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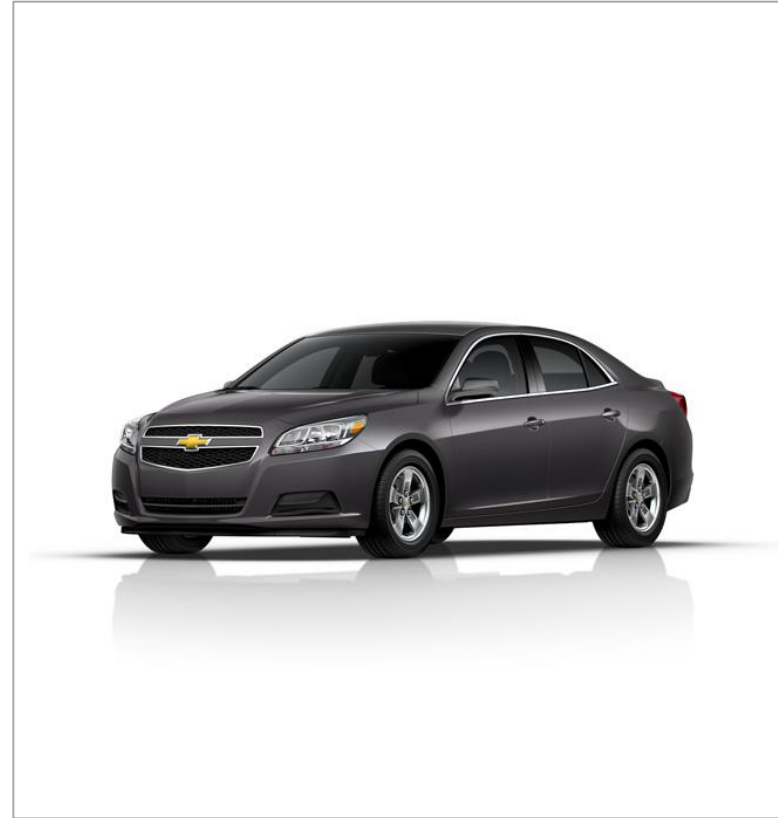
# EPA Benchmarking

2013 Chevrolet Malibu, 2.5L [LCV] I4 GDI

6T40 Transmission Benchmark

Contract No. EP-C-12-014, Work Assignment 1-5

April 30th, 2013



# **Chevrolet Malibu 6-Speed AT – Benchmark Project Overview**

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Contract No. EP-C-12-014, Work Assignment 1-5  
April 30, 2013

- 1. Transmission Specifications**
- 2. Vehicle Shift Map Evaluation**
- 3. Transmission Test Setup**
- 4. Transmission Loaded Efficiency**
- 5. Transmission Spin Loss**
- 6. Transmission Torque Converter Efficiency**

# Chevrolet Malibu 6-Speed AT – Benchmark

## Transmission Information (Manufacturer Specifications)

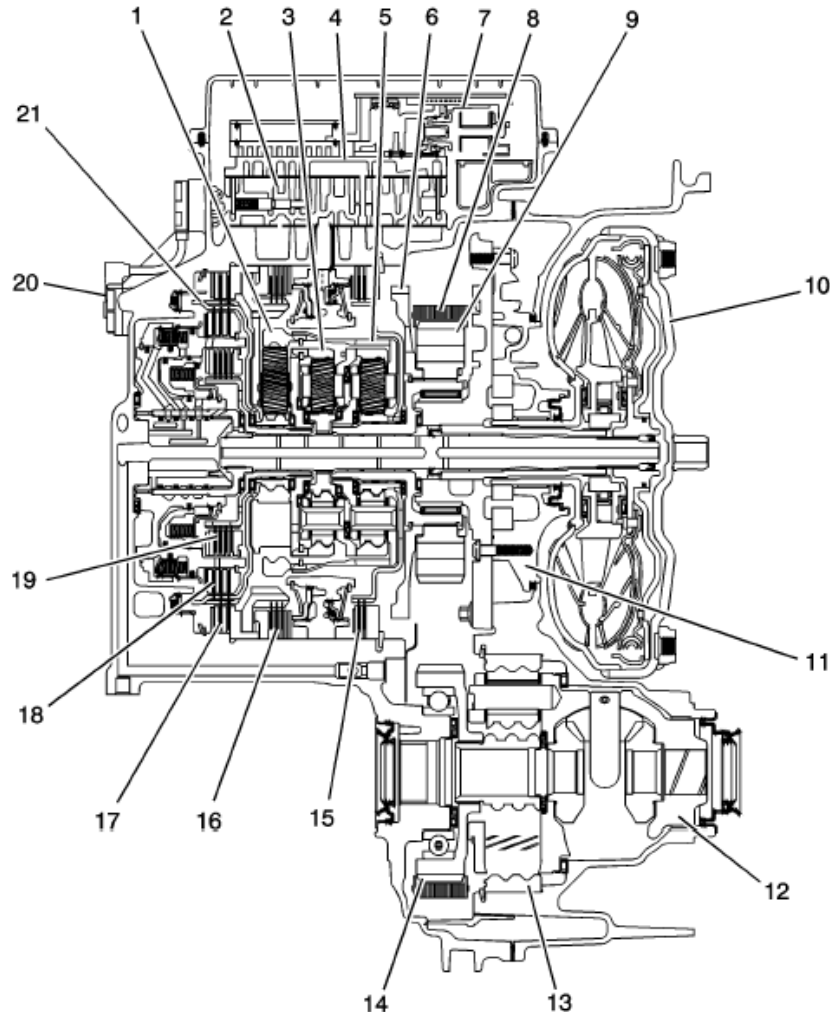
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Contract No. EP-C-12-014, Work Assignment 1-5  
April 30, 2013

