Development and Validation of a Test Procedure for Determining the System Power of Hybrid Electric Vehicles

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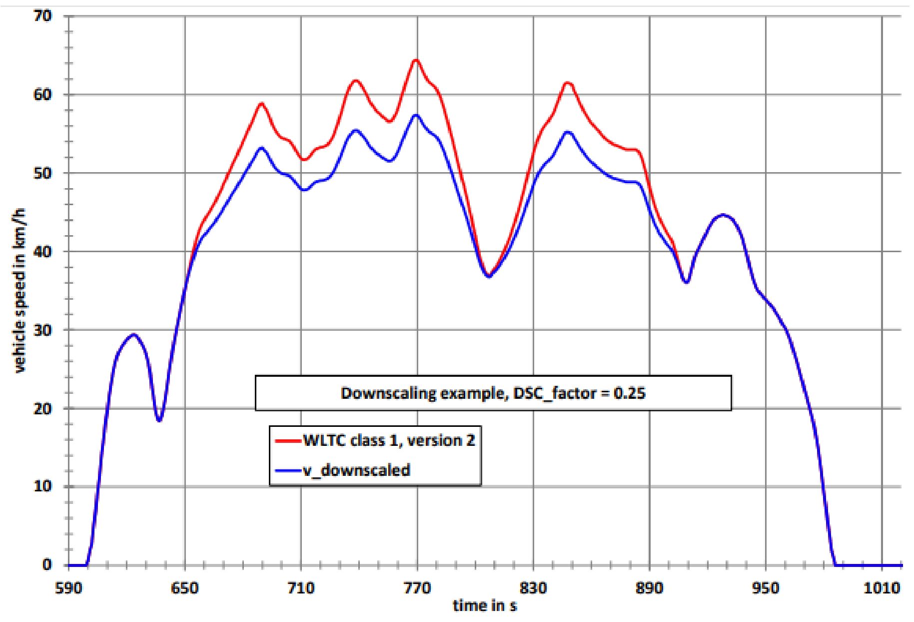
Importance of vehicle power rating

- Passenger vehicles are commonly assigned a power rating
  - Allows comparison of performance between different vehicles
  - Other uses: certification, classification, taxation, marketing

2.8%

Relation to WLTP

- WLTP requires a vehicle power rating for classification and downscaling
  - Power-to-mass ratio is used for vehicle classification
  - Power rating is used to downscale the drive trace for low-powered vehicles
- Currently, HEVs are placed into Class 3 because there is no specified method for determining their power rating

