Preliminary design of twin-cylinder engines for hybrid electric vehicle applications

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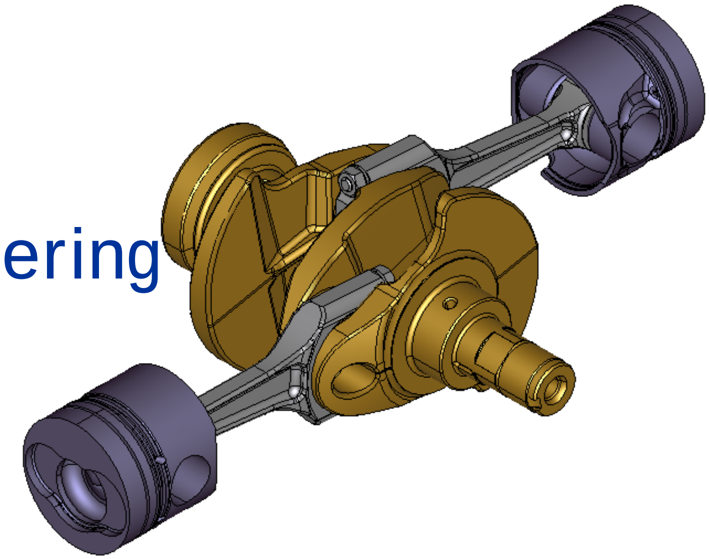

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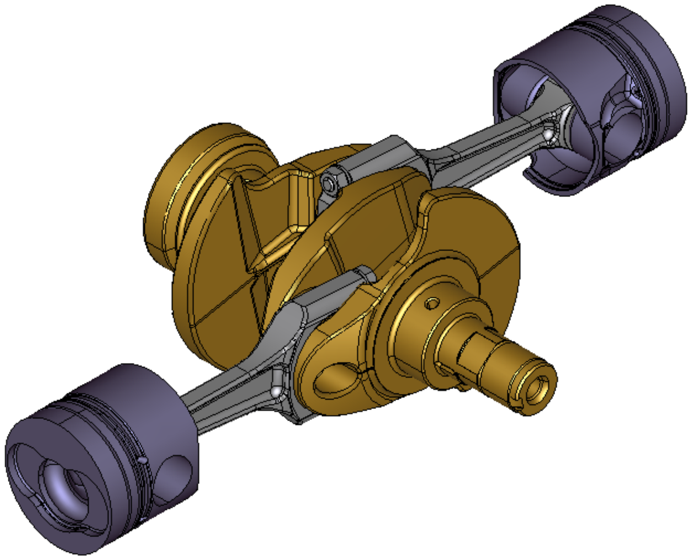
Introduction



Project background

- Growing industrial interest for small ICE (with 2 or 3 cylinders) for urban or hybrid vehicles
- Support to the prototyping of a twin-cylinder engine by BTD
- Research efforts in non-accurate methods for the design of unusual engine configurations
  - Preliminary design tools
  - Calculation based on multibody systems simulation

Topics of the study

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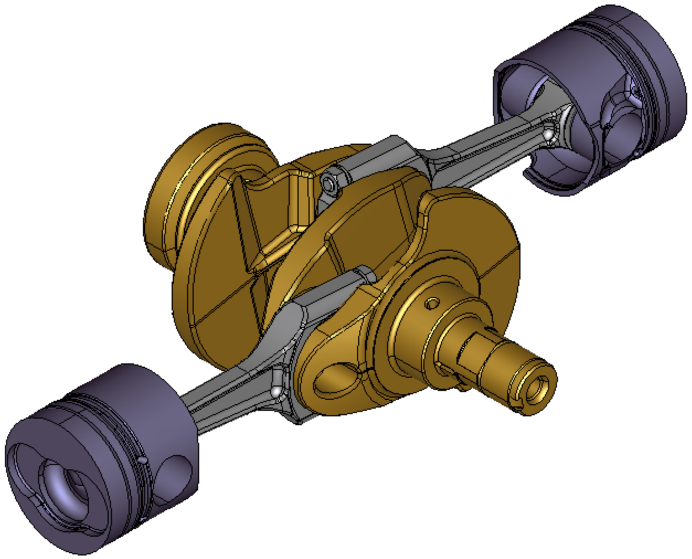
- Determining general ICE requirements for a HEV applications
- Developing simplified models of four different twin-cylinder engine configurations
  - Calculating inertia forces and moments in the engines
  - Balancing the engines
- Comparison of the different engine configurations (from a HEV applications point of view)

