Riding experience enhancement through Engine and Driveline dynamics optimization

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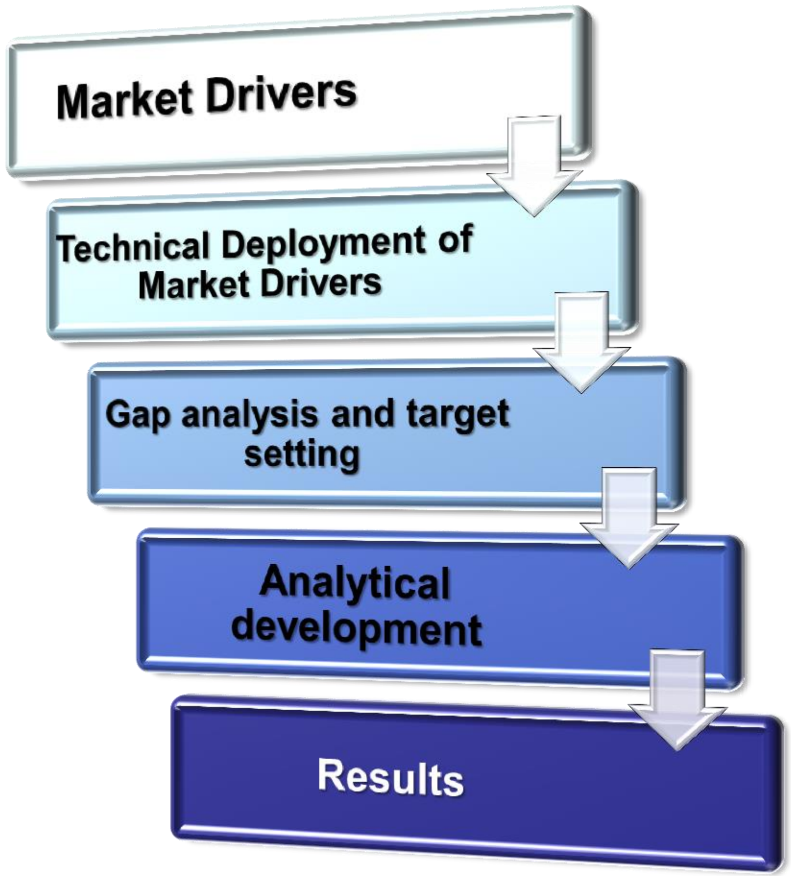
Introduction

- Evolution of demand allowed some space of differentiation in the driving experience as perceived from vibrations induced by engine torque variability;
- First engineering task was to translate market request into manageable engineering parameters;
- Analysis of gaps with respect to market expectations allowed the identification of feasible technical targets
- Novel simulation and optimization procedure put in place to fulfill requirements
- Results, both numerical and experimental confirmed the analytical approach



Market Drivers

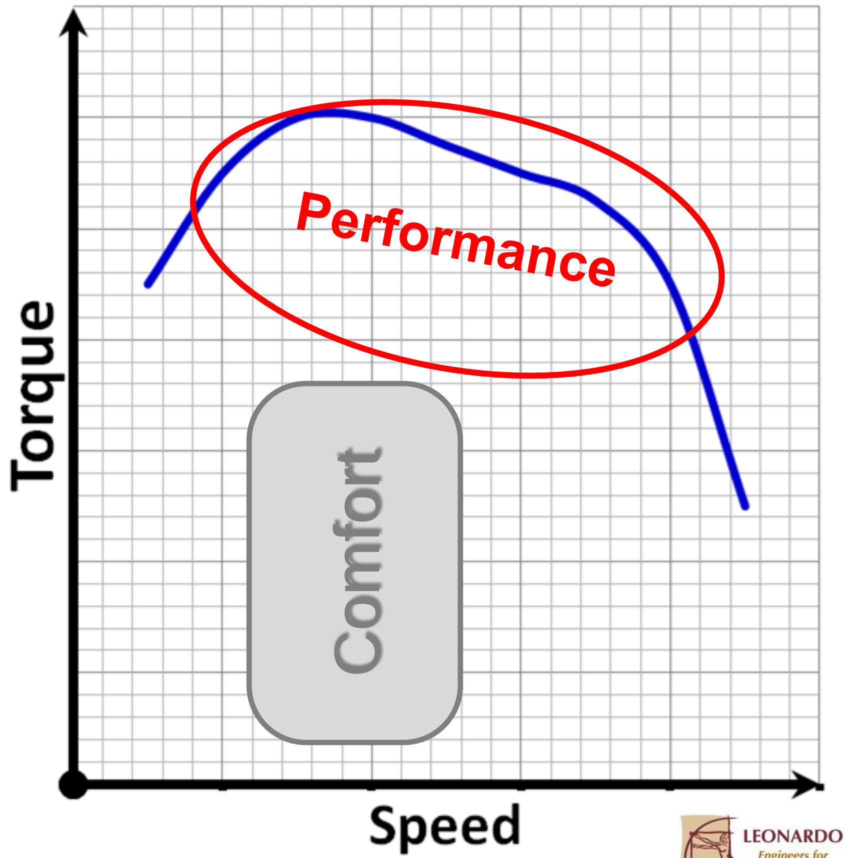
- **Ageing Population of Customers**
  - Motorbikes still desired in the 60s and over …
  - Time availability for medium range tourism;
  - Higher expenditure capabilities than younger people;
- **Conflicting product characteristics**
  - Comfort at average cruising speeds;
  - Power perception only when desired to feel «young» …

