UNIVERSITI PUTRA MALAYSIA

STATIC AND DYNAMIC MECHANICAL PERFORMANCE OF COMPOSITE ELLIPTIC SPRINGS FOR VEHICLE SUSPENSION

GEHAD GOUDAH SOLIMAN MOSLEH HAMDAN

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STATIC AND DYNAMIC MECHANICAL PERFORMANCE OF COMPOSITE ELLIPTIC SPRINGS FOR VEHICLE SUSPENSION

By

GEHAD GOUDAH SOLIMAN MOSLEH HAMDAN

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

May 2007

UPM

TO
THE MEMORY OF
MY MOTHER (LATE)

AND

MY FATHER, BROTHERS, SISTERS
AND ADIB DAJANI
FOR THEIR MORAL SUPPORT AND ENCOURAGEMET

Abstract of the thesis presented to the Senate of University Putra Malaysia in fulfillment of requirements for the degree of Master of Science

STATIC AND DYNAMIC MECHANICAL PERFORMANCE OF COMPOSITE ELLIPTIC SPRINGS FOR VEHICLE SUSPENSION

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May 2007

Chairman: Elsadig Mahdi Ahmed Saad, PhD

Faculty : Engineering

For composites to compete in vehicle suspension applications, it is essential to control their failure by utilizing their strength in principal direction instead of shear. This can be achieved efficiently by employing a new configuration instead of existing one. The innovated product marries between an elliptical configuration and the woven roving composites. The invented composites semi-elliptical spring replaced both the shock absorber and the coil spring. The assembly includes a composite laminate resin-cured structure comprising at least a pair oriented fabric fiber. It can be used for light and heavy trucks and meet the requirements, together with substantial weight saving. Finite element models were developed to optimize the material and geometry of the composite elliptical spring based on the spring rate, vibration frequency, log life and shear stress. The achieved optimum composite spring has been fabricated and tested. The wet wrapping process was used to fabricate the composite spring. The designed and

fabricated composite springs were subjected to compression and cyclic tests to determine their performance. Photographs at any experiment were taken during the test; thus the photograph shows the springs at different stress level. The results showed that the ellipticity ratio significantly influenced the spring rate and the life expectancy of the structure according to the level of loading and number of cycles specified. Composite elliptic spring with ellipticity ratios of $a/b = 2$ displayed to an optimum structure geometry. It is also interesting that no failure was observed and the relaxation of the composite elliptic spring after loading in different displacement modes was evaluated.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

KECEKAPAN MEKANIK STATIK DAN DINAMIK PEGAS KOMPOSIT ELIPTIK UNTUK SUSPENSI KENDERAAN

Oleh

GEHAD GOUDAH SOLIMAN MOSLEH HAMDAN

Mei 2006

Pengerusi: **Elsadig Mahdi Ahmed Saad, PhD**

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Untuk komposit bersaing dengan aplikasi perkembangan kenderaan adalah penting untuk mengawal kegagalan dengan memanfaatkan kekuatan dari arah prinsipal berbanding kekuatan. Ini boleh dicapai secara efisen dengan melaksanakan konfigurasi baru berbanding yang sedia ada. Produk inovasi ini merangkumi konfigurasi elips dan kimpalan komposit. Inovasi sepruh elips pegas komposit ini menggantikan kedua-dua penyerap hentakan dan pegas lingkar. Penemuan ini termasuk struktur resin terawat lamina komposit yang terdiri dari sekurang-kurangnya sepasang orentasi gentian fabrik. Ia boleh digunakan untuk kenderaan berat dan ringan, mengikut keperluan, sekaligus boleh menjimat berat keseluruhan. Model elemen tentu dibangunkan untuk mengoptimumkan bahan dan geometri pegas elips komposit berasaskan kadar pegas, frekuensi getaran, jangka hayat dan tegasan terikan. Pegas komposit optimum yang discapai telah dibina dan diuji. Proses pembungkusan lembap telah digunakan untuk membina pegas komposit. Pegas komposit yang direka dan dibina, diuji kekuatan mampatan dan kitaran untuk mengetahui pencapaiannya. Gambar foto diambil

sepanjang ujikaji dilakukan, dan foto menunjukkan pegas pada tahap tegasan yang berbeza. Keputusan menunjukkan nisbah elips mempengaruhi kadar pegas dan jangkaan jangka hayat struktur berdasarkan kepada tahap bebanan dan bilangan kitaran yang khusus. Pegas elips komposit dengan nisbah elips a/b=2 menunjukkan geometri struktur optimum. Keputusan juga menunjukkan tiada kegagalan di sepanjang pemerhatian dan keadaan pegas elips komposit selepas bebanan pada pusat berbeza dinilai.

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I certify that an Examination Committee met on 04/05/2007 to conduct the final examination of Gehad Goudah Soliman Mosleh Hamdan on his Master of Science thesis entitled "Static and Dynamic Mechanical Performance of Composite Elliptic Springs for Vehicle Suspension" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Putra Malaysia or other institutions.

