Power Determination Validation Program

Observations for Discussion

EVE teleconference

February 13, 2019

Vehicles tested at EPA

- 2013 Chevy Volt
  - Series PHEV
  - Power split gearbox
  - Tested in all-electric mode (engine off)
- 2013 Malibu Eco
  - BAS hybrid
  - 6-speed automatic transmission
  - Engine power (136 kW) >> motor power (11 kW)
- Difference in power sources may highlight difference in ability of each TP to represent power of engine and power of motor

Identifying maximum power

- The test procedure suggests cycling through a series of fixed speeds on the dynamometer
- EPA testing encountered no difficulties in identifying the speed of maximum power by this method
- Malibu Eco shift point made it easy to find the maximum power
- Chevy Volt power curve was very flat
- Maximum power was stable and repeatable for both vehicles

TP1 vs TP2 - 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	

	Sustained	
	TP1	TP2
First pulse	87.0%	93.8%
Second pulse	86.2%	93.8%

Implied downstream efficiency

TP1 vs TP2 – 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	

	Sustained	
	TP1	TP2
First pulse	103.7%	95.4%
Second pulse	104.1%	95.4%

Implied downstream efficiency

TP1 and TP2 comparison

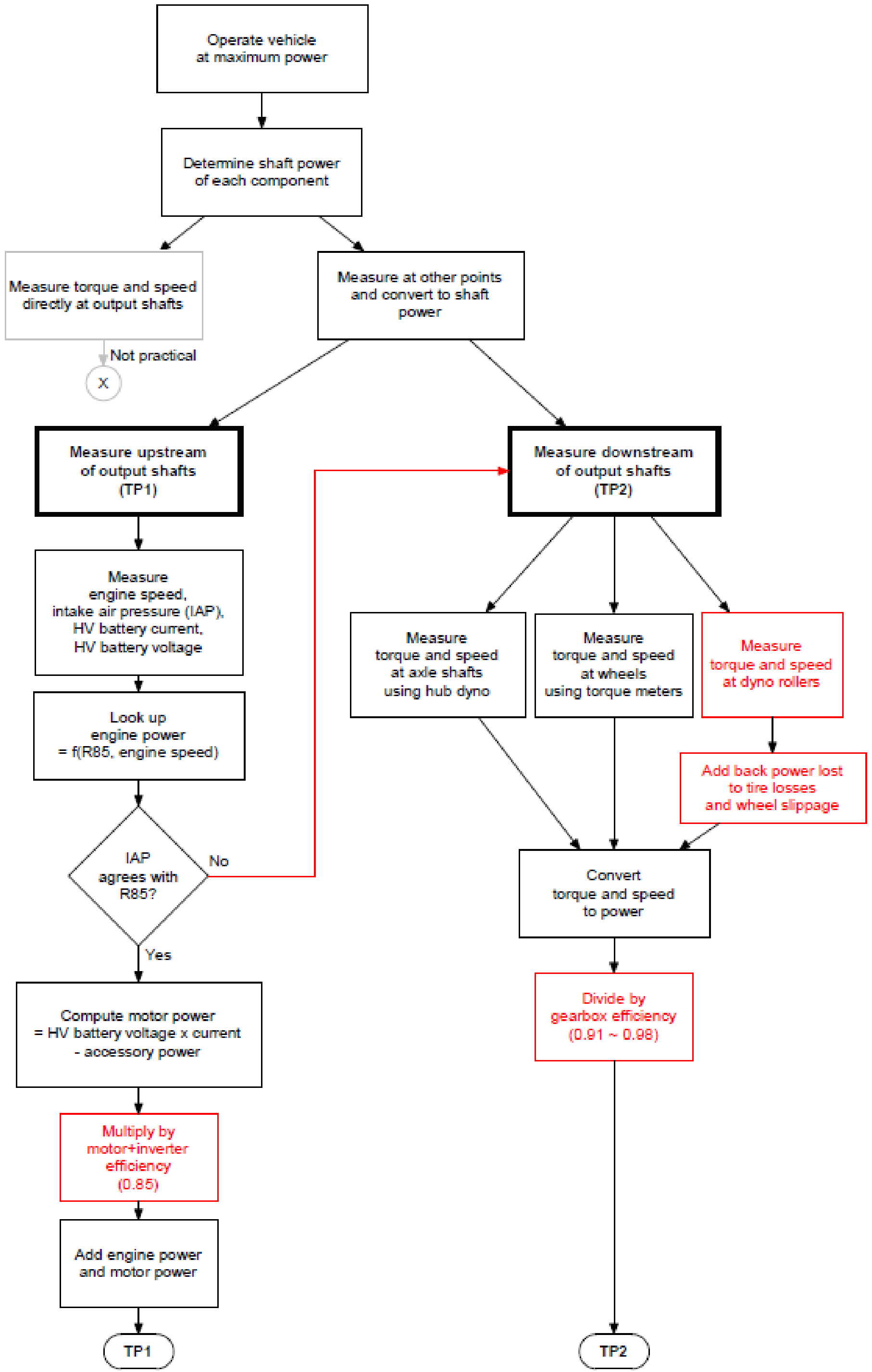
- For both vehicles, results of TP1 and TP2 vary by about 10%
- Variation is not consistent
  - For Chevy Volt, TP1 returns a lower power than TP2
  - For Malibu Eco, TP1 returns a higher power than TP2
- This suggests a differential sensitivity of each TP to specific hybrid architectures
- There are also variations in TP2 resulting from use of dyno roller torque with uncertain correction for tire losses and slippage

