Chain Cam Drive Efficiency Optimization and Comparison to Belt Drives

October 2012

Our Beliefs

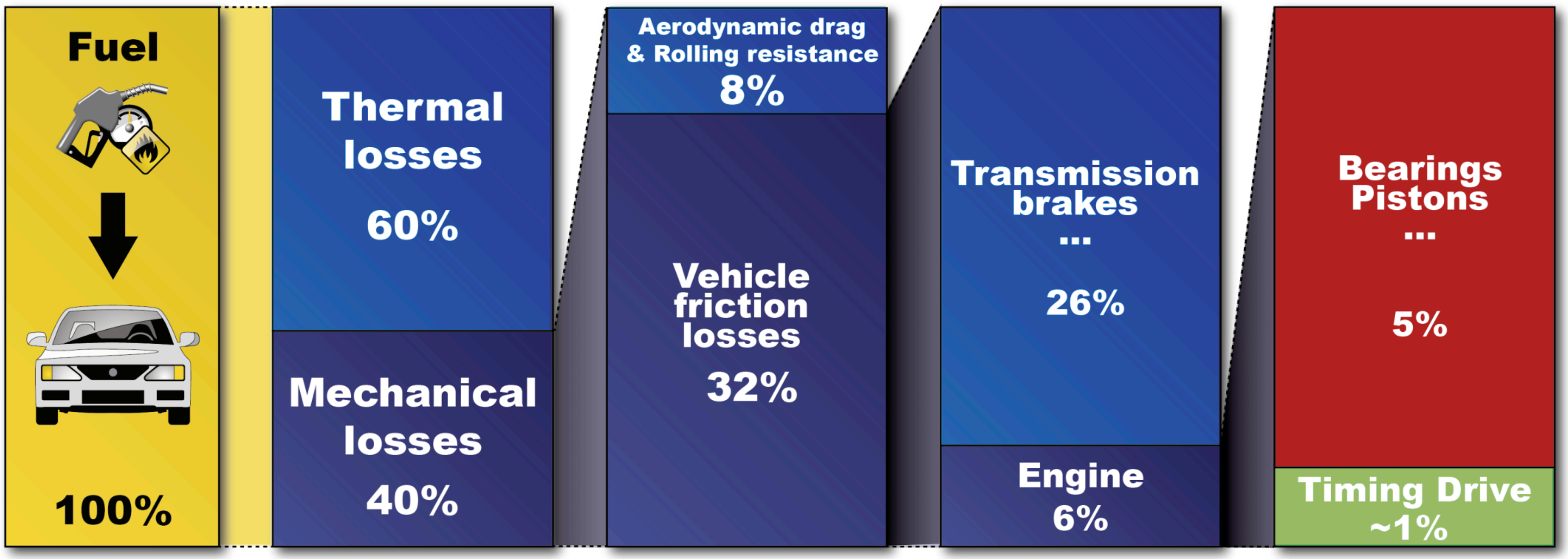
Respect
Collaboration
Excellence
Integrity
Community

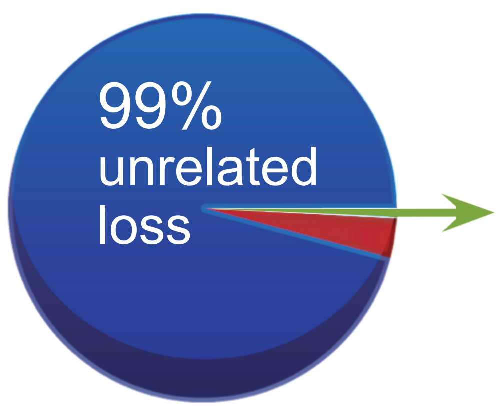
BorgWarner

Outline

- **Intro to Timing Drive Friction**
  - Vehicle Losses
  - Timing Drive Loss
  - Previous Claims
  - Friction Reduction Methods
- **Test Stand & Procedure**
  - Test Stand
  - Test Cycle
  - Data Reduction Method
  - Data Repeatability
- **Wet Belt vs. Chain**
  - Engine Setup
  - Data
  - Conclusions
- **Dry Belt vs. Chain**
  - Engine Setup
  - Data
- **Summary**
  - Conclusions
  - Q&A

System Friction - Background

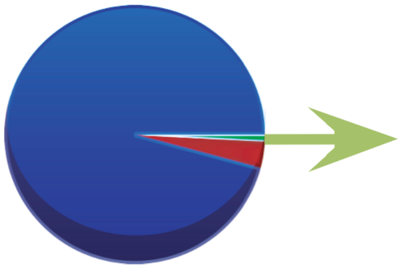


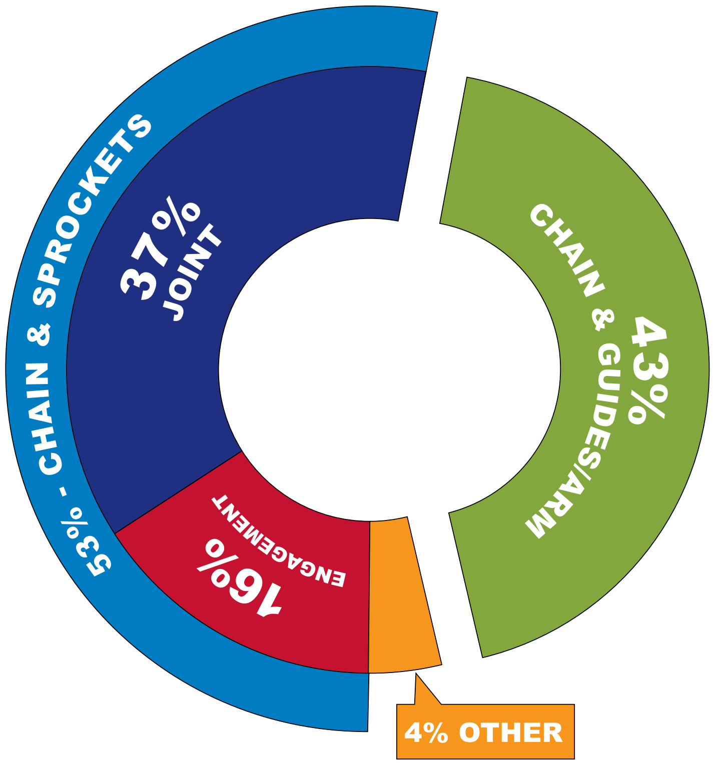


~1%

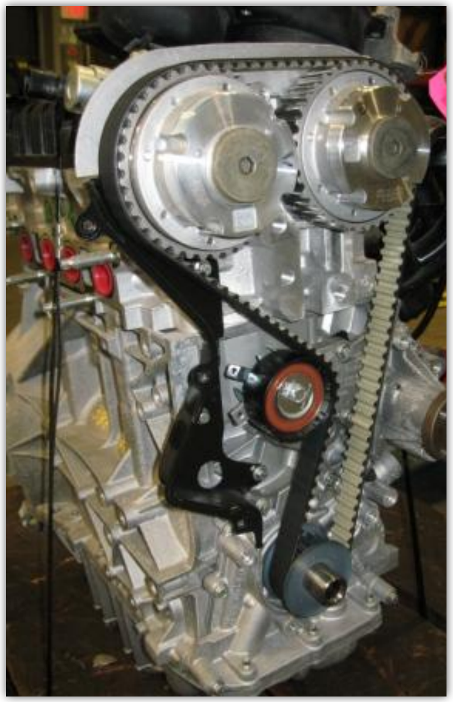
of vehicle total loss is in the timing drive

