DESIGN AND DEVELOPMENT OF A SHIM STACK VISCOUS DAMPER

A Final Year Project Report

Presented to

SCHOOL OF MECHANICAL & MANUFACTURING ENGINEERING

Department of Mechanical Engineering

NUST

ISLAMABAD, PAKISTAN

In Partial Fulfillment

of the Requirements for the Degree of

Bachelor of Mechanical Engineering

by

Muhammad Muneeb Arshad

Muhammad Uzair Sajjad

Azan Akhtar

June 2018

EXAMINATION COMMITTEE

We hereby recommend that the final year project report prepared under our supervision by:

Muhammad Muneeb Arshad	NUST201432274
Muhammad Uzair Sajjad	NUST201433156
Azan Akhtar	NUST201432191

Titled: "Design and Development of a Shim Stack Viscous Damper" be accepted in partial fulfillment of the requirements for the award of Bachelor's in Mechanical Engineering degree.

Supervisor: Dr. Sami ur Rahman Shah (Assistant Professor)

SMME, NUST

____

Dated:

Committee Member: Dr. Jawad Aslam (Assistant Professor)

SMME, NUST

____

Dated:

Committee Member: Dr. Emad Uddin (Assistant Professor)

SMME, NUST

____

Dated:

_______________________ (Head of Department)

___________ (Date)

COUNTERSIGNED

Dated: ________________

_________________________ (Dean / Principal)

ABSTRACT

Shock absorber is a device which is used to reduce the effect of shock impulses by damping them and dissipate kinetic energy. It is used to improve the quality of ride, as well as comfort level, by substantially reducing the magnitude of disturbances. This is specially required in locomotion of vehicles over rough or unsmooth surfaces. Spring is compressed as the vehicle encounters a bump on the road. The reaction force would cause spring to retain its normal length. Due to high momentum, spring would shoot past its normal position and this rebound would lift the body of the vehicle. The weight of vehicle is larger in comparison to this spring force. It would cause the spring to be compressed again. This process is repeated several times, with reducing magnitude. Conventional orifice dampers don't provide effective shock absorption. Shim-stack dampers have greater shock absorbing efficiency and they have already attained preferences in motor-bikes. Our project focuses on the design and development of a shim stack viscous damper. It also encompasses a comparison of its performance with a regular orifice damper.

PREFACE

Motorcycles in Pakistan use a regular plunger orifice damper. The shock absorption ability of the said damper has proven to be quite low as it provides an uncomfortable ride. Other countries have already moved beyond this damper and have developed technologies like shim stack damper and spool valve damper. We have developed a shim stack damper that can absorb shocks more effectively. It is designed to increase the damping ability and efficiently reduce the shocks of a vehicle. Our device uses shim stack technology which are Belleville washers piled up on top of each other. The damping is pressure sensitive and can be adjusted by varying the pressure. A gas canister and a floating piston have also been added to prevent cavitation which occurs at frequent bumps. The main piston has a new design with holes machined at 12.81^o. This innovative design helps to operate the shim stack valving technology more easily.

ACKNOWLEDGEMENT

In this project, everyone we have come across was extremely helpful and encouraging. We really want to thank Dr. Sami ur Rahman Shah, our supervisor, for his exceptional cooperation and support. He has helped us at every single step of our project. Without his guidance and constructive criticism, we would never have been able to complete this project.

We would like to thank Lecturer Hafiz Muhammad Abd-ur-Rehman for his constant support during this whole project.

We would also like to express our gratitude towards Dr. Jawad Aslam and Dr. Emad Uddin for their kind cooperation and encouragement which helped us complete this project.

We are also thankful to the staff of MRC for their help during the fabrication phase of our project.

We have gained technical and theoretical knowledge as well as learned how to tackle stressful situations in a project under the guidance of our supervision committee.

Muhammad Muneeb Arshad

Muhammad Uzair Sajjad

Azan Akhtar

ORIGINALITY REPORT

REEport

ORIGINALITY REPORT

5%	4%	1%	1%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	www.buenastareas.com Internet Source	2%
2	wanderlodgegurus.com Internet Source	<1%
3	nakkertok.ca Internet Source	<1%
4	pdiimages.praxair.com Internet Source	<1%
5	www.slideshare.net Internet Source	<1%
6	www.praxairdirect.com Internet Source	<1%
7	Submitted to University Of Tasmania Student Paper	<1%
8	irdindia.in Internet Source	<1%
9	Submitted to Signature School Student Paper	<1%

10	mr-roboto.me.uiuc.edu Internet Source	<1%
11	Submitted to Coventry University Student Paper	<1%
12	cames.ippt.gov.pl Internet Source	<1%
13	Submitted to Oxford Brookes University Student Paper	<1%
14	www.iccms2016.org Internet Source	<1%
15	brage.bibsys.no Internet Source	<1%
16	Submitted to The University of Manchester Student Paper	<1%
17	www.hastingsdc.govt.nz Internet Source	<1%
18	era.library.ualberta.ca Internet Source	<1%
19	pastel.archives-ouvertes.fr Internet Source	<1%
20	Submitted to Harper Adams University College Student Paper	<1%
21	Submitted to University of Huddersfield Student Paper	<1%

22	digital.library.unt.edu Internet Source	<1%
23	Submitted to Coleg Sir Gar Student Paper	<1%
24	homewood.stanford.edu Internet Source	<1%
25	taylorphysics.org Internet Source	<1%
26	Steven J. Cooke. "Chapter 23 Industrial Gases", Springer Nature, 2017 Publication	<1%
27	Dixon. "Fluid Mechanics", Wiley-Professional Engineering Publishing Series, 09/09/2007 Publication	<1%
28	www.nonsolonews.net Internet Source	<1%
29	Luo, Feng, and Xiao Li Zhang. "A Review of Aeration and Cavitation Phenomena in the Hydraulic Shock Absorber", Applied Mechanics and Materials, 2014. Publication	<1%
30	patents.google.com Internet Source	<1%
31	www.vtt.fi Internet Source	<1%

32	R. V. Kazban. "Measurements of Forces and Temperature Fields in High-Speed Machining of 6061-T6 Aluminum Alloy", Experimental Mechanics, 06/2008 Publication	<1%
33	smme.nust.edu.pk Internet Source	<1%
34	doras.dcu.ie Internet Source	<1%
35	eprints.brighton.ac.uk Internet Source	<1%
36	Igor Crk, Dane Sorensen, Amit Mitra. "chapter 19 Leveraging Knowledge Reuse and System Agility in the Outsourcing Era", IGI Global, 2008 Publication	<1%
37	Yuxin Zhang, Konghui Guo, Shengbo Eben Li, Xiong Shao, Meiyu Zheng. "Prototyping design and experimental validation of membranous dual-cavity based amplitude selective damper", Mechanical Systems and Signal Processing, 2016 Publication	<1%

Exclude quotes Off

Exclude matches Off

Exclude bibliography Off

COPYRIGHT

School of Mechanical and Manufacturing Engineering (SMME)

NUST, H-12

Islamabad

TABLE OF CONTENTS

LIST OF TABLES

TABLE OF FIGURES

NOMENCLATURE

k	Stiffness of spring
d	Thickness of spring coil
D	Major diameter of spring
ω_n	Natural Frequency
ω_d	Damped Frequency
τ_d	Time period of damped vibrations
c_c	Critical damping constant
c	Damping constant
ε	Damping ratio
x	Displacement of damper
$\dot{x}$	Velocity of damper
$F_{rebound}$	Rebound force
$P_{rebound}$	Rebound pressure
d_{piston}	Diameter of piston
d_{rod}	Diameter of rod
$F_{compression}$	Compression force
P_{comp}	Compression pressure
P_{gas}	Gas pressure
$t_{rebound}$	Rebound shim thickness

$t_{compression}$	Compression shim thickness
D_{shim}	Shim outer diameter
C_D	Discharge coefficient
D_{valve}	Major diameter of valve
$A_{reb_{flow}}$	Area of rebound flow
$A_{comp_{flow}}$	Area of compression flow
$Q_{v_{reb}}$	Rebound valve flowrate
$Q_{v_{comp}}$	Compression valve flowrate
Q_{lp}	Piston leakage flowrate
l	Piston circumference
b	Piston height

CHAPTER 1: INTRODUCTION

A very important aspect of a vehicle is a comfortable ride to the user. Comfort is related to the damping ability of the vehicle. Shock absorbers play an important role in reducing shocks and increasing the life of the vehicle. They reduce the motion of both sprung and unsprung masses of the vehicle. The sprung mass includes the components supported by the spring and unsprung mass includes the brake caliper, brake disc, wheel, tire, suspension upright and a part of the suspension arms.

The tire damps the vehicle by approximately 2% but majority of the damping is carried out by the shock absorber. Shock absorbers work like a dynamic spring i.e. they produce force proportional to their velocity.

The primary function of a shock absorber is to damp shocks at their resonant frequencies. Their secondary function is to control the rate of weight transfer during transients such as braking, corner entry and acceleration.

1.1 Motivation

Keeping in mind the difficulties that a rider may face during a riding session and the life of the vehicle, we concluded that a new kind of damper is needed that can absorb shocks more effectively. So, we decided to compare the current damper used in motorcycles in Pakistan, a shim stack damper and a spool valve damper. Even though, spool valve dampers were found to be better than shim stack shock absorbers and the conventional orifice shock absorbers, we chose to proceed with the shim stack technology due to the complexities that would arise during the manufacturing of a spool valve damper. The manufactured shim stack damper would have Belleville washers as the primary component for its operation since Belleville washers are known to deflect less under high loading conditions. These washers would restrict the oil flow through the main piston of the shock absorber to improve damping.

1.2 Working Principle:

Our shock absorber consists of two chambers which are connected together.

First chamber (main cylinder) contains oil, the main piston along with the shim stack and the damper rod. The main piston would move downwards during the compression stroke. The oil would be displaced upward applying a force on the shim stack at the rebound side. The main piston would go back up during the rebound stroke displacing the oil back to the bottom. Now, the oil would apply a force on the shim stack at the compression side. The oil flow would be restricted by the shim stacks on both sides which will slow down the motion of the damper rod. This would increase the efficiency of the damper.

The second chamber (gas canister) contains a floating piston with a gas on one side of the piston and oil on the other side. The introduction of a second chamber is necessary to prevent cavitation. On a bumpy road, the shock absorber would undergo frequent compression and rebound cycles which can increase the temperature of the oil. The oil may change its phase as a result and damping becomes useless. This process is called cavitation.

1.3 Organization of the report:

Our report is divided into four main chapters. In this chapter, an overview about our project and our motivation for doing this project is explained. The working mechanism of our damper is also explained briefly in this chapter.

In the next chapter, literature review and background information of the process is given. Moreover, the background information of the designs is also provided.

Third chapter gives detailed explanation of the process, calculations, design, analysis and our approach to solve the problems. Our calculations include force calculations, shim thickness calculations, the vibrational analysis and the fluid calculations.

Fourth chapter includes the results obtained by analysis and calculations. Fifth chapter includes the results obtained after the manufacturing and testing of our shock absorber.

CHAPTER 2: LITERATURE REVIEW

A shock absorber is an inertial damper that utilizes the viscous properties of a fluid which redirects motion by forcing the fluid through a narrow passage. [1]

Shock absorbers are of different types and vary according to their construction, working and nature of the fluid used. These dampers have different applications in automotive industry depending upon the required nature of damping.

One of our deliverables was the theoretical comparison of orifice dampers, shim stack dampers and spool valve dampers which fall under the category of monotube dampers.

2.1 Monotube dampers: [2]

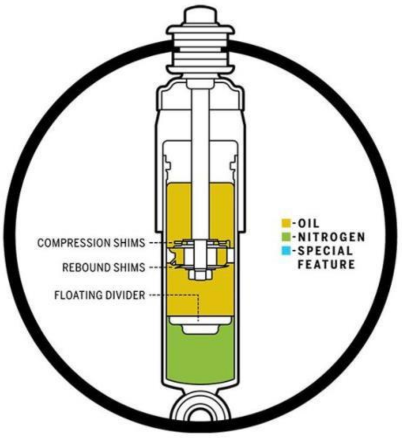


Figure 1: Monotube Damper [2]

Monotube dampers are classified on the basis of the type of the valve used in the damper. Following are the different types of valves:

- Disc Valve (Orifice damper)
- Rod Valve
- Shim Valve (Shim Stack damper)
- Spool Valve (Spool Valve damper)

2.1.1 Disc Valve

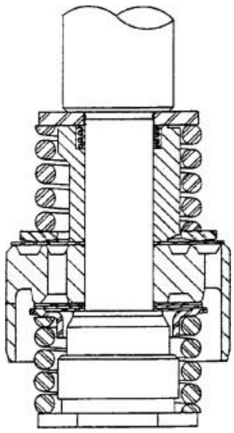


Figure 2: Disc Valve [9]

A disc valve is coupled with a spring. It is opened by attaining a feasible pressure difference. This pressure difference depends on the preload force of spring and active pressure area. This area might be greater in magnitude in comparison to the area for fluid flow. The compression of the spring depends upon its stiffness. A higher-pressure difference would cause an increase in the flow area as well as the flow rate. In practical applications, a stiff spring is not feasible; the actual flow is very minute and a large force would cause a very big flow area. This type of valve is suitable in pre-load conditions where flow constraint in one direction is required. A variation of valve can be attained using a conical spring.

2.1.2 Rod Valve

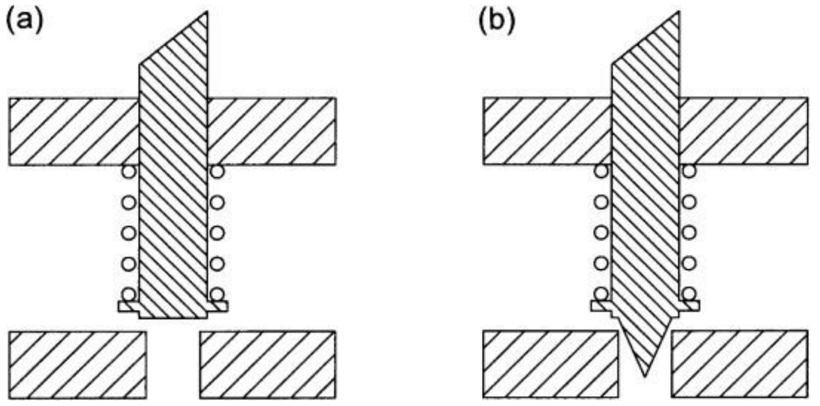


Figure 3: Rod Valve (a) Basic flat ended (b) Taper ended [9]

In rod valve, flow is kept in check by a flat rod which is present at the end of a hole. Size of the hole is dependent upon the feasibility of manufacturing. Effective limit area is limited by the equality of exit area and hole area. Spring is rather stiff, as higher uplift force is required in a small distance. Tapered rod can be used to increase this force for the area under consideration. Long length tapered valve is known as needle valve.

