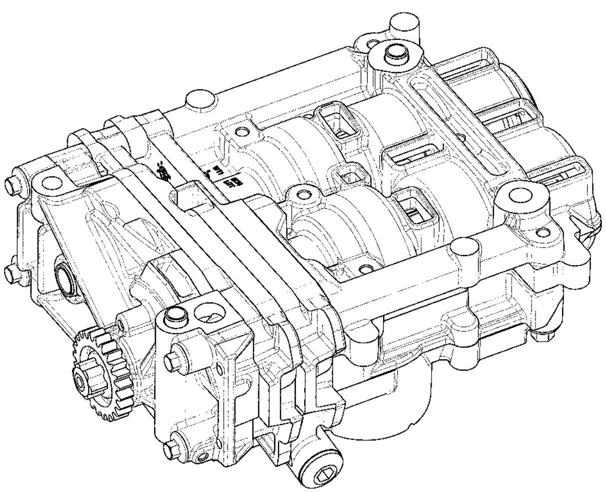
engineexpo2006

New Energy-Efficient Balance Shaft/Oil Pump Module



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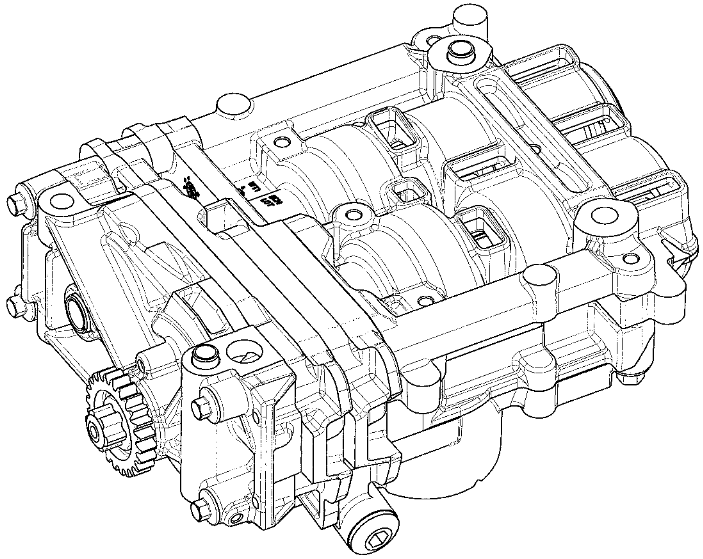
Content Overview

- Introduction - design concept motivation
- Background - technical challenges
- Layout architecture / Features overview
- Design considerations
- Performance results
- Summary

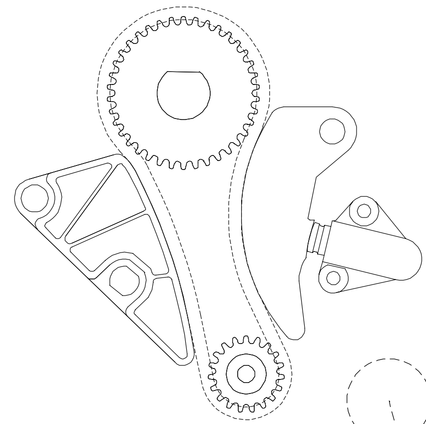


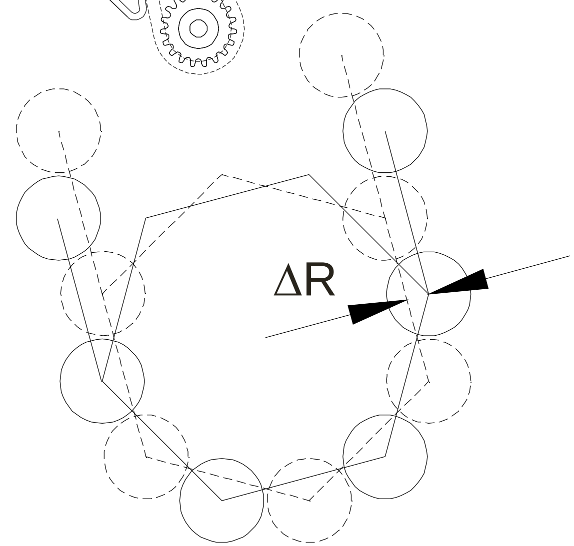
Design concept motivation

- Performance vs. cost pitfall issues understood from prior benchmark applications
  - Drive system noise, vibration & harshness (NVH)
    - Gear rattle control
    - Chain meshing noise
  - Oil pump system NVH emissions
- Challenges with greatly increased oil flow rates
  - Power consumption
  - NVH emissions
- Opportunity to improve best-practice technology
- Customer satisfaction / market competitiveness

Engineering challenges

- Drive system NVH was an identified issue in early chain-driven BSM applications
  - 2:1 chain drives involve compromise between the high chordal action of small driven sprockets and the high mesh velocities of large driver sprockets
    - Chordal action (engagement hop) generates both radial and tangential force excitations
    - Excitations increase with the square of meshing velocity
    - Excitations generate structure-borne noise





Engineering challenges

- Drive system NVH was an identified issue in early gear-driven BSM applications
  - Dimensional variations from differential thermal expansion alone challenge 2:1 direct-to-crankshaft gear drives with aluminum crankcases
    - Backlash varies with effective center distance between gears
    - Large tooth separation magnitudes ➔ high closure impact energy
    - Gear rattle is worst at high temperature, low speed, high load
    - Sufficient reduction of backlash under hot conditions causes forced tight mesh under cool temperatures
    - Tight mesh is noisy, and risks gear tooth fatigue from the high bending stresses of the tooth wedging action

Engineering challenges

- A “vicious circle” is encountered when designing gear teeth to withstand forced tight mesh
  - High pressure angle gear teeth are more robust to bending stresses, but suffer from increased sensitivity of backlash to the effective center distance changes of thermal effects
  - Low contact ratio gear teeth make the avoidance of meshing noise (whine) much more costly to achieve
  - Lack of oil film cushioning area increases sensitivity of gear rattle to backlash

Tight mesh-capable, low contact ratio

NVH-robust high contact ratio

Engineering challenges

- The prior best-practice layout reduced the cost of controlling gear rattle but suffered from pump noise
  - Twice-engine-speed oil pump drag torque was used to provide low cost gear rattle control benefit
    - US Patent No. 5,535,643 Garza, Anti rattle engine balancer which drives associated oil pump
- Increased oil pump system displacement, to supply new-generation engines with VCT, piston cooling jets, etc., only makes matters worse for NVH
  - Increased pressure ripple amplitudes
  - Increased sensitivity to cavitation with 2XERPM pump

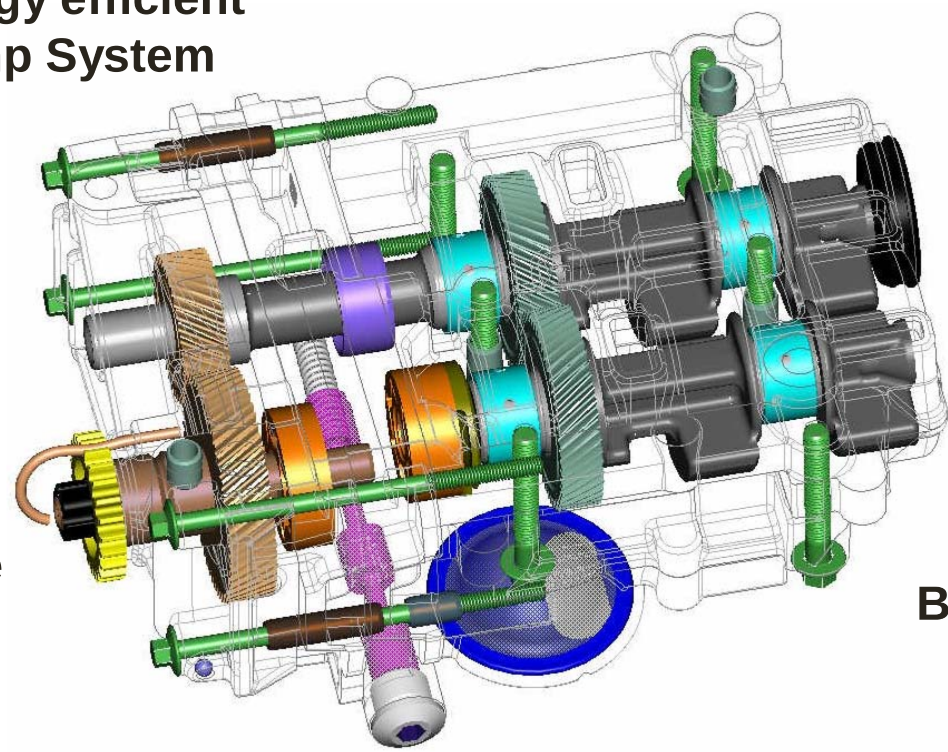
Engineering challenges

- Power consumption minimization, vs. substantial oil pump system displacement requirements
- Packaging density, vs. oil capacity
- Minimization of aeration increase from BSM
- Mass minimization
- Cost minimization