Technical Deployment of Market Drivers

Torque irregularities

- Perceived as powerfulness at WOT;
- Disturbing while cruising at low-medium speeds;
- Frequency: 10 to 30 Hz;
- Throttle position defines required mode:
  - Comfort area around 30%
  - Performance area at WOT;
-

"Comfort" and "Performance" Areas

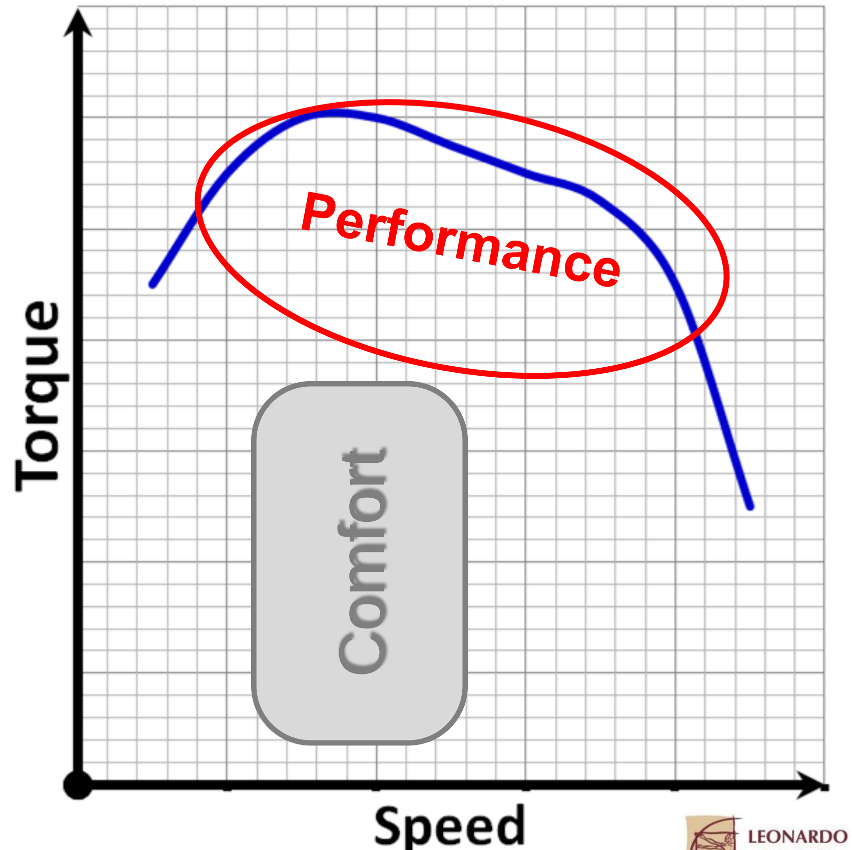


Technical Deployment of Market Drivers

Driveline requirements

- Driving force at wheel determines longitudinal acceleration;
- Engine architecture and driveline dynamic response play key roles;
- Switching from “Comfort” to “Performance” mode through gas demand;