2.1.3 Spool Valve

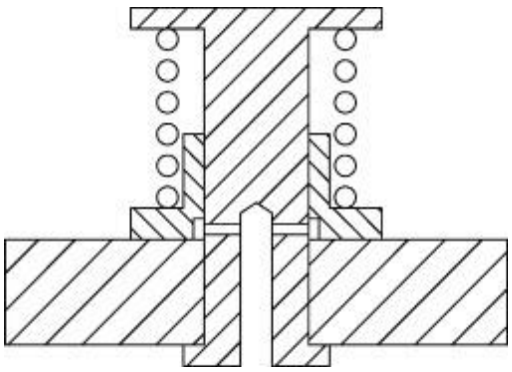


Figure 4: Spool Valve [9]

A spool valve is coupled with a coil spring. Foot valve is a spool valve with four cross-drilled holes. In order to vary flow area with spool position, the profile of exit holes is varied according to requirement. This adaptive construction is a positive aspect of spool valve. So theoretically, all required features are attainable by varying the precision of exit holes and the cost of manufacturing. Broaching is an effective technique to manufacture precise holes. In the case of a single exit spool valve, hysteresis and friction are caused due to large lateral force exertion on fluid. This can be tackled by using two symmetrically positioned exit holes. Spring stiffness ranges between 500-100 kN/m. One variation involves spool valve fixed with a base. A slider attached with it moves alongside it. The slider is controlled by a coil spring.

2.1.4 Shim Valve

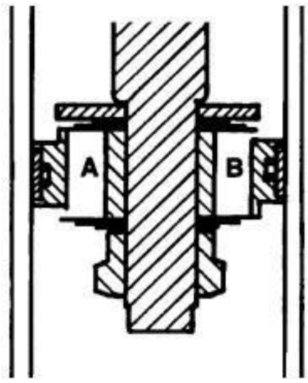


Figure 5: Shim Valve [9]

In practical use, a stack of shims with varying diameters are used instead of same diameter for variable damping. This is desirable in racing cars. These shims sit naturally on the piston without the problem of manufacturing dimensional inconsistencies affecting the preload. Shim stack on one side of the piston is controlled by three holes. Shims have varying thicknesses ranging from 0.2mm-0.5 mm. Leakage path is prevented by coning the piston surface at an angle range of 0.5^{o}-2^{o}. Usually, a shim stack comprises of six shims with reducing diameters allowing for adjustable stiffness. A complex shim stack arrangement requires additional support by adjusting the force before the load acts. This support is provided by an additional shim stack. Extra stiffness can be attained by spacing shim with small diameter discs. This is required for progressive increase in deflection. Radial slots are used in shims when shim valves are dealing with large volume flow. These are supported with a rigid central support. This results in a cantilever of long length.

2.2 Hydraulic Fluid: [11]

A hydraulic fluid is chosen considering the following characteristics.

- Chemical Properties
- Density
- Thermal Expansion
- Compressibility
- Viscosity
- Thermal Capacity
- Thermal Conductivity
- Vapor Pressure

General choice for damper oil is basic mineral oil and its properties are given in Appendix (1).

2.3 Gas Additive: [11]

The choice of the gas additive in damper depends upon the following characteristics.

- Gas density
- Gas viscosity
- Gas compressibility
- Gas absorption
- Emulsification

Nitrogen is most commonly used and its properties along with other gases are tabulated in Appendix (2).

CHAPTER 3: METHODOLOGY

3.1 Why Shim stack viscous damper?

Compared to the traditional disc valve damper, the shim stack damper has many advantages and the spool valve damper is better than the others in terms of precision and accuracy. However, we chose a shim stack damper since the tolerances required for the manufacturing of a spool valve damper were in microns. The equipment required for this purpose in unavailable in Pakistan. Other features of a shim stack damper are discussed below.

3.1.1 Pressure Sensitive Damping

Damping is created by the fluid pressure differential inside the shock. The shims on the face of the piston resist bending, increasing fluid pressure through this.

3.1.2 Adjustable damping

For oil to flow, it has to bend the shims for an opening. If the shims are thin, the oil can easily bend them, allowing a lot more oil to pass through the piston and results in little damping. If the shims are thicker, they are harder to bend and it takes more force for the oil to provide an opening through the piston, increasing the damping effect. Numerous shim stack combinations can be made in view of this fact.

3.1.3 Tapered Stack Configuration

We chose a tapered stack configuration as it smoothens the bend radius at the stack clamp and helps to avoid stressing the shims beyond the yield point. The pyramidal diameter variation makes fine tuning adjustments possible. Tunable features are

- Number of shims
- Thickness of shims
- Diameter of shims

- Number and thickness of face shims
- Stack clamp diameter

3.1.4 Selection Criteria for the damping fluid

The hydraulic oil used should cover the following requirements.

- Reduced friction and wear between the moving parts
- Don’t foam
- Prevent corrosion
- Compatibility with seal material
- Consistent damping force provision

Caltex Chevron Rando HD 68 was chosen to be used in the viscous hydraulic shock absorber because it is most readily available in the market and has properties suitable for the Pakistani environment. Its properties are given in Appendix (3).

3.1.5 Selection Criteria for the gas

Nitrogen is most commonly used in shock absorbers to help prevent the problem of cavitation. Hence, it was chosen to be used in our shock absorber.

3.1.6 Material Selection

We required a material for our pistons that would be compatible with the hydraulic oil and would bear the stresses when the shock absorber is operational. Conventional disc valve shock absorber has a cast iron piston. However, we chose to proceed with aluminum because

- It has lighter weight
- Loads were not that high and aluminum piston could bear them
- Its machining was cheaper

Some of its properties are:

Specification No.	6061-T6
Type/Grade	6061
Min. Tensile Strength [MPa]	310 MPa
Min. Yield Strength [MPa]	276 MPa

Table 1: Properties of Aluminum

The properties stated above were taken from Aluminum Standards and Data 2000.

This material is feasible for our project because of its low cost, high yield strength and easily available machining process in the market.

3.2 Concept Model:

It consists of two chambers which are connected together via a pipe. One chamber contains the viscous oil, the main piston assembly along with the shim stack. The shim stack restricts the viscous oil flow to increase damping. During the compression stroke, the oil is displaced towards the rebound side of the main piston and strikes the rebound shims with enough force to bend the shims. Similarly, during the rebound stroke, the oil is displaced towards the compression side of the main piston and strikes the compression shims with high pressure to deliver a force capable of being the shims to provide a path for the oil. During frequent cycles of vibrations, the oil tends to heat up and may change to vapor phase which might render the damping useless. The holes in the main piston are machined at an angle of 12.81^o to provide a simple path for the oil to hit the shims easily without any losses. Second chamber contains the floating piston, the viscous oil and the gas. It is filled with gas under high pressure on one side of the floating piston. The high gas pressure in this chamber would provide ample resistance to the oil and prevent its phase change.

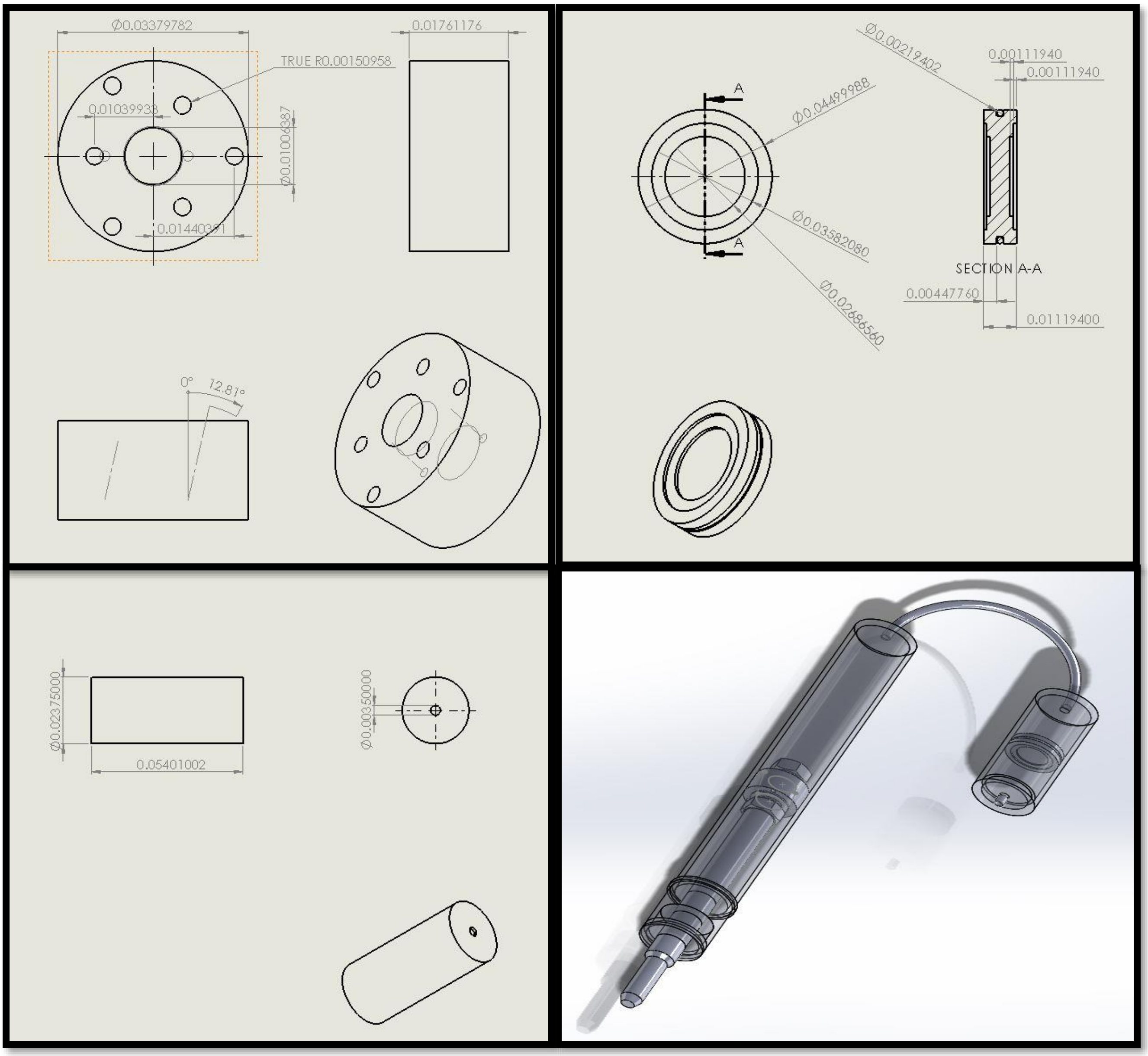


Figure 6: CAD Model of new design

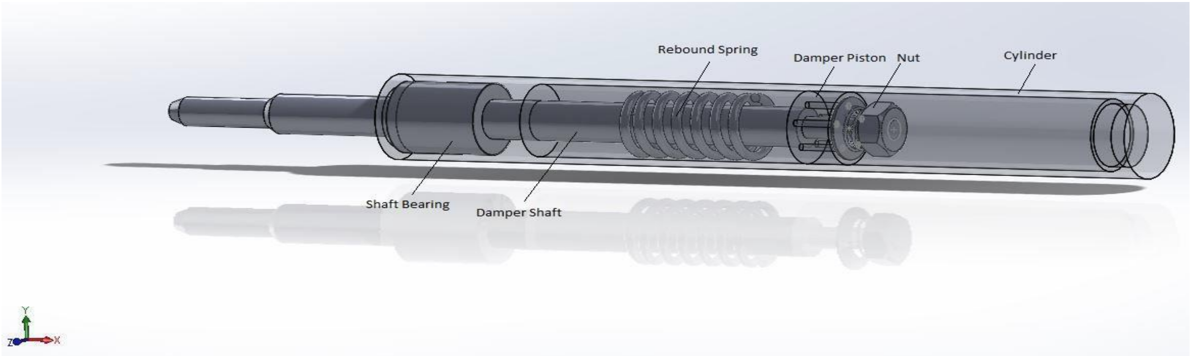


Figure 7: CAD Model of old design

3.3 Vibrational Analysis:

The stiffness of the spring was found by reverse engineering from the following formula

$$k = \frac{d^4 G}{8D^3 N}$$

The spring constant was found out to be 32476.46 N/m. CG125 normally has a mass of 250kg.

$$\omega_n = \sqrt{\frac{k}{m}} = 11.4\, rad/s$$

$$\omega_d = \sqrt{1-\varepsilon^2} = 10.42\, rad/s$$

Where ε was assumed to be 0.4037 since shock absorbers are usually underdamped.

$$\tau_d = \frac{2\pi}{\omega_d} = 0.603\, s$$

$$c_c = 2m\omega_n = 5700\, Ns/m$$

$$c = \varepsilon c_c = 2301.09\, Ns/m$$

$$x = \omega_d X e^{-\varepsilon \omega_n t} = 0.1079\, m$$

$$\dot{x}_o = X\omega_d = 1.12 m/s$$

Generally, a frequency of 1 Hz is required for a comfortable ride. Mathematical modelling was done in MATLAB as well and the code is shown in Appendix (4). The graph for the system is as follows

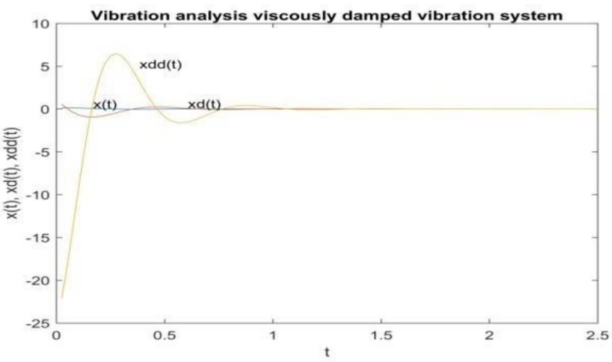


Figure 8: Displacement, velocity and acceleration w.r.t time

3.4 Force Calculations: [14]

When the bike is subjected to a jerk, the main piston in the hydraulic cylinder moves downward exerting a compressive force on the hydraulic oil. To move the piston back to its original position, a rebound force acts upon the piston. Generally, the hydraulic cylinders are designed so that the compressive force is about 1.6 times the rebound force.

$$F_{rebound} = \frac{P_{rebound} \times \pi({d_{piston}}^2 - {d_{rod}}^2)}{400}$$

Where $d_{piston} = 2.015\ cm$, $d_{rod} = 0.99cm$, $P_{rebound} = 25bar$

$$F_{rebound} = 0.60478\ kN$$

$$F_{compression} = 1.6 \times F_{rebound} = 0.96764\ kN$$

The compression force depends on the pressure in the compression region, the pressure in the gas chamber and the area of the compression region. Hence the pressure in the gas chamber can be calculated from the following formula.

$$F_{compression} = \frac{(P_{comp} + P_{gas}) \times \pi({d_{piston}}^2 - {d_{rod}}^2)}{400}$$

$$P_{comp} = 20\ bar$$

$$P_{gas} = 10.34\ bar$$

The shims in the rebound area are subjected to the compression force and their thickness can be calculated from the following formula.

$$t_{rebound} = \frac{1}{10}\sqrt[4]{\frac{F_{compression} D_{shim}}{132.4\ h/t}} = 0.78\ mm$$

where the shims outer and inner diameter are 14.25mm and 6mm respectively.

