INVESTIGATION OF STRESSES IN MASTER LEAF OF LEAF SPRING BY FEM AND ITS EXPERIMENTAL VERIFICATION

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Abstract
The main component of leaf spring is master leaf and it is subjected to cyclic loading. There are many causes of master leaf failure. The maximum stress induced in the master leaf is at support. Due to non geometric linearity and large deflection behavior the stress may be occurred at any section over the span of leaf spring. Hence in this work evaluation of stresses in master leaf over the span is studied using finite element method and strain gauge technique. The stress analysis of half cantilever master leaf of leaf spring with and without extra full length leave is carried out. The result of finite element method is verified with experimental and analytical calculations.

Keywords : Leaf spring, Master leaf, FEM, Strain gauge, Static loading.

1. Introduction

As the name implies, stress analysis is the complete and comprehensive study of stress distribution of specimen under study. The most important task before design engineer is to maintain the working stresses within predetermined specific limits, in order to avoid the failure of a member. The design has to be economical with adequate mass and inertia. To improve the product quality it is necessary to determine the stresses in various components. It is also necessary to know the stress distribution in order to predict the failure of component. This puts the design engineer into indispensable need for stress analysis.

The main cause of failure of leaf spring is due to large bending behavior. The bending stresses on the leaf spring are calculated so far. The approach was based on cantilever beam theory. Using this approach the bending stress must be induced near the support which provides sufficient rigidity to suspension. Hence it is necessary to evaluate the stresses in the leaf spring. The main component of leaf spring is master leaf therefore the stress analysis of master leaf is carried out by different approaches.

In present work stresses in master leaf are evaluated by considering two approaches. In first approach the stress analysis is carried out by considering only the graduated leaves and in other approach the stress on master leaf is carried out by considering one extra full length leave. The analysis is carried out on only half span of leaf. A model of half cantilever spring assembly is developed in ANSYS and finite analysis is carried out in the same software. For the analysis purpose the spring is bolted at the center and static load is applied at the free end i.e. on eye. The results of finite element analysis for both approaches are verified experimentally by using strain gauges.

2. Design parameter and material

The work is carried out in the rear end leaf spring of a commercial vehicle. The leaf spring with and without extra full length leave assembly is used for the analysis. For the analysis the leaves are cut into required length in such way that

Span of first or smallest leaf =L/n= 440/4 =110mm

Span of second leaf =2L/n= 2x440/4 =220mm

Span of third leaf =3L/n= 3x440/4 =330mm

Span of master leaf =L = 440mm

No.of leaves =n= 4

The design parameter of leaf spring are shown below in table 1.

Table 1. Design parameter

Parameter	Values
Material selected (steel)	55Si2Mn90
Tensile strength (N/mm^2)	1962
Yield strength (N/mm^2)	1470
Young's Modulus E(N/mm^2)	$2.1x10^5$
Design stress σ_b (N/mm^2)	653
Camber (mm)	65.5
Span (mm)	880
Inner radius of eye(mm)	10.5
Outer radius of eye(mm)	17.5

3 Methodologies

3.1 *Experimental work*

In experimental analysis , actual prototype is considered under static loading condition . The stress analysis of leaf spring is carried out by using the strain gauge technique. The instrumentation is developed for this work. Instrumentation measures only the change in resistance i.e. ΔR. This change in resistance is very small having a magnitude of few milli volts. So it is necessary to convert this small resistance into a equivalent voltage with the help of instrumentation techniques. The instrumentation consist of Strain Gauges ,Wheatstone bridge circuit and Digital multimeter .

3.1.1 *Experimental set up for graduated leaf spring assembly*

The four graduated leaves leaf sprig assembly is used for the experimental analysis. As the leaf spring is symmetrical and hence analysis is carried out on a half cantilever leaf. For the analysis the leaves are cut into required length . The four strain gauges of each gauge having resistance 120 Ω and Gauge factor 2.0 are located on a master leaf..The strain gauge no. 1,2,3&4 are located at a distance of 15mm,125mm,235mm&345mm

respectively from fixed end of leaf spring. The whole assembly is bolted to the heavy base. The load pan is clamped at free end i.e. on eye. The load is applied on pan . The experimental set up is shown in fig no. 1. Due to application of load, resistance of strain gauge wire is changes. This change in resistance are measured in term of millivoltage which shown by digital multimeter. This change in output voltage is directly propositional to applied strain. The experimental strain is carried out by equation 1

$$dVo = \frac{1}{4} \times Vs \times F \times \varepsilon \quad (1)$$

where

Vs = Supply voltage in volts

dVo=Change in voltage in millivolts

F=Gauge factor=2

ε=Experimental strain

Experimental stress is given is given by

$$\sigma_b = \varepsilon x E \quad (2)$$

E= Young modulus of material of material

Fig. 1 Experimental Setup

3.1.2 *Experimental set up for extra full length spring assembly*

One extra full length leave is placed below the master leaf. The span of graduated leaves is in same as earlier. The experimentation is carried out by repeating the above procedure and observation are noted for each strain gauge location and stresses are calculated at each strain gauge locations.

