

Showa Shock Absorber Investigation.

Figure 1, Suspension Dynamometer Testing

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Showa Shock Absorber Investigation.

Declaration of Authenticity

"This thesis is the result of the author's original research. It has been composed by the author and has not been previously submitted for examination which has led to the award of a degree."

Signed:

Date:

Showa Shock Absorber Investigation.

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Showa Shock Absorber Investigation.

1. Abstract.

This is to be a shock absorber comparison project to investigate Showa Corporations' claim of a major upgrade between of the rear shock absorber between model years of the same motorcycle. The vehicle is a Honda CBR1000RR which between the model years of 2011 and 2013 received a claimed substantial upgrade to its rear shock absorber. The 2011 model uses a conventional monotube design with adjustable rebound and compression damping. The 2013 model with the redesigned rear shock uses twin tube technology, again rebound and compression are adjustable. Twin tube technology isn't new as these are common within the car industry, but does the shock does feature "Balance Free" technology. The meaning and effect of this is to be investigated within this report. This is claimed to be a first on a production motorcycle. It is thought within the industry that this is very similar to Ohlins TTX technology. The first comparison is to be made by way of stripping both shocks, taking many pictures and many measurements followed by a service and rebuild prior to dynamometer testing. Shim stack placement and design are very different between the two shocks so this will be fully documented along with piston and orifice size and design. The compression and rebound adjustment will be investigated for range, quality and complexity and then displayed by means of graphs produced in Excel from raw dyno data. The suspension fluid will be constant between shock absorbers and the characteristics of the fluid discussed.

The next stage will be to carry out numerous dynamometer test with temperature measuring equipment to observe the effect of increasing temperatures, increasing pressures and the work done/temperature/viscosity relationships investigated. This will be recorded by the dynamometer software and exported into Excel for analysis.

Analytical methods will be used as taught in Dynamics and Science lectures.

Showa Shock Absorber Investigation.

2. Aims and objectives.

The aims and objectives of this shock absorber investigation are to fully examine the workings and theory of two different designs of shock absorber from the same manufacturer designed for use on the same vehicle, the model year of the vehicle being the only separator. The physical parameters of the shock absorbers will be measured and compared to the theory of operation of the fundamentally different designs. The shock absorbers are to be rebuilt with new seals and filled using the same suspension fluid to give a stable and consistent base for comparison. The shock absorbers will then be tested on a suspension dynamometer to examine the damping characteristics of both designs to scientifically evaluate, the advantages and disadvantages of each design. The shocks will have the damping adjusters compared in terms of operation with regards to both range and quality of adjustment allowed. The pressure is to be adjusted internally by way of adjusting the Nitrogen pressure within the rubber bladders contained in the shock absorber reservoirs. The temperatures will be monitored to allow calculation of heat energy transfers and losses to both the oil from the work done and from the shock absorber body to the air. The effect of temperature change will be examined and its effect on the density and viscosity of the suspension fluid investigated. From this a conclusion will be drawn as to the more superior design and as to whether the manufacturer claim was correct. Experience and knowledge are also an aim of this project with regards to operating previously unused equipment and the field of fluid dynamics. Damping is often referred to within the industry as v^2 damping, the meaning of this is to be investigated.

Showa Shock Absorber Investigation.

3. Introduction to equipment used.

The Showa shock absorbers used in this investigation were taken from a Honda Fireblade CBR1000rr model years 2011 and 2013. Figure 2 and 3 show the 2011 and the 2013 shock absorbers respectively. Both were purchased from EBay so the past use was unknown, hence the need to strip and recondition both units before any testing was to be carried out. Figure 4 shows a Honda press release highlighting the oil flow differences between the two shock absorbers, this however neglects to include any shim stack detail and is inaccurate in terms of oil path, this will be discussed further with help from more accurate diagrams.

Figure 2, 2011 Shock

Figure 3, 2013 Shock

Figure 4, Honda press release,
www.hondaprokevin.com [Accessed 2017]

Race Tech's *Motorcycle Suspension Bible* contains very well illustrated examples of most current shock absorbers and offers a much more concise visual representation of the workings of the two shock absorbers. These can be seen in figures 5-8 on the following pages.

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3.0 Introduction to equipment used.

In the 2011 shock absorber the oil pathway can be seen between the top adjuster which is the compression adjustment screw. However, the rebound oil route is not highlighted in figure 5, figure 6 is a close-up of the piston assembly which allows the low-speed rebound damping adjuster needle to be seen which obstructs the low-speed rebound adjuster inlet port as well as the adjuster seat. The height of this needle is adjusted by the rebound adjuster screw at the base of the shock absorber. In operation, there is a pressure difference either side of the piston assembly which is relieved by the shims lifting to allow oil to pass by.

Figure 5, 2011 shock absorber representation, Figure 6, 2011 piston assembly, (Thede and Parks, 2010)
(Thede and Parks, 2010)

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3.0 Introduction to equipment used.

The 2013 shock absorber, Figure 7, has a far more complex design with dedicated rebound and compression pistons complete with their own shim stack assemblies as seen in figure 8. The adjuster screws are both located on top of the unit and the piston on the damper rod is solid. There is however a small bleed hole in the solid piston, this may be to overcome rapid pressure rises at high piston velocities. This can be seen at the bottom of the piston in Figure 9.

Figure 7, 2013 shock absorber representation,
(Thede and Parks, 2010)

Figure 8, 2013 shock shim stack assemblies,
(Thede and Parks, 2010)

Figure 9, 2013 damper rod solid piston with small bleed hole

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3. Introduction to equipment used.

The shock absorber was the only difference between the model years, the same linkage was used so no compensation needed to be allowed for different linkage ratios. A Honda dealers' website was utilised to research part numbers between the model years to conform this.

Figures 10-13 show the parts diagrams and part number listing showing identical part numbers for the linkage plates and connecting rods. This means that any differences between the shock absorbers and the way it affects the handling of the motorcycle is purely down to the design of the shock absorber and not any differences in the link ratio.

Figures 10-13 showing identical part numbers for linkage systems between 2011 and 2013 shock absorbers.

Figure 10, 2011 parts diagram,
www.lingshondaparts.com [Accessed 2016]

Figure 11, 2013 parts diagram,
www.lingshondaparts.com [Accessed 2016]

Figure 12, 2011 parts list,
www.lingshondaparts.com [Accessed 2016]

Figure 13, 2013 parts list,
www.lingshondaparts.com [Accessed 2016]

Showa Shock Absorber Investigation.

3. Introduction to equipment used.

Figure 14, 2011 shock absorber dismantled for service

Figure 15, 2013 shock absorber partially dismantled for service

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3. Introduction to equipment used.

Figure 14 and 15 show the shock absorbers dismantled for servicing prior to testing. Figure 15 shows the inner most tube of the twin tube design along with the yet to be dismantled shim stack. The piston and shim stack assemblies before and after disassembly are shown in figures 16 and 17. The number of shims required a work area all of its own! All shims were measured and listed in Excel for future reference. Figure 18 shows the seal head service kits purchased from Reactive Suspension.

Figure 16, shim stack assembly

Figure 17, shim stack disassembled

Figure 18, seal head service kits

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3. Introduction to equipment used.

Figure 19 is a screen shot of the shim measurements made using Vernier calipers and micrometres.

Figure 19, screen shot of shim dimensions

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3. Introduction to equipment used.

New shaft seals and bushes were installed prior to reassembly, both shocks were refilled with Silkolene RSF 7.5 suspension fluid at the recommendation from Gareth Evans from Reactive suspension, who also supplied the suspension rebuild kits. Also, supplied by Reactive suspension was a Nitrogen needle (Figure 20) and pressure data to enable re-pressurisation of the shock absorbers. A Nitrogen bottle complete with a specific to suspension recharging gun was utilised. Figure 21 shows this in action recharging the 2011 shock absorber after rebuilding.

Figure 20, Nitrogen needle

Figure 21, Nitrogen gun with needle attached

The Nitrogen pressures as recommended by Gareth at Reactive suspension are 10 Bar for the 2011 shock absorber and 6 Bar for the 2013 shock absorber.

Showa Shock Absorber Investigation.

3. Introduction to equipment used.

The most expensive and elaborate piece of equipment used was a 3D scanner utilising X-rays that was made available for use in this project very kindly by Grainger & Worrall LTD. This was made possible by fellow student, Juan Vacas, who at the time of writing is undertaking a year in industry at Grainger & Worrall. Figure 22 shows a screenshot of the website that the supplying company, Yxlon, posts on the internet. This scanner was used to give point cloud data of the dimensions of the shock absorber bodies both internally and externally. This would allow the surface areas and volumes of the shock absorbers to be used in calculations such as heat transfer where inner and outer surface areas were needed. Also, the scans, once interoperated with appropriate software gave very insightful images of the usually unseen oilways and internal features of the shock absorbers cast aluminium bodies.

Figure 22, Screenshot of Yxlon website,
<http://www.yxlon.com/products/x-ray-and-ct-inspection-systems> [Accessed 2016]

Showa Shock Absorber Investigation.

3. Introduction to equipment used.

The shock absorber body can be seen in figure 23 just before scanning is commenced and figure 24 shows the shock absorber body mid-scan. Figures 25-28 show the scan data represented in solid using a software package manufactured by a company called GOM and offered free as a download.

Figure 23, shock body awaiting scan Figure 24, shock body mid-scan

Figure 25, 2011 Ext

Figure 26, 2011 Int

Figure 27, 2013 External

Figure 28, 2013 Internal

Showa Shock Absorber Investigation.

3. Introduction to equipment used.

Software supplied as a free download can be used to manipulate the data produced by the X-ray scanning device. This is supplied by GOM and can be found at website address:

<http://www.gom.com/3d-software/open-data-formats.html>

This software is called GOM Inspect and allows accurate measurements to be made of components in terms of volumes and area. It also allows parts to be “cut up” into sections and the missing ends meshed over. This can allow measurement of oil ways on their own for example. This can be refined on an element by element process to allow the finished result to have nicely contoured features resembling that before the cut was made. Figures 29 and 30 are screen shots of this software in use.

Figure 29, screen shot of GOM software in use to measure volume of 2013 shock interior

Figure 30, screen shot of extracted oilway re-meshed to measure volume

Showa Shock Absorber Investigation.

3. Introduction to equipment used.

In order to verify that the GOM software was indeed measuring the correct volume for the inside of the shock absorber bodies, a simple experiment was carried out. The open orifices of the shock bodies were sealed the shock bodies immersed into water until no air bubbles emerged. The water was decanted into a container and measured with a beaker for the main part and the last amounts not a full to a measuring line in the beaker measured though a biuret. The results of this experiment can be seen in figure 31.

Figure 31, real world measurements verifying computer analysis

This simple experiment meant that any measurements taken from the GOM software could be considered as true and accurate. To then obtain the correct oil volumes of the shock absorbers, the internal components are used to offset a known volume of water and the volume of the components then calculated.

Showa Shock Absorber Investigation.

3. Introduction to equipment used.

SPA Suspension Dynamometer, seen in Figure 32.

Figure 32, SPA BTP4000 Dynamometer,

<http://www.spa-uk.co.uk/dynamometers/btp4000/> [Accessed 2016]

Figure 33, 2011 shock absorber

The SPA BTP4000 dynamometer utilises 2.2Kw electric motor to turn a crankshaft which operates a shaft which can be attached by a clevis to part of the suspension system to be tested. The other end of the suspension component is attached by another clevis to the height adjustable platform which also contains the force transducer. There is a temperature sensor which is attached by means of a Velcro strap. There are high resolution velocity and displacement transducers fitted to the shaft drive. The force, displacement and velocity are logged using the supplied software onto a computer and graphically represented in many user selectable forms. The clevis attachments as supplied with the dynamometer are limited to the number of suspension systems that they can fit. This necessitates the need to produce bespoke clevis systems for the particular shock absorber or fork that is being tested. These are produced from solid aluminium billet within the University from student supplied engineering drawings. There are many that have been previously produced, 2 of which fitted the needs of the shock absorbers to be tested perfectly, saving hours of time. Figure 33 shows the 2011 shock absorber installed in the dynamometer with the aluminium clevis systems in place.

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3. Introduction to equipment used.

The dynamometer has an adjustable stroke which is adjusted by moving an offset adjustable wheel on the end of the crank. Great care must be taken to ensure the stroke is set correctly to match the stroke capabilities of the test sample to avoid damage to both the dynamometer and the test sample. This adjustment must only be carried out by a trained technician as severe damage can occur from incorrect adjustment. The mechanism is shown in figure 34.

Figure 34, stroke adjustment

Visible in figure 34 are the controls located on the top panel, this can switch between user selectable stroke speed control and computer controlled. The speed is adjustable in manual mode, this is most useful for testing that the stroke is set in the correct part of the shock absorber of forks working range. When the correct stroke range is assured, the test set up can commence using the supplied software. There are two main methods of testing, single speed and multiple speed. The single speed allows the user to select the frequency that the test sample will be driven at. These are in 1Hz steps. This can be set to run continuously and can be useful for running in shock absorbers or monitoring temperatures over a set amount of time to compare changes such as different oil viscosities. The other test used is that of multiple speed. The setting recommended by technician John Kinsella and also the setting used by most students is that of between 1 and 3Hz. The dynamometer starts sampling at 1Hz and increase in 0.25 increments up to 3Hz. This allows the production of the average Force/Veloccity graphs, which are useful as a quick comparison between setting changes of the sample or for comparing batches to match where multiple dampers are used such as in car use or twin shocks on the rear of some motorcycles. There are many options to produce graphs for comparison between dampers dependent upon the characteristics that are being compared.

Showa Shock Absorber Investigation.

3. Introduction to equipment used.

Two samples of graphs produced by the dynamometer software can be seen in figures 35 and 36. Figure 35 is the Force/Velocity graph as previously discussed, figure 36 is a Force/Displacement graph. Both graphs show the result of adjusting the rebound and compression adjusters on the shock absorber. The compression damping is observed in the upper portions of the graphs and rebound in the lower. Another useful feature of the Force/Velocity graph is to show the transition from low speed to high speed damping. Low speed damping is orifice damping and is controlled by the damping adjusters, high speed damping is controlled by the number and thickness of shims and the piston hole dimensions which they cover. The transition point is referred to as the "Knee", and the piston velocity at which that occurs is referred to as the "Knee Speed".

Figure 35, Force/Velocity graph

Figure 36, Force/Displacement graph

Figure 37, knee speed highlighted,
<http://www.kaztechnologies.com> [Accessed 2016]

Figure 38, Force/Displacement explained
<http://farnorthracing.com> [Accessed 2016]

Showa Shock Absorber Investigation.

3. Introduction to equipment used.

Figure 37 shows a graph with the compression and rebound knees highlighted. Figure 38 helps to explain the Force/Displacement graph in terms of the actions of the shims in the shim stack. This is often referred to as the (Rugby) “Football Graph”.

The graphs produced by the software are sufficient for comparisons between shock absorbers and the difference between adjustments, both from the adjusters or different oil levels, viscosities or shim stack changes. To be able to isolate part of the graphs or to apply trendlines or polynomial equations to lines for further processing, the graphs need to be reproduced in a mathematical program such as Excel. No mention of the export of data is mentioned in the dynamometer user manual so it was found by means of experience, trial and error. There is a data section in the graph tab in the software which displays the raw data from each suspension run, the data was highlighted column by column holding down the shift key then copied using control C and pasted into notepad using control P. This is demonstrated in Figure 39. The data is then copied into Excel in a similar manner and the result seen in Figure 40. The export was carried out like this initially everytime as this was a successful method when dealing with data export when using Ansys CFD software. It was found however that the notepad stage could be negated, saving time and possible data corruption from program to program.

Figure 39, notepad data

Figure 40, raw dynamometer data exported into Excel

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3. Introduction to equipment used.

The data as exported into Excel cannot be utilised in this format as there are a mixture of letters and numbers in the cells which prevent calculations taking place, Figure 41.

3	0.000000 s	156.48 N	-12.44 mm	-42.55 mm/s
4	0.003331 s	81.48 N	-12.47 mm	-30.58 mm/s

Figure 41, Excel data containing both numbers and letters

A method of separating the character was sought and found on a website specialising in Excel coding, <https://exceljet.net>, this can be seen in Figure 42.

Figure 42, code to remove characters from right,
<https://exceljet.net> [Accessed 2017]

Figure 43, Text To Columns

This method was utilised with success however it is a very laborious method when dealing with thousands of lines of data. A more suitable and more time efficient method would be needed to handle the amount of data to be analysed. Advice was taken from a fellow student, Richard Evans and a new method employed. Within Excel a feature called Text To Columns allows such a function. Unfortunately, this is a still very much a manual process. Each line of data need to have a blank column inserted with which to move the text element into before deleting that text column afterwards. This process is displayed in Figure 43.

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3. Introduction to equipment used.

Figures 44 and 45 are pictures from the manufactures website (<http://www.micro-epsilon.co.uk>) of the TIM160 camera that can be used to accurately measure heat radiation from the sample.

Figure 44, TIM160 camera size,
<http://www.micro-epsilon.co.uk> [Accessed 2017]

Figure 45, Tim160 camera,
<http://www.micro-epsilon.co.uk> [Accessed 2017]

The camera is to be used to verify the temperatures being recorded by the dynamometer are recording correctly as well as being used to gain experience with such a device. A screen shot of the image produced can be observed in Figure 46. Figure 47 shows two other method of temperature measurement utilised. The yellow thermometer is used to connect to a thermocouple device and the hand-held unit measures temperature using infra-red spectrum of light.

Figure 46, shock absorber during testing

Figure 47, other methods

Showa Shock Absorber Investigation.

4. Damper theory.

Compression Damping

Compression damping occurs when the motorcycle wheel encounters a bump or the front brakes are operated. The complexity with compression arises from the different types of bump encountered. They can be gradual or short and sharp, both scenarios resulting in different shaft velocities. Velocity being the defining factor where damping is concerned. Figure 48 highlights this.

Figure 48, bump velocities, (Thede and Parks, 2010)

The compression damping deals with the unsprung mass of the motorcycle being pushed upwards as a result of the bump or weight transfer under braking.

Rebound Damping

Rebound damping controls the extending spring as it tries to return to its original position and also is a function of the vehicles sprung mass. As this pushes the wheel back into the ground it is a most important function of maintain grip and “feel” from the rear of the motorcycle during acceleration and cornering. This affects the front also, under braking and cornering. The equations (1)-(5) can be used to calculate the damping and spring rates required for a motorcycle from known specifications.

Showa Shock Absorber Investigation.

4. Damper theory.

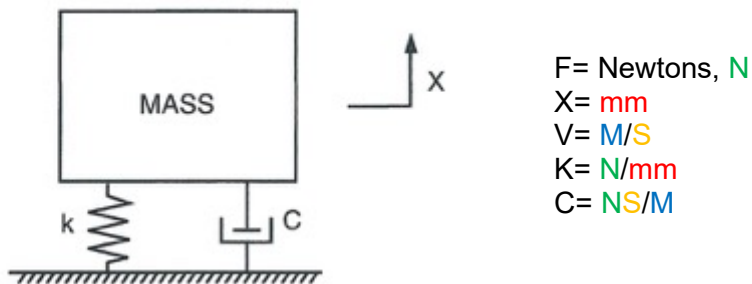


Figure 49, Mass Spring Damper System, (Dixon, 2008)

In Figure 49 a basic mass spring damper system can be seen. The mass can be referred to as *the sprung and damped mass*. The letter k is the spring rate of the spring system measured in N/mm. C is the damping coefficient of the damper system measured in Ns/mm. The displacement measured in mm and is referred to as x . The spring rate can be derived from:

$$F = kx \quad (1)$$

If the force applied is known and the displacement measured then the spring rate is obtained. The natural undamped frequency of a spring is given by:

$$f = \frac{1}{2\pi} \sqrt{\frac{k}{M}} \quad (2)$$

In a similar way, the damping coefficient may be obtained from:

$$F = CV \quad (3)$$

C also defines another parameter of the system, called Critical Damping. This is defined by:

$$C_{crit} = 2\sqrt{kM} \quad (4)$$

The relation of the damping coefficient C to the coefficient at critical damping, i.e., the ratio of C/C_{crit} is fundamental to the choice of damping in all damped spring and mass systems (Milliken and Milliken, 1995)

This is referred to as the damping ratio (zeta):

$$\frac{C}{C_{crit}} = \zeta \quad (5)$$

Showa Shock Absorber Investigation.

4. Damper theory.

The following screen shot in Figure 50 shows a spring rate and damping rate created in Excel. Known variables for a motorcycle can be entered resulting in the generation of damping rates, these are to be compared to dyno results to validate.

Figure 50, Excel worksheet screen shot to show spring rate and damping rate calculator

The worked example of Figure 50 follows.

Mass of bike = 200Kg

Mass of rider = 75Kg

Weight distribution = 0.526F/0.474R

Front unsprung mass = 9Kg

Rear unsprung mass = 12.5Kg

Steering angle = 23°

Link ratio = 2.35

Ride frequency = 2.2

Damping ratio = 0.4

Data supplied with thanks by Gareth at Reactive Suspension.

Showa Shock Absorber Investigation.

4. Damper theory.

Worked example of Figure 50.

$$\text{Sprung mass } F = 0.526 * (200 + 75 - 9) = 139.916Kg$$

$$\text{Sprung mass } R = 0.474 * (200 + 75 - 12.5) = 124.425Kg$$

Using equation (2) transposed for K

$$\text{Spring rate } F = (2 * \pi * 2.2)^2 * 139.916 = 26734.53 \text{ N/m}$$

$$\text{Spring rate } R = (2 * \pi * 2.2)^2 * 124.425 = 23774.57 \text{ N/m}$$

Now correct for steering angle and swing-arm link ratio and changed from N/m to N/mm

$$\text{Spring rate corrected for steering angle } F = 0.5 * \left(\frac{26734.53}{1000}\right) * \cos(23)^2 = 13.19 \text{ N/mm}$$

$$\text{Spring rate corrected for link ratio } R = \left(\frac{23774.57}{1000}\right) * (2.35)^2 = 131.30 \text{ N/mm}$$

Rebound damping

Using equation (4) to calculate C_{crit}

$$C_{crit} \text{ sprung } F = 2 * \sqrt{139.916 * 26734.53} = 3868.12 \text{ Ns/m}$$

$$C_{crit} \text{ sprung } R = 2 * \sqrt{124.425 * 23774.57} = 3439.85 \text{ Ns/m}$$

C_{crit} multiplied by damping ratio to calculate actual damping rate required

Equation (5) transposed for C

$$C \text{ sprung } F = 0.4 * 3868.12 = 1547.25 \text{ Ns/m}$$

$$C \text{ sprung } R = 0.4 * 3439.85 = 1375.94 \text{ Ns/m}$$

Damping rate corrected for steering angle and swing-arm link ratio

$$C \text{ sprung corrected for steering angle } F = 0.5 * 1547.25 * \cos(23)^2 = 763.60 \text{ Ns/m}$$

$$C \text{ sprung corrected for link ratio } R = 1375.94 * (2.35)^2 = 7598.63 \text{ Ns/m}$$

Showa Shock Absorber Investigation.

4. Damper theory.

Worked example of Figure 50 continued.

Compression damping

Using equation (4) to calculate Ccrit

$$C_{crit \text{ unsprung } F} = 2 * \sqrt{9 * 26734.53} = 981.04 \text{ Ns/m}$$

$$C_{crit \text{ unsprung } R} = 2 * \sqrt{12.5 * 23774.57} = 1090.29$$

Ccrit multiplied by damping ratio to calculate actual damping rate required

Equation (5) transposed for C

$$C_{\text{unsprung } F} = 0.4 * 981.04 = 392.41 \text{ Ns/m}$$

$$C_{\text{unsprung } R} = 0.4 * 1090.29 = 436.12 \text{ Ns/m}$$

Damping rate corrected for steering angle and swing-arm link ratio

$$C_{\text{unsprung corrected for steering angle } F} = 0.5 * 392.41 * \cos(23)^2 = 193.96 \text{ Ns/m}$$

$$C_{\text{unsprung corrected for link ratio } R} = 436.12 * (2.35)^2 = 2408.45 \text{ Ns/m}$$

Motorcycle specifications kindly supplied by Gareth Evans at Reactive Suspension.

In summary, the calculated damping rates for the CBR1000rr from the supplied variables are:

Rear shock compression: 2408.45 Ns/m

Rear shock rebound: 7598.63 Ns/m

These figures can be compared to appropriate dynamometer readings to validate the Excel calculations.

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4. Damper theory.

In a damping situation, there are three states that can be mathematically and graphically represented. Underdamped, Overdamped and Critically Damped.

When ζ is less than 1 then the system is considered *Underdamped*.

When ζ is greater than 1 then the system is considered *Overdamped*.

When ζ is equal to 1 then the system is considered *Critically Damped*.

Figure 51 is a graphical representation of these.

Figure 51, graphical representation to show the three different types of damping response, <http://farnorthracing.com> [Accessed 2016]

When the system is Underdamped the sprung and damped mass will oscillate through the X axis until it comes to rest when the energy is dissipated. This oscillation would occur at the frequency of the spring.

When the system is Overdamped the sprung and damped mass will return to rest without traveling through the X axis at a very slow rate.

When the system is Critically Damped the sprung and damped mass will return to the initial position very quickly, sometimes travelling through the X axis by a small amount then coming to rest.

To mathematically represent the three responses second order differential equations are derived and solved using the quadratic equation. From the roots of the quadratic equation the response of the sprung and damped mass can be obtained. There are 3 responses:

1. Real and Different (Overdamped)
2. Real and Equal (Critically Damped)
3. Complex (Underdamped)

The second order differential is derived from first principles, $F=Ma$.

If $F=kx$, $F=Cv$ and $F=Ma$ then:

$$F = Ma + Cv + kx \quad (6)$$

Therefore, if F is 0 at time = 0

$$Ma + Cv + kx = 0 \quad (7)$$

Showa Shock Absorber Investigation.

4. Damper theory.

Velocity, v is given by:

$$\frac{dx}{dt} = \dot{x} \quad (8)$$

Acceleration, a is given by:

$$\frac{d^2x}{dt^2} = \ddot{x} \quad (9)$$

Therefore:

$$M \frac{d^2x}{dt^2} + C \frac{dx}{dt} + kx = 0 \quad (10)$$

In order to be able to solve these equations a substitution needs to be made.

Let:

$$y = e^{mx} \quad (11)$$

Differentiated:

$$\frac{dy}{dx} = me^{mx} \quad (12)$$

Differentiated again:

$$\frac{d^2y}{dx^2} = m^2 e^{mx} \quad (13)$$

Substituting these in to the second order differential:

$$Mm^2 e^{mx} + Cme^{mx} + kxe^{mx} = 0 \quad (14)$$

Factorising out e^{mx} :

$$e^{mx}(Mm^2 + Cm + kx) = 0 \quad (15)$$

Since an exponential when plotted never reaches 0 the e^{mx} term cannot be 0 so the rest of the expression must equal 0.

$$Mm^2 + Cm + c = 0 \quad (16)$$

As this is now in the form of a quadratic depending on the complexity it can either be factorised or the quadratic equation used, taking care not to confuse M and m , C and c .

$$m = \frac{-C \pm \sqrt{C^2 - 4Mc}}{2M} \quad (17)$$

Showa Shock Absorber Investigation.

4. Damper theory.

When solved, the roots of the quadratic will give the damped response of the system:

1. Real and Different (Overdamped) m_1 and m_2
2. Real and Equal (Critically Damped) $m_1 = m_2$
3. Complex (Underdamped) $m = \alpha + i\beta$

There are general solutions to each of the above also and can be written as:

$$1. y = Ae^{m_1x} + Be^{m_2x} \quad (18)$$

$$2. y = (A + Bx)e^{mx} \quad (19)$$

$$3. y = e^{\alpha x} [A \cos(\beta x) + B \sin(\beta x)] \quad (20)$$

An online mathematical resource called WolframAlpha, www.wolframalpha.com, has a very useful function in that it can solve second order differential equations and display the result graphically. The equation needs to be entered in such a way that the program can process it.

$$M \frac{d^2x}{dt^2} + C \frac{dx}{dt} + kx = 0 \quad (10)$$

Must be entered as:

$$My'' + Cy' + kxy = 0 \quad (21)$$

This is shown in Figure 52 as $200y'' + 1500y' + 18000y = 0$, using real motorcycle values.

In most real world situations, a slightly underdamped system is preferred. If the values for a motorcycle are entered into the WolframAlpha input window, the following response is output, seen in Figure 53 as an underdamped system.