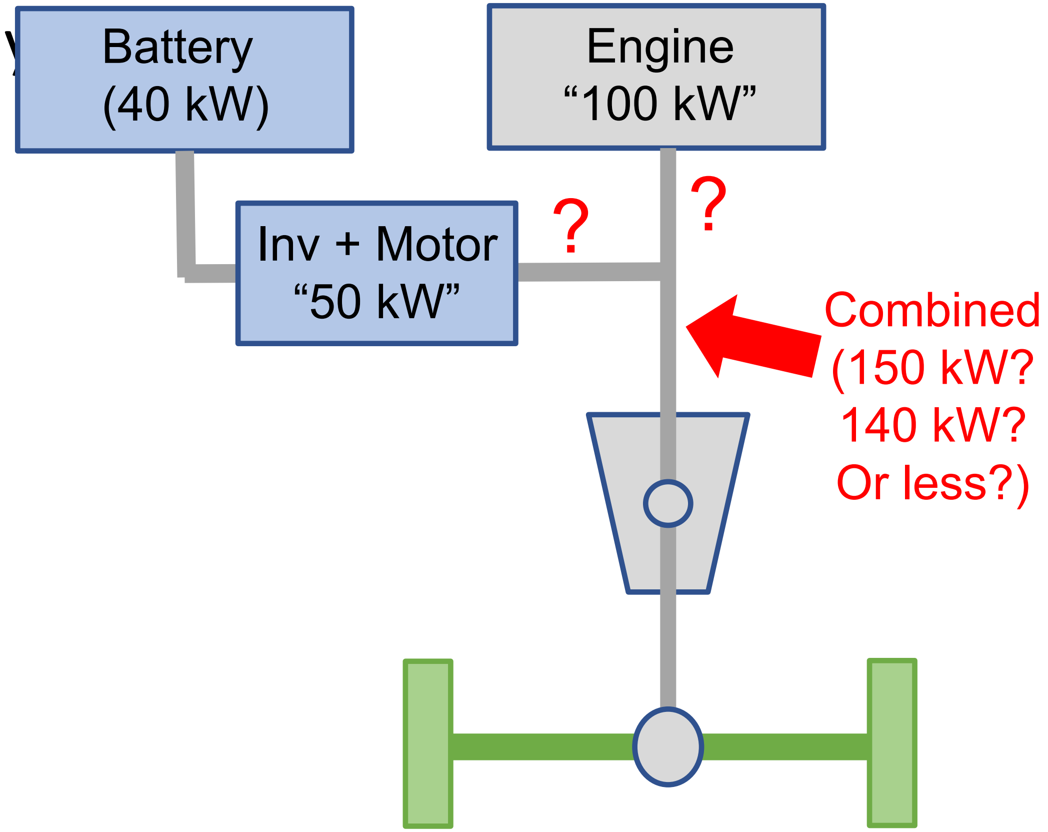


UN ECE mandate

- UN ECE is developing a Global Technical Regulation, "Determination of Electrified Vehicle Power (DEVP)" to provide for HEV power rating
- Delegated to Informal Working Group (IWG) on Electrified Vehicles and the Environment (EVE)
- Power determination test procedure will apply to light-duty:
    - HEVs
    - PHEVs
    - BEVs with more than one propulsion motor

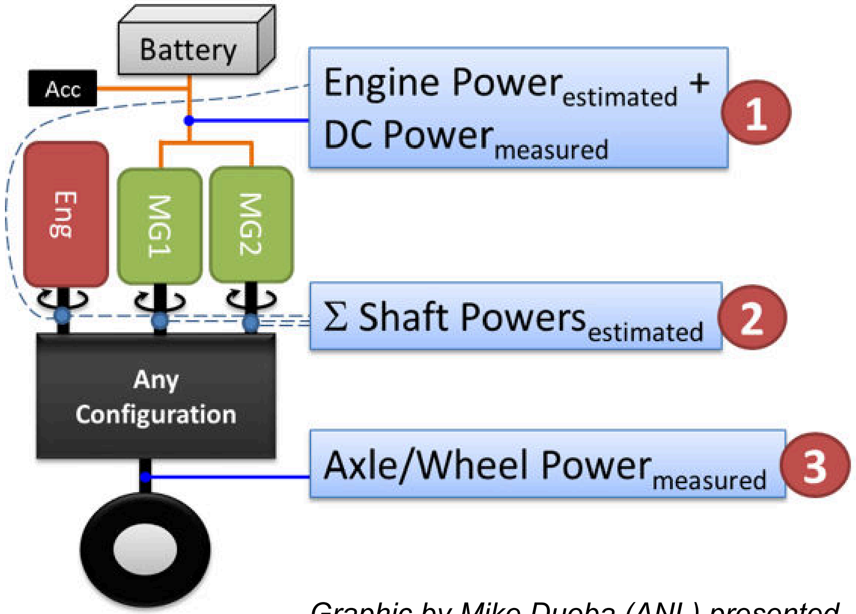
The difficulty with HEVs

- Rated power of a conventional vehicle is simply the rated engine power.
- HEVs combine more than one power source
  - It depends on how they are combined
  - Rated power might not be achieved
  - Rated power may be limited by battery
- So it cannot be a sum of the rated powers
- But it could be a sum of the actual power produced by each component.
- But how do we measure it?