3.2 Finite element analysis

The two model of half leaf spring assembly is developed. The first model is developed only considering the graduated leaves and other by adding one extra full length leave. Both the model are developed using ANSYS software. To reduce the complexity for solution, center band and clamp are not modeled together. After generation of model, 10 node solid 92 tetrahedral element is used for the analysis. The properties of material are provided and mesh model is developed. Contact conditions are formed where bodies meet. For 3-D contact analysis TARGE170 and CONTA174 elements are used. When the load is applied on the plates then it slightly slowly sliding over one another and hence no separation contact behaviors are used for the analysis. The material is deformable hence flexible to flexible as well as surface to surface contact is established with contact manager by taking the small coefficient of friction μ =0.2. The load is applied on the free end i.e. on eye and constraints are provided at each end of the leaf at center. After solving, the first principle stress counter at nodal region is shown in fig. 2 and fig. 3.

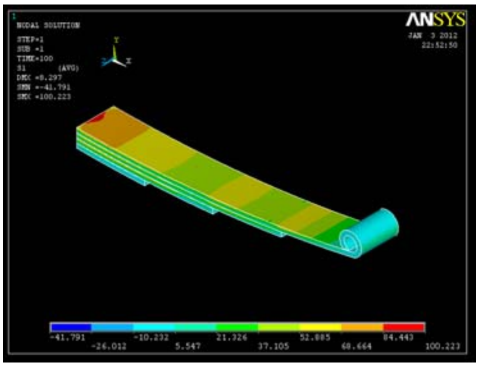

Fig. 2 First principle stress counter for graduated leaf spring assembly

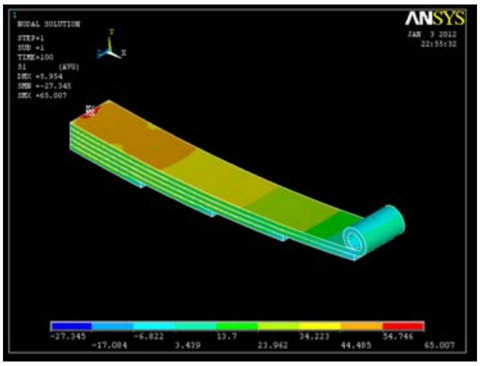

Fig. 3 First principle stress counter for leaf spring assembly with one extra full length leave.

3.3 *Analytical analysis*

3.3.1 *Analytical stresses and deflections on master leaf for graduated leaf spring assembly at strain gauge locations*

For the analytical analysis the following specification are considered
Total weight including wt. Of pan &clamp W=30 kg=294.3N
Span from load end to strain gauge No.1 L_1=425mm
Span from load end to strain gauge No.1 L_2=325mm
Span from load end to strain gauge No.1 L_3=205mm
Span from load end to strain gauge No.1 L_4=95mm
Width of leaf b=60mm
Thickness of leaf t=7mm
No.of leaves n=4
Analytical stress is calculated by

$$\sigma_b = 6\,WL / n\,bt^2 \qquad (3)$$

The stresses at each strain gauge location is calculated by using above equation by changing the value of L.
Analytical deflection is given by

$$\delta = (6 \times W \times L^3) / (n \times E \times b \times t^3) \qquad (4)$$

Modulus of elasticity $E = 2.1X10^5$ N/mm^2
Span from fixed end to strain gauge No.1 L_1=15mm
Span from fixed end to strain gauge No.1 L_2=125mm
Span from fixed end to strain gauge No.1 L_3=235mm
Span from fixed end to strain gauge No.1 L_4=345mm
The analytical deflections at each strain gauge locations is calculated by using above equation by changing the value of L.