“Comfort” and “Performance” Areas

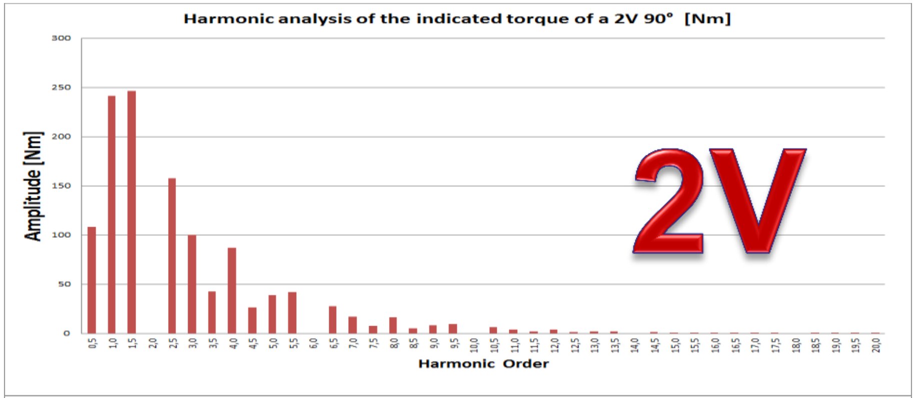


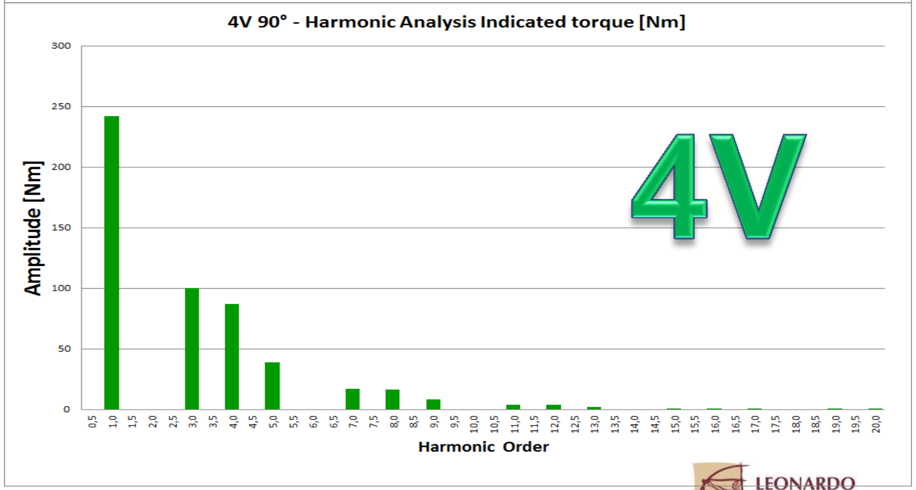
Gap analysis and Target Setting

Target setting

- **2V 90°**
  - High low order harmonic content;
  - Perceived as "Exciting"
  - Disturbing vibration while cruising
- **4V 90°**
  - Very low excitation at low orders;
  - Best in class for comfort;
- **Target behavior**
  - Maintain 2V excitation in the "Performance Area"
  - Behave like a benchmark 4V in the "Comfort Area"

Engine architecture



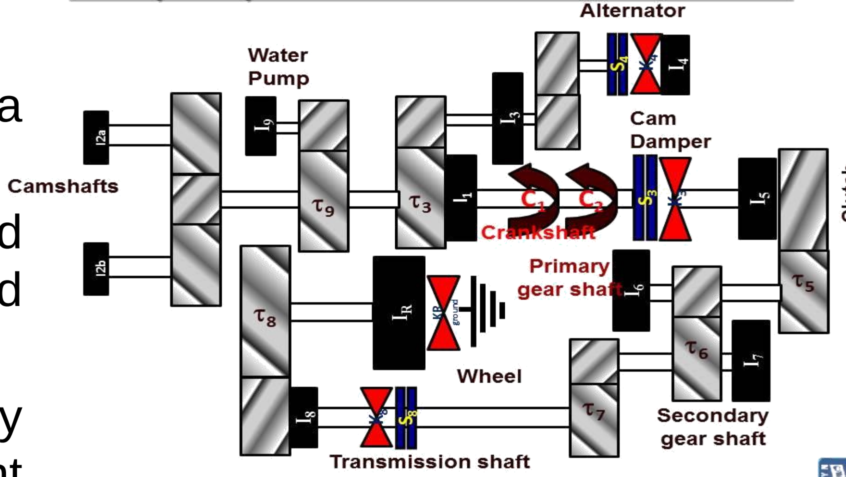


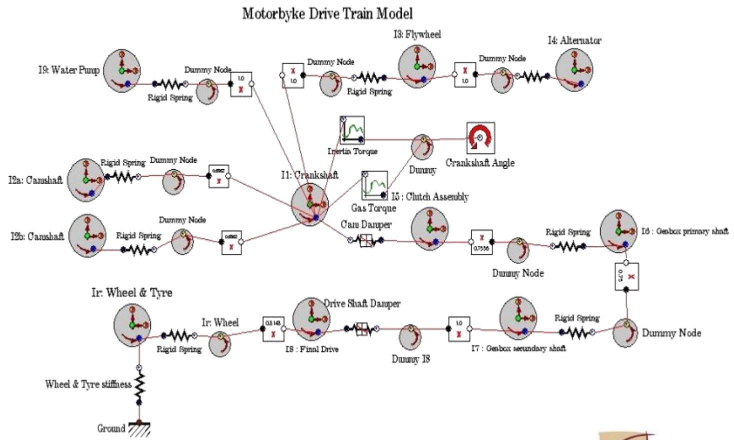
Analytical Development

Lumped Parameters Model

- Analysis in the frequency domain required a locally linear model
- Relevant contributors to engine and driveline dynamics modeled as lumped masses and stiffnesses
- Linear damping coefficients defined by energetic equivalences at relevant frequencies
- Model non linearities accounted for in load dependent stiffnesses;
- Local linearization allowed by the "perturbation" analysis available in Valdyn
- Model output is wheel-to-ground reaction as a function of engine torque input;

