UNDER SEAT SUSPENSION SYSTEM

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ABSTRACT

Safety and comfort are of the utmost importance to truck drivers, as many of them are traveling across the country in the trucks they are operating. Many drivers workat a rate of pay that depends on the number of miles they travel in a given shift. This can attribute to long periods oftime behind the wheel, making it important forthe driver to feel comfortable and safe at all times. According to the Federal Highway Administration, truck drivers can travel between 45,000 and 100,000 miles a year. This makes it pertinent for truck-makers to design vehicles that are comfortable enough to allow extended driving sessions.

Thus, an under the seat suspension system is an essential requirement for the truck drivers to ensure that they have a safe and sound ride while commuting over long distances. The main basis of this system is a push rod type suspension geometry which accounts for all the jerks and excruciations he has to face while driving. Thepush rod system increases weight by an ounce whereas it increases comfort by a mile. In addition to this, the design is highly cost-efficient and uses a single springdamper system to address the weight issue.

Keyword - *Seat Suspension System, Vibration Control, Drivers' Health, Ride Comfort.*

INTRODUCTION

Truck drivers and operators of any earth-moving machine during their operation will experience a wide range of vibrations, most often originating from road surface unevenness. The vibration felt in a typical earth-moving machine vehicle usually happens at frequencies from 0 to 20 Hz. The results for operators are the lack of concentration, tiredness and reduction of the effectiveness of the work being conducted.

- There is a direct link between vibration discomfort frequencies for heavy-duty vehicles and Eigen frequencies of the operator's body. Based on the conducted studies by Paddan, the vibration at low excitation frequencies (0.5–4 Hz) are the principal hazard causes for lumbago or a backache, which harmfully a perfect the mental and physical well-being of operators and travellers and decrease their working performance.

- Most passive suspensions in normal seats are not able to isolate these low-frequency vibrations. It is fully identified that vertical vibration at lower frequencies is the most dominant vibration to the driver's body which influences the ride seat suspension system is required.

Automotive seats must provide drivers of a broad range of sizes with seating over relatively long periods of time and isolate vehicle vibration and shock transmitted to the drivers. To satisfy these conditions, there has been extraordinary progress in automotive seat design during the past decade. Targets have been developed to maximize seat quality and performance and decrease driver's stress during long operating hours. An essential part of the improvement is the driver's seat, so research of seat suspension systems has become the focus of attention in all automotive and truck companies because the driver's body is connected to the vehicle by the seats and all of the vibration is transmitted to the driver's body through the seats.

- Three methods of vibration isolation are applied to the vehicle's seats in order to decrease transmitted vibration from vehicles seat to operators' body, namely, passive, semi-active, and active vibration control systems.

- Active vibration control is a method for decreasing unwanted vibration where some sort of sensor is adopted to measure the motion, force, acceleration, and other parameters related to vibration signals and a powered actuator is applied to generate a force to resist the unwanted motion.

- Passive vibration control does not employ any sensors or actuators and does not use any power; however, mechanical parts are utilized to damp undesired vibrations. The mechanical parts include spring blades, shock absorber, air cushion, etc.

- Semi-active systems with specific types of dampers present a better performance than passive systems and worse performance than active control systems.

- All of the mentioned methods are extensively examined in order to determine the main advantages and disadvantages and to find the best solution for vibration isolation.

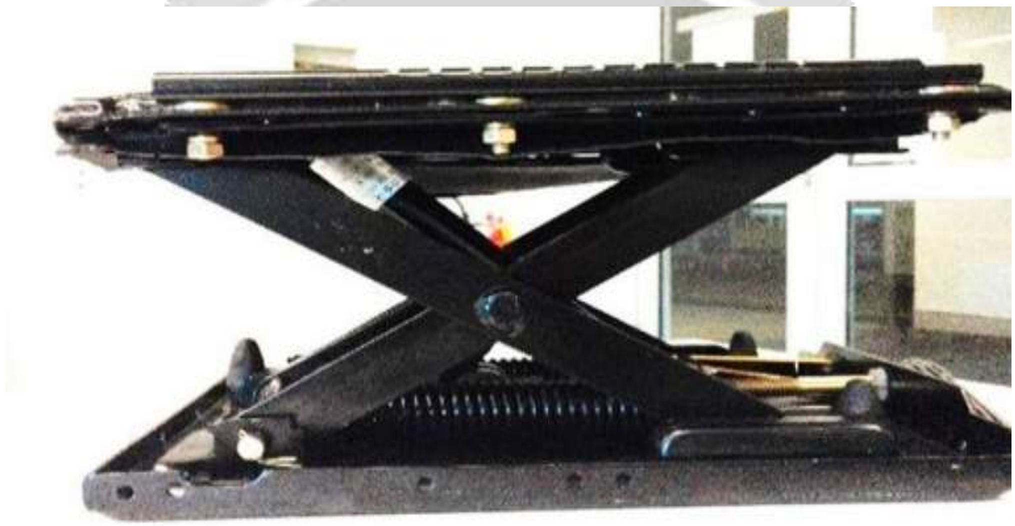


Fig – Prototype of Passive Seat Suspension

Fig - Prototype of Active Seat Suspension

The human body is sensitive to vibrations and the feeling of the vibration is different depending on the frequency and the direction of the vibrations. By using a frequency weight, the feeling can be translated from the vibration in space to how it is felt inside the driver's brain where discomfort is recognized.

- The frequency weight is offered in ISO-2631 and divides the sensitivity into two directions, horizontal and vertical. The horizontal sensation function is used for both lateral and longitudinal accelerations. In ISO-2631, the human filter is presented as a transfer function with various sensitivities for different frequencies.
- In a vibrating system with only one frequency, the experienced discomfort can simply be measured by multiplying the acceleration magnitude with the corresponding sensitivity weighting factor for that frequency.
- In real life, the vibration mechanisms are more complex and it is impossible to define the signal using one frequency and one amplitude. By using Fourier transform, the signal can be converted to a series of trigonometric functions in the frequency domain.

These trigonometric functions can be filtered individually for each frequency and amplitude and then transformed back to the time domain where an RMS value can be estimated. Considering the direct relationship between the vibration exposure levels and the driver's health, it is clear that the ride comfort is fully dependent on the frequency, amplitude and exposure time duration of the transmitted vibration. According to the frequency-weighting curves for single-degree-of-freedom (DOF) system vibration described in ISO 2631-1, the driver's comfort is most seriously affected by 5–8 Hz translational vibration along the z axis (Heave motion), 1–1.25 Hz translational vibration along the x and y axes, and 0.8 Hz rotational vibrations around three axes. Usually, the isolation of the vertical vibration, which is confirmed to have the greatest vibration amplitude and affects drivers' comfort in vehicles, is recognised in designing seat suspension.

- The whole human body system is a complex dynamic system with sophisticated mechanical characteristics. During operation of any land vehicle, the severe vibration generated by bumpy roads and the operation of the machineries generate a load which is transferred to the seat. Thus, the operators regularly feel Whole Body Vibration (WBV).
- To assess human vulnerability due to transmitted vibrations in vehicles, ISO 2631-1 is always utilised, which has set different ways for the analysis of Whole-Body Vibration and presents guidance on the possible impacts of vibration on health, comfort, attention, and motion illness.

WHAT IS A SUSPENSION SYSTEM?

A system of shock absorbers and linkages that allows relative motion between two connected bodies s o as to absorb the jerks encountered during their motion.

REQUIREMENT OF A SUSPENSION SYSTEM

The basic requirement of a suspension system is to reduce the shock forces. A proper suspension system is essential in ensuring a smooth and comfortable ride for the rider.