3.3.2 *Analytical stresses and deflections on master leaf for extra full length leaf spring assembly at strain gauge locations*

Total weight including wt. Of pan &clamp W=30 kg=294.3N
Span from load end to strain gauge No.1 L_1=425mm
Span from load end to strain gauge No.1 L_2=325mm
Span from load end to strain gauge No.1 L_3=205mm

Span from load end to strain gauge No.1 L_4=95mm

Table 2. Comparison of Stresses in master leaf for graduated leaf spring

Sr No.	Length mm	Maximum Stress calculated analytically N/mm^2	Maximum Stresses By FEM N/mm^2	Maximum stress with analysis Experimental Analysis N/mm^2
1	15	63.81	70.03	72.55
2	125	48.79	55.81	42.84
3	235	30.78	60.90	39.68
4	345	14.26	58.50	42.84

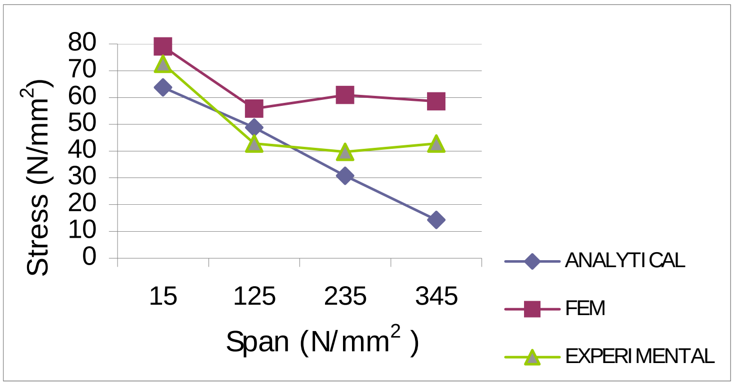

Fig. 4. Variation of Maximum Bending Stresses in a master leaf with respect to span

Table 3. Comparison of deflection in a master leaf in graduated leaf spring assembly

Sr No.	Length from fixed support mm	Maximum deflection calculated analytically Mm	Maximum deflection By FEM mm
1	15	3.4473×10^{-5}	0.1682×10^{-1}
2	125	0.199950	o.76034
3	235	1.325	2.38
4	345	4.19	4.818

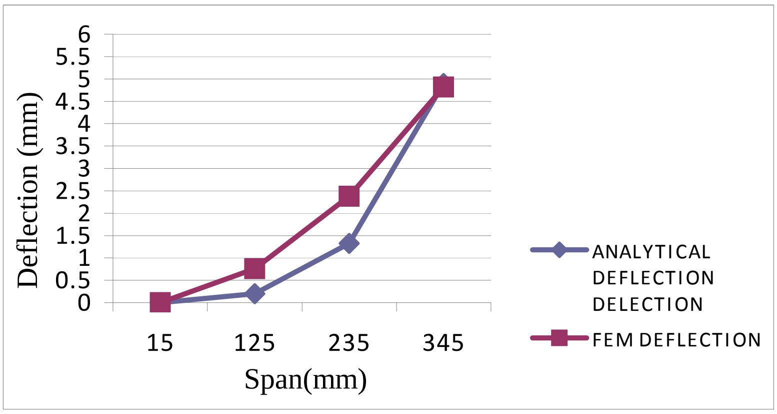

Fig 5 Variation in deflection with span for graduated leaf spring

Table 4. Comparison of Stresses in master leaf for extra full length leaf spring

Sr No.	Length mm	Maximum Stress calculated analytically N/mm^2	Maximum Stresses By FEM N/mm^2	Maximum stress with analysis Experimental Analysis N/mm^2
1	15	46.41	50.794	39.48
2	125	35.49	46.59	36.33
3	235	22.38	41.07	32.97
4	345	10.37	27.94	26.25

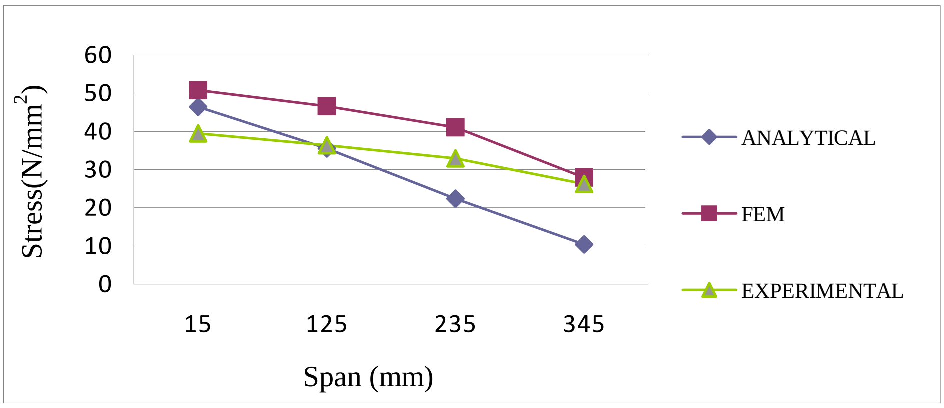

Fig. 6 Variation of Maximum Bending Stresses with respect length

Table 5. Comparison of deflection in master leaf for extra full length leaf spring