Figure 52, screenshot of WolframAlpha www.wolframalpha.com [Accessed 2017]

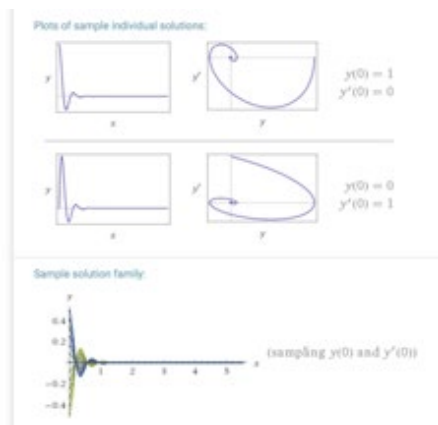


Figure 53, Underdamped output www.wolframalpha.com [Accessed 2017]

Showa Shock Absorber Investigation.

4. Damper Theory.

Without damping a vibration once excited would persist indefinitely. In practice damping exists in three forms: friction, viscous and that due to the presence of air (Bastow and Howard, 1993)

Damping is necessary to control the motion of the spring, the velocity with which it is compressed (Compression Damping) and the rate with which it then tries to extend back to its original condition (Rebound Damping). The spring is sensitive to the position that it is in its stroke in relation to the amount of energy it possesses. The damper however is not dependent or sensitive to the position in its stroke, only to the velocity with which it is acted upon.

Damping is viscous friction. It turns kinetic energy into heat and is sensitive only to damper velocity and not suspension stroke position (Thede and Parks, 2010)

The friction in a damper is due to the drag of the oil and seals interaction with contact surfaces. The viscous element is due to the oil being forced through an orifice called viscous damping and also with a great deal more complexity, forcing oil through a piston hole with a metal shim arrangement causing an obstruction. As the force with which the oil is passed through these holes increases as does the deformation of the shims allowing a greater flow of oil. This action is velocity dependent and is referred to as v^2 damping, which shall be explained in greater depth in this paper.

Viscous damping is a product of the physical size of the orifice and the dynamic viscosity, μ , of the suspension fluid. This occurs at low damper rod velocities where on fluid is forced through the shims and is only passing through the low speed damping orifice. This also will continue even when the shims are lifted, hence when adjusting the low speed adjusters generally the higher speed range will be affected.

Viscous damping can be described by:

$$\bar{v} = \frac{Q}{\pi R^2} \quad (22)$$

Where $\bar{v}$ = Mean of velocity gradient, M/s

Q = Volumetric flow rate, M^3/s

R = Radius of orifice, M

Showa Shock Absorber Investigation.

4. Damper Theory.

At higher damper rod velocities, referred to as v^2 damping, the pressure differential either side of the piston causes shim lift. The v^2 is derived from Bernoulli equation taken from the book *The Shock Absorber Handbook*, (Dixon, 2008):

$$P_1 + \frac{1}{2} + \rho v_1^2 = P_2 + \frac{1}{2} + \rho v_2^2 \quad (23)$$

Becomes:
$$v^2 = \frac{2(P_1 - P_2)}{\rho} \quad (24)$$

(Dixon, 2008)

Where: P = Pressure, Pascal's

ρ = Density of fluid, Kg/M^3

These two equations do not directly incorporate the viscosity of the fluid, this can be described using the Poiseuille equation:

$$Q = \frac{\pi R^4 \Delta P}{8 \mu L} \quad (25)$$

Where: ΔP = Change in pressure, Pascals

μ = Dynamic viscosity of fluid, Pa S

L = length of tube fluid passes through, M

Showa Shock Absorber Investigation.

4. Damper Theory.

2011 CBR1000RR Showa Shock Absorber Layout

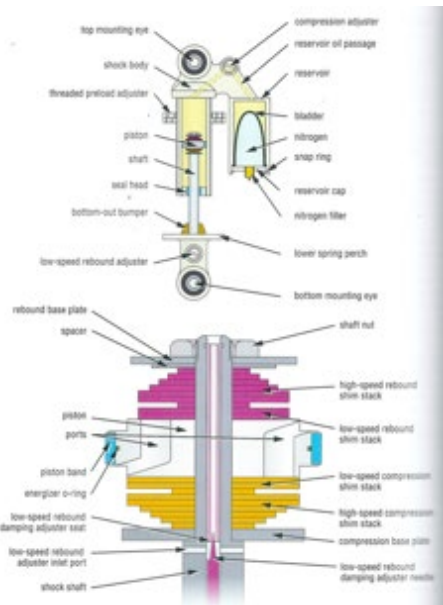


Figure 54, 2011 shock layout, (Thede and Parks, 2010)

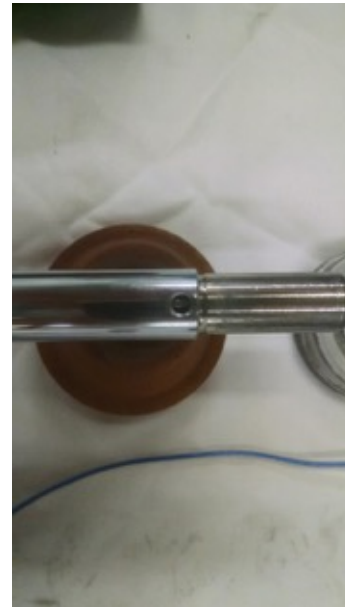


Figure 55, damper rod orifice

On a compression stroke at low damper rod velocity the oil is forced through the compression adjuster valve and into the reservoir against the pressurised bladder. Oil can also flow through the rebound orifice located in the damper rod via the top of the shaft output, seen in Figure 54 near the shaft nut also. In low speed rebound the opposite occurs. When these orifices choke, the high speed element of damping begins. The pressure and therefore the force overcomes the stiffness of the shims allowing oil to flow through the piston orifices.

The speed at which this transition occurs is called the knee speed.

The orifice dimension (Figure 55) has set flow rate which is combined with the adjustable compression and rebound restrictors to provide a combined low speed damping rate. The low speed rebound and compression can be adjusted by turning in the adjuster screws which raise a needle increasing the tapered needle's profile within an orifice, reducing fluid flow.

Showa Shock Absorber Investigation.

4. Damper Theory.

The relatively high pressure difference from one side of the piston to the other can cause a delay in damping response when changing from compression to rebound. This is the reason for the 2013 CBR1000RR having a new design of shock absorber in which the delay was to be reduced. This is achieved by placing the shim stack valving away from the high pressure area at the piston and relocating it by the reservoir. The reduced pressure differential is how Showa described the new design of shock absorber “*Balance Free*”.

2013 CBR1000RR Showa Shock Absorber Layout

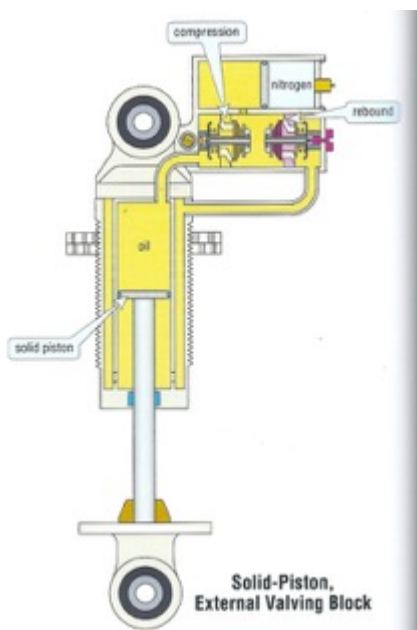


Figure 56, 2013 shock layout, (Thede and Parks, 2010)



Figure 57, 2013 inner tube orifice detail

The main differences between the 2013 CBR1000RR Showa shock absorber and the 2011 models are the twin tube circuit, solid piston and external valving block not being part of the moving damper rod assembly, this is seen in Figure 56. On a low speed compression stroke the oil is forced through the compression adjuster and into both the reservoir and also forcing oil through the rebound oil path through the circuit back through orifices at the base of the inner tube and back up behind the piston. On the rebound stroke the opposite happens. There is a small bleed hole in the solid piston which may be to overcome pressure difference at high piston velocities.

Showa Shock Absorber Investigation.

4. Damper Theory.

2013 CBR1000RR Showa Shock Absorber Layout

In figure 57 the inner tube can be observed along with the piston which is inserted to show the seal in place. The large orifice size and larger oilways suggest that the shock absorber is capable of flowing oil at a faster rate than the 2011 shock absorber. This would allow the shock absorber to respond faster when combined with the lower internal pressure. This results in less time lag when the transition from compression to rebound takes place.

These findings made from dismantling and observing the difference give credibility to the press release from Honda when the new shock absorber was introduced, Figure 58.

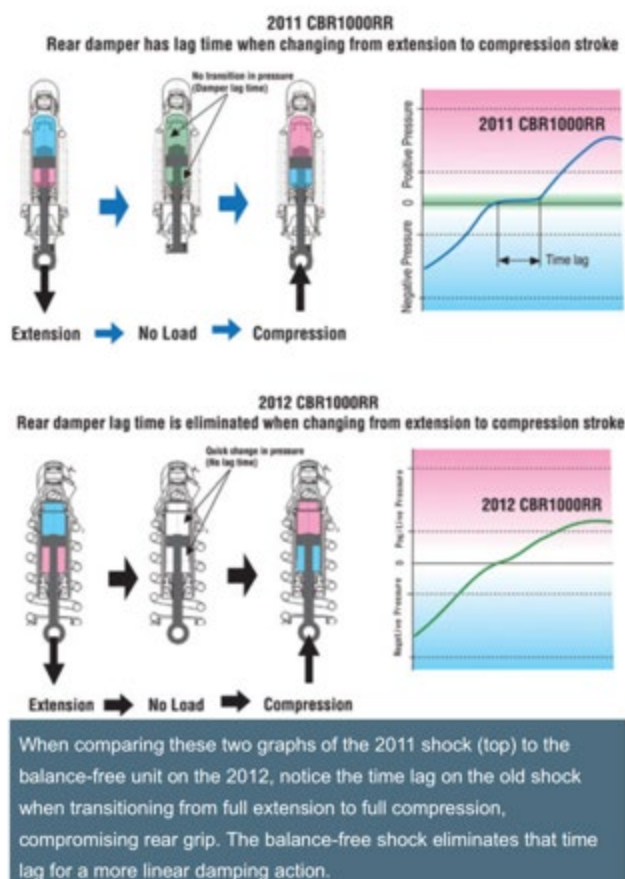


Figure 58, Honda press release, www.hondaprokevin.com [Accessed 2016]

Showa Shock Absorber Investigation.

4. Damper Theory.

High speed damper adjustment can be made in some instances by an adjuster that travels through the shock absorber shaft and allows the preload of the shim stack to be increased or decreased. This has the effect of altering the force which is required to overcome the shims and allow flow of oil. The shim stack can also be preloaded internally in a fixed manner. Two of these methods can be observed in figure 59.

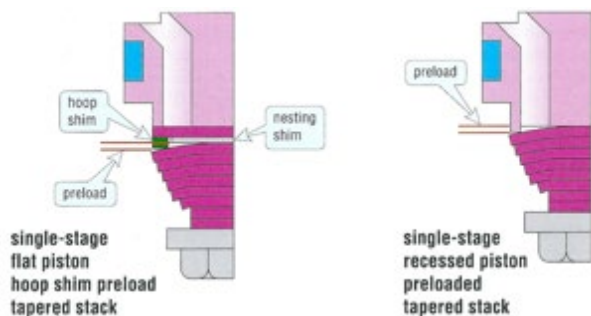


Figure 59, preloaded shim stacks, (Thede and Parks, 2010)

The other method is to physically change the shim stack by replacing shim sizes, both diameter and thickness can be changed to give different characteristics. This gives almost endless possibilities as to the damping response. The way in which the combinations are derived are from a combination of previous designs and experience with altering configurations. There is no direct mathematical link between the damping required and the actual design of the shim stack. Another variation is to restrict the oil port to the shims using internal shims within the piston. A company called Race Tech manufactures pistons which allow this extra tuneability. Figure 60 shows these restrictor stacks. It also highlights *freeload*, which is another form of orifice damping.

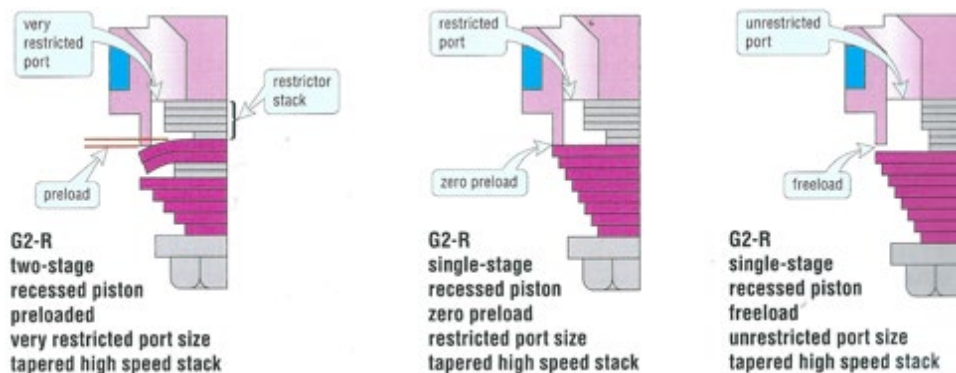


Figure 60, restrictor stacks shown installed into Race Tech G2-R gold piston, (Thede and Parks, 2010)

Showa Shock Absorber Investigation.

4. Damper Theory.

Another possibility within the shim stack itself is to tune for a low and high speed portions of the high speed damping. This is achieved by separating the shim stack by a small shim called a *crossover shim*. There then are effectively two shim stacks in one. When the low speed shims are fully open they are limited by the high speed shims until the force overcomes the preload on the high speed shims allowing both sets of shims to deflect allowing full flow. This is best illustrated by Figure 61.

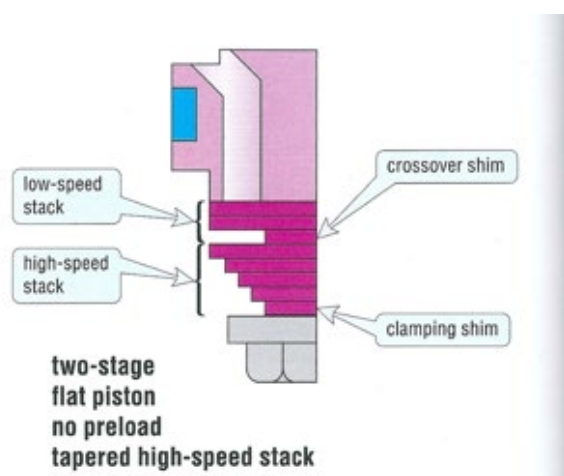


Figure 61, shim stack with low and high speed (high speed) damping, (Thede and Parks, 2010)

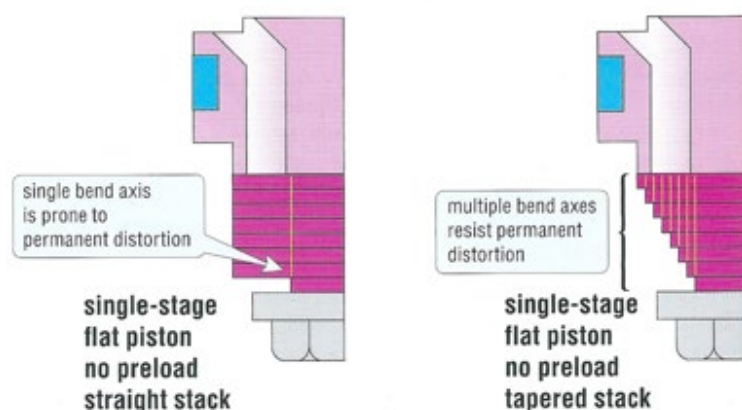


Figure 62, design consideration for shim stack configuration, (Thede and Parks, 2010)

Some shim stacks are designed in a single stage manner or have large portions of the shim stack consisting of the same diameter shims. Stated by the book *Motorcycle Suspension Bible*, (Thede and Parks, 2010), *this can lead to permanent distortion of shims*. The bending axis of the shims is highlighted in yellow in figure 62.

Showa Shock Absorber Investigation.

4. Damper Theory.

Piston design is another opportunity to alter the damping characteristics of the shock absorber. These are easily graphed on a dynamometer for their effect to allow the appropriate damping strategy to be chosen. Not only are there many different pistons design available, each can also be specified with a differing degree of “dish” which allows a different preload to be applied and the response “feel” to be tuned. This means not only is the required damping rate achievable but also the manner with which it is delivered is also tunable. Figure 63 is the amalgamation of many of the piston designs available from Penske and can be viewed at www.penskeshocks.com

There is also a piston available with variable diameter bleed holes, highlighting the myriad of suspension damper options available to the suspension engineer.

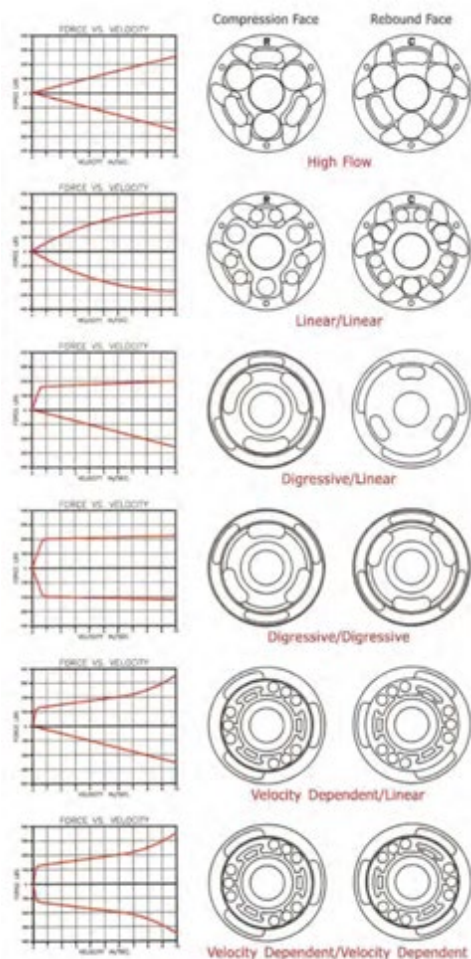


Figure 63, Penske piston chart, www.penskeshocks.com [Accessed 2017]

Showa Shock Absorber Investigation.

4. Damper Theory.

Cavitation.

Cavitation is the formation of vapour bubbles and is created within the suspension fluid when the pressure in the system drops below the vapour pressure of the suspension fluid. The dissolved bubbles in the fluid expand and cause pockets of compressible area that hinder the generation of damping until they have collapsed. This delays the build up of the force required to facilitate the damping action.

Cavitation occurs when the oil vapour pressure exceeds the local static pressure. This is analogous to boiling, but happens because of the pressure reduction rather than by temperature and vapour pressure increases. (Dixon, 2008)

One method of limiting cavitation is to pressurise the shock absorber. This helps by balancing the pressure either side of the piston, if the pressure drop can be avoided by design then cavitation can be limited. Cavitation can also occur due to low speed orifice design, if the orifice is too small and cannot flow enough oil during the piston stroke then an area of low pressure will be created allowing cavitation to occur. This was a failing of the damper rod style of design where all of the damping was generated purely by the orifice. This style rarely exists now except in the cheapest of dampers. In Figure 64 the generation of cavitation can be observed.

Cavitation may be avoided by correct design, such that the pressure at all points in the damper exceeds the vapour pressure. (Dixon, 2008)

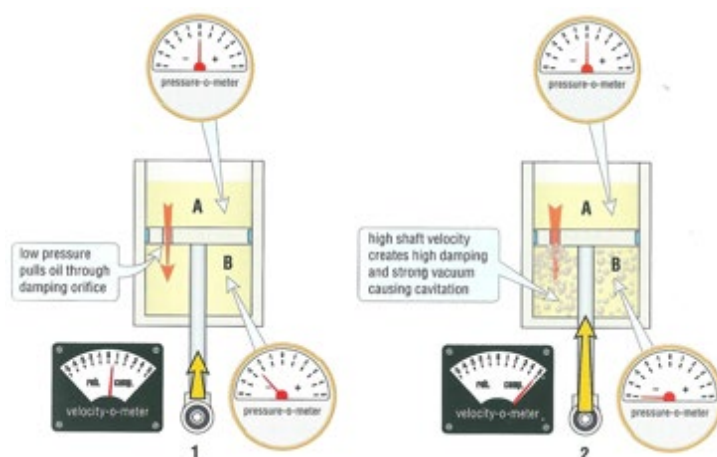


Figure 64, generation of cavitation, (Thede and Parkes, 2010)

Showa Shock Absorber Investigation.

4. Damper Theory.

Hysteresis.

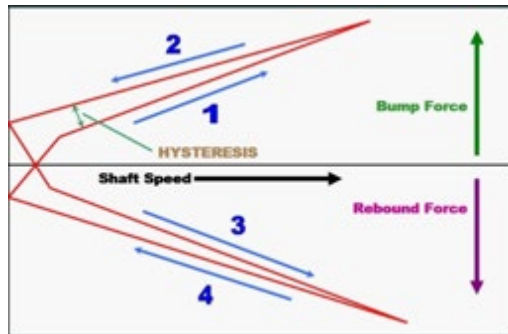


Figure 65, hysteresis shown in graph, <http://farnorthracing.com>, [Accessed 2016]

Hysteresis can be defined as the difference between the forces generated by the shock absorber as the transition occurs between acceleration and deceleration as it travels either in the rebound or compression direction. Hysteresis can lead to a delay in the damping motion. This is better described by the online Oxford Dictionary:

The phenomenon in which the value of a physical property lags behind changes in the effect causing it, as for instance when magnetic induction lags behind the magnetizing force.

(<https://en.oxforddictionaries.com/definition/hysteresis> [Accessed 14/02/2017])

When observing the kind of Force/Velocity graph as seen in Figure 65, the further apart the lines in each section of the graph, the greater the Hysteresis.

This lag can be attributed to compressibility of suspension fluid, cavitation, and damper rod seal drag. An example of a poor quality suspension seal which has far too much stiction was observed at Reactive Suspension where a fork stanchion could not fall under effect of gravity upon it through a fork tube fitted with a certain manufacturer of aftermarket “upgrade” seal. Upon installing the OE (original equipment) seal, the fork stanchion behaved as expected and fell in a controlled manner.

Showa Shock Absorber Investigation.

4. Damper Theory.

Suspension fluids are either mineral oil or synthetic blends that can have stabilisers added to make them less temperature sensitive. These are called *viscosity index modifiers*. Oil viscosity can be defined as the oil's resistance to flow. When a damper has a force applied the pressure increases and forces the oil through any opening causing a flow of fluid and therefore viscous friction. The flow rate is governed by the hole size and the viscosity of the oil. If the oil has a higher viscosity it will offer more resistance to flow than a lower viscosity oil. The damping generated by this resistance to flow increases with the reduction in flow rate. The viscosity is related to the temperature, at low temperature the oil is "thicker" and at high temperatures it is "thinner". A lower viscosity oil would be preferable as it would perform better initially and with the correct stabilisers added would continue to perform as the damper heated up. However, there is a risk of cavitation with lower viscosity oils as stated by Dixon:

Lower viscosity oils would perform well, but have a higher vapour pressure and would therefore be prone to cavitation. (Dixon, 2008)

The properties of the oil to be discussed are the density and viscosity. Viscosity is measured in two ways and is linked by the density.

Kinematic viscosity is described by the Oxford dictionary as:

A quantity representing the dynamic viscosity of a fluid per unit density.
[https://en.oxforddictionaries.com/definition/kinematic viscosity](https://en.oxforddictionaries.com/definition/kinematic%20viscosity) [Accessed 16/02/2017]

Dynamic viscosity:

A quantity measuring the force needed to overcome internal friction in a fluid.
[https://en.oxforddictionaries.com/definition/dynamic viscosity](https://en.oxforddictionaries.com/definition/dynamic%20viscosity) [Accessed 16/02/2017]

Density:

The quantity of mass per unit volume of a substance.
<https://en.oxforddictionaries.com/definition/density> [Accessed 16/02/2017]

Showa Shock Absorber Investigation.

4. Damper Theory.

$$v = \frac{\mu}{\rho} \quad (26)$$

(Dixon, 2008)

ν = ν = kinematic viscosity measured in Centistokes (Cts) or m^2/s . 1 Cts = 0.000001 m^2/s .

μ = μ = dynamic viscosity measured in $N s/m^2$ or $Pa s$. 1 $N s/m^2$ = 1 $Pa s$.

ρ = ρ = density measured in Kg/m^3 .

Dynamic viscosity when related to damper systems is generally seen as $mPa s$. This is called millipascal seconds. 1 $Pa s$ = 1000 $mPa s$.

The suspension oil used in this investigation as recommended by Gareth at Reactive Suspension was Fuchs-Silkolene RSF 7.5. This is a mineral oil fluid. The data for the fluid for calculations was supplied by the technical manager at Silkolene, Andrew Brown, via email. Sean Zolghadri kindly supplied the specific heat capacity.

Figures 66-68 show excerpts of the conversations.



Figure 66, kinematic viscosity (Cts)



Figure 67, density (g/cm³)



Figure 68, specific heat (Kj/Kg/K)

Showa Shock Absorber Investigation.

4. Damper Theory.

The oil characteristics supplied by Fuchs-Silkolene were tabulated in Excel and graphs produced. This allows a polynomial to be applied to the curve for future calculations. Figure 69 shows a screen shot of the Excel workbook.

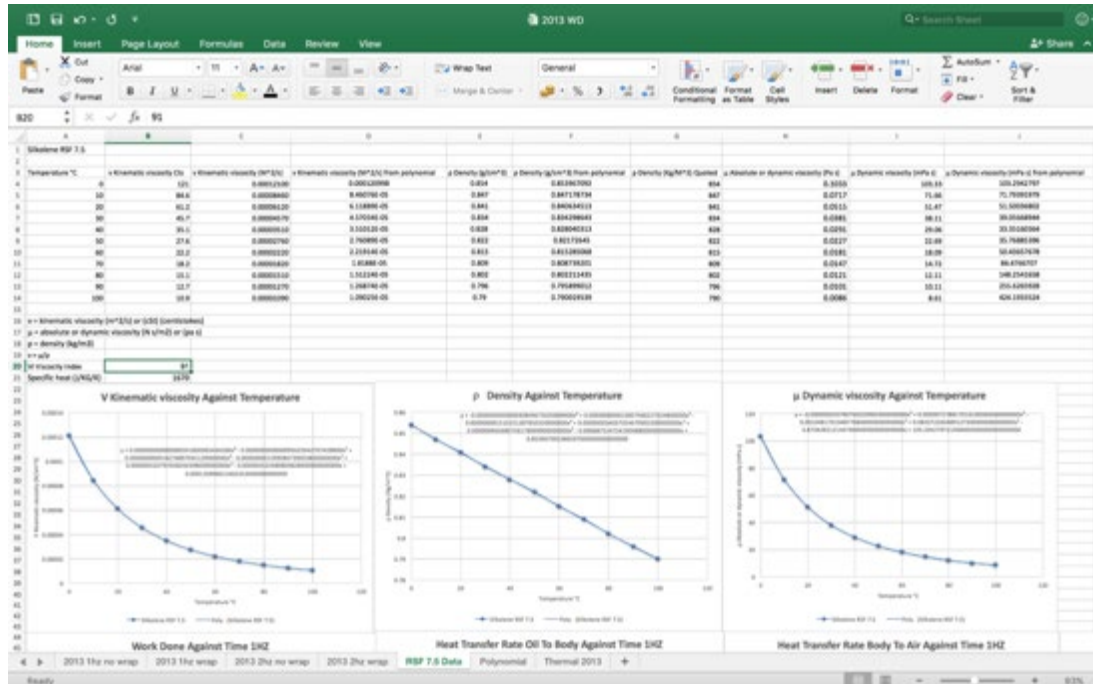


Figure 69, screen shot of Excel work book

It can be observed from the graphs in Figure 69 that there is a very large drop in viscosity from 0-20°C in comparison to the rest of the curve. Therefore, oils are given a working temperature range in their specifications.

A common way for suspension fluids to be marketed are by their “weight” however this can be misleading as it can vary from manufacturer to manufacturer. A much more accurate comparison is to use the viscosity index (VI). This is now quoted by suspension fluid manufactures and is a function of the Cts at 40°C and the Cts at 100°C.

The higher the viscosity, the more stable it (oil) is. (Thede and Parks, 2010)

The equation was found at the website address:

http://www.petervedone.com/wiki/index.php?title=Suspension_Fluid

This tested against two online calculators and proven to be reliable and accurate. This equation can be viewed in Figure 70.

Showa Shock Absorber Investigation.

