Investigation of the Deflections of Leaf Springs when subject to Static Point Loading

By

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BEng. (Honours) In Mechanical Engineering

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Date: 09/05/2016

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1. Declaration

I hereby declare that the project entitled “Investigation of the Deflections of Leaf Springs when subject to Static Point Loading” submitted for the Semester 8 Project Report is a record of research which has been conducted solely through my own efforts under the guidance of Mr. Derek Thornton, Department of Mechanical Engineering LyIT.

2. Abstract

Leaf Springs are an early form of Suspension in vehicles which are still in use in the modern era due to the load bearing qualities that they possess.

The focus of this project is to determine the deflection of a leaf spring when subject to a static point loading. In order to obtain this information; the design specifications and parameters of a leaf spring had to be determined. The key variables relating to their design are outlined this document and hence equations for the deflections of a leaf spring under static point loading are obtained.

The findings of this report will be used to design a leaf Spring, find the theoretical deflections under loading, and compare results to a physical model built in the machine workshop.

3. Acknowledgements

I wish to acknowledge and express my most sincere thanks to the following persons who have contributed to the development of my project:

Lecturer Derek Thornton, Project Manager, for his continued advice on the project throughout the research process which ultimately helped in obtaining the findings of this report.

Lecturers Charles Young, Nicola Anderson and David Kavanagh for their continued advice throughout the year, particularly in understanding derivations of formulas contained within this report.

I would like to thank the workshop Technician, Chris Roulston, who also gave continued advice throughout the course of the project as required and helped in obtaining material for the physical leaf spring build.

Finally, I would like to thank the Mechanics Technician, Richard Alcorn, who gave great advice in devising an apparatus for testing, and setting up the machine for testing the leaves in compression.

4. Table of Contents

5. Introduction

5.1 Aim

The aim for this project is to investigate the deflections of a leaf spring of a various number of leaves when subject to specific static point loading, accounting for the factors which determine the spring's profile, and to determine the relationship between the number of leaves and the load applied.

5.2 Inspiration

Inspiration for choosing this project was based on my farming experience at home, having observed the suspension system adopted in the axles of trailers, which hence led to a contemplation of why this system was still being incorporated in some applications in today's era over newer technologies developed.

5.3 General Introduction to terms

5.3.1 Static Loading

This is the load applied to a body which remains a constant. (Static v. Dynamic loading, 2015)

5.3.2 Dynamic Loading

This is the loading applied to a body which changes in value, hence not remaining constant. (Static v. Dynamic loading, 2015)

5.3.3 Spring-Rate

The Spring Rate of a material is the term given to the relationship between the load applied and the subsequent deflection; where the load, P, (in pounds) is divided by the spring deflection at the centre, y_c, (in inches), (Collins, Busby, and Stab, 2009), hence,

$$Spring\ Rate, k = \frac{P}{y_c} \qquad \text{(Eqn. 5.1)}$$

5.3.4 Resonance

The resonance value of a spring is the frequency value at which, whilst oscillating, the natural frequency of the spring is reached. (Collins, Busby, and Stab, 2009)

5.3.5 Suspension

The suspension in a vehicle is the system that connects the chassis to the wheels and carries out a number of key functions. It supports the overall weight of the vehicle, maintains contact between the vehicle's wheels and the road surface to induce traction, and provides a smooth ride quality for the passengers. (Autohaus Arizona Inc. 2006)

5.3.6 Leaf Springs

Leaf springs are one of the earliest forms of suspension used in vehicles, and have dominated in suspension for a number of decades until they were super-seeded by coil springs which offered an improved suspension and more comfort for passengers.

They are based on the principal of curved flat plates attached to the chassis via the "eyes" at each end, one end pivoting and the other mounted on a shackle which allows the spring to extend and contract accordingly as the vehicle traverses a bump/hollow in the roadway, (Leaf Springs 2015), as can be seen below in figure 5.1.

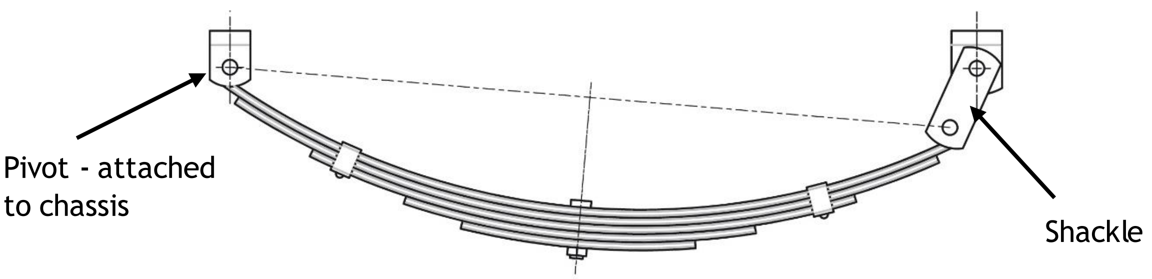


Fig. 5.1 (Ark Corporation 2015)

However, leaf springs are still in use today in heavy duty applications, where heavy loads are experienced, such as in Lorries, and in trailers, as they have "an array of mounting points" allowing the load to be spread over the length of the spring, whereas in the coil spring the loading is concentrated solely in one spot i.e. the centre of the spring, reducing its load bearing capacities. (Leaf Springs 2015)

There are two types of leaf spring commonly used in vehicle suspension; a single/ mono-leaf spring and a multi-leaf spring. (Polak 1991)
Multi-leaf Springs consist of a main leaf which attaches to the chassis, and hence a number of smaller leaves reducing in lengths accordingly attach to this main leaf. Incorporating a multiple number of leaves of varying lengths, cancels out the resonance frequency induced in any one leaf whilst subject to dynamic loading, and also allows for a shorter overall length, L, of the leaf spring. (Leaf Springs 2015)

6. Literature Review

6.1 Springs

A spring is an elastic device such that, when a force is applied which in turn stretches it, and that force is hence removed, the spring will return to its original shape. This property is defined as the elasticity of the material, which means that when stressed, (either in tension or compression) within the yield strength, the material will extend and contract proportionally to the force applied until the force is removed, hence the material is returned to its original shape. If the force applied stresses the material passed its yield point, the material will enter its plastic range, no longer exhibiting elastic properties resulting in permanent damage of the spring. (How springs is made 2015)

6.2 Materials

In choosing a material from which to manufacture leaf springs, it is essential that the material exhibits good elastic properties, as the spring will be subject to not only static but also dynamic loading, and must be designed to be capable of absorbing these loads and returning to its initial shape when this loading is removed.

The material used in the manufacture of leaf springs is required to be of a solid form which exhibits rigid properties.

A Martensitic structure arranges its atoms in a Body-Centred-Tetragonal Lattice, where an atom is arranged at the 8 corners of a cube with one in the centre as outlined in figure 6.1 below. (Martensite, 2015)

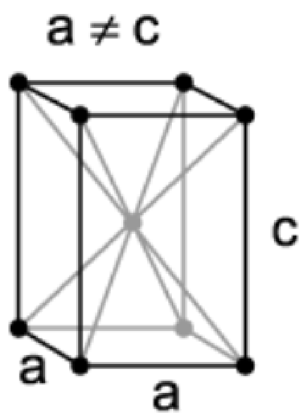


Fig. 6.1 (Martensite. 2015)

It is essentially a cubic structure which is slightly stretched in the vertical direction, hence having top and bottom faces of equal lengths and widths, a, and the side faces of a longer length, c.
This structure is as a result of some carbon dissolved in iron, which is then rapidly cooled, giving increased hardness characteristics to the material, giving high resistance to shear stress, hence preventing it from being easily deformed or scratched. (Martensite 2015)
Caron-Steel, otherwise known as Spring steel is chosen as the optimum material in the manufacture of leaf springs as it possesses the properties necessary to provide the leaf spring with its desired qualities. It comes in a number of different grades of varying iron-carbon ratios, and heat treatments, giving different properties to the material for specific applications. They are usually made from AISI 1050, 1065, 1074, or 1095 steel, which possess these qualities, and are then cold-rolled to give the initial curvature.