Similarly,

$$t_{compression} = \frac{1}{10}\sqrt[4]{\frac{F_{rebound}D_{shim}}{132.4\ h/t}} = 0.69\ mm$$

The h/t ratio for the above equation were taken from the graph as shown in Appendix (5).

3.5 Fluid Calculations: [15]

The flowrate through the piston valves is given by the following equation

$$Q_v = A_{flow}C_D\sqrt{\frac{2(P_{compression} - P_{rebound})}{\rho}}$$

$$A_{flow} = \alpha\pi D_{valve}x$$

Talbott has used $\alpha = 0.5$ for modelling a shock absorber in his paper for compression flow and rebound flow with three holes in the main piston. The coefficient of discharge for holes at 12.81^o with vertical axis was found to be 0.51375.

$$A_{reb_{flow}} = 9.109\ \times 10^{-7}\ m^2$$

$$A_{comp_{flow}} = 8.03\ \times 10^{-7}\ m^2$$

$$Q_{v_{reb}} = 1.64\ \times 10^{-5} m^3/s$$

$$Q_{v_{comp}} = 1.46\ \times 10^{-5} m^3/s$$

The viscosity of the damper oil was found to be 64.6 cSt at 40^{o}C. The leakage flow from the piston was found by the following equation.

$$Q_{lp} = \left(\frac{\Delta P b^3}{12\mu l} + \frac{\dot{x}b}{2}\right)\pi d_{piston}$$

Where l is the circumference of the piston and b is the height of the piston.

$$Q_{lp} = (1.274 \times 10^{-5} + 5.25 \times 10^{-3}\dot{x})0.063\ m^3/s$$

The piston leakage flowrate comes out to be a function of the damper velocity.

3.6 Finite Element Analysis:

The purpose for conducting a simulation test for our product is to ensure and reconfirm that the results obtained theoretically are accurate.

Since our project involves a pressure difference of about 5 bars, a simulation of the shims was done to get insight on stress that they will endure and the deformation they will undergo. Another simulation was conducted for the floating piston which must bear the compression pressure and the gas pressure. It was done to account for the stresses and deformations.

Both simulations were conducted using ANSYS R18.0.

3.6.1 Material

As it was stated earlier that the material selected for the shims was spring steel and the material selected for the floating piston was aluminum.

3.6.2 Pressure Simulation

Simulation was carried out considering the following pressures.

$$P_{reb} = 25\ bar$$

$$P_{comp} = 20\ bar$$

$$P_{gas} = 10.34\ bar$$

Units used for the simulation are:

Unit system	Metric (mm, kg, N, s, mV, mA) Degrees rad/s Celsius
Angle	Degrees
Rotational Velocity	Rad/s
Temperature	Celsius

Table 2: Units of simulation

3.6.3 Model

The initial model was made using SolidWorks and was later imported in ANSYS. The dimensions of the shim are given below.

Internal diameter	10.5mm
External diameter	17.4mm
Thickness	0.75mm

Table 3: Geometric model of shim

The dimensions of the floating piston are given below.

External diameter	45mm
Thickness	11mm

Table 4: Geometric model of floating piston

3.6.4 Contours of the analysis obtained

Compression shim

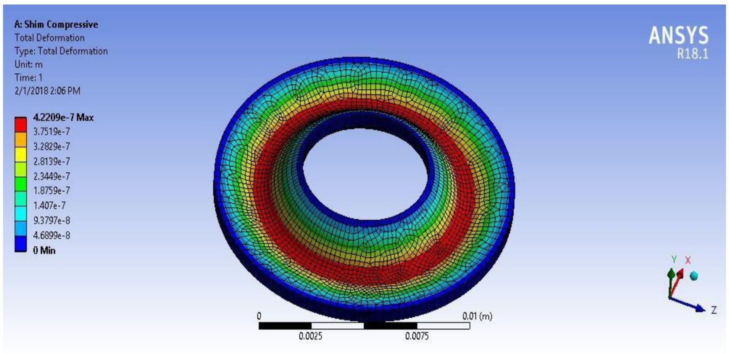


Figure 9: Total deformation (Compression Shim)

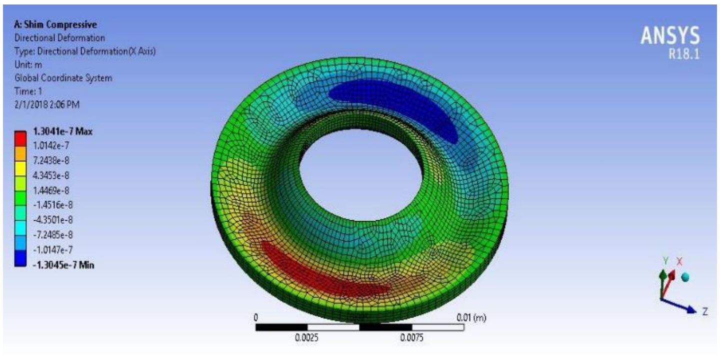


Figure 10: Directional Deformation (Compression Shim)

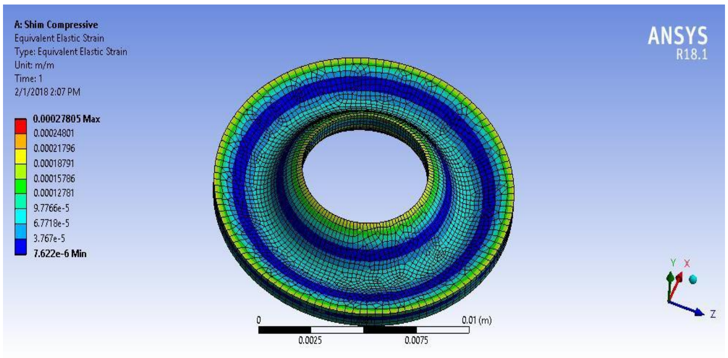


Figure 11: Equivalent Elastic Strain (Compression Shim)

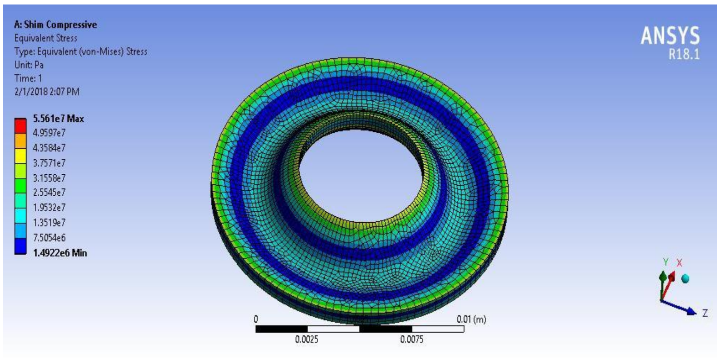


Figure 12: Equivalent Stress (Compression Shim)

Rebound shim

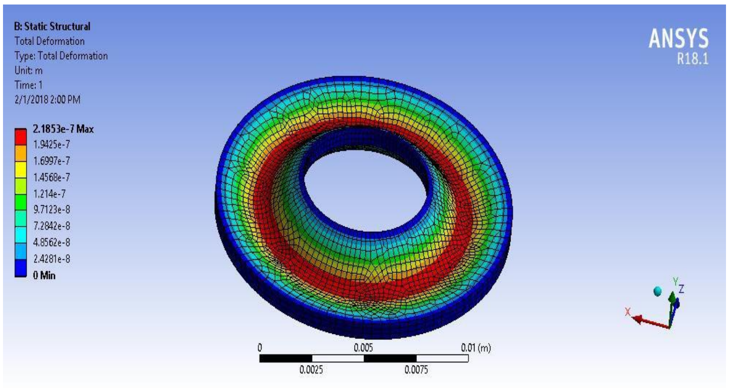


Figure 13: Total Deformation (Rebound Shim)

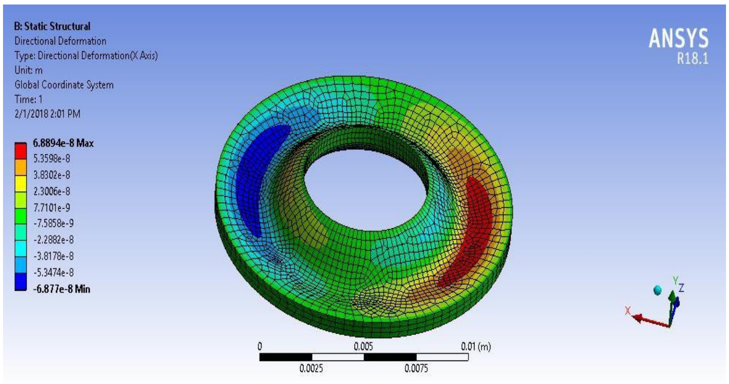


Figure 14: Directional Deformation (Rebound Shim)

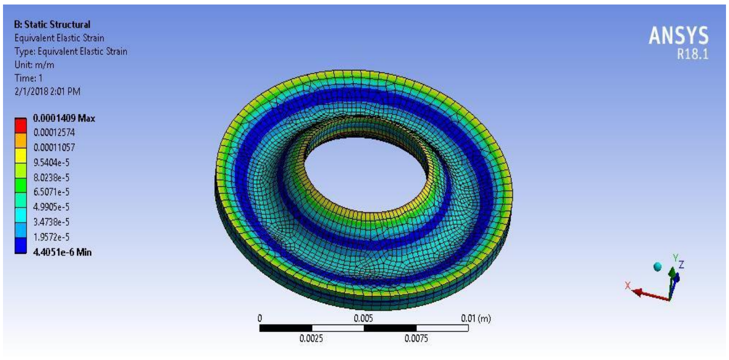


Figure 15: Equivalent Elastic Strain (Rebound Shim)

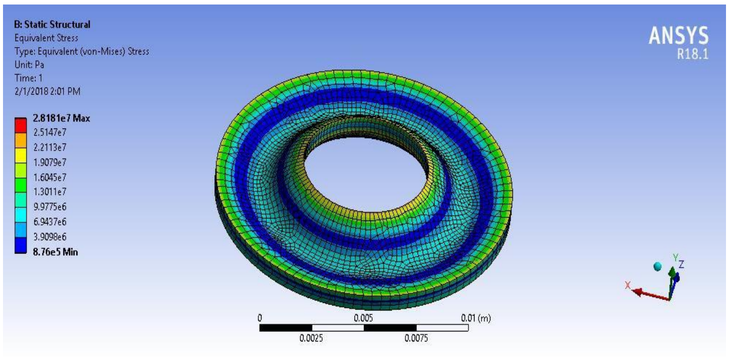


Figure 16: Equivalent Stress (Rebound Shim)

Floating Piston

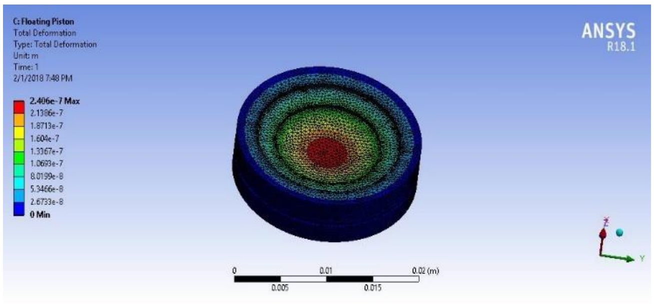


Figure 17: Total Deformation (Floating Piston)

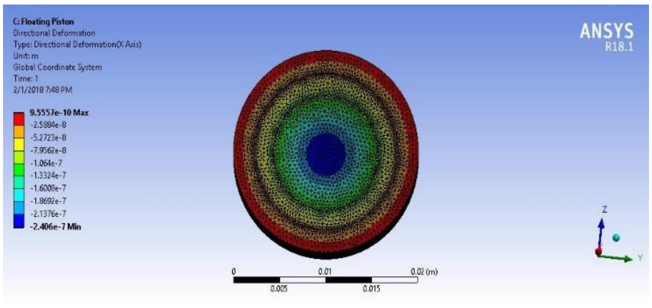


Figure 18: Directional Deformation (Floating Piston)

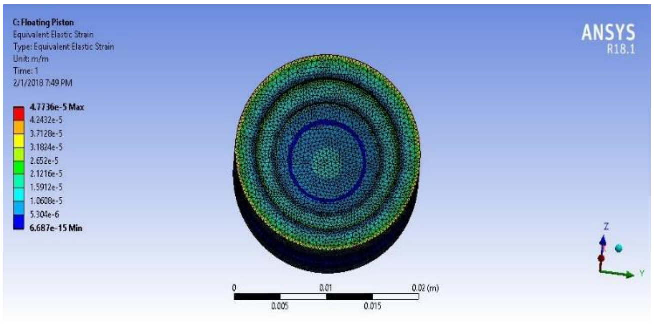


Figure 19: Equivalent Elastic Strain (Floating Piston)

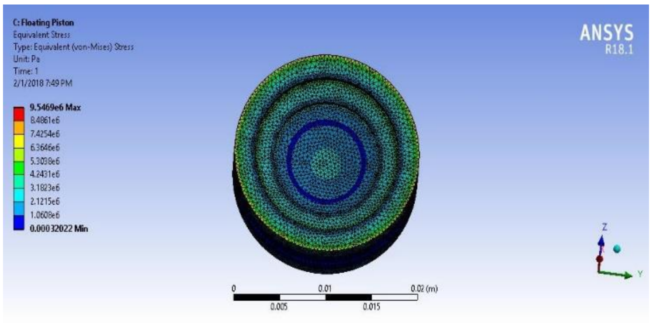


Figure 20: Equivalent Stress (Floating Piston)

CHAPTER 4: RESULTS AND DISCUSSIONS

The shock absorbers were attached to the rear of a Honda CG125. The accelerometer used was from Samsung Galaxy S6. The phone was attached to the strut of the bike and the data was collected by Accelerometer Analyzer android application.

4.1 Disc Valve damper results:

Firstly, the original conventional disc valve damper was tested and the generated readings are in Appendix (6). The graphs obtained from these readings are as follows.