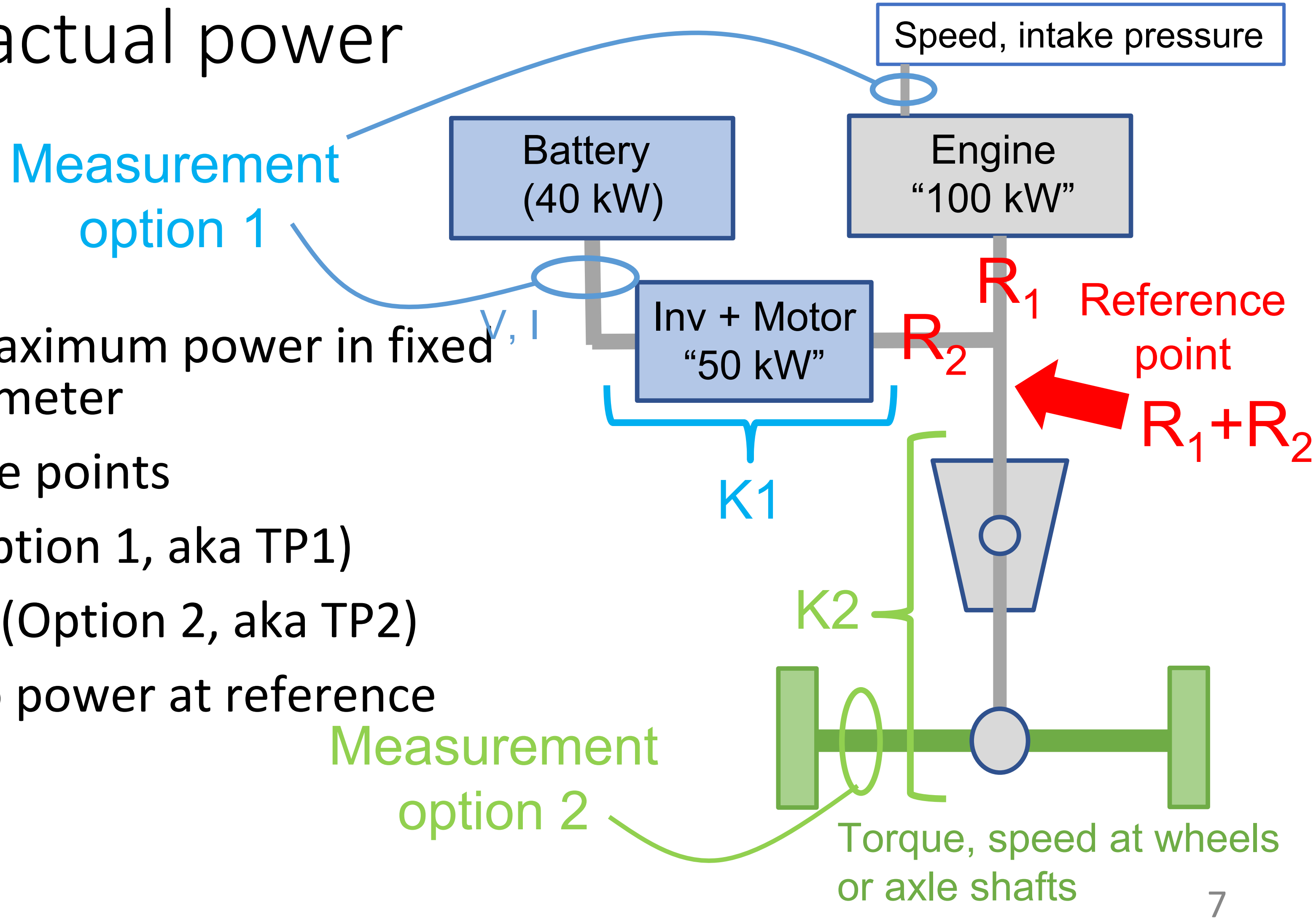
Power measurement standards

- Several standards bodies have developed solutions
  - SAE J2908 Vehicle Power Test for Electrified Powertrains
  - ISO 20762 Electrically propelled road vehicles -- Determination of power for propulsion of hybrid electric vehicle
  - Korea Automobile Testing & Research Institute (KATRI) has explored similar methods
- EVE IWG considered each of these
- Ultimately, we selected ISO 20762 as a basis
- The goal is to estimate actual shaft output power



Graphic by Mike Duoba (ANL) presented at EVE-16, Ottawa, October 2015

Approach: measuring actual power



1) Operate the vehicle at its maximum power in fixed speed mode of the dynamometer
2) Measure power at accessible points
   - Upstream of reference (Option 1, aka TP1)
   - Downstream of reference (Option 2, aka TP2)
3) Apply K1 or K2 to convert to power at reference point (R1 + R2)

Outline of procedure

- Vehicle soak and charge (if applicable)
- Conditioning cycle – 20 minutes at 60 kph
- Battery SOC recovery
- Identify speed of maximum power
  - Maximum pedal command at various fixed dynamometer speeds
- Conduct five repetitions at speed of maximum power
- Compute TP1 or TP2 and compute average of last 4 observations

