e.GO – agile simulation to verify vehicle concepts in early development stages
March 2018
e.GO will boost e-mobility, exciting customers with cars that are fun, practical and affordable.
e.GO has clearly positioned itself since the company’s foundation and is shaping a new form of electromobility

**Fun**
- Acceleration 0 - 50 km/h: 3,2 sec
- Agile & maneuverable
- Inspiring design
- Safety first

**Practical**
- Made for most daily needs and ranges
- Compact exterior and interior
- First choice for second car

**Affordable**
- Price from 15.900 €; before subsidies
- Total Cost of Ownership (TCO) 40% lower than conventional cars
- Worthwhile without subsidies
Highly iterative development is supported by the rapid implementation and testing of prototypes.

Rapid implementation of prototypes ...

- Concept design
- Body parts
- Building of a functional prototype
- Fast expert tests

... the example of e.GO Life

The rapid market expedition with functional prototypes is a success factor in the development of radical innovations in the e-mobility market.
e.GO enables the production of affordable vehicles with the latest technologies

**How to develop a highly iterative Prototype?**

### Digital Prototype

- **CAx – Design: DMU (Full-Vehicle Package)**
- **Digital Twin**
- **Simulation of Mechanical Strength (FEA)**
- **Full Vehicle Simulation – Ensuring Requirement Fit**

### Physical Prototype

- **Process Validation**
- **Empowerment of Prototyping and Production Team**
- **Fast validation of Technical Concepts**
- **Durability Tests in early stages**
High Level Requirements

Concept`s ability to fulfill the requirements

<table>
<thead>
<tr>
<th></th>
<th>e.GO Life 20</th>
<th>e.GO Life 40</th>
<th>e.GO Life 60</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENGINE POWER</td>
<td>20 kW</td>
<td>40 kW</td>
<td>60 kW</td>
</tr>
<tr>
<td>TOP SPEED</td>
<td>116 km/h</td>
<td>150 km/h</td>
<td>160 km/h</td>
</tr>
<tr>
<td>ACCELERATION 0–50 km/h</td>
<td>6.6 sec.</td>
<td>4.1 sec.</td>
<td>3.2 sec.</td>
</tr>
<tr>
<td>ACCELERATION 0–100 km/h</td>
<td>35.0 sec.</td>
<td>12.0 sec.</td>
<td>8.6 sec.</td>
</tr>
<tr>
<td>ELECTRIC RANGE NE20C</td>
<td>136 km</td>
<td>146 km</td>
<td>194 km</td>
</tr>
<tr>
<td>ELECTRIC RANGE Actual City Traffic</td>
<td>104 km</td>
<td>114 km</td>
<td>154 km</td>
</tr>
<tr>
<td>BATTERY CAPACITY</td>
<td>14.9 kWh</td>
<td>17.9 kWh</td>
<td>23.9 kWh</td>
</tr>
<tr>
<td>CONSUMPTION 100 km (NE20C)</td>
<td>9.0 kWh</td>
<td>10.9 kWh</td>
<td>11.1 kWh</td>
</tr>
<tr>
<td>CHARGING TIME Schuko Plug 230 V</td>
<td>6.0 hrs</td>
<td>7.5 hrs</td>
<td>9.6 hrs</td>
</tr>
<tr>
<td>CHARGING TIME IEC Type 2 Connector, Single Phase</td>
<td>3.1 hrs</td>
<td>3.6 hrs</td>
<td>4.6 hrs</td>
</tr>
<tr>
<td>DIMENSIONS</td>
<td>3348 x 1700 x 1567 mm (L/B/H)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Does the vehicle concept fulfill the requirements set by the product management?