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GEHAD GOUDAH SOLIMAN MOSLEH HAMDAN

Date: 13 JUNE 2007

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LIST OF ABBREVIATIONS

SAE	The society of automotive engineers
SEC	The specific stored energy coefficient
FRP	Fibre reinforced polymer
CFRP	Carbon fiber reinforced polymer
GRP	Glass reinforced polymer
FEA	Finite element analysis
NVH	Noise, vibration, and harshness
WRLW	Woven roving laminated wrapped
θ	Fiber orientation angle (degree)
v_f	Fibre volume fraction
ρ_m	Matrix density (kg/m^3)
ρ_f	Fiber density (kg/m^3)
w_f	Fiber weight fraction
w_m	Matrix weight fraction
F	The vertical force (N)
T	The torque
D	The mean diameter of the coil spring (mm)
d	Diameter of wire of the coil spring (mm)
N	The number of coils or Leaves
G	Shear modulus (N/m^2)
σ	The stress (N/m^2)

υ	Poisson's ratio
E	The Young's modulus (N/m²)
ε	The strain
S_{ij}	Compliance matrix
$[\overline{Q}]$	The transformed reduced stiffness matrix
N	The resultant stress
M	The resultant moment
[A]	Extensional stiffness matrix (N/m)
[B]	Coupling stiffness matrix (N)
[D]	Bending stiffness matrix (N.m)
P, W , F	The load or force (N)
Q	Shear force (N)
M_o	Bending moment
L	The length of the cantilever section (mm)
h	The thickness of material (mm)
b	The width of the material (mm)
K_x	Spring constant in the direction of principal axes x (N/m)
K_y	Spring constant in the direction of principal axes y (N/m)
K_{xy}	Spring constant of in-plane bending-shear (N/m)
K_{xz} ,K_{yz}	Spring constant of in-plane bending-torsional (N/m)
$[K_e]$	Element stiffness matrix
$\{F_e\}$	The element load vector of a finite element
$\{U_e\}$	The nodal displacement vector for an element

$[B_e]$	The strain-displacement matrix
$\left[D_{ep}\right]$	The elastoplastic constitutive matrix
$\|J\|$	The determinate of the Jacobian matrix
$\boldsymbol{u_x}, \boldsymbol{u_y}, \boldsymbol{u_z}$	Displacements components
ϕ_x, ϕ_y	Rotation components
$N_1, N_2, \ldots N_8$	The shape functions
$\left[\ddot{U}\right]$	The acceleration
$\left[\dot{U}\right]$	The velocity
$[C]$	The damping matrix
[M]	The mass matrix
k_s	The suspension stiffness (N/m)
m_s	The sprung mass (kg)
m_u	The unsprung mass (kg)

CHAPTER 1

INTRODUCTION

1.1 Background

In recent years, automobile makers and part manufacturers have been attempting to reduce the weight of vehicles to meet the needs of natural resources conservation and energy economy. To reduce vehicle weight, three factors have been considered: rationalizing the body structure, utilizing light weight materials for parts and decreasing the size of vehicle (Tanabe et al., 1982). The suspension system parts are one of the potential elements for weight reduction in automobiles as it leads to the reduction of the unsprung weight of automobile (Rajendran et al., 2001). The elements whose weights are not transmitted to the suspension spring are called the unsprung elements of the automobile. In current suspension systems, these include wheel assembly, axles, and part of the weight of suspension spring and shock absorber (Lupkin et al., 1989). However, springs are crucial suspension elements in cars, necessary to minimize the vertical vibrations, impacts and bumps due to road irregularities and provide a comfortable ride (Shokrieh and Rezaei, 2003).

According to Roberts and M. INST B.E.(1954), there is no exaggeration to say that springs are the life blood of modern civilized life, for without springs the great development which has taken place in engineering and mechanical science would have been impossible. Simple everyday actions, such as the latching or locking of a door, or turning on an electric light, are controlled by springs. Springs are essential

for working of clocks, watches, gramophone, wireless, the intricate mechanism of automatic telephone, and the gigantic printing presses and weaving looms. Modern travel would be impossible without springs, many thousands of different types being used in bicycles, motor cycles, cars and aircraft.

Springs are unlike other machine/structure components in that they undergo significant deformation when loaded; their compliance enables them to store readily recoverable mechanical energy. It is well known that springs, in general, are designed to absorb and store energy and then release it. Hence, the strain energy of the material and the shape become a major factor in designing the springs (Al-Qureshi, 2001). In a vehicle suspension, when the wheel meets an obstacle, the springing allows movement of the wheel over the obstacle and thereafter returns the wheel to its normal position (i.e. to be resilient). The elliptic composite springs described by Mallick (1987) represents the first step in introducing fibre reinforced composite elliptic springs for automotive applications. Mechanical performance and failure modes of composite elliptic spring elements under static load conditions were also reported. Key design parameters, such as spring rate and failure load were measured as a function of spring thickness.

Nowadays, the industrial vehicles have to reduce their tare weight and to improve safety as well as life expectancy; one solution to this is the replacement of steel springs with composite. As stated by Sardou and Djomseu (2000), there are three ways to introduce composite on vehicle suspension. The first is to take away a metal leaf spring and put in place a composite leaf spring. Second is to design a composite axle doing anti roll as well as spring and guidance task. The last one is to design a

metal suspension and to use composite spring only for its vehicle properties. First and second solutions design the composite to carry a complex job of wheel control and suspension spring. The task is rather complex for composite and end up with a relatively small benefit in weight and cost, on top of that suspension quality is relatively poor. However, in the field of vehicle suspension, the industry looks for a cost effective composite spring with minimum mass capable of resisting corrosion and possessing a high degree of durability. Therefore, the automobile industry has shown increased interest in the replacement of steel springs with composite springs especially glass fibre composites rather than others such as carbon fibre due to the cost factor.

1.2 Objectives

The main aim of this study is therefore to introduce a new configuration of composite suspension spring by utilizing fibre reinforced composite strength in principal direction instead of shear. The detailed objectives of the present study can be summarized as follows:

1) To predict the effect of ellipticity ratio, fibre orientation angle and laminate stacking sequence on the behaviour of composite semi-elliptic springs.
2) To examine the effect of cyclic loading on the performance of the optimised and fabricated composite semi-elliptic springs.
3) To study the effect of hybridization on the behaviour of composite semi-elliptic springs.
4) To study the vibration capability of the composite semi-elliptic springs.