Layout / features overview

Patented **energy efficient Dual Oil Pump System**

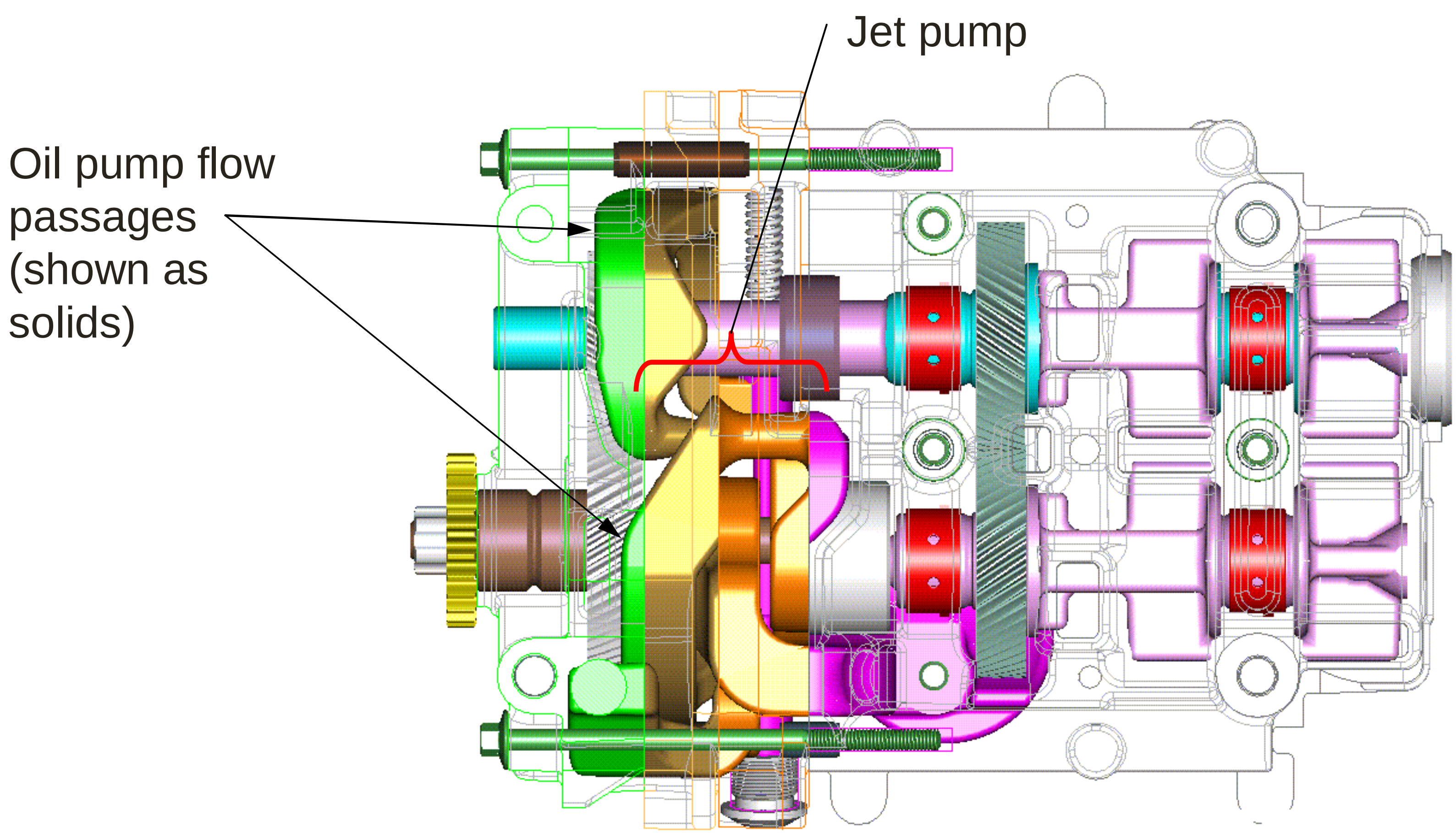
Upper Balance Shaft Housing with ***Patented*** **Oil Aeration Control Features**



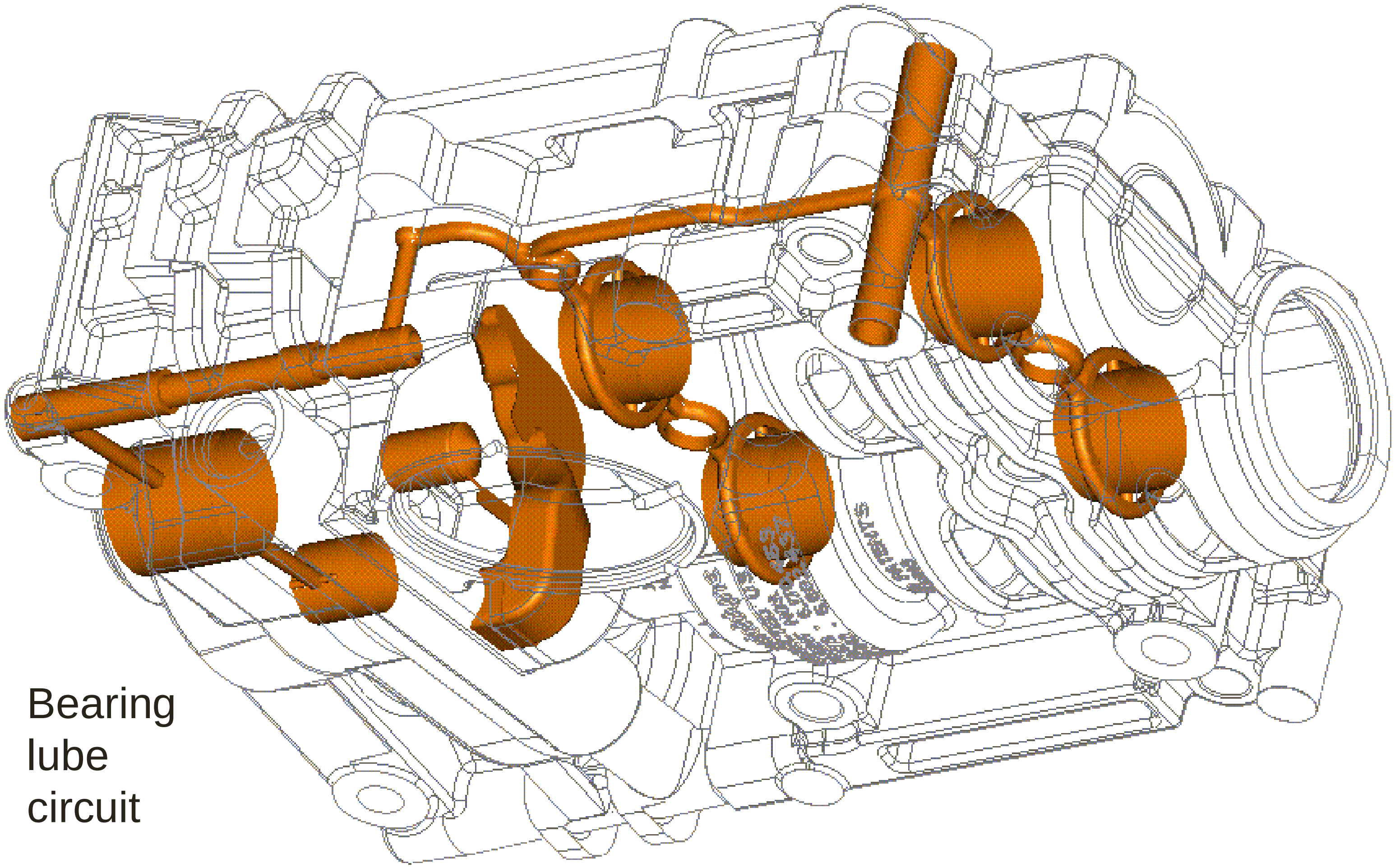
Internal 1.6:1 Ratio Gear Set & 1.25:1 Chain Drive for Optimum Drive System Noise and Durability