TP1

Default = 0.85

$$P_{HEV\ system}\ [kW] = ICE\ power + \left(\frac{U_{battery} \times I_{battery}}{1000} - P_{DCDC} - P_{auxiliaries}\right) \times K1$$

K1 is efficiency of [inverter + motor] during vehicle maximum power

TP2

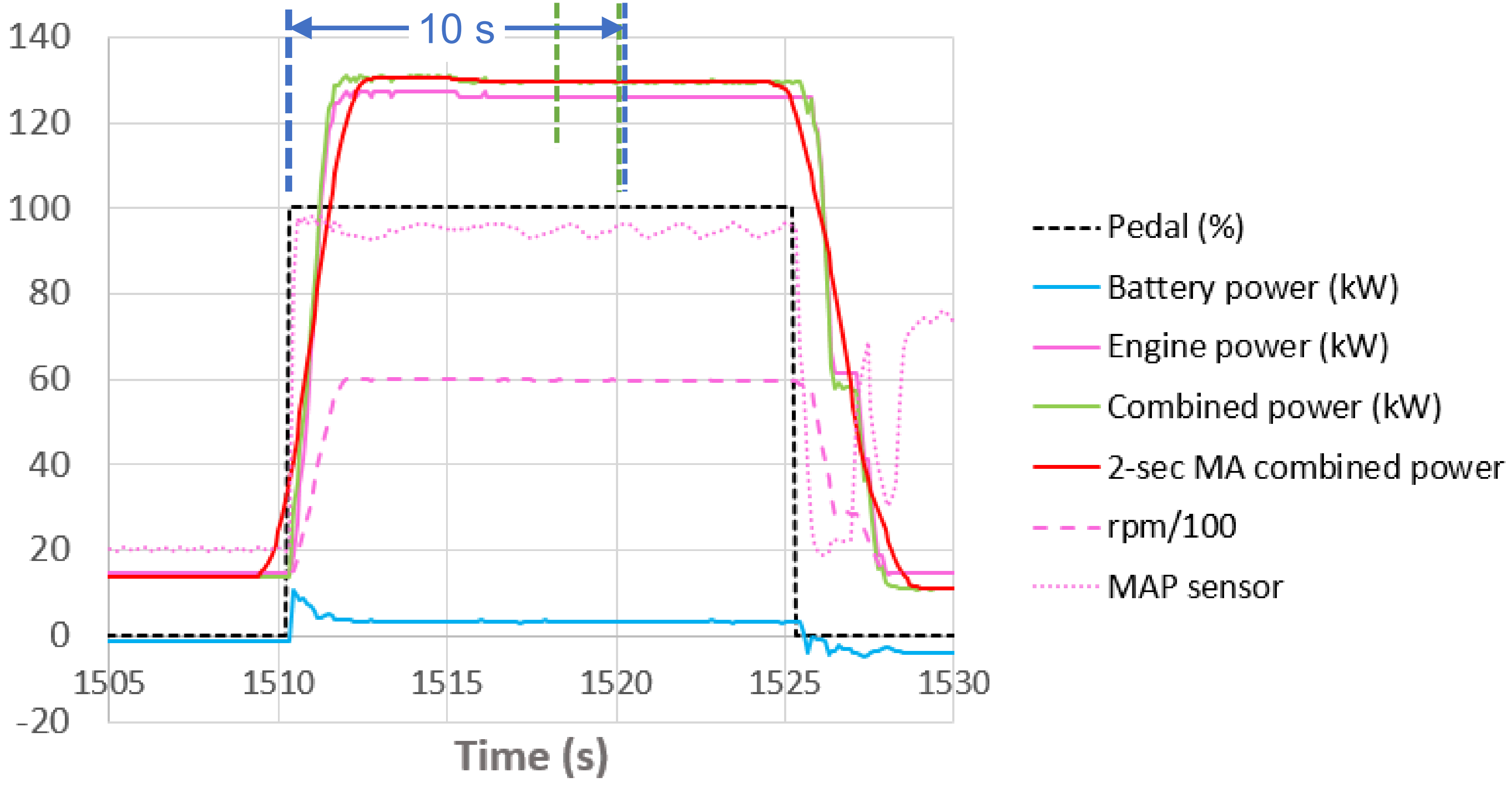
$$P_{HEV\ system}\ [kW] = \frac{P_{wheels}}{K2}$$