■ Transmission Model:	GM6T40 (MH8)
■ Maximum Engine Power/Torque:	134 kW / 240 Nm
■ Transmission Weight:	82 kg (wet)
■ Fluid Capacity (DEXRON VI):	7.77 L
■ Transfer Design:	3-axes; output chain
■ Gear Ratios:	4.58; 2.96; 1.91; 1.45; 1; 0.75; -2.94 FR: 2.89
■ Ratio spread:	6.1
■ Vehicle Application:	2013 Chevrolet Malibu

# Chevrolet Malibu 6-Speed AT – Benchmark Transmission Information (Manufacturer Specifications)

Contract No. EP-C-12-014, Work Assignment 1-5  
April 30, 2013



- (1) Reaction Carrier Assembly
- (2) Control Valve Body Assembly
- (3) Input Carrier Assembly
- (4) Valve Channel Plate
- (5) Output Carrier Assembly
- (6) Park Gear
- (7) Control Solenoid (w/Body and TCM) Valve Assembly
- (8) Drive Link Assembly
- (9) Drive Sprocket
- (10) Torque Converter Assembly
- (11) A/Trans Fluid Pump Assembly
- (12) Differential Carrier Assembly
- (13) Front Differential Ring Gear
- (14) Driven Sprocket
- (15) 1-2-3-4 Clutch Assembly
- (16) Low and Reverse Clutch Assembly
- (17) 2-6 Clutch Assembly
- (18) 3-5 Reverse Clutch Assembly
- (19) 4-5-6 Clutch Assembly
- (20) A/Trans Input Speed Sensor Assembly
- (21) Reaction Sun Gear Assembly

# Chevrolet Malibu 6-Speed AT – Benchmark Vehicle Testing – Shift Map Evaluation

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Contract No. EP-C-12-014, Work Assignment 1-5  
April 30, 2013



## 2. Vehicle Shift Map

### ■ Upshift

- Conducted on level road (proving grounds)
- Upshifts have been recorded for the following gas pedal positions
  - 0 – 10 % in 2.5% increments
  - 10 – 40 % in 10% increments
  - 40- 100 % in 20% increments
  - No kick-down button in vehicle

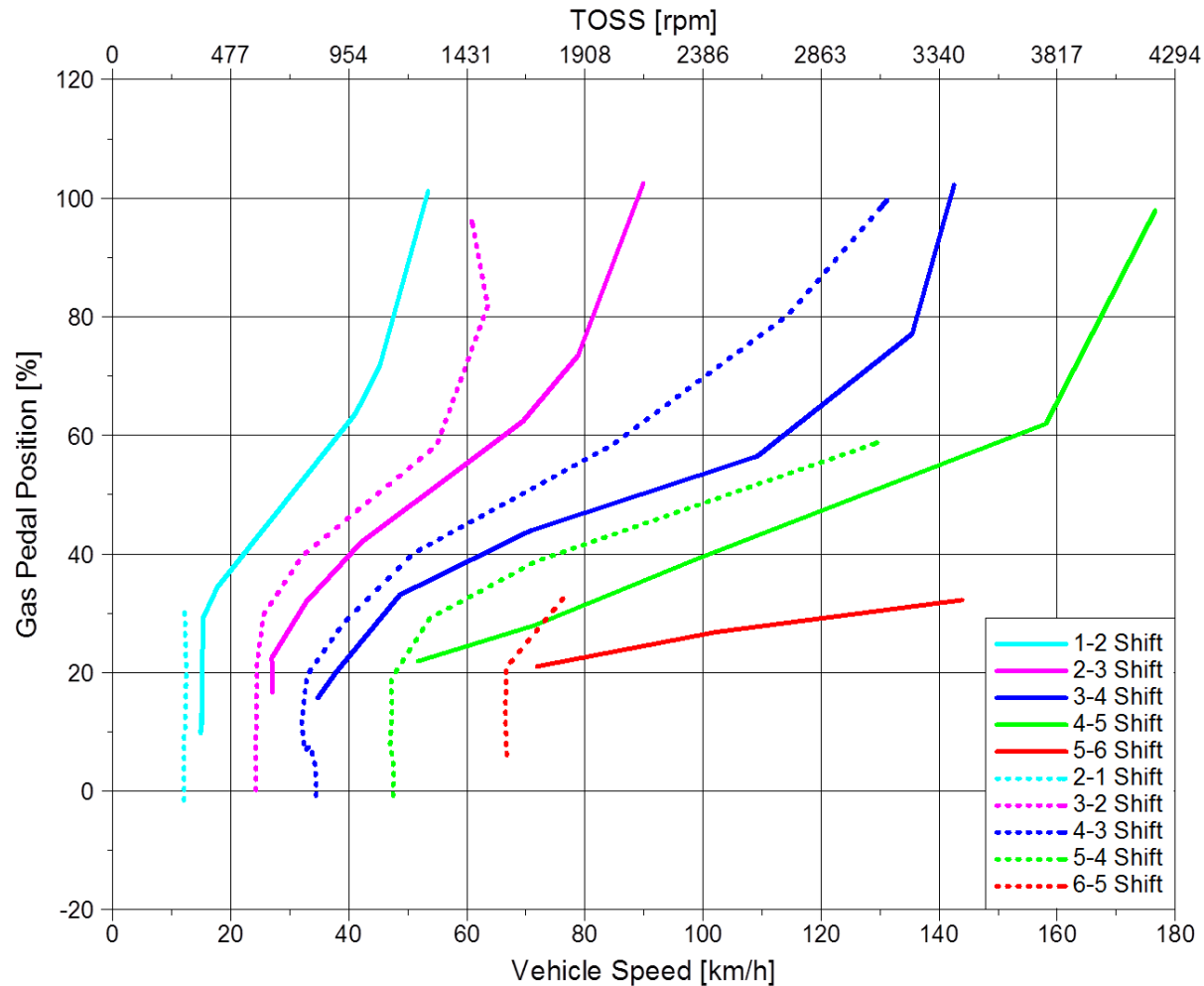
### ■ Downshift

- Conducted on chassis dyno at FEV
- Downshifts have been recorded for the same pedal positions as upshifts
- After highest gear (for actual pedal position) was reached, chassis dyno decelerated vehicle over 30s to 0 km/h