Patented **Mass-Minimizing Twin Counter Rotating Balance Shafts with** ***Patented*** **3-counterweight Deflection Control**

Layout / features overview



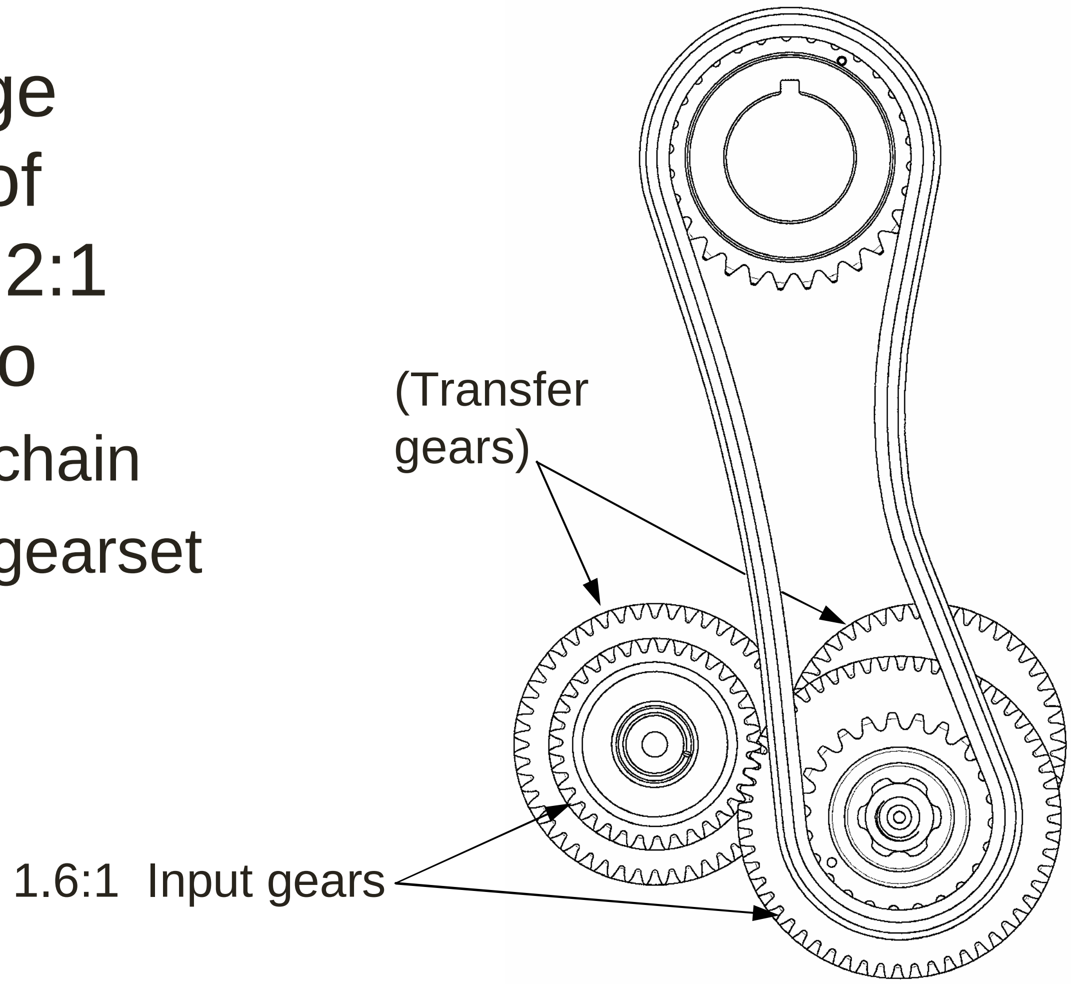
Layout / features overview



Bearing lube circuit

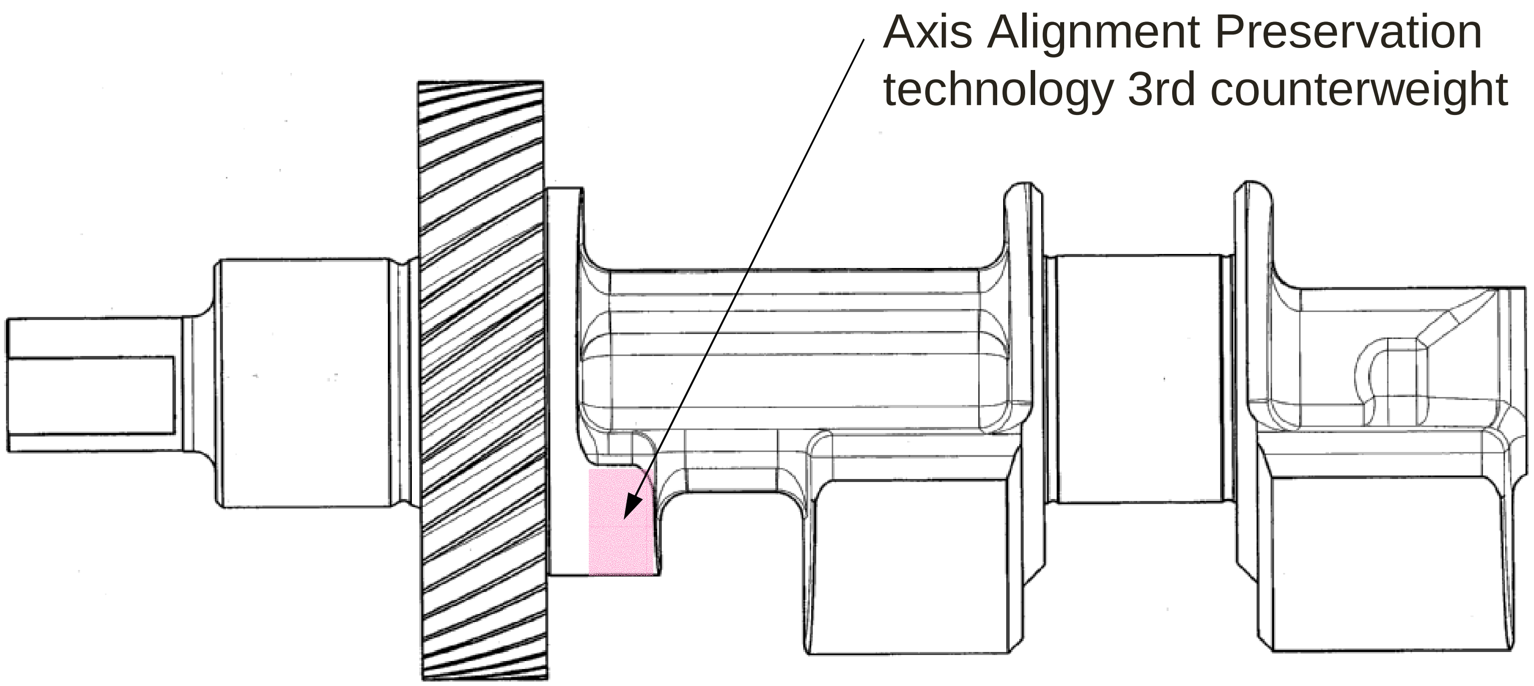
Layout / features overview

- Two-stage step-up of required 2:1 drive ratio
  - 1.25:1 chain
  - 1.60:1 gearset