4. Damper Theory.

ASTM D2270-04 Standard Practice for Calculating Viscosity Index From Kinematic Viscosity at 40 and 100°C

The Viscosity Index is calculated as such:

$$VI = 100 + \frac{10}{0.00715} \ln \left(\frac{e^{1.0727 - 0.6175 \ln(cSt @ 100)} - 0.9744 \ln(cSt @ 100)^2 - 0.3764 \ln(cSt @ 100)^3 + 0.04824 \ln(cSt @ 100)^4}{cSt @ 40} \right)$$

As Microsoft Excel sees it:

$$VI = 100 + \{10 * [LN([EXP(1.0727 + 0.6175 * LN(cSt @ 100) + 0.9744 * (LN(cSt @ 100)^2) + (-0.3764) * (LN(cSt @ 100)^3) + 0.04824 * (LN(cSt @ 100)^4)]) / (cSt @ 40) / LN(cSt @ 100)] - 1\} / 0.00715$$

(27)

Figure 70, calculation of VI, <http://www.peterverdone.com> [Accessed 2017]

The equation as written in excel is as in Figure 71:

=100+(10*(LN([EXP(1.0727+0.6175*LN(B14)+0.9744*(LN(B14)^2)+(-0.3764)*(LN(B14)^3)+0.04824*(LN(B14)^4)]/(B8/LN(B14))-1)/0.00715					
A	B	C	D	E	F
Silkolene RSF 7.5					
Temperature °C	v Kinematic viscosity cSt	v Kinematic viscosity (M ² /s)	v Kinematic viscosity (M ² /s) from polynomial	p Density (g/cm ³)	p Density (g/cm ³) from polynomial
0	121	0.00012100	0.000120998	0.854	0.853967092
10	84.6	0.00008460	8.46071E-05	0.847	0.847178734
20	61.2	0.00006120	6.11889E-05	0.841	0.840634513
30	45.7	0.00004570	4.57034E-05	0.834	0.834298643
40	35.1	0.00003510	3.51012E-05	0.828	0.828040313
50	27.6	0.00002760	2.76089E-05	0.822	0.82172645
60	22.2	0.00002220	2.21914E-05	0.815	0.815285068
70	18.2	0.00001820	1.8188E-05	0.809	0.808739201
80	15.1	0.00001510	1.51224E-05	0.802	0.802211435
90	12.7	0.00001270	1.26874E-05	0.796	0.795899012
100	10.9	0.00001090	1.09025E-05	0.79	0.790019539
v = kinematic viscosity (m ² /s) or (cSt) (centistokes)					
μ = absolute or dynamic viscosity (N s/m ²) or (po s)					
ρ = density (kg/m ³)					
v = μ/ρ					
VI Viscosity Index	323.2551043				
Specific heat (J/KG/K)	1670				

Figure 71, Excel sheet with calculation of VI

The result given by Excel is seen in figure 72:

VI Viscosity Index 323.2551043

Figure 72, Excel screen shot of VI result

Two online calculators were used to test the function of the VI calculator in Excel, the result of each can be seen in Figures 73 and 74.

ASTM D2270 / Viscosity Index (VI)
Standard Practice for Calculating Viscosity Index From Kinematic Viscosity at 40 and 100°C

Kinematic viscosity 1: 35.1 at 40°C
Kinematic viscosity 2: 10.9 at 100°C

Calculate

Result: 321.32

Figure 73, VI online calculator, <http://www.viscopedia.com> [Accessed 2017]

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Viscosity index
Base oil mixtures
CCS viscosity of group 1 base oils

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Blending tools - Viscosity index
Viscosity index

Viscosity index (VI) calculator

40/40 °C cSt (mm²/s): 35.1
100/100 °C cSt (mm²/s): 10.9
Viscosity index: 323

Calculate **Clear**

Figure 74, VI online calculator, <http://oil-additives.evonik.com> [Accessed 2017]

Showa Shock Absorber Investigation.

5. Work carried out and results.

Test 1 Flow rate and dynamic viscosity experiment.

In order to calculate the flow rate of the damper orifice of the 2013 shock absorber, an experiment was conducted with a vessel at a measured height containing a fluid of known volume which would pass through a tube of known length. The volume of fluid was allowed to pass through the damper orifice, which can be observed just above the threaded section of the rod seen in Figure 75, until the vessel was empty. This experiment was conducted three times to gain an average. The arrangement for the experiment is shown by Figure 76.



Figure 75, damper orifice



Figure 76, experimental setup

From the timed result and fluid specification supplied by the manufacturer the flow rate could be determined and the calculated dynamic viscosity compared to quoted figures.

The measured values for calculation were:

Temp = 20°C

Volume of fluid = 0.0002m³

Radius of orifice = R = 0.0015m

Height of vessel = H = 1.5m

Length of tube = L = 0.87m

Density at 20 C of fluid = ρ = 841Kg/m³

Average time = 6.296 mins = T = 377.76s

Gravity = g = 9.81 m/s²

Showa Shock Absorber Investigation.

5. Work carried out and results.

Test 1 Flow rate and dynamic viscosity experiment.

Pressure generated by pressure head:

$$H * \rho * g \quad (28)$$

$$1.5 * 841 * 9.81 = 12375.315 \text{ Pa} = \Delta P$$

$$\text{Flow rate Vel} = Q \quad \frac{\text{Volume}}{\text{Time}} \text{ m}^3/\text{s} \quad (29)$$

$$\frac{0.0002}{377.76} = 0.5294 \times 10^{-6} \text{ m}^3/\text{s}$$

Average velocity in tube due to velocity gradient = $\bar{v} \text{ m/s}$

$$\bar{v} = \frac{Q}{\pi * R^2} \text{ m/s} \quad (30)$$

$$\frac{0.5294 \times 10^{-6}}{\pi * (0.0015)^2} = 0.07489 \text{ m/s}$$

Using equation (25) transposed for μ :

$$\mu = \frac{\Delta P * R^4}{8 * L * \bar{v}} \text{ m}^3/\text{s} \quad (31)$$

$$\mu = \frac{12375.315 * (0.0015)^4}{8 * 0.87 * 0.07489} = 0.05342 \text{ Pa s}$$

Dynamic viscosity is often quoted in mPa s:

For a representative damper oil, which would usually be a light mineral oil, the dynamic viscosity is typically around 40 mPa s at 15°C. (Dixon, 2008)

To represent 0.05342 Pa s as mPa s, the figure is multiplied by a factor of 1000.

$$0.05342 * 1000 = 53.42 \text{ mPa s}$$

Showa Shock Absorber Investigation.

5. Work carried out and results.

Test 1 Flow rate and dynamic viscosity experiment.

This figure calculated is very close in value to the figure supplied by Fuchs-Silkolene and can be observed in the screen shot of the Excel worksheet in Figure 77:

Dynamic Viscosity Test at 20 degrees centigrade			
h (M)	1.5	$V=Q=Volume/Time \text{ M}^3/s$	5.29381E-07
ρ (Kg/m ³)	841	$Vbar(Mean)=Q/Pi*R^2$	0.074892038
g (M/s)	9.81	$\Delta P=h*\rho *g =Pa$	12375.315
L (M)	0.87	$\mu=\Delta P*R^2/8*L*Vbar = Pa \text{ s}$	0.053418771
R (M)	0.0015	$\mu \text{ mPa s} = Pa \text{ s} *1000$	53.4187707
T1	6.32	Quoted mPa s @ 20 Deg C	51.4692
T2	6.43		
T3	6.14		
Tave	6.296666667		
Vol M ³	0.0002		

Figure 77, Excel worksheet showing manufacturer quoted values dynamic viscosity for RSF 7.5 against experimentally calculated dynamic viscosity

The difference between the figures is $(53.42-51.47) = 1.95 \text{ mPa s}$, which would be attributed to experimental error or temperature variation between tests.

Unfortunately, an appropriate fitting was not able to be found to fit the 2011 shock absorber damper rod, so this experiment could not be repeated to gain a comparison for flow rate of damper orifices.

Showa Shock Absorber Investigation.

5. Work carried out and results.

Test 2 Initial dynamometer test.

Upon obtaining the two shock absorbers, the first works carried out before any testing could take place was to dismantle, clean and service the units. As mentioned in an earlier chapter, seal head service kits were purchased and installed, the pistons flattened off on an engineering block with extremely fine grade engineering paper and the shim stacks dismantled and cleaned. While the units were dismantled the sizes and orientation of the individual shims were noted if not for the purpose of calculation then in case they were disturbed (dropped, mixed up!). Upon rebuilding the shock absorbers, they were then subjected to initial testing on the dynamometer. This set of initial tests was to begin to understand the functionality of the dynamometer and obtain graphs to show the effect of adjusting the compression and rebound adjusters. The adjusters on both shocks are of the step-less variety where as many other shocks have a “clicker” adjuster. The number of half turns with a screwdriver were counted so that a mid setting could be achieved. Each shock was then tested with every combination of Compression and Rebound comprising of Soft, Medium and Hard. Figure 78 is a typical example of a pre-prepared test schedule.

Multiple 2011 shock 10 bar settings test NORMAL record data and graph					
S/S					
S/M					
S/H					
M/S					
M/M					
M/H					
H/S					
H/M					
H/H					

Figure 78, section of a typical test schedule

Each test planned was to have a test schedule to keep track of tests completed and any other information such as ambient temperature or any problems encountered.

Showa Shock Absorber Investigation.

5. Work carried out and results.

Test 2 Initial dynamometer test.

Screen shots of the tests completed can be seen in Figures 79-84. This is an example of the graphs recorded and not a complete listing. The damper dynamometer was set to multiple velocity, 1-3 Hz.

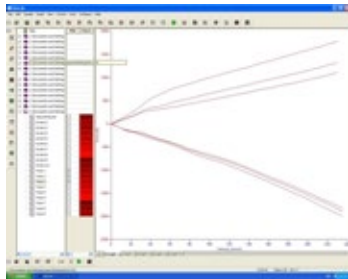


Figure 79, 2013 SS

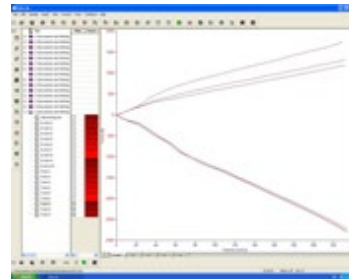


Figure 80, 2013 HH

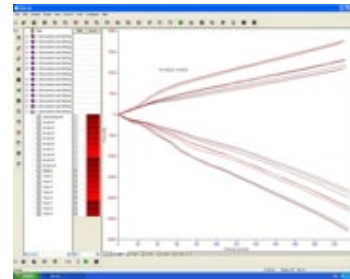


Figure 81, 2013 full range

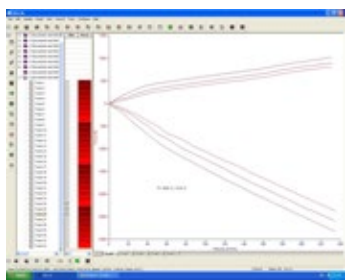


Figure 82, 2011 SS

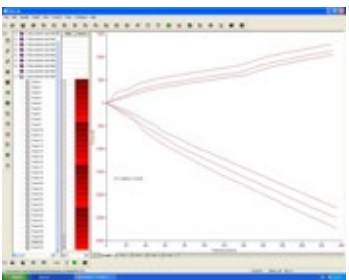


Figure 83, 2011 HH

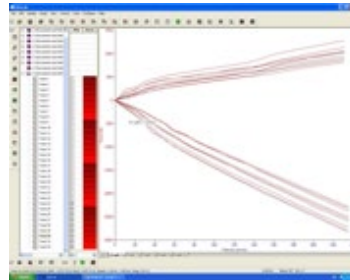


Figure 84, 2011 full range

2011/2013 Initial damper test				
Setting	2011 Force (N)	Range	2013 Force (N)	Range
Max Comp H	1250	500	1750	650
Min Comp S	750		1100	
Max Reb H	2800	550	2750	1000
Min Reb S	2250		1750	

Figure 85, initial test results

The test results can be read from the graphs and seen in Figure 85. Compression damping is the line at the top of the graph and rebound the line at the bottom. The test shows that the 2013 shock absorber has a greater range of adjustment than the 2011 shock absorber. It can also be observed that adjusting the rebound setting on the 2011 shock absorber also affect the compression and vice versa, whereas the 2013 shock absorber keeps a separate function to both adjusters.

Showa Shock Absorber Investigation.

5. Work carried out and results.

Test 3 Pressure adjustment test.

Test 2 was carried out to investigate the effect of changing the Nitrogen pressure which is held within the shock absorber bladder when charging after rebuilding. The shock absorbers feature a self-sealing rubber bung through which the Nitrogen needle is passed and Nitrogen introduced in to the reservoir. Each shock absorber was tested with the compression adjuster set to soft and the rebound adjusted soft, medium and hard. The damper dynamometer was set to multiple velocity, 1-3 Hz. Pressures were initially 5 Bar followed by 10 Bar. The results of which may be seen in Figures 86-89.

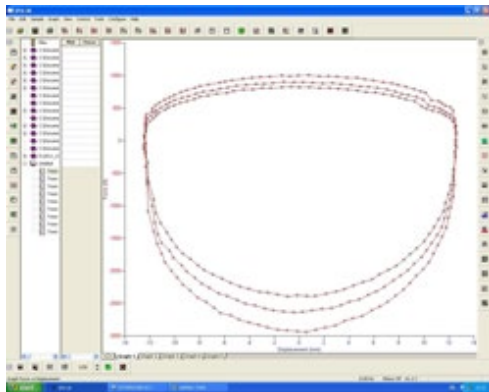


Figure 86, 2011 5 bar comp s rs/m/h

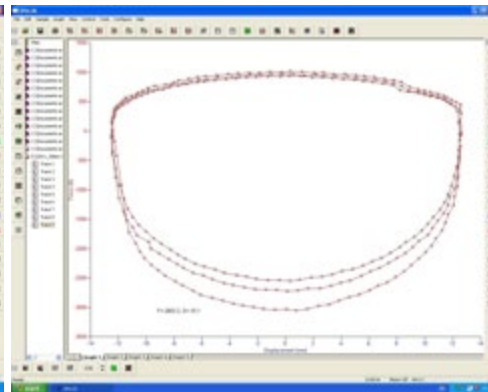


Figure 87, 2011 10 bar comp s rs/m/h

It can be observed from Figures 86 and 87 that increasing the internal pressure increased the amount of force required and also reduced the effect of the adjustments.

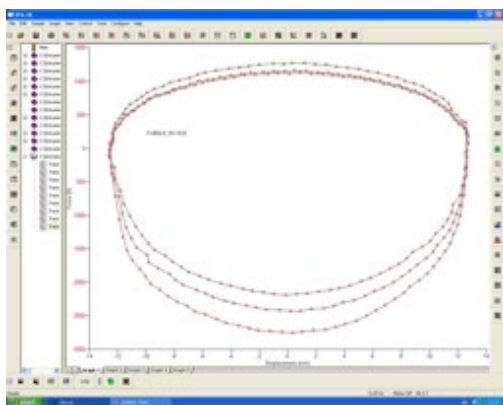


Figure 88, 2013 5 bar comp s rs/m/h

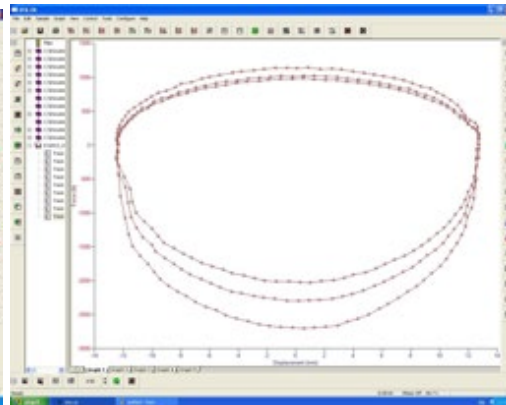


Figure 89, 2013 10 bar comp s rs/m/h

Increasing the pressure in the 2013 shock absorber had little effect on the damping rates observed, Figures 88 and 89.

Showa Shock Absorber Investigation.

5. Work carried out and results.

Test 4 2013 Frequency test.

The 2013 shock absorber was installed in the dynamometer and tested at two different single speed settings with frequency ranges of 1Hz and 2Hz. The dyno graphs produced can be seen in Figures 90 and 91.

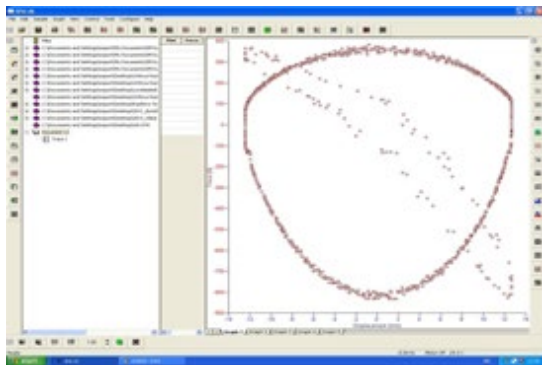


Figure 90, 1Hz test

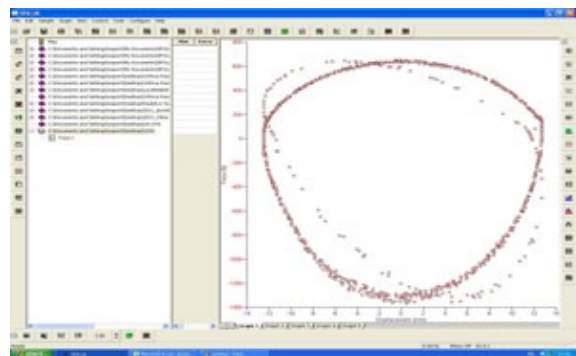


Figure 91, 2Hz test

During the 1Hz test a maximum force of nearly 400N Compression and a minimum of -850N Rebound was observed. At 2Hz a maximum of 700N Compression and -1350N Rebound was observed. For more accurate observation of results the raw data was exported in to Excel using the method described in section 3 of this report and illustrated by Figures 39-42. When the data had been processed, graphs were created to try to simulate the graphs generated by the dynamometer software. The force/velocity graphs looked nothing like expected and the force/displacement not quite as in Figures 90 and 91. The result is seen in Figure 92 and 93. As a problem with the data was apparent the test was abandoned.

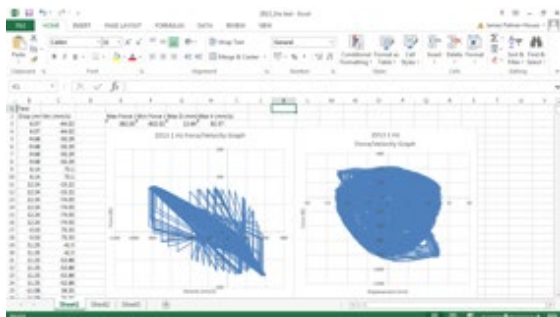


Figure 92, dynamometer data export into Excel, 1Hz

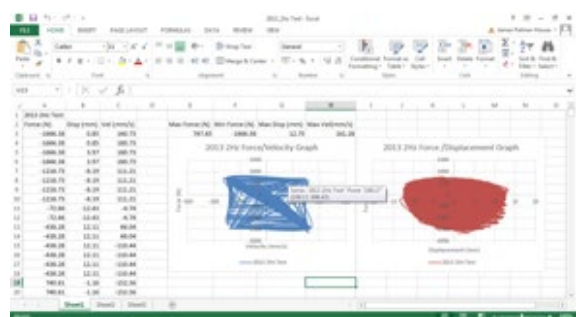


Figure 93, dynamometer data export into Excel, 2Hz

Showa Shock Absorber Investigation.

5. Work carried out and results.

Test 5 Correct function of graphs.

As the previous attempt to recreate the graphs had been unsuccessful an alternative sampling method was tried with the dynamometer. Again the 2013 shock absorber was used as it still had the clevis attached to it from the previous test (3). It was decided to try two different pressures in the shock absorber, 7.5 Bar and 10 Bar to give two different traces to plot and to compare the look of the plotted graphs against those obtained in test 2. The dynamometer was set to 1-3Hz multi-speed setting and data recorded and exported into Excel as before. This time the graphs were successful in replicated that of the dynamometer software. However as seen in Figure 94, there was a problem with the shock absorber highlighted by the “tail” on the force/velocity graph. This shows hysteresis and required a rebuild of the shock absorber. This could be dirt ingress or incorrect bleeding of the air from the shock absorber during previous rebuild.

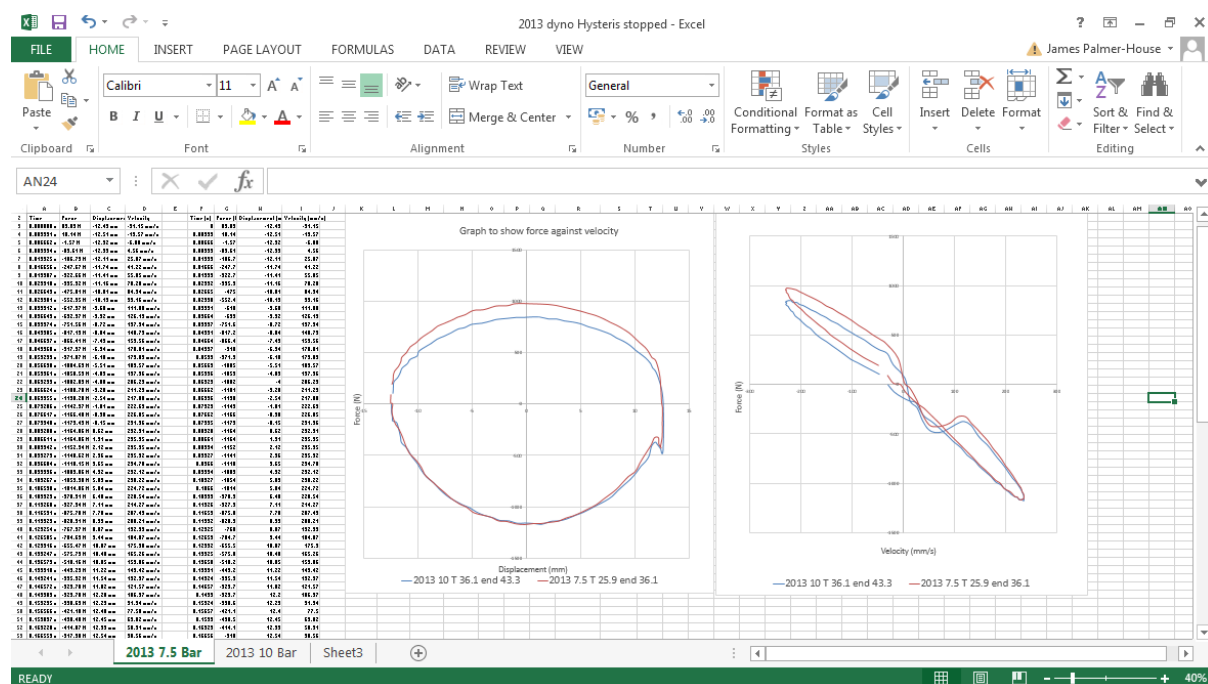


Figure 94, successfully plotted graphs from exported data, hysteresis observed.

Showa Shock Absorber Investigation.

5. Work carried out and results.

Test 6.1 Advanced 2011 adjustment test.

Following successful recreation of graphs within Excel the previous adjustment test was repeated to be able to overlay the traces in a much more satisfactory manner than that displayed by the dynamometer software. The 2011 shock absorber was fitted into the dynamometer and the multi-speed 1-3Hz method used. The data and subsequent graphs can be seen in Figure 95. The shock was again tested in the following combinations:

Compression S S S M M M H H H

Rebound S M H S M H S M H

Where:

S = soft

M = medium

H = hard

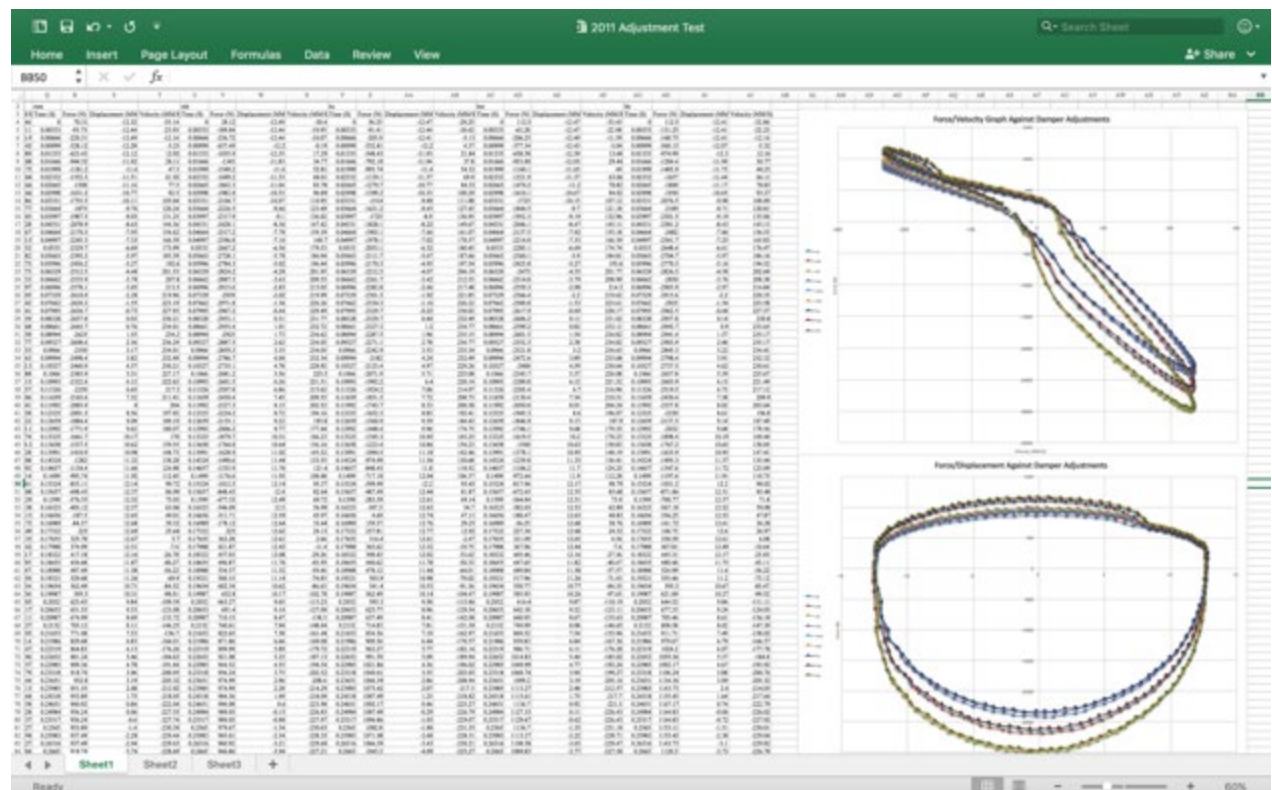


Figure 95, adjustment test 2011 shock absorber

Showa Shock Absorber Investigation.

5. Work carried out and results.

Test 6.1 Advanced 2011 adjustment test.