Methods



ICE requirements for HEV

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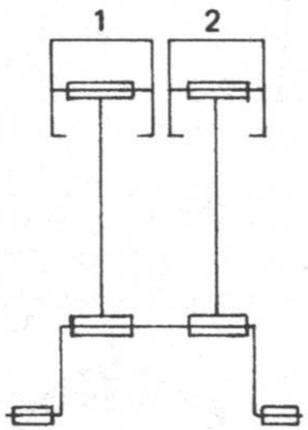
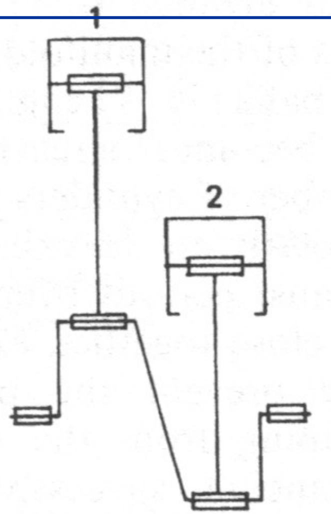
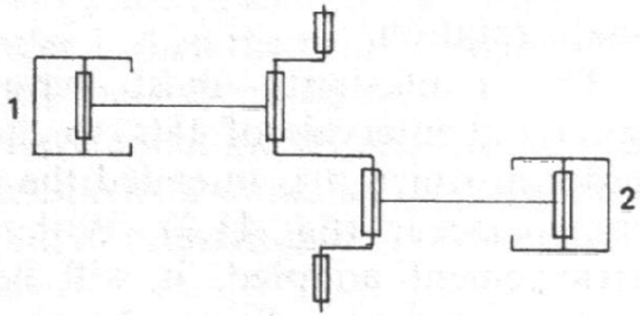
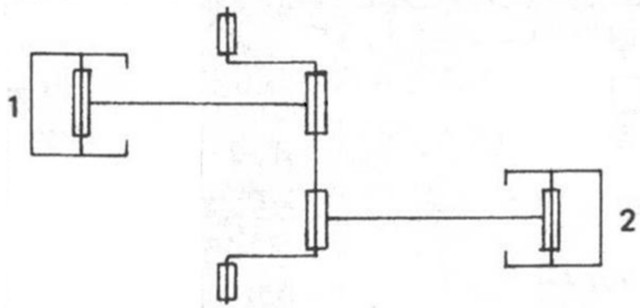
- Working at full load most of the time
- Rapid and reliable start
- As light as possible
- Compact and easy to pack in the vehicle
- High overall efficiency and low fuel consumption
- Not expensive

=> Twin-cylinder engine

- But small engines show some balancing problems

Engine configurations

	In-phase	Out-of-phase
In-line		
Boxer		

Simulation steps

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- Calculation of inertia forces and moments with respect to the crankshaft angle for the different engine configurations (based on simplified models)
- Balancing the engine using crankshaft counterweights and balancing shaft(s) (first or second order)
- Introducing the gas pressure effect in the simulation
- Comparison between the twin-cylinder engines and an equivalent four-cylinder engine (reference level for inertia forces and moments)

Simplified models

- Calculation of inertia forces produced by pistons motion

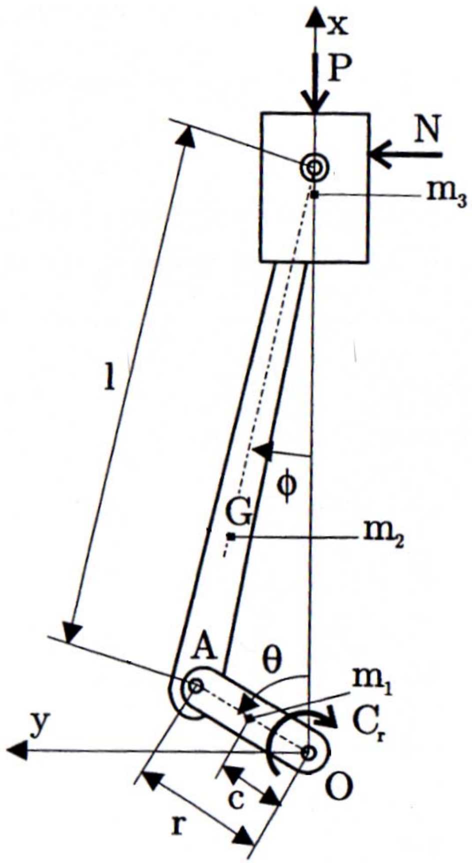
$$F_x = r \cdot \omega^2 \cdot [m_r \cdot \cos\theta + m_o \cdot (\cos\theta + A_2 \cdot \cos 2\theta + A_4 \cdot \cos 4\theta + A_6 \cdot \cos 6\theta + \ldots)]$$

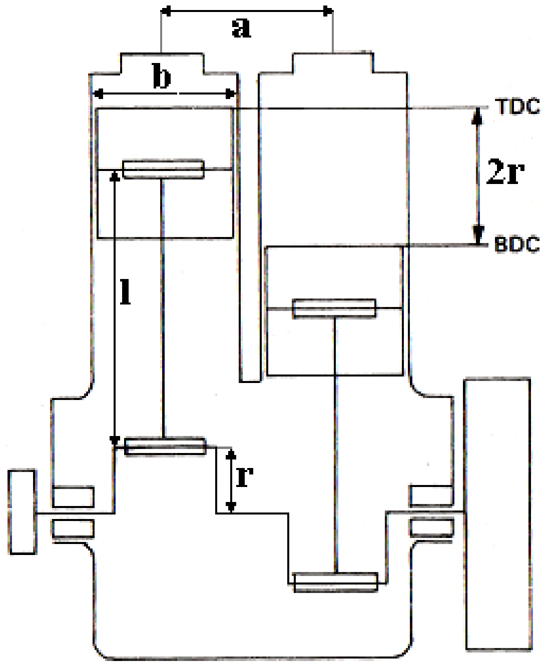
$$F_y = r \cdot \omega^2 \cdot m_r \cdot \sin\theta$$

