Università degli Studi di Padova
Dipartimento di Ingegneria Industriale

Hybrid vehicles with two or three wheels

Ph.D. Research Activity

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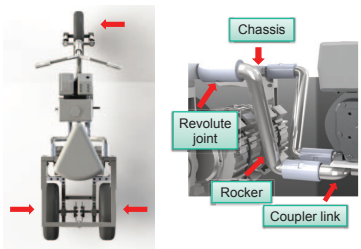
Topics

Hybrid vehicles equipped with three wheels and four-bar linkage, study and design of series and parallel hybrid propulsion systems, design of a computer code for a better integration of the mechanical design with the hybrid propulsion system, design of an innovative *Velomobile* equipped with linkage and characterized by hybrid propulsion system (electric and human power), feasibility study and realization of a mild-hybrid motorcycle in cooperation with Aprilia (MO.bi regional project).

Hybrid three wheeled vehicles equipped with linkage

Electric and hybrid vehicles with narrow track are very suited to sustainable urban mobility. A particular tilting three wheeled vehicle (totally electric) has been developed at Padova University. It is composed of a tilting front module (one wheel) and a non-tilting rear module (two wheels) connected by means of a four-bar linkage in order to improve the stability.

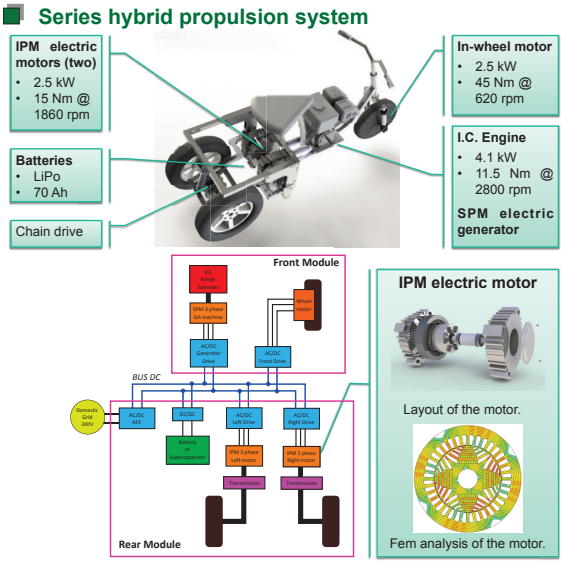
Three wheeled vehicle with linkage



Mechanical characteristics of the vehicle.

- **Three wheeled vehicle:** for urban and sub-urban mobility; it is suitable to novel rider.
- **Tilting front module** (one wheel) and non-tilting rear module (two wheels).
- **Four-bar linkage:** to improve the stability and the handling of the motorcycle.
- **Transmission:** chain drive without differential.
- **Good dynamics** performance and **comfort**.
- **Passenger** and/or auxiliary bags are allowed.

Series hybrid propulsion system

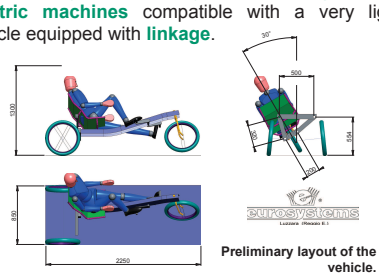


Working modes:

1. only electric mode with regenerative braking and i. c. engine switched off;
2. electric mode with regenerative braking and i. c. engine switched on;
3. plug-in mode for the batteries charge.

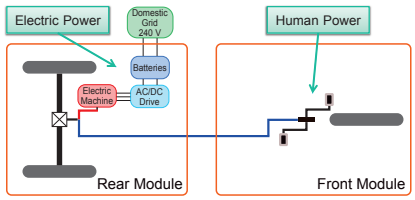
Project Velomobile

A **velomobile** or **bicycle car** is a human-powered vehicle, enclosed for aerodynamic advantage and protection from weather and collisions.
The goal is to design an hybrid vehicle with both **electric** and **human** propulsion systems.
The challenge is to **analyze and design small electric machines** compatible with a very light vehicle equipped with **linkage**.



Preliminary layout of the vehicle.