Default = 0.91 to 0.98

K2 is efficiency of transmission/gearbox during vehicle max power

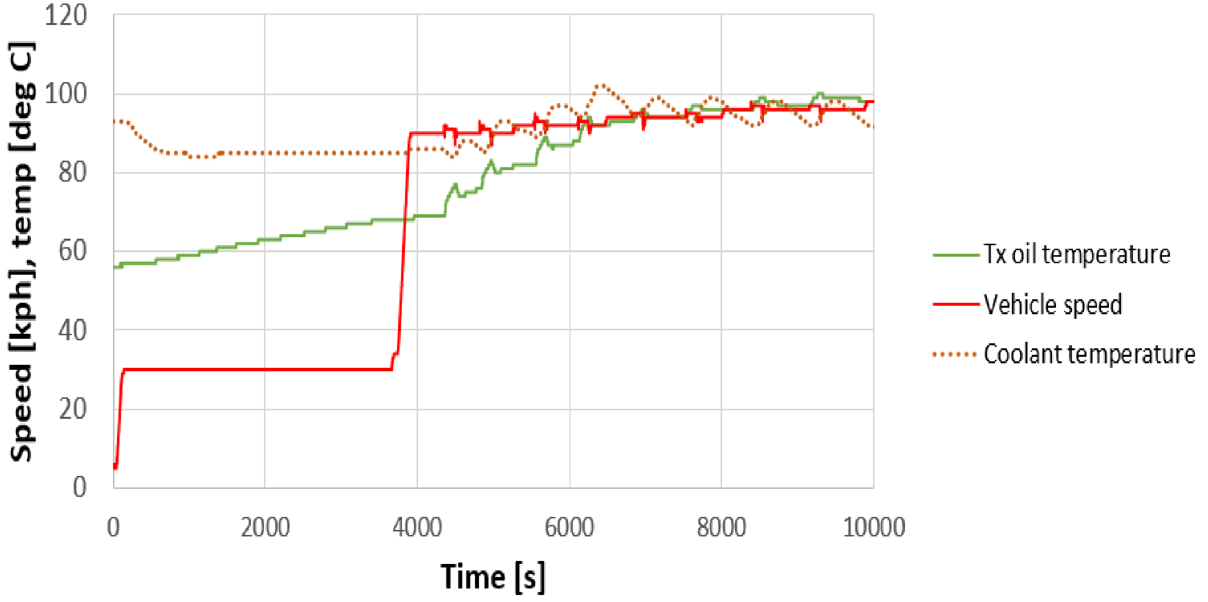
Peak power = maximum of 2-sec moving average during 1st 10 seconds