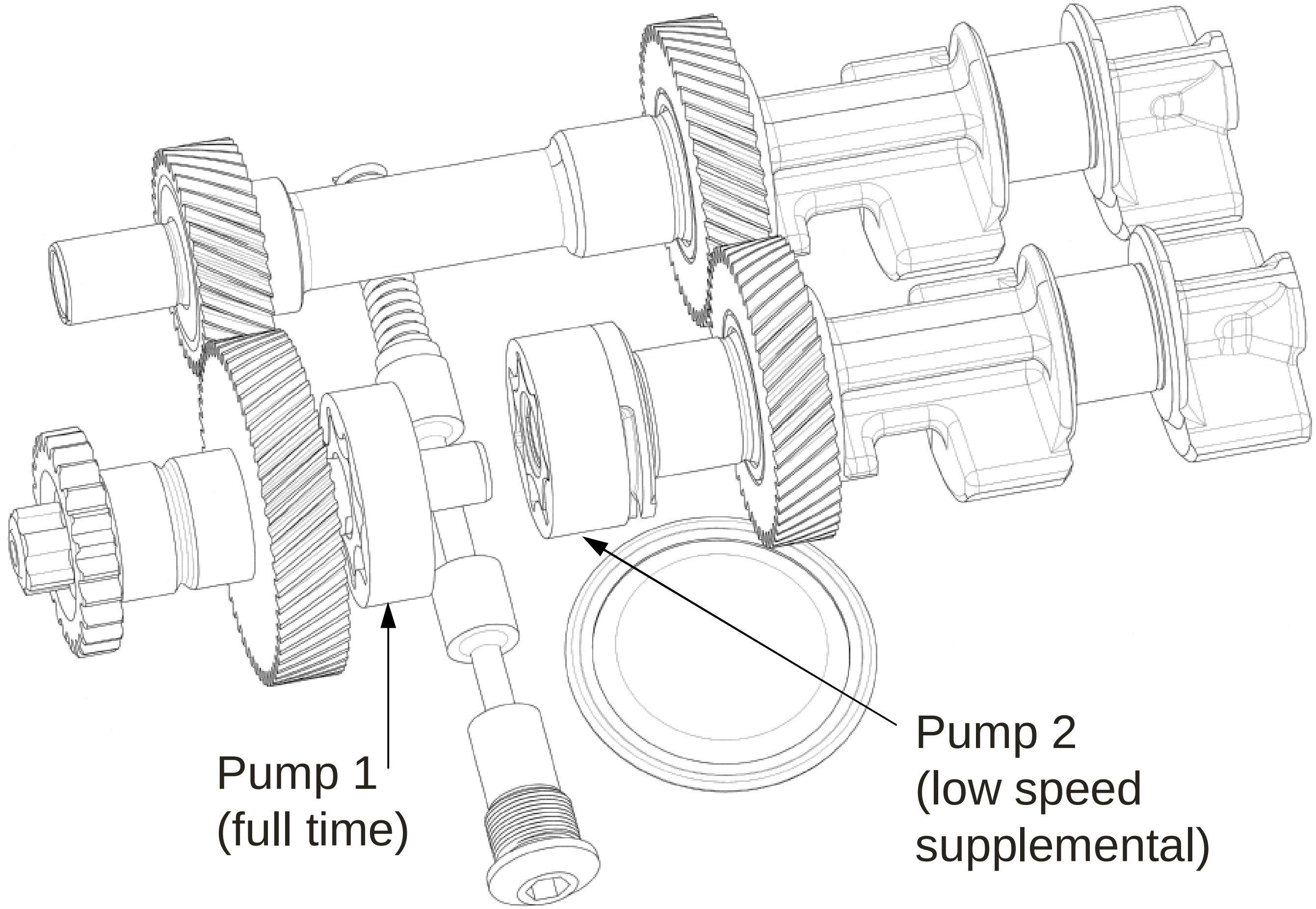
Layout / features overview

- 3-Counterweight balance shafts



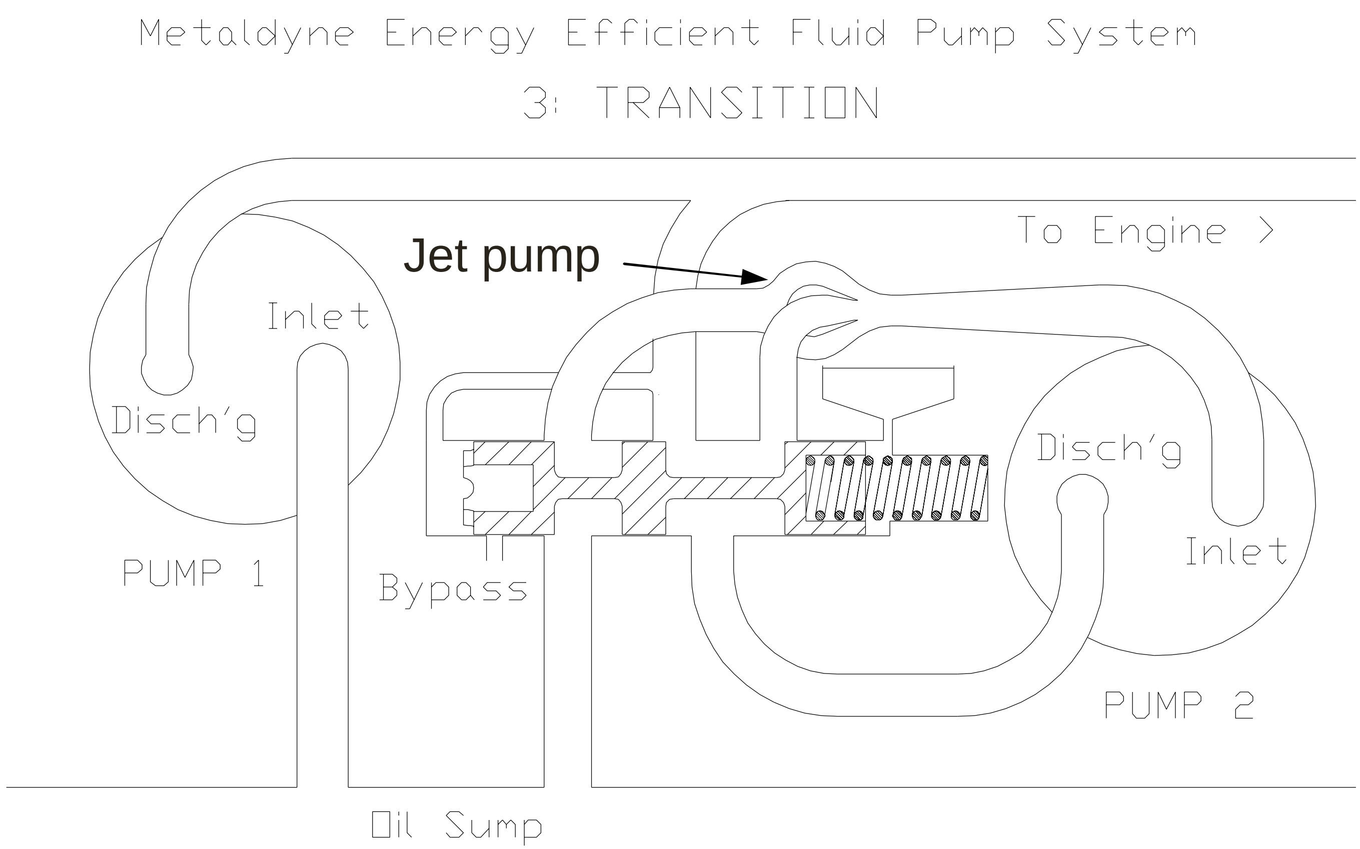
Layout / features overview

- Dual oil pumps



Layout / features overview

- Jet pump recirculation



Design considerations

1. Why include a two-stage drive ratio step-up?

2. Why utilize 3-counterweight balance shafts?

3. Why integrate dual pumps?

4. Why incorporate jet pump recirculation?

1. Why a two-stage drive ratio step-up?

- Minimizes excitation energy combination of chordal action and meshing velocity of chain
  - 30/24 tooth count (~1/2 the energy of 38/19T 2:1 drive)
- Avoids thermal backlash challenge of direct 2:1 gear drive between crankshaft & BSM
  - Effective center distance variations are easily managed by chain tensioner
- Provides choice of Pump 1 drive ratio
  - Packaging density
  - Cavitation avoidance

