in small wheel cylinder and pistons operated the brakes, though some vehicles continued with purely mechanical systems for decades.

As the shoes in drum brakes wear, brakes required regular manual adjustment until the introduction of self-adjusting drum brakes in the 1950s. Drums are prone to brake fading with repeated use. In 1953, Jaguar fielded three cars equipped with disc brakes at Le Mans, where they won, in large part due to their superior braking over drum-equipped rivals. This spelled the beginning of the crossover of drum brakes to disc brakes in passenger cars.

Compared to drum brakes, disc brakes provide better braking Performance because the disc cools more easily. From the 1960s to the 1980s, disc brakes gradually replaced drum brakes on the front wheels of cars. Now practically all cars use disc brakes on the front wheels, and many use disc brakes on all four wheels. A disc brake consists of a cast iron disk screwed to the axle of the wheel and a fixed housing called stirrup. The stirrup is connected to a fixed part of the vehicle, such as the axle box or Rocket, since it is launched in two parts, each contains a piston. Between each piston and the disc, a friction pad is maintained in place retaining pins, spring plates. The passages are perforated in the stirrup so that the fluid enters or leaves each living place. The passages are also connected to another one for bleeding each cylinder contains a rubber ring between the cylinder and the piston.

The discs consist mainly of gray cast iron, so the discs are damaged in three ways: scars, cracks, deformities or excessive rust. The service workshops will sometimes respond to any disk problem by completely changing the disks. It is mainly when the cost of a new disc can really be lower than the cost of workers to fix the surface of the original disc.

A. Conventional Hand brake system

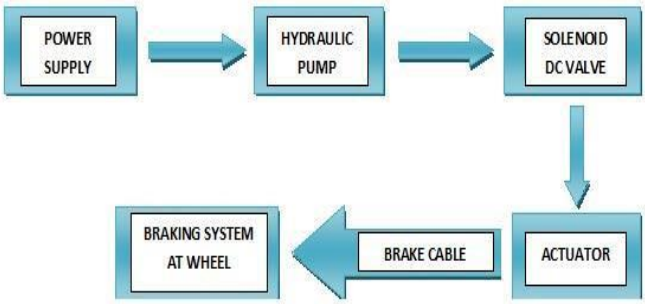


Fig. 1.1: Braking system block diagram

When we lower the lever the brake cable will become loose and brake is released. When we need to apply the hand brake while parking a vehicle we pull the hand brake lever upward side, due to this the hand brake cable is pulled which causes expansion of brake shoe in brake drum of wheel, which caused for applying hand brake.

Later on simple hydraulic/pneumatic system with simple circuit is used in brake system. This system consist of hydraulic pump/Pneumatic pump, 4x2 solenoid operated direction control valve, pressure relief valve , single acting actuator, oil reservoir/compressor, hoses and fittings. The hand brake cable is attached to the end of actuator rod. When power supply is made on means ignition of vehicle is on it will rotates the motor and then the pump suck the oil from reservoir or compressed air and pressurized it at certain pressure. The pressurized oil or air enters in single acting actuator through solenoid operated direction control valve and oil/air pushes the piston of actuator in forward , hand brake cable become loose and brake will be release. When ignition key is off it will stops the pump and direction control valve changes its position simultaneously, due to this oil/air returns to tank from actuator. Which causes backward movement of actuator piston, the brake cable will get pull and thus hand

brake gets applied. which involves oil/air leakage cause rolling of vehicle in case of slopes in parking area or occur accident.

II. LITERATURE REVIEW

The transient and contact analysis of functionally graded (FG) brake disk is presented. The analysis was carried out using ANSYS parametric design language (APDL). The FG brake disk is made of metal–ceramic material. [1]

An analysis of thermo elastic contact problem of functionally graded (FG) rotating brake disk with heat source due to contact friction is presented. Finite element method (FEM) is used. The material properties of disk are assumed to be represented by power-law distributions in the radial direction. [2]

A two-element model of braking process for a tribo-system consisting of the pad (the strip) sliding with the time-dependent velocity (braking at uniform retardation) on a surface of the disc (the semi-space) is studied. The dependences of temperature and thermal stresses on the boundary conditions on upper surface of the ceramic–metal strip were investigated. [3]

In this paper the development of a test bench which can be used to check the behaviour of bicycle brakes (disc brakes and in the next stage of extension rim brakes) during a brake cycle under dry and wet conditions is described. [4]

The paper develops a self-tuning PID control scheme with an application to ABS via combinations of fuzzy and genetic algorithms (GAs). The control objective is to minimize the stopping distance, while keeping the slip ratio of the tires within desired range. [5]