$$m_r = m_1 + \frac{2}{3} \cdot m_2$$

$$m_o = m_3 + \frac{1}{3} \cdot m_2$$

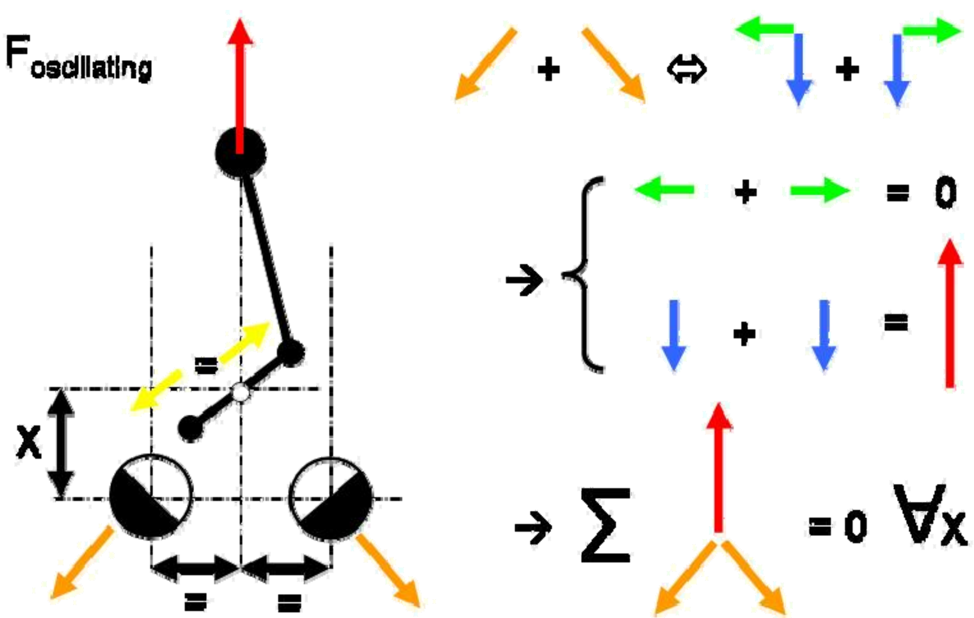
$$F_{res} = \sqrt{F_x^2 + F_y^2}$$



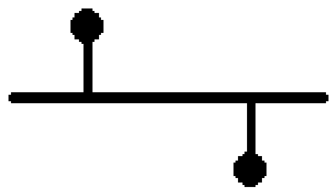


Balancing systems

- Optimization of the crankshaft counterweight
- Adding first or second order balance shafts

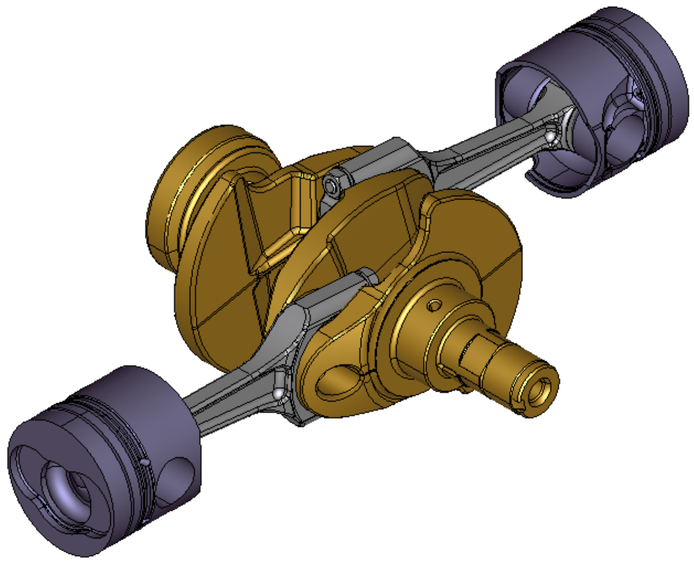


Normal balance shaft
(inertia forces)



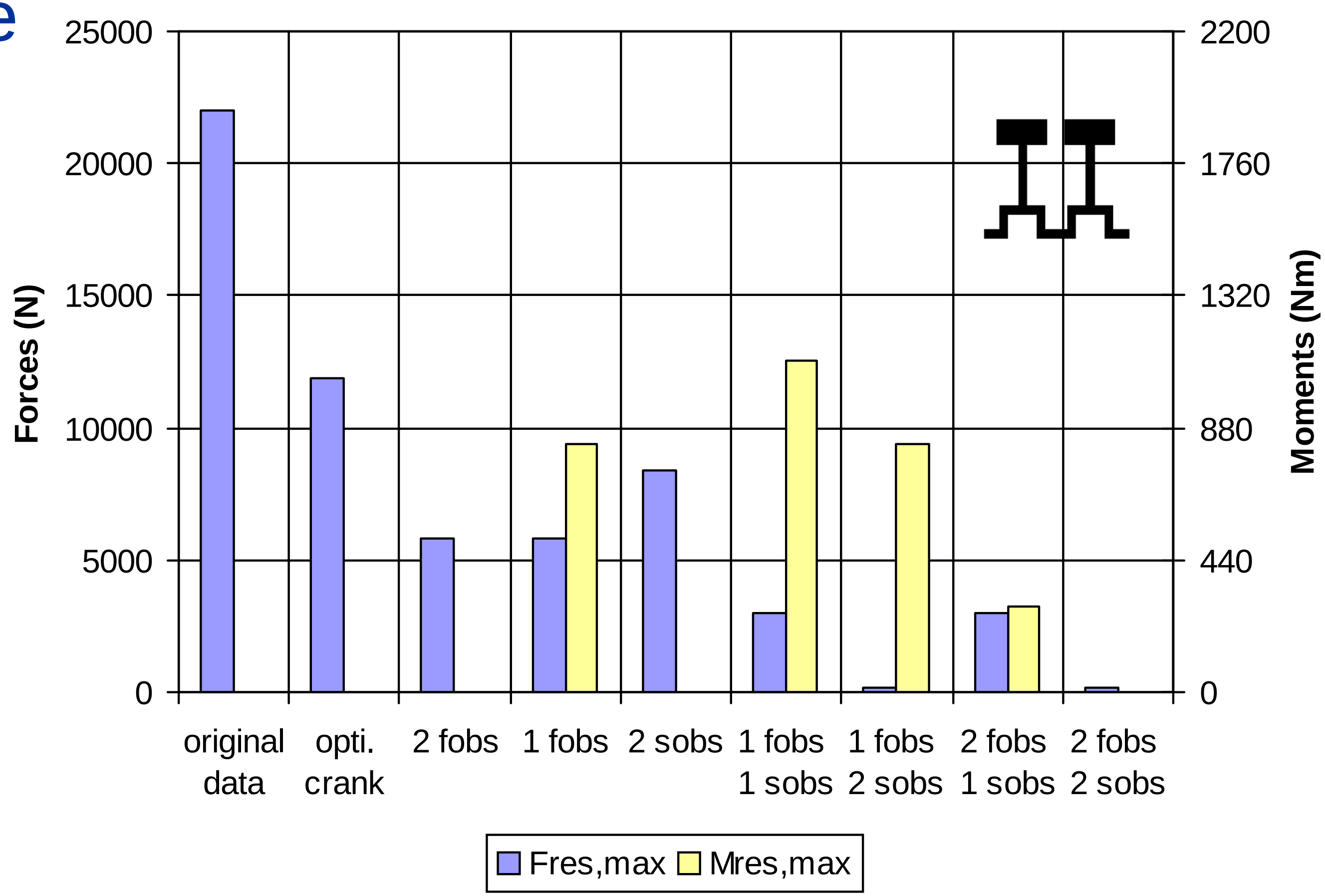
Double balance shaft
(inertia moments)