Sustained power = average power between 8th and 10th second

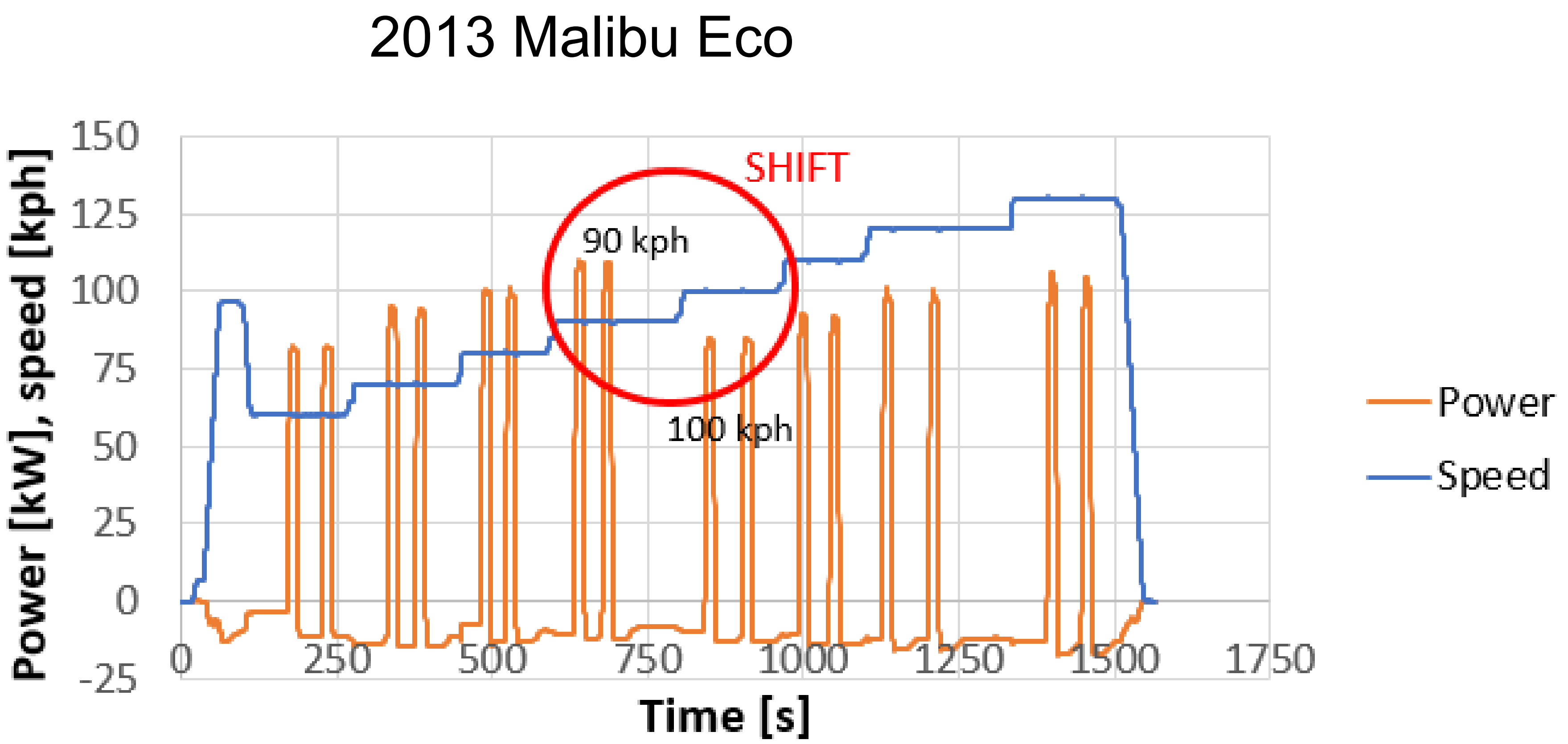


Results: Conditioning cycle

- Was adequate for most components to reach operating temperature
- Transmission oil temperature continued to rise
- Propose longer conditioning time, monitoring of temperature, or segmenting the test



Results: Identifying speed of maximum power



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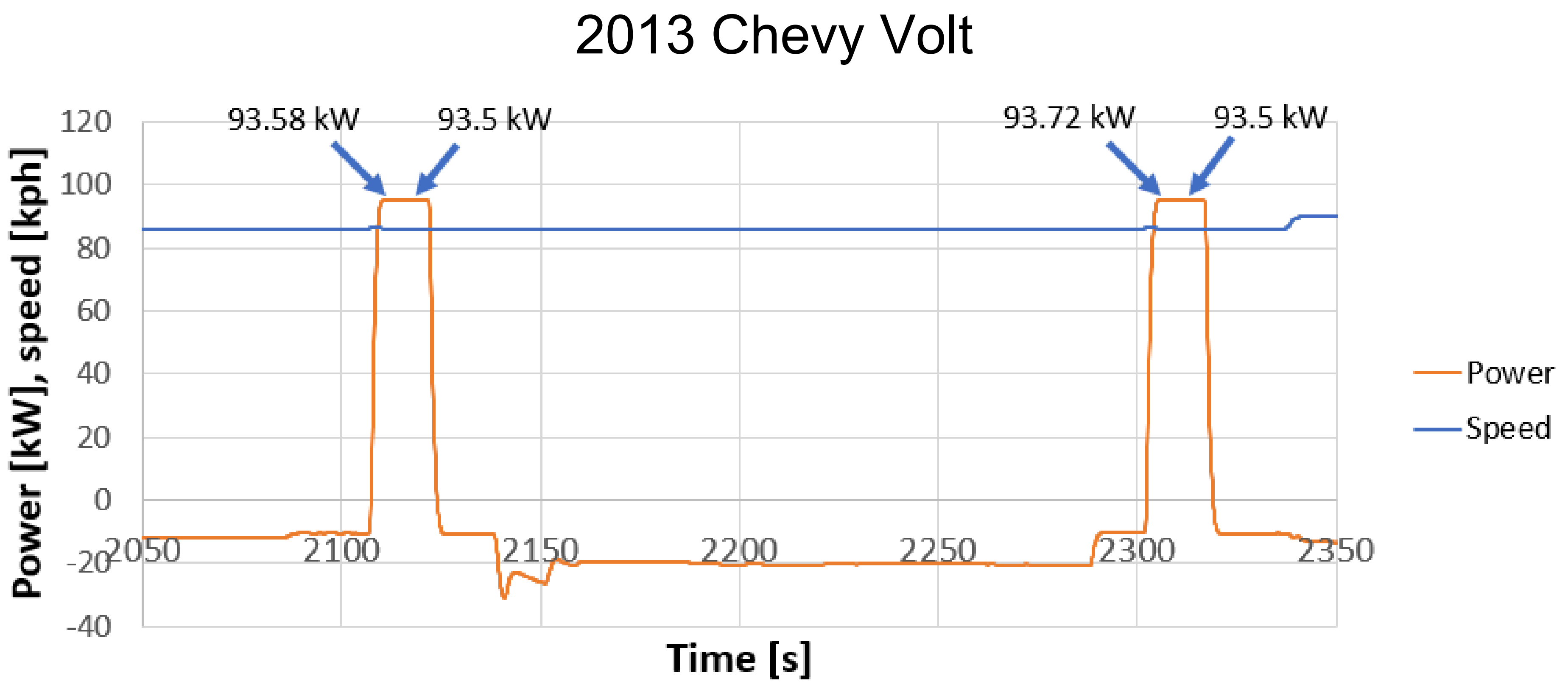