TYPES OF SUSPENSION GEOMETRY

1. **MacPherson Strut Suspension**:
Generally used in commercial cars. A MacPherson strut uses a wishbone, or a substantial compression link stabilized by a secondary link, which provides a mounting point for the hub carrier or axle of the wheel. This lower arm system provides both lateral and longitudinal location of the wheel. The upper part of the hub carrier is rigidly fixed to the bottom of the outer part of the strut proper; this slides up and down the inner part of it, which extends upwards directly to a mounting in the body shell of the vehicle.
2. Push-Rod Suspension:

Generally used in F1 cars. In push-rod suspension, the suspension arm is usually at a 45-degree angle to the bodywork/tyre in an F1 car. When the car goes over a bump the movement is transferred through the tyre and rim to the suspension upright and then into the suspension arm, this then transfer the loads into the "actual" suspension.

3. Pull-Rod Suspension:

Push-rod and pull-rod suspension are similar yet distinct in design, with the main difference being the placement of the rocker arm that controls shock damping in relation to the upper control arm. For pull-rod suspension systems, the only difference is the orientation of the rocker arms. In a pull-rod system however, the rocker arms are located between the upper and lower control arms, at the centre of the assembly.

4. Leaf Suspension:

A leaf spring takes the form of a slender arc-shaped length of spring
steel of rectangular cross-section. In the most common configuration, the center of the arc provides location for the axle, while loops formed at either end provide for attaching to the vehicle chassis. For very heavy vehicles, a leaf spring can be made from several leaves stacked on top of each other in several layers, often with progressively shorter leaves.

Leaf springs can serve locating and to some extent damping as well as springing functions. While the interleaf friction provides a damping action, it is not well controlled and results in stiction in the motion of the suspension. For this reason, some manufacturers have used mono-leaf springs.

DIFFERENT TYPES OF SEAT SUSPENSION

There are three main kinds of seat suspension reported in the literature. These are passive, active and semi active suspension. Traditional passive seat suspension's natural frequency is usually between 1.5 and 4 Hz. This may limit the seat performance in the low frequency range because heavy-duty vehicles normally suffer from high levels of vertical vibration in the frequency range of 1–20 Hz, especially from 3 to 5 Hz,4,5 and hence, passive suspension could amplify vibration in the low frequency range so that ride comfort is affected.

Table 1. Comparison of the three seat suspension systems.

	Active	Semi-Active	Passive
Advantages	Extensive range of force. Compatible with any force and velocity. Gaining better performance. More efficiency.	Less implementation cost. Lower energy use. Simple control. Simple design. Easy to set up.	Simple design and configuration. Lower price in comparison with other suspension systems.
Disadvantages	Higher weight-to-power ratio. Higher price. Considerable modification should be done before setting it into the existing vehicle.	Damper limitation. Narrow efficiency range. Better performance than passive systems but performance is not as good as active systems	Performance is not as good as active and semi – active systems.

WORKING PRINCIPLE

Nowadays, considering the advancement of different technologies, motor vehicle manufacturers have concentrated on the research to find new techniques to promote the safety and comfort of the ground vehicle operators. Plenty of investigations have been carried out and researchers have proposed several criteria for estimating discomfort and the fitness of various vehicles' seats such as those of trucks, cars and agricultural vehicles in operating condition.

- One of the challenging tasks for engineers in automotive industries is the design of the suspension system. It is crucial to design reliable, safe and convenient seats to eliminate road excitation, since transmitted vibrations to the driver's body may cause some damaging effects on their health and efficiency.
- Truck drivers and operators of any earth-moving machine during their operation will experience a wide range of vibrations, most often originating from road surface unevenness. The vibration felt in a typical earth-moving machine vehicle usually happens at frequencies from 0 to 20 Hz. The results for operators are the lack of concentration, tiredness and reduction of the effectiveness of the work being conducted.

- There is a direct link between vibration discomfort frequencies for heavy-duty vehicles and Eigen frequencies of the operator's body. Based on the conducted studies by Paddan, the vibration at low excitation frequencies (0.5–4 Hz) are the principal hazard causes for lumbago or a backache, which harmfully affect the mental and physical well-being of operators and travelers and decrease their working performance.

However, in order to lower the vertical vibration acceleration felt by the human body, a seat suspension system is required. Automotive seats must provide drivers of a broad range of sizes with seating over relatively long periods of time and isolate vehicle vibration and shock transmitted to the drivers.

- To satisfy these conditions, there has been extraordinary progress in automotive seat design during the past decade. Targets have been developed to maximize seat quality and performance and decrease driver's stress during long operating hours.
- An essential part of the improvement is the driver's seat, so research of seat suspension systems has become the focus of attention in all automotive and truck companies because the driver's body is connected to the vehicle by the seats and all of the vibration is transmitted to the driver's body through the seats.

Thus, we came up with the idea of an under-seat active suspension system that would absorb low as well as medium to high frequency vibrations and provide the driver with the requisite comfort and smoothened driving conditions.

LITERATURE SURVEY

Trucks require especially comfortable seats since drivers spend long hours in them and discomfort over long periods of time can lead to some serious problems. It's the reason why many truck drivers end up swapping seats in their trucks for aftermarket products with better seat suspension and ergonomic features.

- Tesla, which has been developing its own seats for its vehicles for a while now, has attempted to build its own seat for the Tesla Semi, its upcoming all-electric semi-truck, and today, we've learned that they have designed a new suspension system for it. The automaker applied for a patent on the new seat suspension technology.
- Tesla came up with their truck called semi that includes the following seat suspension technology.

In one aspect, a vehicle seat includes: a suspension system having a multi post architecture, the suspension system including sleeves pivotally coupled to respective pairs of lift links, a first pair of lift links coupled to each other at a first pivot point, a second pair of lift links coupled to each other at a second pivot point; and a height adjustment system that is adjustable independently of the suspension system; wherein the suspension system is configured for passive suspension upon a passive component being coupled between the first and second pivot points, and for active suspension upon an active component being coupled between the first and second pivot points.
Implementations can include any or all of the following features.

- The multi-post architecture includes first through fourth posts, and the suspension system includes respective first through fourth sleeves for the first through fourth posts.
- The first and second sleeves are pivotally coupled to the first pair of lift links, and the third and fourth sleeves are pivotally coupled to the second pair of lift links.
- The vehicle seat has a front end and a rear end, the first pair of lift links is positioned toward the front end and the second pair of lift links is positioned toward the rear end. The first pair of lift links and the second pair of lift links are positioned side-by-side.

At least one of the lift links has a Y-shape. A corresponding one of the first and second pivot points is located at a base of the Y-shape. The passive component comprises a coil over. The active component comprises an actuator. The height adjustment system comprises a four-bar linkage. The height adjustment system is positioned on top of the suspension system. The vehicle seat further includes a plate riding on the suspension system, the sleeves are coupled to the plate, and respective first ends of the pairs of lift links are pivotally coupled to the plate. The multi-post architecture includes posts coupled to a plate configured for fore/aft adjustment on a track.

The objective of obtaining a biodynamic model for a seated body is to be able to predict the performance of seat design and support the suspension control system configuration. Biodynamic modelling of the seated human body has attracted considerable attention in recent years, and many mathematical models ranging from 1-DOF to 11-DOF have been offered.

These models are obtained from different modelling methods, such as lumped-mass models, finite element models, and multi-body models. The lumped-mass body model can be expressed in the frequency domain as a transfer function or in the time domain as a differential equation of motion. A driver's biodynamic responses to vehicle vibration should be focused when designing seating systems. However, combining a human body biodynamic model with a seating system design has also not been fully discussed in research to date.
In studies on seating systems, Because the frequency range plays a vital role in vehicle ride comfort, the head acceleration or a rigid driver and passenger body acceleration usually is considered as a performance index to evaluate ride comfort. However, neither a sprung mass acceleration nor rigid body acceleration can accurately show human bio-dynamical characteristics.