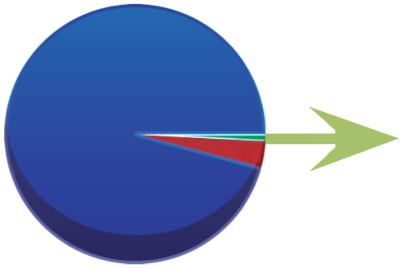
Chain Drive Losses





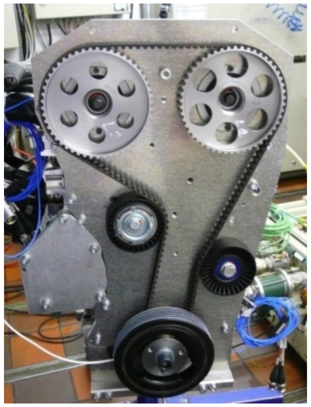
Belt Drive Losses





- Belt Tooth Compression
- Cam Seals
- Stretching of belt fibers
- Wrapping / Engagement / Sliding losses
- Pumping losses (oil/air out of tooth)
- Tensioner / Idler bearing and friction surface losses

Previous Claims vs. BW Study



Previous Claims:

- Significant belt efficiency benefit in some publications
- Other publications indicate efficiency benefit from chains

BW Study:

- Reports torque to turn measured at crank
- Fuel economy not included due to calculation assumptions required

Strategies for timing drive system optimization

- Layout Geometry
- Tensioner Tuning
- Chain Internal Friction
- Face Material

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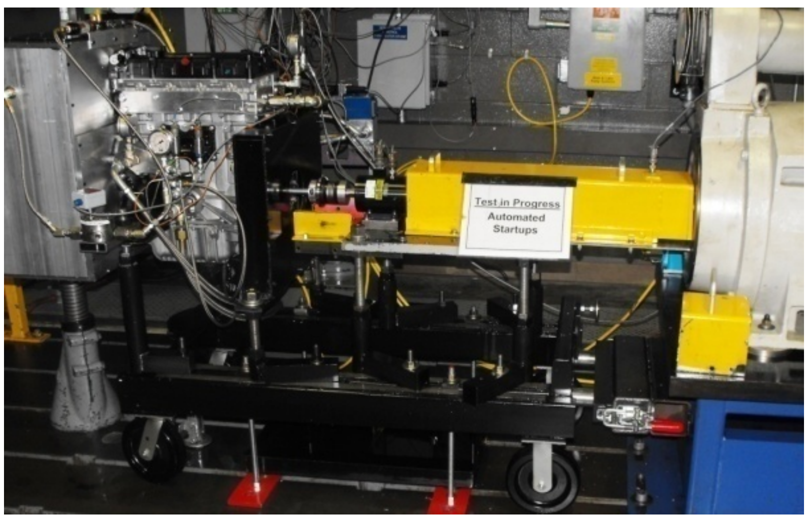
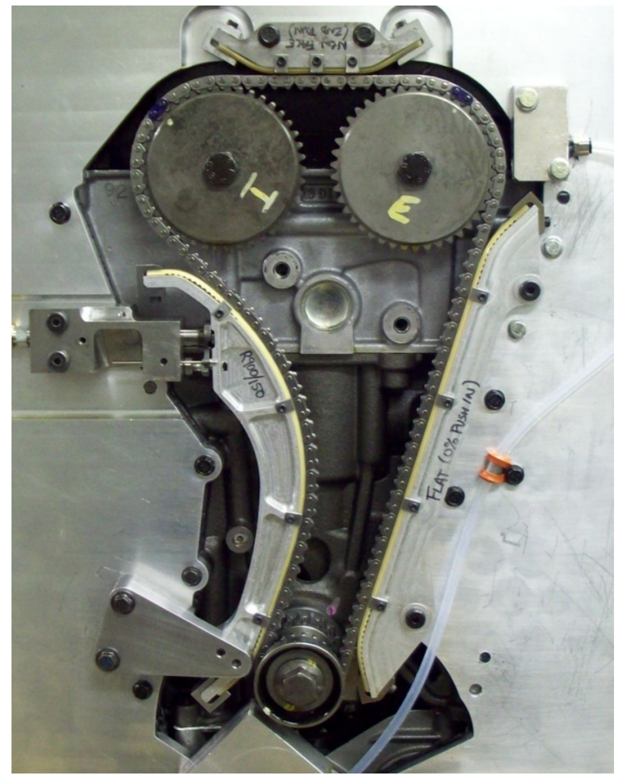
Motored Engine Friction Test Stand

- The Motored Engine Friction Test Stand is designed to measure friction of the entire timing system
  - A motored engine is a non-firing engine powered by an electric motor
  - Chain tensions are induced by the camshaft torques and tensioner dynamics





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Motored Engine Friction Test Stand [4/6]

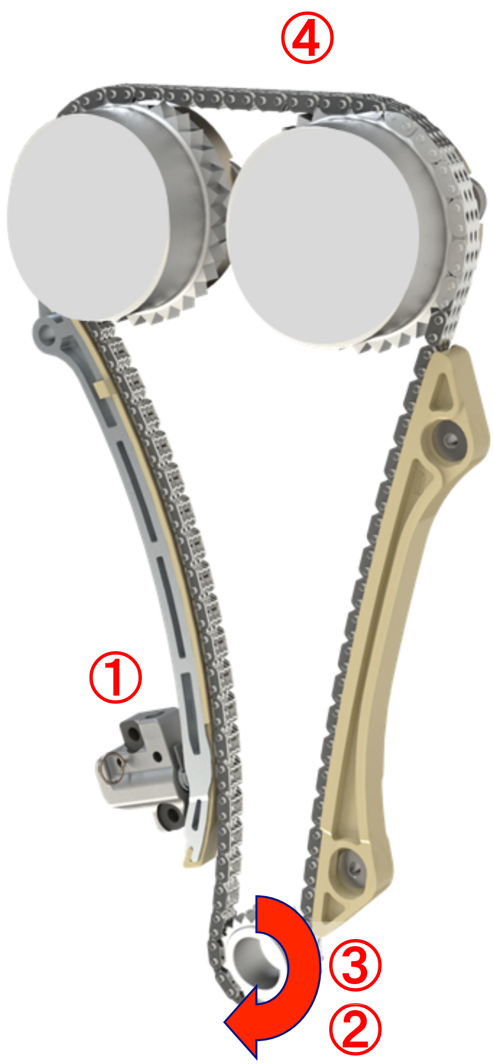
Controlled Test Stand Inputs

shaft speed	***500～5000rpm***
oil type	***5W-20***
oil flow rate	***1.0 L/min***
Oil pressure	***0-700 kPa***
oil temperature	***93℃ ± 2°C***