Background on the measurement problem

- For comparability with ICE, hybrid vehicle power is to be measured at a similar point in the powertrain: the engine output shaft
  - Not at the wheels
  - Not at the battery
- But with a hybrid vehicle that has more than one power source, max power on test stand is <u>not necessarily</u> same as on vehicle
  - Depends on how motor and engine power are combined during maximum acceleration
  - Battery may limit power instead of motor
- Therefore, we cannot rely on component rated power
- The power must be measured while in operation on the vehicle

Background on the measurement problem

- To measure power on the vehicle:
  1. Need way to repeatably elicit maximum power of the vehicle
     - We do this by max acceleration at a fixed speed of the dyno
     - Seems reliable so far (except for some JRC tests)
  2. Need way to measure the power from each component
     - (a) Measure torque and speed at the output shafts
       - Invasive, costly, may be impractical or impossible
       - Not suitable for type approval situation
     - (b) Measure at more convenient points, and convert to shaft power
       - (b1) Measure upstream of the output shafts (TP1)
       - (b2) Measure downstream of the output shafts (TP2)


Operate vehicle at maximum power
Determine shaft power of each component
Measure torque and speed directly at output shafts
Not practical
X
Measure at other points and convert to shaft power
Measure upstream of output shafts (TP1)
Measure downstream of output shafts (TP2)
Measure engine speed, intake air pressure (IAP), HV battery current, HV battery voltage
Look up engine power = f(R85, engine speed)
IAP agrees with R85?
No
Yes
Compute motor power = HV battery voltage x current - accessory power
Multiply by motor+inverter efficiency (0.85)
Add engine power and motor power
TP1
Measure torque and speed at axle shafts using hub dyno
Measure torque and speed at wheels using torque meters
Measure torque and speed at dyno rollers
Add back power lost to tire losses and wheel slippage
Convert torque and speed to power
Divide by gearbox efficiency (0.91 ~ 0.98)
TP2

Observations

- In theory, both TP1 and TP2 should deliver the same results
- However, for this to be true, the respective K factors must be accurate
- The default K factors are rarely accurate for any specific vehicle (only coincidentally)
- Without accurate K factor for both TP1 and TP2, we should not expect the two results to be the same for any specific vehicle
- If the results are not the same, cherry picking becomes possible

Possible directions

A. Accept the variation as is
B. Tighten up the causes of the variation
    A. Provide more specific default K factors
    B. Limit TP2 measurement options
C. Eliminate default K factors and require verified K from manufacturer
D. Allow default K, but for "provisional" ratings only
E. Limit GTR to only TP1 or only TP2
F. Delegate the decision to the legislation that references the procedure (next slide)
G. Others?

Delegate to the referencing legislation?

- Draft the GTR more or less as currently defined. Drafting task becomes a codification of the ISO procedure (aligned to WLTP)
- Acknowledge in the GTR that TP1 and TP2 may deliver different results
  - Depending on accuracy of the K factors
  - Depending on TP2 measurement options
  - Designate calculations that utilize default K as “provisional” rating
  - Designate calculations that utilize measured K as “reference” rating
- Recommend that the referencing legislation specify how to navigate the uncertainty, appropriate to the specific aim of the legislation
- For example, GTR 15 could specify (options):
  - A. Perform provisional TP1 and TP2, and take the larger (or average?) of the two
  - B. Perform reference TP1 and TP2, and take the larger (or average?) of the two
  - C. Perform provisional TP1, unless R85 does not validate, then perform provisional TP2
  - D. etc
- Legislation for taxation or consumer information could specify differently

Backup slides

TP1 procedure

- Inputs:
  - R85 engine power results (speed vs. power, and intake manifold pressure)
  - Battery current and voltage
  - K factor (default 0.85) representing motor and inverter efficiency
- Conditions specific to EPA validation tests:
  - No R85 results available for the Malibu Eco or Chevy Volt engine
  - For Malibu Eco, EPA test data for similar engine was substituted for R85
  - Chevy Volt was tested in all-electric mode (no R85 needed)
  - Battery current and voltage taken from CAN bus in both cases

TP2 procedure

- Inputs:
  - Torque and speed measured at a point past gearbox
    - Options: Hub dyno, or 6-axis wheel torque sensors, or dyno rollers
  - K factor representing gearbox efficiency
- Conditions specific to EPA validation tests:
  - Torque and speed measured at dyno rollers (only available option)
  - This requires accounting for tire losses and slippage
  - Tire losses approximated by Crr and normal force
  - Slippage observed but not accounted for

TP1 basis: Measure upstream of output shafts

- For engine shaft power:
  - Measure speed, intake manifold pressure, fuel flow rate
  - Use R85 results to convert speed to output power (assuming WOT)
  - Verify WOT by comparing measured intake manifold pressure and/or fuel flow rate to that observed in R85 results
  - If correction for altitude needed, apply designated correction
- For motor shaft power:
  - Measure battery current and voltage = motor input power
  - Multiply by motor and inverter efficiency to yield motor output power
- Vulnerabilities:
  - TP1 fails if R85 engine power fails to be verified by intake manifold pressure
    - Not operating at WOT
  - Engine power at output shaft might split off to generator, reducing power to wheels
  - Motor and inverter efficiency must be accurate

TP2 basis: Measure downstream of shafts

- For combined shaft power:
  - Measure power past gearbox. Options:
    - (1) Measure at axle shafts using hub dyno
    - (2) Measure at wheels using properly calibrated 6-axis torque meters
    - (3) Measure at dyno rollers and correct for tire losses and wheel slippage
  - Divide by gearbox efficiency to yield combined output power
  - If correction for altitude needed:
    - Use measured battery current and voltage to derive motor power
    - Subtract motor power and apply correction to the difference
- Vulnerabilities:
  - Gearbox efficiency must be accurate (also, can be affected by temperature)
  - If correction for altitude needed, motor and inverter efficiency also must be accurate
  - Having three options for measuring power can lead to variability