Fig 3 – Seating System

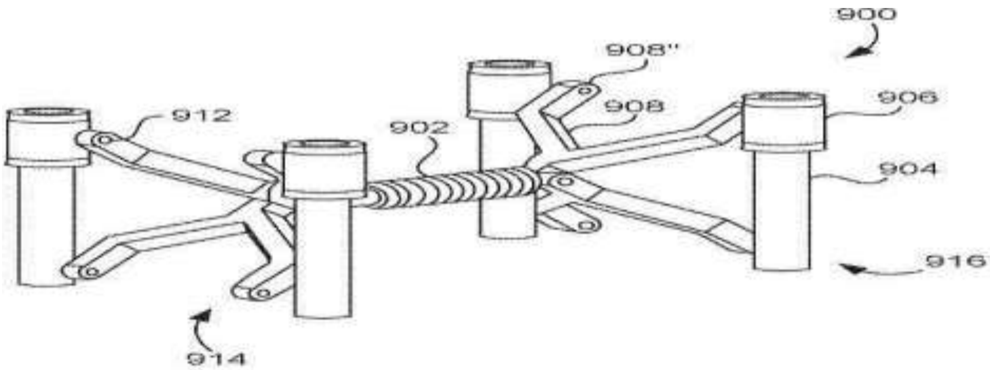


FIG. 9A

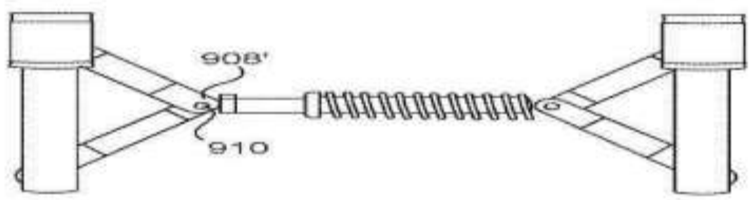


FIG. 9B

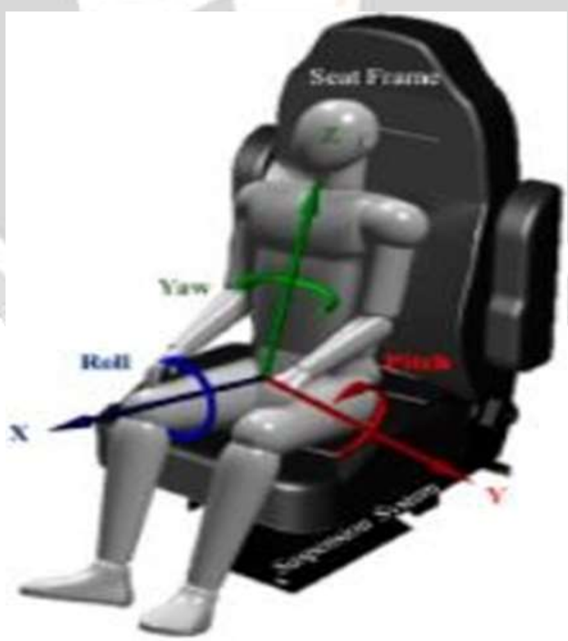
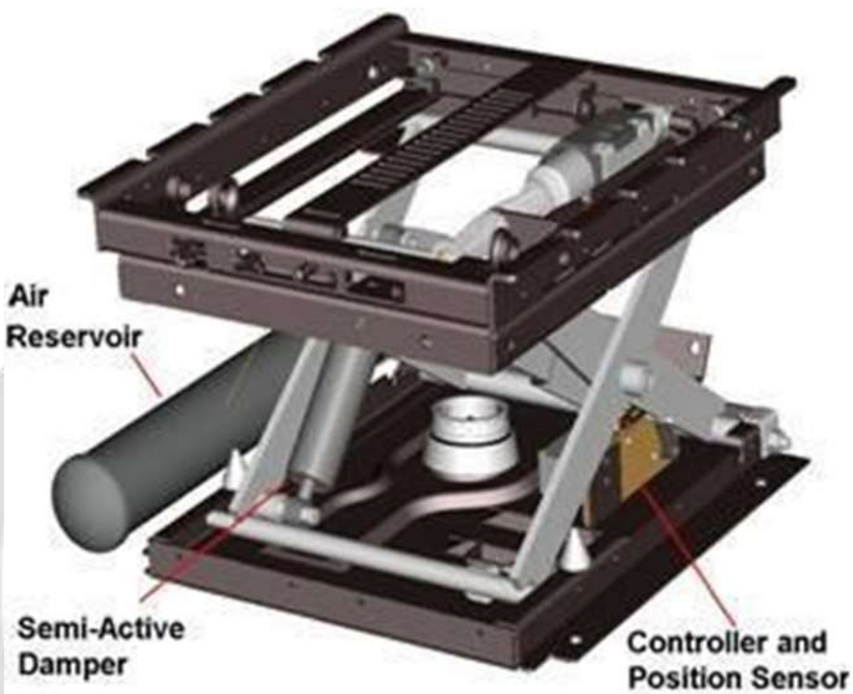


Fig - whole body vibration of a seated human body.

There after *John Deere* came up with active seat in itself with an integrated semi active suspension system. The semi-active suspension contains air suspension components with two important additions – a cylinder containing Magneto rheological (MR) fluid and a controller. These components electronically dampen the ride by exposing the MR fluid to a variable magnetic field around the piston orifice. This changes the viscosity of the fluid and thereby assists the air suspension with dampening. The suspension also contains new fore, aft, and lateral isolators that offer significant improvements in vibration isolation and end-stop control. The self-contained semi-active suspension can be installed in approximately one hour and uses the vehicles original seat top.



Thus, we have come up with the idea of a much simpler push-rod type seat suspension system which is highly cost efficient as well. The setup is a basic type of geometry which houses a system of rocker arms and dampers.

SELECTION OF GEOMETRY

From the various types of available geometry both push-rod and pull-rod types of geometry are the most convenient types of geometry used for the purpose.

- Push-rod and pull-rod suspension are similar yet distinct in design, with the main difference being the placement of the rocker arm that controls shock damping in relation to the upper control arm.
- In effect, this means that both push-rod and pull-rod systems are functionally the same design.

As such, push-rod suspension systems allow for much greater high-speed stability, much lower levels of body-roll, and a much lower centre of gravity for the vehicle.

- For pull-rod suspension systems, the only difference is the orientation of the rocker arms. In a push-rod system, the rocker arms are placed at the highest point in the assembly. As such, the rod is under pressure as it transfers compression forces upwards into the rocker arms.

- In a pull-rod system however, the rocker arms are located between the upper and lower control arms, at the centre of the assembly. As such, the rod is under tension as it pulls against the rocker arms.
-

As a result of these factors, the push-rod layout is distinct from other suspension systems as, unlike others, it is able to be designed and assembled with components closer to, or further from, the centre of gravity of the vehicle. As a result, engineers are able to optimise the performance of their vehicle in this area as they sacrifice comfort and practicality in favour of aerodynamics, handling, and stability on track.

These are some of the factors which resulted in the selection of **pushrod type geometry** for the above project.

SELECTION OF MATERIAL

For Bell Cranks: Aluminium 6061 T6

T6 temper 6061 has:
- Ultimate tensile strength of at least 290 MPa (42,000 psi)
- Yield strength of at least 240 MPa (35,000 psi).
- More typical values are 310 MPa (45 ksi) and 270 MPa (39 ksi), respectively.