Test Stand Outputs

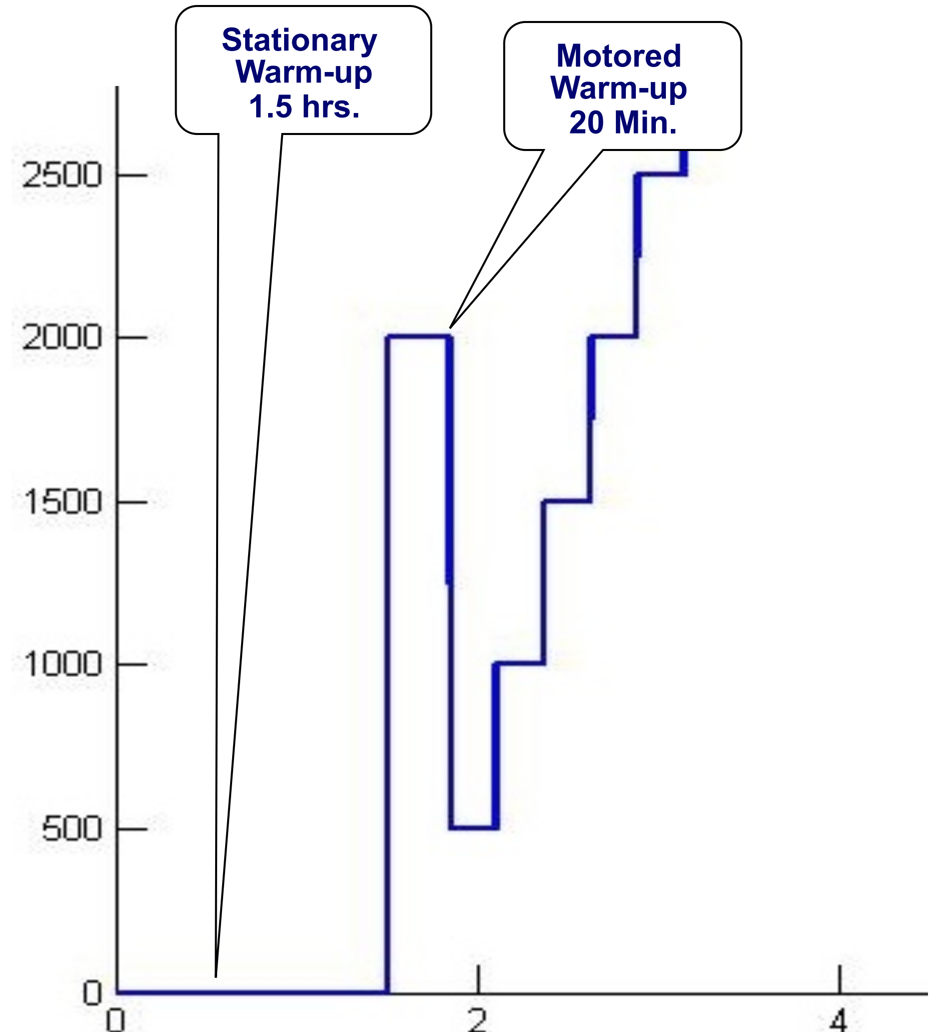
1	***chain tension***
2	***torque***
3	***speed***
4	***temperature in engine***

- Torque meter accuracy of ± 0.037 Nm
- Unmanned automated test operation



Motored Engine Friction Test Cycle [1/3]

- Test cycle consists of 3 parts
  - Test stand warm-up runs for 1.5 hrs. prior to starting friction test cycles
  - Engine warm-up motors stand at 2000 RPM to stabilize engine temperatures