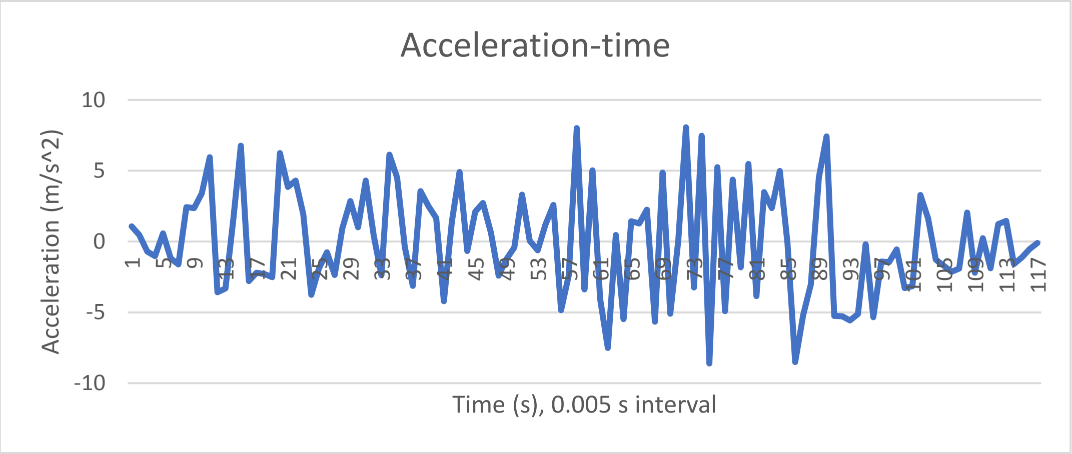


Figure 21: Acceleration time graph (Disc Valve damper)

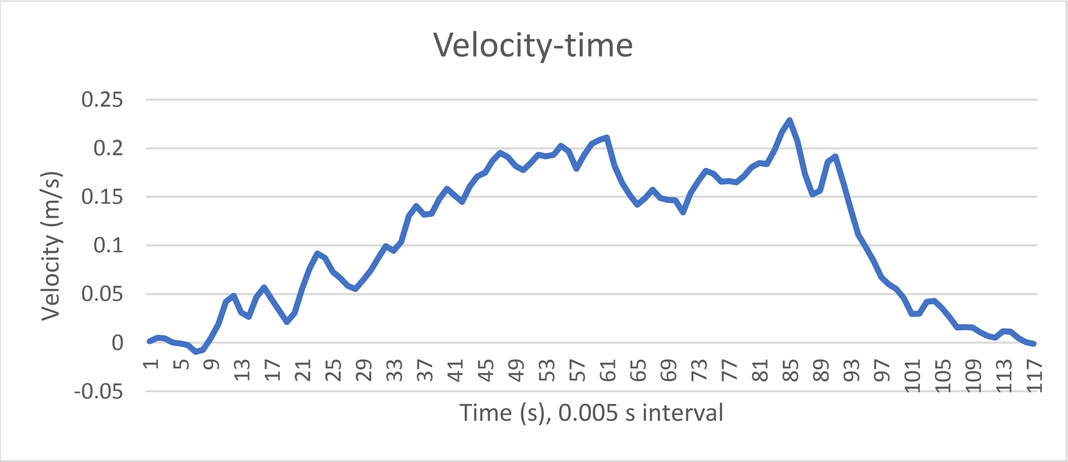


Figure 22: Velocity time graph (Disc Valve Damper)

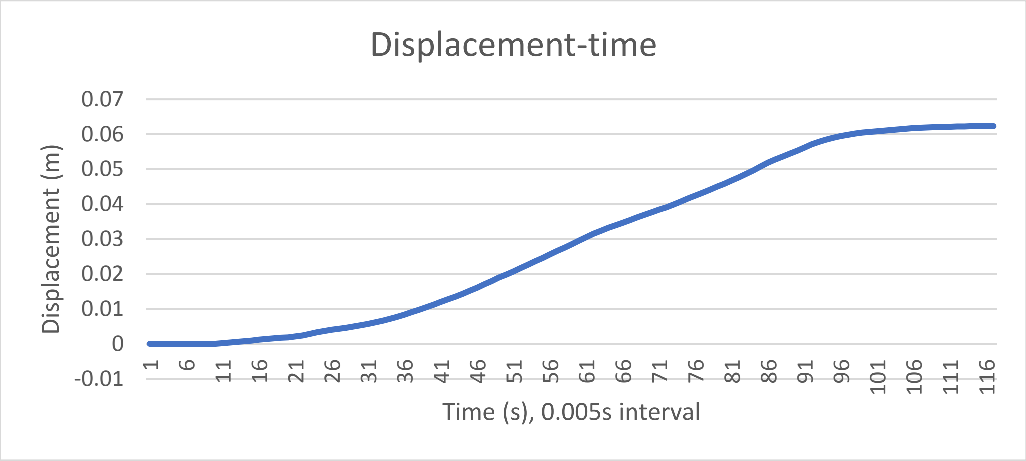


Figure 23: Displacement time graph (Disc valve damper)

4.2 Shim stack damper results:

Only pressure up to 2 bar was available so we took two readings, one at 1 bar and the other at 2 bar. A place with pressure up to 5 bar available was found later. Following graphs were plotted from the two readings.

4.2.1 Results at 1 bar

The generated readings are shown in Appendix (7).

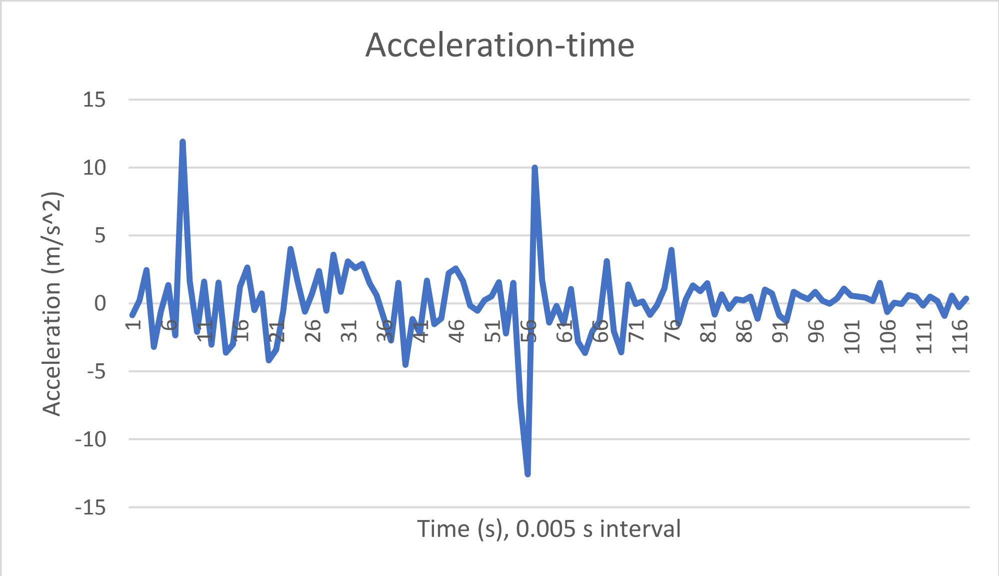


Figure 24: Acceleration time graph (Shim stack damper @ 1 bar)

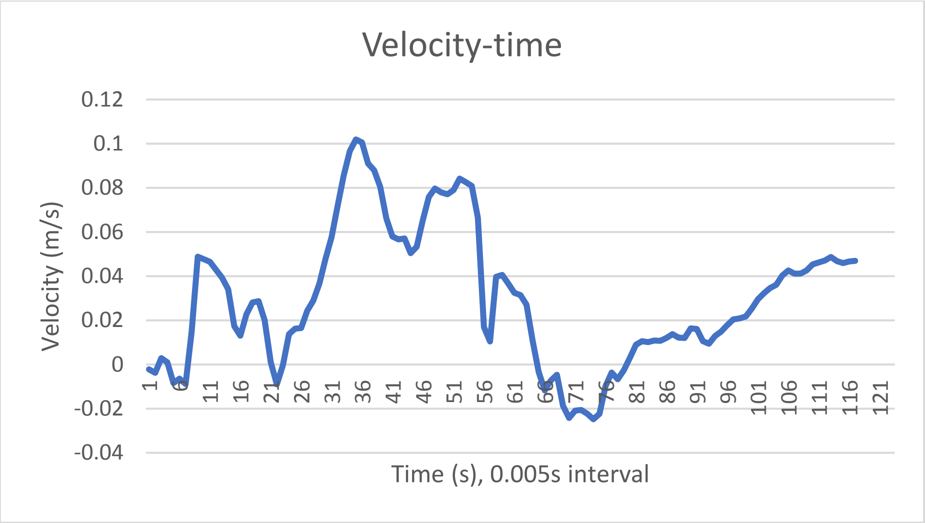


Figure 25: Velocity time graph (Shim stack damper @ 1bar)

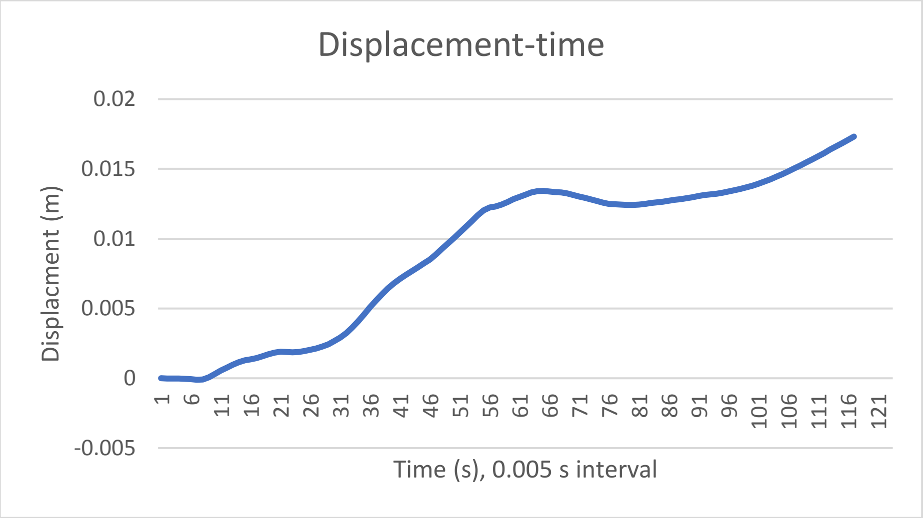


Figure 26: Displacement time graph (Shim stack damper @ 1bar)

4.2.2 Results at 2 bar

The generated are shown in Appendix (8).

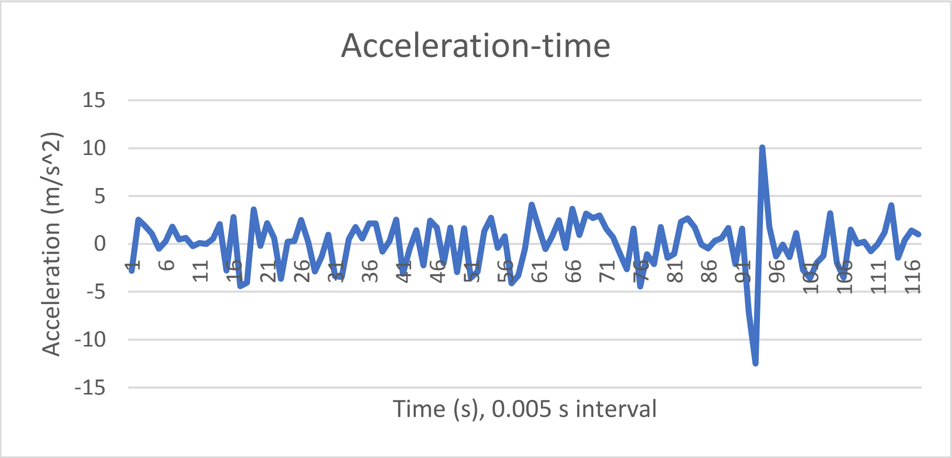


Figure 27: Acceleration time graph (Shim stack damper @ 2 bar)

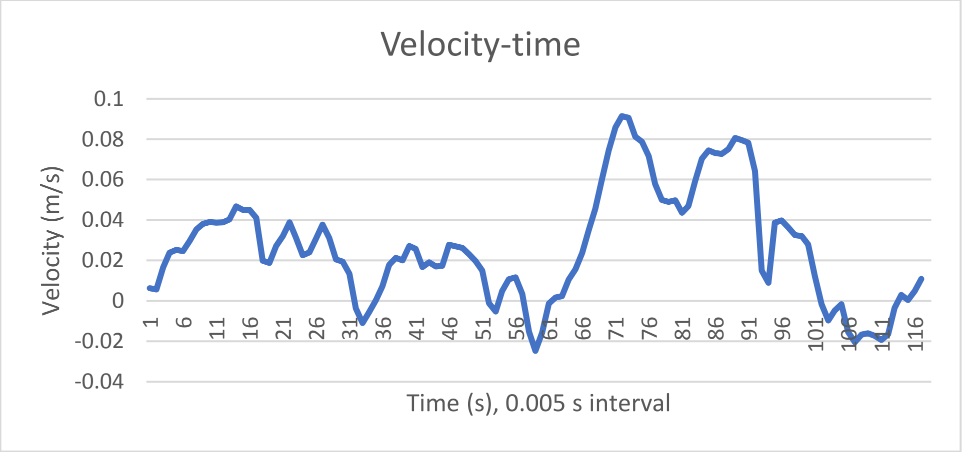


Figure 28: Velocity time graph (Shim stack damper @ 2bar)

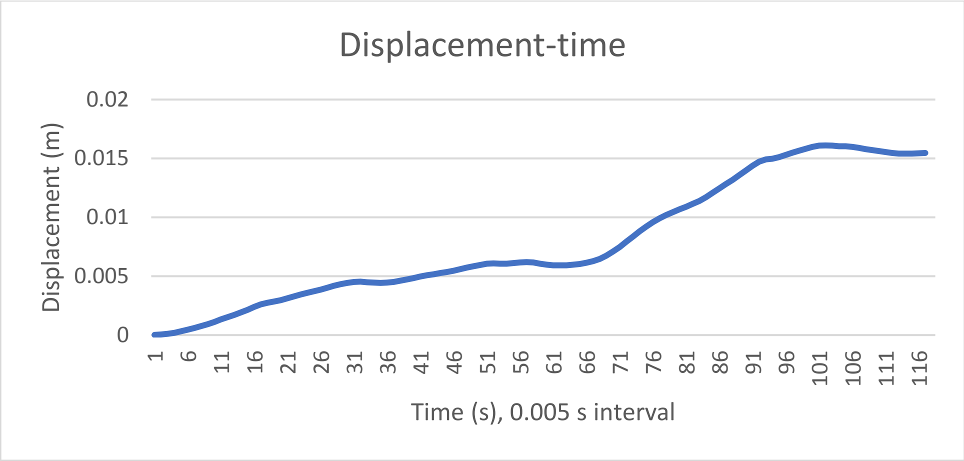


Figure 29: Displacement time graph (Shim stack damper @ 2bar)

4.2.3 Results at 5 bar

The generated readings are shown in Appendix (9).