Power train overview

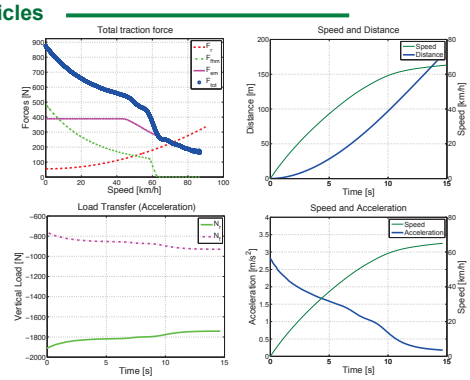


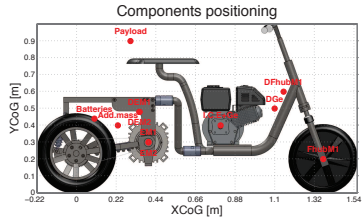
Matlab code for the designing of three wheeled vehicles

A computer code has been developed for better integrating the mechanical design of the chassis with the hybrid propulsion system. The program features are:

- **Estimation of dimensions and weights** of electric components and optimal position of every component on the vehicle.
- **Calculation of vehicle range**, only electric mode , with electric generator switched on, regenerative braking.
- **Performance calculation**: acceleration, speed.
- **Curve stability** (Steady Turning).

Graphical examples concerning the performance calculation are given.





- **Maximum speed**: 70 – 75 km/h.
- **Maximum acceleration** : 4.7 m/s^2.
- **Maximum slope**: 15 %.
- **Range** of 45 km, only electric mode and 130 km with the electric generator switched on.

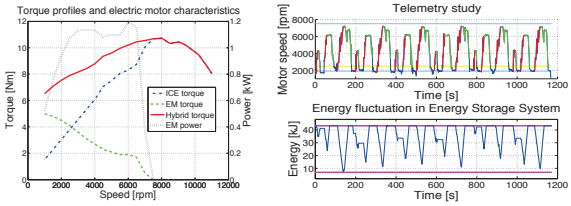
MO.bi regional project - Aprilia RS4 125 Hybrid

Feasibility study of a mild-hybrid motorcycle

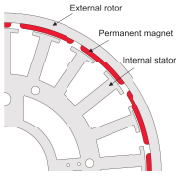
The **goal** was to estimate the increase of weight and volume due to the substitution of the traditional alternator with a more powerful one, in order to improve the thermal engine torque (*I.C.E. torque*) realizing a **parallel hybrid**.

A specific **torque profile** (*hybrid torque*) has been designed for satisfying the limitation in terms of maximum power (11 kW). The project of an optimized **SPM machine** has been carried out.

A **computer code** has been developed for testing the system composed by the motor, the drive and the energy storage, in terms of range calculation on a reference cycle for motorcycle (WMTC).



Practice realization

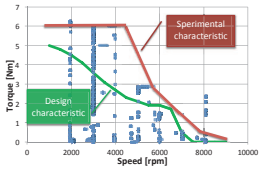


Layout of the electric machine.

Electric machine parameters.

Feature	Value
N° phases	3
N° slots	27
N° poles	18
I_{phase_max} [A_{pk}]	25
V_{phase_max} [V_{pk}]	220
Diameter $_{ext}$ [mm]	178
L_{stack} [mm]	35
Weight [kg]	5

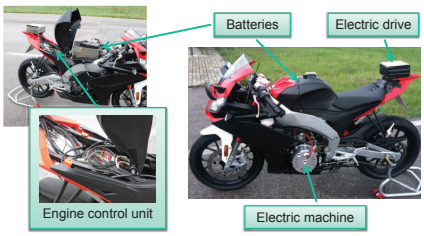
The **mechanical characteristic** of the electric motor has been obtained experimentally by means of a specific test bench in Aprilia.



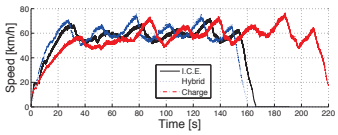
Experimental mechanical characteristic of the electric motor.

Final results

Layout of Aprilia RS4 125 Hybrid.



Finally the **whole motorcycle** has been tested on the private track of Piaggio factory. Telemetries concerning the motorcycle behavior have been acquired.



Experimental telemetries obtained on the private track of Piaggio factory.

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Future Works

- Improving of the matlab code in order to estimate the advantage of a variable transmission between the electric motor and the wheels.
- Design of the electric machine for the *Velomobile* and realizing of a prototype of the whole vehicle in cooperation with **EUROSYSTEMS Company**.