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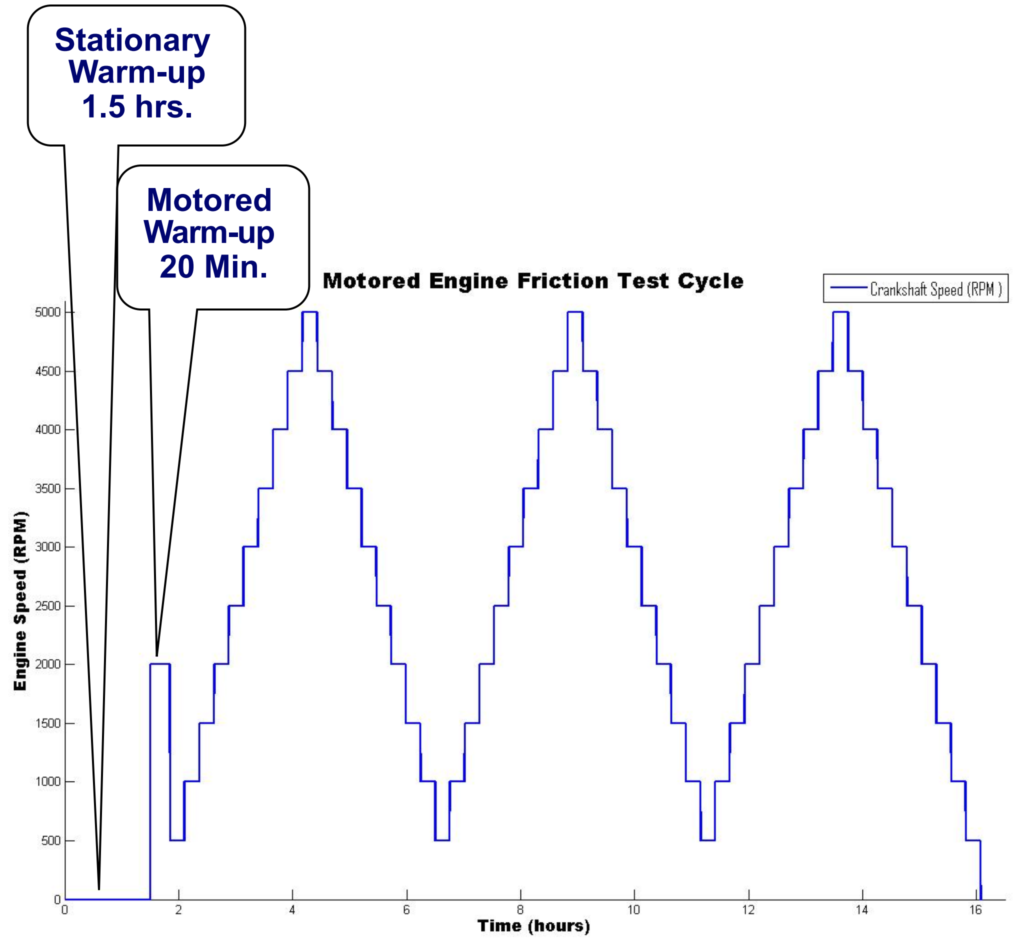
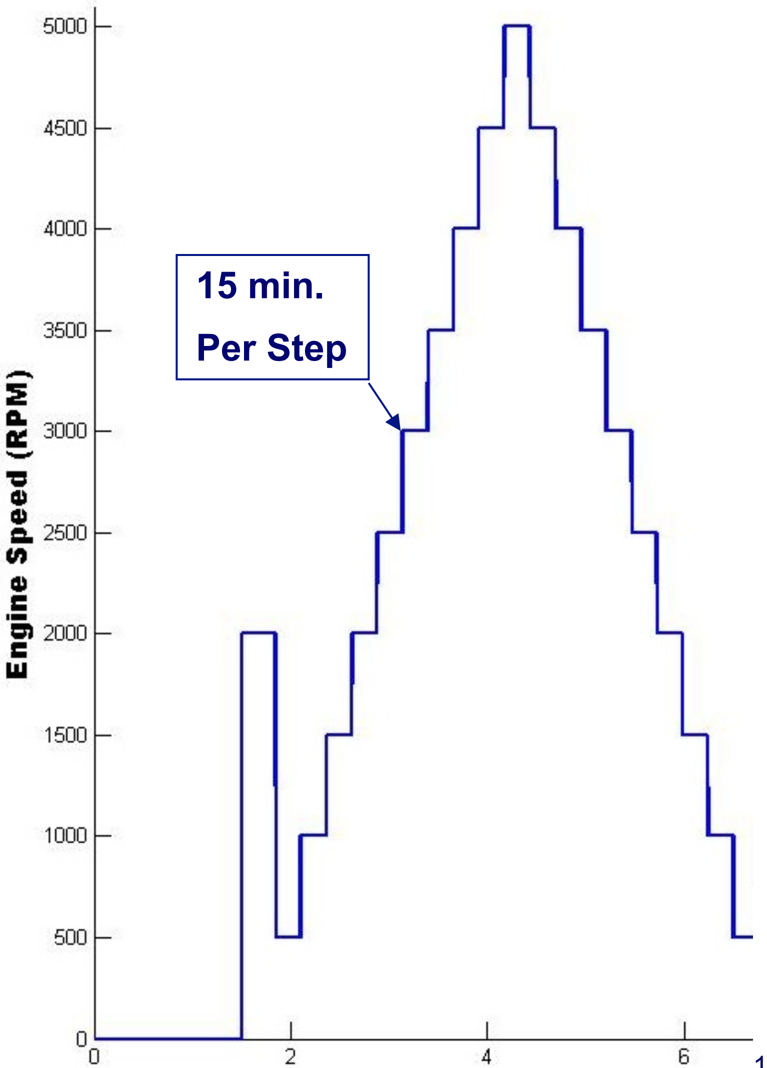
Motored Engine Friction Test Cycle [2/3]

- Test cycle consists of 3 parts
  - Test stand warm-up runs for 1.5 hrs. prior to starting friction test cycles
  - Engine warm-up motors stand at 2000 RPM to stabilize engine temperatures
  - Test cycle consists of 3 cycles to monitor and stabilize timing drive and engine friction



Motored Engine Friction Test Cycle [3/3]

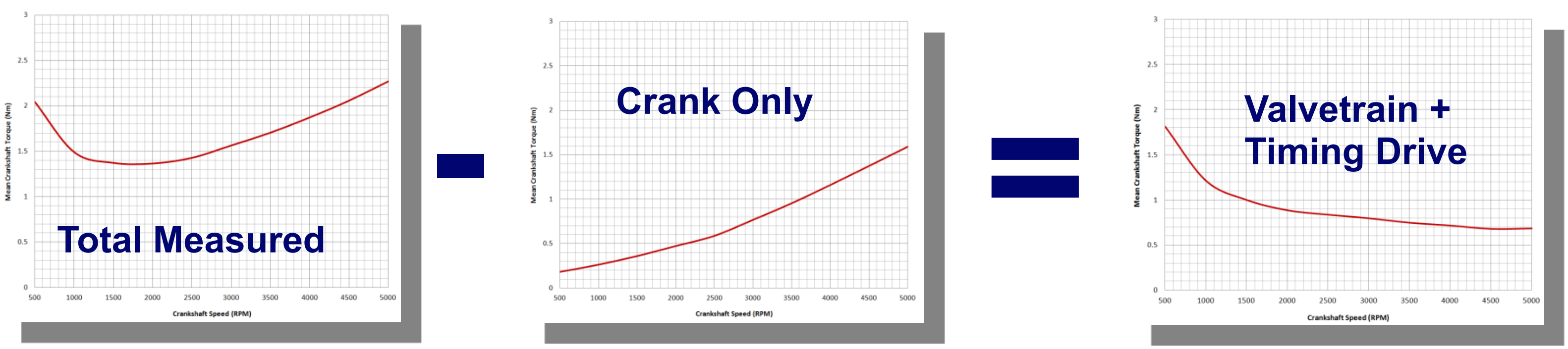
- Test cycle consists of 3 parts
  - Test stand warm-up runs for 1.5 hrs. prior to starting friction test cycles
  - Engine warm-up motors stand at 2000 RPM to stabilize engine temperatures
  - Test cycle consists of 3 cycles to monitor and stabilize timing drive and engine friction
- Each test cycle measures friction at 10 different speeds.
  - Each speed is run 15 min. to stabilize friction
  - Each speed is measured 3 times while speed is ramped up and 3 times while speed is ramped down.