The properties of flat spring steel strip are outline in table 6.1 below:

Material	S_{ut} MPa	Rockwell Hardness	Elongation (2 in) percent
Spring Steel	1700	C50	2

Table 1 (Collins, Busby, and Stab, 2009)

6.3 Determining Design Parameters

The profile of the multi-leaf spring is based on the triangular planform illustrated below in fig. 6.3 as it is more practical to manufacture over a parabolic thickness profile illustrated in fig. 6.2 which is based on a tailored-shape which eliminates stresses at the free end.

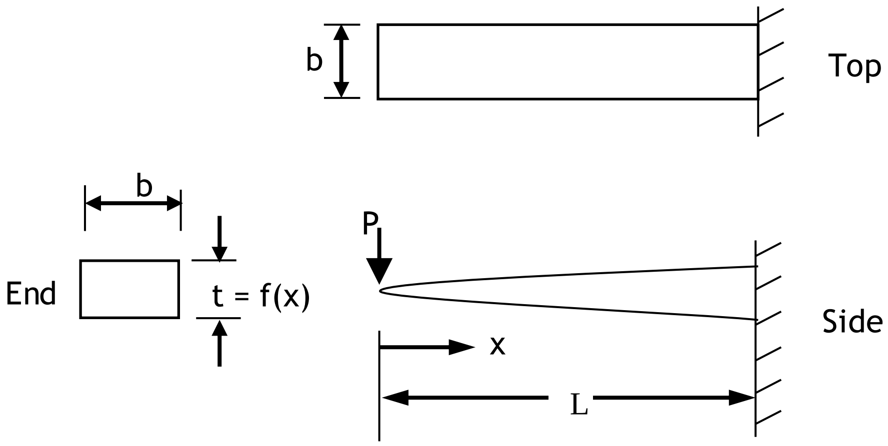


Fig. 6.2

Tailored-shape Leaf Spring (Collins, Busby, and Stab, 2009)

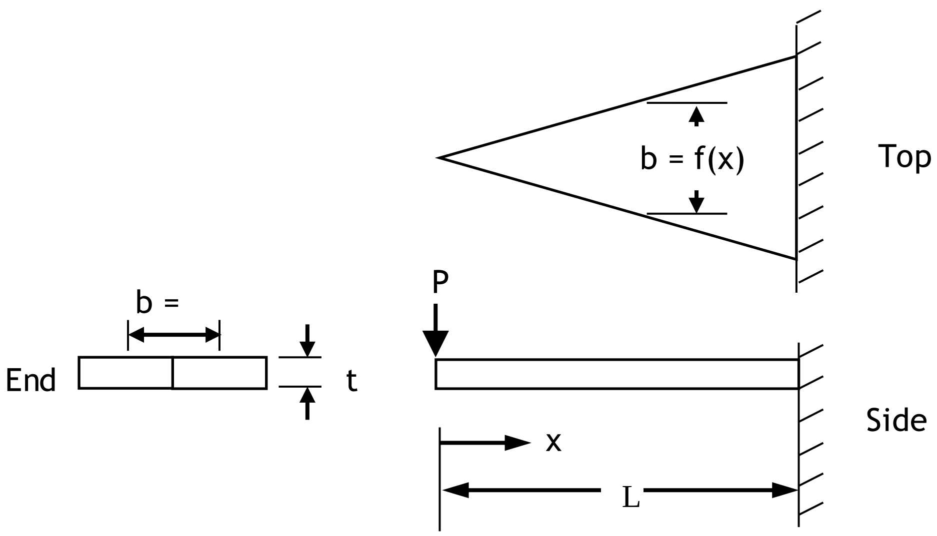


Fig. 6.3

Triangular Planform Leaf Spring (Collins, Busby, and Stab, 2009)

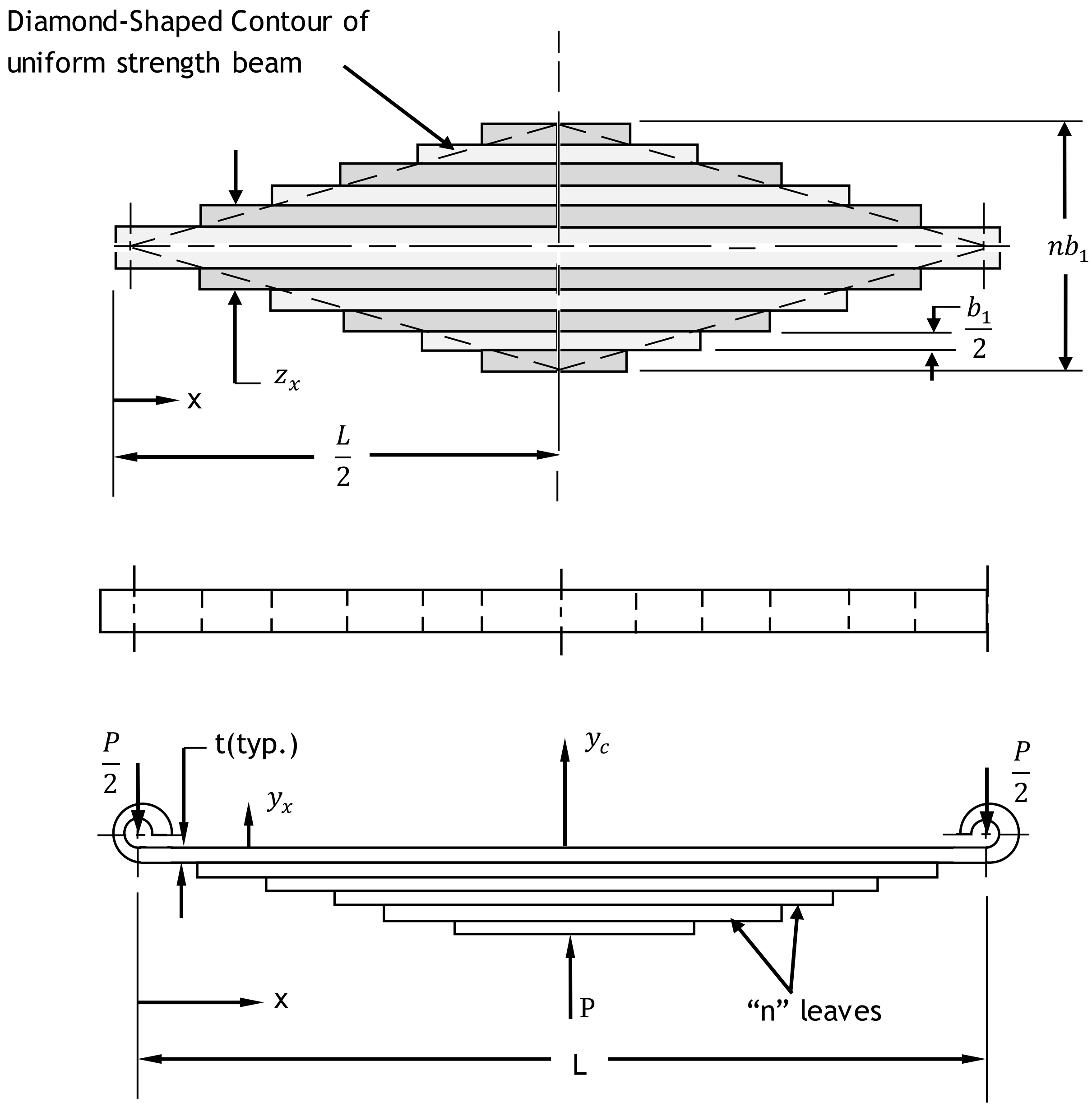


Fig. 6.4 - Diamond shaped planform (Collins, Busby, and Stab, 2009)

Figure 6.4 above illustrates a diamond shaped planform based on the triangular planform in figure 6.3, with two simply supported multi-leaf springs joined together lengthwise along the main leaves.