2. Why 3-counterweight balance shafts?

- Gear axis alignment preservation is key to cost-effective gear noise control
- Straddle-journal counterweights offer the best solution for balance shaft optimization challenge
  - packaging density
  - power consumption
  - mass minimization
- Operating shape change at high speed causes gear axis misalignment
  - Requires compromised gear tooth geometry
  - Controlled by Axis Alignment Preservation technology

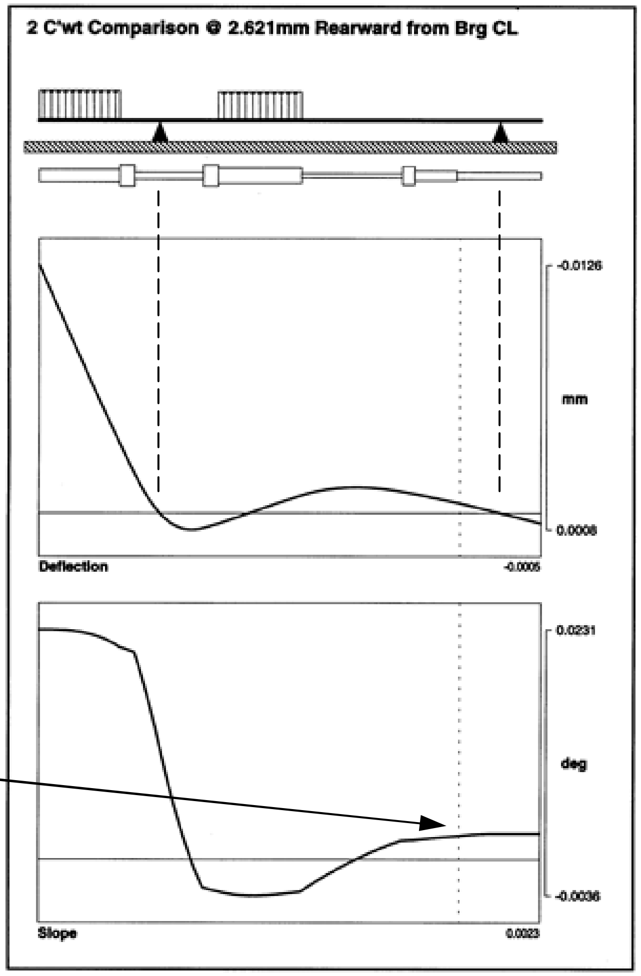
Comparison of analytical deflections and slopes

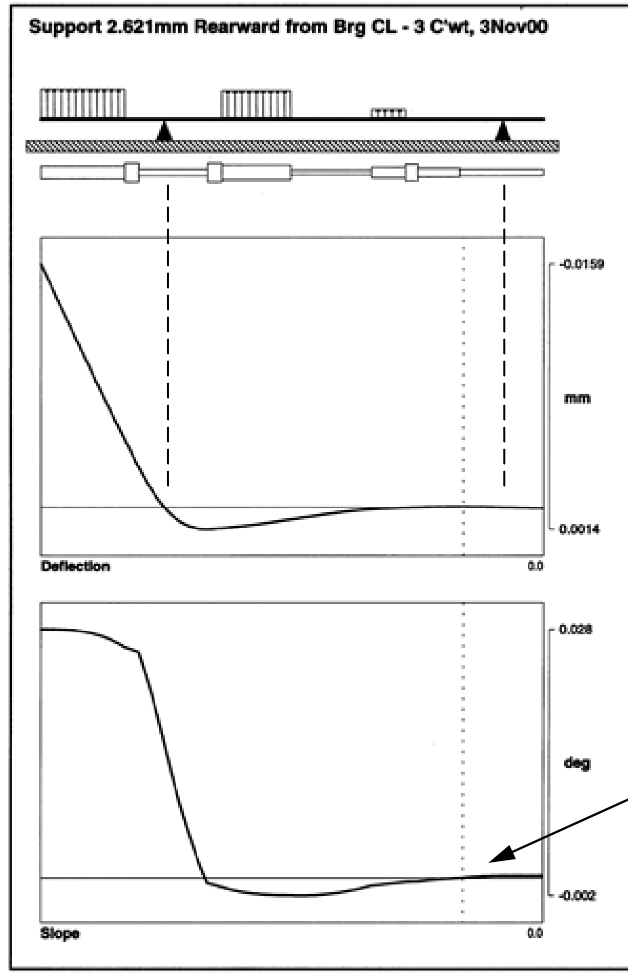
2 c'wts

2 c'wt Shaft Deflection Shape

2 c'wt Slope

Non-zero slope at gear end





3 c'wts

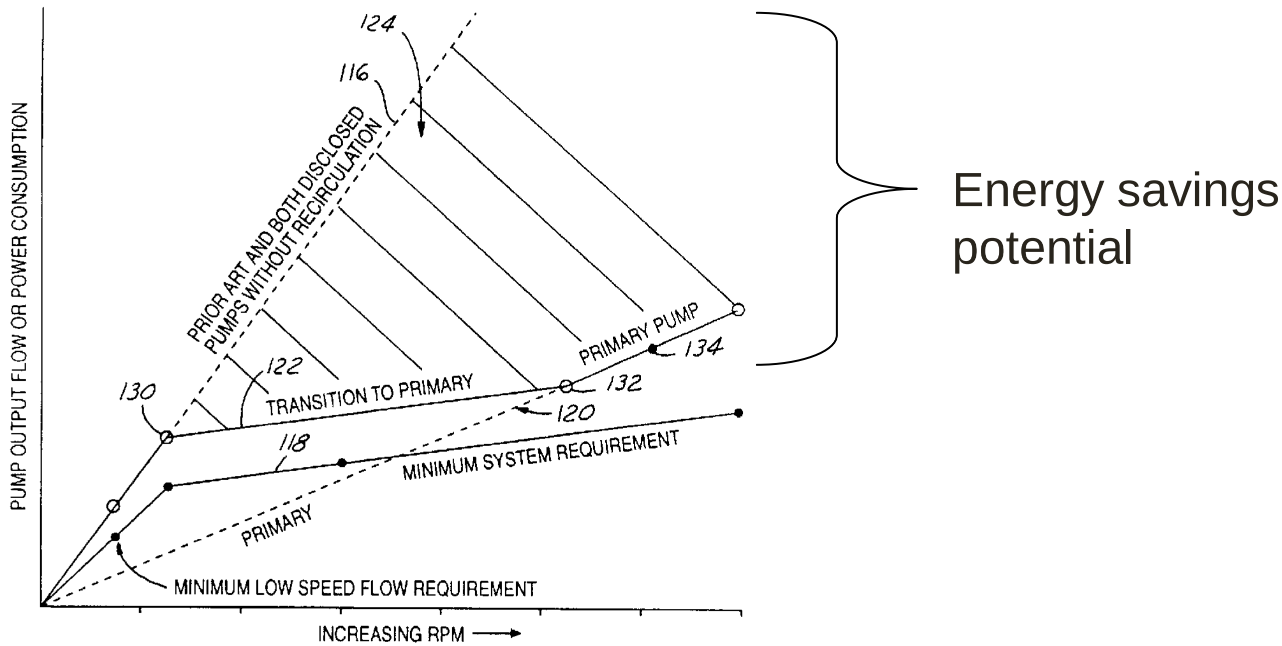
3 c'wt Shaft Deflection Shape

3 c'wt Slope

Zero slope at gear end

3. Why dual pumps?

- Recirculation energy savings vs. fixed displacement systems
  - Full output is only needed at low speeds, with hot oil