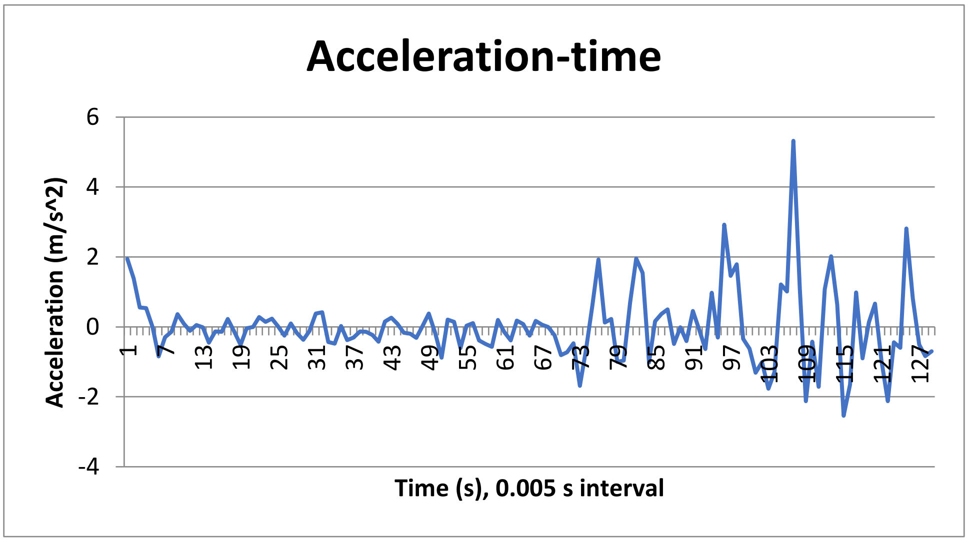


Figure 30: Acceleration time graph (Shim stack damper @ 5 bar)

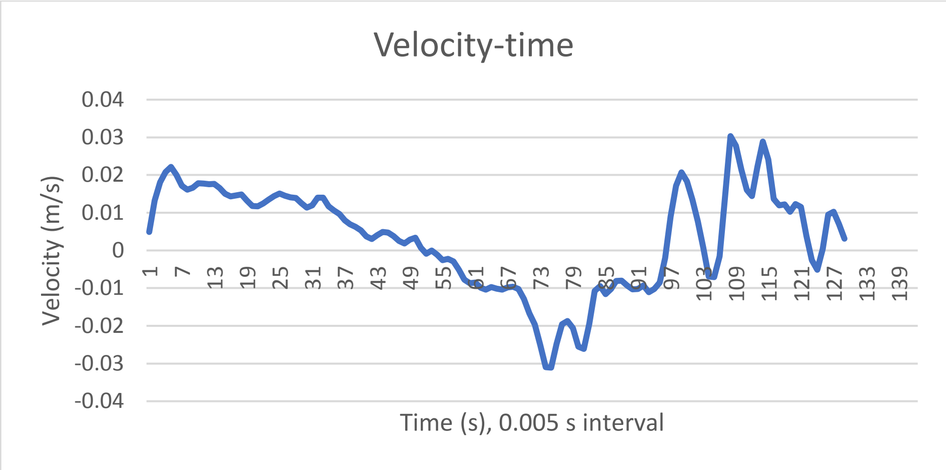


Figure 31: Velocity time graph (Shim stack damper @ 5 bar)

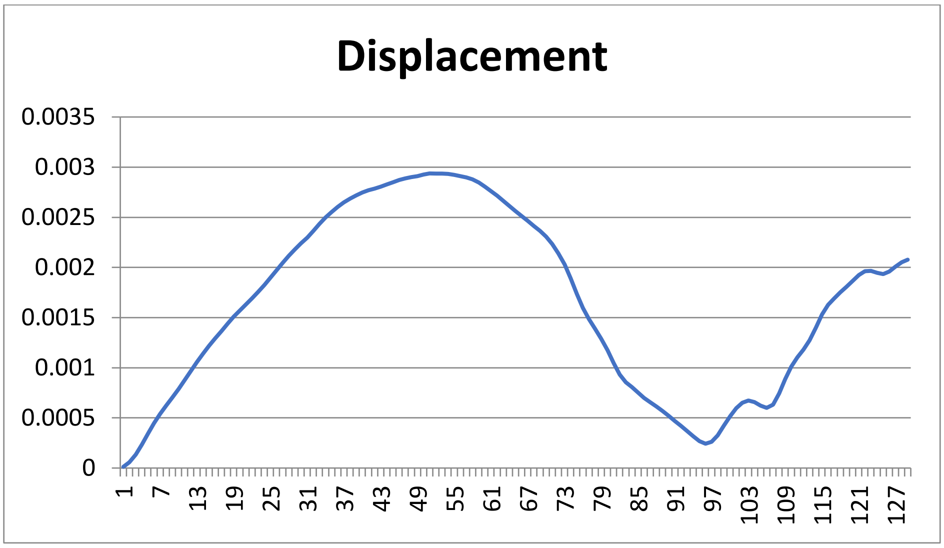


Figure 32: Displacement time graph (Shim stack damper @ 5 bar)

4.3 Discussion:

In the acceleration-time graph for the disc valve damper, it is quite evident that the bike undergoes frequent jumps and the required damping is not provided. From the velocity-time graph, the damping constant for the conventional disc valve damper was found to be 2.36 Ns/mm. The maximum displacement the bike undergoes is slightly above 0.06m.

In the acceleration-time graph for the shim stack viscous damper at 1 bar pressure, the acceleration stays below 5m/s^2 throughout the ride except for the speed breaker where the acceleration reaches 10m/s^2 or slightly above it. From the velocity-time graph, the damping constant for shim stack damper at 1 bar was found to be 2.45 Ns/mm which is about 3.8% increase in the damping constant. The maximum displacement the bike undergoes is about 0.017m which is very less compared to 0.06m.

In the acceleration-time graph for the shim stack viscous damper at 2 bar pressure, the acceleration stays below $5m/s^2$ throughout the ride but only goes at $10m/s^2$ at the speed breaker. From the velocity-time graph, the damping constant for shim stack damper at 1 bar was found to be 2.64 Ns/mm which is about 11.8% increase in the damping constant. The maximum displacement the bike undergoes is slightly above 0.015.

In the acceleration-time graph for the shim stack viscous damper at 5 bar pressure, the acceleration stays below $6m/s^2$ throughout the ride. However, there are abrupt changes in the acceleration at the speed breaker. This minute error can be attributed to the vibrations the bike undergoes during gear shift. From the velocity-time graph, the damping constant for shim stack damper at 1 bar was found to be 2.72 Ns/mm which is about 15.2% increase in the damping constant. The maximum displacement the bike undergoes is slightly below 0.003.

The theoretically calculated damping value by vibrational analysis was 2.302 Ns/mm which is quite close to the values obtained from the theoretical results.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

Our project is designed on the basis of the calculations stated above. We tested our shock absorber and came to the conclusion that it works correctly as proposed i.e. the damping is pressure sensitive and it can be adjusted either by varying the pressure in the gas canister or by changing the configuration of the shim stack on the main piston.

5.1 Recommendations:

Based on the results and time limitation for fabrication, following recommendations can help improve the overall model.

1. The results can be improved by using a pressure up to 10 bars.
2. The results can be improved by using a higher quality damping fluid.
3. Using a less stiff spring or making the configuration of the shims less stiff to provide a less stiff and more comfortable ride.
4. The main cylinder can be made twin tube for better performance.
5. The diameter of the main cylinder and the main piston can be increased to provide more room for oil and hence, improve damping.

REFERENCES

[1] Inertia damper retrieved from:

https://en.wikipedia.org/wiki/Inertia_damper

[2] Damper and Awe: 6 types of Automotive dampers explained, retrieved from:
https://www.caranddriver.com/features/automotive-dampers-explained-how-6-common-types-work-feature

[3] Poynor, James Connor. *Innovative design for magnetorheological dampers.* Diss. Virginia Tech, 2001.

[4] Ishibashi, Ryo, and Motoyoshi Andoh. “Spool valve.” U.S. Patent No. 7,926,513. 19 Apr. 2011.

[5] Petek, Nicholas K. *An electronically controlled shock absorber using electrorheological fluid*. No. 920275. SAE Technical Paper, 1992.

[6] Kasprzak, Jim. "Understanding your dampers: A guide from jimkasprzak." *Kaz Technologies website* 25 (2008).

[7] Czop, Piotr, and Jacek Gniłka. "Reducing aeration and cavitation effect in shock absorbers using fluid-structure interaction simulation." *Computer Assisted Methods in Engineering and Science* 23.4 (2017): 171-189.

[8] Fox, Robert C. "Damper with pressure-sensitive compression damping." U.S. Patent No. 7,374,028. 20 May 2008.

[9] Dixon, John C. *The shock absorber handbook*. John Wiley & Sons, 2008.

[10] Damper properties, retrieved from:

http://www.mototribology.com/articles/suspension-fluids/

[11] Industrial gas properties, retrieved from:
http://www.globalspec.com/learnmore/materials_chemicals_adhesives/industrial_specialty_gases/industrial_specialty_gases

[12] Collins, Jack A., Henry R. Busby, and George H. Staab. *Mechanical design of machine elements and machines: a failure prevention perspective*. John Wiley & Sons, 2010.

[13] Belleville force and thickness formulae retrieved from:

http://www.tribology-abc.com/calculators/t14_6.htm

[14] Force and pressure equations retrieved from:
https://www.roemheld-gruppe.de/fileadmin/user_upload/downloads/technische_informationen/Wissenswertes_Hydraulikzylinder_en_0212.pdf

[15] Satpute, Nitin V., Shankar Singh, and S. M. Sawant. "Fluid flow modelling of a fluid damper with shim loaded relief valve." *International Journal of Mechanical Engineering* 2.1 (2013): 65-74.

[16] Spring steel properties, retrieved from:
https://en.wikipedia.org/wiki/Spring_steel

Appendix I: Damper Oil Properties

Representative Damper oil properties (Basic mineral oil)				
1	Density @ 15^oC	ρ	≈ 860	kg/m^3
2	Viscosity @ 15^oC	μ	≈ 40	$mPa.s$
3	Temperature Range	T	$\approx -40\ to + 130$	℃
4	Pressure Range	P	$\approx 0\ to\ 20$	MPa
5	Compressibility	$(d\rho/dP)/\rho$	≈ 0.05	$\%/MPa$
6	Thermal Conductivity	k	≈ 0.14	$W/m.K$
7	Thermal Capacity	C_p	≈ 2.5	$kJ/kg.K$
8	Viscosity-temperature sensitivity	$(d\mu/dT)/\mu$	≈ -2	%/℃
9	Viscosity-pressure sensitivity	$(d\mu/dP)/\mu$	$\approx +3$	$\%/MPa$
10	Surface Tension	σ_s	≈ 25	mN/m
11	Air absorption effect	k_A	≈ 1.0	$kg/m^3.MPa$

Appendix II: Physical Properties of Gases

Physical Properties of Gases								
Gas			**Argon**	**CO_2**	**Helium**	**Hydrogen**	**Nitrogen**	**Oxygen**
Atomic Weight			39.948	44.010	4.0026	2.016	28.01	31.999
Normal Boiling Point		°F	-302.6	-109.3	-452.1	-423.0	-320.4	-297.3
Freezing Point		°F	-308.9	-109.3	--------	--------	-346.0	-361.8
Triple Point		°F	-308.9	-69.8	--------	-436.0	-346.0	-361.8
		psia	10.0	75.2	--------	1.04	1.8	0.022
Critical point		°F	-188.1	87.9	-450.3	-399.9	-232.5	-181.1
		psia	710.0	1071.0	33.2	190.8	493.0	731.4
Density	Gas, NTP	lb/ft^3	0.1034	0.1144	0.01034	0.005209	0.07245	0.08281
	Gas, STP	lb/ft^3	0.1114	0.1234	0.001114	0.005611	0.05618	0.08921
	Vapor, nbp	lb/ft^3	0.363	--------	1.04	0.0831	0.287	0.279
	Liquid, nbp	lb/ft^3	86.98	63.35**	7.798	4.428	50.46	71.27
Specific Heat			0.125	0.20	1.25	3.42	0.249	0.220
Specific Heat Ratio			1.67	1.31	1.66	1.42	1.41	1.40
Heat of vaporization		Btu/lb	70.2	246.6*	8.72	191.7	85.6	91.7
Heat of fusion		Btu/lb	12.7	85.6	--------	25.0	11.1	6.0
*Denotes Sublimation temperature at 1 atm **Liquid density at 2 °F and 302 psig								

Appendix III: Properties of Rando HD Oil Series

ISO Grade	10	22	32	46	68
Product Number	*273252*	*273276*	*273277*	*273278*	*273279*
SDS/MSDS Number					
USA	*23706*	*23548*	*23556*	*23556*	*23556*
Colombia	—	—	*33476*	*33476*	*33476*
El Salvador	—	—	*33477*	*33477*	*33477*
AGMA Grade	—	—	—	1	2
API Gravity	27.7	33.7	32.6	31.8	31.6
Viscosity, Kinematic					
cSt at 40°C	10.3	23.1	30.4	43.7	64.6
cSt at 100°C	2.5	4.4	5.2	6.5	8.4
Viscosity, Saybolt					
SUS at 100°F	63	120	157	225	334
SUS at 210°F	35	41	44	48	54
Viscosity Index	48	98	99	97	98
Flash Point, °C(°F)	154(309)	177(351)	220(428)	226(439)	235(455)
Pour Point, °C(°F)	-39(-38)	-36(-33)	-33(-27)	-30(-22)	-30(-22)
Oxidation Stability Hours to 2.0 mg KOH/g acid number, ASTM D943	—	—	>5000	>5000	>5000