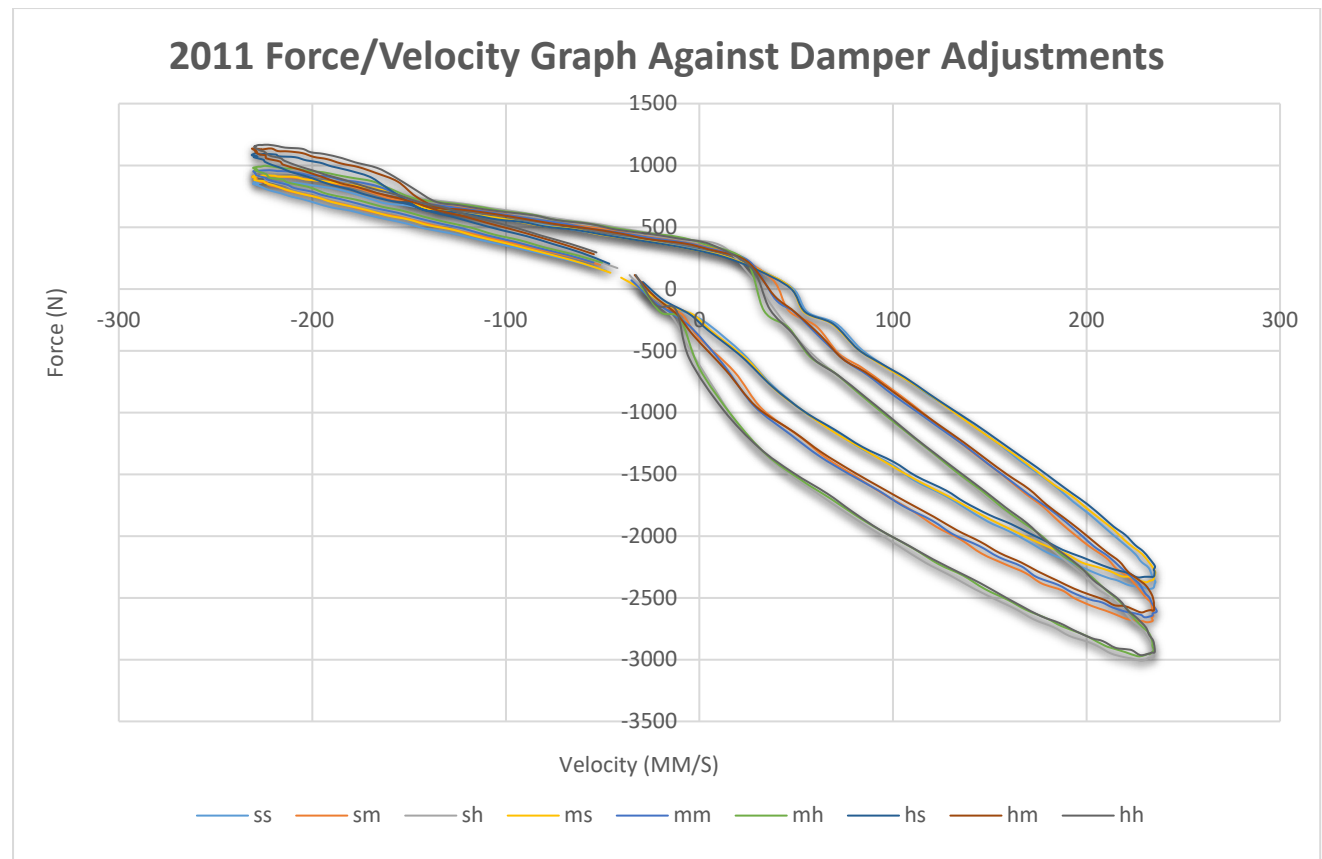


Figure 96, force/velocity graph

This graph (Figure 96) is a different version of a force velocity graphs in Figures 79-84. The graph in Figure 96 is actual force and velocity data at specific time samples, whereas the graphs in Figures 79-84 are generated from averages recorded by the dynamometer software as the motor changes speed steps. These steps are from 1-3Hz in 0.25 increments. These cannot be generated from the Excel data.

Showa Shock Absorber Investigation.

5. Work carried out and results.

Test 6.1 Advanced 2011 adjustment test.

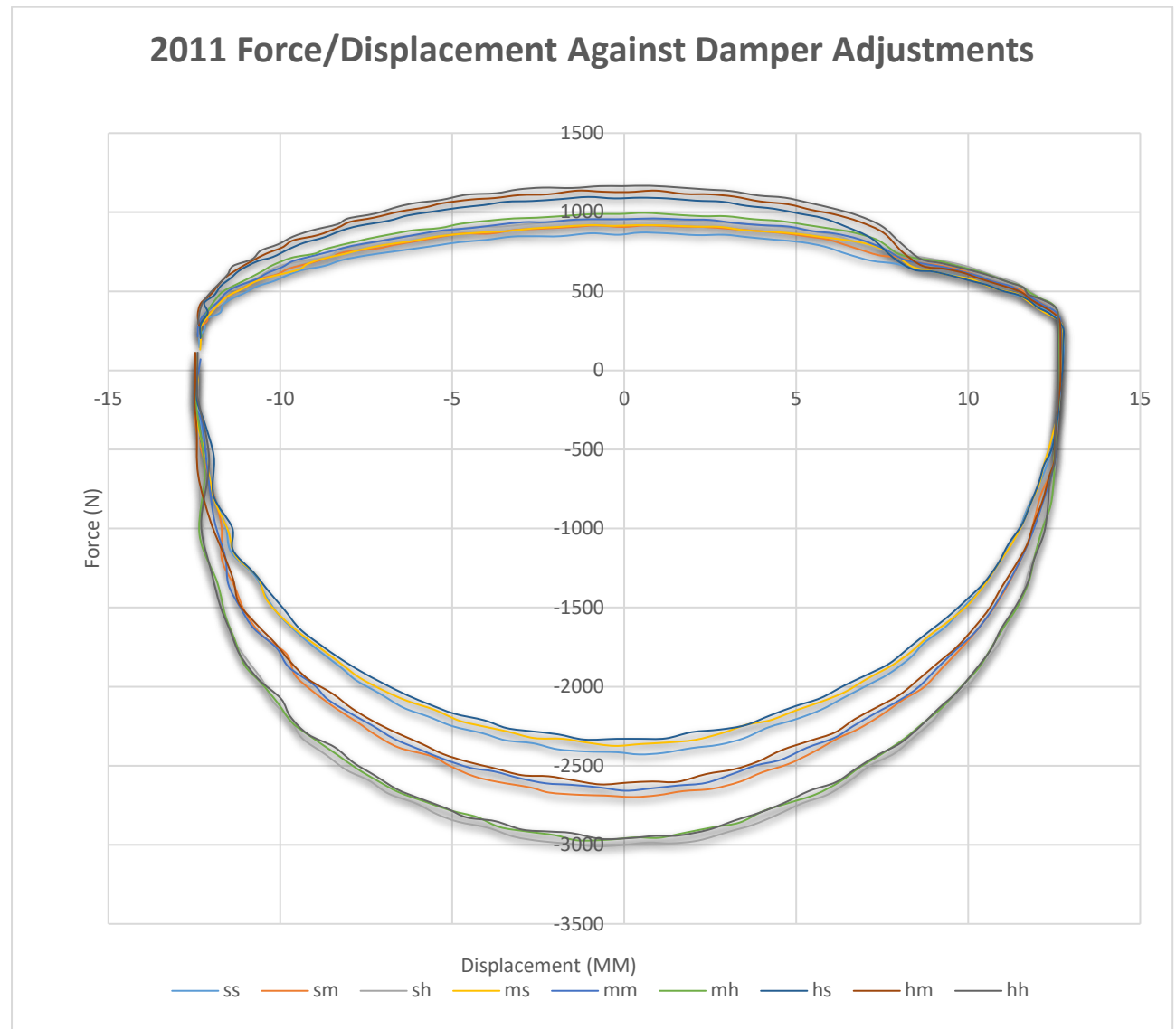


Figure 97, force/displacement graph

The graph in Figure 97 is the force/displacement graph and looks very similar to those generated by the dynamometer as seen in Figures 86-89. The top half of the graph is compression damping and the bottom section, rebound damping.

Showa Shock Absorber Investigation.

5. Work carried out and results.

Test 6.1 Advanced 2011 adjustment test.

The results of the adjustment test can be summarised using the max and min function in Excel to give the max compression and rebound forces recorded during the test.

Table 1 shows the results.

C/R	ss	sm	sh	ms	mm	mh	hs	hm	hh	Max/Min
Max F (N)	871.86	916.39	956.24	918.74	960.92	996.08	1096.86	1136.7	1167.17	1167.17
Min F (N)	-2428.09	-2697.62	-3009.33	-2374.19	-2657.78	-2971.83	-2334.34	-2617.93	-2962.46	-3009.33
Max V (M/s)	235.53	234.57	234.98	235.53	236.29	234.62	235.34	234.82	235.17	236.29

Table 1, maximum and minimum force and maximum velocity figures from test 5.1

Max force is the compression damping and Min force is rebound damping as seen in Figure 96. The minus symbol indicated direction and not magnitude of force. Therefore, the maximum recorded compression damping figure was 1167.17N which occurred with the hh setting which is compression Hard and rebound Hard. The maximum recorded rebound force was 3009.33N which occurred at the sh setting which is compression Soft and rebound Hard. This can be confirmed by observing Figure 96. Both maximum values occurred at hard settings of each but not at hh, Hard/Hard as expected due to increased restriction. This suggests that the settings interact with each other and are not separate. The maximum velocity was expected to be at ss as there would be least restriction, however this occurred at mm.

Showa Shock Absorber Investigation.

5. Work carried out and results.

Test 6.2 Advanced 2013 adjustment test.

The 2013 shock absorber was now installed into the dynamometer and the same test conducted as in test 5.1. The results can be observed in Figure 98. Shock absorber settings:

Rebound S S S M M M H H H

Compression S M H S M H S M H

Where:

S = soft

M = medium

H = hard

These settings were the opposite way around from test 5.1 to help differentiate between tests.

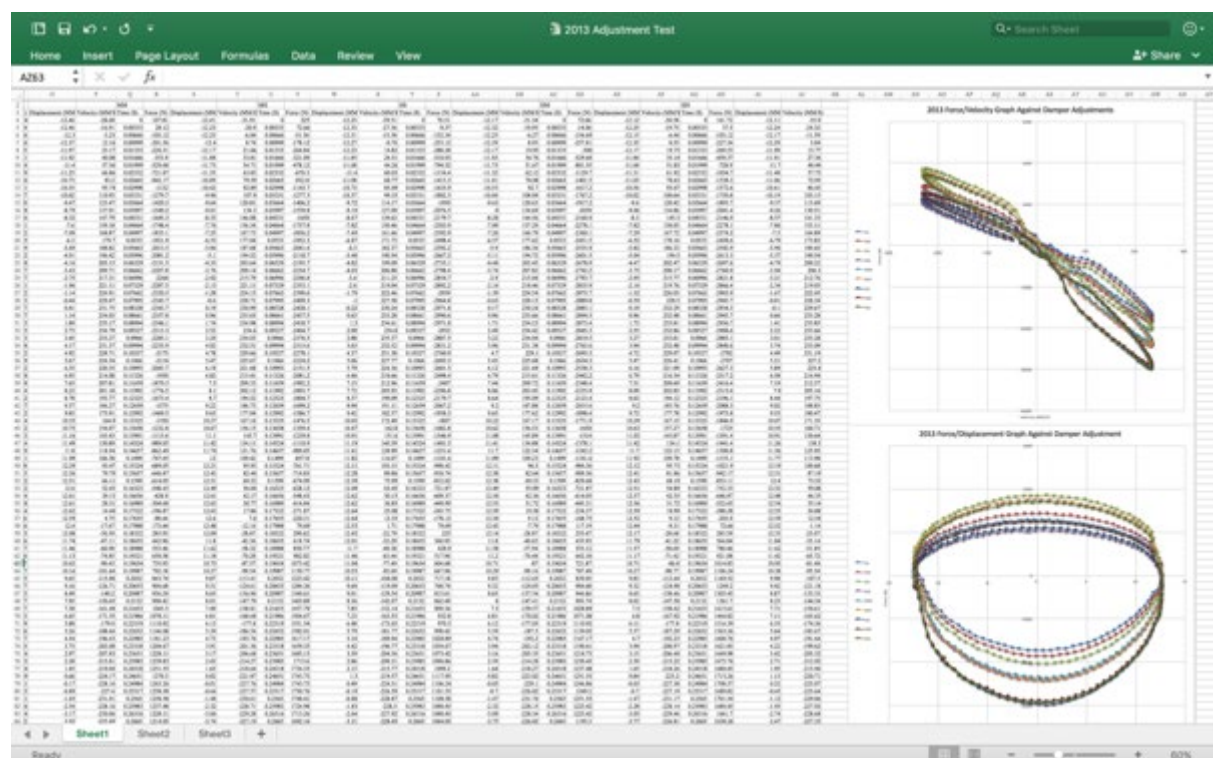


Figure 98, adjustment test 2013 shock absorber

Showa Shock Absorber Investigation.

5. Work carried out and results.

Test 6.2 Advanced 2013 adjustment test.

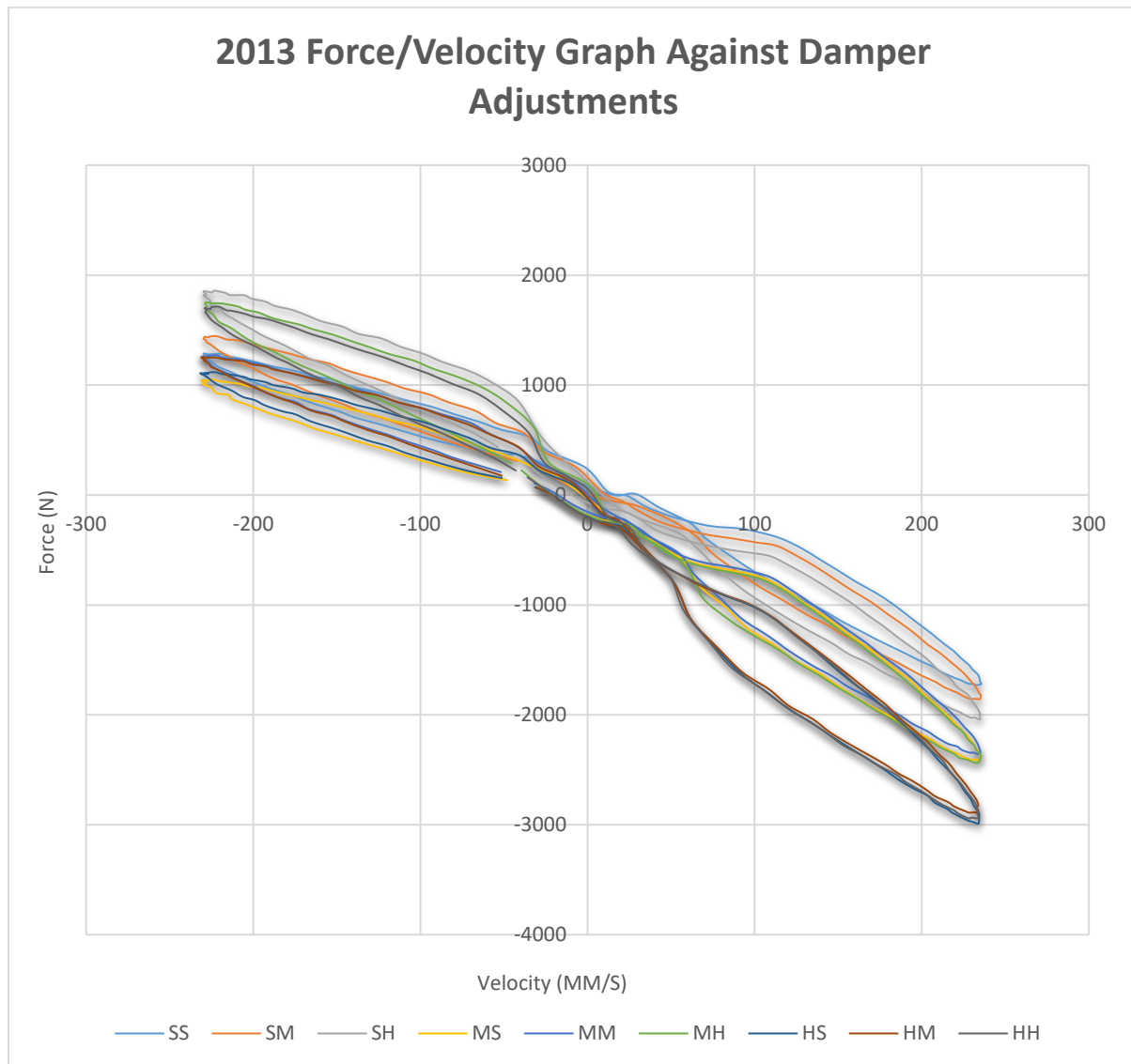


Figure 99, force/velocity graph

Figure 99 shows the force/velocity graph generated from the Excel data. It shows maximum compression damping of around 1900N with the SH setting and maximum rebound of 3000N at the HS setting.

Showa Shock Absorber Investigation.

5. Work carried out and results.

Test 6.2 Advanced 2013 adjustment test.

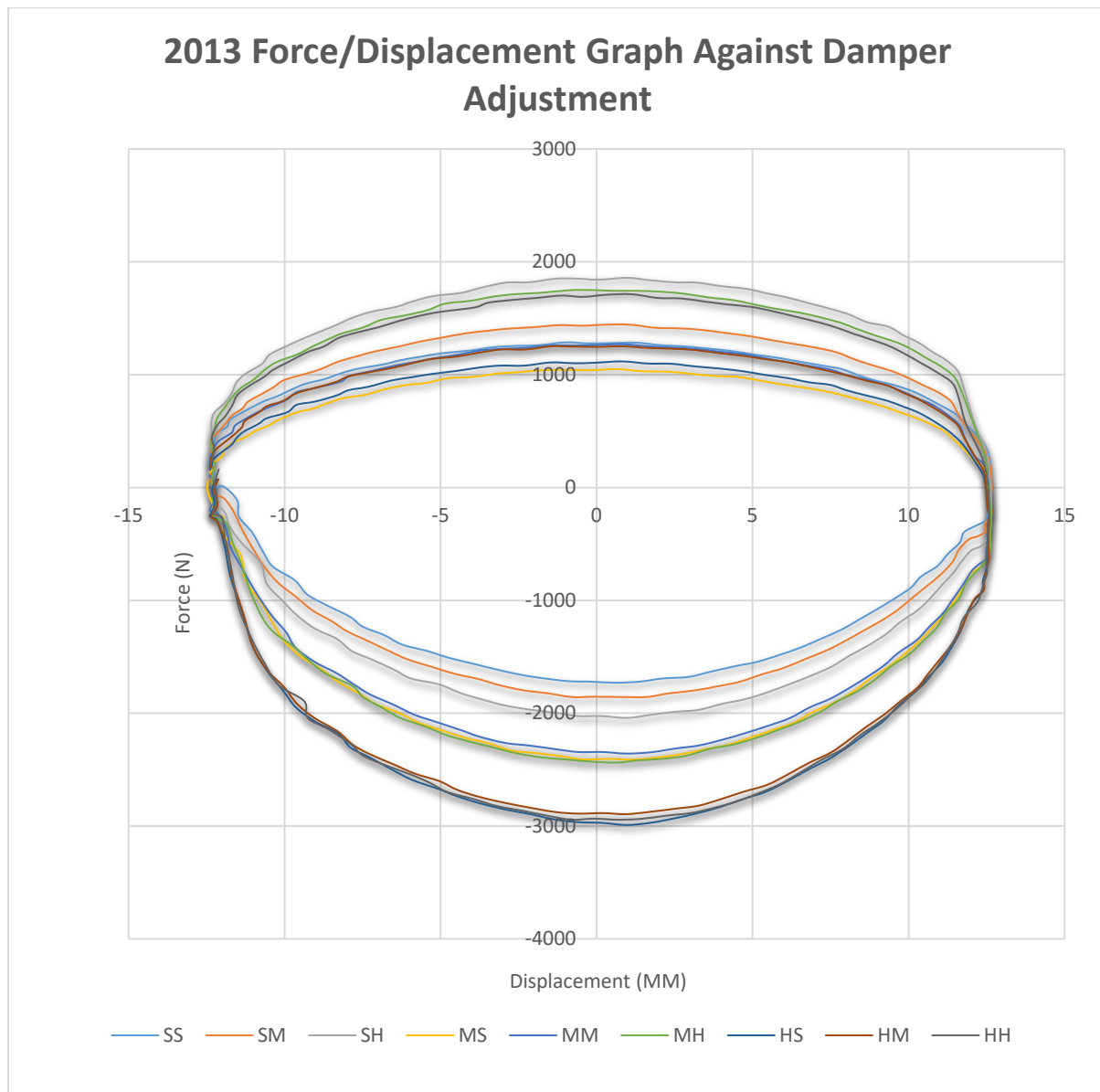


Figure 100, force/displacement graph

Showa Shock Absorber Investigation.

5. Work carried out and results.

Test 6.2 Advanced 2013 adjustment test.

Table 2 shows the results of test 5.2

R/C	ss	sm	sh	ms	mm	mh	hs	hm	hh	Max/Min
Max F (N)	1286.7	1443.73	1858.57	1049.99	1270.3	1750.76	1117.95	1251.55	1713.26	1858.57
Min F (N)	-1729.66	-1856.22	-2041.38	-2411.69	-2357.78	-2437.47	-2990.58	-2894.49	-2943.71	-2990.58
Max V (M/s)	235.55	235.38	234.77	235.17	234.98	235.37	234.42	233.81	233.85	235.55

Table 2, maximum and minimum force and maximum velocity figures from test 5.2

Both the compression and rebound maximum force figures occurred at a hard setting of each as expected. The maximum compression force occurred at the sh setting which was rebound Soft and Compression Hard. The maximum value of rebound damping occurred at the hs setting which was rebound Hard and compression Soft. This is confirmed by the graph in Figure 99. Maximum velocity occurred at the ss setting as to be expected. The fact that the two maximum values for force happened at the opposite ends of the setting spectrum suggests little interaction between settings as claimed by the manufacturer.

Showa Shock Absorber Investigation.

5. Work carried out and results.

Test 7.1 Advanced 2011 Pressure adjustment test.

As in test 5, an earlier test was repeated with the data being exported into Excel. Figure 101 shows the range of pressures tested in the 2011 shock absorber. These were 7.5, 10, 12.5 and 15 Bar. The rebound was set to soft as was the compression. A work done (J) equation was added to the data but the resulting graph merely showed the sinusoidal action of the dynamometer.

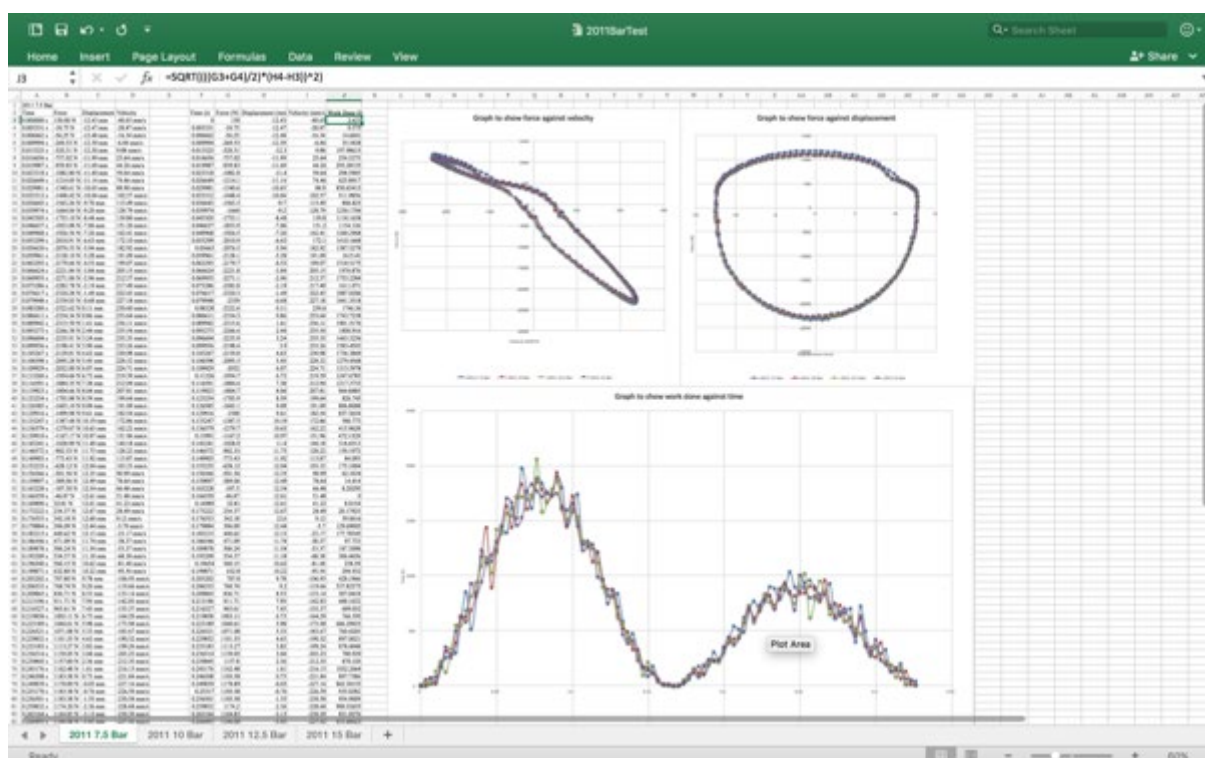


Figure 101, 2011 advanced pressure adjustment test

Showa Shock Absorber Investigation.

5. Work carried out and results.

Test 7.1 Advanced 2011 Pressure adjustment test.

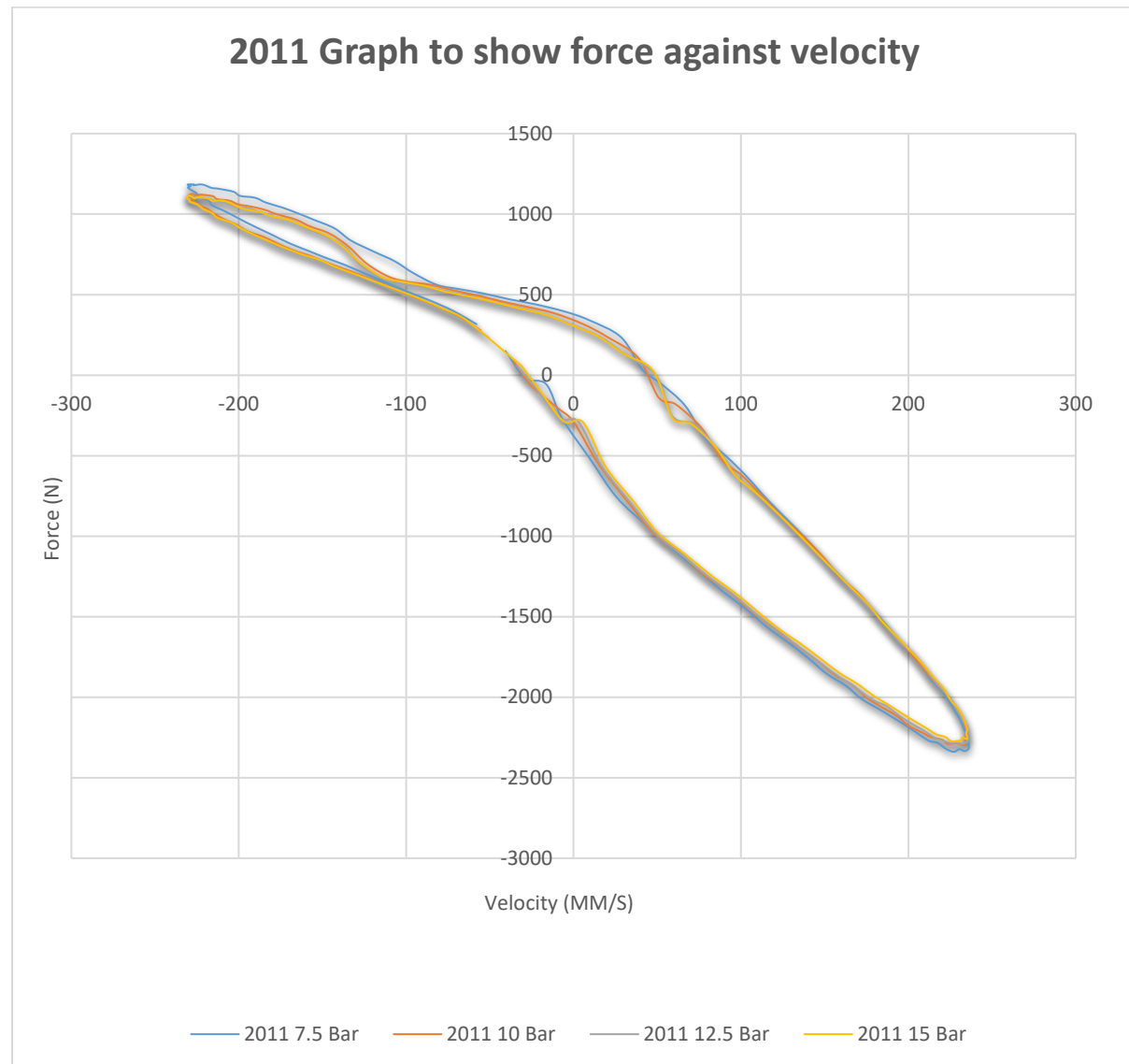


Figure 102, force/velocity graph

Figure 102 shows that the highest force is generated when the internal gas pressure was set to 7.5 Bar. The lowest forces appear to occur at 15 Bar.

Showa Shock Absorber Investigation.

5. Work carried out and results.

Test 7.1 Advanced 2011 Pressure adjustment test.