This paper presents work on model-based automation of failure-modes-and-effects analysis (FMEA) applied to the hydraulic part of a vehicle braking system. The FMEA task and the application problem are briefly described, and the foundations for automating the task based on a (compositional) system model are outlined. The essential parts of models of hydraulic components suitable to generate the predictions needed for the FMEA are introduced. [6]

An optimum range of labyrinth clearance between the brake drum and the brake panel was recommended for the brake system of cast and spoke wheels. [7]

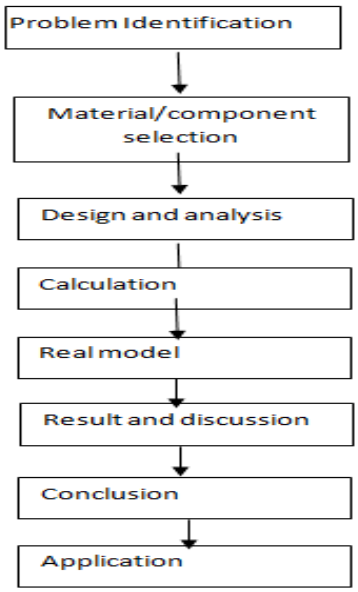
A multiscale modeling is proposed in this paper to study needled carbon/carbon composite. [8]

This article mainly discusses the research status and development trends of ceramics for automotive disc-brakes. According to the ceramic disc-brakes, various properties and characteristics, including fracture toughness, strength, compactness, corrosion resistance, wear resistance, micro-morphology, and thermal stabilities are analyzed. [9]

III. PROBLEM IDENTIFICATION

Conventional system works by operating handbrake lever or hydraulic/pneumatic system with manually/semi automated. In this system, it is observed due to manual errors the brakes remain engaged when vehicle is moving. As well as failure in oil/air leakage may lead an accident. This condition causes safety hazards which may cause damage the system components. During travel on the steep slope in upward direction, if the vehicle accidently goes into neutral or engine stops, the tendency of the vehicle is roll backwards, here we need the downhill locker. The objective of the project is design and analysis of disc brake to develop a smart/automated handbrake system that resolves all safety issue while parking vehicles.

IV. METHODOLOGY



V. COMPONENT SELECTION

A. Rack And Pinion

A rack is a toothed bar or rod that can be thought of as a sector gear with an infinitely large radius of curvature. Torque can be converted to linear force by meshing a rack with a pinion: the pinion turns; the rack moves in a straight line. Such a mechanism is used in automobiles to convert the rotation of the steering wheel into the left-to-right motion of the tie rod(s). Racks also feature in the theory of gear geometry, where, for instance, the tooth shape of an interchangeable set of gears may be specified for the rack (infinite radius), and the tooth shapes for gears of particular actual radii then derived from that. The rack and pinion gear type is employed in a rack railway.

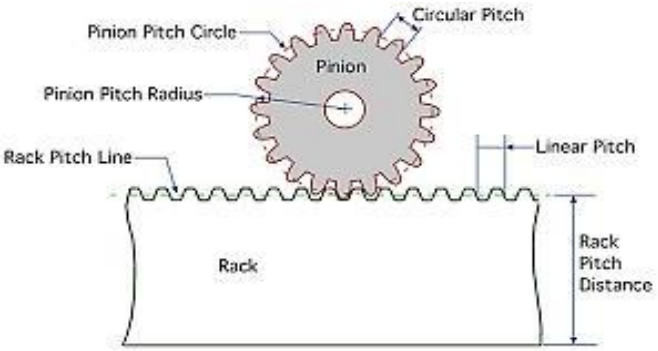


Fig.5.1 Rack and pinion

A rack and pinion is a pair of gears which convert rotational motion into linear motion. The circular pinion engages teeth on a flat bar - the rack. Rotational motion applied to the pinion will cause the rack to move to the side, up to the limit

of its travel. The pinion is in mesh with a rack. The circular motion of the pinion is transferred into the linear rack movement.

B. Microcontroller

A Micro controller consists of a powerful CPU tightly coupled with memory (RAM, ROM or EPROM), various I / O features such as Serial ports, Parallel Ports, Timer/Counters, Interrupt Controller, Data Acquisition interfaces-Analog to Digital Converter (ADC), Digital to Analog Converter (DAC), everything integrated onto a single Silicon Chip.

It does not mean that any micro controller should have all the above said features on chip, Depending on the need and area of application for which it is designed, the on chip features present in it may or may not include all the individual section said above.