Lumped parameters driveline model



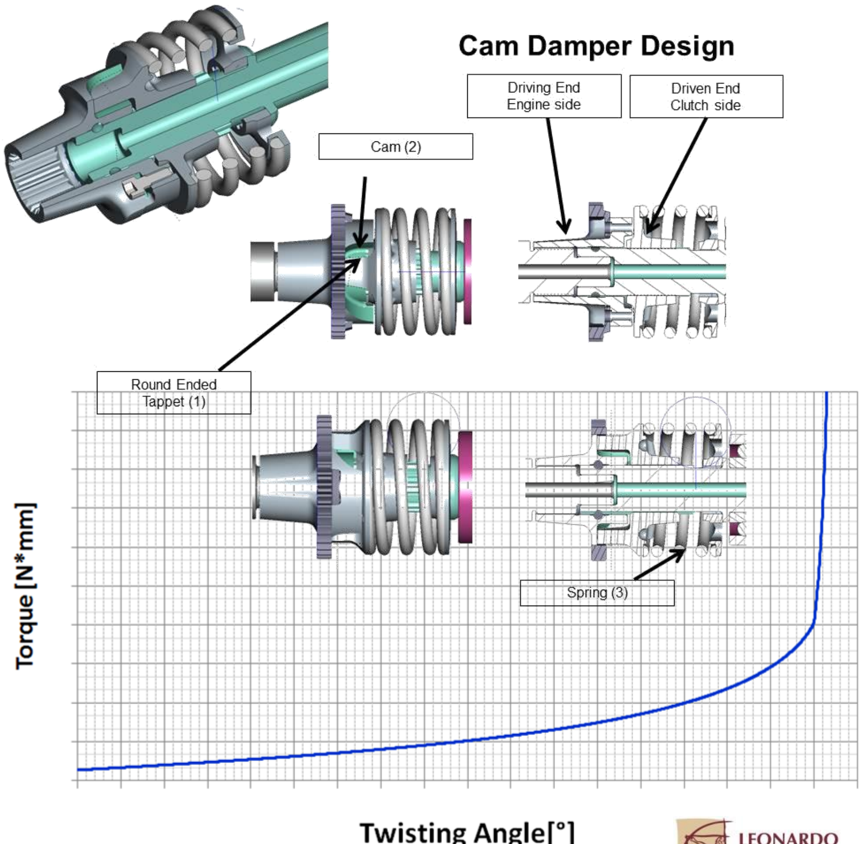


Analytical Development

Driveline non linearity

- Torque dependency of driveline dynamic response requires a torque dependent stiffness element
- Variable stiffness damper developed to the scope;
- Spring loaded cylindrical follower pushed against a cam profile;
- Balance between spring load and average applied torque;
- Elastic characteristics defined through the cam profile;
- Local stiffness variation with load depending on cam curvature;