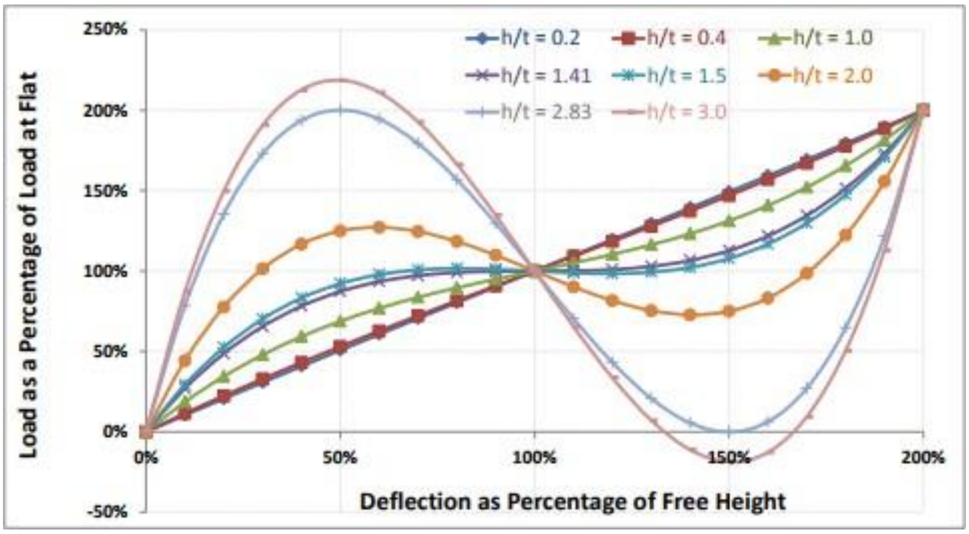
Appendix IV: MATLAB Code for vibrational analysis

```
%=================================================================
%
%Program2.m
%Program for calling the subroutine FREVIB
%
%=================================================================
%Run "Program2" in MATLAB Command Window. Program2.m and frevib.m
%should be in the same file folder, and set the path to this folder
%following 7 lines contain problem-dependent data
m=250;
k=32476.46;
c=2301.09;
x0=0.11;
xd0=1.144;
n=100;
delt=0.025;
%end of problem-dependent data
[x,xd,xdd,t,ii]=FREVIB(m,k,c,x0,xd0,n,delt);
fprintf('Free vibration analysis \n');
fprintf('of a single degree of freedom analysis \n\n');
fprintf('Data:\n\n');
fprintf('m=      %8.8e \n',m);
fprintf('k=      %8.8e \n',k);
fprintf('c=      %8.8e \n',c);
fprintf('x0=     %8.8e \n',x0);
fprintf('xd0=    %8.8e \n',xd0);
fprintf('n=      %2.0f \n',n);
fprintf('delt=   %8.8e \n\n\n',delt);
if ii==1
   fprintf('system is undamped \n\n');
elseif ii==2
   fprintf('system is under damped \n\n');
elseif ii==3
   fprintf('system is critically damped \n\n');
else
   fprintf('system is over damped \n\n');
end
fprintf('Results:\n\n');
fprintf(' i    time(i)            x(i)            xd(i)            xdd(i)');
fprintf('\n\n');
for i=1:100
   fprintf('%2.0f  %8.6e   %8.6e   %8.6e   %8.6e \n',i,t(i),x(i),...
       xd(i), xdd(i));
end
plot(t,x);
hold on;
gtext('x(t)');
plot(t,xd);
gtext('xd(t)');
plot(t,xdd);
gtext('xdd(t)');
xlabel('t');
ylabel('x(t), xd(t), xdd(t)');
title('Vibration analysis viscously damped vibration system');
```

```
%===============================================================
%
%Subroutine frevib.m
%
%===============================================================
function [x,xd,xdd,t,ii]=frevib(m,k,c,x0,xd0,n,delt);
omn=sqrt(k/m);
%undamped system
if (abs(c)>1.0e-6)
   ccrit=2.0*sqrt(k*m);
   xai=c/ccrit;
   if xai<1.0
      %Underdamped system
      ii=2;
      omd=sqrt(1.0-(xai^2))*omn;
      cp1=x0;
      cp2=(xd0+xai*omn*x0)/omd;
      a=sqrt(cp1^2+cp2^2);
      phi=atan(cp1/cp2);
      for i=1:n
         if i>1
            t(i)=t(i-1)+delt;
         else
            t(i)=delt;
         end
         tt=t(i);
         x(i)=a*exp(-xai*omn*tt)*sin(omd*tt+phi);
         xd(i)=a*exp(-xai*omn*tt)*(omd*cos(omd*tt+phi)-xai*omn*...
             sin(omd*tt+phi));
         xdd(i)=-(c*xd(i)+k*x(i))/m;
      end
   elseif xai==1.0
      %critically damped system
      ii=3;
      for i=1:n
         if i>1
            t(i)=t(i-1)+delt;
         else
            t(i)=delt;
         end
         tt=t(i);
         x(i)=(x0+(xd0+omn*x0)*tt)*exp(-omn*tt);
         xd(i)=-(x0+(xd0+omn*x0)*tt)*omn*exp(-omn*tt)+(xd0+omn*x0)*...
             exp(-omn*tt);
         xdd(i)=-(c*xd(i)+k*x(i))/m;
      end
   elseif xai>0
      %overdamped system
      ii=4;
      x1=sqrt(xai^2-1.0);
      c1=(x0*omn*(xai+x1)+xd0)/(2.0*omn*x1);
      c2=(-x0*omn*(xai-x1)-xd0)/(2.0*omn*x1);
      for i=1:n
         if i>1
            t(i)=t(i-1)+delt;
         else
            t(i)=delt;
         end
         tt=t(i);
```

```
         x(i)=c1*exp((-xai+x1)*omn*tt)+c2*exp((-xai-x1)*omn*tt);
         xd(i)=c1*(-xai+x1)*omn*exp((-xai+x1)*omn*tt)
         +c2*(-xai-x1)*omn*exp((-xai-x1)*omn*tt);
         xdd(i)=-(c*xd(i)+k*x(i))/m;
      end
   end
else
   ii=1;
   omn=sqrt(k/m);
   a=sqrt(x0^2+(xd0/omn)^2);
   phi=atan(xd0/(x0*omn));
   for i=1:n
      if i>1
         t(i)=t(i-1)+delt;
      else
         t(i)=delt;
      end
      tt=t(i);
      x(i)=a*cos(omn*tt-phi);
      xd(i)=a*omn*cos(omn*tt-phi+1.5708);
      xdd(i)=-(c*xd(i)+k*x(i))/m;
   end
end
```

Appendix V: h/t ratio graph for shim equations



Appendix VI: Accelerometer readings of old damper

Accelerometer Data File
Started @Tue Nov 28 15:43:04 GMT+05:00 2017
#
#
sensor Vendor: Invensense
sensor Name: MPU6500 Acceleration Sensor
sensor Resolution: 0.0011971008m/sec^2; Max Range: 39.2266; Min Delay: 5000 microseconds
The sensor's attributes are the result hardware and the Android capabilities.
It means that the Android may not utilize all features provided by the hardware.
#
Some devices and Android versions save battery too much so the device may go to sleep.
It just happens after couple of minutes from turning off the scree and it is easy to find it out.
#
The following file provides the data from accelerometer in the m/s^2 format.
The diff value is just a time delta between the samples
#
#
data format:
so we have 4 columns with values separated by the " "
X Y Z time_from_previous_sample(ms)

sensor speed set to:NORMAL
units set to: m/sec^2
gravity NOT filtered out
Accuracy: HIGH

Data	Acceleration	Velocity	Displacement
10.758	0.290106192	0.000362633	4.53291E-07
10.152	0.124739715	0.001399748	4.85924E-06
8.979	-0.195350841	0.00122322	1.14167E-05
8.664	-0.281308663	3.15709E-05	1.45536E-05
10.277	0.158849962	-0.000274576	1.39461E-05
8.513	-0.322513841	-0.000683736	1.15503E-05
8.074	-0.442309028	-0.002595793	3.35152E-06
12.119	0.661498559	-0.002047819	-8.2575E-06
12.063	0.646217168	0.00122147	-1.03234E-05
13.093	0.927285602	0.005155227	5.61837E-06
15.649	1.624771929	0.011535371	4.73449E-05
6.123	-0.974701761	0.013160547	0.000109085
6.375	-0.905935503	0.008458953	0.000163133
11.15	0.397075926	0.007186805	0.000202248
16.47	1.848808031	0.012801514	0.000252219
6.91	-0.759943647	0.015523675	0.000323032

7.498	-0.599489046	0.012125094	0.000392153
7.41	-0.623502659	0.009067614	0.000445135
7.164	-0.690631625	0.005782279	0.00048226
15.94	1.704180584	0.008316151	0.000517506
13.549	1.051719783	0.015205902	0.000576311
14.001	1.175062435	0.020772858	0.000666258
11.619	0.525057572	0.025023158	0.000780748
5.936	-1.02573069	0.023771475	0.000902735
7.808	-0.514895634	0.019919909	0.001011963
8.935	-0.207357648	0.018114276	0.001107049
7.339	-0.64287728	0.015988688	0.001192306
10.642	0.258451883	0.015027625	0.001269847
12.546	0.778019162	0.017618803	0.001351463
10.688	0.271004453	0.020241362	0.001446113
13.998	1.174243789	0.023854482	0.001556353
10.101	0.110822734	0.027067148	0.001683657
7.317	-0.648880683	0.025722004	0.00181563
15.819	1.671161865	0.028277707	0.001950629
14.213	1.232913414	0.035537895	0.002110168
9.299	-0.108028609	0.038350107	0.002294888
6.56	-0.855452338	0.035941404	0.002480617
13.255	0.971492482	0.036231505	0.002661049
12.187	0.680054533	0.040360372	0.002852529
11.354	0.452743848	0.043192368	0.003061411
5.471	-1.152620808	0.041442676	0.003272998
11.101	0.383704709	0.039520386	0.003475406
14.616	1.34288485	0.04383686	0.003683799
9.032	-0.180888097	0.046741851	0.003910246
11.796	0.573357681	0.047723025	0.004146408
12.425	0.745000443	0.051018921	0.004393263
10.31	0.167855067	0.053301059	0.004654063
7.293	-0.655429851	0.052082122	0.004917521
8.443	-0.34161558	0.049589509	0.0051717
9.275	-0.114577777	0.048449026	0.005416796
12.999	0.901634697	0.050416668	0.005663961
9.755	0.016405571	0.052711768	0.005921782
9.07	-0.170518582	0.052326486	0.006184377
10.875	0.322033383	0.052705273	0.006446957
12.288	0.707615613	0.055279395	0.006716918
4.847	-1.32289916	0.053741187	0.00698947
7.313	-0.649972211	0.048809008	0.007245845
17.697	2.183634214	0.052643163	0.007499476
6.321	-0.92067113	0.055800571	0.007770585

14.714	1.369627283	0.056922961	0.008052394
5.633	-1.108413928	0.057575995	0.008338641
2.176	-2.051766915	0.049675543	0.00860677
10.168	0.129105827	0.04486889	0.008843131
4.217	-1.494814804	0.041454617	0.00905894
11.134	0.392709814	0.038699355	0.009259325
10.972	0.348502934	0.040552387	0.009457454
11.948	0.614835741	0.042960733	0.009666237
4.031	-1.545570852	0.040633896	0.009875224
14.574	1.331423807	0.040098528	0.010077055
4.599	-1.39057389	0.039950653	0.010277178
9.769	0.020225919	0.036524783	0.010468366
17.761	2.20109866	0.042078094	0.010664873
6.451	-0.885196473	0.04536785	0.010883488
17.167	2.039006767	0.048252376	0.011117539
1.084	-2.349754031	0.047475507	0.011356859
14.938	1.430752846	0.045178004	0.011588492
4.769	-1.344183954	0.045394427	0.011814923
14.071	1.194164174	0.045019377	0.012040958
7.872	-0.497431187	0.04676121	0.012270409
15.176	1.495698755	0.049256879	0.012510455
5.847	-1.050017186	0.050371083	0.012759524
13.193	0.9545738	0.050132474	0.013010783
12.051	0.642942585	0.054126265	0.01327143
14.682	1.36089506	0.059135859	0.013554586
9.578	-0.031894538	0.06245836	0.013858571
1.183	-2.322738715	0.056571777	0.014156146
4.51	-1.414860386	0.04722778	0.014415645
6.671	-0.825162439	0.041627722	0.014637784
14.214	1.233186296	0.042647782	0.014848473
17.122	2.026727078	0.050797566	0.015082086
4.432	-1.43614518	0.05227402	0.015339765
4.426	-1.437782472	0.045089201	0.015583173
4.112	-1.523467412	0.037686076	0.015790111
4.566	-1.399578995	0.03037846	0.015960273
9.503	-0.052360687	0.026748611	0.01610309
4.343	-1.460431676	0.02296663	0.016227379
8.271	-0.388551279	0.018344173	0.016330656
8.242	-0.396464857	0.016381633	0.01641747
9.15	-0.148688024	0.01501875	0.016495971
6.404	-0.898021926	0.012401976	0.016564523
6.552	-0.857635394	0.008012832	0.01661556
12.976	0.895358411	0.00810714	0.01665586

11.337	0.448104855	0.011465798	0.016704792
8.422	-0.347346101	0.011717695	0.016762751
7.977	-0.46877858	0.009677383	0.016816239
7.565	-0.581205953	0.007052422	0.016858063
7.775	-0.523900739	0.004289655	0.016886418
11.75	0.56080511	0.004381916	0.016908097
7.495	-0.600307692	0.00428316	0.01692976
9.929	0.063887035	0.002942108	0.016947823
7.797	-0.517897335	0.001807082	0.016959696
10.933	0.337860537	0.00135699	0.016967606
11.162	0.400350509	0.003202518	0.016979005
8.101	-0.434941215	0.003116041	0.016994801
8.58	-0.304230749	0.001268111	0.017005762
9.17	-0.143230384	0.000149458	0.017009306
9.582	-0.030803011	-0.000285625	0.017008965

Completed @Tue Nov 28 15:43:26 GMT+05:00 2017

Appendix VII: Accelerometer readings for new damper at 1 bar

```
# Accelerometer Data File
# Started @Mon May 07 12:00:06 GMT+05:00 2018
#
#
# sensor Vendor: Invensense
# sensor Name: MPU6500 Acceleration Sensor
# sensor Resolution: 0.0011971008m/sec^2; Max Range: 39.2266; Min Delay: 5000
microseconds
# The sensor's attributes are the result hardware and the Android
capabilities.
# It means that the Android may not utilize all features provided by the
hardware.
#
# Some devices and Android versions save battery too much so the device may
go to sleep.
# It just happens after couple of minutes from turning off the scree and it
is easy to find it out.
#
# The following file provides the data from accelerometer in the m/s^2
format.
# The diff value is just a time delta between the samples
#
#
# data format:
# so we have 4 columns with values separated by the " "
# X Y Z time_from_previous_sample(ms)

# sensor speed set to:NORMAL
# units set to: m/sec^2
# gravity NOT filtered out
# Accuracy: HIGH
```

Data	Acceleration	Velocity	Displacement
9.406	-0.16199664	-0.00162	-1.61997E-05
9.707	0.000137449	0.18951	0.001862701
9.674	-0.01763805	0.38332	0.007591002
9.904	0.106251785	0.5791	0.017215202
9.78	0.039459005	0.77594	0.030765603
9.752	0.024376764	0.97126	0.048237604
9.485	-0.11944317	1.16363	0.069586504
9.712	0.002830706	1.3556	0.094778805
9.394	-0.16846046	1.54666	0.123801406
9.179	-0.28427052	1.73239	0.156591906
9.373	-0.17977214	1.91791	0.193094907
9.56	-0.07904431	2.10724	0.233346408
9.902	0.105174482	2.30186	0.277437408
9.66	-0.02517917	2.49748	0.325430809
9.752	0.024376764	2.6916	0.37732161
9.671	-0.019254	2.88583	0.43309591