Any microcomputer system requires memory to store a sequence of instructions making up a program, parallel port or serial port for communicating with an external system, timer / counter for control purposes like generating time delays, apart from the controlling unit called the Central processing unit.

C.IR Sensor

An infrared sensor is a device that can detect infrared light for use to a purpose. Most of the remote controls for TVs and other entertainment equipment use infrared energy as the transmission medium to carry information between the control unit and the equipment to be operated.

There are two types of infrared sensors: active and passive. Active infrared sensors both emit and detect infrared radiation. Active IR sensors have two parts: a light emitting diode (LED) and a receiver. When an object comes close to the sensor, the infrared light from the LED reflects off the object and is detected by the receiver. Active IR sensors act as proximity sensors, and they are commonly used in obstacle detection systems.

D.Motor

The source of current is obtained from the 12 v dc battery from the car. The speed of motor is variated by means of an electronic speed variator. Motor is a commutator motor i.e., the current to motor is supplied to motor by means of carbon brushes. The power input to motor is varied by changing the current supply to these brushes by the electronic speed variator, thereby the speed is also is changes.

E. Spring

Extension springs are attached at both ends of the components. When these components move apart, the spring tries to bring them together again. Extension spring absorbs and store energy as well as creates a resistance to a pulling force. It is initial tension that determines how tightly together an extension spring is coiled. The spring is interlinked with hand brake lever at center to the base to make the disengagement easier.

F. Lock set

A lock set is the hardware and the components that make up the locking or latching mechanism that is usually found in doors or other hinged object but can also include sliding doors and drivers. But we are using the lock for arrest the motion of rack at the one end. The push button will be released at the end when the rack exceeds the marked position and prevent the rack from sliding back. This button is directly coupled with gear lever so that when the gear is changed, the push button will be released.

G.Relays

Relays are the electrically operated switch. Many relays use an electromagnet to mechanically operate a switch, but other operating principals are also used such as solid state relays. Relays are used where it is necessary to control a circuit by low power signal (with complete electrical isolation between control unit and controlled circuits).We are using the relays for switching the motor ON or OFF. For making automatic hand brake system more efficient, these relays should be operated perfectly in all driving and climatic conditions.

VI. DESIGN AND ANALYSIS OF DISC BRAKE

A. Material selection

First important work is to design replica of project in solid edge ensuring diameter of brake drum. If brake drum diameter is finalized then design is finalized for further analysis. After brainstorming with team, we decide the following thickness and diameter of the brake drum.

Table 6.1 Brake drum specification

Brake Drum Diameter	As per thickness I kept it at 6.85 inch
Brake Drum Thickness	Axle brake – not less than 6.4 inch Disc brake – not less than 3.2 inch

Table 6.2 Material selection for disc brake

Properties	Cast iron	Stainless steel	Carbon-Carbon composite
Density (Kg/m^3)	7300	7800	1900
Young Modulus (GPa)	125	190	95
Poison Ratio	0.25	0.3	0.31
Thermal conductivity (W/m-K)	54.5	26	40
Specific heat (J/Kg-K)	586	500	755
Coefficient friction	0.2	0.22	0.3

Based on many journals to final achieve these readings. Also take help from Strength of materials book by BC.Punmia and RK.Rajput. After input the above said values in required design then convert that into part file as we want to transfer this into workbench.

Following are the properties that is kept for brake disc for Ansys for material used in manufacture of disc and which we should use for practical purpose

B. Calculation of disc brake

Disc Brake Standard
Rotor disc dimension = 240 mm. (240×10^{-3} m)
Rotor disc material = Carbon Ceramic Matrix
Pad brake area = 2000 mm^2 (2000×10^{-6} m)
Pad brake material = Asbestos
Coefficient of friction (Wet) = 0.07-0.13
Coefficient of friction (Dry) = 0.3-0.5
Maximum temperature = 350 ºC
Maximum pressure = 1MPa (106 Pa)

1) Tangential force between pad and rotor (Inner face)-FTRI

FTRI = μ1.FRI

Where, FTRI = Normal force between pad brake
And Rotor (Inner)
μ1 = Coefficient of friction = 0.5
FRI = P max / 2 × A pad brake area

So, FTRI = μ1.FRI
FTRI = (0.5) (0.5)(1×106 N/m2) (2000×106 m^2)
FTRI = 500 N.

Tangential force between pad and rotor (outer face) - FTRO.