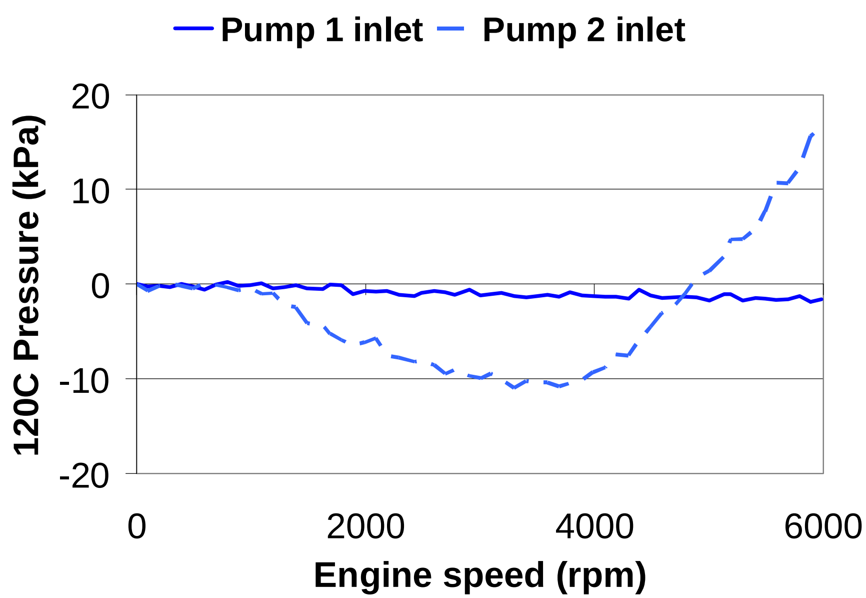


3. Why dual pumps?

- NVH benefits
  - Lower amplitude flow ripple / pressure ripple excitations vs. equivalent displacement single pump
  - Low speed gear rattle benefit of Pump 2 drag torque
    - Phases out with recirculation at high speeds where no longer needed
  - Cavitation avoidance
    - Smaller 2XERPM pump fills more easily
- VCT phaser low speed responsiveness
  - Idle speed oil pressure ~2X typical pump system
    - Without the high speed power consumption penalties of a comparable-displacement single pump

4. Why jet pump recirculation?

- Conservation of already-invested pressure energy allows "hydraulic unloading" of Pump 2 at high speeds



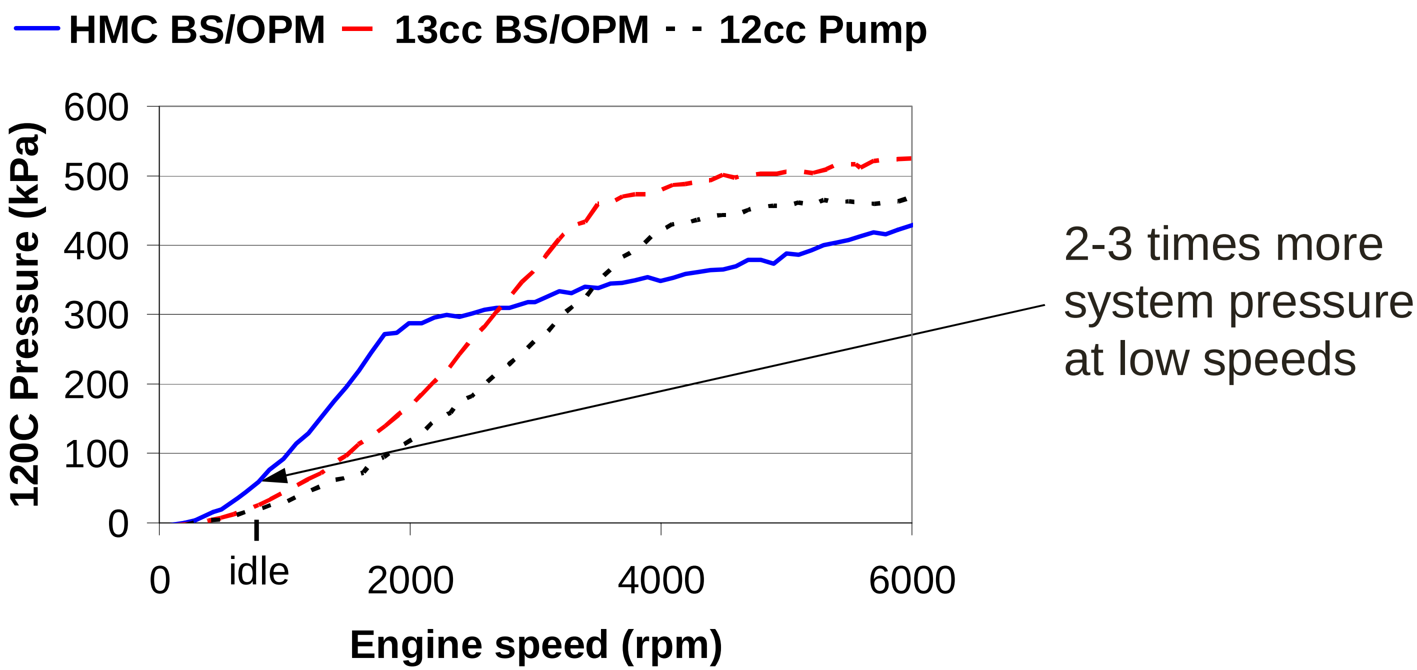
  – Power consumption benefit at high speeds, high "unused oil" flow rates

4. Why jet pump recirculation?

- Breaks the “cavitation barrier”
  - Actual inlet pressurization increases cavitation speed beyond traditional speed/displacement limitations
    - Including those of other “dual pump” strategies
  - Provides low cost gear rattle control benefits of 2X engine speed oil pump drag torque to well beyond the speed/displacement limitations of current technology