9.598	-0.05857556	3.07852	0.492739411
9.69	-0.00901963	3.2714	0.556238612
11.022	0.708464111	3.47852	0.623737812
10.293	0.315787201	3.69167	0.695439713
10.536	0.446679504	3.89996	0.771356014
10.052	0.185972201	4.10584	0.851414014
10.099	0.211288819	4.30735	0.935545915
9.756	0.02653137	4.5059	1.023678416
9.433	-0.14745305	4.69779	1.115715316
9.339	-0.19808629	4.88551	1.211548317
11.493	0.962168945	5.09383	1.311341718
15.258	2.990191669	5.36134	1.415893418
10.845	0.613122803	5.62237	1.525730519
9.12	-0.31605095	5.82202	1.64017442
10.982	0.686918053	6.02304	1.758625021
10.243	0.288854628	6.23529	1.881208321
9.045	-0.35644981	6.42817	2.007842922
9.817	0.059389109	6.61679	2.138292523
10.824	0.601811123	6.8232	2.272692423
9.792	0.045922823	7.02936	2.411218024
8.397	-0.70549596	7.21125	2.553624125
7.74	-1.05938996	7.37262	2.699462825
10.912	0.649212451	7.55914	2.848780426
11.652	1.047814527	7.78478	3.002219627
10.159	0.243607906	8.00289	3.160096327
10.915	0.650828405	8.21363	3.322261528
6.236	-1.86952175	8.38514	3.488249229
9.306	-0.21586178	8.54056	3.657506229
9.879	0.092785499	8.73241	3.83023593
8.878	-0.44640461	8.91998	4.006759831
10.21	0.27107913	9.11086	4.187068231
9.167	-0.29073434	9.30463	4.371223132
9.475	-0.12482969	9.49105	4.559179933
11.261	0.837201808	9.69841	4.751074533
10.776	0.575955853	9.91878	4.947246434
12.41	1.456112329	10.15064	5.147940635
10.828	0.603965729	10.38302	5.353277235
9.428	-0.15014631	10.58558	5.562963236
11.529	0.981560398	10.79515	5.776770537
12.051	1.262736457	11.03095	5.995031537
8.81	-0.48303291	11.23956	6.217736638
12.873	1.705507952	11.45639	6.444696139
9.981	0.147727947	11.68493	6.676109339

11.037	0.716543882	11.89511	6.91190974
10.68	0.524245313	12.11228	7.151983641
9.896	0.101942574	12.31804	7.396286841
9.005	-0.37799587	12.50705	7.644537742
10.65	0.50808577	12.7036	7.896644243
10.177	0.253303632	12.91187	8.152798943
9.324	-0.20616606	13.10688	8.412986444
10.093	0.20805691	13.30105	8.677065745
9.06	-0.34837004	13.49258	8.945002045
10.534	0.445602201	13.68852	9.216813046
9.591	-0.06234612	13.88977	9.492595947
8.052	-0.89133071	14.0662	9.772155647
8.202	-0.81053299	14.22874	10.05510505
9.64	-0.0359522	14.40716	10.34146405
9.348	-0.19323842	14.59704	10.63150605
8.881	-0.44478865	14.77933	10.92526975
10.168	0.248455769	14.96982	11.22276125
9.902	0.105174482	15.17052	11.52416465
10.232	0.282929462	15.37186	11.82958845
8.878	-0.44640461	15.56296	12.13893665
10.016	0.166580748	15.7519	12.45208525
8.355	-0.72811932	15.93561	12.76896035
11.036	0.716005231	16.12952	13.08961165
10.353	0.348106288	16.34341	13.41434096
9.803	0.051847989	16.54497	13.74322476
9.288	-0.22555751	16.73588	14.07603326
11.013	0.703616248	16.93889	14.41278096
9.026	-0.36668419	17.13928	14.75356266
9.742	0.01899025	17.32696	15.09822506
11.337	0.878139319	17.53775	15.44687216
10.684	0.526399919	17.75796	15.79982926
8.401	-0.70334135	17.94881	16.15689696
9.313	-0.21209122	18.12595	16.51764456
10.386	0.365881786	18.32294	16.88213346
11.02	0.707386808	18.537	17.25073286
10.229	0.281313508	18.74949	17.62359776
9.206	-0.26972693	18.94384	18.00053106
9.775	0.036765748	19.13365	18.38130596
8.683	-0.55144164	19.31823	18.76582477
10.517	0.436445127	19.51023	19.15410937
10.481	0.417053674	19.72021	19.54641377
8.738	-0.52181581	19.9124	19.94273987
10.916	0.651367057	20.10894	20.34295327

9.394	-0.16846046	20.31204	20.74716307
10.087	0.204825001	20.50685	21.15535197
9.604	-0.05534365	20.70376	21.56745807
9.554	-0.08227622	20.89534	21.98344907
11.817	1.136692016	21.10905	22.40349297
9.864	0.084705727	21.32586	22.82784207
8.367	-0.7216555	21.50817	23.25618237
7.481	-1.19890069	21.66665	23.68793057
10.071	0.196206578	21.84217	24.12301877
10.235	0.284545417	22.04523	24.56189277
9.901	0.104635831	22.24659	25.00481098
9.988	0.151498507	22.44548	25.45173168
9.534	-0.09304925	22.6407	25.90259348
9.2	-0.27295884	22.82804	26.35728088
9.771	0.034611142	23.01775	26.81573878
9.728	0.01144913	23.21274	27.27804368
9.575	-0.07096454	23.40577	27.74422878
9.514	-0.10382228	23.59666	28.21425308
9.246	-0.24818087	23.78426	28.68806228
8.76	-0.50996548	23.96432	29.16554808
10.315	0.327637533	24.15507	29.64674198
9.646	-0.03272029	24.35468	30.13183948
8.966	-0.39900328	24.5408	30.62079428
9.703	-0.00201716	24.72749	31.11347718
8.941	-0.41246956	24.91393	31.60989139
8.07	-0.88163498	25.08404	32.10987109
13.113	1.8347843	25.29587	32.61367019
9.616	-0.04887983	25.52316	33.12186049
6.684	-1.6282059	25.68616	33.63395369
12.01	1.240651747	25.8731	34.14954629
11.344	0.881909879	26.10664	34.66934369
10.546	0.452066019	26.32554	35.19366549
8.995	-0.38338239	26.52095	35.72213039
9.743	0.019528901	26.70833	36.25442319
11.273	0.843665626	26.91849	36.79069139
9.963	0.138032221	27.13085	37.33118479
10.104	0.213982076	27.33152	37.87580849
9.245	-0.24871952	27.52501	38.42437379
9.568	-0.0747351	27.71314	38.97675529
9.497	-0.11297936	27.90379	39.5329246
10.028	0.173044566	28.09904	40.0929529
11.548	0.991794775	28.3148	40.6570913
6.714	-1.61204635	28.49742	41.2252135

12.3	1.396860669	28.68756	41.7970633
5.063	-2.5013599	28.86119	42.3725508
5.45	-2.29290179	28.96632	42.9508259
13.074	1.813776894	29.15156	43.5320047
9.265	-0.23794649	29.37495	44.1172698
11.639	1.040812058	29.58399	44.7068592
10.08	0.201054441	29.80118	45.3007109
5.826	-2.09036884	29.96024	45.8983251
9.721	0.007678569	30.11571	46.4990846
9.786	0.042690914	30.31078	47.1033495
11.99	1.229878718	30.52854	47.7117427
9.701	-0.00309446	30.74545	48.32448261
6.607	-1.66968206	30.90853	48.94102241
8.128	-0.8503932	31.05588	49.56066651
10.437	0.39335301	31.24153	50.18364061
6.112	-1.93631453	31.40702	50.81012611
6.044	-1.97294283	31.52858	51.43948211
9.983	0.14880525	31.68885	52.07165641
11.251	0.831815294	31.90119	52.70755681
10.05	0.184894898	32.1142	53.34771071
11.626	1.033809589	32.33096	53.99216231
11.631	1.036502846	32.56353	54.64110721
8.695	-0.54497782	32.76679	55.29441041
9.783	0.041074959	32.95157	55.95159401
12.032	1.252502079	33.16972	56.61280691
6.375	-1.79464919	33.35379	57.27804201
8.992	-0.38499834	33.50746	57.94665452
10.923	0.655137617	33.70661	58.61879522
7.229	-1.33464085	33.88813	59.29474262
11.911	1.187325253	34.07953	59.97441922
11.2	0.804344069	34.31064	60.65832092
7.478	-1.20051664	34.49742	61.34640152
11.178	0.792493737	34.68398	62.03821552
6.545	-1.70307845	34.86121	62.73366742
11.104	0.75263353	35.0377	63.43265652
5.943	-2.02734662	35.20817	64.13511522
6.566	-1.69176677	35.33326	64.84052952
10.809	0.593731351	35.50701	65.54893222
12.228	1.358077764	35.73738	66.26137612
9.069	-0.34352218	35.95035	66.97825342
10.295	0.316864504	36.14399	67.69919682
5.368	-2.33707121	36.30062	68.42364293
6.169	-1.90561139	36.41599	69.15080903

8.979	-0.39200081	36.56747	69.88064363
13.593	2.093336998	36.79319	70.61425023
11.18	0.79357104	37.04092	71.35259133
8.961	-0.40169654	37.24233	72.09542383
10.287	0.312555292	37.43481	72.84219523
11.961	1.214257826	37.65729	73.59311623
9.041	-0.35860442	37.86731	74.34836223
13.165	1.862794176	38.08937	75.10792903
10.432	0.390659753	38.32534	75.87207613
12.666	1.594007101	38.55632	76.64089273
12.18	1.332222494	38.80478	77.41450373
12.465	1.485738158	39.05123	78.19306383
11.063	0.73054882	39.28651	78.97644123
10.174	0.251687678	39.49888	79.76429514
8.439	-0.68287259	39.68501	80.55613404
6.852	-1.53771245	39.83792	81.35136334
11.081	0.740244546	40.01725	82.14991504
5.05	-2.50836237	40.17856	82.95187314
8.418	-0.69418427	40.31324	83.75679114
7.376	-1.25545909	40.47118	84.56463534
11.253	0.832892597	40.65747	85.37592184
8.052	-0.89133071	40.85052	86.19100174
8.457	-0.67317687	41.01561	87.00966304
11.803	1.129150896	41.21821	87.83200124
12.152	1.317140253	41.45776	88.65876094
11.214	0.81188519	41.69142	89.49025274
9.418	-0.15553282	41.89774	90.32614434
9.023	-0.36830015	42.08215	91.16594324
9.812	0.056695852	42.2705	92.00946975
10.086	0.20428635	42.46948	92.85686955
11.137	0.770409028	42.68171	93.70838145
7.36	-1.26407751	42.86668	94.56386535
11.083	0.741321849	43.05111	95.42304325
2.309	-3.98480601	43.18503	96.28540465
-3.011	-6.85043174	43.17801	97.14903505
19.567	5.311240783	43.34357	98.01425085
11.273	0.843665626	43.65197	98.88420625
8.173	-0.82615388	43.84643	99.75919025
9.398	-0.16630585	44.02214	100.637876
8.1	-0.86547544	44.19712	101.5200686
10.626	0.495158135	44.38438	102.4058836
6.758	-1.58834569	44.55822	103.2953096
5.918	-2.04081291	44.68498	104.1877416

7.521	-1.17735463	44.81937	105.0827851
8.231	-0.7949121	44.97689	105.9807477
12.691	1.607473387	45.18611	106.8823777
7.517	-1.17950923	45.38819	107.7881207
5.972	-2.01172573	45.52308	108.6972334
10.976	0.683686144	45.69256	109.6093898
9.527	-0.09681981	45.89759	110.5252913
9.707	0.000137449	46.08993	111.4451665
8.724	-0.52935693	46.27424	112.3688082
9.441	-0.14314384	46.45589	113.2961095
10.676	0.522090708	46.65706	114.227239
13.511	2.049167579	46.89893	115.1627989
8.057	-0.88863745	47.11461	116.1029343
9.885	0.096017408	47.29403	117.0470207
10.888	0.636284816	47.50176	117.9949786
10.467	0.409512554	47.71531	118.9471493
11.055	0.726239609	47.93053	119.9036077
8.74	-0.52073851	48.12848	120.8641978
10.238	0.286161371	48.31826	121.8286652
9.186	-0.28049996	48.5125	122.7969728
9.877	0.091708196	48.70313	123.7691291
9.783	0.041074959	48.89973	124.7451577
10.066	0.193513321	49.09822	125.7251372
8.444	-0.68017934	49.28332	126.7089526
10.599	0.480614546	49.47375	127.6965233
10.314	0.327098881	49.68288	128.6880896
8.677	-0.55467355	49.87279	129.6836463
8.257	-0.78090716	50.04213	130.6827955
10.413	0.380425375	50.22883	131.6855051
10.115	0.219907242	50.43411	132.6921345
9.873	0.08955359	50.63399	133.7028155
10.419	0.383657284	50.83691	134.7175245
9.764	0.030840582	51.03874	135.736281
9.543	-0.08820139	51.23181	136.7589865
9.939	0.125104586	51.42663	137.7855709
10.66	0.513472284	51.63262	138.8161634
10.146	0.236605437	51.84068	139.8508964
10.075	0.198361184	52.04289	140.8897321
10.008	0.162271537	52.24372	141.9325982
9.736	0.015758341	52.44116	142.979447
11.077	0.738089941	52.64929	144.0303515
8.95	-0.4076217	52.84956	145.08534
9.622	-0.04564792	53.03528	146.1441884

9.521	-0.10005172	53.22671	147.2068083
10.198	0.264615313	53.4239	148.2733144
10.05	0.184894898	53.62638	149.3438172
9.405	-0.16253529	53.82093	150.4182903
10.081	0.201593093	54.01579	151.4966575
9.732	0.013603735	54.21392	152.5789546
8.649	-0.56975579	54.39773	153.6650711
10.143	0.234989483	54.58565	154.7549049
9.297	-0.22070965	54.78005	155.8485619
9.933	0.121872678	54.97235	156.9460859
9.369	-0.18192674	55.16537	158.0474631
8.796	-0.49057403	55.34702	159.152587
8.486	-0.65755598	55.51984	160.2612556
9.824	0.063159669	55.70294	161.3734834
10.34	0.341103819	55.90458	162.4895586
9.773	0.035688445	56.10571	163.6096615

Completed @Mon May 07 12:03:29 GMT+05:00 2018

Appendix VIII: Accelerometer readings for new damper at 2 bar

```
# Accelerometer Data File
# Started @Mon May 07 12:54:27 GMT+05:00 2018
#
#
# sensor Vendor: Invensense
# sensor Name: MPU6500 Acceleration Sensor
# sensor Resolution: 0.0011971008m/sec^2; Max Range: 39.2266; Min Delay: 5000
microseconds
# The sensor's attributes are the result hardware and the Android
capabilities.
# It means that the Android may not utilize all features provided by the
hardware.
#
# Some devices and Android versions save battery too much so the device may
go to sleep.
# It just happens after couple of minutes from turning off the scree and it
is easy to find it out.
#
# The following file provides the data from accelerometer in the m/s^2
format.
# The diff value is just a time delta between the samples
#
#
# data format:
# so we have 4 columns with values separated by the " "
# X Y Z time_from_previous_sample(ms)

# sensor speed set to:NORMAL
# units set to: m/sec^2
# gravity NOT filtered out
# Accuracy: HIGH
```