In this FTRO equal FTRI because same normal force and same material

2) Brake Torque (TB)

With the assumption of equal coefficients of friction and normal forces FR on the inner and outer faces:

TB = FT.R

Where TB = Brake torque
μ = Coefficient of friction

FT = Total normal forces on disc brake= FTRI + FTRO
FT = 1000 N.
R = Radius of rotor disc.
So, TB = (1000) (120×10^{-3})
TB = 120 N.m

3) Brake Distance (x)

We know that tangential braking force acting at the point of contact of the brake, and Work done = FT. x .....(Equation A)
Where FT = FTRI + FTRO

X = Distance travelled (in meter) by the vehicle before it come to rest.

We know kinetic energy of the vehicle.
Kinetic energy = $(mv^2) / 2$ .....(Equation B)
Where m = Mass of vehicle

v = Velocity of vehicle

In order to bring the vehicle to rest, the work done against friction must be equal to kinetic energy of the vehicle. Therefore equating (Equation A) and (Equation B)

FT. x = $(mv^2) / 2$
Assumption v = 100 kg/h = 27.77 m/s
M = 132 kg. (Dry weight of Vehicle)
So we get x = $(mv^2) / 2$ FT

x = (132×27.772) / (2×1000) m.
x = 50.89 m
Heat Generated (Q) = M .Cp. ΔT J/S

4) Carbon Ceramic Matrix

Heat generated Q= m*cp*ΔT
Mass of disc = 0.5 kg

Specific Heat Capacity = 800 J/kg 0 c
Time taken Stopping the Vehicle = 5sec
Developed Temperature difference = 15 0 c
Q = 0.5 * 800 * 15= 6000 J

Area of Disc = Π * $(R^2 - r^2)$ = Π * $(0.120^2 - 0.055^2)$
= 0.03573 m^2

Flux (q) = Q/A W/m²
Heat Flux = Heat Generated /Second /area
= 6000 /5 / 0.0357
= 33.585 kw/m^2

Thermal Gradient (K) = q / k K / m
Thermal Gradient = Heat Flux / Thermal Conductivity
= 33.582*10 3 / 40

= 839.63 k/m

C. Design and analysis

After that I open part file in Ansys for flow, thermal and stress analysis. In this first design is converted in rectangular matrix giving various load values in that matrix to check the maximum load where design should fail. Stress analysis shows the area in red part is critical if more load is applied at that part it will fail. Thermal analysis shows equal distribution of heat in design which part accumulates more heat and has to be cooled down for longer use. I also did flow analysis as hydraulic fluid is used hence check weather fluid is distributes to drum area for normal and efficient braking function. After input these values in design properties then it is converted into mesh for further analysis. Meshing is important as it chooses small rectangles for analysis, the compile it all together for analysis.

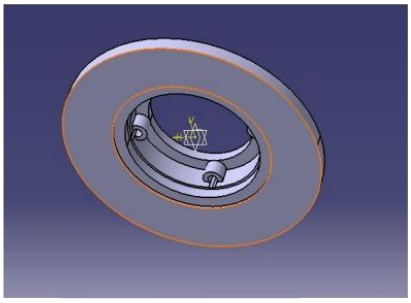


Fig 6.3.a Isometric view of disc

After this disk is input with pre-defined properties of material and run for analysis for temperature and stress distribution.

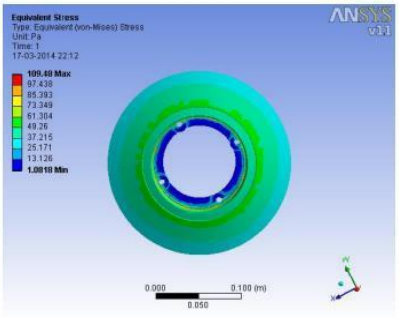


Fig 6.3.b Circular meshed disc

1) Stress Analysis

As I take three metals into consideration so stress analysis for them is done. After many iterations is a circular patch comes before me in which blue colour shows safe design and red colour shows that is maximum stress applied at that part and no more load should be applied. After analysis I proved that out of three material we used carbon composite is only material that can withstand high possible amount of stress and therefore can be used in design.

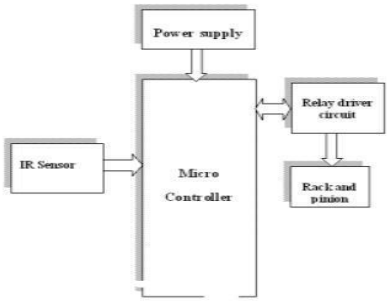


Fig 6.3.c Equivalent stress analysis of disc

2) Temperature Analysis

After that temperature analysis is done by me same as stress analysis only this profile view of temperature distribution. High temperature zone is defined as red colour and low temperature zone with low temperature zone. In this analysis I also come out with result that carbon composite is best material can withstand 217-470 degree Celsius.