Torque-To-Turn Measurement Methodology

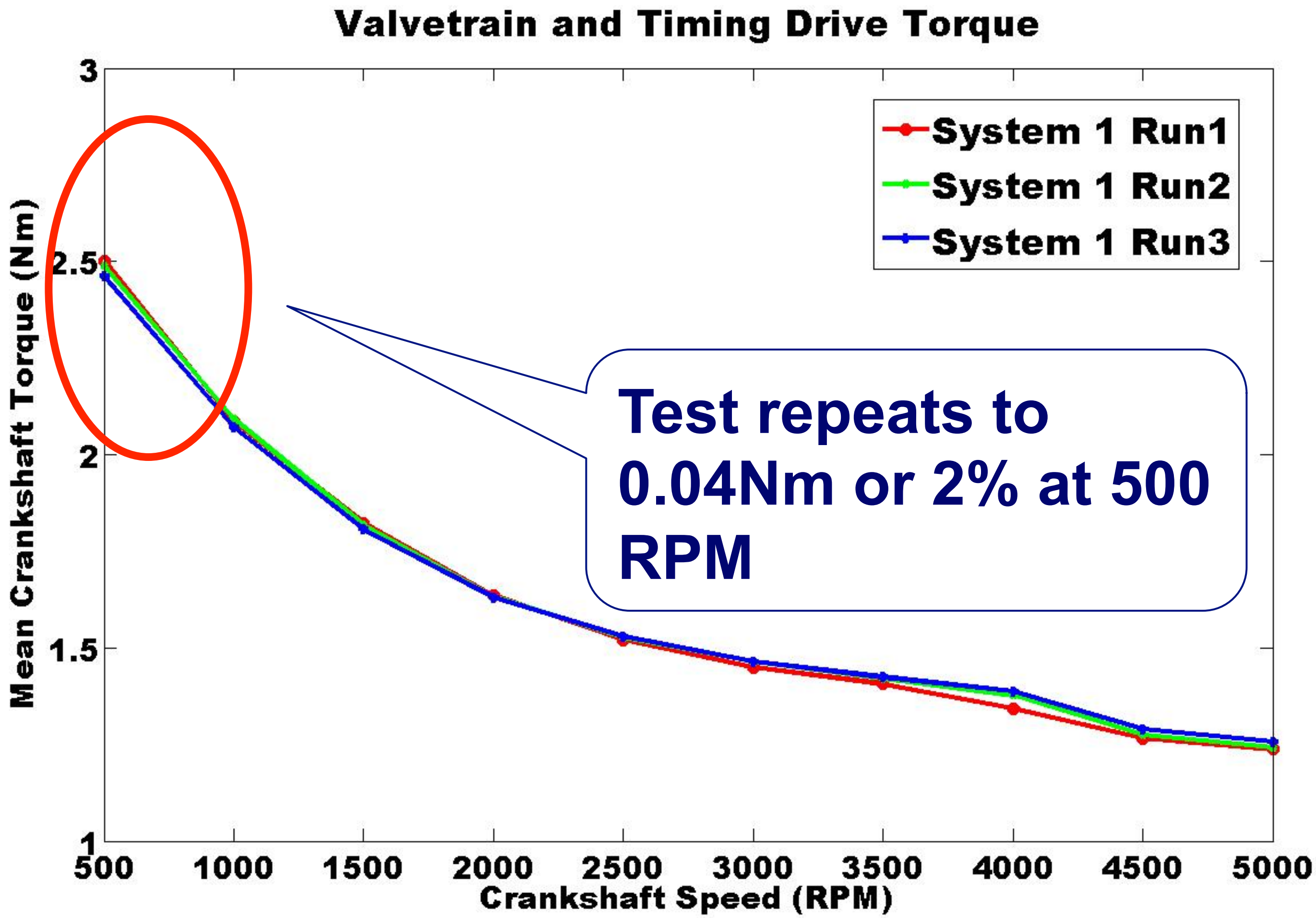
Strip Method:

- Chain or Belt drive assembled
- Measure torque at crank to spin engine
- Chain or Belt is removed
- Measure torque to spin crank only
- Subtract crank torque from total engine torque
- Resultant torque is timing drive & valvetrain torque



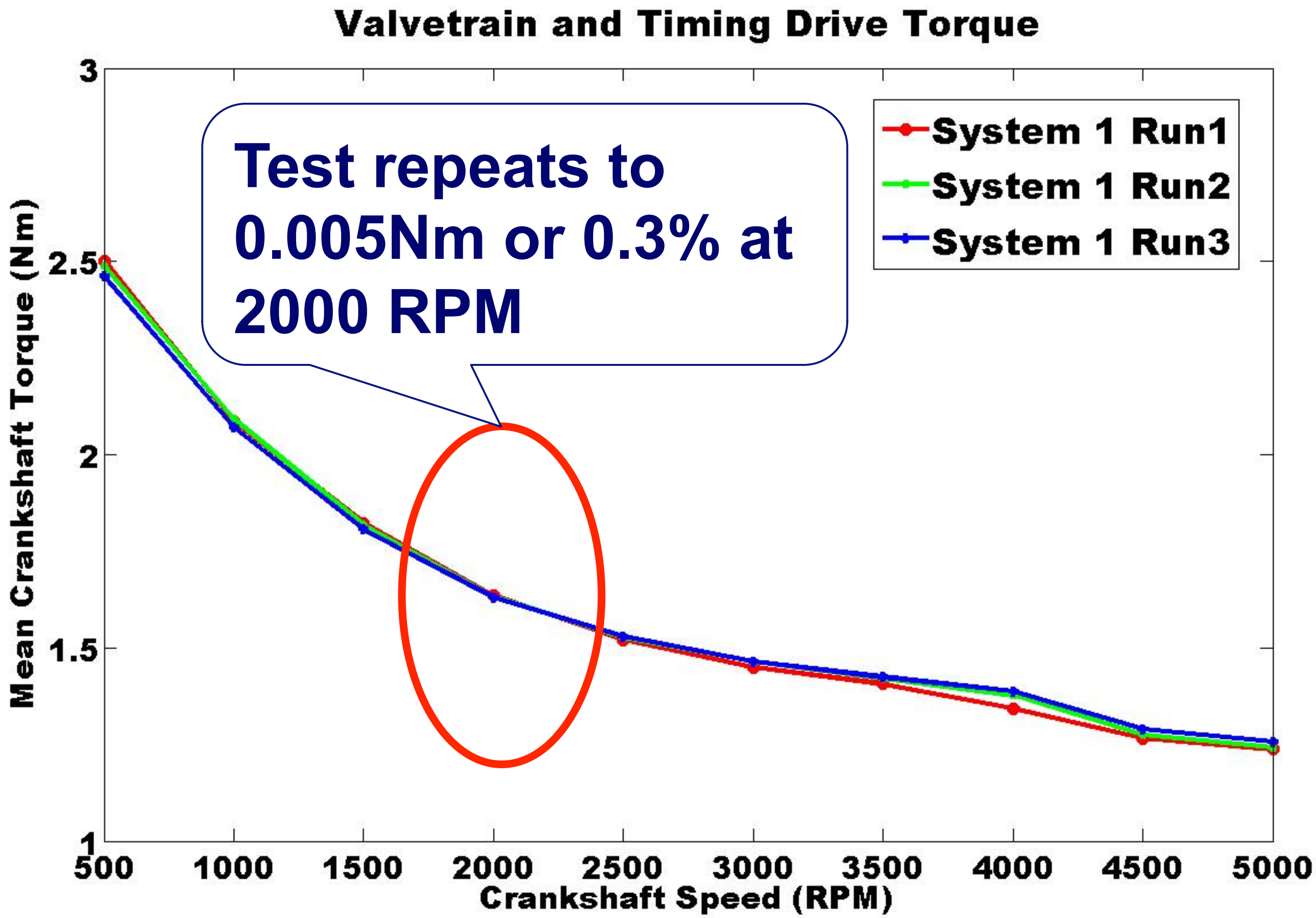
Motored Engine Friction Data [1/3]