# Chevrolet Malibu 6-Speed AT – Benchmark Vehicle Testing – Shift Map Evaluation

Contract No. EP-C-12-014, Work Assignment 1-5  
April 30, 2013

*2013 Chevrolet Malibu - Transmission Shift Map 6T40*



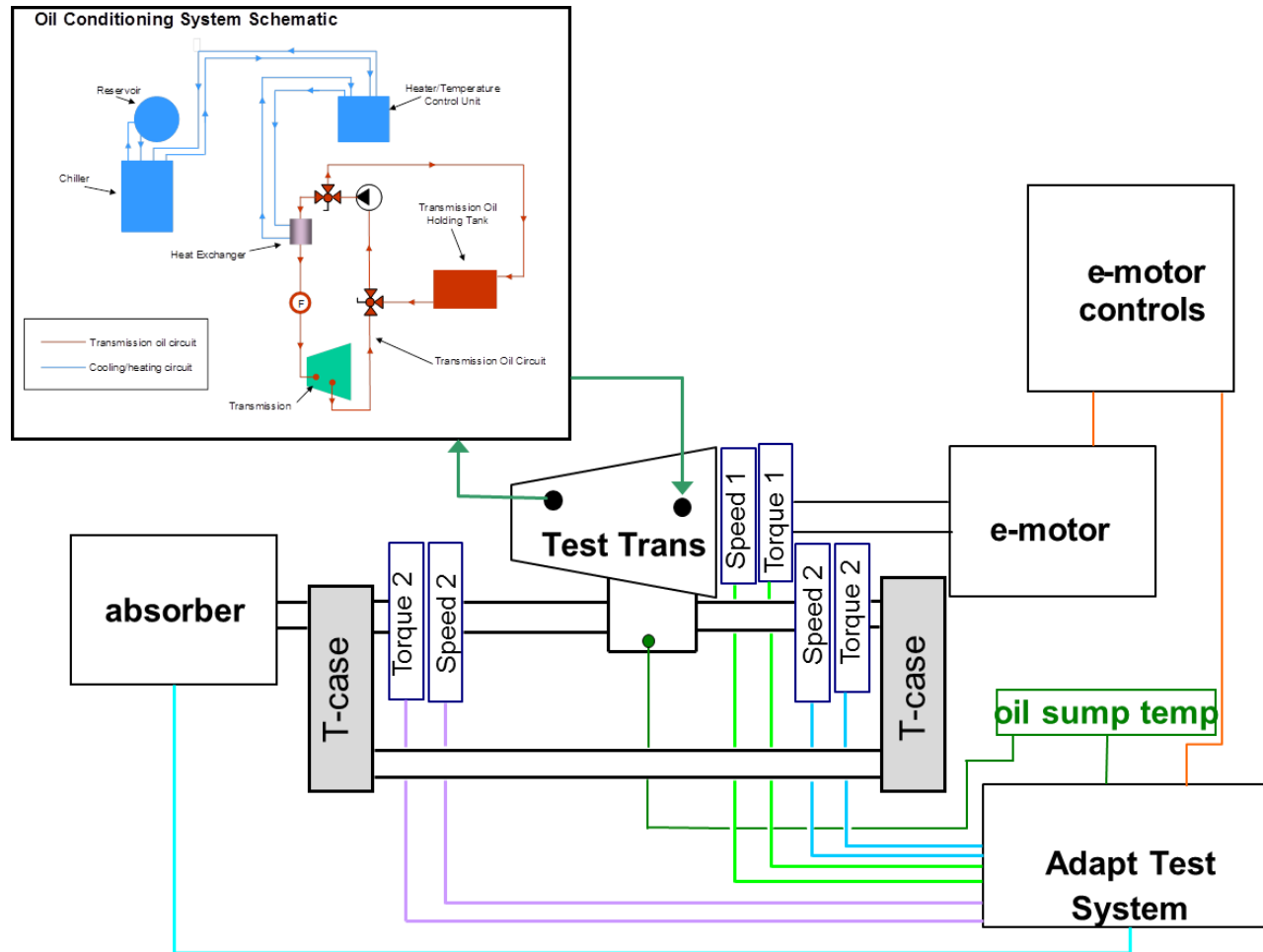
TOSS signal has been calculated from vehicle speed [km/h] using factor 23.86. The factor has been verified on several different data sets that contain TISS signal => very good correlation between TOSS calculated from TISS and TOSS calculated from vehicle speed using factor 23.86.

