Design of a novel tilting electric four-wheeler

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RESOLVE Project

Making light electric mobility an option

Horizon 2020 Program
Electric two-wheelers and new light vehicle concepts
(H2020-GV.5-2014)

Project Start
May 2015

Duration
36 months

Project Coordination
Piaggio & C. S.p.A.

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Project Overview

Overcome limiting factors of ELV widespread adoption

Policy factors

Cost
Develop a range of electric powertrain

Energy Efficiency
Demonstrate through two tilting 4-wheelers prototypes

Attractiveness in urban areas
Improve rider experience

Willingness to use
Increasing willingness to use of ELVs

RESOLVE CONCEPT: making Electric LVs practical alternatives to cars

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RESOLVE Consortium

- AIT (A)
- IDIADA (SP)
- KTM (A)
- Piaggio (IT) - coordinator
- Ricardo (D)
- University of Pisa (IT)
- University of Warwick (UK)

- Bosch (D)
- KISKA (A)
- Marelli (IT)
- RE:Lab (IT)
- University of Firenze (IT)
- University of Prague (CZ)
- Wamtechnik (PL)

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Partners tasks

AIT (A)
- Longitudinal simulations
- Multibody simulations

University of Pisa (IT)
- Lateral dynamics simulations
- Finite element structural simulation
- Multibody simulations

KTM (A)
- Simulation workpackage coordination
- D2 Demonstrator design and construction

Piaggio (IT)
- Project coordination
- D1 Demonstrator design and construction

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Design Outline

Powertrain architectures

Longitudinal dynamics

Numerical models for stability

Multibody models for handling

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Longitudinal Dynamics

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Stability and Dynamics

Why?
Assess the uncontrolled stability behavior of the vehicle and compare it with the natural stability behavior of 2-wheelers.

Does the rider perceive a similar vehicle behavior?

Literature fundamentals

THE STABILITY AND CONTROL OF MOTORCYCLES
By R. S. Sharp*

Mathematical models of a motorcycle and rider dependent on three alternative assumptions concerning the tyre behaviour are developed. Stability characteristics deduced from them are compared, and minimum requirements for the model greater than have been previously satisfied are established. Using the most sophisticated of the models, the effects of design changes are calculated, and the design implications are discussed.

Fig. 5. Stability and natural frequencies of standard machine as a function of forward speed with the full tyre treatment
Stability and Dynamics

Numerical model

Hypotheses

- Rigid bodies
- Flat and horizontal road
- Locked suspensions
- Rigid and lenticular wheels
- Linear tire behavior

State variables

- Longitudinal speed \( u \)
- Lateral speed \( v \)
- Yaw rate \( r \)
- Steering angle \( \delta \)
- Roll angle \( \phi \)
Stability and Dynamics

Natural modes

Capsize (non-oscillatory)

Weave

Wobble


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Stability and Dynamics

Natural modes behavior similar to classical 2-wheelers and 3-wheelers

Similar rider perception

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Stability and Dynamics

Natural modes with suspensions

In-phase motion of the front and rear wheels

Same design criteria of 2-wheelers

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Stability and Dynamics

Tilting mechanism dynamic model

\[ M \ddot{w} + C \dot{w} + Kw = 0 \quad \text{con} \quad w = (\theta(t), y_1(t), y_2(t)) \]

Optimal range of lever inertia

Alternatively: active control of suspensions

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Multibody model

Virtual rider

Steering law: roll-angle follower

\[ \dot{\delta} = k_1 \dot{\phi} + k_2 \dot{\phi} + k_3 (\phi_t(t) - \phi(t)) \]

*PID controller on target roll angle rate*

Drive torque law: speed follower

\[ T_{21} = \int_0^t c_1 (u_t(t) - u(t)) \, dt + c_2 (u_t(t) - u(t)) + k(t) \]

\[ T_{22} = \int_0^t c_1 (u_t(t) - u(t)) \, dt + c_2 (u_t(t) - u(t)) - k(t) \]

*PID controller on target longitudinal speed*

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Multibody model - Exemplification maneuvers

Steering pad

Counter-steering turn-in

Slalom

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Rear drive torque – Yaw control

\[ T_{21} = \int_{0}^{\tilde{t}} c_1(u_t(t) - u(t)) \, dt + c_2(u_t(t) - u(t)) + k(t) \]

\[ T_{22} = \int_{0}^{\tilde{t}} c_1(u_t(t) - u(t)) \, dt + c_2(u_t(t) - u(t)) - k(t) \]

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Rear drive torque – Yaw control

... torque control for ride assistance
... safe stabilizing aid in case of fall

Yawing torque

Counter-yawing torque

Same roll angle
Different load transfer
and handlebar angles

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Conclusions

- Aim of the project: make electrical L-category vehicles a valuable option
- Safe and enjoyable ride experience perception
- Modular and cost effective powertrains development
- Dynamic simulations to reproduce motorcycle-like riding behavior
- Possibility of torque and tilting control to aid rider and improve safety
Thank you for your attention

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