Young's modulus (E): 68.9 GPa (9,990 ksi)
Elongation (ε) at break: 12–25%
Density (ρ): 2.70 g/cm3
Thermal conductivity (k): 151–202 W/(m·K)

PROPERTIES
- Resistance to corrosion
- A high value of hardness
- Easy machinability
- Rigidity and toughness
- Light Weight with high yield strength
- Good weld ability

For Pushrods and Mountings: **AISI 4130 Chromoly Steel 19*1 mm**

MECHANICAL PROPERTIES

PROPERTIES	METRIC
Tensile strength, ultimate	560 MPa
Tensile strength, yield	460 MPa
Modulus of elasticity	190-210 GPa
Bulk modulus (Typical for steel)	140 GPa
Shear modulus (Typical for steel)	80 GPa

Poisson's ratio	0.27-0.30
Elongation at break (in 50 mm)	21.50%
Reduction of area	59.6
Hardness, Brinell	217
Hardness, Knoop (Converted from Brinell hardness)	240
Hardness, Rockwell B (Converted from Brinell hardness)	95
Hardness, Rockwell C (Converted from Brinell hardness, value below normal HRC range, for comparison purposes only.)	17
Hardness, Vickers (Converted from Brinell hardness)	228
Machinability (Annealed and cold drawn. Based on 100% machinability for AISI 1212 steel.)	70

Thermal Properties:

Thermal conductivity (100°C) - 42.7 W/mK

Mechanical Properties:

- Easy machinability
- Good atmospheric corrosion resistance
- Reasonable strength
- High Strength to weight ratio

The spring damper system is an OEM part from DNM springs. The model used is Burner RCP- 2S with a stiffness(k) = 140 pounds/inch.

DESIGN PROCEDURE

- A standard seat model was taken.
- The suspension geometry was decided.
- A spring-damper system was selected instead of regular springs to dampen the active vibrations.
- All the calculations for the forces were done.