# Chevrolet Malibu 6-Speed AT – Benchmark Transmission Testing – Test Setup

Contract No. EP-C-12-014, Work Assignment 1-5  
April 30, 2013

## 3. Transmission Test Setup

- Transmission set up on FWD test stand - schematic

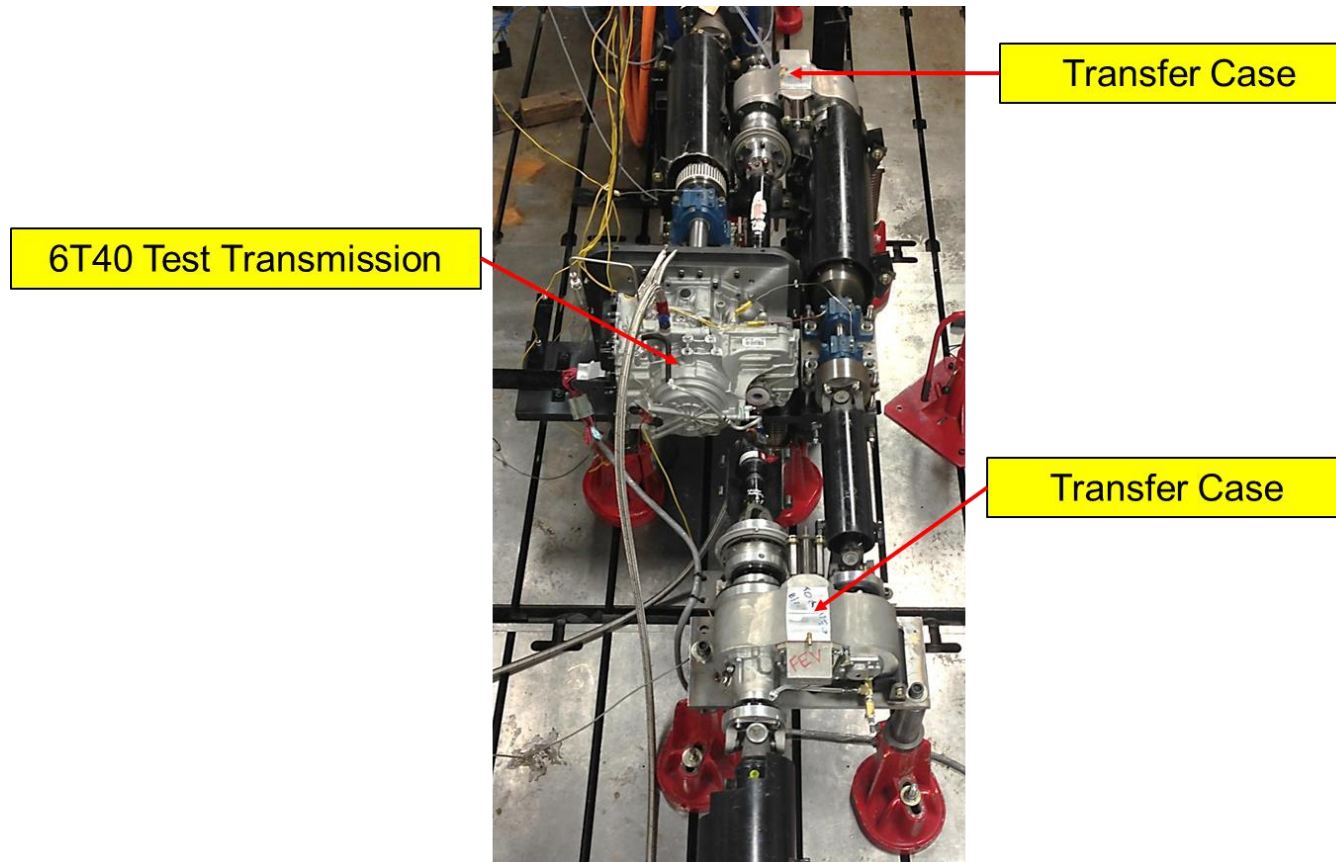


# Chevrolet Malibu 6-Speed AT – Benchmark Transmission Testing – Test Setup

Contract No. EP-C-12-014, Work Assignment 1-5  
April 30, 2013

## 3. Transmission Test Setup

- Transmission set up on FWD test stand





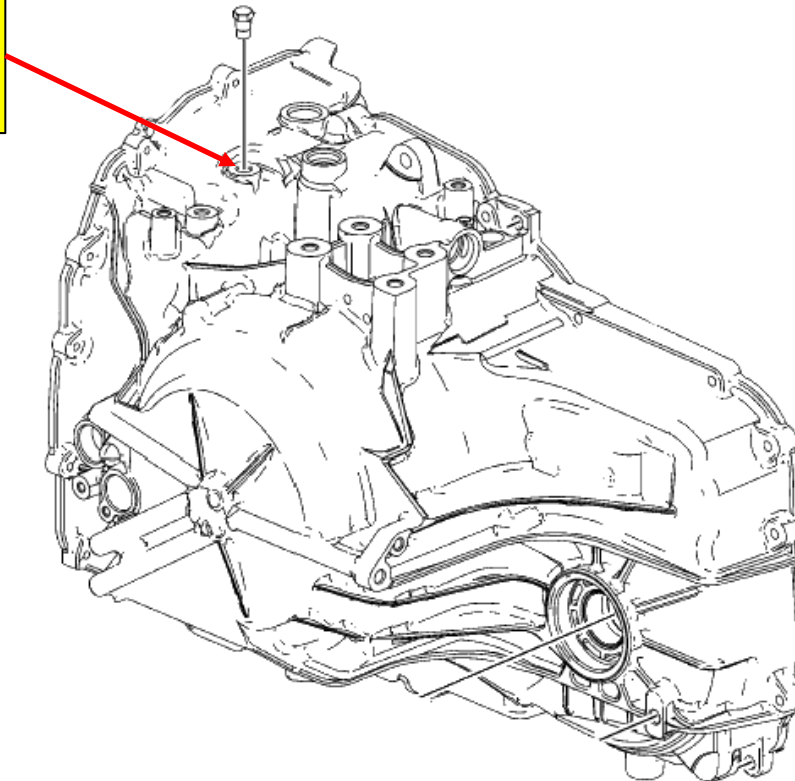
# Chevrolet Malibu 6-Speed AT – Benchmark Transmission Testing – Test Setup

Contract No. EP-C-12-014, Work Assignment 1-5  
April 30, 2013

## 3. Transmission Test Setup

- Main line pressure reading

FEV to add pressure sensor to this port for feedback to control line pressure during testing