The semi-elliptical leaf spring adopted in suspension consists of a number of leaves, n. In this analogy, each leaf is taken to be two strips of metal divided lengthwise down the middle, giving a leaf width of $b_1/2$. Hence the material at the ends of the leaves, outside of the diamond shape developed can be removed as it is lightly stressed.

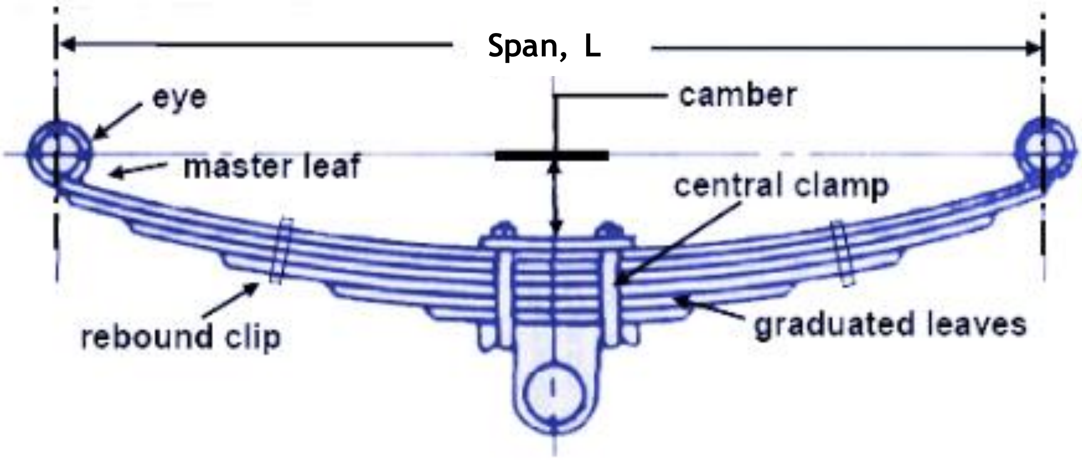


Fig. 5 Engineers Edge (2015)

In practicality, the material is not removed from the ends of the leaves as outlined in figure 6.3, hence each leaf end is square, which allows for ease of machining and only slightly affects the stress concentrations in the leaf ends.
Referring to Collins, Busby, and Stab (2009), the variables of a leaf spring's design are determined as follows:
The stress along the length of the beam, σ_x, is taken to be a constant value and equal to the design stress, σ_d, and is given by:

$$\sigma_x = \frac{M_x c}{I} = \frac{(Px)\left(\frac{t}{2}\right)}{\left(\frac{bt^3}{12}\right)} = \left(\frac{6P}{bt^2}\right)x \qquad \text{(Eqn. 6.1)}$$

Where: σ_x = Stress at any position, x, along the main leaf

x = Distance along the main leaf in relation to the free end

M_x = Bending Moment at any position, x, along the main leaf

c = Constant value for material

I = Area moment of inertia

P_x = Loading (N) at any position, x, along the main leaf

t = Leaf Thickness (mm)

Z_x = leaf width at any position, x, along the leaf

E = Modulus of Rigidity of the material

The area moment of inertia, I_x, of the leaf is given by:

$$I_x = \frac{Z_x t^3}{12} \quad \text{(Eqn. 6.2)}$$

A constant, c, is used where

$$c = \frac{t}{2} \quad \text{(Eqn. 6.3)}$$

The Bending Moment, M_x, is calculated by dividing the load by 2 and multiplying by the distance along the main leaf, x:

$$M_x = \left(\frac{P}{2}\right)x \quad \text{(Eqn. 6.4)}$$

These values can now be subbed into equation 1 and rearranging to give:

$$\sigma_x = \frac{M_x\, c}{I} = \frac{\left(\frac{Px}{2}\right)\left(\frac{t}{2}\right)}{\left(\frac{nb_1 t^3 x}{6L}\right)} = \frac{3PL}{2nb_1 t^2} \quad \text{(Eqn. 6.5)}$$

Equation 4 hence allows an alternative method to calculate leaf spring variables depending on the specifications and known values. (Collins, Busby, and Stab, 2009)

Following derivations and integrations of equation 4, above, the deflection, y_c, at the centre point of the leaf spring is found to be:

$$y_c = \frac{3PL^3}{8Enb_1 t^3} \quad \text{(Eqn. 6.6)}$$

The spring rate, k, which is the load divided by deflection at the centre point of the spring, can be written as:

$$k = \frac{P}{y_c} = \frac{8Enb_1 t^3}{3L^3} \quad \text{(Eqn. 6.7)}$$

(Collins, Busby, and Stab, 2009)

6.4 Leaf Spring Design Procedure

In the design of a leaf spring the material must first be specified and a design safety factor, n_d, chosen. (Collins, Busby, and Stab, 2009)
The design stress, σ_d, is then calculated from the equation:

$$\sigma_d = \frac{S_{fm}}{n_d} \quad \text{(Eqn. 6.8)}$$

Where S_{fm} = Failure strength of selected material relating to the dominant failure mode.

n_d = Design Safety Factor

Based on the space in which the leaf spring is to be designed for, an initial value of leaf width, b, is chosen from Table 12.1, (See Appendices), and an initial number of leaves, n, chosen. The leaf thickness, t, is calculated from equation 6.5. The value obtained for t is compared to those in table 12.1 and the nearest table value is taken as t.
Using these values of b, t and n, the spring rate, k, is calculated, compared to initially specified design requirements, and if not satisfactory, these variables are altered and requirements re-calculated until the result proves satisfactory.
(Collins, Busby, and Stab, 2009)

6.5 Designing Leaf Spring

For the purpose of this project a typical leaf was taken and scaled down from a typical span of 900mm eye-eye, to that of 300mm eye-eye. This in turn reduced the overall loading required for the spring to deflect, reducing the risk of unexpected slippage of the leaves in testing, which could potentially cause harm. From a cost perspective, the reduced material also reduces the overall cost of the project whilst satisfying the aim to which the project initially set out to determine.
Choosing an initial Camber height for the Main Leaf to be 50mm; the Radius of Curvature, R, of the Leaf is found from the following formula:

$$R = \frac{H}{2} + \frac{W^2}{8H} \quad \text{(Eqn. 6.9)}$$

Hence,

$$R = \frac{50}{2} + \frac{300^2}{8(50)} = 250mm$$

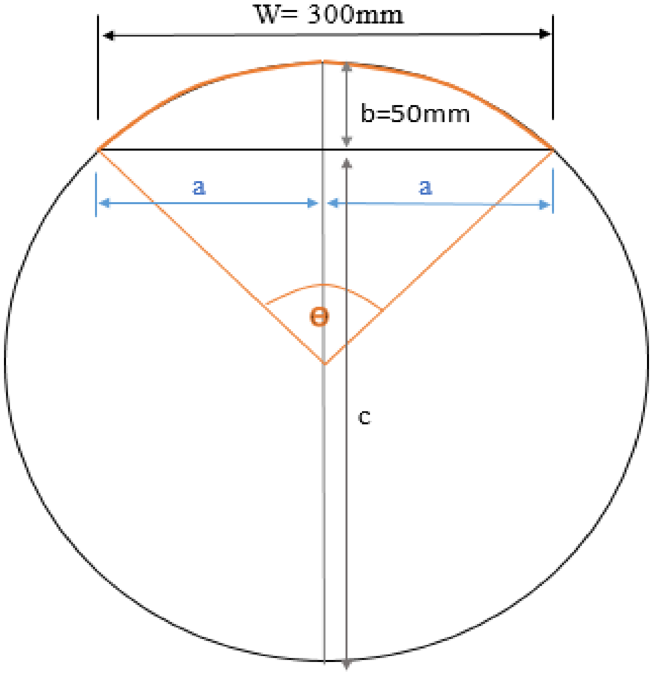


Fig. 6.6

Having found the Radius of Curvature of the Main Leaf to be 250mm; through trigonometry, the Curved Length of the Leaf, S, was found to be 322mm, as outlined below:

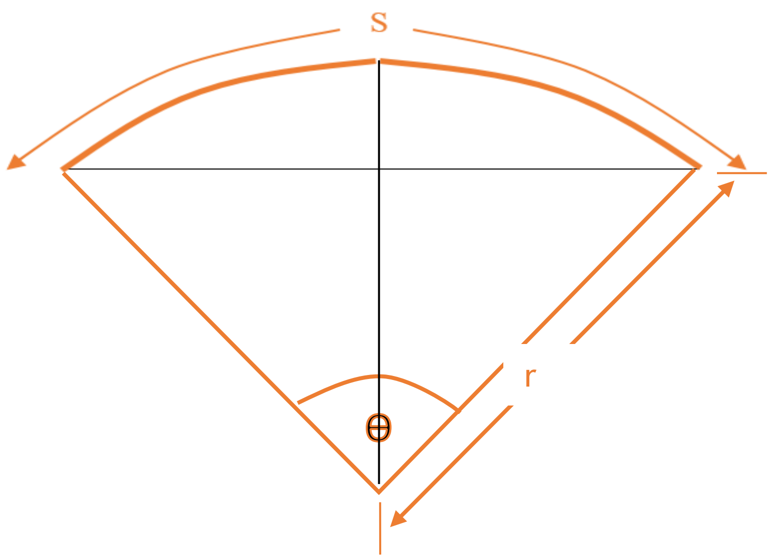


Fig. 6.7

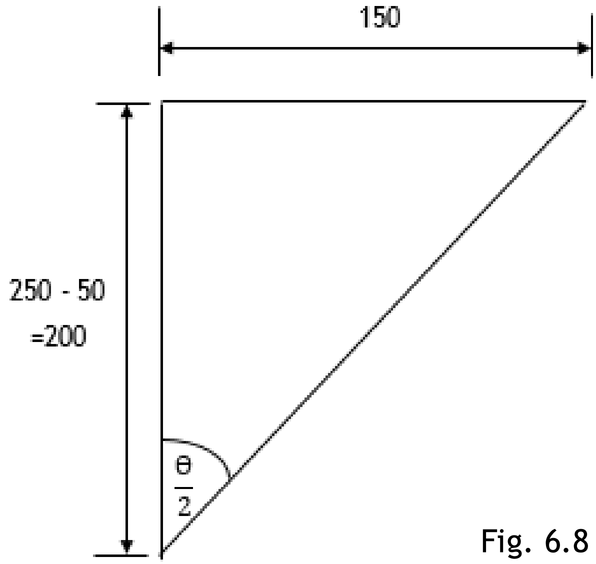


Fig. 6.8

$$H^2 = O^2 + A^2$$
$$(250)^2 = (150)^2 + (200)^2$$
$$62500 = 62500$$

$$Sin\ \frac{\theta}{2} = \frac{O}{H} \longrightarrow \frac{\theta}{2} = Sin^{-1}(\frac{O}{H})$$
$$= Sin^{-1}(\frac{150}{250})$$
$$= 0.6435$$
$$\frac{\theta}{2} = 0.6435\ x\ 2 = 1.287\ Rads$$
$$1.287\ x \frac{360}{2\pi} = 73.74\ Degrees$$

$$S = \theta r$$
$$= (1.287)(250)$$
$= 321.75 = 322mm$ = Curved Length of Main Leaf

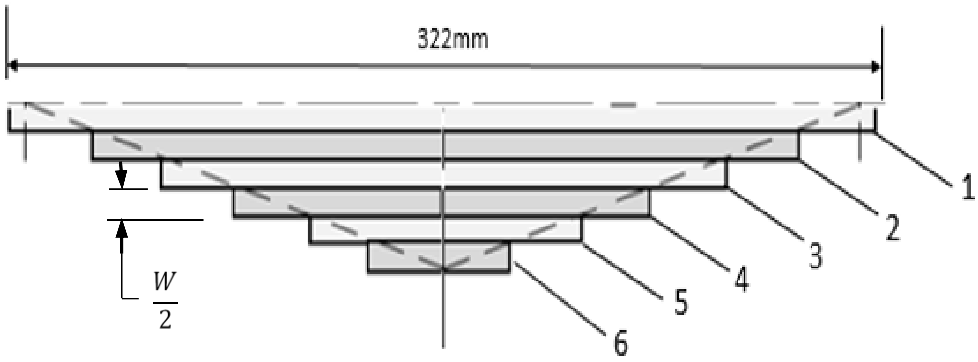


Fig. 6.9

Taking the length of the main leaf to be 322mm and employing the triangular planform graduation to a number of 6 leaves, as in figure 6.9 above; each graduated leaf length is then calculated using a combination of Pythagoras' theorem and trigonometry as follows;

Determining Angle, ϴ, of Triangular Planform from Main Leaf, Leaf 1, given that (A) equals the sum of the widths of 6 leaves (each @ width of 20mm) divided by two to give 60mm.

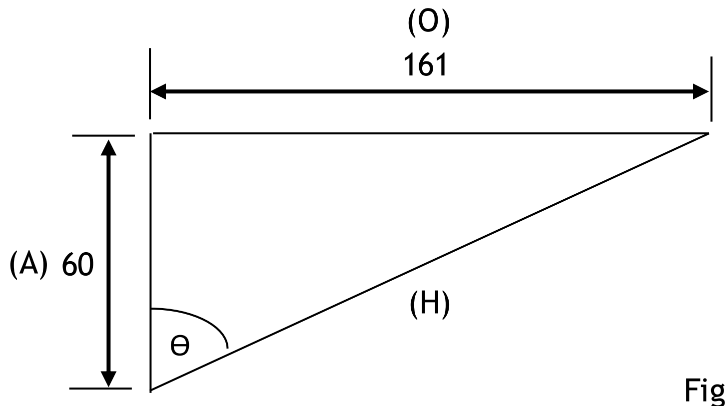


Fig. 6.10

$$H^2 = O^2 + A^2$$
$$= (150)^2 + (200)^2$$
$$H = \sqrt{(150)^2 + (200)^2}$$
$$= 171.8 = 172mm$$

$$Cos\,\Theta = \frac{A}{H} \qquad \Theta = Cos^{-1}\left(\frac{A}{H}\right)$$
$$= Cos^{-1}\left(\frac{60}{172}\right)$$
$$= 69.58 \text{ Degrees}$$

Having obtained the Angle ϴ to be 69.58 degrees, the length of Leaf 2 is calculated using trigonometry, based on an overall width of 100mm, divided by two giving 50mm:

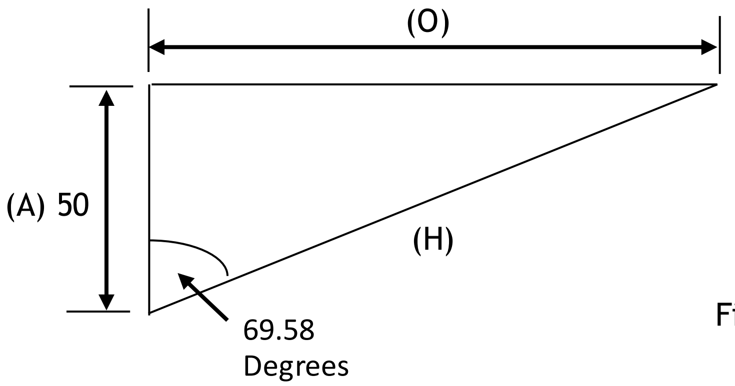


Fig. 6.11

$$Tan\,\Theta = \frac{O}{A} \qquad Tan\,(69.58) = \left(\frac{(O)}{A}\right)$$

$$(O) = Tan(69.58).(50)$$

$$= 134.302 = 134\text{mm}$$

The Lengths of the rest of the leaves, 3, 4, 5 & 6, were then calculated similarly to Leaf 2, to be 107mm, 81mm, 54mm, and 27mm respectively. (See appendices)
As these calculations determined the lengths of half of each leaf, the full length of each leaf from longest to shortest are found to be 322mm, 268mm, 215mm, 107mm and 54mm respectively.

6.6 Theoretical Results

When Subject to loading of 200kg:
Maximum Stress

$$\sigma_{max} = \frac{3PL}{2nb_1t^2} = \frac{3(200\ x\ 9.81)(0.3)}{2(6)(0.02)(0.003)^2} = 817.5\ MPa$$

Maximum Deflection

$$\delta_{max} = y_c = \frac{3PL^3}{8Enb_1t^3} = \frac{3(200\ x\ 9.81)(0.3)^3}{8(200\,x10^9)(6)(0.02)(0.003)^3} = 30.66\text{mm}$$

7. Methodology

In order to conduct Physical Testing of a leaf spring to obtain deflections under specific loadings, Spring Steel Strips of the previously determined lengths in Section 6.5 were ordered, pre-dimensioned from Fernite of Sheffield.

On obtaining the material, the curvature was required to be applied to the material. However it was discovered that the lengths of material were too short to be capable of applying an initial specific curvature of Radius 250mm, as they would need an extra length of 250mm on each end of the leaves in order for the machine to apply the specific curvatures.

Using a small set of rollers, somewhat of a curvature was capable of being applied to the top three leaves, however the bottom three leaves were too short to apply curvature to. The resulting Camber heights applied to Leaves 1, 2, & 3 were measured to be 42mm, 21mm and 13mm respectively, however Leaf 1 became slightly kinked in the process resulting in an uneven curvature over the span of the leaf.

As Curvatures were applied to Leaves 1, 2 & 3 only, this meant that the leaf widths did not graduate down evenly to the outermost point in the middle of the shortest leaf, as proposed by the triangular planform analogy. This, in turn, meant that on recalculating the deflections for a leaf spring of three leaves under loading, the values obtained would represent an evenly graduated three leaf spring, differing somewhat to the graduation of the leaf lengths in question.

On Recalculating theoretical deflections for each of the three leaves singularly, and each leaf combination using the same formula, although not obeying the triangular based analogy of length graduation; the value for the number of leaves, n, and the length of the main leaf, L, were varied accordingly for each test in order to find the deflections for each leaf singularly, leaves 2 & 3 combined, and leaves 1, 2 & 3 combined, whilst subject to increasing incremental loads, P, of 0.1kN as the load meter attached to the tensile tester measures in increments of 0.1kN.

7.1 Testing

7.1.1 Apparatus

To test each leaf and combination of leaves under loading; an apparatus was required to be designed that would attach to the tensile tester, in which to deflect the leaves.

The apparatus which was designed can be seen in the Photographs below, and simply composed of 6 square pieces of steel welded to a base, to form slot in which the leaves could deflect.

To allow the leaves to deflect to their maximum capability and to allow observation of their deflections, given the small initial cambers applied to leaves 2 and 3 especially; a slot was left in the middle of the of the apparatus which was not fully closed in, as can be observed in the photos in section 7.1 below.

7.1.2 Safety in testing

To ensure safety in testing, two plates of steel at both ends of the apparatus, were moved along its length accordingly, to sit close to the curvature of the leaf being deflected and clamped to the apparatus by means of toolmakers clamps. This ensured that should the applied load position on the leaf slip, or should there otherwise be slippage of the leaves under load, they would not shoot out from the apparatus, potentially resulting in serious injury or damage.

Enclosed channel in which leaves could deflect

Plates clamped at each end to prevent leaves removing themselves from the apparatus

Fig. 7.1

Fig. 7.2

Guard placed in front of apparatus for safety in the event of something going wrong.

Fig. 7.3

Dial test indicator set up to take readings of deflection of leaves

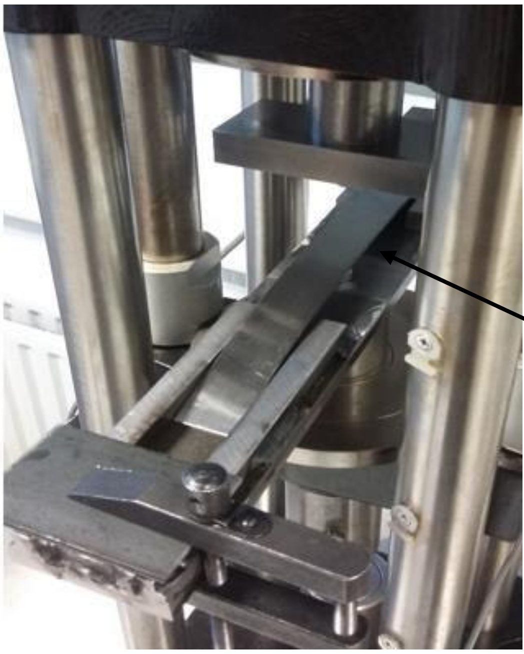


Fig. 7.4

Leaf placed in channel and point loading applied in centre when subject to compression loading

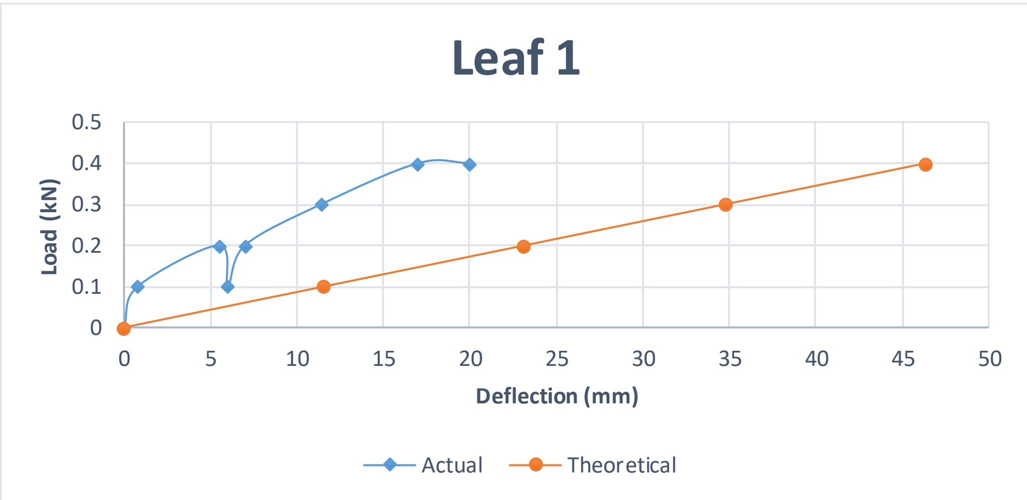
In deflecting the leaf combinations together, the leaves were held together by mean of clamps of the form of two plates held together by means of threaded bar and loosened or tightened as required to allow enough movement of the leaves relative to each other whilst deflecting.