Results



Inertia forces and moments

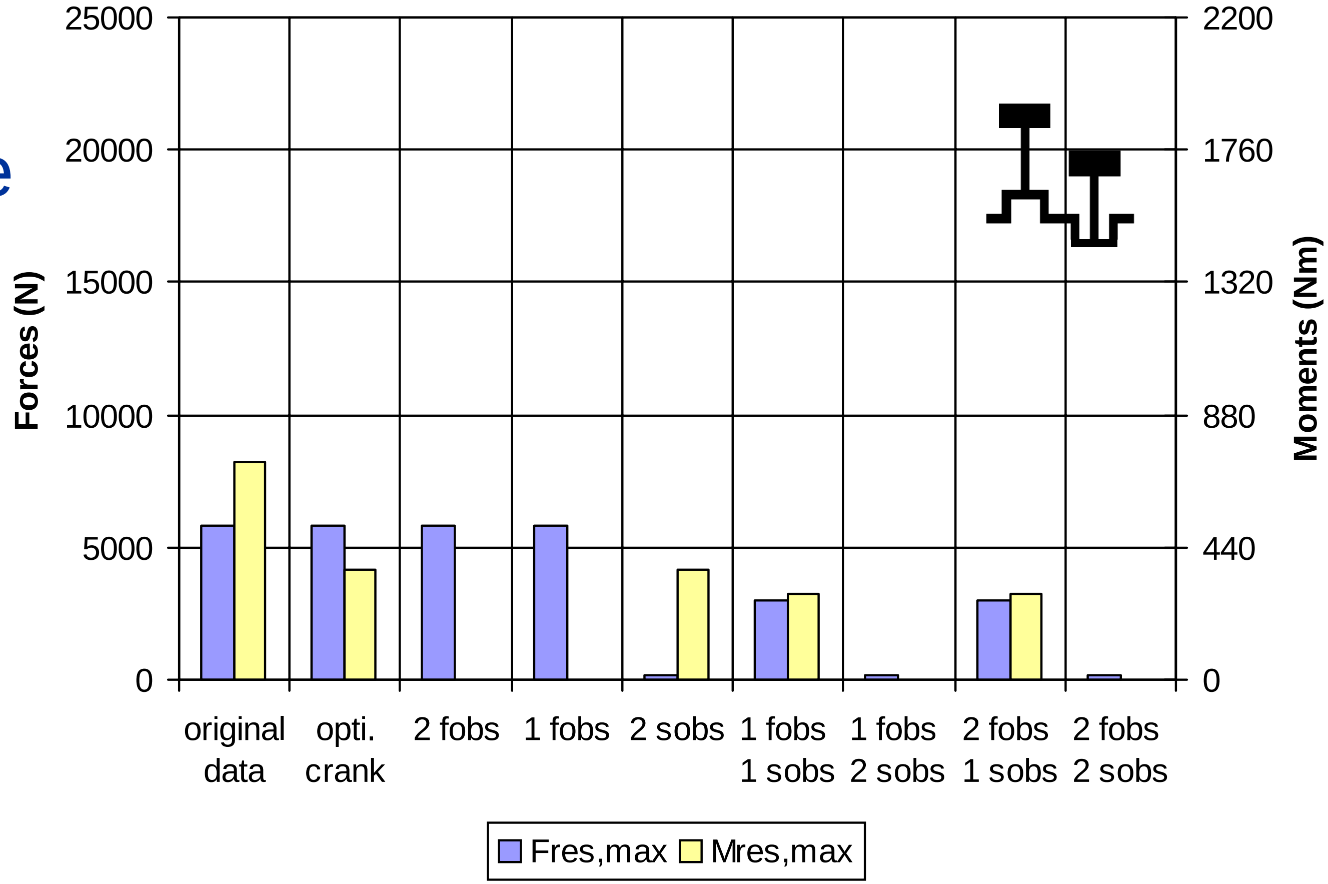
- In-phase in-line twin-cylinder engine



fobs: first order balance shaft(s) (rotating at the crankshaft speed)
sobs: second order balance shaft(s) (rotating at twice the crankshaft speed)