Variable Stiffness Damper

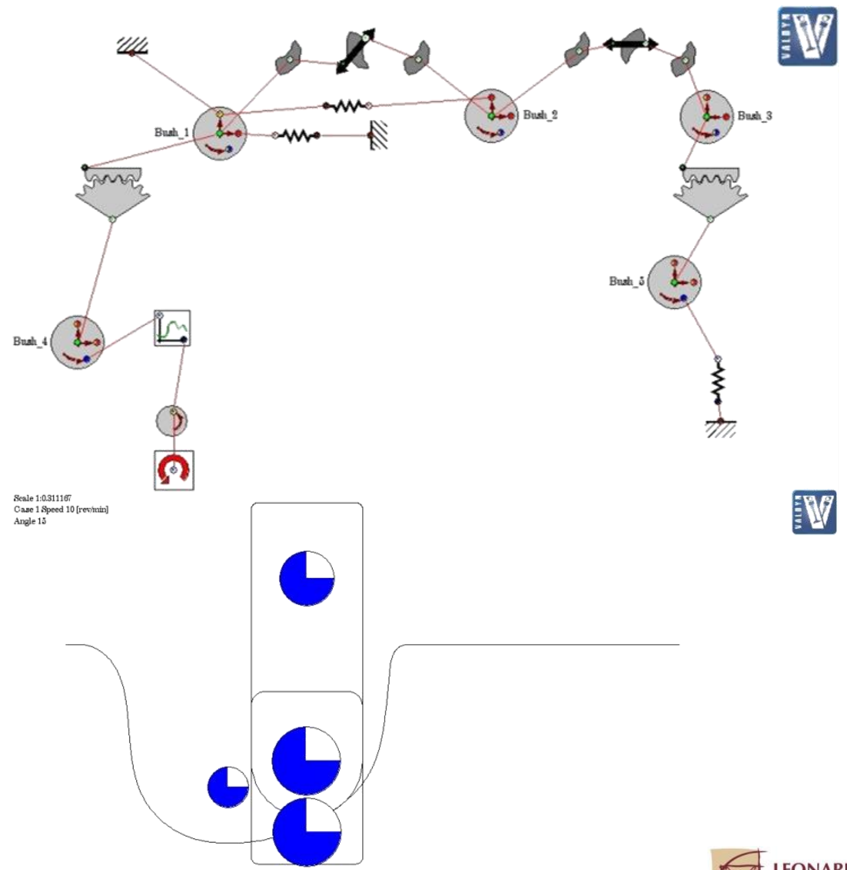


Analytical Development

Valdyn Model of Damper

- Cam mechanism developed along the average cylinder to reconduct it to a 2D problem;
- Use of LAMINA elements for the cam and the axial guide of the follower;
- Model defined in order to supply the stiffness and damping characteristics to insert in the driveline model as an XSTIFF element or as a complete model;
- Cam profile developed from the required curvature law with an Excel spreadsheet using Runge-Kutta forth order forward integration;

Variable Stiffness Damper

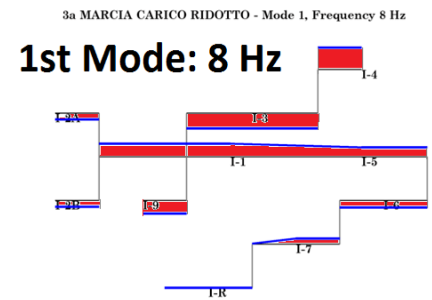


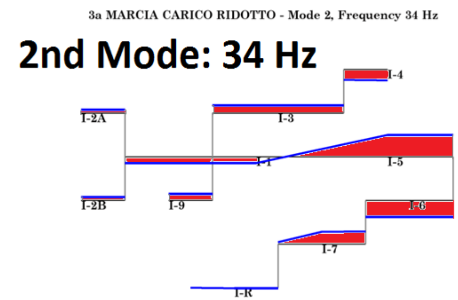
Analytical Development

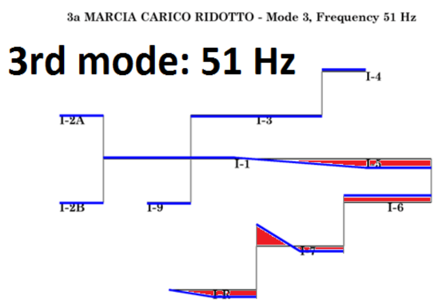
Modal Analysis

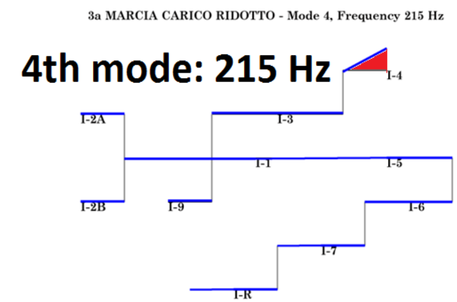
- 2V 90° engine:
  - WOT behavior naturally at target
  - Focus on irregularities containment at low load and cruising speed;
- Modal analysis
  - Preliminary dimensioning of the cam;
  - 1° and 2° mode relevant for comfort;
  - 3° mode may be perceived even though frequency is high;
  - 4° mode irrelevant for comfort, modal shape affects only alternator and its belt;