8. Results:

On compilation of the deflection data; both theoretical and that obtained in testing, they can be compared and contrasted from the graphs constructed below:

Leaf 1			
Theoretical		Physical Testing	
Load (kN)	Deflection (mm)	Load (kN)	Deflection (mm)
0.1	11.592	0.1	0.8
0.2	23.185	0.2	5.5
0.3	34.777	0.1	6.0
0.4	46.37	0.2	7.0
		0.3	11.4
		0.4	17.1

Table 8.1

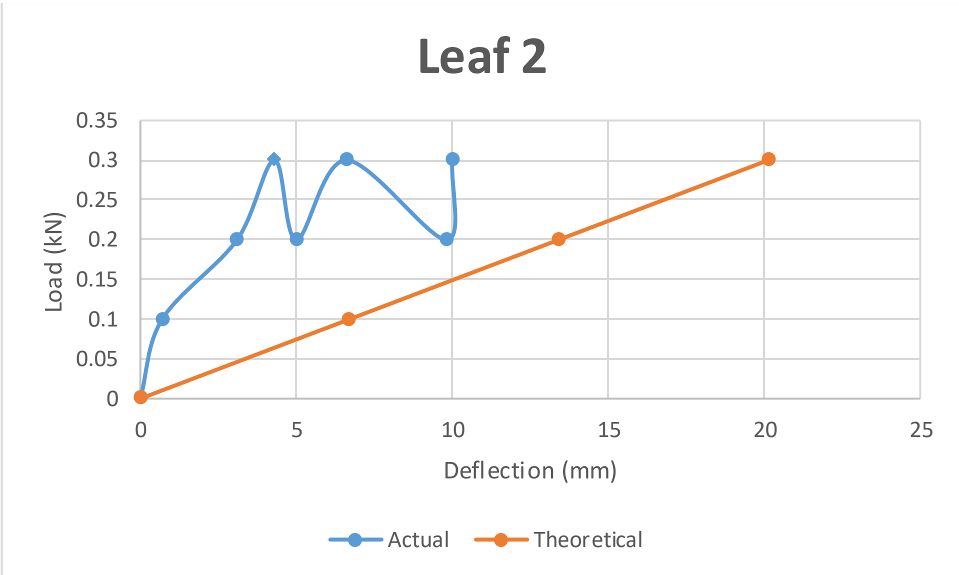


Graph 8.1

Leaf 1, or the Main Leaf, in testing; is seen to deflect somewhat linearly under increased until the leaf becomes almost flat, withstanding loading of up to 0.4kN, or 400N. The theoretical calculations also give a linear relationship of deflection with respect to increased loading; although however, the deflection is much greater with each incremental load.

Leaf 2			
Theoretical		Physical Testing	
Load (kN)	Deflection (mm)	Load (kN)	Deflection (mm)
0.1	6.7086	0.1	0.7
0.2	13.417	0.2	3.1
0.3	20.126	0.3	4.3
		0.2	5.0
		0.3	6.6
		0.2	9.8
		0.3	10

Table 8.2



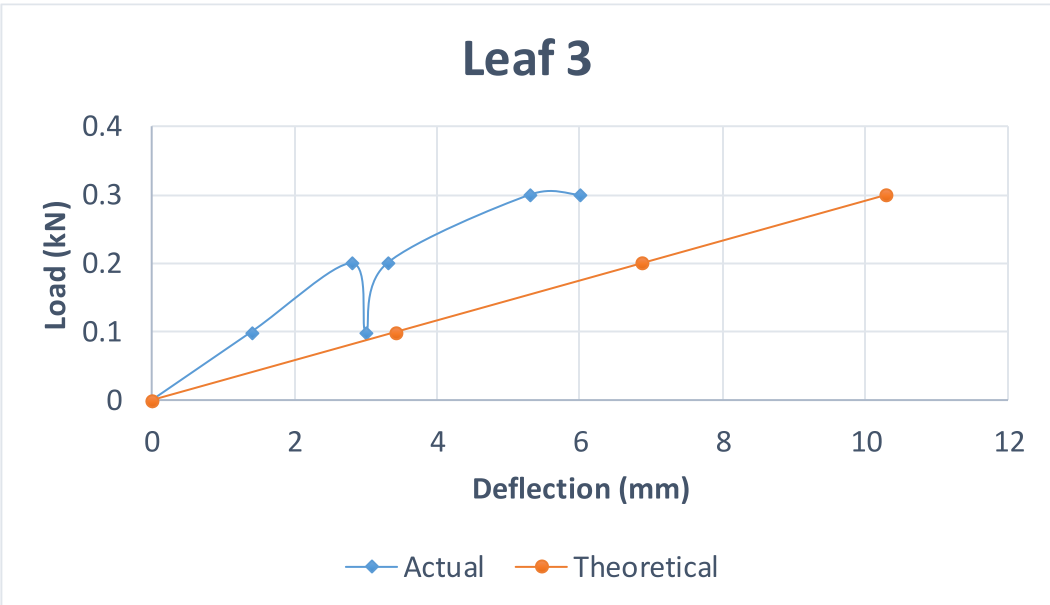
Graph 8.2

Leaf 2, under loading, deflects linearly both in theory and in practice, with the theoretical deflecting almost twice as much as the actual. There also appears to be fluctuations in the actual loading, with the applied load observed to drop on the load meter attached to the machine whilst the material continued to deflect, as the dial test indicator continued to rotate at the same rate as it had previously.

The fluctuations in loading vs deflection may be due to oil in the machine, or relaxing of the load on the leaves given sufficient force is applied to give a deflection.

Leaf 3			
Theoretical		Physical Testing	
Load (kN)	Deflection (mm)	Load (kN)	Deflection (mm)
0.1	3.4348	0.1	1.4
0.2	6.8695	0.2	2.8
0.3	10.304	0.1	3.0
0.4	13.7839	0.2	3.3
		0.3	5.3
		0.3	6.0

Table 8.3

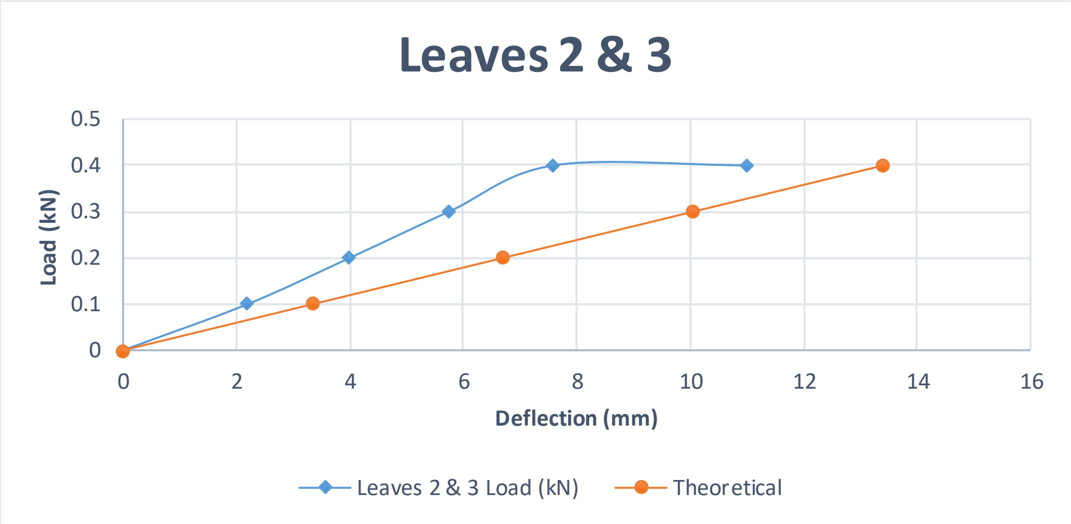


Graph 8.3

Leaf 3, under loading, is also observed to deflect in a similar manner to the previous two leaves, with the Actual being almost twice as stiff as the Theoretical, coming to a peak load of 0.4kN at a deflection of 5mm, while the theoretical peaks at a deflection of approximately 11mm.