➔ To answer this question in an early development stage, e.GO used Matlab / Simulink to simulate the vehicle quite without a physical prototype.
Driving Cycle / Testing

*Developing a city cycle to fulfill customer requirements*

- A new car concept needs a new driving cycle!
- Tracking of an inner-city driving cycle (s \( \sim \) 19 km, t \( \sim \) 45 min, \( v_{\text{average}} \) = 25 km/h)
- Also using standard cycles to ensure comparability to other vehicle concepts
Simulation of an electric vehicle

**Elements of the Simulation Model**

- The complex interaction of components is simulated in the Simulink model
- Validation of the model with rapid prototypes

**Input Data**

**Physical Components**
- Battery
- Motor & Inverter
- Gearbox
- Cooling System
- Vehicle

**Driver Model**

**Controller Models**

**Output Data**
Validation

Elements of the Validation Process

- **Several Model-elements**
- **Validation of model with rapid prototypes**
- **Finalization of e.GO Life Vehicle Concept**

**Simulink Model**
- Inclusion of all components
- Defining Environmental Inputs
- Defining Input & Output-Parameter

**Funktional Prototype**
- Testing of selective functions
- Improving the simulation model
- Increasing the prototype maturity

**Final vehicle**
- Validation of the final system design
- Matching the physical vehicle and the simulation model
**Vehicel Model**

**Longitudinal Dynamics Simulation**

\[
\begin{align*}
F_{\text{Req}} &= (F_{\text{Air}} + F_{\text{Roll}} + F_{\text{Accel}}) \cdot V \\
F_{\text{Air}} &= \frac{1}{2} \rho_{\text{Air}} \cdot C_{\text{W}} \cdot A_{\text{Veh}} \cdot V^2 \\
F_{\text{Roll}} &= (m_{\text{Veh}} + m_{\text{Add}}) \cdot \gamma \cdot f_{\text{Roll}} \cdot \cos(\alpha) \\
F_{\text{Accel}} &= (m_{\text{Veh}} + m_{\text{Add}}) \cdot \gamma \cdot f_{\text{Accel}} \\
\end{align*}
\]

- **Driving resistance**
  - Drag (Air resistance)
  - Rolling resistance
  - Acceleration resistance
  - Slope resistance

**Battery Simulation**

- Internal resistance
- Thermal behavior
- SoC, DoD, SoH
- Current
- Voltage

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Modellbeschreibung und Simulationsmethodik

BATTERIEMODELL/ ÜBERBLICK

- Modell mit äquivalenter elektrischer Schaltung
- Energieverlust von Komponenten basiert auf dem Innenwiderstand

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## Modellbeschreibung und Simulationsmethodik

### Batteriemo dell / Detail

#### Physisches Modell

- Battery current is given by:
  \[
  I_{\text{Batt}} = \frac{(V_{\text{OC}} - (V_{\text{OC}}^2 - 4P_{\text{Batt,Req}} \cdot R_{\text{int}})^{\frac{1}{2}})}{2R_{\text{int}}}
  \]

- Battery voltage is calculated:
  \[
  V_{\text{Batt}} = V_{\text{OC}} - R_{\text{int}} \cdot I_{\text{Batt}}
  \]

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I_{\text{Batt}}$</td>
<td>Battery current / A</td>
</tr>
<tr>
<td>$V_{\text{OC}}$</td>
<td>Battery open circuit voltage / V</td>
</tr>
<tr>
<td>$V_{\text{Batt}}$</td>
<td>Battery voltage / V</td>
</tr>
<tr>
<td>$P_{\text{Batt,Req}}$</td>
<td>Power requested from battery / W</td>
</tr>
<tr>
<td>$R_{\text{int}}$</td>
<td>Battery internal resistance / Ω</td>
</tr>
</tbody>
</table>

#### Beschreibung

- $I_{\text{Batt}}$: Batteriestrom / A
- $V_{\text{OC}}$: Batterie Leerlaufspannung / V
- $V_{\text{Batt}}$: Batteriespannung / V
- $P_{\text{Batt,Req}}$: Leistungsanforderung von der Batterie / V
- $R_{\text{int}}$: Batterie Innenwiderstand / Ω

#### Eingang

- Eingangsgröße:
  - Leistung der EM
  - Leistung der Hochspannungsbatterie

#### Ausgang

- Ausgangsgröße:
  - Batterie SoC
  - Batteriestrom
  - Batteriespannung

#### Modell mit äquivalenter elektrischer Schaltung

- Energieverlust von Komponenten basierend auf dem Innenwiderstand