- Example of Motored Engine Friction Repeatability



Motored Engine Friction Data [2/3]

- Example of Motored Engine Friction Repeatability



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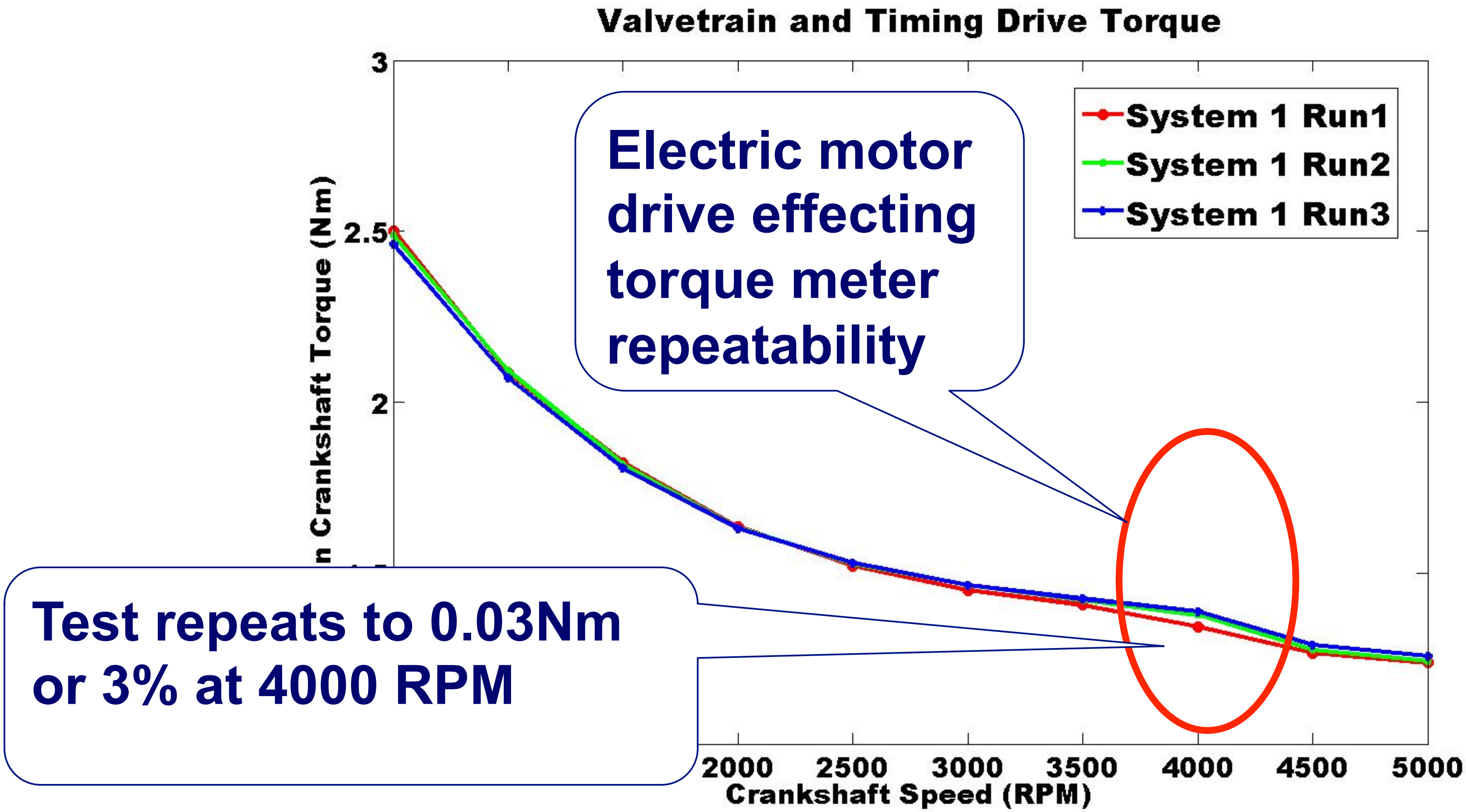

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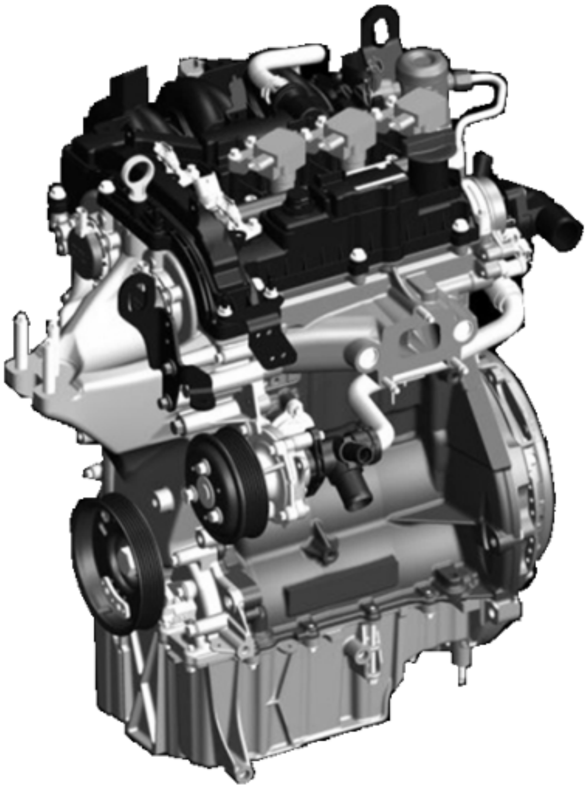
Test Set up – 1.0L I3 BIO Drive

Engine Configuration:

- SOP 2012 1.0L I3 engine
- Plate mounted to the front of the engine block
- Crank seals removed
- Crank balanced
- Con rods removed
- Pistons fixed
- Intake and exhaust blocked
- FIP removed