Leaves 2 & 3			
Theoretical		Physical Testing	
Load (kN)	Deflection (mm)	Load (kN)	Deflection (mm)
0.1	3.3543	0.1	2.2
0.2	6.7086	0.2	4.0
0.3	10.063	0.3	5.75
0.4	13.417	0.4	7.6
		0.4	11.0

Table 8.4



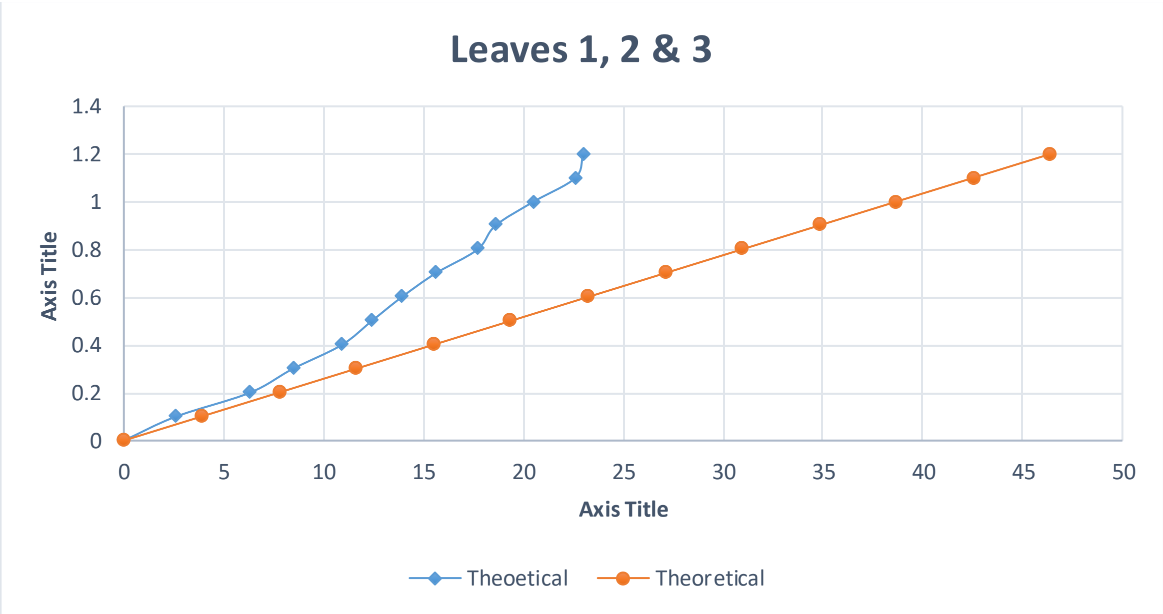
Graph 8.4

On combing leaves 2 &3, and testing together in deflection under loading; the load bearing capacity of the leaves is observed to increase from 0.3kN to 0.4kN under similar deflections to that observed in leaf 2 singularly.

The fluctuations in loading, observed in the previous tests are not exhibited in this test. This may be due to the increased stiffness of the spring now requiring more force to deflect the leaves, not allowing any relaxing of the load in the machine to take place.

Leaf 1, 2 & 3			
Theoretical		Physical Testing	
Load (kN)	Deflection (mm)	Load (kN)	Deflection (mm)
0.1	3.8641	0.1	3.6
0.2	7.7283	0.2	7.3
0.3	11.592	0.3	11.45
0.4	15.457	0.4	14.9
0.5	19.3207	0.5	18.4
0.6	23.185	0.6	21.9
0.7	27.049	0.7	25.6
0.8	30.913	0.8	29.7
0.9	34.7773	0.9	33.6
1.0	38.6415	1.0	37.5
1.1	42.5056	1.1	40.6
1.2	46.3698	1.2	44

Table 8.5



Graph 8.5

On combing leaves 1, 2 & 3, and testing deflections under loading; the load required to deflect the combination increases significantly from the 0.4kN of leaves 2 & 3 combined to 1.2kN, with the third leaf significantly increasing the load bearing capacity

From the results of the physical testing; the Maximum Loadings recorded in testing compared to the Maximum deflections recorded at these same loads can be compared the deflections calculated at each of these loads using the deflection formula, in Table 8.6 below;

Leaf	Load (kN)	Deflection (mm)	
		Theoretical	Physical Testing
Leaf 1	0.4	46.37	17.1
Leaf 2	0.3	20.126	10
Leaf 3	0.3	10.304	6
Leaves 2 & 3	0.3	10.063	11
Leaves 1, 2 & 3	1.2	46.3698	23

Table 8.6

9. Discussion and Conclusion of Research

Having conducted this investigation into the Static Deflection of Leaf Springs under Point Loading, a number of conclusions can be reached in relation to the design characteristics of a leaf spring.

Having subjected each leaf singularly to Point loading, it can be concluded that:

- As the length increases, the deflections under loading also increase i.e. in comparing the deflections of leaves 1, 2 and 3; under a Point load of 0.2kN, Leaf 1 was observed to deflect 7mm, Leaf 2 deflected 5mm, and Leaf 3 deflected 3.3mm.
- With each increasing load, the relationship between the load increments applied and the deflections recorded remained linear with each leaf.

On combining leaves 2 & 3, and leaves 1, 2 & 3; the following conclusions can be made:

- On comparison to the deflections recorded under loading of the multiple leaves, the loading required to deflect the leaves was significantly greater than of that required to deflect the leaves singularly.
- Leaves 2 & 3 combined deflected by 7.2mm under a load of 0.4kN, whilst leaf 2 singularly deflected by the same amount under 0.3kN.
- As leaf 1 became slightly kinked in testing a fair comparison could not be made to its combined deflection with leaves 2 and 3, under a load of 0.4kN. However, when subject to further loading; and the kinked surface fully came into contact with the other leaves, a max load of 1.2kN was required to deflect the combination through 23mm, again significantly increasing the load bearing capacity of the spring.

Having conducted this investigation, the overall conclusions may be drawn as follows:

1) There is a Linear Relationship between loading and deflection of leaves
2) The Load capacity increases with increased no. of leaves
3) Variations between theoretical calculations and physical testing may be due to leaves not graduating according to the aforementioned triangular planform on which the theory is based, as the curvatures could not be applied as intended.

10. Recommendations

Future Recommendations for a project in this area of Research would be:

- Conduct a build with Mild Steel strips and compare relationship under loading to that of Spring Steel Strips to determine whether the relationship between the deflections of the leaves varies proportionally similar with the differing material properties.
- Curve one long strip of material of the combined lengths of each leaf of the spring including an extra amount required by the rolling equipment to start the curve. This in turn would allow the material to be curved to a specific initial radius from which the lengths of each leaf could be cut in turn and assembled and tested as required.
- An essentiality would be to employ stricter Project Management and follow a stricter Gantt chart; in order to specify time in which to solve a problem/aspect of the project. This in turn would allow a decision to be made upon other possible avenues in which to explore with the project.

Another aspect to investigate would be the effect of the Initial Camber value, as in Fig. 6.5, applied to the spring, as the findings of this report have not determined how the Camber value is determined, i.e. whether it varies with the overall length based on a formula, or whether it is selected based on the conditions which are to be imposed on it. This would hence determine whether a varied Camber value would change how the spring responds to the applied load in deflection.