Inertia forces and moments

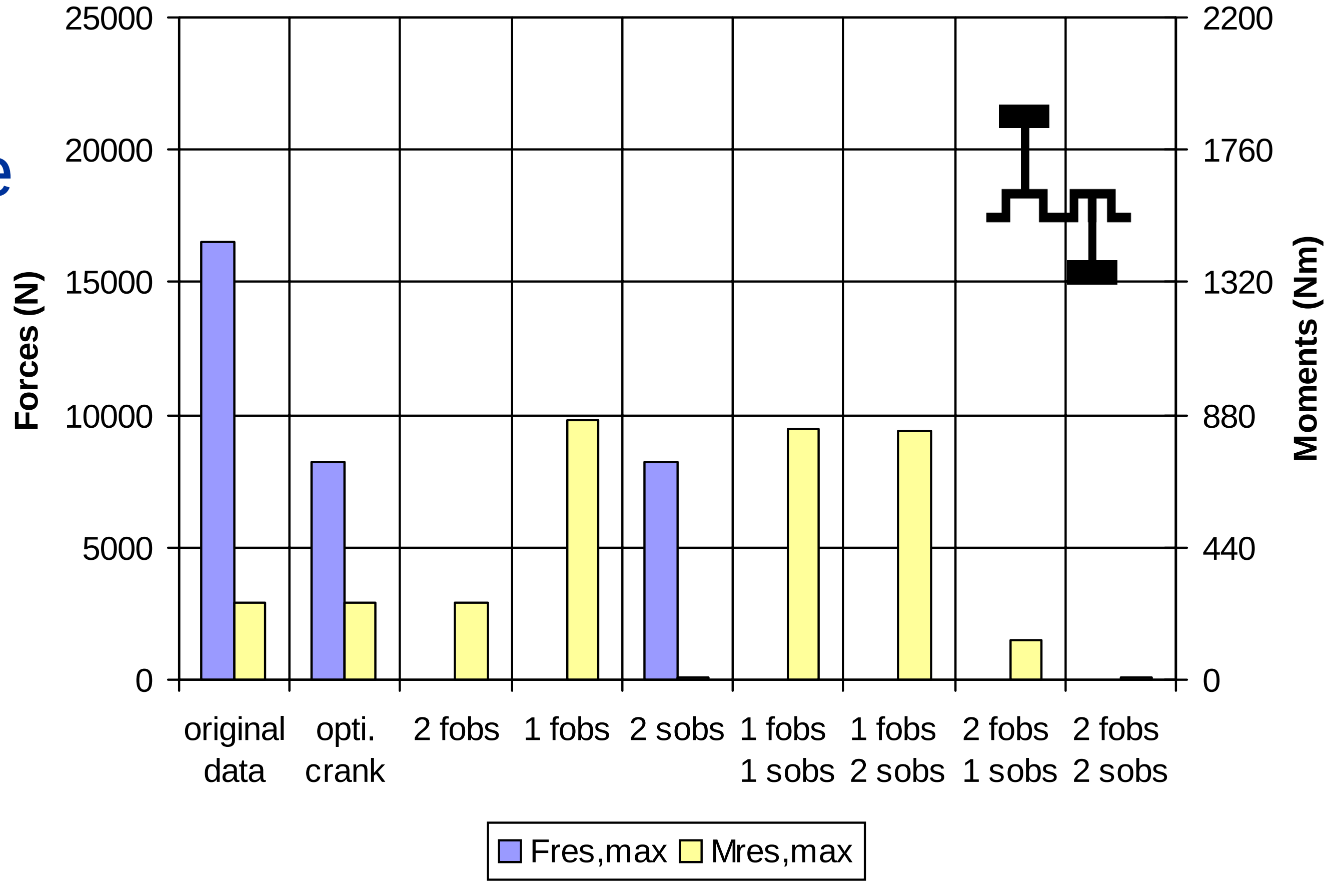
- Out-of-phase in-line twin-cylinder engine



fobs: first order balance shaft(s) (rotating at the crankshaft speed)
sobs: second order balance shaft(s) (rotating at twice the crankshaft speed)