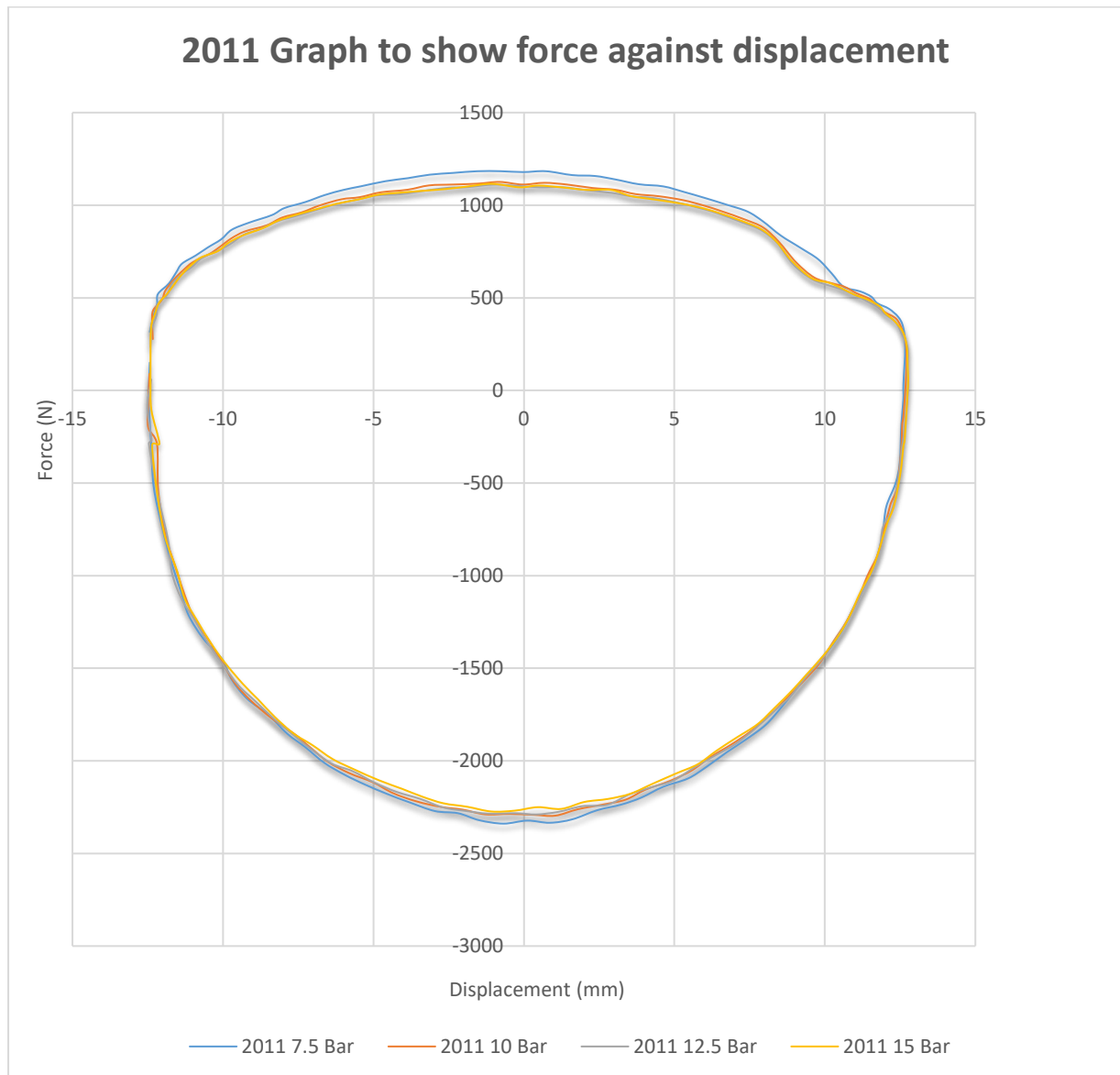


Figure 103, force/displacement graph

Showa Shock Absorber Investigation.

5. Work carried out and results.

Test 7.1 Advanced 2011 Pressure adjustment test.

Bar	7.5	10	12.5	15	Max/Min
Max F (N)	1183.58	1125.7	1111.14	1115.47	1183.58
Min F (N)	-2339.03	-2296.13	-2289.59	-2273.54	-2339.03
Max V (M/S)	236.11	234.76	235.55	235.15	236.11
Min V (M/S)	-230.58	-230.22	-230.8	-230.98	-230.98

Table 3, results of test 6.1

Table 3 shows the result of test 6.1, again the minus sign is an indication of direction rather than magnitude. The maximum force recorded for compression and rebound occurred at the lowest pressure of Nitrogen in the shock absorber. This was as expected as there is less pressure opposing the operation of the shock absorber causing less heat generation.

The highest shaft velocity was also at the lower pressure as expected.

Showa Shock Absorber Investigation.

5. Work carried out and results.

Test 7.2 Advanced 2013 Pressure adjustment test.

The test was repeated with the 2013 shock absorber, again the settings were rebound soft and compression soft. The results can be observed in Figure 104. Again, a work done graph was plotted but no conclusion drawn from it.

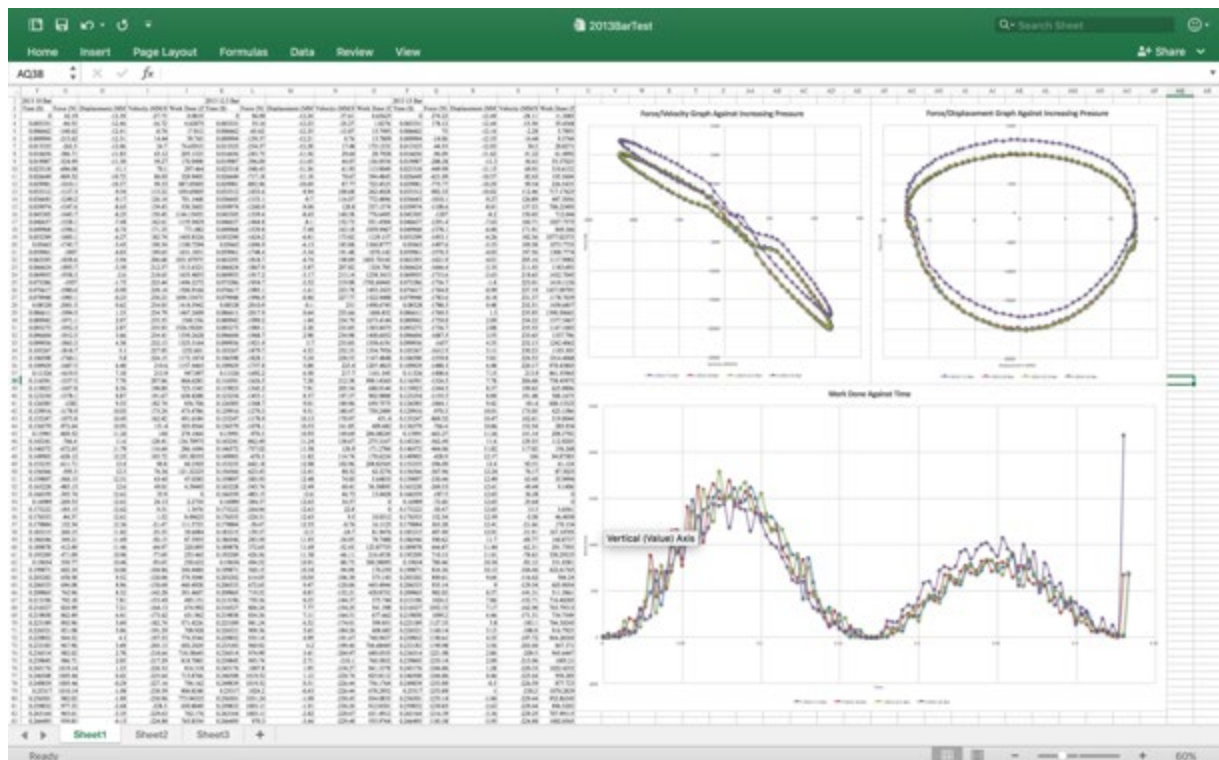


Figure 104, 2011 advanced pressure adjustment test

Showa Shock Absorber Investigation.

5. Work carried out and results.

Test 7.2 Advanced 2013 Pressure adjustment test.

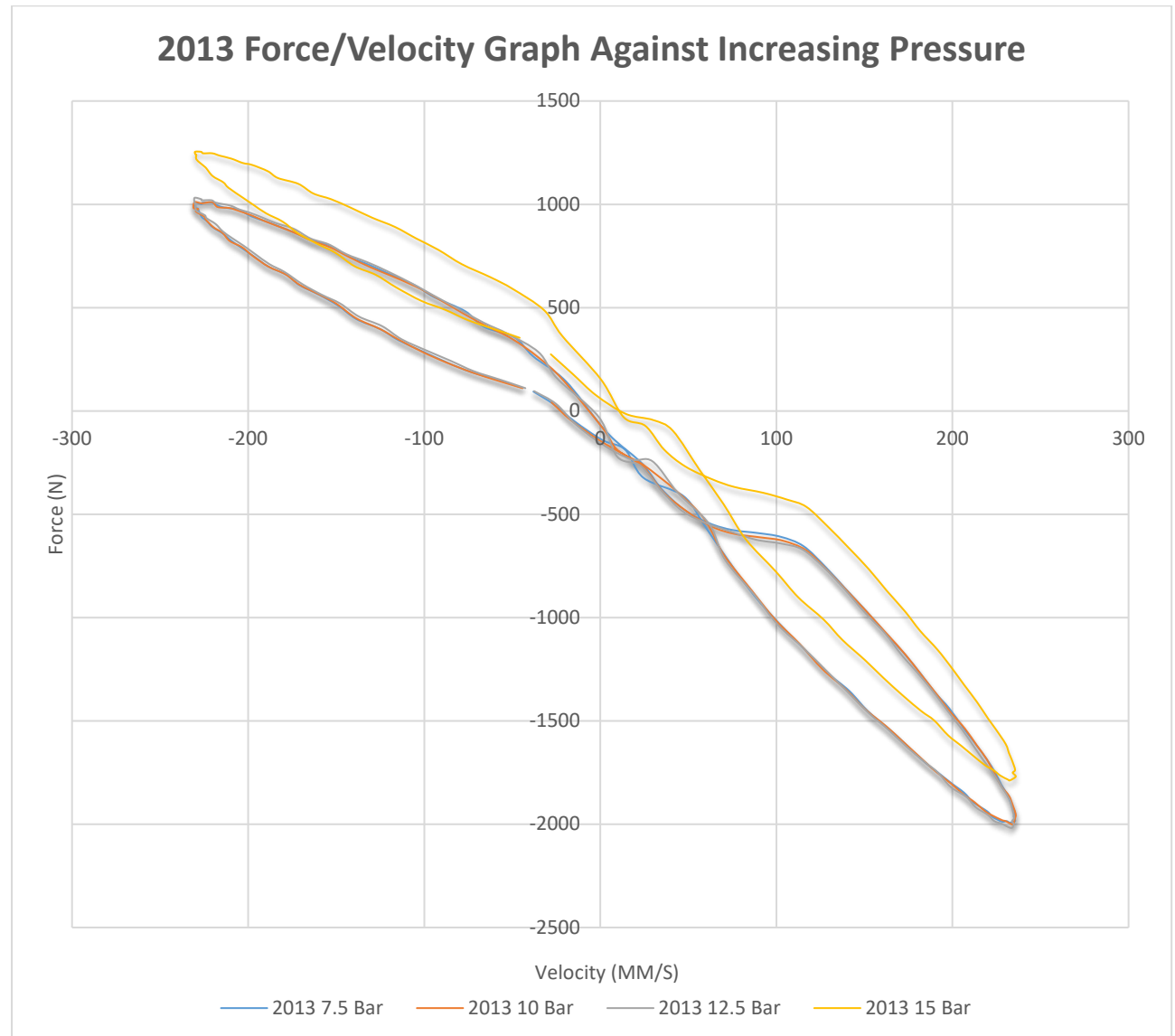


Figure 105, force velocity graph

Figure 105 shows a much more marked effect of pressure change with the 2013 shock absorber over the 2011 version. The force doesn't change much until the pressure was increased to 15 Bar. This is the other way around to the 2011 shock absorber. The large change at 15 bar would warrant further investigation.

Showa Shock Absorber Investigation.

5. Work carried out and results.

Test 7.2 Advanced 2013 Pressure adjustment test.

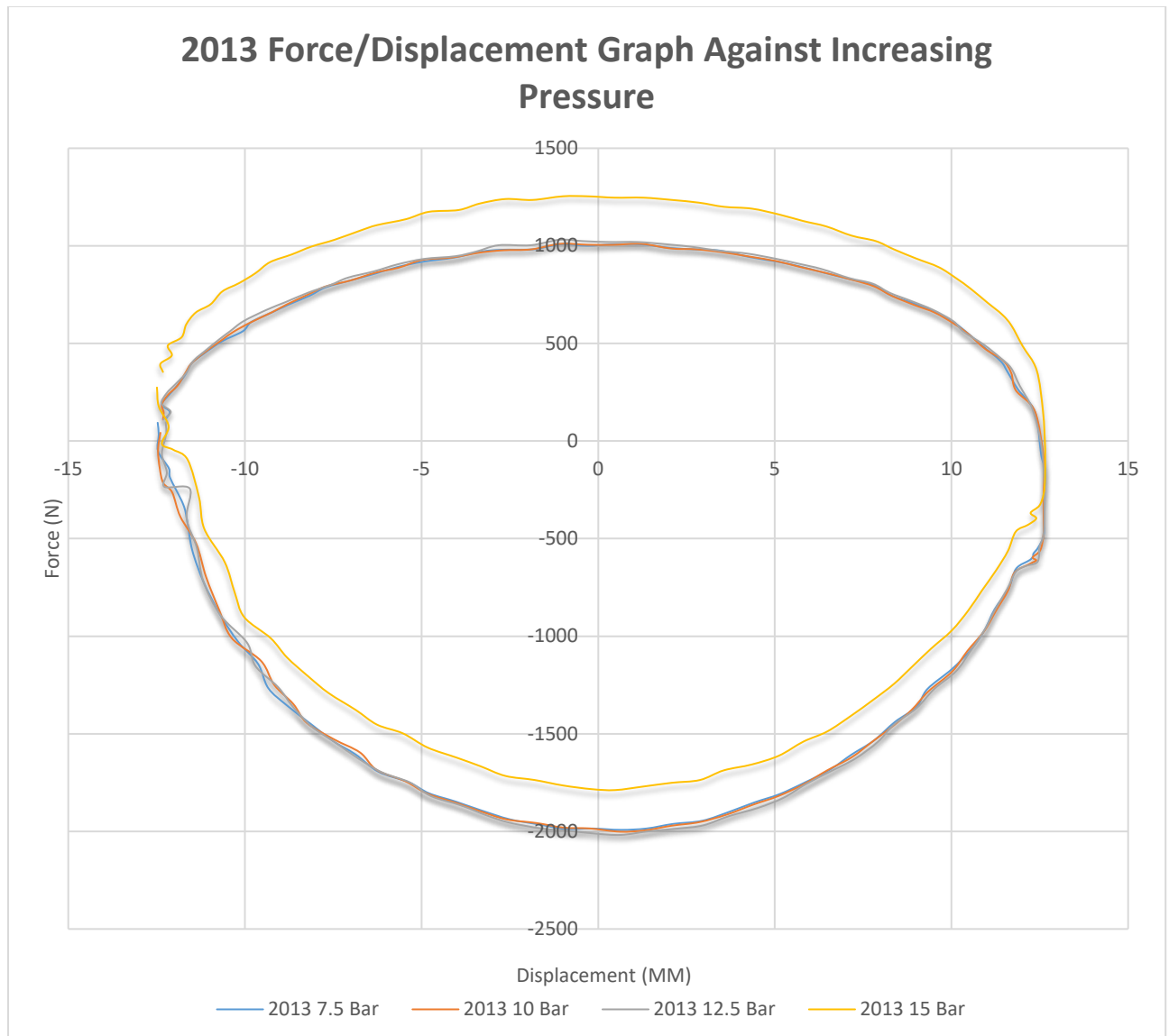


Figure 106, force/displacement graph

Showa Shock Absorber Investigation.

5. Work carried out and results.

Test 7.2 Advanced 2013 Pressure adjustment test.

Bar	7.5	10	12.5	15	Max/Min
Max F (N)	1007.8	1010.14	1031.24	1253.89	1253.89
Min F (N)	-1992.16	-2001.54	-2017.9	-1788.26	-2017.94
Max V (M/S)	235.55	235.93	234.98	235.93	235.93
Min V (M/S)	-230.23	-230.96	-230.43	-230.2	-230.96

Table 4, results of test 6.2

Test 6.2 yielded somewhat surprising results. The highest compression force was at the highest pressure and the highest rebound force at the second highest pressure. This is the opposite way to the 2011 shock absorber highlighting a fundamental difference in their design and the effect that has on operation. The large change that occurred at 15 Bar is of interest, what could be causing such an effect?

The highest recorded shaft velocity was at the highest pressure, the opposite way around to the 2011 shock absorber.

Showa Shock Absorber Investigation.

5. Work carried out and results.

Test 8 Temperature against frequency increase 2013 shock absorber.

During previous testing, it was noted that the shock absorber bodies transmitted heat generated from the work done input and transformed into heat via the damping. It was decided to begin to monitor temperatures during dynamometer testing. This was achieved by attaching by means of a Velcro strap, a thermocouple that is supplied with the dynamometer. The temperatures were manually recorded every 30 seconds for 300 seconds at a single speed setting of the dynamometer. This setting was chosen as the dynamometer will continue operating until the user stops it. The test was conducted at 1Hz and 2Hz. The resulting temperatures were then plotted in Excel (Figure 107).

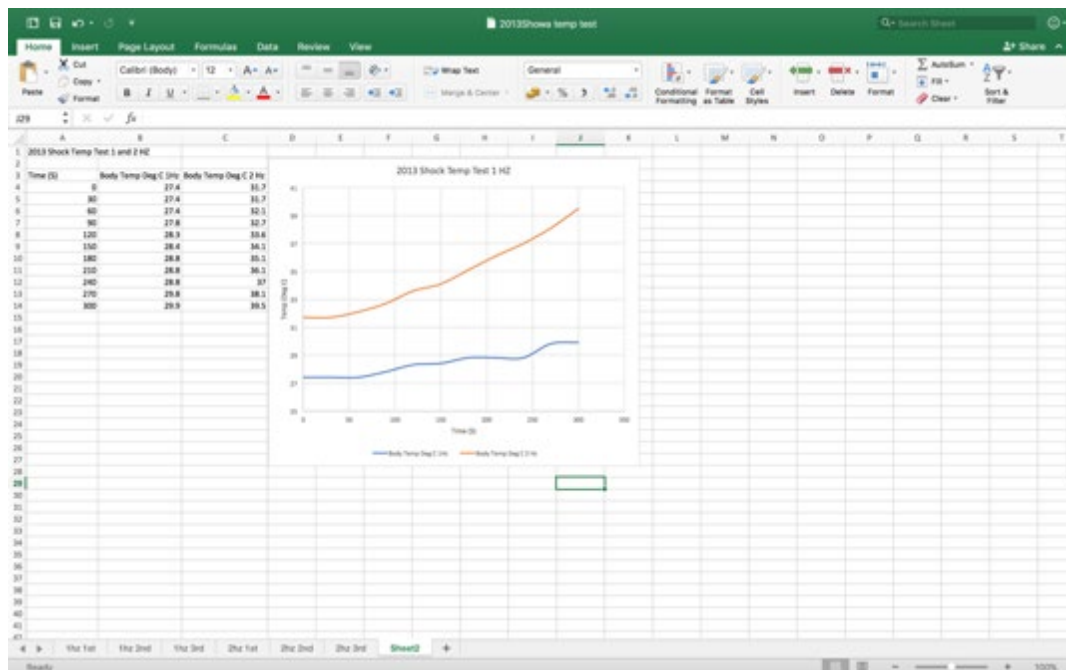


Figure 107, temperatures at 1Hz and 2Hz over 300 seconds, 2013 shock absorber

The temperature gain at 1Hz was 2.5°C, at 2Hz 7.8°C. This was not a surprise as the higher velocity within the damper would be expected to generate more work and thus more heat. Something that was noted and of interest was the 1Hz trace. The wave appearance suggested that something was happening within the shock absorber at 1Hz, whether that was a mechanical or thermal or combination of the two, needed investigating.

Showa Shock Absorber Investigation.

5. Work carried out and results.

Test 9 Temperature against frequency increase with oil temperature 2013 shock absorber.

The decision to investigate the temperature anomaly from test 7 led to the requirement to measure oil temperature. On the 2013 shock absorber there is a screw which is removed (Figure 108) with a torx driver. This has a yellow oil seal as seen in Figure 109 and 110.



Figure 108, screw hole



Figure 109, screws



Figure 110, thermocouple fitted



Figure 111, sealant applied



Figure 112, installed thermocouple



Figure 113, oil temperature reading

Showa Shock Absorber Investigation.

5. Work carried out and results.

Test 9 Temperature against frequency increase with oil temperature 2013 shock absorber.

Rather than risk damaging the original screw, it was taken to a bolt supplier in Swansea where 10 screws were purchased which were deemed to have the same thread and angle of chamfer. Using a pillar drill a 1.1mm hole was drilled through the centre of the screw. Also, a m10 bolt had the threaded portion cut off and the centre drilled through, also with a 1.1mm hole. The screw and bolt head were then bonded together (Figure 109). 10 of these were made for future use. Figure 110 shows a wire thermocouple passed through the hole and Figure 111 shows the wire bonded in place. The assembled part was left to cure overnight. The next day the thermocouple screw was installed into the shock absorber. As oil had escaped removing the screw and air admitted, the shock absorber required rebuilding. Each rebuild usually takes an hour minimum. The shock absorber was then subjected to a 1Hz continual dynamometer test and temperature of the oil observed (Figure 113).

The tests were conducted at 1 and 2Hz for 5 minutes with temperatures being recorded every 30 seconds. The work done was calculated and heat required for the temperature raise compared to the work put into the system. This was repeated 3 times for each frequency range tested to account for any inconsistency and the shock absorbers warmed up.

Showa Shock Absorber Investigation.

5. Work carried out and results.

Test 9 Temperature against frequency increase with oil temperature 2013 shock absorber.

Work done equations used in the creation of the final working Excel workbook:

Work done:

$$\sqrt{\left(\frac{\left(\frac{D1}{1000}\right)+\left(\frac{D2}{1000}\right)}{2}\right)*\left(F2-F1\right))^2}=J \quad (32)$$

Where:

D1 = Displacement 1 (M)

D2 = Displacement 2 (M)

F1 = Force 1 (N)

F2 = Force 2 (N)

Heat into oil:

$$(Specific\ Heat_{oil} * Mass_{oil}) * (T2 - T1) = KJ/Kg.K \quad (33)$$

Where:

T1 = Temperature 1 (C°)

T2 = Temperature 2 (C°)

Heat into body:

$$(Specific\ Heat_{body} * Mass_{body}) * (T2 - T1) = KJ/Kg.K \quad (34)$$

Specific heat of oil supplied by Fuchs-Silkolene.

Specific heat and density of die cast aluminium shock absorber body researched from CES Edupack, available from UWTSD computers. Data was also found as in Figure 114:

		Austenitic casting alloys												Bismuth		
		ASTM						BS						DIN		
		A312			A314			A315			A316			A317		
		PSL	PSL	PSL	PSL	PSL	PSL	PSL	PSL	PSL	PSL	PSL	PSL	PSL	PSL	PSL
		1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P
		1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P
		1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P
		1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P
		1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P
		1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P
		1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P
		1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P
		1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P
		1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P
		1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P
		1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P
		1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P
		1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P
		1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P
		1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P
		1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P
		1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P
		1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P
		1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P
		1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P
		1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P
		1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P
		1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P
		1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P
		1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P
		1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P
		1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P
		1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P
		1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P
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		1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P
		1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P
		1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P
		1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P
		1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P
		1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P
		1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P
		1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P
		1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P
		1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P
		1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P
		1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P
		1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P
		1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P
		1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P
		1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P
		1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P	1/2 P
		1/2 P	1/2 P	1												

Figure 114, die cast aluminium properties, <http://www.alteams.com/alteams-tech-centre/design-assistance/cast-aluminium-properties.html> [Accessed 2017]

Showa Shock Absorber Investigation.

5. Work carried out and results.

Test 9 Temperature against frequency increase with oil temperature 2013 shock absorber.

Work done equations used in the creation of the Excel workbooks:

Heat from oil to body:

$$\text{Work done} - \text{heat into oil} = J \quad (35)$$

Heat from body to air:

$$\text{Work done} - \text{heat into body} = J \quad (36)$$

Enthalpy, h, oil to body:

$$\left(\frac{\text{Heat oil to body}}{\text{Area of inner surface}} \right) * \text{Heat from oil to body} * 180s = \text{Kj/Kg.K} \quad (37)$$

Enthalpy, h, body to air:

$$\left(\frac{\text{Heat body to air}}{\text{Area of outer surface}} \right) * \text{Heat from body to air} * 180s = \text{Kj/Kg.K} \quad (38)$$

Where:

T = 180 = Seconds

Inner and outer surface area of shock bodies calculated from GOM software.

Heat transfer rate Q oil to body:

$$h * \text{Area of inner surface} * \text{Heat from oil to body} = \text{Kj/Kg.K} \quad (39)$$

Heat transfer rate Q body to air:

$$h * \text{Area of outer surface} * \text{Heat from body to air} = \text{Kj/Kg.K} \quad (40)$$

Showa Shock Absorber Investigation.

5. Work carried out and results.

Test 9 Temperature measured against frequency increase with oil temperature 2013 shock absorber.

The dyno data was exported in the usual manner and combined with temperature measurements to produce the workbook seen in Figure 115.

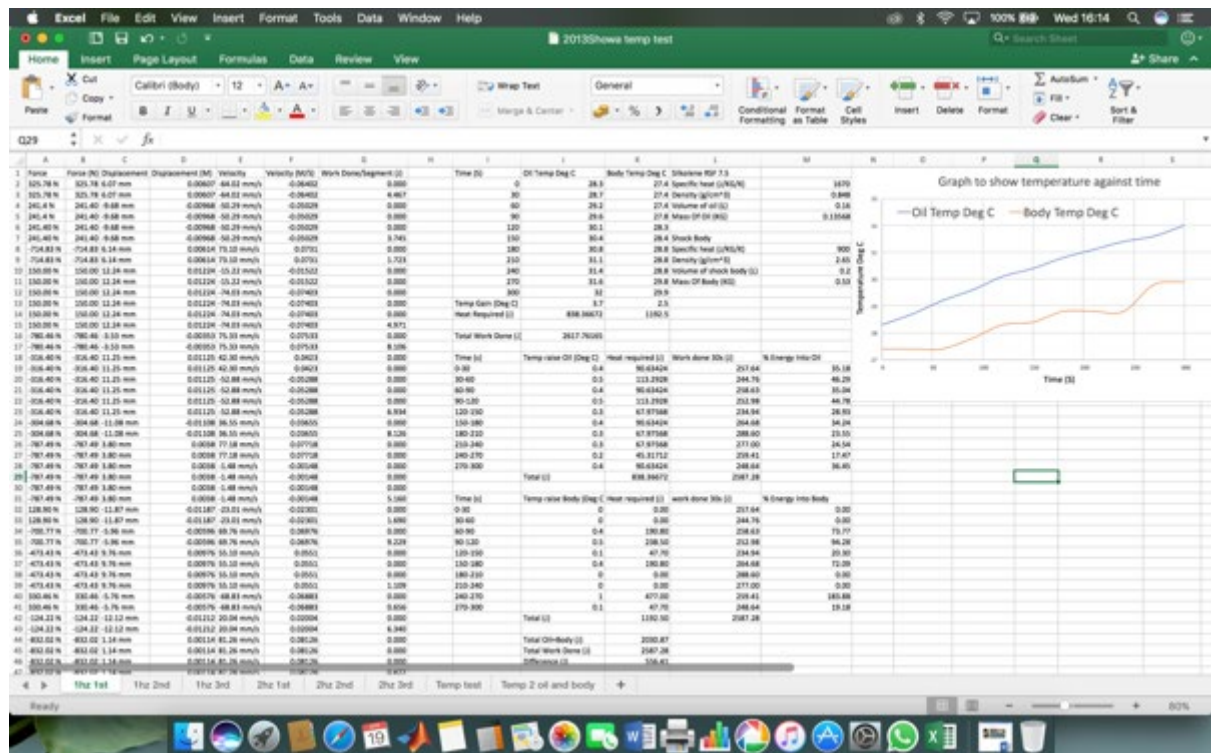


Figure 115, work done, oil and shock absorber body temperature workbook 1Hz 1st run

Total work done was 2587 J and the heat required was 2030.87 J, leaving a lost heat of 556.41 J. This could be down to frictional loss as well as heat transferred to the air.