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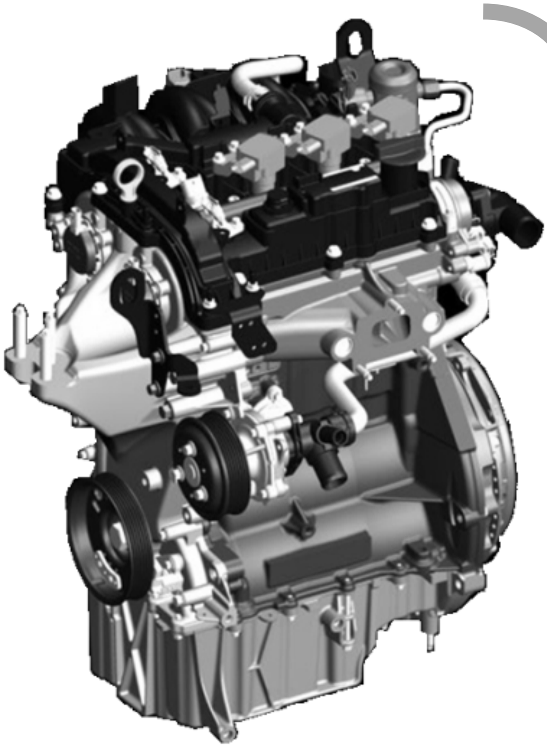
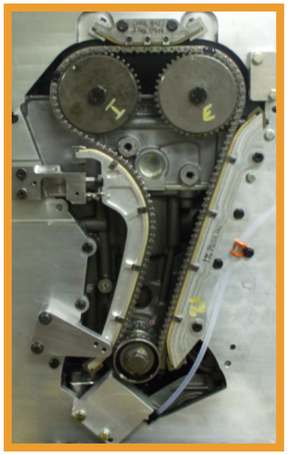
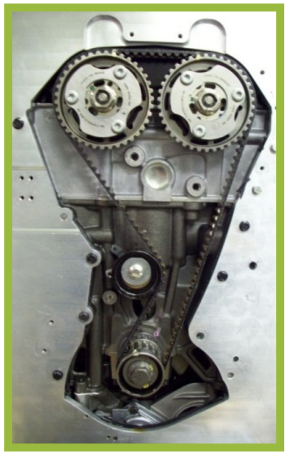




Chain Drive

- BW 8mm Pitch IT Chain
- 12.7mm Hydraulic Tensioner
- Machined crank sprocket
- Machined cam sprockets (inertia matched to VCTs)

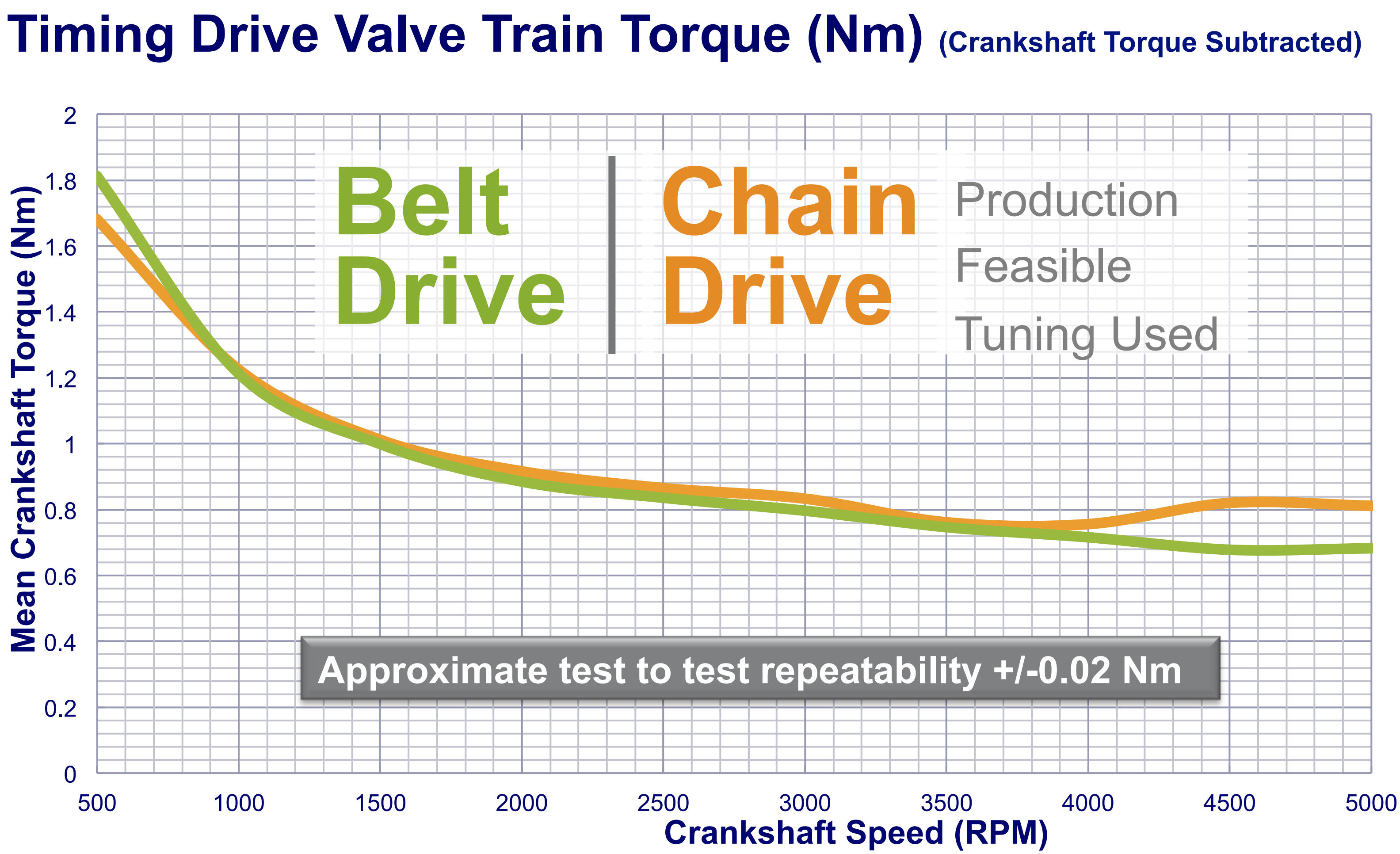
OR



Belt Drive

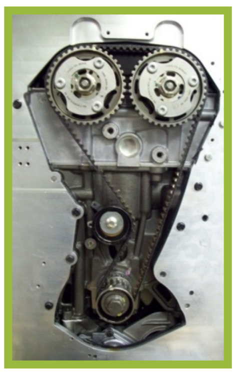
- VCT locked and electrically disconnected
- OEM Belt, VCT, Tensioner, and crank pulley

1.0L I3 Chain vs. BIO Results



Efficiency Considerations

- **Systems as shown have the same efficiency**
- **Chain system already contains the necessary elements to adapt to additional engine variants.**
- **Belt system - What is impact on efficiency of specific application requirements?**
  - Increased belt width due to higher tensions on new variant?
  - Additional tight strand guide or snubber required for other variant
  - Belt Tensioner– Increased preload due to higher amplitude inputs, to maintain dynamic stability?