Modal Shapes







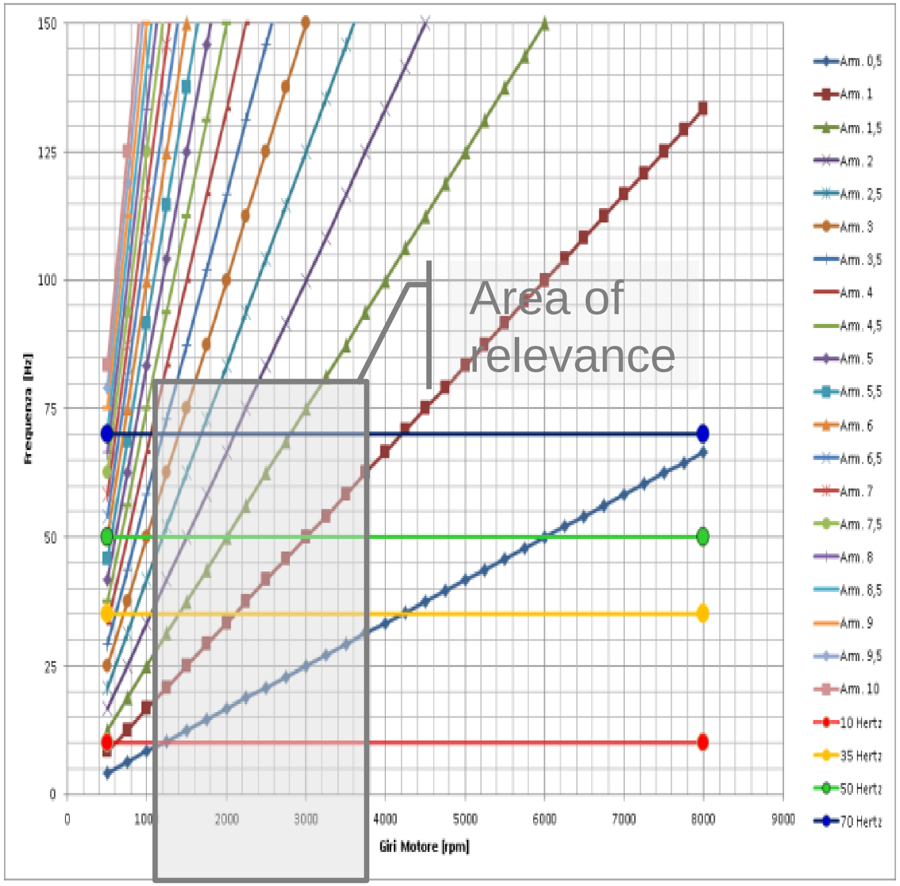


Analytical Development

Modal Analysis

- Relevant Harmonic:
  - Engine excitation harmonics intersection in the area of relevance define target modes for mitigation;
  - Most relevant are the intersections around 10 Hz and 30 Hz;
  - Only low order harmonics are interesting;
  - This explains the perception of 4V 90° engines as benchmark for comfort;
- Target for Cam profile development
  - Reduce 1st and 2nd mode frequency to bring both of them out of the relevant working area;
  - Do not reduce 3rd mode frequency;
  - Have low order mode shape such that one node lie at damper position to exploit its damping function;

Harmonic – Modes intersection



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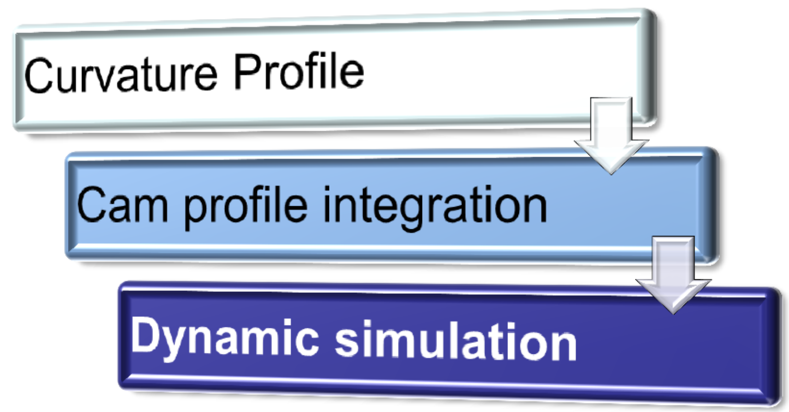
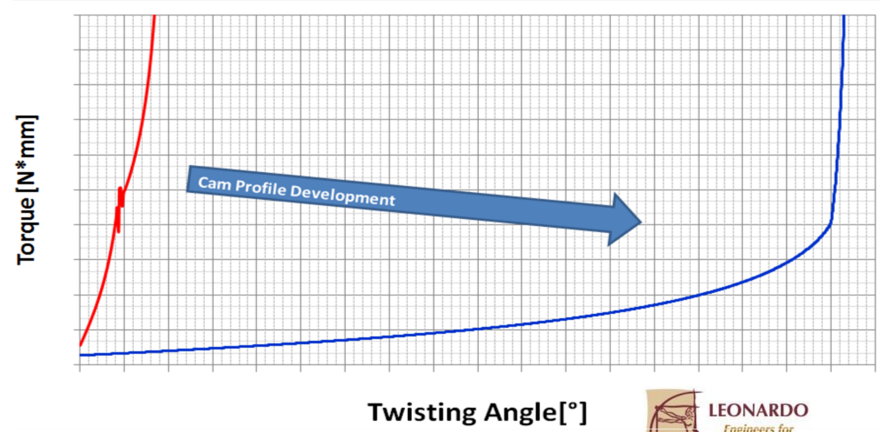
Analytical Development

Cam Profile Definition

- Origination from a desired curvature profile to avoid unfeasible cam profiles;
- Sharp step in stiffness at higher load to keep the “performance” feeling;
- As low as possible stiffness at low torque to:
  - Isolate engine from clutch and gearbox inertia in the first mode, reducing its frequency well below working range;
  - Avoid excitation of the 2nd mode, where the damper acts as nodal stiffness on the excitation side;
  - Act as an extremity damper in the 3rd mode, where it is at the boundary of the mode shape, engine side, without impacting its frequency;