Showa Shock Absorber Investigation.

5. Work carried out and results.

Test 9 Temperature against frequency increase with oil temperature 2013 shock absorber.

Figure 116 shows the Excel workbook for 1Hz 2nd run.

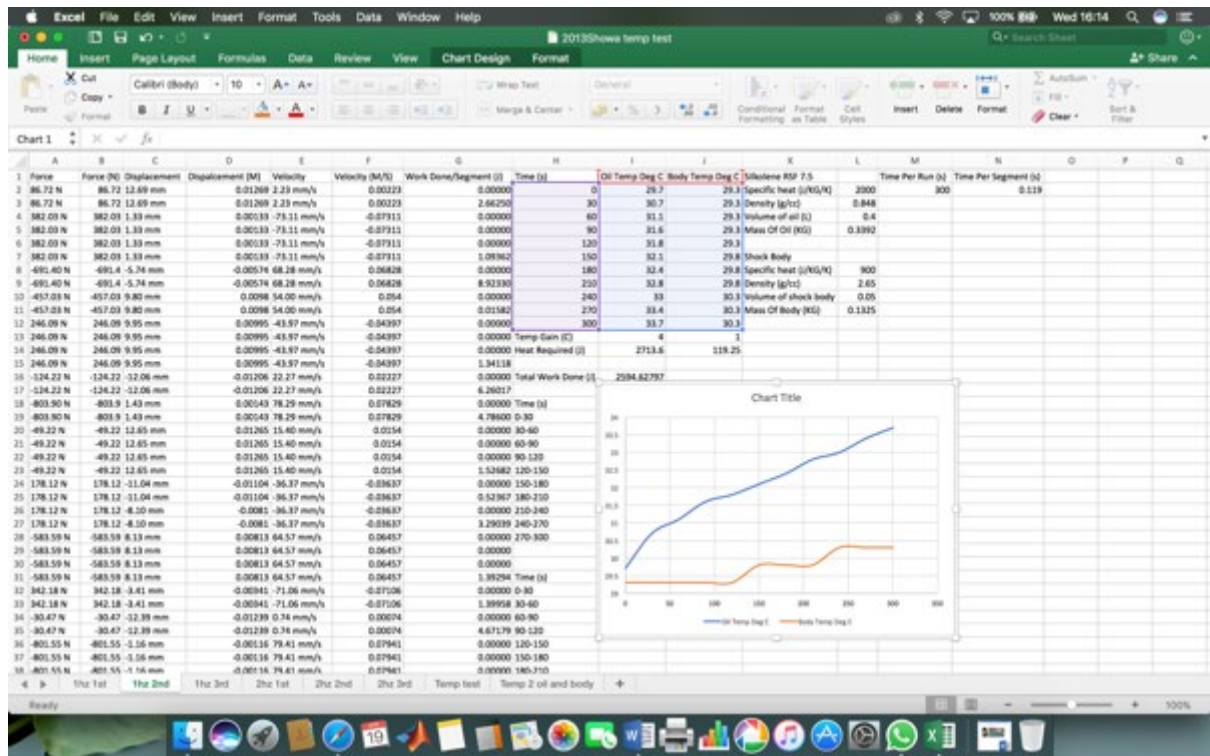


Figure 116, work done, oil and shock absorber body temperature workbook 1Hz 2nd run

Total work done was 2594.63 J and the heat required was 2832.85 J, leaving an energy deficit of 238.22 J. This means that more heat was produced than was created, which is not possible. This could be an erroring temperature reading.

Showa Shock Absorber Investigation.

5. Work carried out and results.

Test 9 Temperature against frequency increase with oil temperature 2013 shock absorber.

Figure 118 shows the 1st run at 2Hz

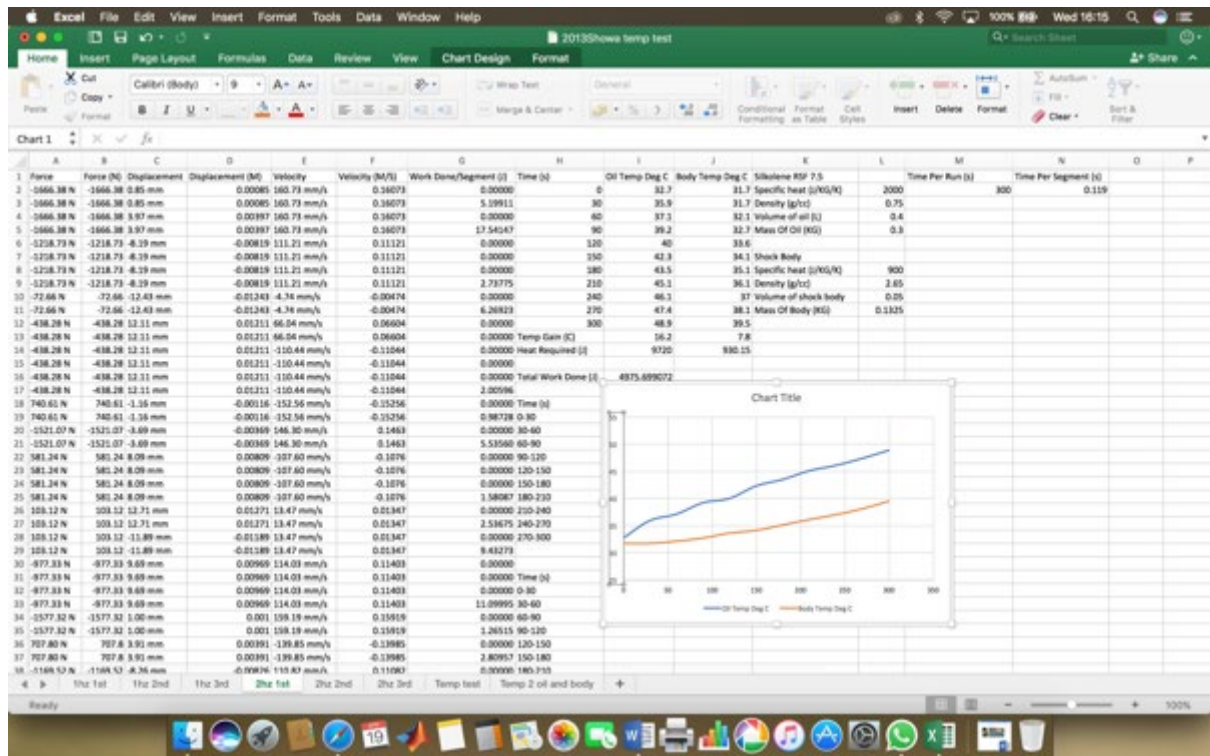


Figure 118, work done, oil and shock absorber body temperature workbook 2Hz 1st run

Total work done was 4975.70 J and the heat required was 10650 J, leaving an energy deficit of 5674.3 J. This and subsequent tests at 2Hz yielded similar results so there was obviously something incorrect with the testing method. The wave pattern was not apparent in the body temperature trace.

At 1Hz the wave pattern to the temperature trace persisted, could this anomaly be something effecting the results? The mechanical aspect was thought to be connected to the compression and rebound assembly which has an oil path leading to the reservoir. It was thought it a possibility that cooler oil was somehow being introduced through the valve assembly and into the rest of the oil effecting the body temperature. There is an oil way leading from and to the valving assembly so it was decided to install two thermocouples through the shock body to monitor these incoming and outgoing oil streams. This forms the basis of test 9.

Showa Shock Absorber Investigation.

5. Work carried out and results.

Test 10 Temperature against frequency increase with oil temperature 2013 shock absorber with two oil temperature measurements.

The 2013 shock absorber was dismantled and thoroughly cleaned then 2 suitable positions for drilling into the shock body decided upon. Two 1.5mm metal body thermocouples were obtained from John Kinsella in the motorcycle workshop, 1.5mm holes drilled in the shock body and once again thoroughly cleaned. When dry, the thermocouples were fitted and bonded in place with Araldite 2-part clear epoxy resin. This was allowed to set for 24 hours as per the instructions. The shock was then reassembled and installed into the dynamometer. Figure 119 shows the 2013 shock absorber with twin thermocouples installed and figure 120 shows the two temperature readings observed.



Figure 119, twin thermocouples



Figure 120, twin thermometers

Showa Shock Absorber Investigation.

5. Work carried out and results.

Test 10 Temperature against frequency increase with oil temperature 2013 shock absorber with two oil temperature measurements.

The tests were completed at 1 and 2Hz and also with the low speed adjusters both set to soft and then to hard to see the effect on temperatures. Pressure was set to the recommended 6 bar. The results are observed in Figure 121.

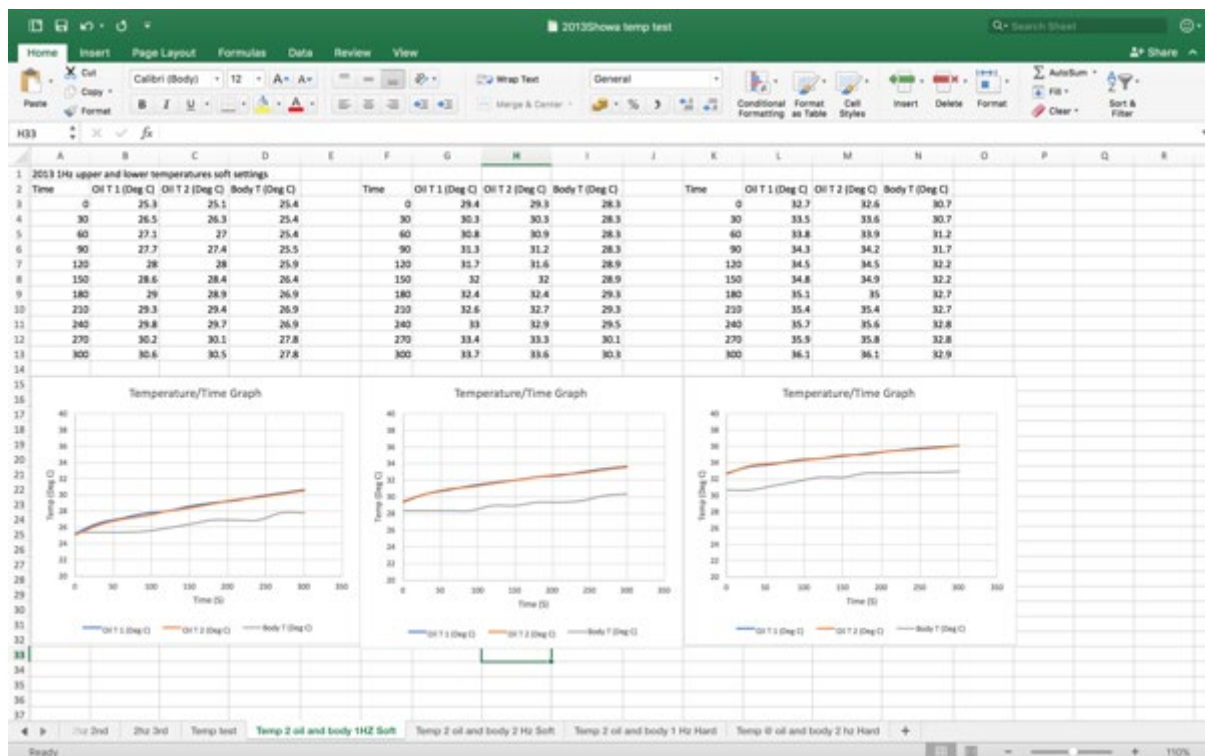


Figure 121, test at 1Hz, adjusters set to soft

The test was repeated 3 times for constancy and to observe the anomaly with regards to the wave in the 1Hz trace. At 1Hz with the adjusters set to soft, the wave pattern persisted and the shock absorber got progressively warmer with subsequent dynamometer runs. The oil temperatures stayed very consistent with each other.

The average temperature gain of the shock body between runs was 2.2°C

The average temperature gain of the oil was 4.35°C

It was noted that as the oil and body got warmer the rate of increase decreased.

Showa Shock Absorber Investigation.

5. Work carried out and results.

Test 10 Temperature against frequency increase with oil temperature 2013 shock absorber with two oil temperature measurements.

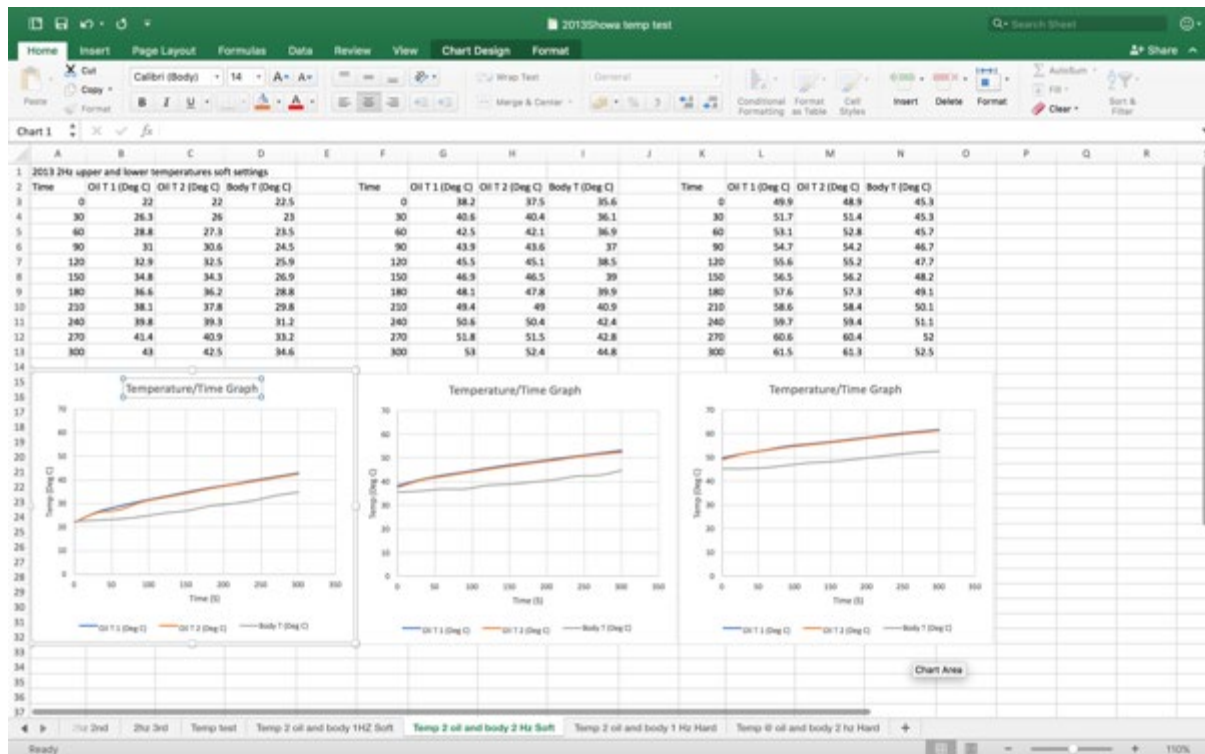


Figure 122, test at 2Hz, adjusters set to soft

Figure 122 shows the results when the frequency was set to 2Hz and the low speed adjusters set to soft. As in the previous test at 1Hz and soft, the oil temperatures were almost identical and the wave observed in the body temperature was reduced, as found in test 8.

The average temperature gain of the shock body between runs was 9.5°C

The average temperature gain of the oil between runs was 15.87°C

It was noted that as the oil and body got warmer the rate of increase decreased.

Showa Shock Absorber Investigation.

5. Work carried out and results.

Test 10 Temperature against frequency increase with oil temperature 2013 shock absorber with two oil temperature measurements.

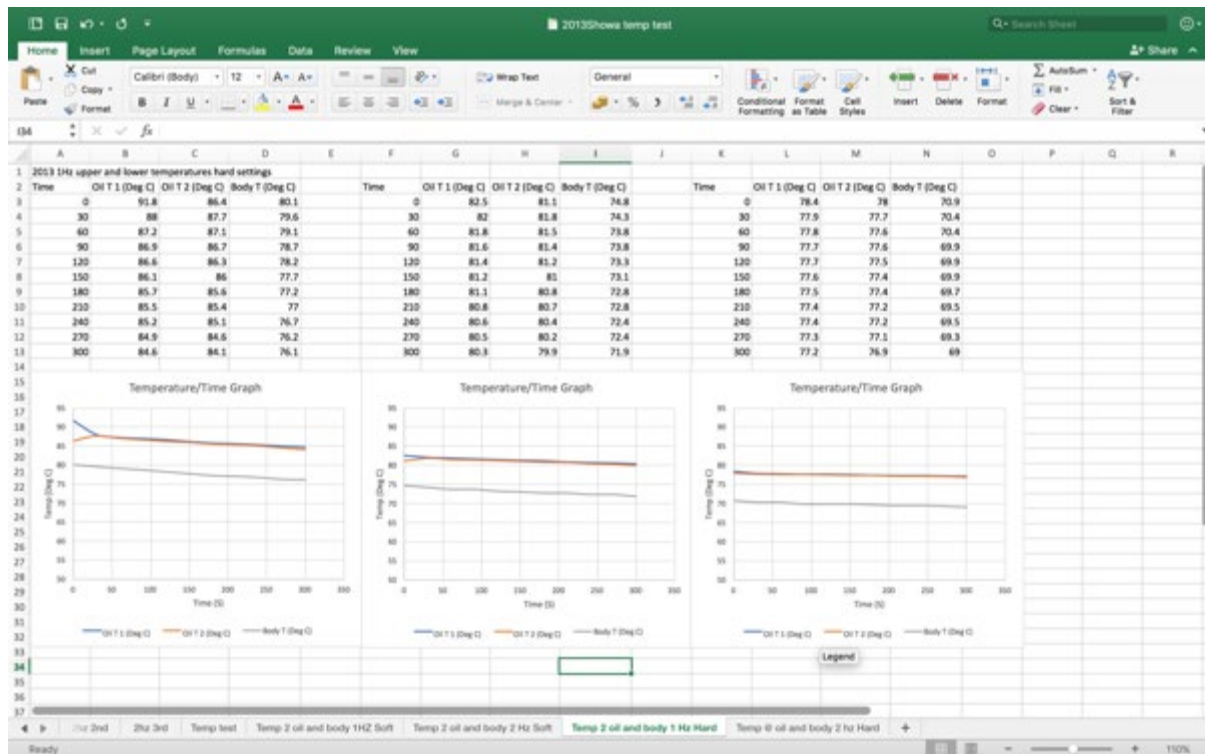


Figure 123, test at 1Hz, adjusters set to hard

Figure 123 shows the results when the frequency was set to 1Hz and the low speed adjusters set to hard. As in the previous test at 1Hz and soft, the oil temperatures were almost identical and the wave observed in the body temperature was reduced.

The average temperature gain of the shock body between runs was 2.93°C

The average temperature loss of the oil between runs was 2.53°C

This test highlighted the effect of shaft velocity within the damper, at a lower velocity than at 2Hz previous, the shock absorber was losing heat at a faster rate than could be generated by the work done. As the oil and body cooled the rate of temperature reduction reduced between runs.

Showa Shock Absorber Investigation.

5. Work carried out and results.

Test 10 Temperature against frequency increase with oil temperature 2013 shock absorber with two oil temperature measurements.

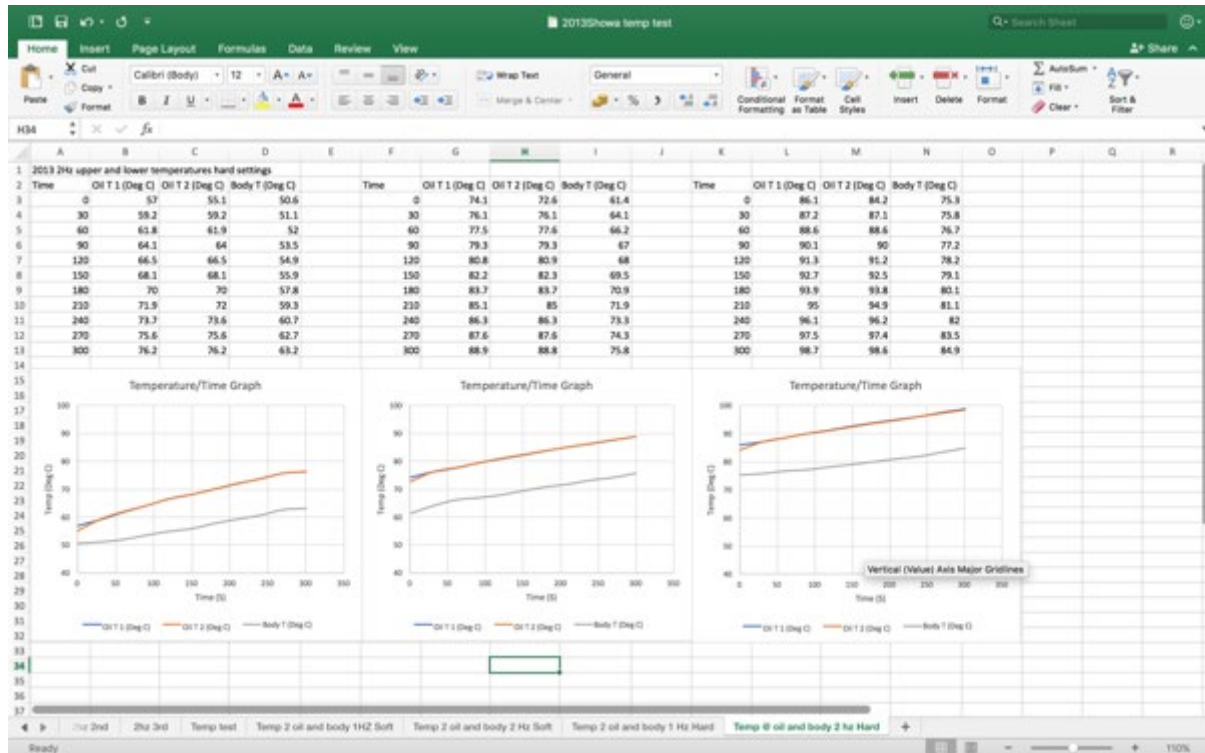


Figure 124, test at 2Hz, adjusters set to hard

Figure 124 shows the results when the frequency was set to 2Hz and the low speed adjusters set to hard. As in the previous test at 2Hz and soft, the oil temperatures were almost identical and the wave observed in the body temperature was reduced, as found in test 8.

The average temperature gain of the shock body between runs was 12.2°C

The average temperature gain of the oil between runs was 15.58°C

It was noted that as the oil and body got warmer the rate of increase decreased, apart for an anomaly on the second run where the rate of body temperature gain increased but then decreased with the next run.

Showa Shock Absorber Investigation.

5. Work carried out and results.

Test 10 Temperature against frequency increase with oil temperature 2013 shock absorber with two oil temperature measurements.

The results from this test (9) show that the temperature anomaly in the shock body temperature trace must be down to heat transfer and not a mechanical feature of the 2013 shock absorber. The differing heat transfer rates were of interest, requiring further investigation. The 2013 shock absorber was once again dismantled to remove one of the thermocouples as was now redundant. This was installed into the 2011 shock absorber in the same manner as the drilling method for the 2013 shock absorber. There was not a screw present to gain access to the oil so this was a necessary procedure. The same tests were to be conducted to compare to the 2013 shock absorber. The two shock absorbers were reassembled and left overnight for testing the following day. Unfortunately, both shock absorbers were found to be leaking through the epoxy resin, this meant both units require dismantling again and the old resin removing. JB Weld metal 2-part adhesive was purchased allowing the two shock absorbers to have the thermocouples installed. The units were left for 24 hours to allow the resin to cure, then both units reassembled. The shock absorbers can be seen in Figure 125.



Figure 125, 2013 and 2011 shock absorbers with thermocouples installed

Showa Shock Absorber Investigation.

5. Work carried out and results.

Problems!

The 2011 shock absorber was fitted to the dynamometer and tested at 1Hz. This was set to continuous to check for leaks and the dynamometer graphs used to check for hysteresis.

Unfortunately, the shock absorber started leaking through the JB Weld and along the thermocouple. The unit was once again dismantled, cleaned and the old resin removed. The thermocouple was then refitted with much more JB Weld around the thermocouple shaft and force into the hole around it. This was allowed to set for 24 hours before rebuilding the shock absorber and attempting the test again. The same problem occurred. Again, an attempt was made to seal the shock absorber, this time another layer of JB Weld was applied after the 24 hours curing time. This was left to cure. The unit was rebuilt yet again and yet again leaked. A more professional and hopefully leak free solution was sought. Thermocouple fittings were purchased from TC Direct by mail order. When these arrived, it was evident that they would not fit the application.

It was at that point the investigation had to change. The 2011 shock absorber could no longer be used, changing somewhat the brief. It was decided to continue with the new-found investigation of heat transfer and viscosity utilising the 2013 shock absorber.

Showa Shock Absorber Investigation.

5. Work carried out and results.

Test 11 Thermal imaging camera test.

Figure 126 is screen shot of the Excel workbook showing results of a trial with a thermal imaging camera made available by Dr Peter Charlton, lecturer at UWTSD Swansea.

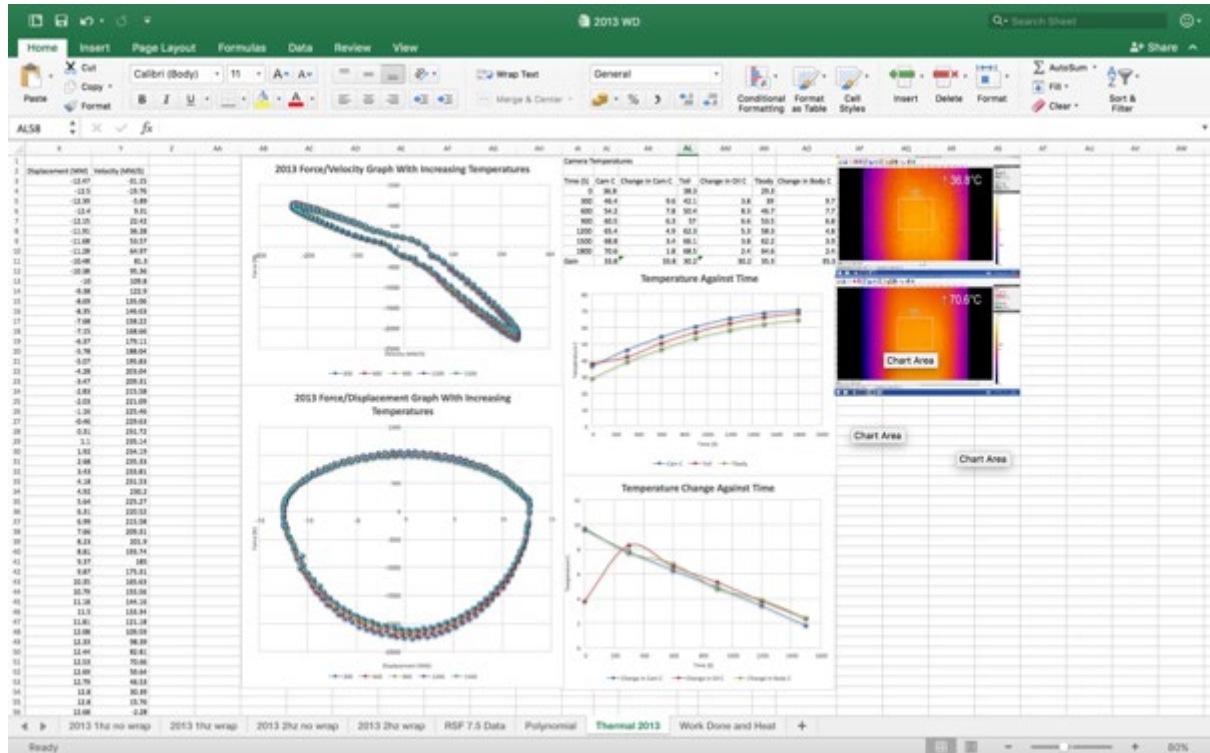


Figure 126, thermal imaging camera workbook

The 2013 shock absorber was installed into the dynamometer and ran at 1Hz for 1800 seconds with oil, body and thermal imaging camera temperatures recorded at 300 second intervals. The results of which were plotted along with force/velocity and force/displacement graphs, exporting and processing the dynamometer in the usual manner. The camera read an initially higher temperature than the body temperature but the increases were very similar. The overall temperature gain recorded by the thermal imaging camera was 33.8°C, the overall gain of the body temperature was 35.3°C. This together with the very similar graphs meant that there was no advantage to using the thermal imaging camera for the external temperature monitoring over the dynamometer thermocouple.