Inertia forces and moments

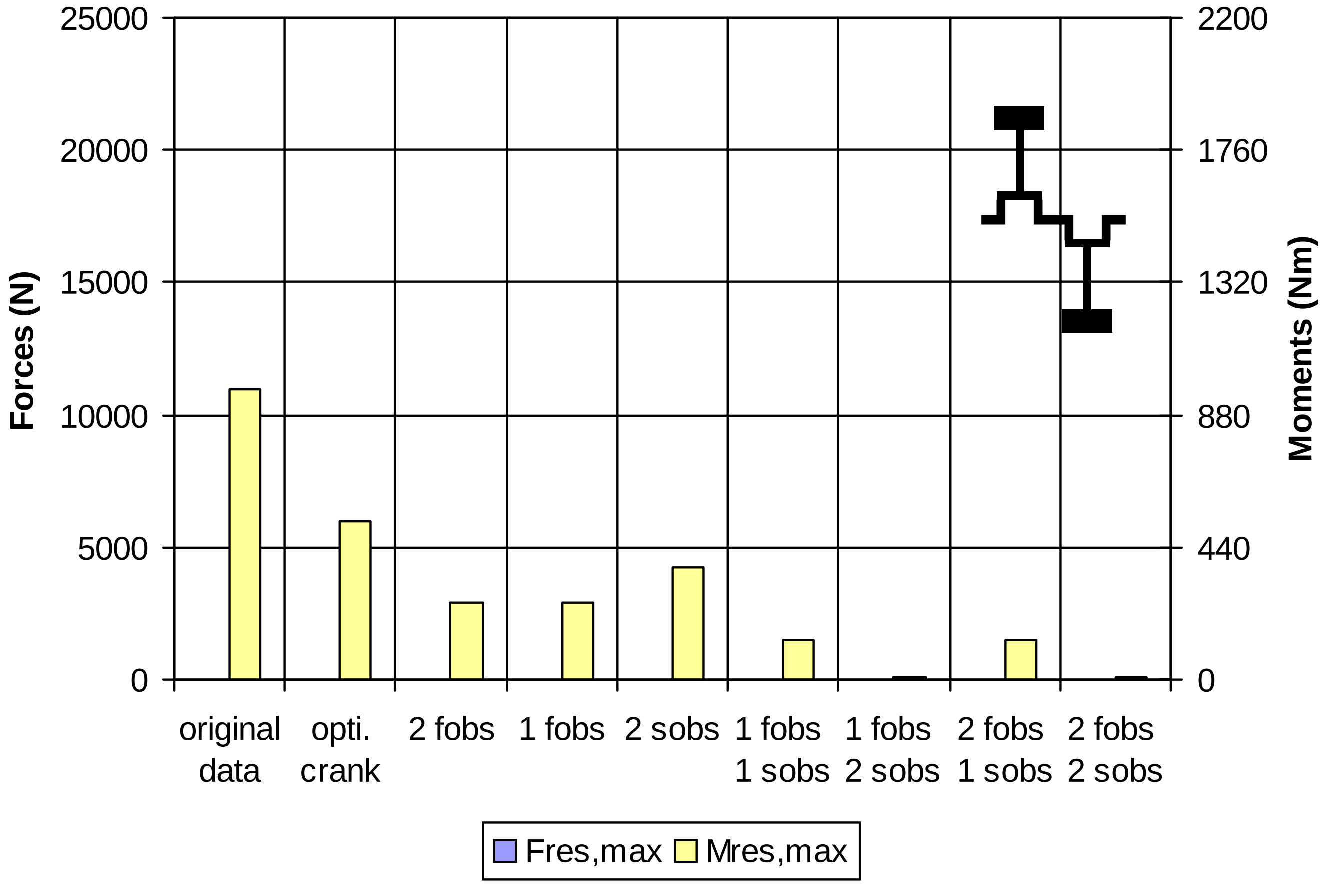
- Out-of-phase boxer twin-cylinder engine



fobs: first order balance shaft(s) (rotating at the crankshaft speed)
sobs: second order balance shaft(s) (rotating at twice the crankshaft speed)