Optimization loop



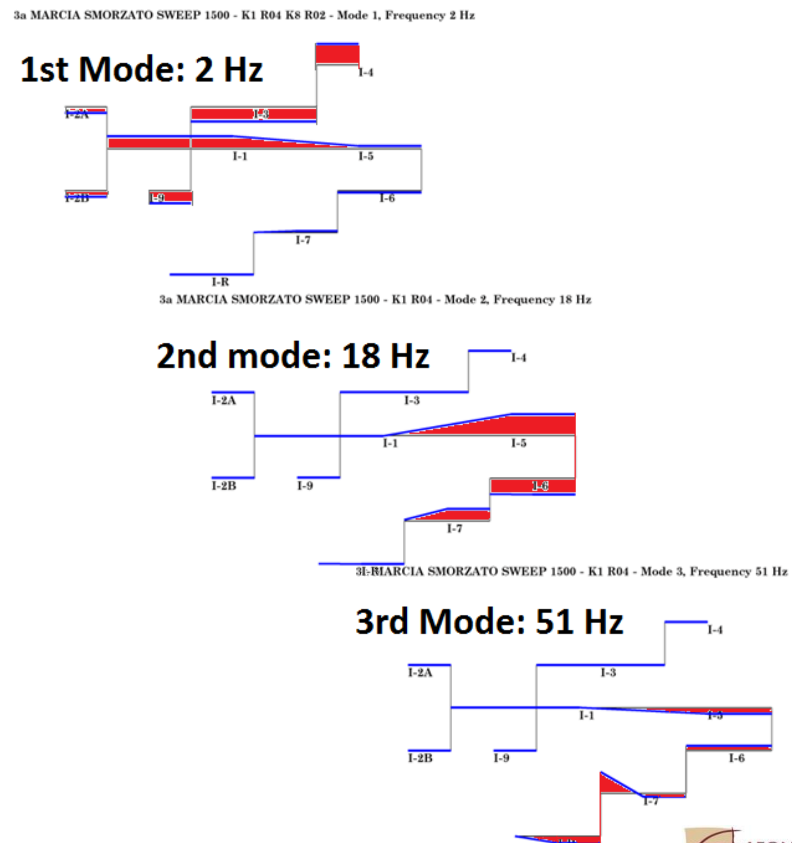


Analytical Development

Impact on modes

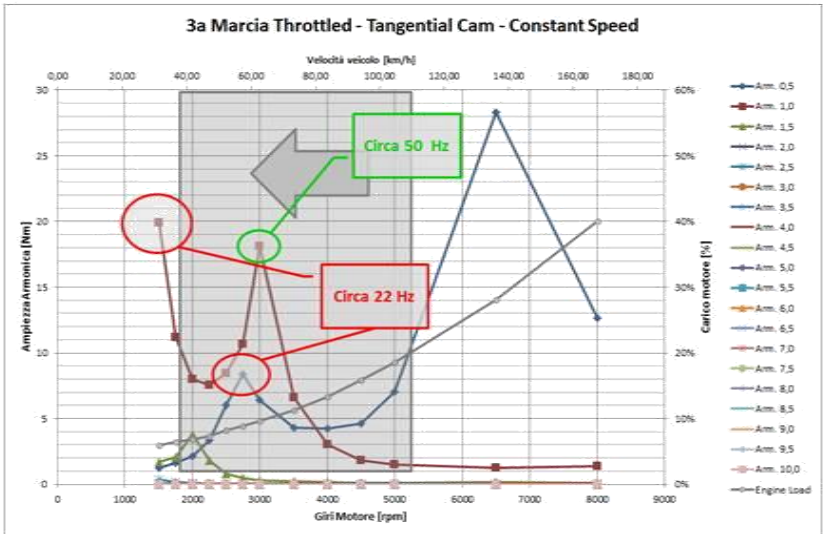
- The first mode, at very low frequency, cuts out engine excitation to the rest of the driveline;
- The very low stiffness of the damper reduces and damps out excitation from the engine, acting the exciting torques on a negligible modal component;
- 3rd mode frequency is almost untouched and excitation is severely reduced by the very low stiffness of the damper;