Showa Shock Absorber Investigation.

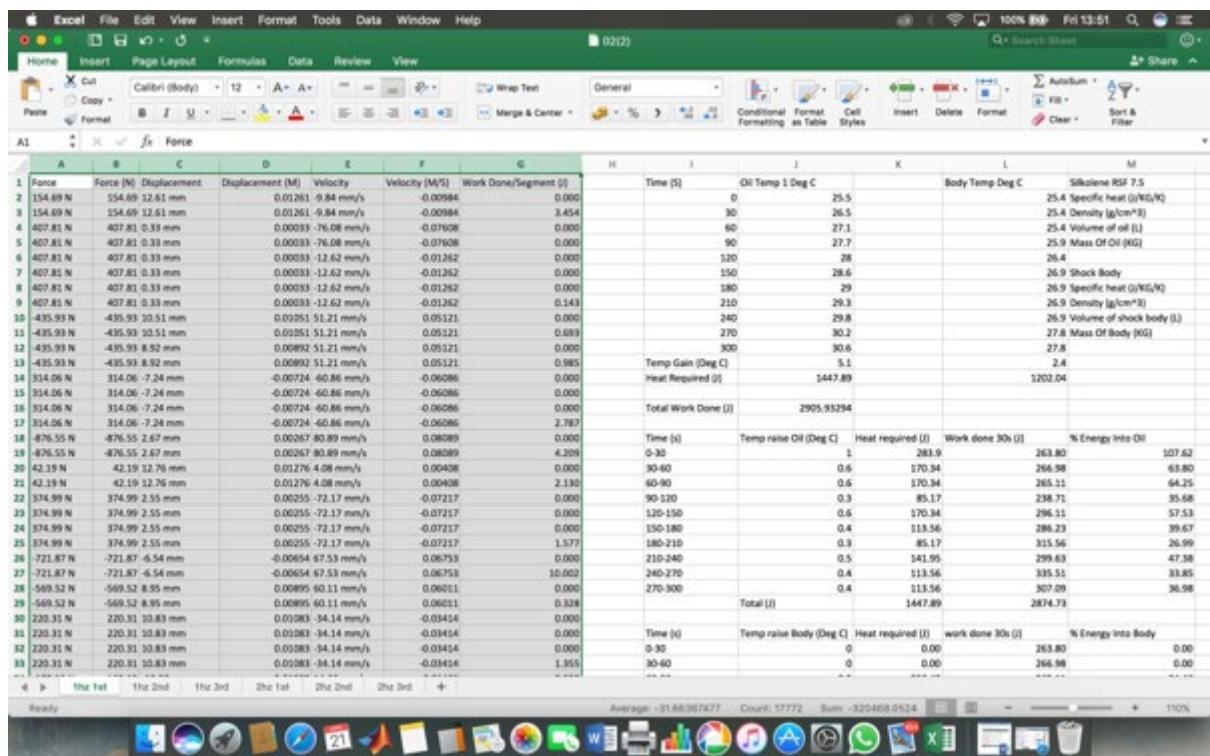
5. Work carried out and results.

Test 12.1 Frequency, temperature and work done.

The dynamometer was set to single speed control and data taken at 1 and 2Hz, three times each to check for anomalies.

After a day of testing and the following time required for processing the data into Excel it was evident that there was a problem. The energy required to generate the temperature when the dyno was operated at 2Hz was much higher than the actual work done. This would indicate a major problem with the sampling of data from the dynamometer. This was also observed in test 8. It was not at first noticed the repeating of Force, Displacement and Velocity figures until the work done per segment was generated. Some of the segments returned a negative work done figure which was corrected by using the performing a square root function followed by squaring the answer to eliminate the negative figure. This must have been the cause of achieving less work done than anticipated to allow the measured heat generation. This along with the poor graph generation from test 3, led to the reasoning that the single speed method as used was not suitable for his kind of investigation.

Figure 127 is a screen shot of the workbook highlighting this issue.



Showa Shock Absorber Investigation.

5. Work carried out and results.

Test 12.1 Frequency, temperature and work done.

It was decided to try the 1-3 Hz sampling method. The problem with this is that the dynamometer only records 1 sample at a time and will not store the data required over a longer time span. SPA technical department were contacted however, they could not offer a solution. The sampling rate was 0.33000s and this was the amount of data stored within that time frame each time. Changing the number of samples required in the software drop-down box had no effect, the dynamometer would only record one sampling rate at a time.

The ongoing experiment was split into 30 second intervals over 300 seconds, this was the times at which the temperatures were recorded. An averaging method was devised whereby the data would be extracted at the end of a 300s run, the work done calculated and multiplied by 900 to achieve work done in 300 seconds as there were 900 samples in 300 seconds. Figure 128 shows the work done at the end of a sample taken after 300 seconds.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
72	0.226521 s	1084.59 N	5.45 mm	-183.65 mm/s		0.226521	1084.59	5.45	0.00545	-183.65	-0.18165	0.7046368							
73	0.229852 s	1117.40 N	4.81 mm	-188.82 mm/s		0.229852	1117.4	4.81	0.00481	-188.82	-0.18882	0.905172							
74	0.233183 s	1145.53 N	4.01 mm	-197.37 mm/s		0.233183	1145.53	4.01	0.00401	-197.37	-0.19737	0.9026511							
75	0.236514 s	1168.96 N	3.23 mm	-204.02 mm/s		0.236514	1168.96	3.23	0.00323	-204.02	-0.20402	0.83661785							
76	0.239845 s	1187.71 N	2.52 mm	-209.72 mm/s		0.239845	1187.71	2.52	0.00252	-209.72	-0.20972	0.8670283							
77	0.243176 s	1187.71 N	1.79 mm	-215.99 mm/s		0.243176	1187.71	1.79	0.00179	-215.99	-0.21599	1.0554984							
78	0.246508 s	1211.55 N	0.91 mm	-219.03 mm/s		0.246508	1211.55	0.91	0.00091	-219.03	-0.21903	0.9800838							
79	0.249839 s	1208.81 N	0.10 mm	-226.44 mm/s		0.249839	1208.81	0.1	0.0001	-226.44	-0.22644	0.8196006							
80	0.253170 s	1205.78 N	-0.58 mm	-235.68 mm/s		0.25317	1205.78	-0.58	-0.00508	-235.68	-0.23568	0.842884							
81	0.256501 s	1206.46 N	-1.28 mm	-231.30 mm/s		0.256501	1206.46	-1.28	-0.00128	-231	-0.231	1.1197562							
82	0.259832 s	1176.00 N	-2.21 mm	-229.10 mm/s		0.259832	1176	-2.22	-0.00222	-229.1	-0.2291	0.85674815							
83	0.263164 s	1171.31 N	-2.95 mm	-230.34 mm/s		0.263164	1171.31	-2.95	-0.00295	-230.34	-0.23034	0.6268104							
84	0.266495 s	1150.21 N	-3.49 mm	-238.72 mm/s		0.266495	1150.21	-3.49	-0.00349	-238.72	-0.23872	1.0008416							
85	0.269826 s	1124.43 N	-4.37 mm	-236.82 mm/s		0.269826	1124.43	-4.37	-0.00437	-236.82	-0.23682	0.842992							
86	0.273157 s	1093.97 N	-5.13 mm	-234.92 mm/s		0.273157	1093.97	-5.13	-0.00513	-234.92	-0.23492	0.7551145							
87	0.276488 s	1063.50 N	-5.83 mm	-219.22 mm/s		0.276488	1063.5	-5.83	-0.00583	-219.22	-0.21922	0.6708896							
88	0.279820 s	1033.03 N	-6.47 mm	-217.51 mm/s		0.27982	1033.03	-6.47	-0.00647	-217.51	-0.21751	0.7058894							
89	0.283151 s	983.81 N	-7.17 mm	-210.48 mm/s		0.283151	983.81	-7.17	-0.00717	-210.48	-0.21048	0.6562408							
90	0.286482 s	946.31 N	-7.85 mm	-205.16 mm/s		0.286482	946.31	-7.85	-0.00785	-205.16	-0.20516	0.4620225							
91	0.289813 s	901.78 N	-8.35 mm	-197.56 mm/s		0.289813	901.78	-8.35	-0.00835	-197.56	-0.19756	0.4530812							
92	0.293144 s	840.84 N	-8.87 mm	-189.39 mm/s		0.293144	840.84	-8.87	-0.00887	-189.39	-0.18939	0.45343925							
93	0.296475 s	808.03 N	-9.42 mm	-180.47 mm/s		0.296475	808.03	-9.42	-0.00942	-180.47	-0.18047	0.5038893							
94	0.299807 s	742.41 N	-10.07 mm	-171.73 mm/s		0.299807	742.41	-10.07	-0.01007	-171.73	-0.17173	0.2428569							
95	0.303138 s	686.16 N	-10.43 mm	-161.66 mm/s		0.303138	686.16	-10.41	-0.01041	-161.66	-0.16166	0.263214							
96	0.306469 s	629.91 N	-10.81 mm	-151.02 mm/s		0.306469	629.91	-10.81	-0.01081	-151.02	-0.15102	0.24480895							
97	0.309800 s	564.28 N	-11.22 mm	-140.19 mm/s		0.3098	564.28	-11.22	-0.01122	-140.19	-0.14019	0.14444595							
98	0.313131 s	505.49 N	-11.49 mm	-127.85 mm/s		0.313131	505.49	-11.49	-0.01149	-127.85	-0.12785	0.11798935							
99	0.316463 s	442.41 N	-11.76 mm	-116.83 mm/s		0.316463	442.41	-11.76	-0.01176	-116.83	-0.11683	0.09393775							
100	0.319794 s	374.44 N	-11.99 mm	-102.77 mm/s		0.319794	374.44	-11.99	-0.01199	-102.77	-0.10277	0.10699495							
101	0.323125 s	315.85 N	-12.30 mm	-90.04 mm/s		0.323125	315.85	-12.3	-0.0123	-90.04	-0.09004	0.0332056							
102	0.326456 s	264.29 N	-12.38 mm	-75.23 mm/s		0.326456	264.29	-12.38	-0.01238	-75.23	-0.07523	0.004837							
103	0.329787 s	217.41 N	-12.36 mm	-61.17 mm/s		0.329787	217.41	-12.36	-0.01236	-61.17	-0.06117	0.0058896							
104	0.333118 s	175.23 N	-12.39 mm	-46.73 mm/s		0.333118	175.23	-12.39	-0.01239	-46.73	-0.04673								
105												Total Work (J)	64.2286238						
106	600s																		
107	0.000000 s	86.72 N	-12.43 mm	-41.79 mm/s		0	86.72	-12.43	-0.01241	-41.79	-0.04179	0.00670345							
108	0.003333 s	16.41 N	-12.54 mm	-29.63 mm/s		0.003333	16.41	-12.54	-0.01254	-29.63	-0.02963	0.0003984							

Figure 128, work done generated at the end of a sample

Showa Shock Absorber Investigation.

5. Work carried out and results.

Test 12.1 Frequency, temperature and work done.

The test was conducted and data exported to Excel where the workbook was compiled. The figures for work done were found to be of a disproportionate value to the heat generated, so advice was sought from Senior Lecturer Malcolm McDonald. This worry was confirmed and the test method deemed to be unsuitable. Figure 129 shows these figures.

Total work done = 941694.3725 J

Total heat measured = 35300.93408 J

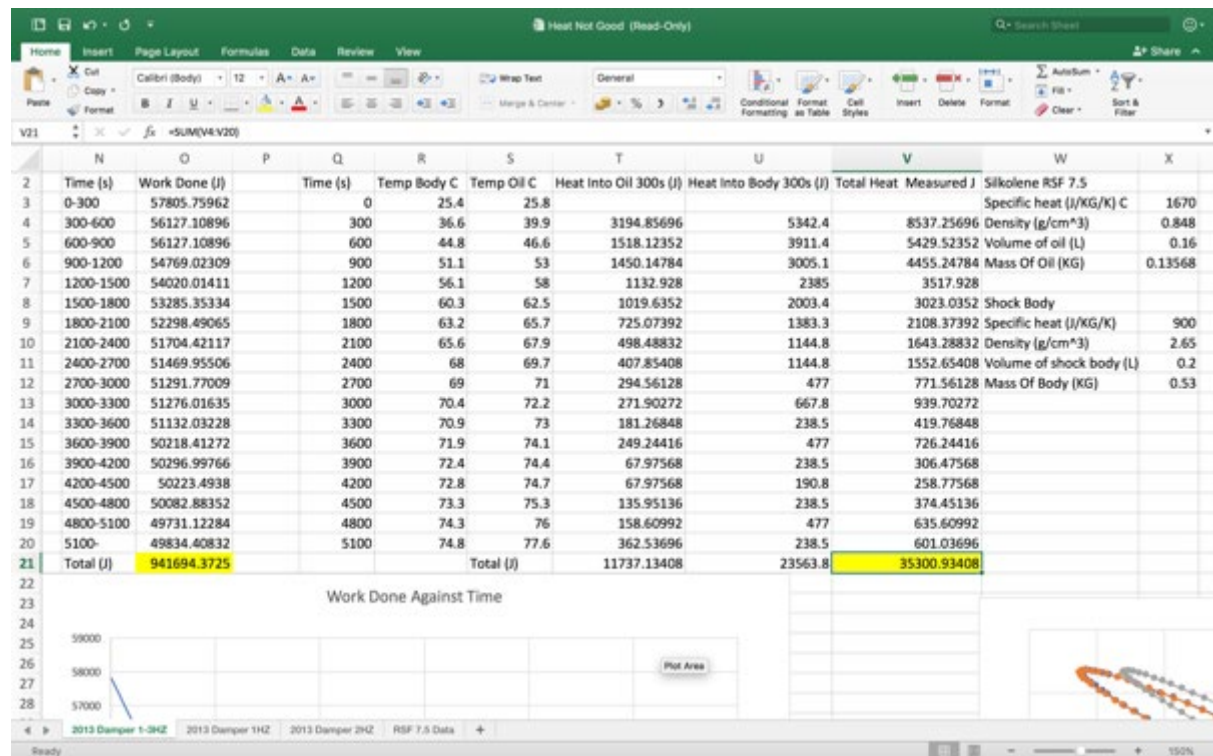


Figure 129, Excel workbook showing too high work done figures.

Showa Shock Absorber Investigation.

5. Work carried out and results.

Test 12.2 Frequency, temperature and work done.

The project had now encountered two major problems, one was a now non-functioning 2011 shock absorber for continuing comparison with the 2013 shock absorber. The second being no satisfactory way having been found to accurately and reliably measure and calculate the work done by the 2013 shock absorber to continue the investigation.

A day spent investigating the dynamometer handbook both paper copy and online copy yielded no answers. In desperation, every combination of setting available in the dynamometer were tried. Eventually a setting not thought of before was tried. In the multispeed setting where usually the setting is 1Hz starting speed and 3Hz final speed is entered, 1Hz starting speed and 1Hz final speed was tried. It was also found that the number of samples could be changed, up to 3000. This was immediately tested and timed, the dynamometer ran for 180 seconds and also recorded the entire sampling time. 2-2Hz could be used also with a sampling time of 90 seconds. A solution had been found that was not in the instruction manual or passed on as knowledge through SPA technical. A sample of the generated workbook can be seen in Figure 130. Unfortunately, there were now more than 20971 lines of data for each aspect of each sample meaning a lot of time and computer processing power were required to produce the working spreadsheet from the original exported data from the dynamometer.

	A	B	C	D	E	F	G	H	I	J	K
20955	179.867	360.93	0.48	-72.73	0.01029375	179.866961	374.99	0.12	-77.18	0.0054914	179.867
20956	179.8755	363.28	-0.23	-74.4	0.01397195	179.875546	372.65	-0.54	-76.07	0.005	179.8755
20957	179.8841	370.31	-0.9	-74.03	0.01583905	179.884131	372.65	-1.25	-77.37	0.01621285	179.8841
20958	179.8927	365.62	-1.59	-75.7	0.01	179.892716	365.62	-1.94	-75.14	0.0156932	179.8927
20959	179.9013	365.62	-2.26	-73.47	0.01	179.901301	360.93	-2.62	-75.7	0.02577365	179.9013
20960	179.9099	365.62	-2.94	-74.21	0.0405462	179.909887	353.9	-3.29	-72.91	0.0134365	179.9099
20961	179.9185	356.25	-3.58	-71.24	0.01	179.918472	356.25	-3.89	-74.21	0.0445836	179.9185
20962	179.9271	356.25	-4.18	-72.73	0.0311988	179.927057	346.87	-4.55	-72.54	0.05067875	179.9271
20963	179.9356	351.56	-4.86	-70.69	0.0705924	179.935642	337.5	-5.2	-70.69	0.0566369	179.9356
20964	179.9442	339.84	-5.48	-71.06	0.0371551	179.944227	328.12	-5.81	-68.09	0.03372625	179.9442
20965	179.9528	335.15	-6.1	-67.72	0.05481625	179.952812	323.43	-6.44	-66.05	0.05213615	179.9528
20966	179.9614	328.12	-6.65	-66.98	0.07516835	179.961397	316.4	-6.97	-64.01	0.0219065	179.9614
20967	179.97	318.75	-7.26	-63.08	0.0453157	179.969982	314.06	-7.48	-62.71	0.1142462	179.97
20968	179.9786	314.06	-7.8	-62.71	0.1419364	179.978568	300	-8.06	-60.85	0.0831354	179.9786
20969	179.9872	297.65	-8.28	-59.56	0.1100302	179.987153	290.62	-8.6	-57.33	0.1085462	179.9872
20970	179.9957	285.93	-8.79	-58.26	0.1370321	179.995738	278.9	-9.07	-54.73	0.07027355	179.9957
20971	180.0043	271.87	-9.28	-53.43	1.2714768	180.004323	271.87	-9.5	-50.46	1.2963825	180.0043
20972				Total Work (J)	4570.046607				Total Work (J)	4374.468451	
20973											
20974											
20975											
20976											
20977											
20978											
20979											

Figure 130, successful Excel workbook

Showa Shock Absorber Investigation.

5. Work carried out and results.

Test 12.2 Frequency, temperature and work done.

The tests completed were with the shock absorber installed into the dynamometer and the speed range selected 1-1Hz. This time, the heat loss from the shock absorber was also to be investigated. Exhaust glass fibre wrap was used to insulate the shock absorber as seen in Figure 131. The shock absorber was removed between tests and cooled in a water bath and then reinstalled and allowed to sit until it was at approximately the same temperature at the start point as in previous tests. The tests were:

- 1: 1Hz no wrap
- 2: 1Hz wrapped
- 3: 2Hz no wrap
- 4: 2Hz wrapped



Figure 131, wrapped 2013 shock absorber

As the heat transfer rates were to be investigated, the ambient temperature was measured during the testing. As the data was now a continuous sample, there was no temperature drop when extracting data between dynamometer runs as was necessary previously.

Showa Shock Absorber Investigation.

5. Work carried out and results.

Test 12.2 Frequency, temperature and work done.

In order to obtain a work done against dynamic viscosity graph, an interpolation method was needed to find values of dynamic viscosities at the temperatures measured. The most efficient method of obtaining these values is to apply a polynomial equation to the curve of the dynamic viscosity graph and apply that equation to the temperatures tested. This was attempted with the (mPa s) graph (Figure 132). Unfortunately, as these figures had been calculated from the original kinematic viscosity and density supplied by Fuchs-Silkolene the polynomial did not quite fit even as a 6th order and with 30 decimal places. The check for this is to apply the polynomial found to the known temperatures and values. They matched up to 40 degrees but then varied away. The next method, all be it a much longer method was to try the polynomial for the kinematic viscosity in M²/s which when applied to the original known data matched. The same method was applied to the density, this also matched. A new workbook was compiled (Figure 133) which allowed the calculation of the dynamic viscosity at each of the experimentally measured temperatures which allowed the production of work done against kinematic viscosity graphs.

Figure 132 shows the calculated polynomials matching known values.

=100*(10*(LN((EXP(1.0727+0.6175*LN(B14)+0.9744*(LN(B14)^2)+(-0.3764)*(LN(B14)^3)+0.04824*(LN(B14)^4))/88)/LN(B14))-1)/0.00715					
A	B	C	D	E	F
Silkolene RSF 7.5					
Temperature °C	v Kinematic viscosity Cts	v Kinematic viscosity (M ² /s)	v Kinematic viscosity (M ² /s) from polynomial	p Density (g/cm ³)	p Density (g/cm ³) from polynomial
0	121	0.00012100	0.000120998	0.854	0.853967092
10	84.6	0.00008460	8.46076E-05	0.847	0.847178734
20	61.2	0.00006120	6.11889E-05	0.841	0.840634513
30	45.7	0.00004570	4.57034E-05	0.834	0.834298643
40	35.1	0.00003510	3.51012E-05	0.828	0.828040313
50	27.6	0.00002760	2.76089E-05	0.822	0.82172645
60	22.2	0.00002220	2.21914E-05	0.815	0.815285068
70	18.2	0.00001820	1.8188E-05	0.809	0.808739201
80	15.1	0.00001510	1.51224E-05	0.802	0.802211435
90	12.7	0.00001270	1.26874E-05	0.796	0.795899012
100	10.9	0.00001090	1.09025E-05	0.79	0.790019539
v = kinematic viscosity (m ² /s) or (cSt) (centistokes)					
μ = absolute or dynamic viscosity (N s/m ²) or (pa s)					
ρ = density (kg/m ³)					
v = μ/ρ					
VI Viscosity Index	323.2551043				
Specific heat (J/KG/K)	1670				

Figure 132, polynomial calculations

Showa Shock Absorber Investigation.

5. Work carried out and results.

Test 12.2 Frequency, temperature and work done.

Figures 133 and 134, polynomial generation workbooks.

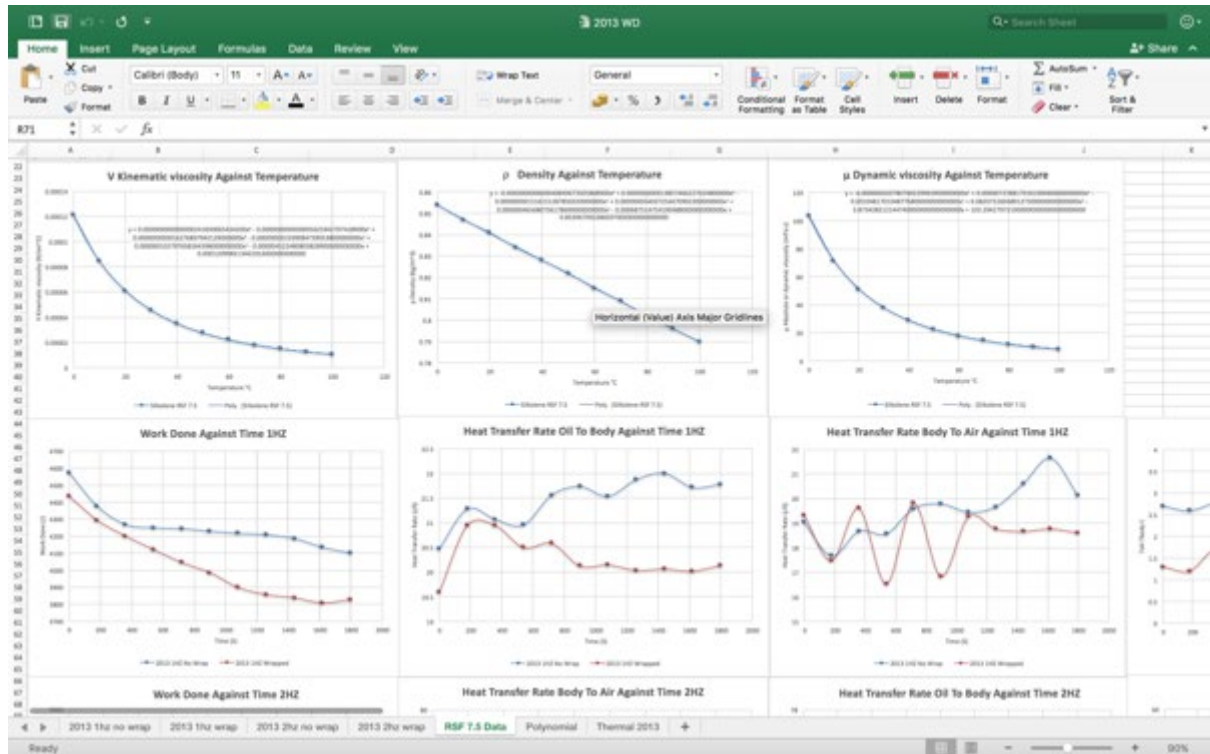


Figure 133, polynomials applied to curves

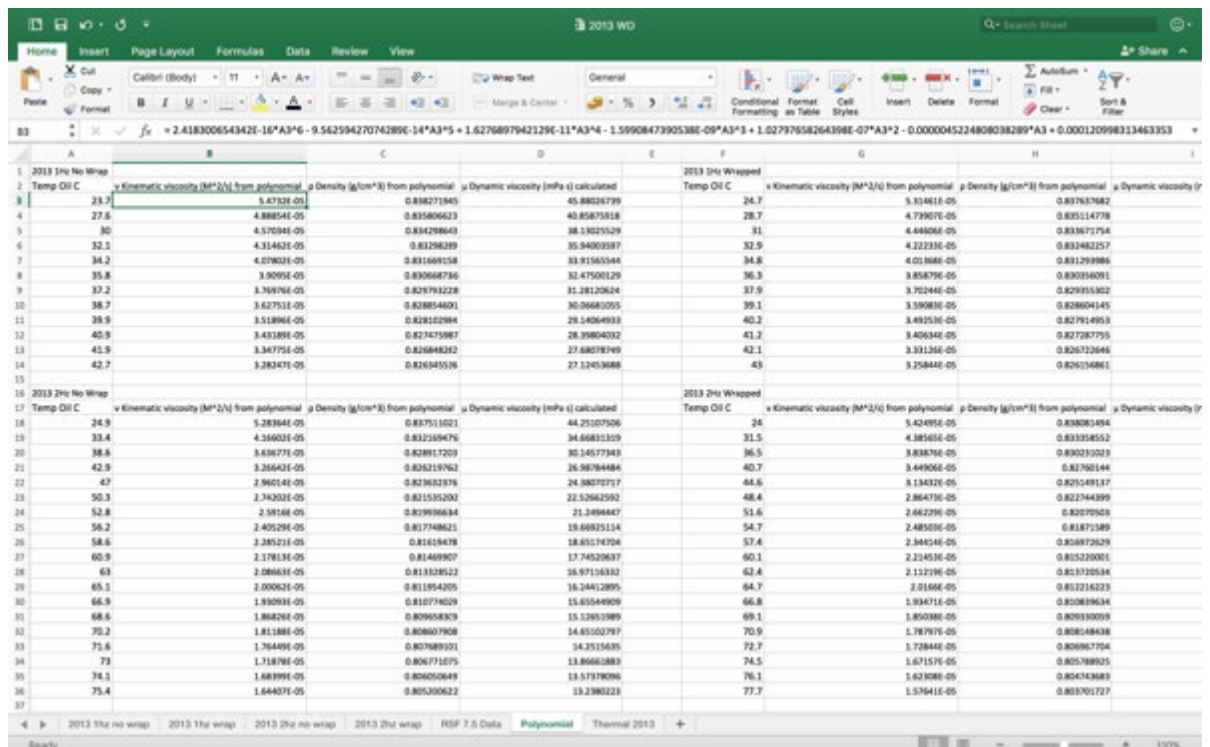


Figure 134, polynomial workbook

Showa Shock Absorber Investigation.

5. Work carried out and results.

Test 12.2 Frequency, temperature and work done.