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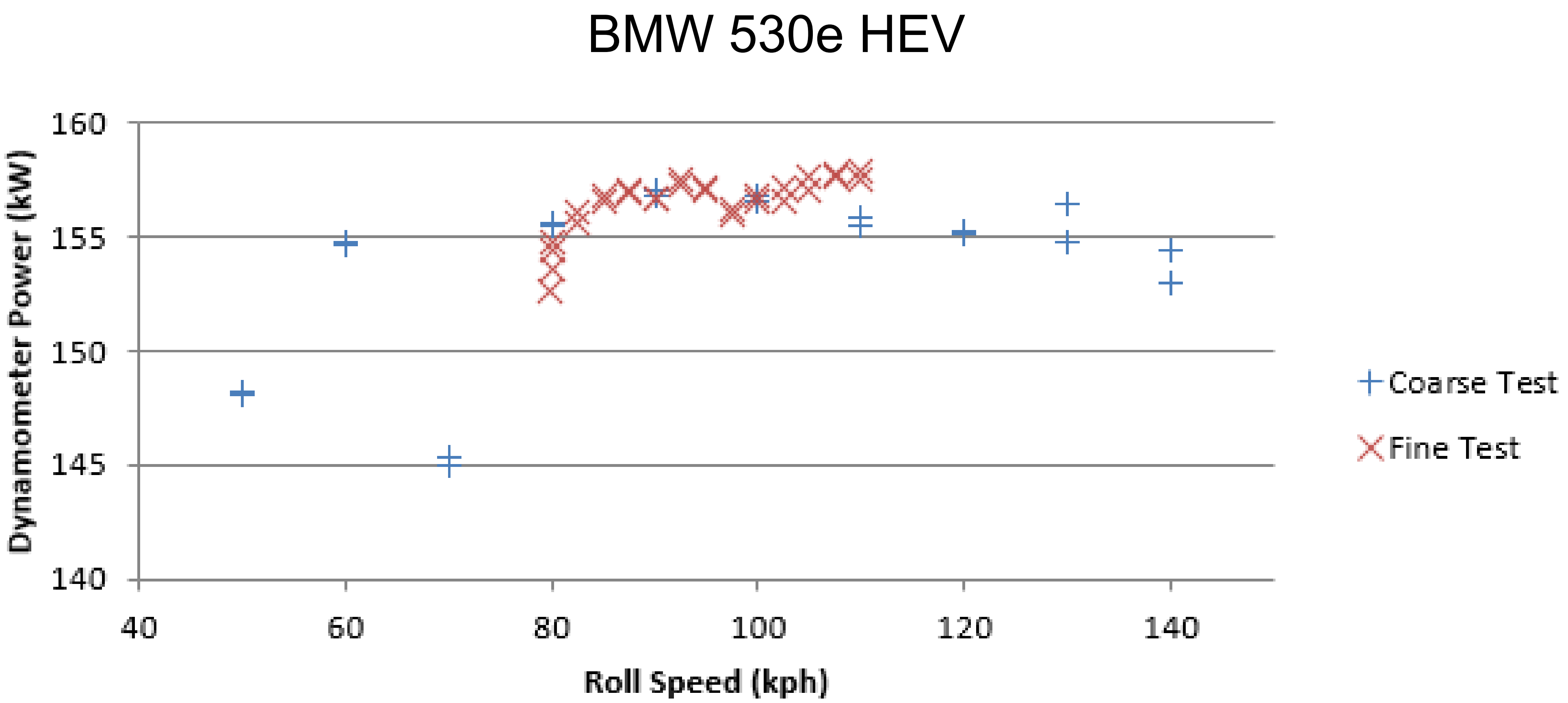