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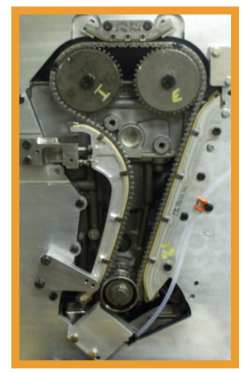

BIO – Mechanical Roller Element

Chain – Hydraulic Tensioner

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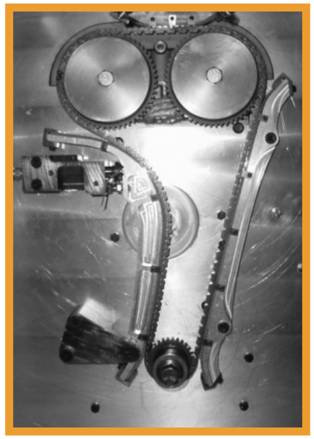
Test Set up – 1.6L I4 Dry Belt Drive

Engine Configuration:

- 1.6L I4 Existing production dry belt timing drive
- Plate mounted to the front of the engine block
- Crank seals removed
- Crank balanced
- Con rods removed
- Pistons fixed
- Intake and exhaust blocked
- FIP removed

Test Set up – 1.6L I4 Dry Belt Drive



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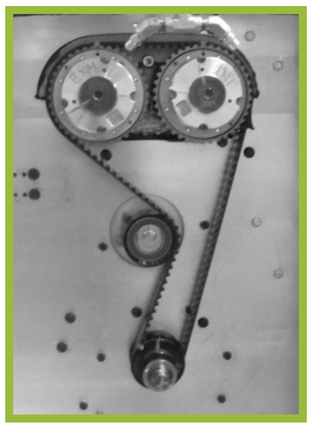


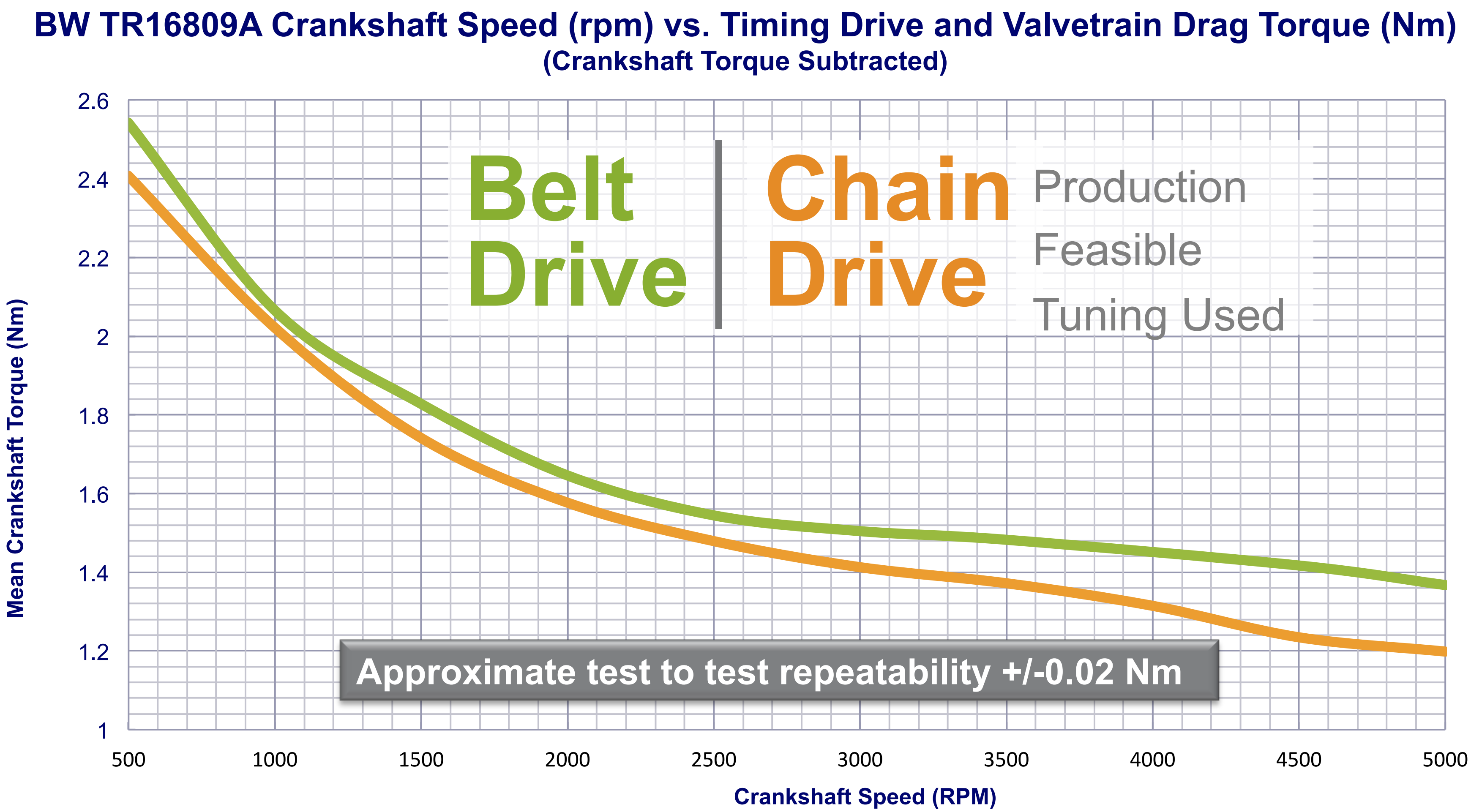
Chain Drive

- BW 6.35mm Pitch IT Chain
- 12.7mm Hydraulic Tensioner
- Machined Crank Sprocket
- Machined Cam Sprockets (inertia matched to VCTs)

Belt Drive

- OEM Belt, VCT, Tensioner, and Crank Pulley
- VCT locked and electrically disconnected

1.6L I4 Chain vs. Dry Belt Results [1/2]



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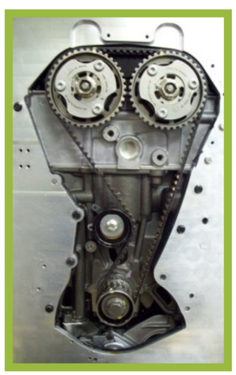
Conclusions

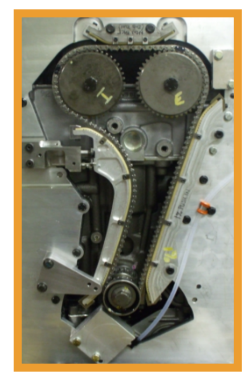
1) When both chain and belt drives are optimized they have similar efficiency

2) Timing drive design decisions should be made considering all design criteria.



Belt in Oil Drive

EFFICIENCY =



Chain Drive

Conclusions

3) Chains are often the best solution for timing drives due to:

- Minimized Package
- Optimized Efficiency
- Robustness Against Dynamic Instability
- Proven Long Term Field Durability
- Proven Adaptability Across Multiple Variants

Q&A

Thank You


feel good
about driving
better fuel economy
reduced emissions
great performance