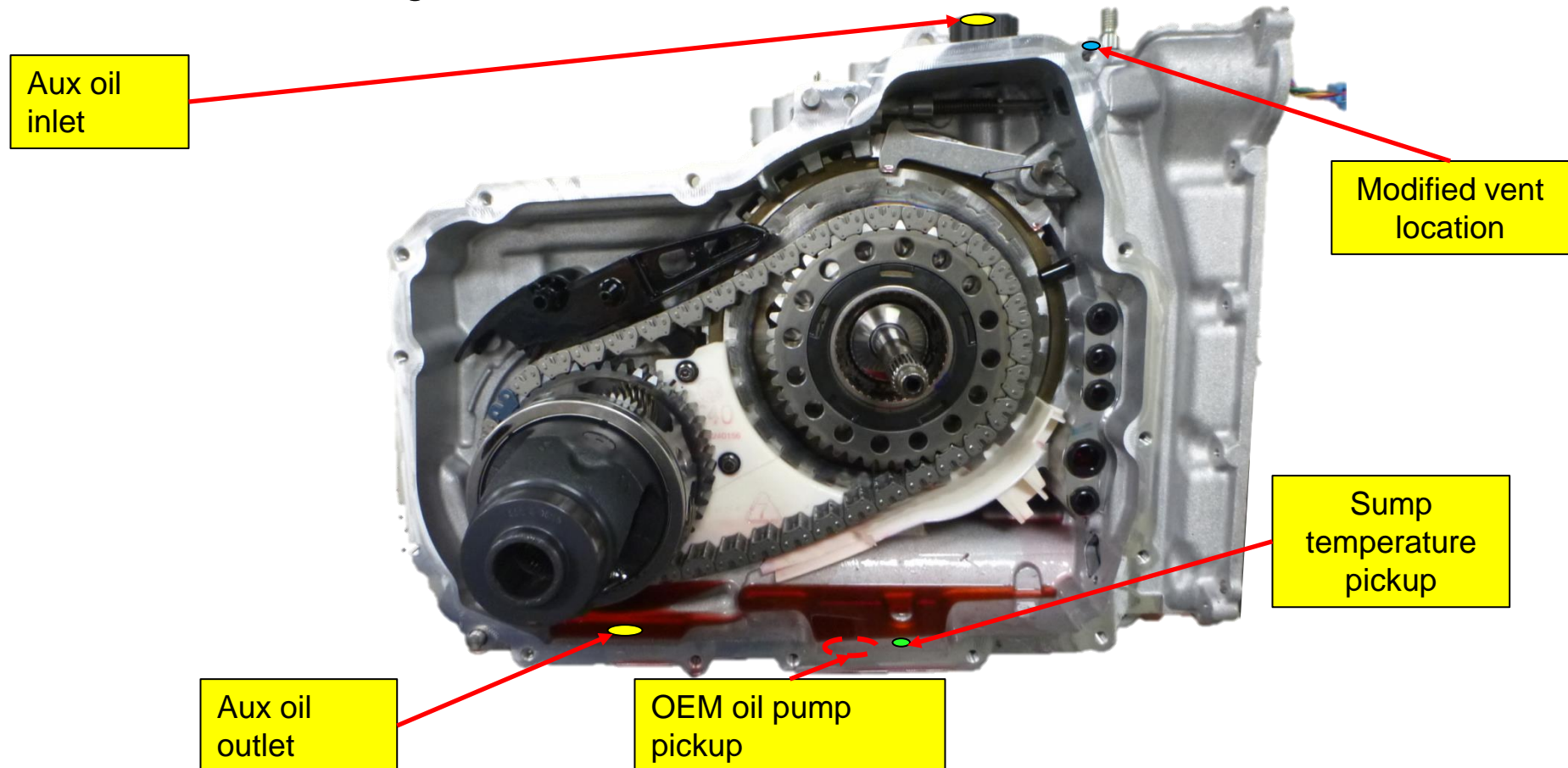


# Chevrolet Malibu 6-Speed AT – Benchmark Transmission Testing – Test Setup

Contract No. EP-C-12-014, Work Assignment 1-5  
April 30, 2013

## 3. Transmission Test Setup

### ■ Oil conditioning

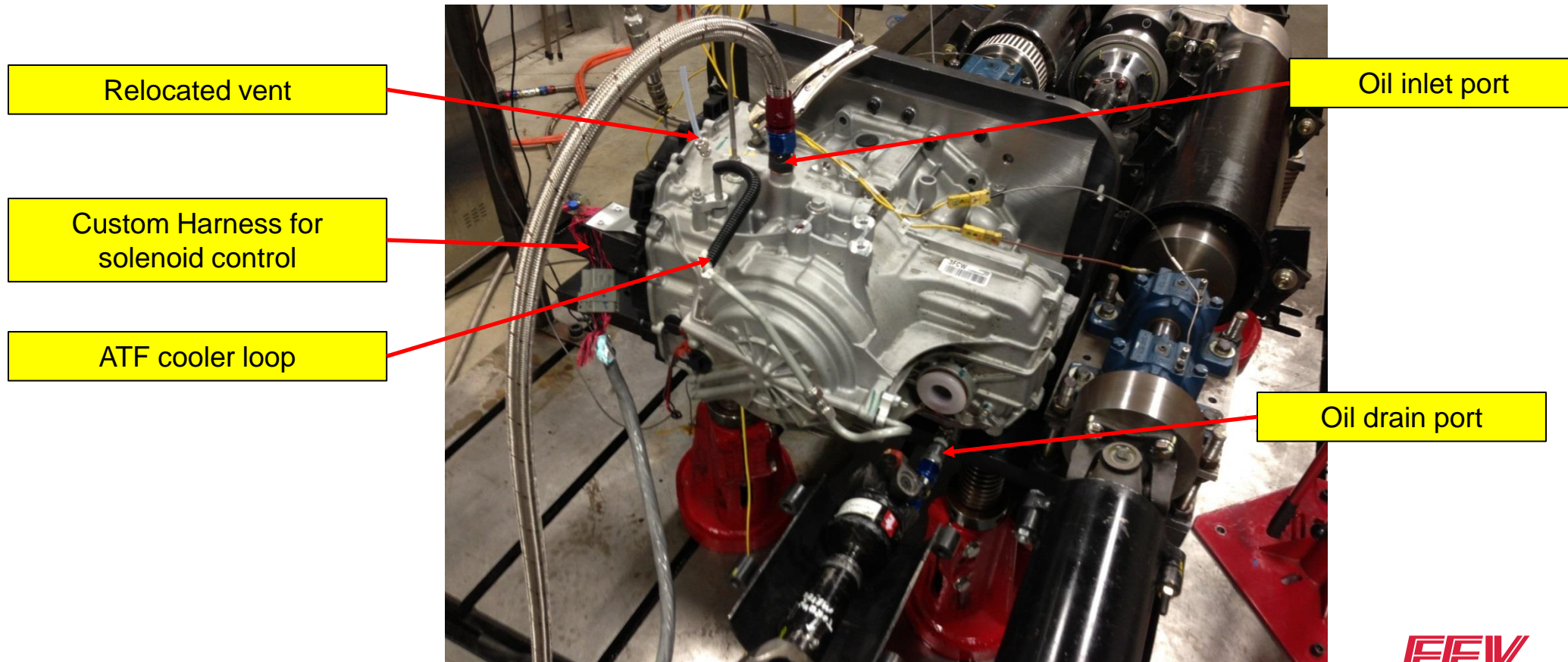


# Chevrolet Malibu 6-Speed AT – Benchmark Transmission Testing – Test Setup

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April 30, 2013

## 3. Transmission Test Setup

### ■ Oil conditioning



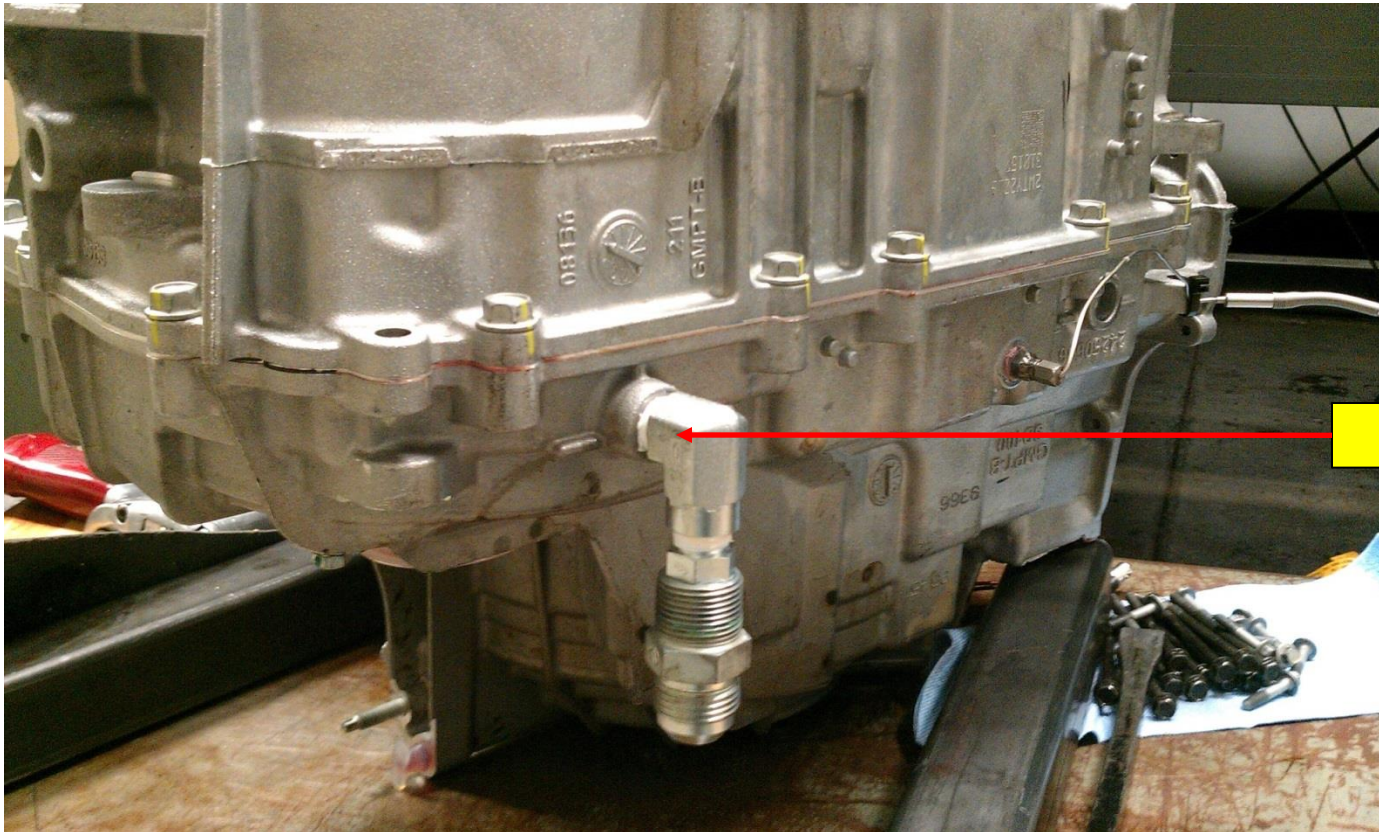


# Chevrolet Malibu 6-Speed AT – Benchmark Transmission Testing – Test Setup

Contract No. EP-C-12-014, Work Assignment 1-5  
April 30, 2013