Results: Difference between TP1 and TP2

2013 Malibu Eco

	Peak power			Sustained power		
	TP1	TP2	Difference	TP1	TP2	Difference
First pulse	130.73 kW	121.07 kW	-9.66 kW	129.57 kW	120.15 kW	-9.42 kW
Second pulse	130.04 kW	119.87 kW	-10.17 kW	129.54 kW	118.99 kW	-10.55 kW
Difference	-0.69 kW	-1.2 kW		-0.03 kW	-1.16 kW	

2013 Chevy Volt

	Peak power			Sustained power		
	TP1	TP2	Difference	TP1	TP2	Difference
First pulse	94.31 kW	103.29 kW	+8.98 kW	92.91 kW	101.00 kW	+8.09 kW
Second pulse	93.21 kW	102.31 kW	+9.10 kW	92.67 kW	101.19 kW	+8.51 kW
Difference	-1.10 kW	-0.98 kW		-0.24 kW	+0.18 kW	

Downstream efficiency check

- No matter which TP, we know power at wheels (from dyno rolls)
- We can compare the computed TP value to the power at wheels
  - Suppose result = 100 kW, and 90 kW was measured at rolls
  - Implied downstream efficiency (IDE) = 90 / 100 = 90%

	Sustained		
	TP1	TP2	Difference
First pulse	87.0%	93.8%	+6.8
Second pulse	86.2%	93.8%	+7.6
Difference	-0.8	0.0	

Implied downstream efficiency, 2013 Malibu Eco

TP1 result was smaller than power measured at wheels

	Sustained		
	TP1	TP2	Difference
First pulse	103.7%	95.4%	-8.3
Second pulse	104.1%	95.4%	-8.7
Difference	+0.4	0.0	

Implied downstream efficiency, 2013 Chevy Volt

Role of default K factors

- Draft procedure provides default K factors as backup
  - Default K1 = 0.85 for all electric machines
  - Default K2 = 0.91 to 0.98 depending on gearbox type
- Result is sensitive to accuracy of the K factor with respect to the vehicle being tested
- If the respective K factors for TP1 and TP2 are not comparably accurate, TP1 and TP2 are likely to vary
- EVE IWG is considering elimination of default values in favor of verifiable manufacturer-supplied values

Accounting for tire losses in TP2

- Draft procedure allows collecting torque and speed from dyno rollers
- It does not specify how to account for tire losses (Crr) or slippage
- Losses can be estimated, but normal force is often unknown when vehicle is installed on the dyno
- Torque and speed meters, or hub dyno, will remove this uncertainty
- EVE IWG is planning to eliminate use of dyno rollers as an option

Areas for improvement

- A difference between TP1 and TP2 is undesirable
  - Use of default K factors contributes in an unpredictable way
  - Use of dyno roller data for TP2 leads to uncertainty and variation
- Internal validation and reality checks needed
  - How to verify supplied K factors, particularly for gearbox
  - Solving for K by setting TP1 = TP2 can provide a reality check
- Novel hybrid architectures require additional care
  - TP1 and TP2 are comparable for simple parallel hybrids
  - Other architectures where power flow follows separate paths to the destination will need additional K factors and instrumentation

Summary and conclusions

- US, Canada, and European Commission JRC have tested 11 hybrid electric vehicles and applied the draft procedure
  - Areas of ambiguity have been identified and clarified
  - Difference between TP1 and TP2 observed and sources identified
- The EVE IWG continues its work to develop the procedure
  - Minimize or eliminate the difference between TP1 and TP2
  - Continue to validate the evolving procedure by testing additional vehicles and novel hybrid configurations