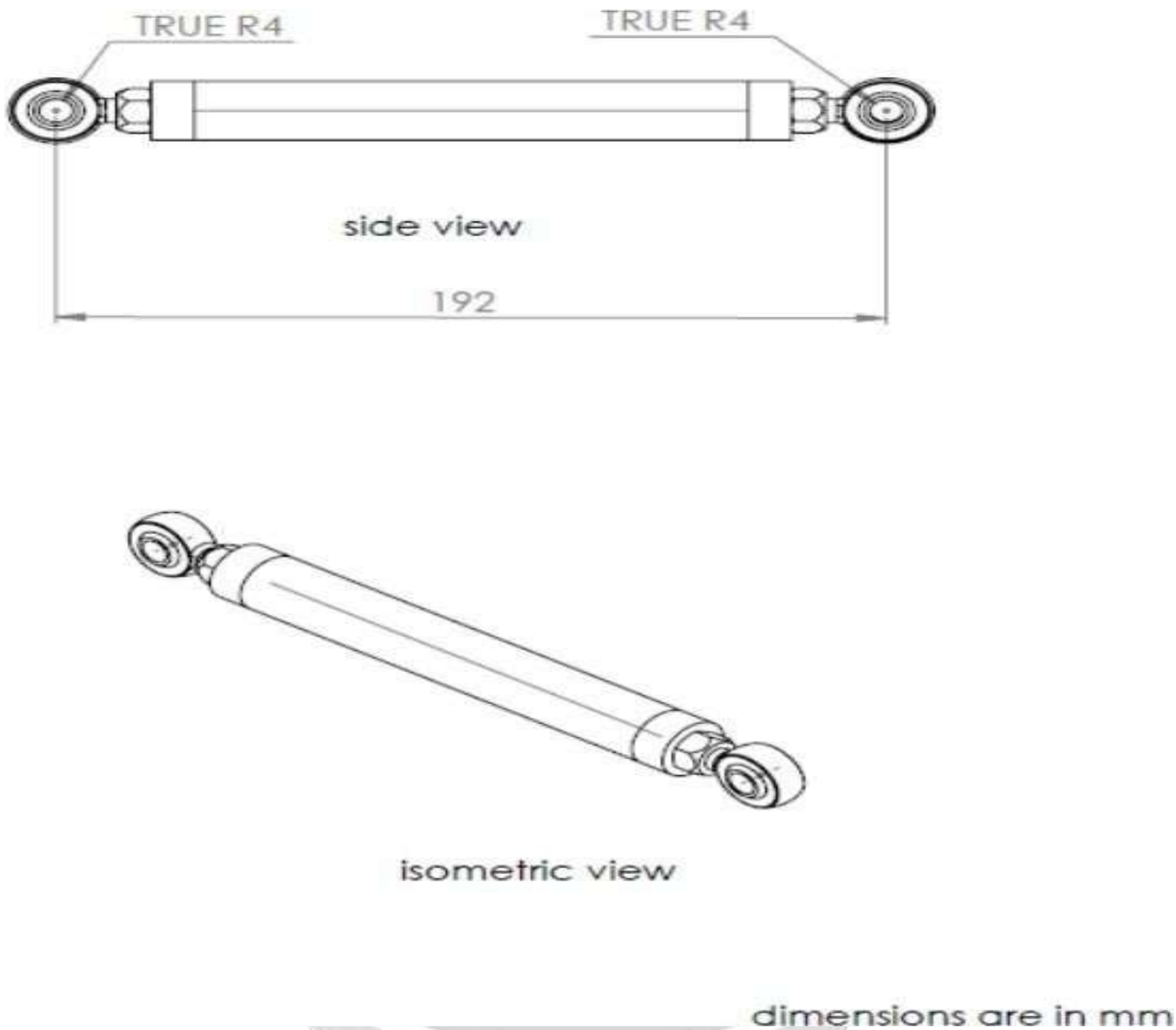

TRUE R4
TRUE R4
side view
192
isometric view
dimensions are in mm

Fig – Pushrod

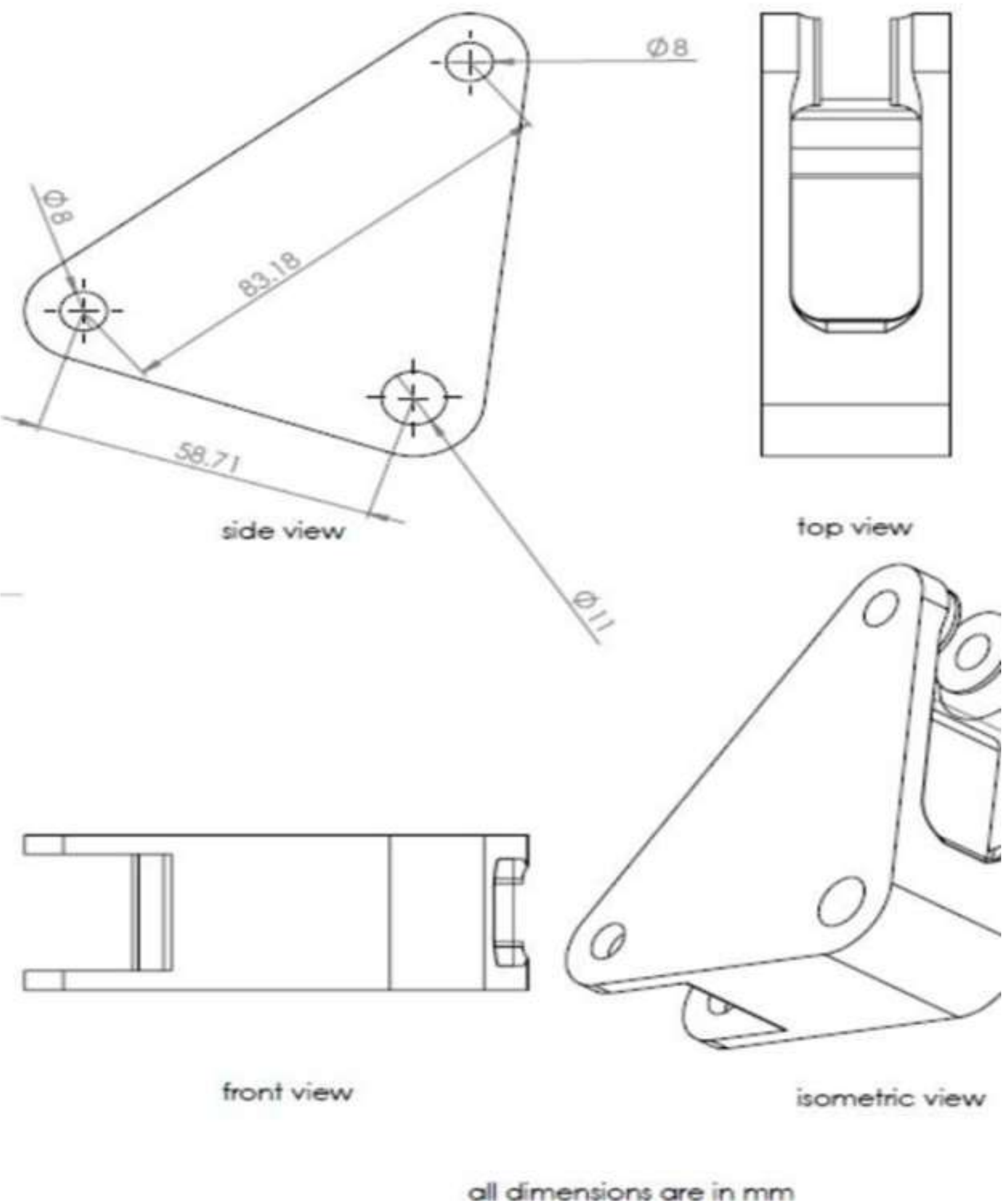


Fig – Bell Crank

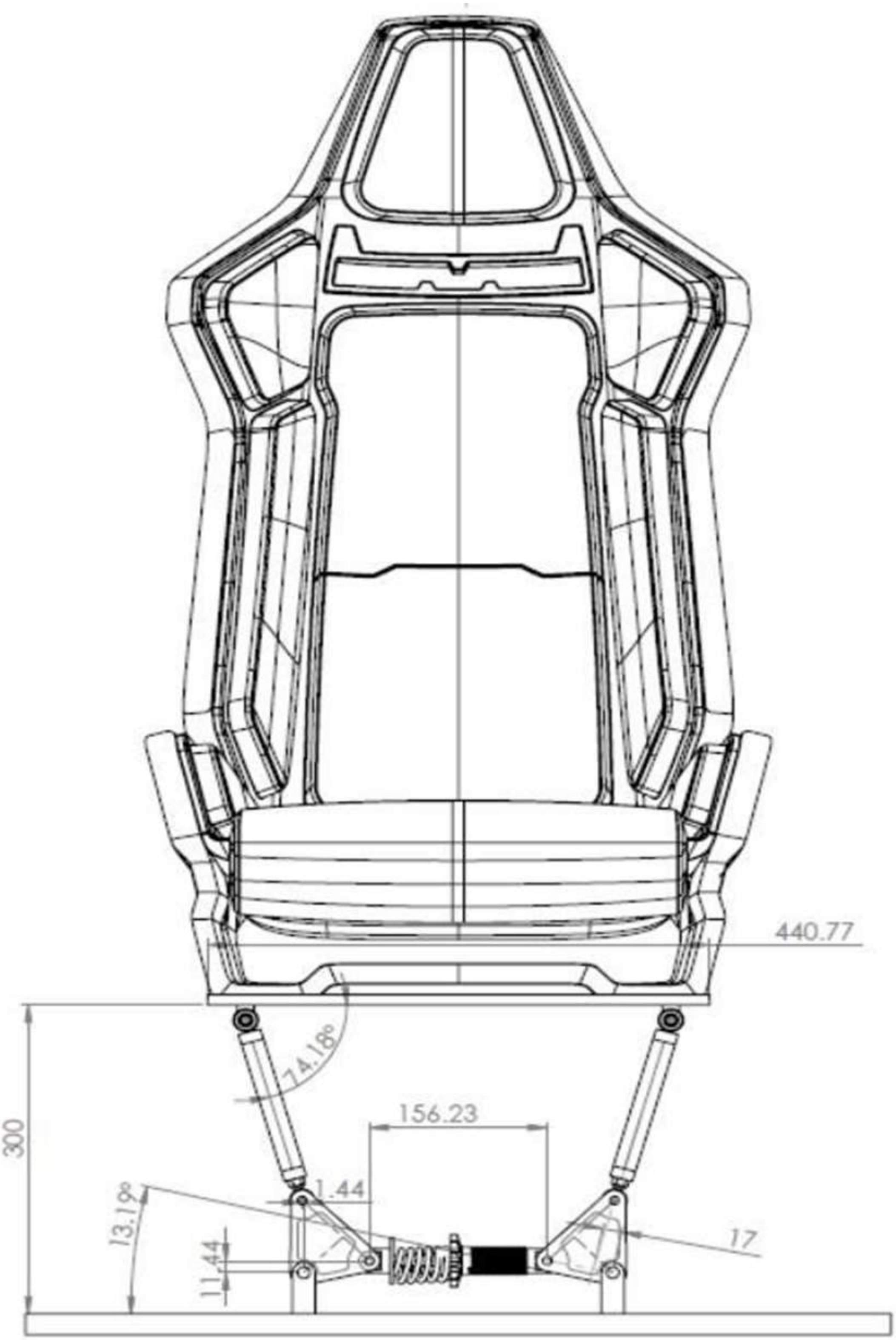


Fig – Seat

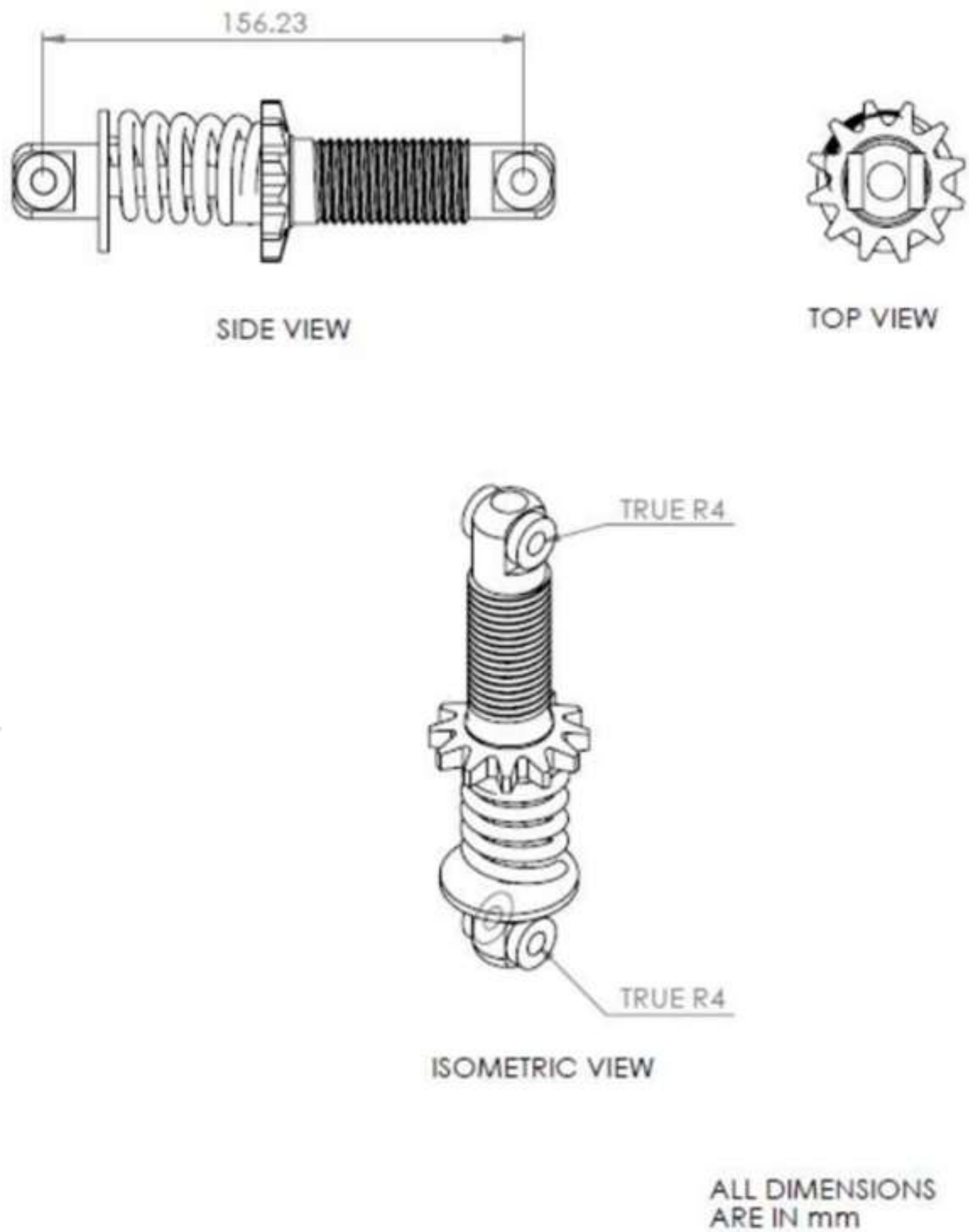


Fig – Shock Absorber

Fig – Isometric View of the Seat

Fig – Front View of the Seat

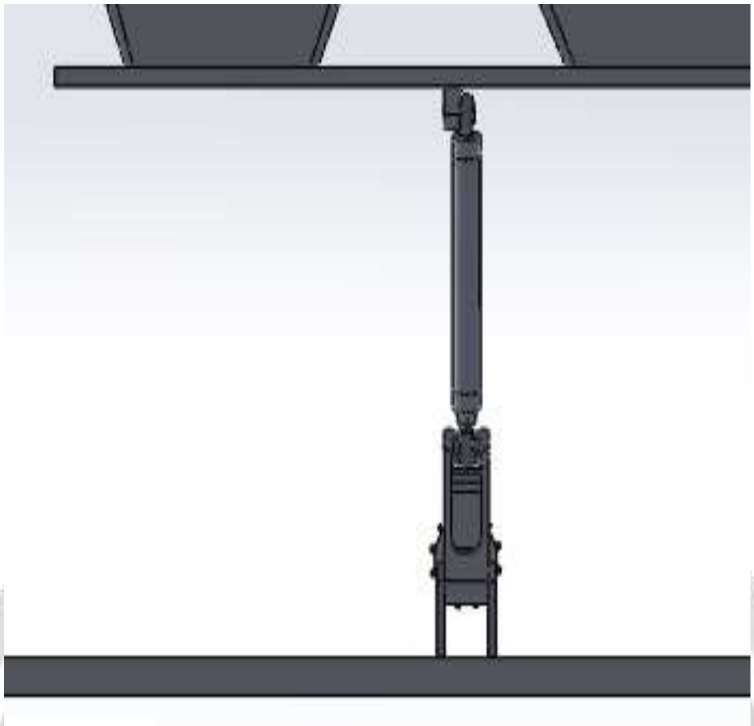


Fig – Side View

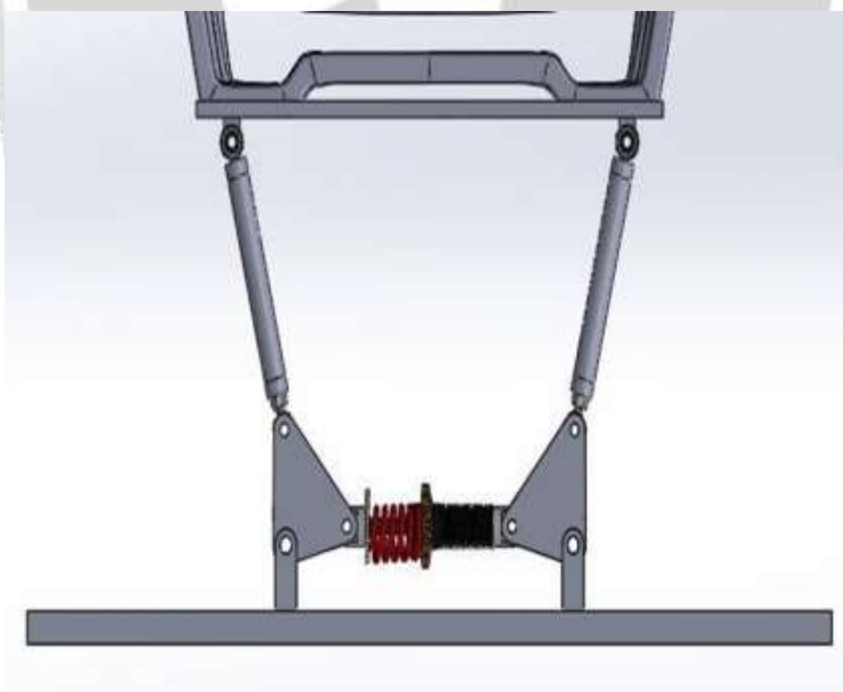


Fig- Base Set View

ANALYSIS REPORT