## 3. Transmission Test Setup

### ■ Oil conditioning



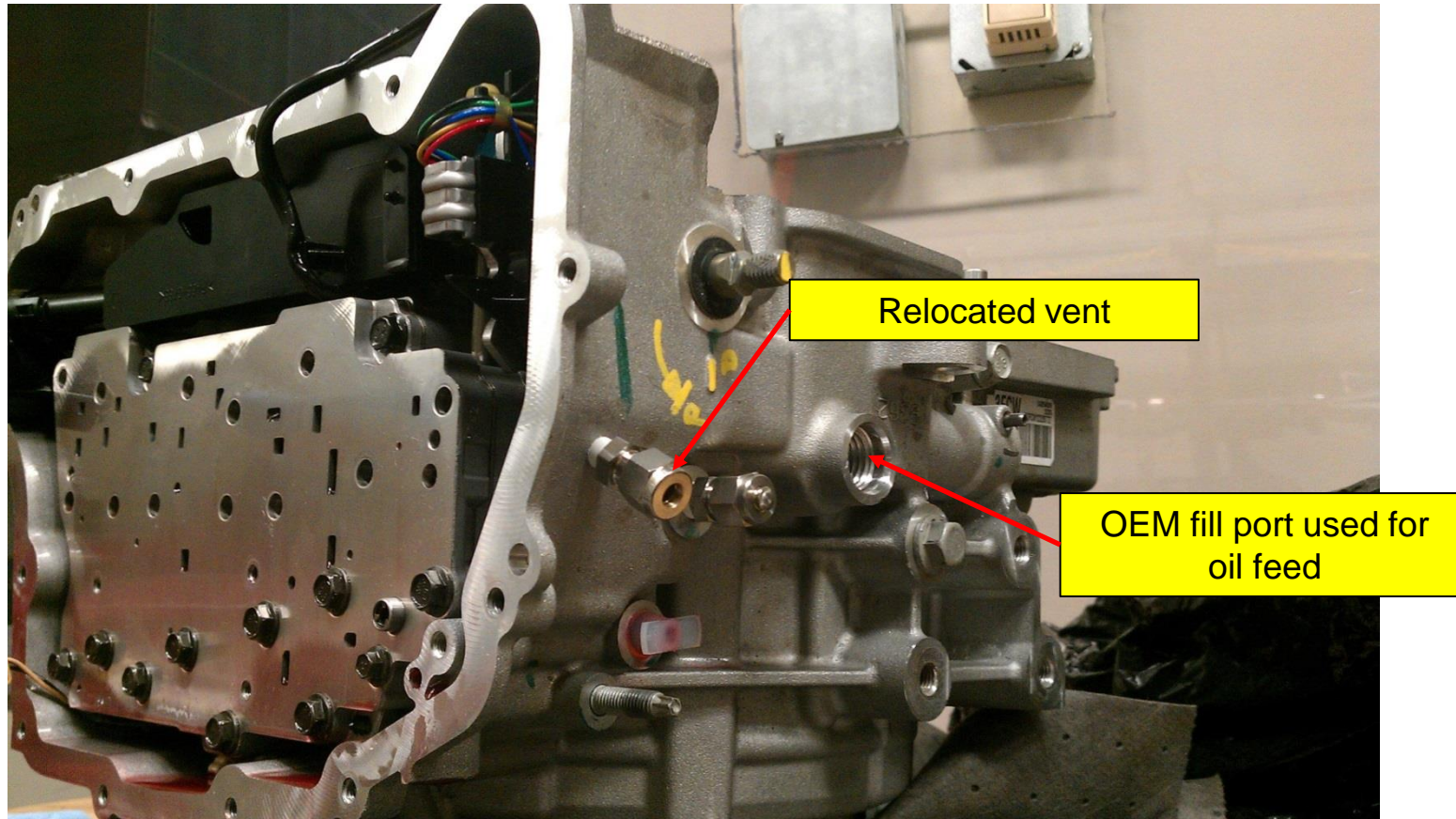
Oil drain port

# Chevrolet Malibu 6-Speed AT – Benchmark Transmission Testing – Test Setup

Contract No. EP-C-12-014, Work Assignment 1-5  
April 30, 2013

## 3. Transmission Test Setup

### ■ Oil conditioning

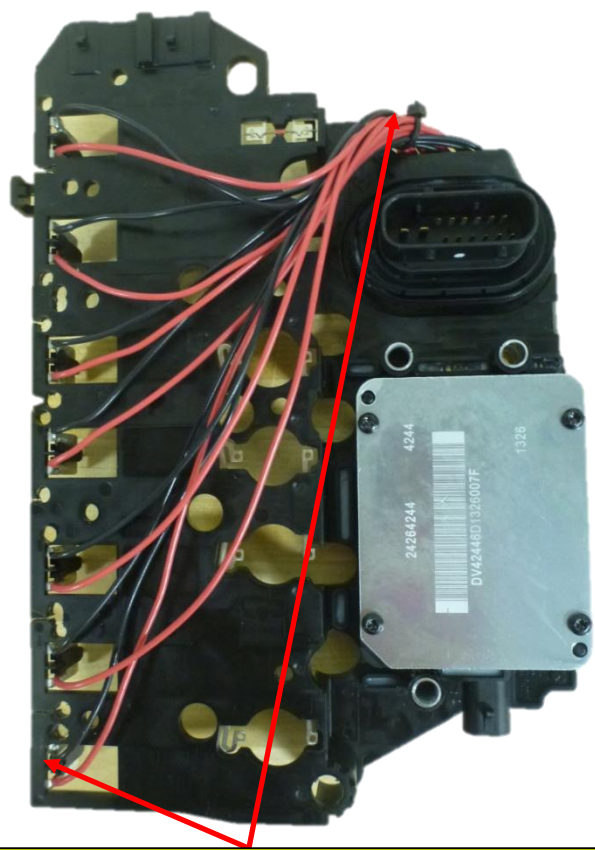




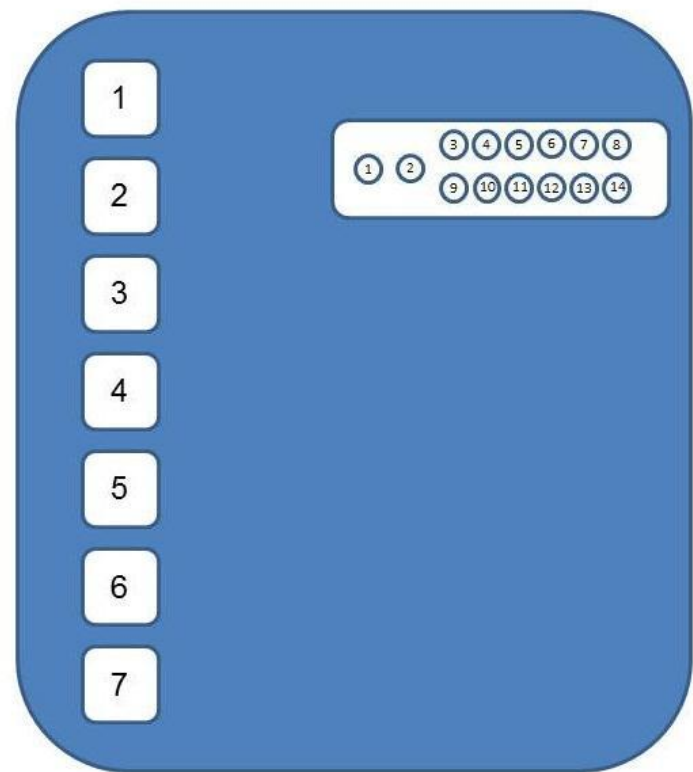
# Chevrolet Malibu 6-Speed AT – Benchmark Transmission Testing – Test Setup

## 3. Transmission Test Setup

- Gear Controls



- Hard-wired solenoid terminals to connector pins  
- Original OEM connections to TCU removed



Wiring legend

Pin	Sol	+/-
1	1	+
2	1	-
3	2	+
4	2	-
5	3	+
6	3	-
7	4	+
8	4	-
9	5	+
10	5	-
11	6	+
12	6	-
13	7	+
14	7	-