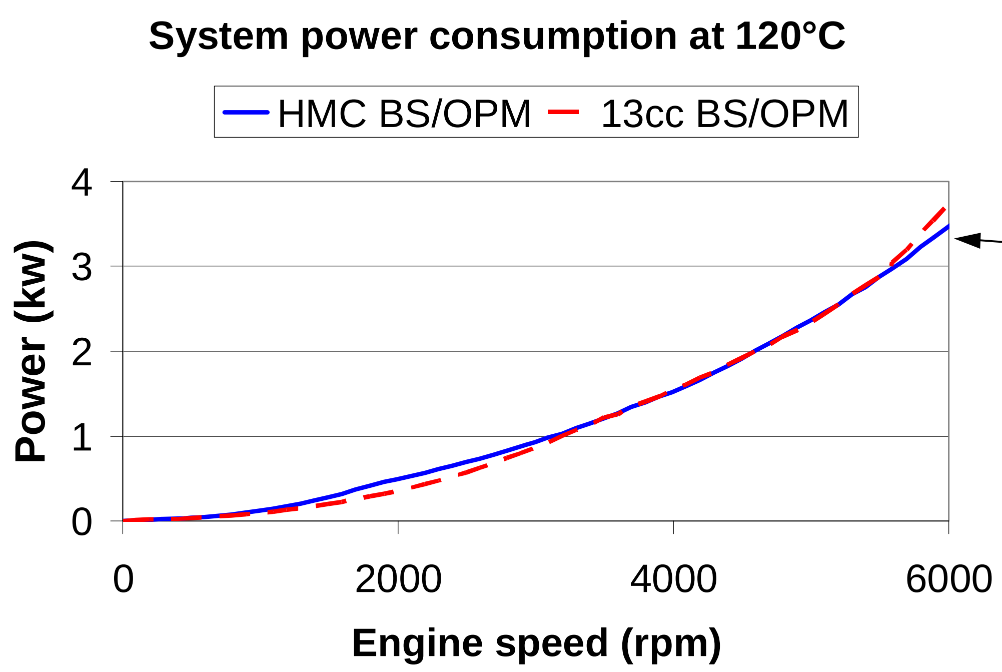
Performance Results

- Low speed pressure advantage of 18.7 cc/rev pump displacement



Performance Results

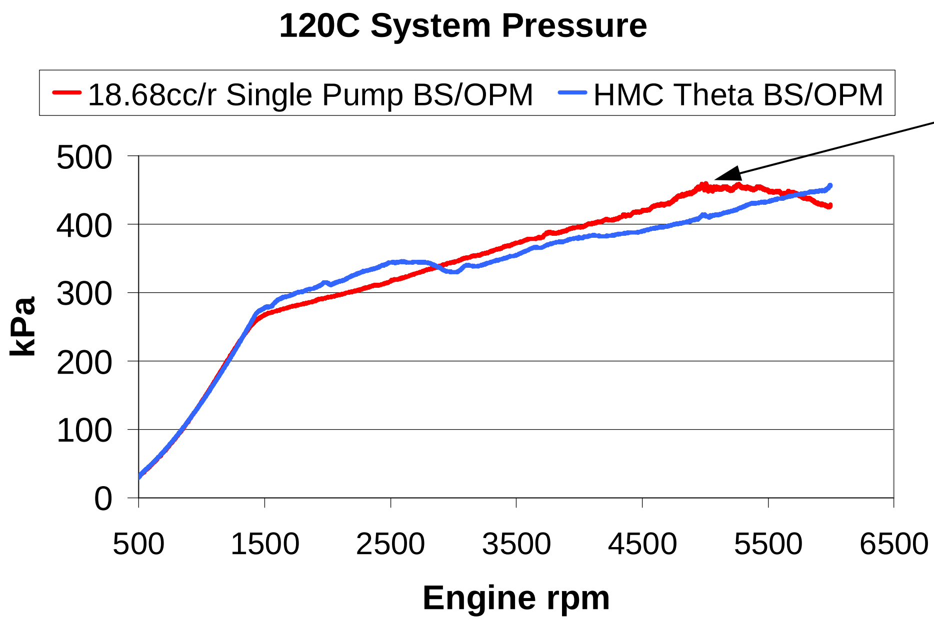
- Low speed oil pressure development does not penalize high speed power consumption



"Hydraulic unloading" power savings, vs. 13cc/rev system

Performance Results

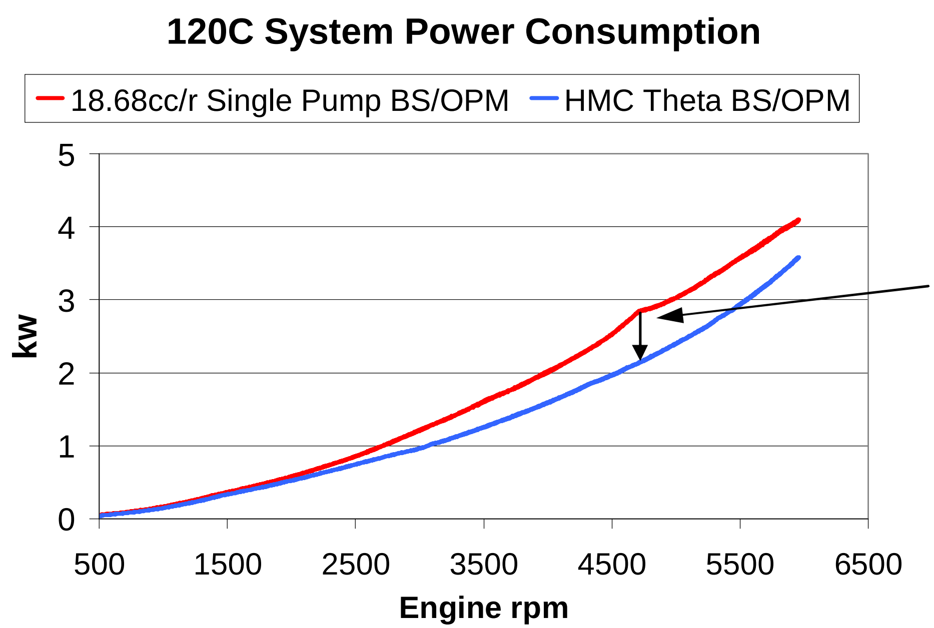
- Comparison with same-displacement single pump module
  - best-match of pressure curves via PRV spring choice



2XERPM single pump with same low speed displacement reaches “cavitation barrier” early

Performance Results

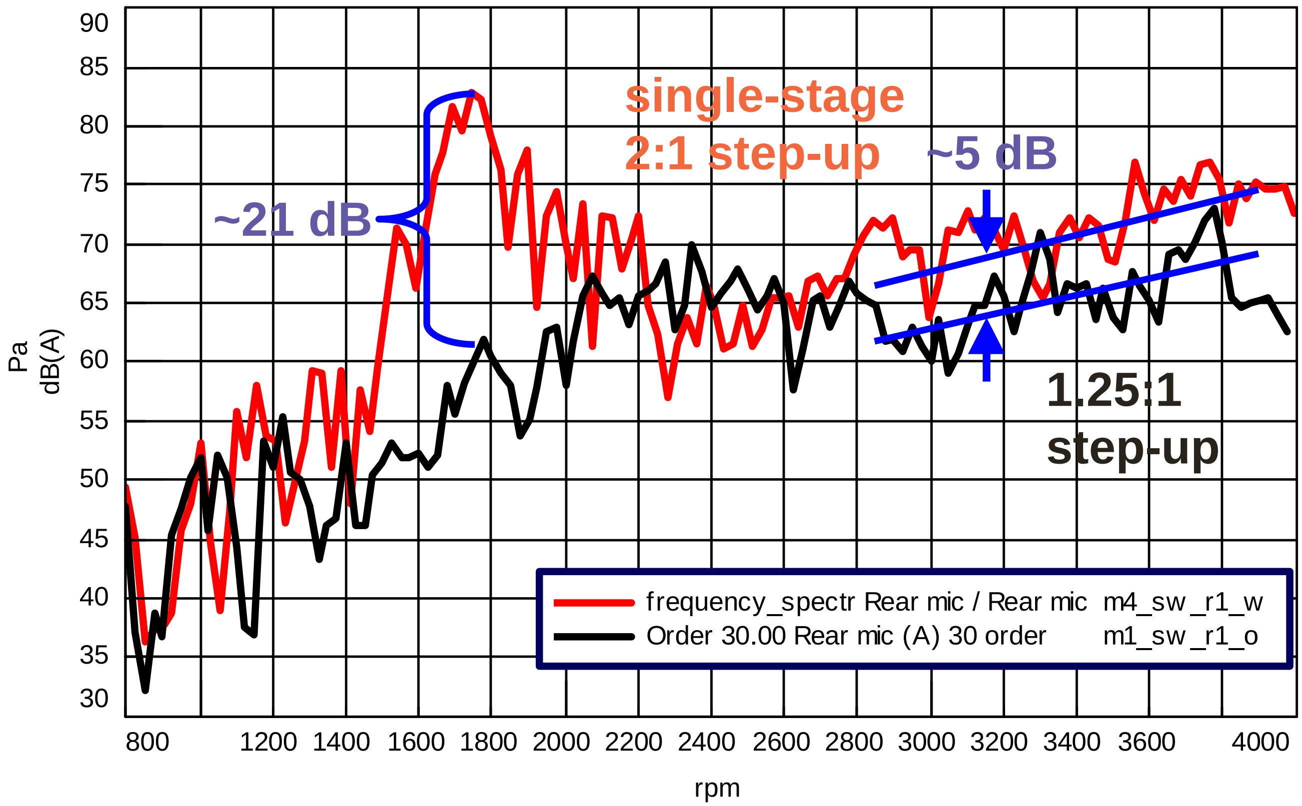
- Comparison with same-displacement single pump module reveals significant power consumption advantage at all speeds