Sr No.	Length from fixed support mm	Maximum deflection calculated analytically mm	Maximum deflection By FEM mm
1	15	$2.50x10^{-4}$	$-0.1011x10^{-1}$
2	125	0.1450	0.5059
3	235	0.9640	1.706
4	345	3.045	3.59

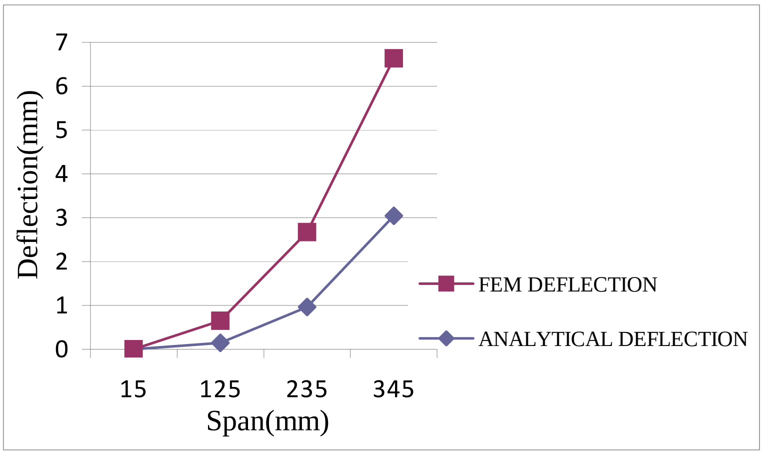

Fig 7. Variation in deflection with respect to span

5 Discussion and conclusion

Though the detailed results are presented in earlier, here an attempt is made to compare the results obtained analytically, by FEM and experimentation. For comparison of stresses first principle stress is considered. The detailed discussion is as

5.1 Variation of stress and deflection in graduated leaf spring

The stress are evaluated at varies distances varying from 15mm to 345mm measured from support. The results are given in table 2. It is observed from this table that the FE stresses are in good agreement with experimentally calculated stresses with few exceptions. This non agreement mainly at strain gauge location of 235mm from support may be due to improper bonding of strain gauge. It is also seen that the analytical stress decreases from fixed end to free end which is very natural from theoretical point of view in which the beam theory is used. But the FE analysis revealed that the stress are almost constant in master leaf at the location were the leaves terminate. This find is also confirmed by experimental analysis. This revealed that the maximum stresses in the master leaf are present at many places over its length. This fact was not revealed by analytical analysis. But the analytical analysis revealed the maximum stress of 63.81 N/mm^2 nearer to support which is in the range of 58.5 to 70.3 N/mm^2 stress calculated by FEM. Though the analytical equation do not give the equal stress at various locations on the master leaf but it can be predict the maximum stress values present in the master leaf variations. The variation in the deflection at various point along master leaf is shown in table no .3.which is calculate analytically and by FEM. It is seen from fig. 5 that the nature of variation of deflection is identical.

5.2 Variation of stress and deflection in extra full length leaf spring

To study the effect of extra full length leaf, one extra full length leaf ,one extra full length leave added to graduated leaves & FE analysis & experimental analysis is performed and the stress are evaluated at distance 15mm,125mm,235mm&345mm from fixed end on master leaf. The result are presented in table no4..It is seen from the table that the stress calculated by FEM and experimental analysis are in closer agreement with minor deviations. The trained of analytical calculated stresses is remain same that of earlier discussion. In this case also the maximum stress near to support is nearly same with analytical calculation by FEM and experimental analysis. This fact again proved that the maximum stress near the support can be evaluated by analytical equation. But the analytical equation failed to determine the stresses away from the support. It is also observed from table 4. that with the addition of extra full length leaf the stresses are reduced drastically. Thus to strengthen the leaf spring extra full length leave are recommended. The variation in the deflection at various points along master leaf is shown in fig. 7 which is calculated analytically and by FEM. It is seen from fig.7 that the nature of variation of deflection is identical.

5.3 Overall conclusion

From this study it is conclude that though the analytical equation failed to give the maximum stress values in a master leaf away from the support but it is useful to know the values of maximum stress at the support. But to determine the variation in the stresses at the point away from the support finite element method or experimental technique should be used. In present case the stresses on master leaf can not fallow cantilever beam theory but when one extra full length leaves are added to the assembly this theory is valided. So, length of graduated leaves plays a significant role in the stresses on master leaf. Hence in actual practice one or two extra full length leaves are used to strengthen the master leaf.

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