Inertia forces and moments

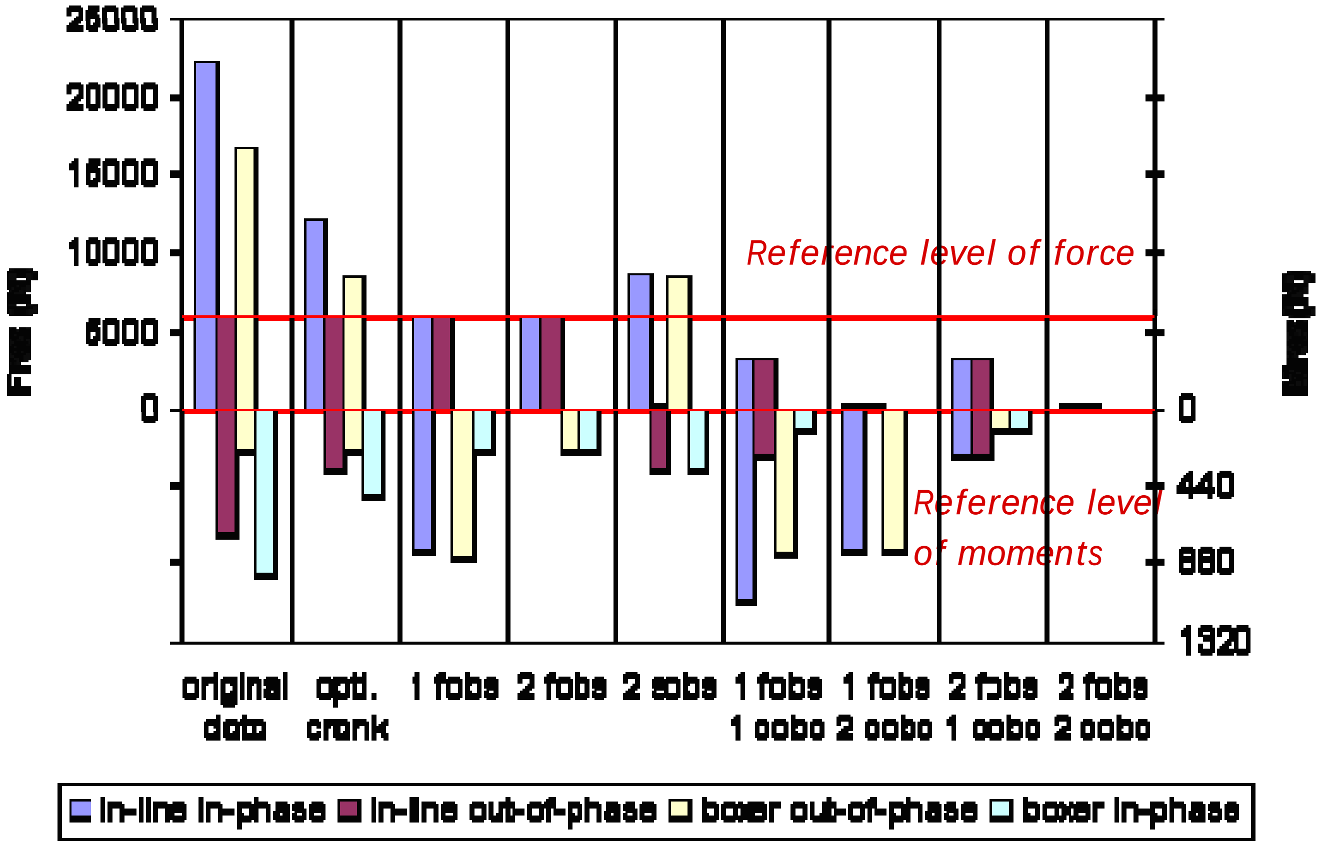
- In-phase boxer twin-cylinder engine



fobs: first order balance shaft(s) (rotating at the crankshaft speed)
sobs: second order balance shaft(s) (rotating at twice the crankshaft speed)

Comparison

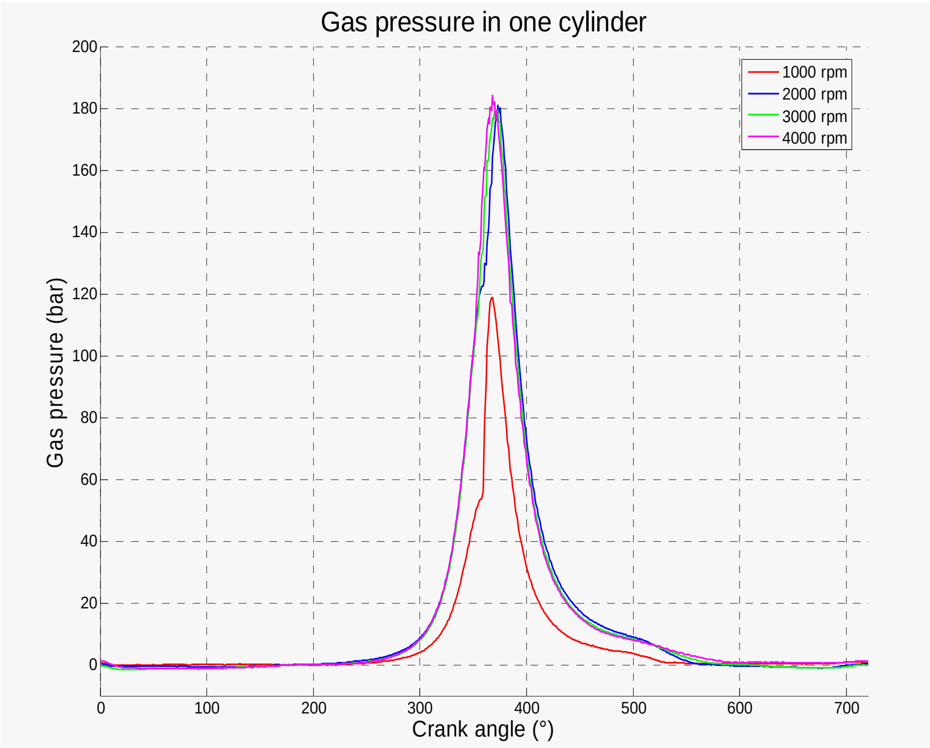
- Comparison between the twin-cylinder engines and an equivalent four-cylinder engine (reference level)

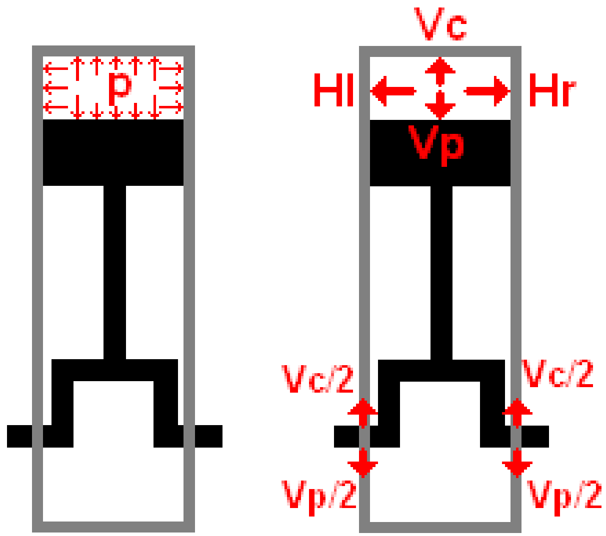


fobs: first order balance shaft(s) (rotating at the crankshaft speed)
sobs: second order balance shaft(s) (rotating at twice the crankshaft speed)

Gas pressure

- Gas pressure inside one cylinder (various rotation speed)