Power consumption advantage reaches -24% before "cavitation barrier" unloading of the single pump system flattens the slope of its power curve

Performance Results

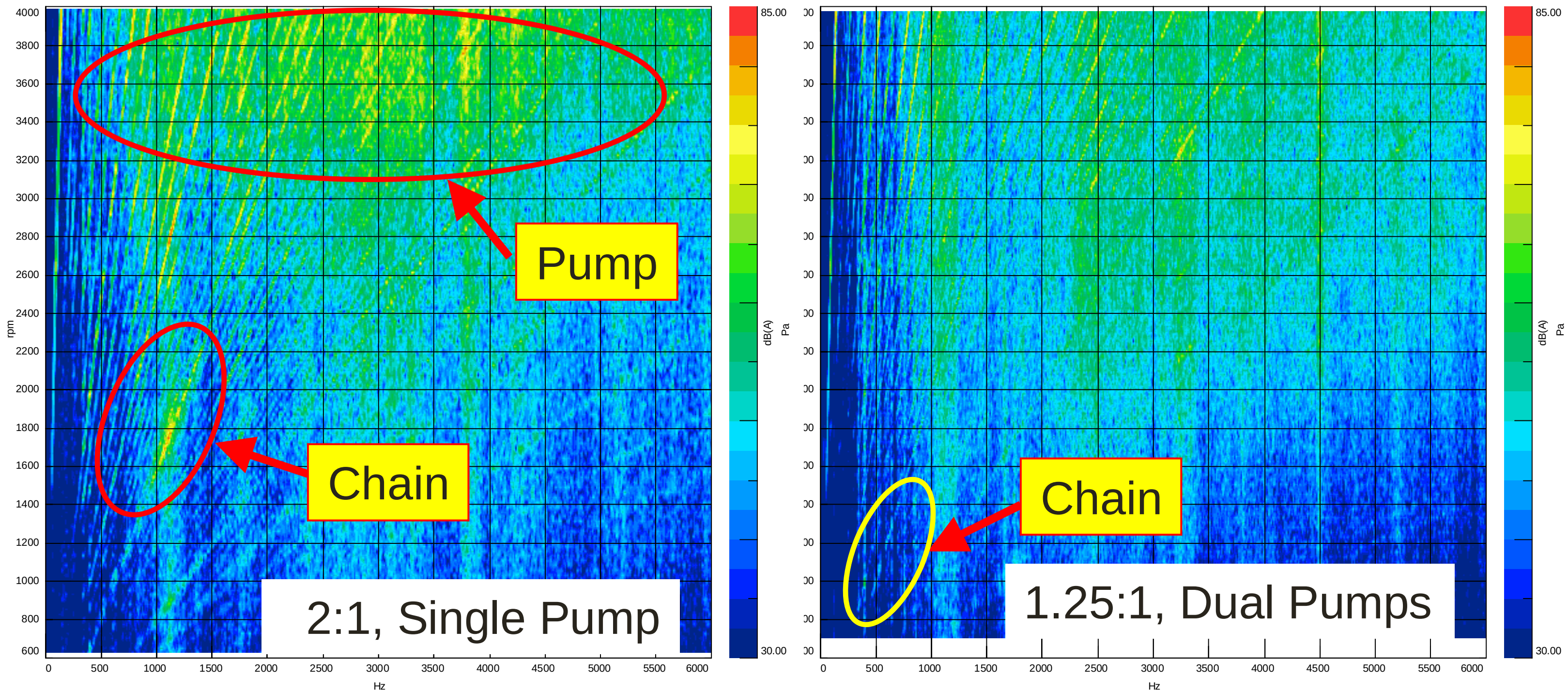
- Chain order comparison with single 2:1 step-up



Performance Results

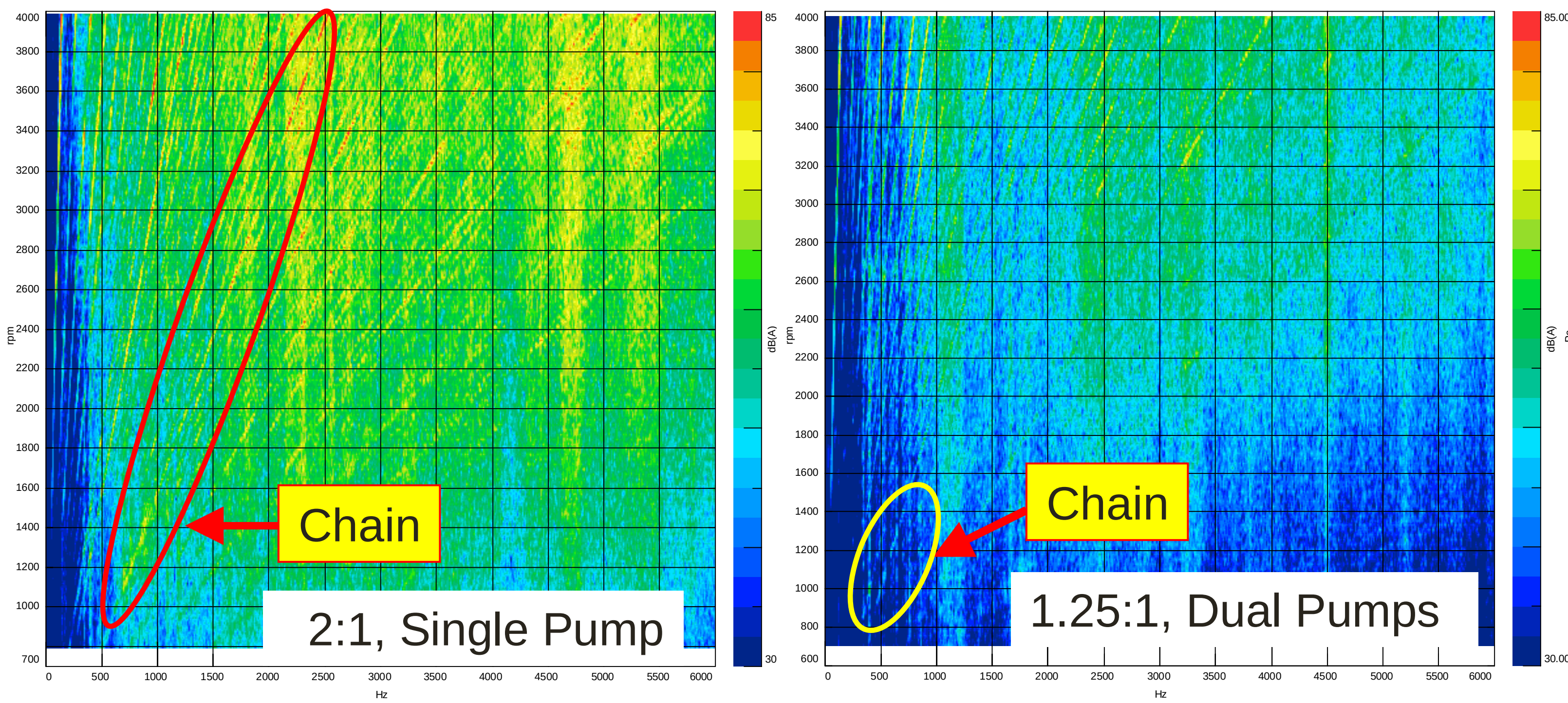
- NVH comparison with single 2:1 step-up, same output (18.7cc/rev) single pump module

dB(A) scales 45 - 80



Performance Results

- NVH comparison with competitive single pump module (2:1 chain drive, 11.9 cc/rev output)



Summary

- Advances in BSM performance and functionality, without premium manufacturing process costs**:**
  - New benchmark for drive system NVH performance
  - Increased oil flow delivery at low speeds without high speed penalties
  - Improved oil pump system NVH performance

It's about product **synergy**.

THANK YOU!