The mesh size for this model is taken as 5 mm. Because when we change the mesh size to 4mm or 6mm the equivalent stress almost remains the same. The shape of the mesh is taken as triangular by default.

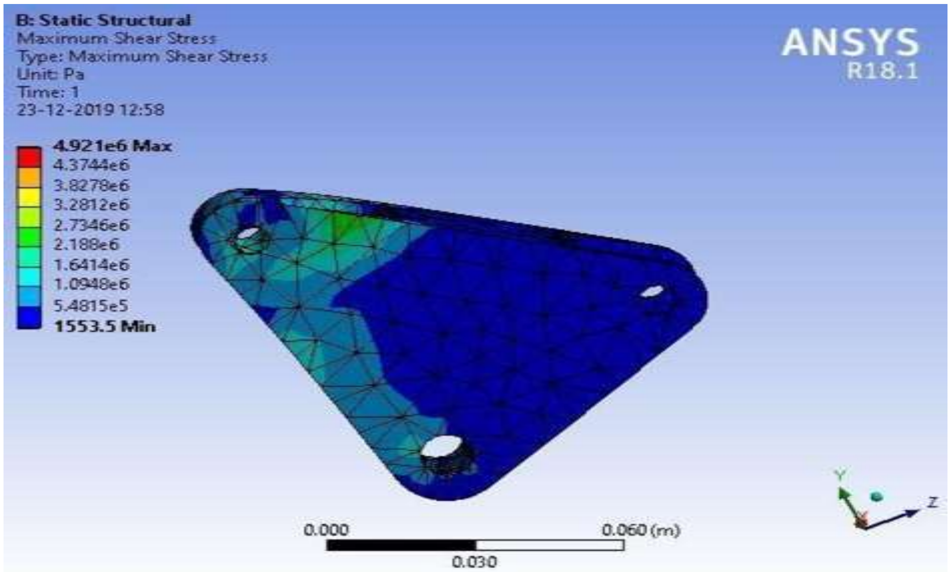


Fig – Maximum Shear Stress

Maximum Shear stress found is to be 4.921e6 Pascal
Minimum Shear stress found is to be 1553.5 Pascal

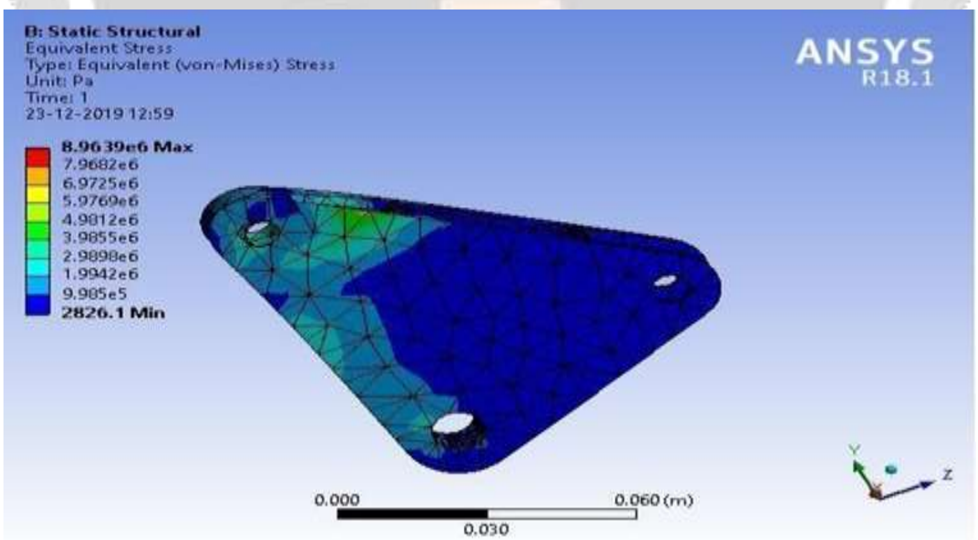


Fig – Equivalent Stress

Maximum Equivalent stress is found to be 8.9639e6 Pa
Minimum Equivalent stress is found to be 2826.1 Pa