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12. Appendices

12.1 Preferred Widths and Thicknesses for Flat Strip Leaf Spring Slock Cross Sections

Width		Thickness					
in	mm	in	mm	in	mm	in	mm
1.57	40.0	0.28	7.10	0.52	13.20	0.98	25.00
1.77	45.0	0.30	7.50	0.55	14.00	1.04	26.50
1.97	50.0	0.31	8.00	0.59	15.00	1.10	28.00
2.20	56.0	0.33	8.50	0.63	16.00	1.18	30.00
2.48	63.0	0.35	9.00	0.67	17.00	1.24	31.50
2.95	75.0	0.37	9.50	0.71	18.00	1.32	33.50
3.54	90.0	0.39	10.00	0.75	19.00	1.40	35.50
3.94	100.0	0.42	10.60	0.79	20.00	1.48	37.50
4.92	125.0	0.44	11.20	0.83	21.20	---------	---------
5.91	150.0	0.46	11.80	0.88	22.40	---------	---------
---------	---------	0.49	12.50	0.93	23.40	---------	---------

Table 12.1 (Collins, Busby, and Stab, 2009)

12.2 Carbon Steel (AISI 1050)

12.2.1 Composition:

Element	Weight %
C	0.48-0.55
Mn	0.60-0.90
P	0.04 (max)
S	0.05 (max)

Table 12.2 (EFunda 2015)

12.2.2 Mechanical Properties:

Properties		Conditions	
		T (°C)	Treatment
Density (×1000 kg/m^3)	7.7-8.03	25	
Poisson's Ratio	0.27-0.30	25	
Elastic Modulus (GPa)	190-210	25	
Tensile Strength (Mpa)	636.0	25	annealed at 790°C more
Yield Strength (Mpa)	365.4		
Elongation (%)	23.7		
Reduction in Area (%)	39.9		
Hardness (HB)	187	25	annealed at 790°C more
Impact Strength (J) (*Izod*)	16.9	25	annealed at 790°C more

Table 12.3 (EFunda 2015)

Length of Leaf 3 is determined based on Angle Θ = 69.58 degrees and overall width of 80mm, divided by two giving width of 40mm:

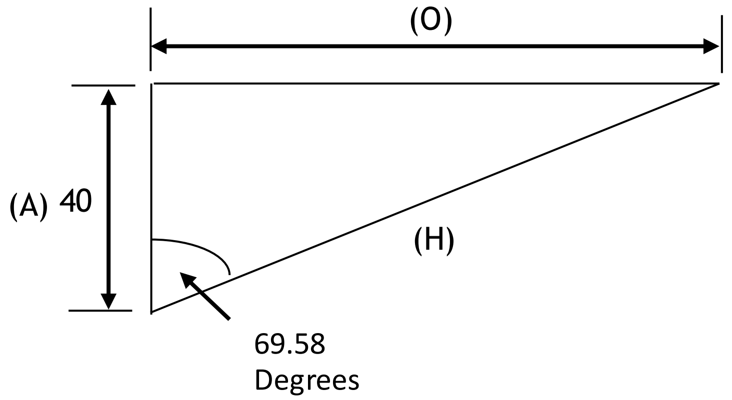

Fig. 12.1

$Tan\ \Theta = \frac{O}{A}$ $\qquad Tan\ (69.58)\ = (\frac{(O)}{A})$

$$(O) = Tan(69.58).(40)$$

$$= 107.442 = 107\text{mm}$$

Length of Leaf 4 is determined based on Angle ϴ = 69.58 degrees and overall width of 60mm, divided by two giving width of 30mm:

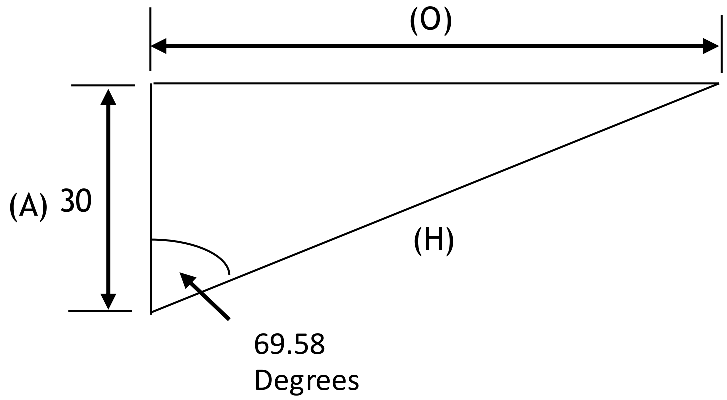

Fig. 12.2

$$Tan\ \Theta = \frac{O}{A} \qquad Tan\ (69.58)\ = (\frac{(O)}{A})$$

$$(O) = Tan(69.58).(30)$$

$$= 80.58 = 81\text{mm}$$

Length of Leaf 5 is determined based on Angle ϴ = 69.58 degrees and overall width of 40mm, divided by two giving width of 20mm:

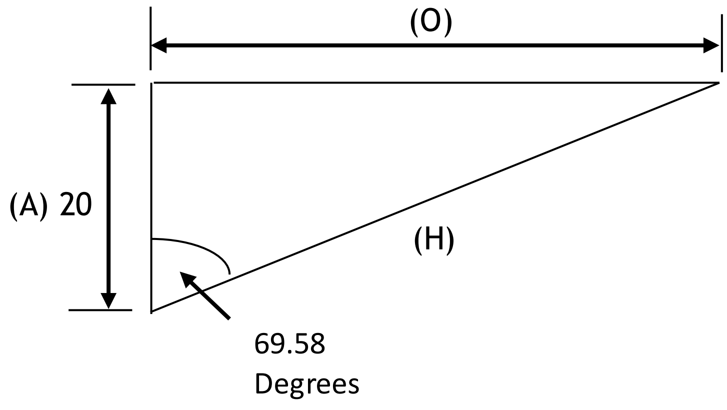

Fig. 12.3

$$Tan\ \Theta = \frac{O}{A} \qquad Tan\ (69.58)\ = (\frac{(O)}{A})$$

$$(O) = Tan(69.58).(30)$$

$$= 53.721 = 54\text{mm}$$

Length of Leaf 6 is determined based on Angle Θ = 69.58 degrees and overall width of 20mm, divided by two giving width of 10mm:

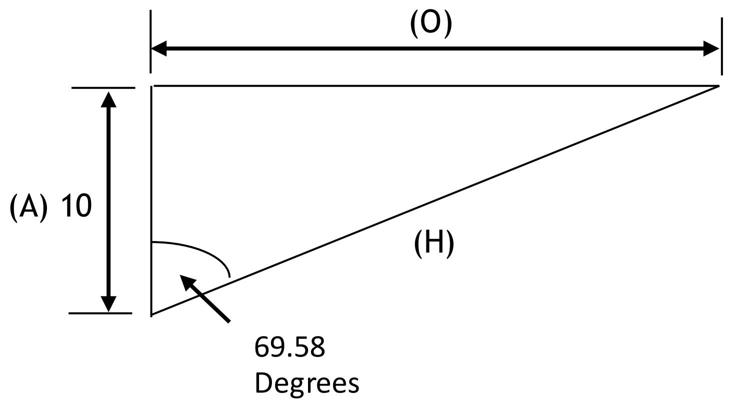

Fig. 12.4

$Tan\ \Theta = \frac{O}{A}$ $\quad\quad$ $Tan\ (69.58) = (\frac{(O)}{A})$

$$(O) = Tan(69.58).(10)$$

$$= 26.861 = 27\text{mm}$$