Final modal shapes



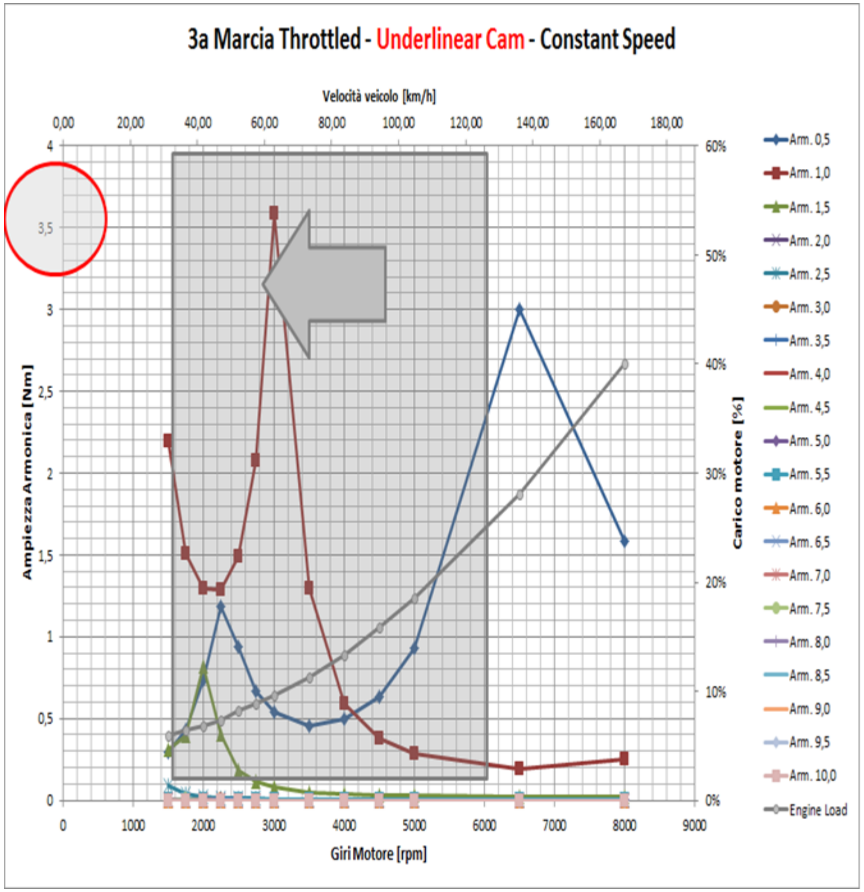
Results

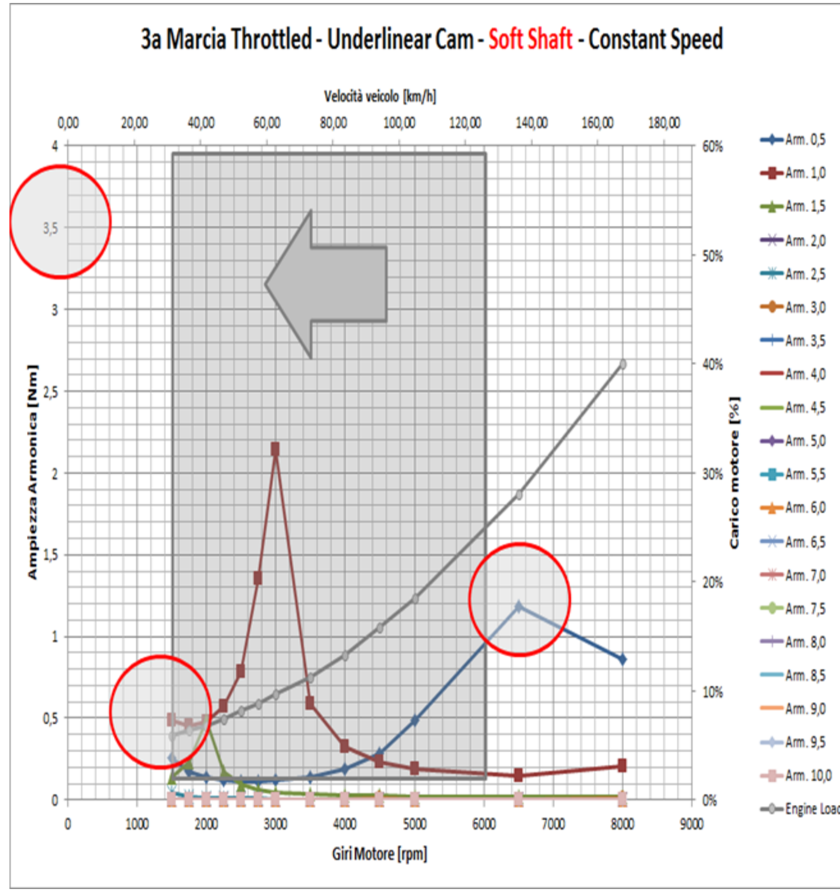
Effect of cam optimization on vehicle excitations



- Result are reported as contribution of each harmonic to tractive force irregularities during a slow acceleration in 3° gear;
- The analysis shows that irregularities due to low orders are reduced by an order of magnitude;
- Qualitative returns from driving tests confirmed the significantly increased level of comfort, while quantitative measurements are on going;

Results





- The dynamic model allowed for a conceptually similar optimization of the drive shaft stiffness, leading to further improvement as shown in the comparison graph;

Thank you for your attention

for any further information please write to:
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