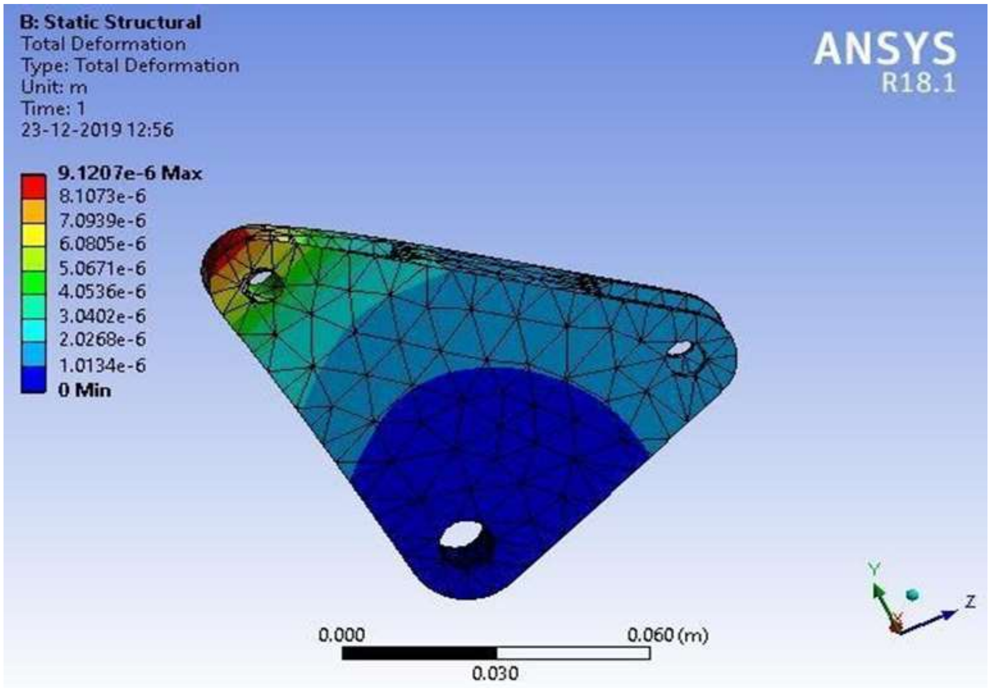


Fig – Total Deformation

Maximum deformation found is 9.12079e-6 meter

RESULTS AND FINAL DECISION

The maximum deformation of the model (under extreme condition) is found to be 9.12e-6 which is almost negligible. The factor of safety for the model under cyclic load is found to be 1.45. The equivalent stresses are well below the yield and ultimate tensile strength of the material (Aluminium 6061 T6). Considering the obtained results, we decided to finalize the design of the bell crank without any changes to it.

CALCULATIONS

Weight of an average Driver = 78 kg
Weight of the cushioned seat = 2 kg
Total Weight = 80 kg

In a seating position the total weight of the driver is taken as 73% of the total weight,

Driver Weight = 57 kg
Now, total weight acting on the setup = 59 kg
Vertical Load (P_1) = (59*9.8)/2 = 289.1 cos (15.82) = 278.14 N,
Load on Pushrod (Fp) = 289.1* cos (15.82) = 278.14 N,

Now to find the spring force (Fs) we have to balance the moments about the pivot point of the bell crank,
Fs * 11.44 = Fp * 17,
Fs = (278.14*17)/11.44,
Fs = 413.31 N
K = 140Psi = 25 N/m

Wn = √(K/m)
= √ (25/80)
= 0.55
Cc = 2mWn
= 88 Ns/mm
We have to keep the damping condition as C < Cc, for Under damping condition.
$K = Gd^4/8D^3$

[K = 25N/mm (given), G = $2.1*10^5$ MPa, C = d/D = 6 (assume) , n = 6 (assume)]
25 = $2.1*10^5 d^4/8*216*6$

- d = 5mm
- D=30mm

Free length of spring, L_f = nd+ (n-1)
= 6*5 + 5 = 35mm
X_{st} = Compression in the spring in static condition
= Fs/K
=413.31/25= 16.53 mm

TRANSFER FUNCTION

A transfer function of an electronic or control system component is a mathematical function which theoretically models the device's output for each possible input. In its simplest form, this function is a two-dimensional graph of an independent scalar input versus the dependent scalar output, called a transfer curve or characteristic curve. Transfer functions for components are used to design and analyse systems assembled from components, particularly using the block diagram technique.

The term "transfer function" is also used in the frequency domain analysis of systems using transform methods such as the Laplace transform; here it means the amplitude of the output as a function of the frequency of the input signal. For example, the transfer function of an electronic filter is the voltage amplitude at the output as a function of the frequency of a constant amplitude sine wave applied to the input. For optical imaging devices, the optical transfer function is the Fourier transform of the point spread function (hence a function of spatial frequen cy).

The transfer function was the primary tool used in classical control engineering. However, it has proven to be unwieldy for the analysis of multiple-input multiple-output (MIMO) systems, and has been largely supplanted by state space representations for such systems] In spite of this, a transfer matrix can always be obtained for any linear system, in order to analyse its dynamics and other properties: each element of a transfer matrix is a transfer function relating a particular input variable to an output variable.

- A transfer function represents the relationship between the output signal of a control system and th e input signal, for all possible input values.

- The transfer function of a system is the Laplace transform of **its** impulse response under assumption of zero initial conditions.

- A Transfer Function is the ratio of the **output** of a system to the **input** of a system, in the Laplace domain considering its initial conditions and equilibrium point to be zero. This assumption is relaxed for sys tems observing transience.

WHY TRANSFER FUNCTIONS ARE USED

A transfer function is a convenient way to represent a linear, time-invariant system in terms of its input-output relationship. It is obtained by applying a Laplace transform to the differential equations describing system dynamics, assuming zero initial conditions. In the absence of these equations, a transfer function can also be estimated from measured input-output data.

Transfer functions are frequently used in block diagram representations of systems and are popular for performing time-domain and frequency-domain analyses and controller design. The key advantage of transfer functions is that they allow engineers to use simple algebraic equations instead of complex differential equations for analysing and designing systems.

ADVANTAGES

- A transfer function has no limitation. We can solve every network circuits using transfer function approach, also transfer function can be applied everywhere.

- Transfer functions allow engineers to use simple algebraic equations instead of complex differential equations for analysing and designing systems.

- If transfer function of a system is known, the response of the system to any input can be determined very easily.

IMPORTANCE OF TRANSFER FUNCTIONS IN PRACTICAL LIFE

In general, a transfer function describes the relationship between the input to a system to the output from that system. It gives us a way to mathematically analyse the behaviour of a physical system.

- So, one practical use is that we can analyse a system mathematically, as opposed to tediously performing experiments on a physical implementation and measuring. We can infer the system's behaviour over a wide range of inputs all on paper (or in simulation), without ever having to build it.
- Conversely, it allows us to design a system based on its required behaviour by first constructing the desired transfer function, and then working backward to a physical realization of that design.

The dimensions and units of the transfer function model the output response of the device for a range of possible inputs.

EXAMPLES

- The transfer function of a two-port electronic circuit like an amplifier might be a two-dimensional graph of the scalar voltage at the output as a function of the scalar voltage applied to the input
- The transfer function of an electromechanical actuator might be the mechanical displacement of the movable arm as a function of electrical current applied to the device
- The transfer function of a photo detector might be the output voltage as a function of the luminous intensity of incident light of a given wavelength.

