EFFECT OF UNBALANCED OVERLOADING ON THE CORNERING STABILITY PROFILE OF NONHOLONOMIC TWO IN-WHEEL COMPACT ELECTRIC VEHICLE

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I hereby declare that the work in this 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 Malaysia Pahang or any other institutions.

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ABSTRAK

Seiring dengan perkembangan revolusi industri keempat, revolusi kenderaan konvensional telah mengalami perubahan yang drastik, di mana kenderaan konvensional kini telah berevolusi kepada kenderaan elektrik dan dipacu sendiri. Antara teknologi baru di dalam pembinaan kenderaan elektrik adalah teknologi berasaskan pacuan motor dari dalam tayar (IWMEV). Seperti kenderaan pembakaran dalaman konvensional, IWMEV juga mudah terdedah kepada ketidakstabilan yang boleh mengundang kemalangan. Kemalangan boleh dibahagikan kepada tiga kategori berdasarkan punca, iaitu keadaan kenderaan, kesilapan manusia dan keadaan alam sekitar. Kebanyakan kemalangan yang berlaku adalah hasil tingkah laku manusia. Beban berlebihan yang tidak seimbang telah dikenalpasti sebagai salah satu faktor yang mempengaruhi kestabilan kenderaan sehingga menyebabkan kemalangan berlaku. Peningkatan beban hanya di satu sisi kenderaan mengubah kedudukan pusat graviti yang membawa kepada peningkatan kebarangkalian untuk ketidakstabilan kenderaan berlaku. Berbanding kenderaan pembakaran dalaman konvensional, IWMEV dianggap sebagai kenderaan ringan kerana ketiadaan struktur mekanikal dan enjin yang kompleks. Objektif penyelidikan ini adalah untuk mengenalpasti kesan pengagihan beban berlebihan yang tidak seimbang terhadap kestabilan kenderaan elektrik. Oleh itu, model simulasi matematik EV dihasilkan dengan menggabungkan persamaan pemindahan beban, model tayar Dugoff, gabungan persamaan dinamik kenderaan dan model motor arus terus. Model matematik yang dibangunkan divalidasi menggunakan kereta EV kompak. Seterusnya, model ini digunakan untuk mengenal pasti kesan pengagihan beban di sebelah kiri dan kanan kereta EV semasa pusingan tajam. Simulasi dijalankan dengan menggunakan empat profil halaju iaitu 10 km/j, 15 km/j, 20 km/j dan 25 km/j. Keputusan analisis menunjukkan bahawa kenderaan mencapai had kestabilan kadar pekali bulatan geseran (FCC) pada 60% daripada pengedaran beban di sebelah kanan semasa pusingan ke kanan pada 25km/j. Ini menyebabkan kenderaan tersebut untuk terbabas. Selain itu, satu indeks kestabilan berdasarkan beban yang dinamakan Binary Attribute Stability Indicator (BASI), diperkenalkan untuk mengukur kesan pengedaran beban terhadap kestabilan EV. BASI boleh membantu mengenalpasti tahap kestabilan EV tersebut berdasarkan pecutan sisi, kadar olengan, pekali bulatan geseran (FCC) dan indeks golekan.

ABSTRACT

The recent development of vehicle technology is shifting towards the autonomous and electric vehicle. Electric vehicle technology has grown to pave a path towards wheel motored electric vehicles (IWMEV). Like conventional internal combustion vehicle, IWMEV are also susceptible to instability which could result in accidents. Accidents are divided into three categories based on the cause, namely vehicle condition, human error and environmental condition. Most accidents that occur are results of human behaviour. Unbalanced overloading is identified as one of the factors that affect the stability of the vehicle thus, leading to accidents. Increasing load on one side of the vehicle moves the position of the centre of gravity leading to an increase in the probability of vehicle instability. Moreover, compared to conventional internal combustion vehicle, IWMEV are considered lightweight vehicle due to the absence of mechanical linkage and engine. This causes IWMEVs to be affected by unbalanced overloading. Therefore, the objective of this research is to identify the effect of unbalanced overloading on the stability profile of the electric vehicle. Thus, a simulation model of an IWMEV is developed by combining the load transfer equation, Dugoff's tire model, nonlinear vehicle dynamic equation and the DC motor model. The developed model is verified using a compact IWMEV. Then, the model is used to identify the effect of load increase at the left and right side during a sharp right turn. The vehicle is set to run at four different velocities namely 10 km/h, 15 km/h, 20 km/h and 25 km/h. It is observed that the vehicle reaches the Friction Circle Coefficient limit at the front left tire for a 60% right load increase condition. This causes the vehicle to crash. A load stability index named Binary Attribute Stability Indicator (BASI) is proposed to identify the stability of the vehicle at different load distribution. The BASI can help determine the stability level of the vehicle based on lateral acceleration, yaw rate, FCC, and rollover index.

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LIST OF SYMBOLS

F_{xf}	Longitudinal force acting on front tires
F_{xr}	Longitudinal force acting on rear tires
F_{aero}	Aerodynamic drag force
R_{xf}	Front tire rolling resistance force
R_{xr}	Rear tire rolling resistance force
m	Total mass of the vehicle
g	Gravitational acceleration
θ	Angle of inclination of the road which the vehicle is traversing
F_{yfl}	Lateral force acting on front left tire
F_{yfr}	Lateral force acting on front right tire
F_{yrl}	Lateral force acting on rear left tire
F_{yrr}	Lateral force acting on rear right tire
$\ddot{y}$	Acceleration produced due to motion along y-axis
m_{Sij}	Static mass of the vehicle where i= front, rear and j= right, left
$load_{ij}$	Extra load distributed at each tire where i= front, rear and j= right, left
F_{xfl}	Longitudinal force acting on front left tire
F_{xfr}	Longitudinal force acting on front right tire
F_{xrl}	Longitudinal force acting on rear left tire
F_{xrr}	Longitudinal force acting on rear right tire
a_x	Longitudinal acceleration
V_x	Longitudinal velocity
$\ddot{\varphi}$	Yaw acceleration of the vehicle
β	Body slip angle
μ_{ij}	Tire-road friction coefficient where i= front, rear and j= right, left
$C_{\alpha f}$	Front tire cornering stiffness
$C_{\alpha r}$	Rear tire cornering stiffness
C_{σ}	Longitudinal tire stiffness
M_x	Moment of load
V_T	Total voltage

V_R	Voltage across the resistor
V_L	Voltage across the inductor
V_M	Voltage across the motor
h_{cg}	Height of the centre of gravity of the vehicle from the ground
d_w	Width between the centre of the rear tires
FCC_{ij}	Friction circle coefficient where i= front, rear and j= right, left
I_w	Rotational moment of inertia for each tire
I_z	Vehicle yaw moment of inertia
ij	i= front, rear and j= right, left
V	Resultant vehicle velocity

LIST OF ABBREVIATIONS

TRFC	Tire-road friction coefficient
IWMEV	In-wheel motored electric vehicle
FCC	Friction circle coefficient
ICEV	Internal combustion engine vehicle
ABS	Anti-lock braking system
ESC	Electronic stability control
EV	Electric vehicle
DC	Direct current
BLDC	Brushless DC motor
SLAM	Simultaneous localization and mapping
RI	Rollover index
RTA	Road traffic accident
LTR	Load transfer ratio
IMU	Inertial measurement unit

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