1: 1Hz no wrap

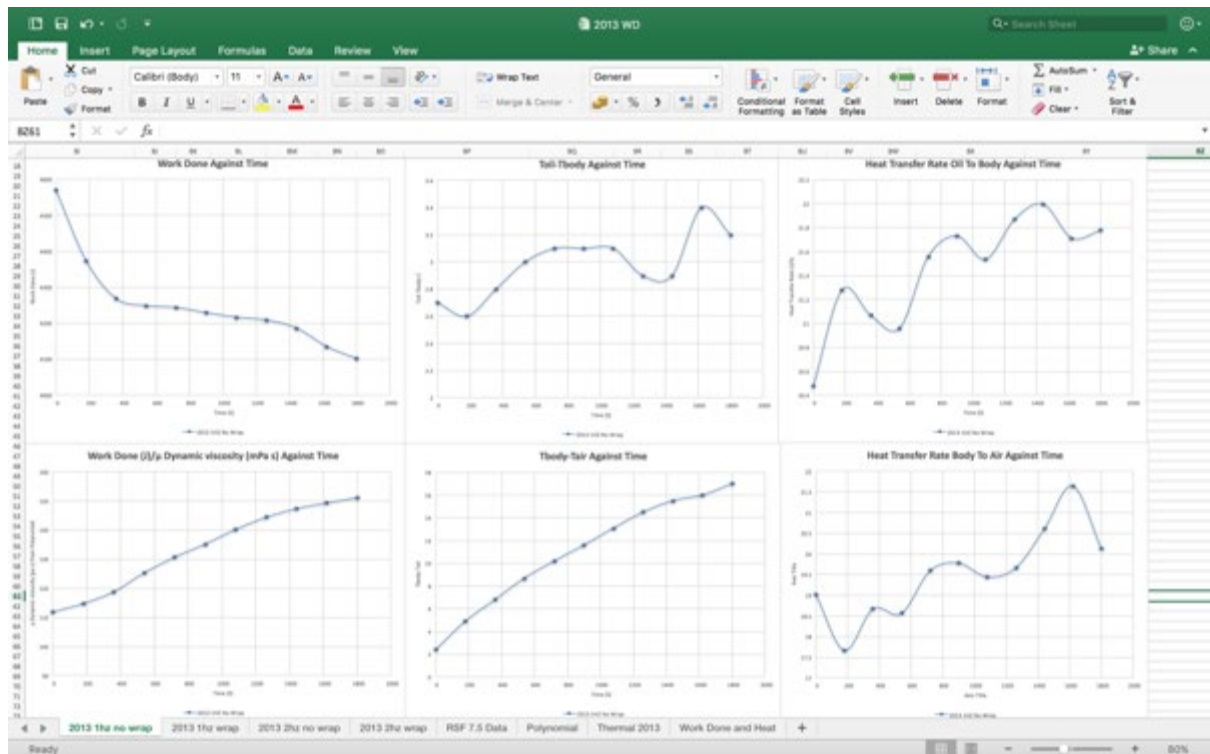


Figure 135, 1Hz no wrap test results graphically reproduced

The first thing that is apparent is the undulating nature of the heat transfer rates both from oil to body and body to air, this is the cause of the wavy line seen in the temperature traces in tests 9 and 10. The heat transfer rates continue increasing as the shock absorber warms up. The work done is decreasing as the viscosity of the oil decreases with temperature. The work done divided by the dynamic viscosity is increasing with time in what appears to be inversely proportional rate to the work done against time.

The total work done over the time of the test was: 46781.61 J

The total heat generated over the time of the test was: 12414.13 J

The measured heat generated was 26.54% of the work done.

Showa Shock Absorber Investigation.

5. Work carried out and results.

Test 12.2 Frequency, temperature and work done.

2: 1Hz wrapped

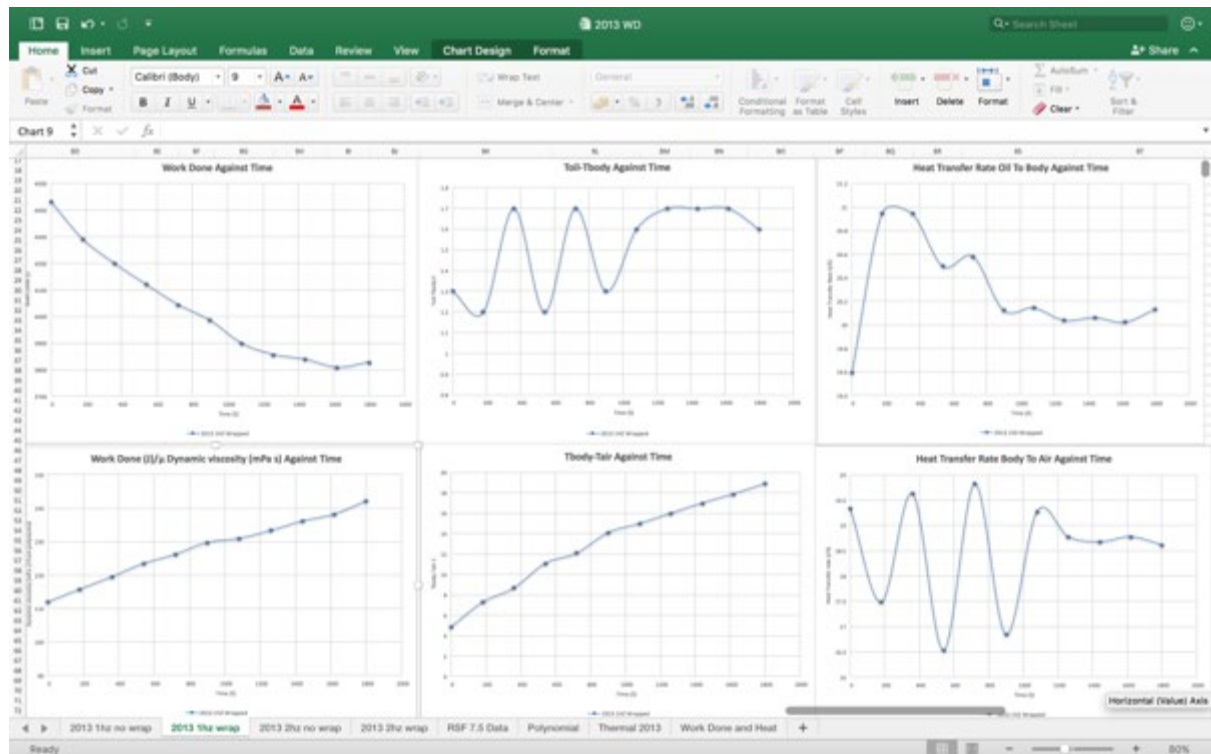


Figure 136, 1Hz wrapped test results graphically reproduced

With the shock absorber wrapped the heat transfer rates are slowed as expected, with the heat transfer rate of the oil being slowed down after an initial raise. This is the opposite of the 1Hz no wrap test. The rates appear to be levelling out. As with the previous 1Hz no wrap test, the work done is decreasing as the viscosity of the oil decreases with temperature. The work done divided by the dynamic viscosity is increasing with time in what appears to be inversely proportional rate to the work done against time.

The total work done over the time of the test was: 44305.05 J

The total measured heat generated over the time of the test was: 11778.52 J

The measured heat generated was 26.59% of the work done.

Showa Shock Absorber Investigation.

5. Work carried out and results.

Test 12.2 Frequency, temperature and work done.

3: 2Hz no wrap

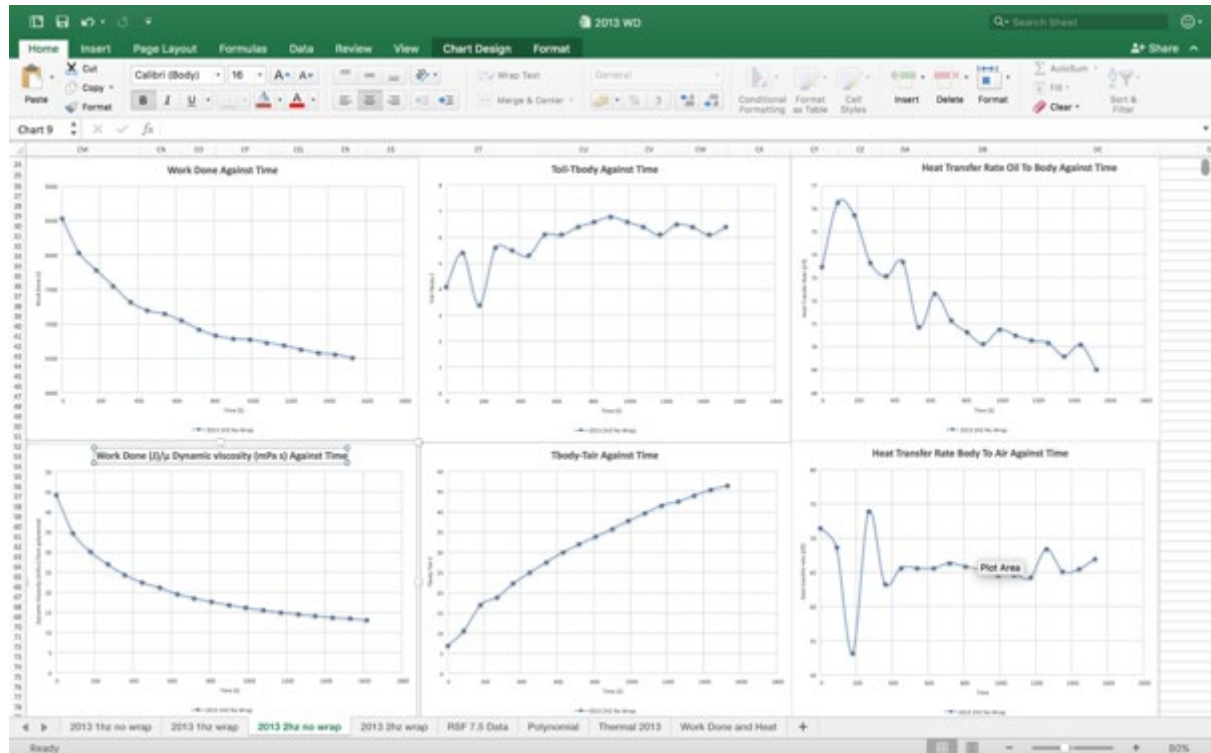


Figure 137, 2Hz no wrap test results graphically reproduced

With a change in frequency from 1Hz to 2Hz the work done divided by dynamic viscosity graph is no longer rising, as in the 1Hz tests. It is now following the curve of the work done graph. There is now a proportionality between them. The heat transfer graphs seem to follow the pattern of the 1Hz wrapped rather than no wrap curves.

The total work done over the time of the test was: 127658.93 J
 The total measured heat generated over the time of the test was: 32478.27 J

The measured heat generated was 25.44% of the work done.

Showa Shock Absorber Investigation.

5. Work carried out and results.

Test 12.2 Frequency, temperature and work done.

4: 2Hz wrapped

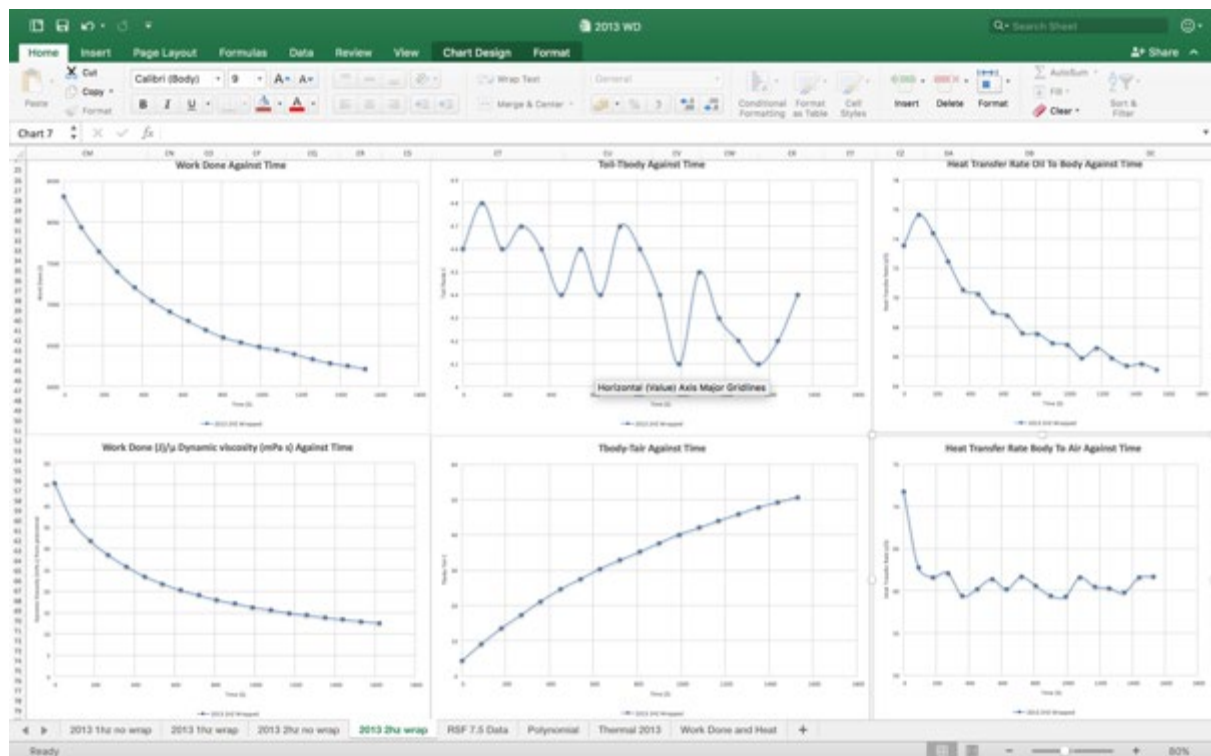


Figure 138, 2Hz wrapped test results graphically reproduced

With the shock absorber wrapped and operated at 2Hz the heat transfer graphs were similar in shape, the work done and work done divided by dynamic viscosity also following a similar curve as in the 2Hz test with no wrap.

The total work done over the time of the test was: 123580.72 J

The total measured heat generated over the time of the test was: 36160.75 J

The measured heat generated was 29.26 % of the work done.

Showa Shock Absorber Investigation.

5. Work carried out and results.

Test 12.2 Frequency, temperature and work done.

Work done and heat transfer graphs summarised in Figure 139.

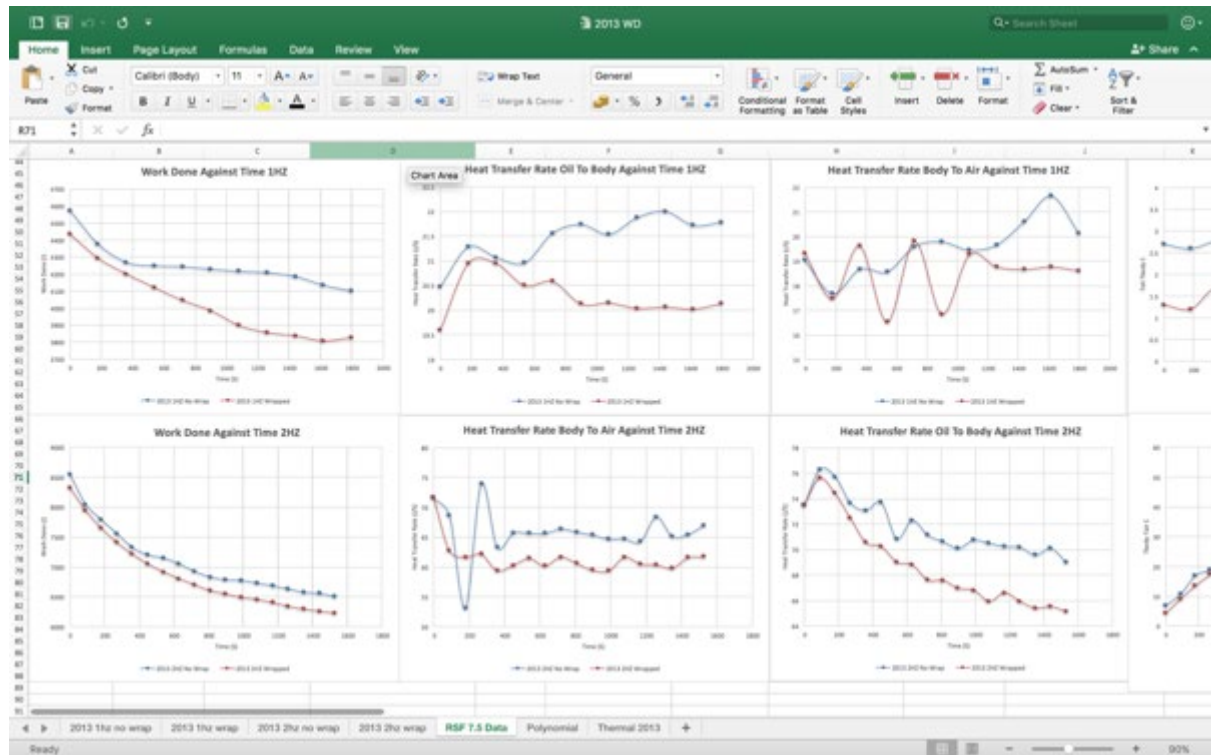


Figure 139, summarised test results graphically reproduced 1Hz and 2Hz

The work done against time curves differ in shape seen in the 1Hz test whereas the curve is similar in shape if not in magnitude for the 2 Hz test.

In the 1 Hz test the exhaust wrap may be getting heated up but not transferring heat to the air quickly enough to allow the heat transfer from oil to body quickly enough.

Showa Shock Absorber Investigation.

5. Work carried out and results.

Test 12.2 Frequency, temperature and work done.

Work done and heat transfer graphs summarised in Figure 140.

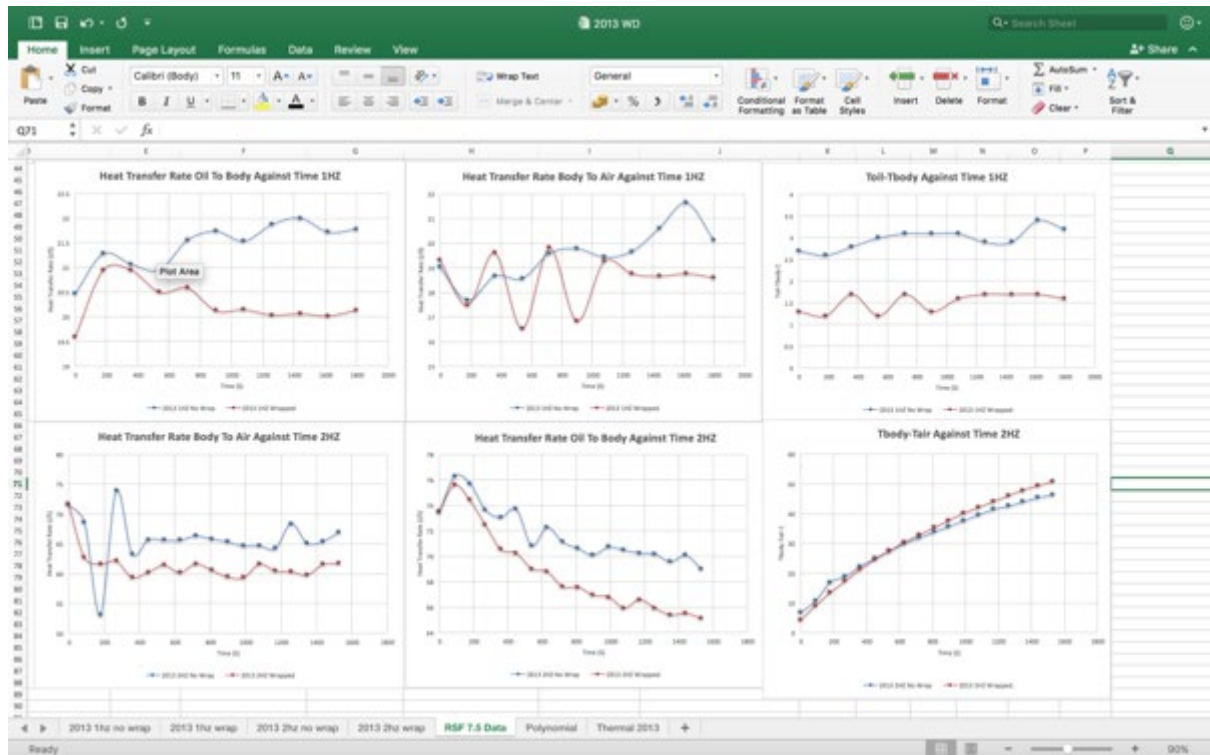


Figure 140, summarised test results graphically reproduced 1Hz and 2Hz

The largest effect between having the shock absorber wrapped occurs at 1Hz. At 2Hz the rates are similar in the shape of the curves but not necessarily in magnitude.

Showa Shock Absorber Investigation.

5. Work carried out and results.

Test 12.2 Frequency, temperature and work done.

Work done and measured heat generated can be seen summarised in Figure 141.

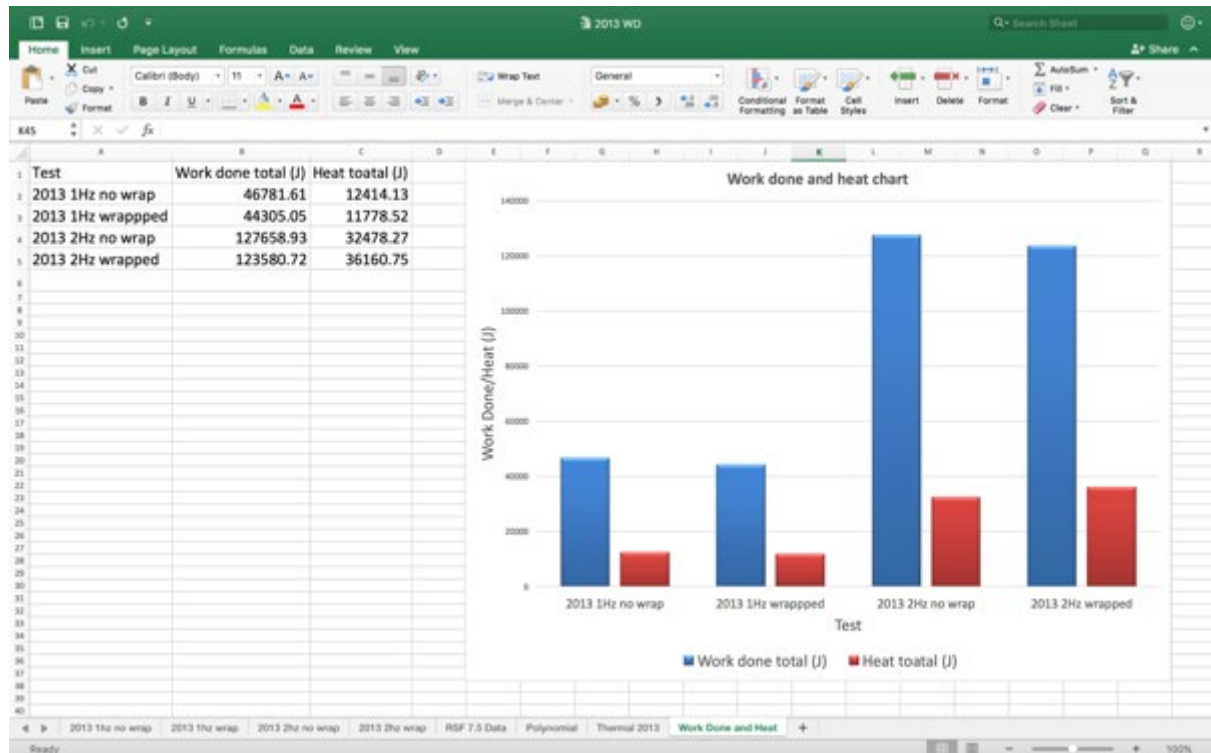


Figure 141, work done and heat generated summarised in bar chart

The bar chart seen in Figure 141 highlights the effect of increasing the speed with which the damper is operated rather than temperature dependency.

Showa Shock Absorber Investigation.

6. Conclusion.

Tests 2 - 7.2, shock absorber comparison tests.

The 2013 shock absorber had more defined differences when adjusting the compression and rebound setting than the 2011 shock absorber. The 2013 adjustments had little effect on each other whereas when adjusting the 2011 shock absorber one effected the other, as claimed by Honda and Showa when releasing the new model to market. This must be down to the design of the damper rod and its orifice damping. When the rebound damping is adjusted, it limits oil through the damper rod however the oil is free to flow through the rod on both rebound and compression stroke as there is no check valve in place to limit this so is unavoidable. When adjusting the compression adjuster on the 2011 shock absorber the oil displaced through it to the reservoir causing higher pressure in the shock absorber on the compression stroke and a low pressure or even a vacuum on the rebound stroke which could cause cavitation to occur. The fundamentals of the design differences must be the explanation for the pressure adjustment tests. When testing the 2011 shock absorber, as the pressure was increased the forces generated were reduced. With the 2013 shock absorber, as the pressure was increased the forces generated increased.

Showa Shock Absorber Investigation.

6. Conclusion.

Tests 8 - 12.2, Work done and heat transfer tests.

It was apparent whilst wrapping the shock absorber with exhaust wrap made a difference to the heat transfer rates, this effect was nowhere near the difference that changing the frequency of operation had on the shock absorber. When increasing the frequency from 1 to 2Hz, the work done divided by dynamic viscosity graph inverted. This is due to the dynamic viscosity remaining constant at tested temperatures between tests and the work done increasing as the shaft velocity is increased.

At 1Hz unwrapped after 1620 seconds, the work done drops from 4570.05 to 4186.34 J, a reduction of 8.4%. This occurs between the oil temperature ranges of 27.6°C and 40.9°C, where the values of dynamic viscosity are 40.86 and 28.4 mPa s respectively. Within that temperature range there is a reduction of dynamic viscosity of approximately 30.5%.

At 2Hz unwrapped after 1620 seconds, the work done drops from 8536.84 to 6506.18 J, a reduction of 23.79%. This occurs between the temperature ranges of 33.4°C and 75.4°C, where the values of dynamic viscosity are 34.67 and 13.24 mPa s respectively. Within that temperature range there is a reduction of dynamic viscosity of approximately 61.81%.

Because the most significant change in results came about from altering the frequency and hence the speed of the damper rod, this suggests the damper operates mainly under the rules of the Bernoulli equation.

$$P_1 + \frac{1}{2} + \rho v_1^2 = P_2 + \frac{1}{2} + \rho v_2^2 \quad (23)$$

Becomes:

$$v^2 = \frac{2(P_1 - P_2)}{\rho} \quad (24)$$

(Dixon, 2008)

Hence change in velocity has the most effect in a damper system due to v^2 .

Showa Shock Absorber Investigation.

7. Recommended further work.

Further work would primarily be to weld the hole in the body of the 2011 shock absorber and obtain a fitting that would allow oil temperatures to be measured. This would allow the full range of tests to be completed to provide a more concise comparison between the two shock absorbers as was in the original brief.

Secondarily and as whole investigation is itself would be to repeat test 12.2 with a finer increments of shaft velocity from 0.1 to 3.0. This would allow the identification of the point at which the low speed orifice damping is combined with high speed piston port and shim lift damping. This should correspond with the “knee speed” observed on the graph. Further investigation into whether low speed damping is purely viscous or partially Bernoulli equation bound would be highlighted by this test also.

Showa Shock Absorber Investigation.

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Showa Shock Absorber Investigation.

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Showa Shock Absorber Investigation.

11. Appendix.

ThermoIMAGER TIM 160 specifications

Miniaturised thermal imaging camera with USB interface

Measuring range from -20°C to 900°C (special edition up to 1500°C) *f*Excellent thermal sensitivity (NEDT) of 0.08K

Exchangeable lenses with 6°/23°/48°FOV or 72°FOV

Real-time thermography with 120Hz frame rate via USB 2.0 interface *f*Power supply and data transfer via USB interface

Extremely lightweight (195g) and robust (IP67)

Extremely compact dimensions 45x45x62mm

Analogue input and output, trigger interface

Software Developer Kit and LabVIEW samples included

Software

Display of the thermal image in real time (120Hz) with recording function (video, snapshot)

Complete set up of parameters and remote control of the camera

Detailed analysis of fast, thermodynamic processes

Output of analogue temperature or alert values via the process interface

Digital communication via RS232 or DLL for software integration

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11. Appendix.

SPA BTB4000 specifications

Data Acquisition Hardware

USB Connectivity

1500kg Load Cell

High Resolution Velocity and Displacement Transducers

Built in Temperature Sensor

Variable Sample Rate up to 100,000Hz

Hardware

CNC Machined Hard Anodised Chassis

2.2kW Variable Speed Motor

Adjustable stroke 12.5mm to 100mm

Direct Stroke Scotch Yoke System

Optional Stand Mounting

Manual Control Dash

Peak Velocity up to 1.32m/s

Software

Fully Customisable User Interface

10 Graph Displays with Overlay Capabilities

Multi-Step and Single Step Plot Options

Customisable Test Methods for Springs and Dampers

Data Tables-Force, Displacement and Velocity

Data Import/Export (ASC11 Format)

Windows Compatible