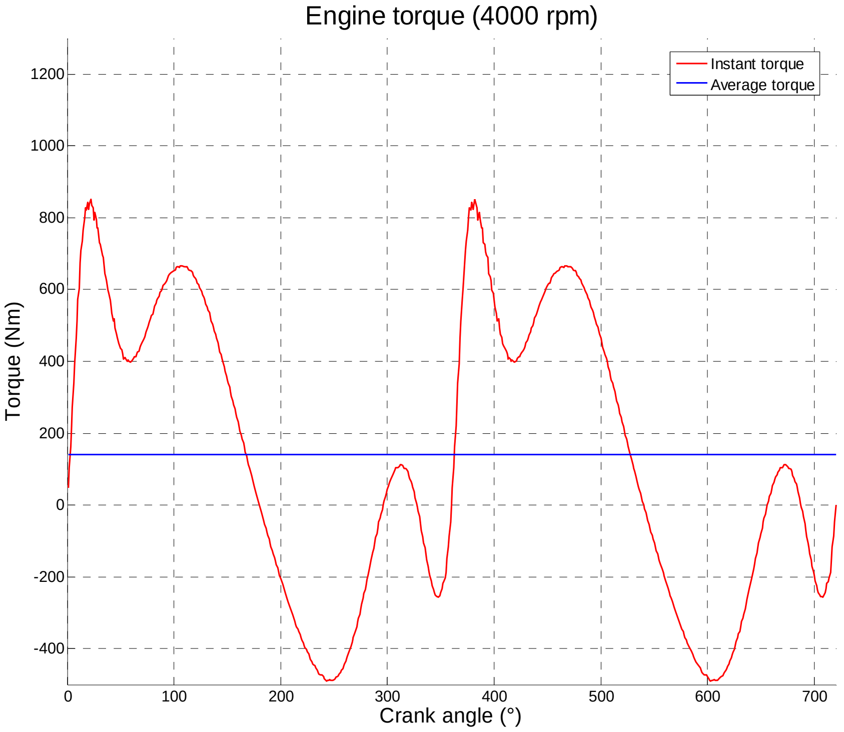


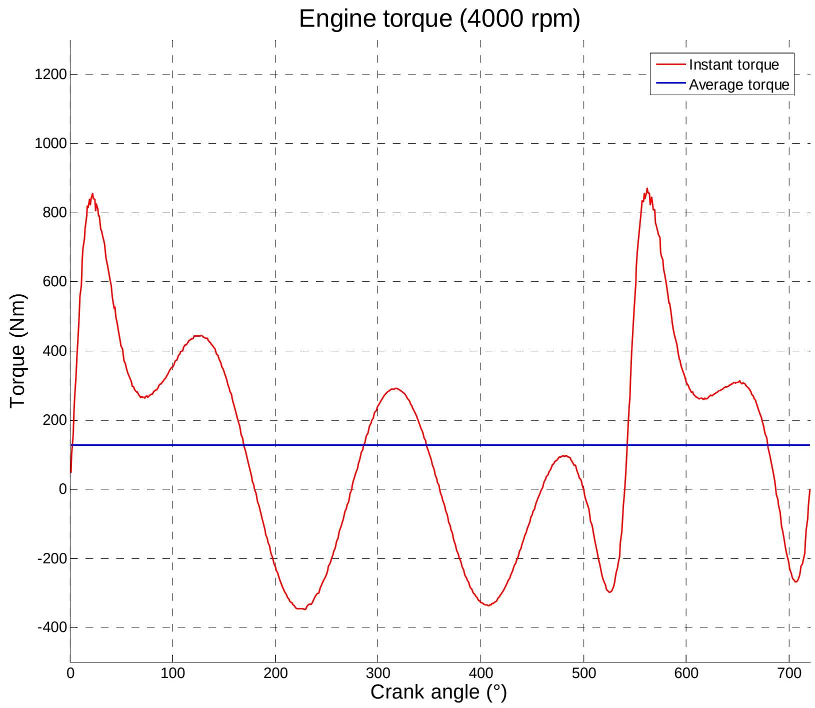


- No effect of the gas pressure on the force transmitted to the engine mounts

Gas pressure

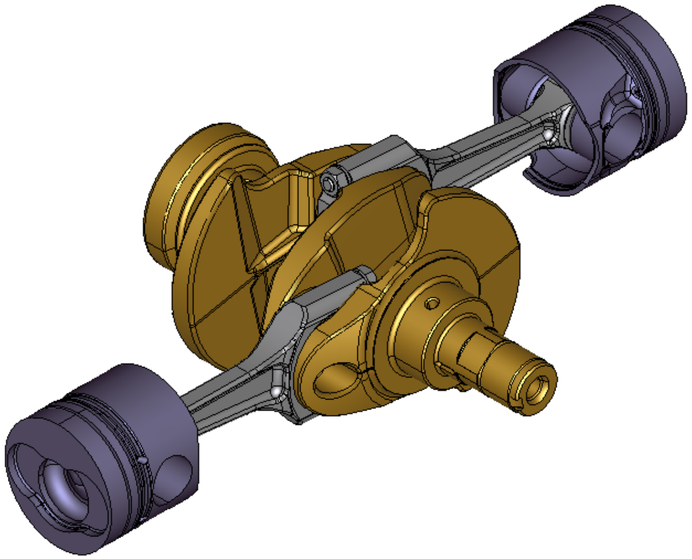
- Variation of torque inside an in-phase engine (boxer or in-line) rotating at 4000 rpm





- Variation of torque inside an out-of-phase engine (boxer or in-line) rotating at 4000 rpm

Conclusion



Conclusion

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- Each configuration of engine has its own characteristics in term of inertia forces and moments. These loads can be reduced by addition of counterweights or balance shafts

	First order forces	High order forces	First order moments	High order moments
In-line, in-phase	Yes	Yes	No	No
In-line, out-of-phase	No	Yes	Yes	No
Boxer, in-phase	No	No	Yes	Yes
Boxer, out-of-phase	Yes	No	No	Yes

Conclusion

- Twin-cylinder engines offer interesting prospects thanks to their
  - small size
  - low weight
  - low cost
- Among them, the in-phase boxer engine is promising because
  - its inertia forces are naturally balanced
  - It has a small height (it allows an easy packaging in the vehicle)

Perspectives

- Improve multibody simulations of engine dynamics
- Stress analysis of engine parts
- Design and fabrication of a twin-cylinder prototype engine (BTD)

Thank you for your attention