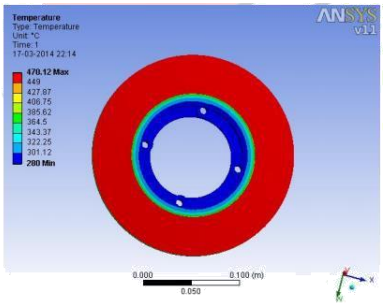


Fig 6.3.d Temperature distribution of disc

VII. WORKING PRINCIPLE

In further step to design Block diagram for control system that will actuate sensor control having microprocessor and IR sensor using MATLAB as per ignition on and off process.

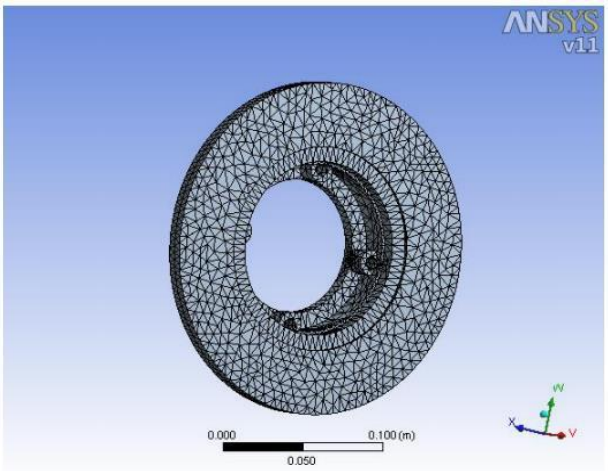


Fig 7.1 Block diagram for control unit

The Hand brake lever is coupled with rack and pinion setup. A motor used to apply and release the hand brake through Rack. Motor driven by the Micro controller unit with aid of sensors. Then Sensors give a signal to control unit when the vehicles is in rest stage. One sensor placed near gear lever to find lever in neutral position and another sensor placed near any one wheel of vehicle to confirm the wheel is not running state the last sensors is used to detect whether the ignition is ON or OFF.

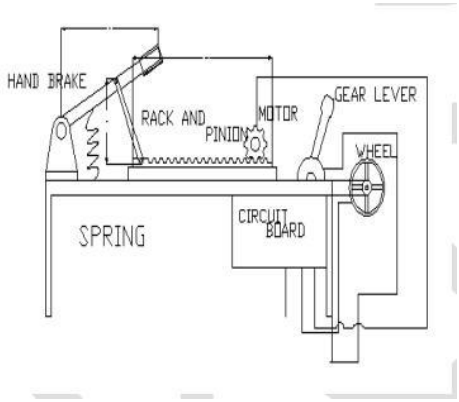


Fig 7.2 Line diagram design

Control unit attach the Hand brake when vehicle is in idle stage that is confirmed by the sensors. Also control unit will release the brake when gear lever is changed from neutral.

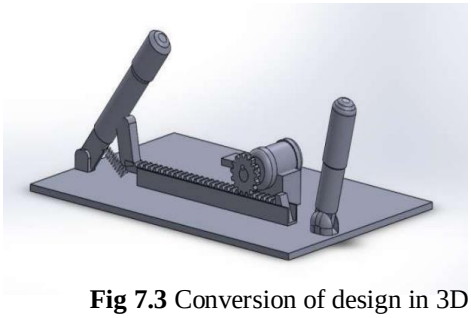


Fig 7.3 Conversion of design in 3D

When the vehicle is to be started, the ignition key is locked for ignition, this sends the command to the control unit which actuates the stepper motor and lead screw to release the hand brake based on operating conditions. When the vehicle parked and the key is taken off, this sends a signal to the control unit which reverses the motor direction such that hand brake is applied.

Fig 7.4 Work model without controller unit

So, by ignition system we can control the braking system in automobile.

VIII. Conclusion

Comparing the different results obtained from analysis, it is concluded that Carbon-carbon composite is the best material for disc brake.

Modifying the current conventional hand brake system to automatic hand brake system would provide effective solution for reducing human effort which is required for applying manual hand brake. This system can provide highly parking safety and braking effect. It provides quick braking and also simple in operation. Thus the use of conventional hand brake system can be eliminated using this system and the error occurring due to operator can be eliminated completely.

IX. Acknowledgement

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