Data	Acceleration	Velocity	Displacement
6.684	-1.06201395	0.002389	5.97246E-06
12.01	0.955594003	0.002123	1.72523E-05
11.344	0.703298303	0.00627	3.8235E-05
10.546	0.40099805	0.009031	7.64877E-05
8.995	-0.18655545	0.009567	0.000122982
9.743	0.096803686	0.009343	0.000170257
11.273	0.676401915	0.011276	0.000221802
9.963	0.180144608	0.013417	0.000283534
10.104	0.233558562	0.014451	0.000353205
9.245	-0.09184986	0.014806	0.000426347
9.568	0.030509771	0.014652	0.000499991
9.497	0.003613383	0.014738	0.000573465
10.028	0.204768062	0.015258	0.000648455
11.548	0.780578067	0.017722	0.000730906
6.714	-1.05064928	0.017047	0.000817827
12.3	1.06545249	0.017084	0.000903153

5.063	-1.67608501	0.015557	0.000984755
5.45	-1.52948076	0.007543	0.001042505
13.074	1.358661006	0.007116	0.001079153
9.265	-0.08427341	0.010302	0.001122699
11.639	0.815050903	0.012129	0.001178776
10.08	0.224466825	0.014728	0.001245919
5.826	-1.38704354	0.011821	0.001312292
9.721	0.088469594	0.008575	0.001363282
9.786	0.113093048	0.009079	0.001407417
11.99	0.948017555	0.011732	0.001459443
9.701	0.080893146	0.014304	0.001524532
6.607	-1.09118327	0.011778	0.001589737
8.128	-0.51499444	0.007763	0.001638589
10.437	0.359706412	0.007375	0.001676432
6.112	-1.27870035	0.005077	0.001707561
6.044	-1.30446027	-0.00138	0.001716801
9.983	0.187721055	-0.00417	0.001702917
11.251	0.668067822	-0.00203	0.001687402
10.05	0.213102154	0.00017	0.001682743
11.626	0.810126212	0.002728	0.001689987
11.631	0.812020324	0.006783	0.001713764
8.695	-0.30020216	0.008063	0.001750878
9.783	0.111956581	0.007592	0.001790015
12.032	0.963928095	0.010282	0.0018347
6.375	-1.17907006	0.009744	0.001884764
8.992	-0.18769192	0.006327	0.001924941
10.923	0.543814085	0.007217	0.001958802
7.229	-0.85555576	0.006438	0.00199294
11.911	0.918090588	0.006594	0.00202552
11.2	0.648747882	0.010511	0.002068284
7.478	-0.76122899	0.01023	0.002120138
11.178	0.640413789	0.009928	0.002170534
6.545	-1.11467026	0.008742	0.002217211
11.104	0.612380934	0.007487	0.002257784
5.943	-1.34272133	0.005661	0.002290653
6.566	-1.10671499	-0.00046	0.002303649
10.809	0.500628334	-0.00198	0.002297547
12.228	1.03817728	0.001869	0.002297275
9.069	-0.15852259	0.004068	0.002312119
10.295	0.305913635	0.004437	0.002333381
5.368	-1.56054419	0.0013	0.002347723
6.169	-1.25710747	-0.00574	0.002336614
8.979	-0.19261661	-0.00937	0.002298833

13.593	1.555269817	-0.00596	0.002260508
11.18	0.641171434	-0.00047	0.002244428
8.961	-0.19943541	0.000634	0.002244836
10.287	0.302883056	0.000892	0.002248652
11.961	0.937031706	0.003992	0.002260863
9.041	-0.16912962	0.005912	0.002285624
13.165	1.393133842	0.008972	0.002322834
10.432	0.3578123	0.013349	0.002378637
12.666	1.204101478	0.017254	0.002455145
12.18	1.019993806	0.022814	0.002555317
12.465	1.127958182	0.028184	0.002682813
11.063	0.596849217	0.032496	0.002834514
10.174	0.260076128	0.034639	0.003002351
8.439	-0.39718069	0.034296	0.003174687
6.852	-0.99837179	0.030807	0.003337444
11.081	0.603668019	0.02982	0.003489012
5.05	-1.6810097	0.027127	0.003631379
8.418	-0.40513596	0.021911	0.003753975
7.376	-0.79986887	0.018899	0.003856001
11.253	0.668825467	0.018571	0.003949677
8.052	-0.54378494	0.018884	0.004043315
8.457	-0.39036188	0.016549	0.004131896
11.803	0.877177772	0.017766	0.004217682
12.152	1.009386779	0.022482	0.004318301
11.214	0.654051395	0.026641	0.004441107
9.418	-0.02631358	0.02821	0.004578234
9.023	-0.17594842	0.027704	0.004718019
9.812	0.12294243	0.027572	0.004856209
10.086	0.22673976	0.028446	0.004996254
11.137	0.624882072	0.030575	0.005143806
7.36	-0.80593003	0.030122	0.00529555
11.083	0.604425664	0.029619	0.005444903
2.309	-2.71936182	0.024331	0.005579778
-3.011	-4.73469684	0.005696	0.005654847
19.567	3.818354665	0.003405	0.0056776
11.273	0.676401915	0.014642	0.005722719
8.173	-0.49794744	0.015088	0.005797046
9.398	-0.03389003	0.013759	0.005869163
8.1	-0.52560147	0.01236	0.00593446
10.626	0.43130384	0.012124	0.005995671
6.758	-1.03398109	0.010618	0.006052526
5.918	-1.35219189	0.004652	0.0060907
7.521	-0.74493962	-0.00059	0.006100854

8.231	-0.47597574	-0.00364	0.00609027
12.691	1.213572038	-0.0018	0.006076665
7.517	-0.74645491	-0.00063	0.00607059
5.972	-1.33173548	-0.00583	0.006054445
10.976	0.56389167	-0.00775	0.006020513
9.527	0.014978054	-0.0063	0.005985399
9.707	0.083166081	-0.00605	0.005954517
8.724	-0.28921631	-0.00657	0.005922961
9.441	-0.01760067	-0.00734	0.005888199
10.676	0.450244959	-0.00625	0.005854223
13.511	1.524206382	-0.00132	0.005835292
8.057	-0.54189083	0.001138	0.005834841
9.885	0.150596463	0.000159	0.005838084
10.888	0.530555302	0.001862	0.005843138
10.467	0.371071083	0.004116	0.005858084

Completed @Mon May 07 12:56:02 GMT+05:00 2018

Appendix IX: Accelerometer readings for new damper at 5 bar

```
# Accelerometer Data File
# Started @Fri May 11 10:20:20 GMT+05:00 2018
#
#
# sensor Vendor: Invensense
# sensor Name: MPU6500 Acceleration Sensor
# sensor Resolution: 0.0011971008m/sec^2; Max Range: 39.2266; Min Delay: 5000
microseconds
# The sensor's attributes are the result hardware and the Android
capabilities.
# It means that the Android may not utilize all features provided by the
hardware.
#
# Some devices and Android versions save battery too much so the device may
go to sleep.
# It just happens after couple of minutes from turning off the scree and it
is easy to find it out.
#
# The following file provides the data from accelerometer in the m/s^2
format.
# The diff value is just a time delta between the samples
#
#
# data format:
# so we have 4 columns with values separated by the " "
# X Y Z time_from_previous_sample(ms)

# sensor speed set to:NORMAL
# units set to: m/sec^2
# gravity NOT filtered out
# Accuracy: HIGH
```

Data	Acceleration	Velocity	Displacement
12.247	1.949420905	0.004873552	1.21839E-05
11.481	1.384292957	0.013207837	5.73874E-05
10.36	0.557258455	0.018061715	0.000135561
10.335	0.538814331	0.020801897	0.00023272
9.603	-0.001229608	0.022145859	0.00034009
8.455	-0.848183764	0.020022326	0.00044551
9.21	-0.291171231	0.017173938	0.000538501

9.414	-0.140667183	0.016094342	0.000621671
10.097	0.363226274	0.01665074	0.000703534
9.726	0.08951548	0.017782594	0.000789618
9.455	-0.11041882	0.017730336	0.0008784
9.673	0.050413938	0.017580324	0.000966676
9.588	-0.012296082	0.017675618	0.001054816
8.993	-0.451266224	0.016516713	0.001140297
9.425	-0.132551768	0.015057168	0.001219232
9.414	-0.140667183	0.01437412	0.00129281
9.909	0.224526465	0.014583769	0.001365205
9.425	-0.132551768	0.014813705	0.001438699
8.91	-0.512500715	0.013201074	0.001508735
9.551	-0.039593385	0.011820839	0.00157129
9.606	0.000983687	0.011724315	0.001630153
9.991	0.28502319	0.012439332	0.001690562
9.797	0.141896791	0.013506632	0.001755427
9.92	0.232641879	0.014442978	0.001825301
9.627	0.01647675	0.015065775	0.001899073
9.265	-0.250594159	0.014480481	0.001972939
9.744	0.102795249	0.014110984	0.002044417
9.361	-0.179768725	0.01391855	0.002114491
9.106	-0.367898786	0.012549382	0.002180661

9.446	-0.117058705	0.011336988	0.002240377
10.121	0.380932633	0.011996673	0.002298711
10.171	0.41782088	0.013993557	0.002363687
9.02	-0.431346571	0.013959742	0.00243357
8.959	-0.476350232	0.0116905	0.002497696
9.642	0.027543225	0.010568483	0.002553343
9.097	-0.37453867	0.009700994	0.002604017
9.187	-0.308139825	0.007994298	0.002648255
9.434	-0.125911884	0.006909169	0.002685514
9.416	-0.139191653	0.00624641	0.002718403
9.291	-0.231412271	0.0053199	0.002747318
9.029	-0.424706686	0.003679603	0.002769817
9.815	0.15517656	0.003005777	0.002786531
9.963	0.264365772	0.004054633	0.002804182
9.73	0.09246654	0.004946714	0.002826685
9.373	-0.170915545	0.004750591	0.002850928
9.342	-0.193786259	0.003838837	0.002872402
9.174	-0.317730769	0.002560044	0.002888399
9.646	0.030494284	0.001841953	0.002899404
10.126	0.384621458	0.002879742	0.002911208
9.368	-0.17460437	0.003404785	0.002926919
8.415	-0.877694362	0.000774038	0.002937367

9.888	0.209033401	-0.000897614	0.002937058
9.804	0.147061146	-7.37765E-06	0.002934795
8.789	-0.601770273	-0.00114415	0.002931916
9.648	0.031969814	-0.002568652	0.002922634
9.745	0.103533014	-0.002229895	0.002910638
9.077	-0.389293969	-0.002944297	0.002897702
8.95	-0.482990117	-0.005125007	0.002877529
8.831	-0.570784145	-0.007759443	0.002845318
9.877	0.200917987	-0.008684108	0.002804209
9.405	-0.147307067	-0.008550081	0.002761124
9.075	-0.390769499	-0.009895272	0.00271501
9.853	0.183211628	-0.010414167	0.002664237
9.714	0.080662301	-0.009754482	0.002613815
9.269	-0.2476431	-0.010171934	0.002563999
9.837	0.171407389	-0.010362523	0.002512663
9.691	0.063693707	-0.009774771	0.00246232
9.229	-0.004526104	-0.009626852	0.002413816
9.278	-0.241003215	-0.010240675	0.002364147
8.508	-0.809082222	-0.012865889	0.00230638
8.623	-0.724239254	-0.016699192	0.002232468
8.971	-0.467497053	-0.019678533	0.002141523
7.316	-1.688498036	-0.025068521	0.002029656

8.704	-0.664480293	-0.030950967	0.001889607
10.436	0.61332859	-0.031078846	0.001734533
12.215	1.925812426	-0.024730993	0.001595008
9.781	0.130092552	-0.019591231	0.001484202
9.917	0.230428584	-0.018689928	0.001388499
8.256	-0.994998988	-0.020601354	0.001290271
8.305	-0.958848506	-0.025485973	0.001175053
10.552	0.698909324	-0.026135821	0.001045998
12.253	1.953847494	-0.019503929	0.000931899
11.702	1.54733901	-0.010750962	0.000856262
8.221	-1.020820761	-0.009434667	0.000805798
9.823	0.16107868	-0.011584022	0.000753251
10.107	0.370603924	-0.010254815	0.000698654
10.289	0.504877144	-0.008066113	0.000652852
8.947	-0.485203412	-0.008016928	0.000612644
9.585	-0.014509377	-0.00926621	0.000569436
9.054	-0.406262563	-0.01031814	0.000520475
10.222	0.455446892	-0.010195179	0.000469192
9.484	-0.089023637	-0.009279121	0.000420506
8.75	-0.630543106	-0.011078038	0.000369613
10.924	0.973357883	-0.010221001	0.000316366
9.196	-0.301499941	-0.008541356	0.00026946

13.569	2.924746161	-0.001983241	0.000243148
11.587	1.462496041	0.008984865	0.000260652
12.032	1.790801442	0.017118108	0.00032591
9.139	-0.343552542	0.020736231	0.000420546
8.76	-0.623165456	0.018319436	0.000518185
7.827	-1.311500149	0.013482772	0.00059769
8.243	-1.004589933	0.007692546	0.000650629
7.207	-1.768914415	0.000758786	0.000671757
7.848	-1.296007086	-0.006903518	0.000656395
11.246	1.210918195	-0.00711624	0.000621346
10.972	1.008770601	-0.001567018	0.000599638
16.818	5.321744465	0.014259269	0.000631368
11.101	1.103942278	0.030323486	0.000742825
6.72	-2.128205943	0.027762827	0.000888041
9.029	-0.424706686	0.021380545	0.001010899
7.28	-1.715057574	0.016031135	0.001104429
11.07	1.081071565	0.01444617	0.001180622
12.342	2.019508574	0.02219762	0.001272231
10.469	0.637674834	0.028840579	0.001399827
6.161	-2.540616547	0.024083224	0.001532136
7.375	-1.644969904	0.013619258	0.001626393
10.942	0.986637652	0.011973427	0.001690374

8.391	-0.895400721	0.01220152	0.001750812
9.787	0.134519142	0.010299316	0.001807064
10.502	0.662021077	0.012290666	0.001863539
8.313	-0.952946386	0.011563353	0.001923174
6.72	-2.128205943	0.003860472	0.001961733
9.012	-0.43724869	-0.002553164	0.001965002
8.798	-0.595130388	-0.005134112	0.001945783
13.417	2.812605889	0.000409577	0.001933972
10.714	0.818427245	0.00948716	0.001958714
8.919	-0.50586083	0.010268576	0.002008103
8.477	-0.831952936	0.006924041	0.002051085
8.661	0.696204186	0.003103648	0.002076154

Completed @Fri May 11 10:21:22 GMT+05:00 2018