Transfer functions are commonly used in the analysis of systems such as single-input single output filters in the fields of signal processing, communication theory, and control theory. The term is often used exclusively to refer to linear time-invariant (LTI) systems. Most real systems have non-linear input/output characteristics, but many systems, when operated within nominal parameters (not "over-driven") have behavior close enough to linear that LTI system theory is an acceptable representation of the input/output behavior.

MATHEMATICAL MODEL

Considering a basic model and developing a mathematical relationship using newtons law of motions.

From newton's laws of motion for m_o:
$M_{0\ddot{x}} = K_{s1}(x\text{-}y) - C_{s1}(\dot{x}\text{-}\dot{y})$
$M_{0\ddot{x}} + C_{s1} + K_{s1}x = C_{s1}\dot{y} + K_{s1}y$ --------(1)

Equation of motion for m_c
$mcy'' = K_{s1}(x - y) = C_{s1}(\dot{x}\text{-}\dot{y}) + K_{s2}(y - z) - C_{s2}(\dot{y} - z')$
$m_c y'' + (C_{s1} + C_{s2})\,\dot{y} + (K_s 1 + K_s 2)\,y = C_{s1}\dot{x} + C_{s2}z' + K_{s1}x + K_{s2}z$ --------(2)

Equation of motion for m_s
$M_s z'' = K_{s2}\,(y\text{-}\ z) + C_{s2}(y' - z')\ \text{-}\ K_t z + F$
$M_s z'' + C_{s2}z' + (K_{s2} + K_{t)\,z} = C_{s2}y' + K_{s2}y + F$ --------(3)

(1), (2), (3) are the equations for the given motion.

AN OVERVIEW FOR FUTURE WORK

As the active vibration control approach is associated with the reverse dynamics of the force actuator and the primary controller, studies about various methods of optimization of active control.
Systems such as using motor, hydraulic and pneumatic actuators and servo motors were reported. Advantage and disadvantages were compared and discussed.

- According to the acquired results, the integrated seat and suspension control system would provide the best performance in terms of ride comfort in comparison to other seat suspension systems, but it needs to be optimized to find the novel control algorithms and methods to improve the seating system performance.

- The development and design of control systems in vehicle seating systems still have not overcome many obstacles such as the low frequency of transmitted vibrations to the operator's body because of the multidisciplinary nature of the environment where vehicles or trucks are operating.

To design and control the dynamical behaviour of the seat and human body must be modelled. For simplification of complexity a two-mass oscillation system was assumed.

While the human body performs vertical motions by the seat cushion, the resilience of the back cushion in normal direction results in a pitching movement for the passenger. The two degrees of freedom are modelled by the states Z_d and M_d with respect to the centre O_d of the human mass m_d.

Explained model parameters (such as forces causing the vibrations and frequency of vibration etc.) are determined by an evaluation of measurements using a **hydraulic shaker** with a passive seat.

- The vertical and pitching motions of the seat are described by the states Zs and Ms. The horizontal position of O_s is given by the length l_f and l_r with respect to the supporting points at the front and rear side. For simplicity it is assumed that the centres Od and Os of the human body and the seat are identical i.e., $l_z = 0$. Therefore, complex couplings between the vertical and pitching movements of the seat and the human body don't occur.

- Inputs of the active suspension system are the forces Ff, Fr at the front and rear side of the movable frame as well as the disturbances Z_{cf} and Z_{cr} induced by the chassis of the vehicle. In order to describe the inputs with respect to the horizontal position of the considered mass centres, the force FZ and the torque TM of vertical and pitching movement are given by

$F_Z = F_f + F_r$ ………… (1)
$T_M = F_f l_f - F_r l_r$ ………… (2)

While the disturbances Z_{cf} and Z_{cr} are given by

$Z_c = (Z_{cf} l_r + Z_{cr} l_f) / (l_f + l_r)$ ……………. (3)
$Mc = (Z_{cf} - Z_{cr}) / (lf + lr)$ ……………. (4)

From the above equations the design parameters for the dynamic loading can be calculated.

VARIOUS TESTS TO BE DONE IN FUTURE

Vibration Testing and Shaker Testing

Vibration testing is done to introduce a forcing function into a structure, usually with the use of a vibration test shaker or vibration testing machine. These induced vibrations, vibration tests, or shaker tests are used in the laboratory or production floor for a variety of things, including qualifying products during design, meeting standards, regulatory qualifications (e.g., MIL-STD 810, etc.), fatigue testing, screening products, and evaluating performance.

- Most often electrodynamic and servo-hydraulic shakers are used, depending on the frequency range and displacement required.

- Data Physics, incorporating a long history of Ling Electronics technology, produces industry-standard electrodynamic vibration and shaker equipment for vibration tests, vibration testing, and shaker testing.

- Data Physics is a turnkey supplier of vibration test systems from electrodynamic shakers to intuitive and advanced vibration controllers.

Accelerometer Sensor

An accelerometer is a sensor that measures the dynamic acceleration of a physical device as a voltage. Accelerometers are full-contact transducers typically mounted directly on high-frequency elements, such as rolling-element bearings, gearboxes, or spinning blades.

- These versatile sensors can also be used in shock measurements (explosions and failure tests) and slower, low-frequency vibration measurements.

- The benefits of an accelerometer include linearity over a wide frequency range and a large dynamic range.

Working of Accelerometer Sensor

Most accelerometers rely on the use of the piezoelectric effect, which occurs when a voltage is generated across certain types of crystals as they are stressed.

- The acceleration of the test structure is transmitted to a seismic mass inside the accelerometer that generates a proportional force on the piezoelectric crystal.

- This external stress on the crystal then generates a high-impedance, electrical charge proportional to the applied force and, thus, proportional to the acceleration.

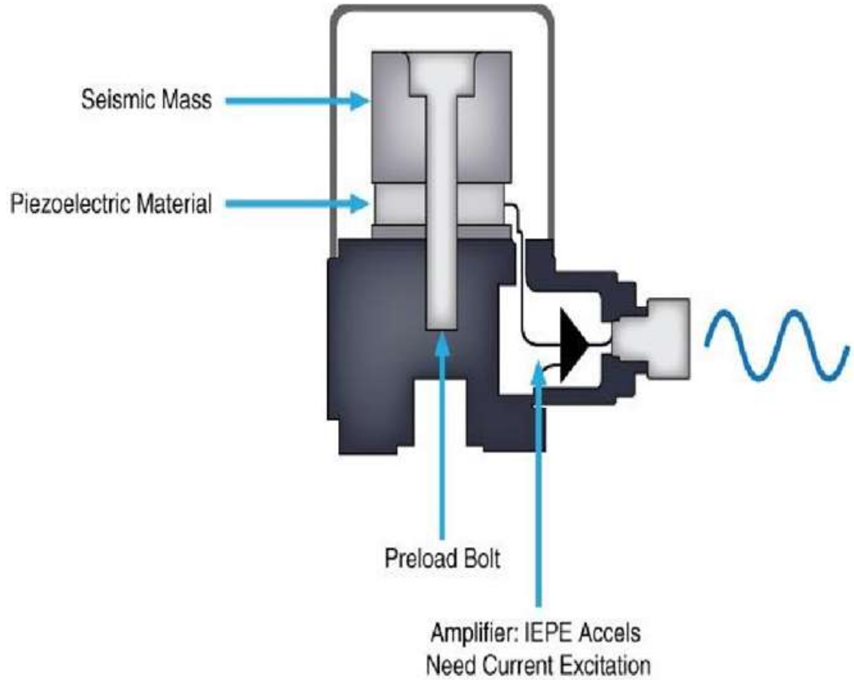


Figure 3. *IEPE accelerometers output voltage signals proportional to the force of the vibration on the piezoelectric crystal.*

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