# Chevrolet Malibu 6-Speed AT – Benchmark Transmission Testing – Test Setup

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Contract No. EP-C-12-014, Work Assignment 1-5  
April 30, 2013



## 3. Transmission Test Setup

### ■ Gear Controls

- Manufacturer's information regarding the solenoid schedule was found to be incorrect
- Additional efforts taken in order to determine correct solenoid schedule
- Inconsistency in service documentation most likely related to hardware update in transmission valvebody without update of documentation

# Chevrolet Malibu 6-Speed AT – Benchmark Transmission Testing – Test Setup

## 3. Transmission Test Setup

- Gear Controls

Solenoid schedule as  
evaluated by FEV

		1st	2nd	3rd	4th	5th	6th
PCS5	normal high	OFF	OFF	OFF	OFF	ON	ON
PCS2	normal low	OFF	OFF	ON	OFF	ON	OFF
PCS3	normal high	OFF	ON	ON	OFF	OFF	OFF
PCS4	normal low	OFF	ON	OFF	OFF	OFF	ON
SL	normal closed	ON	OFF	OFF	OFF	OFF	OFF

		1st	2nd	3rd	4th	5th	6th
PCS5	normal high	ON	ON	ON	ON	OFF	OFF
PCS2	normal low	OFF	OFF	ON	OFF	ON	OFF
PCS3	normal high	OFF	OFF	OFF	ON	ON	ON
PCS4	normal low	OFF	ON	OFF	OFF	OFF	ON
SL	normal closed	OFF	OFF	OFF	OFF	OFF	OFF

Solenoid schedule as  
provided in GM service  
literature





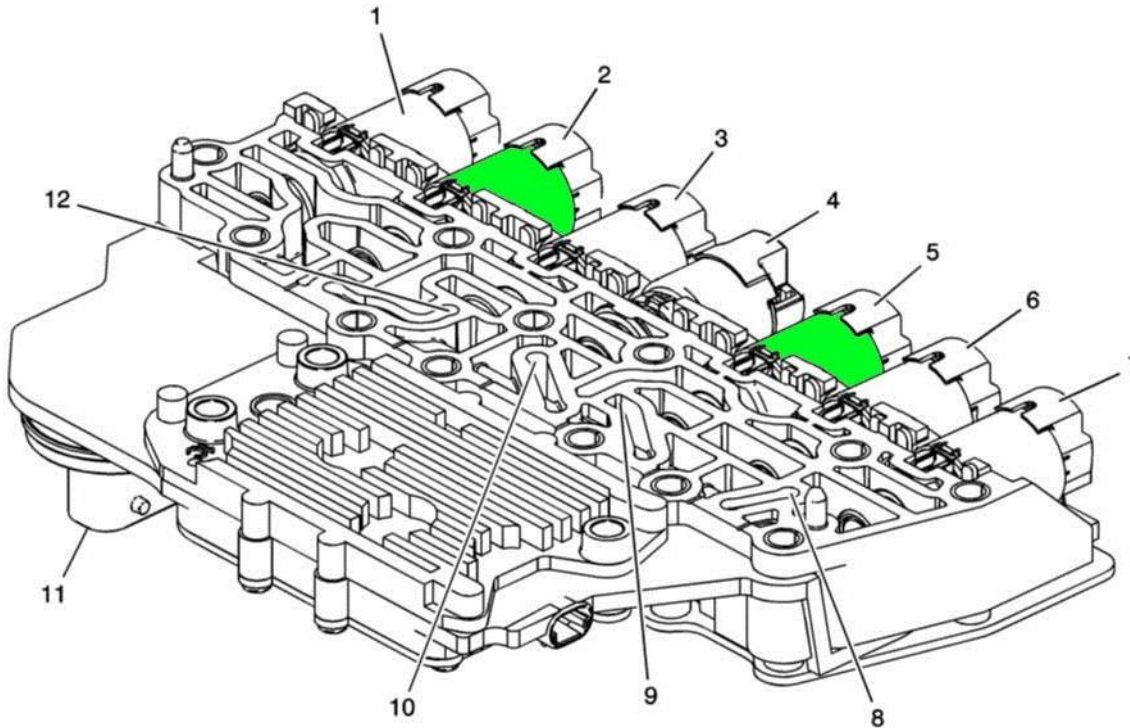
# Chevrolet Malibu 6-Speed AT – Benchmark Transmission Testing – Test Setup

Contract No. EP-C-12-014, Work Assignment 1-5  
April 30, 2013

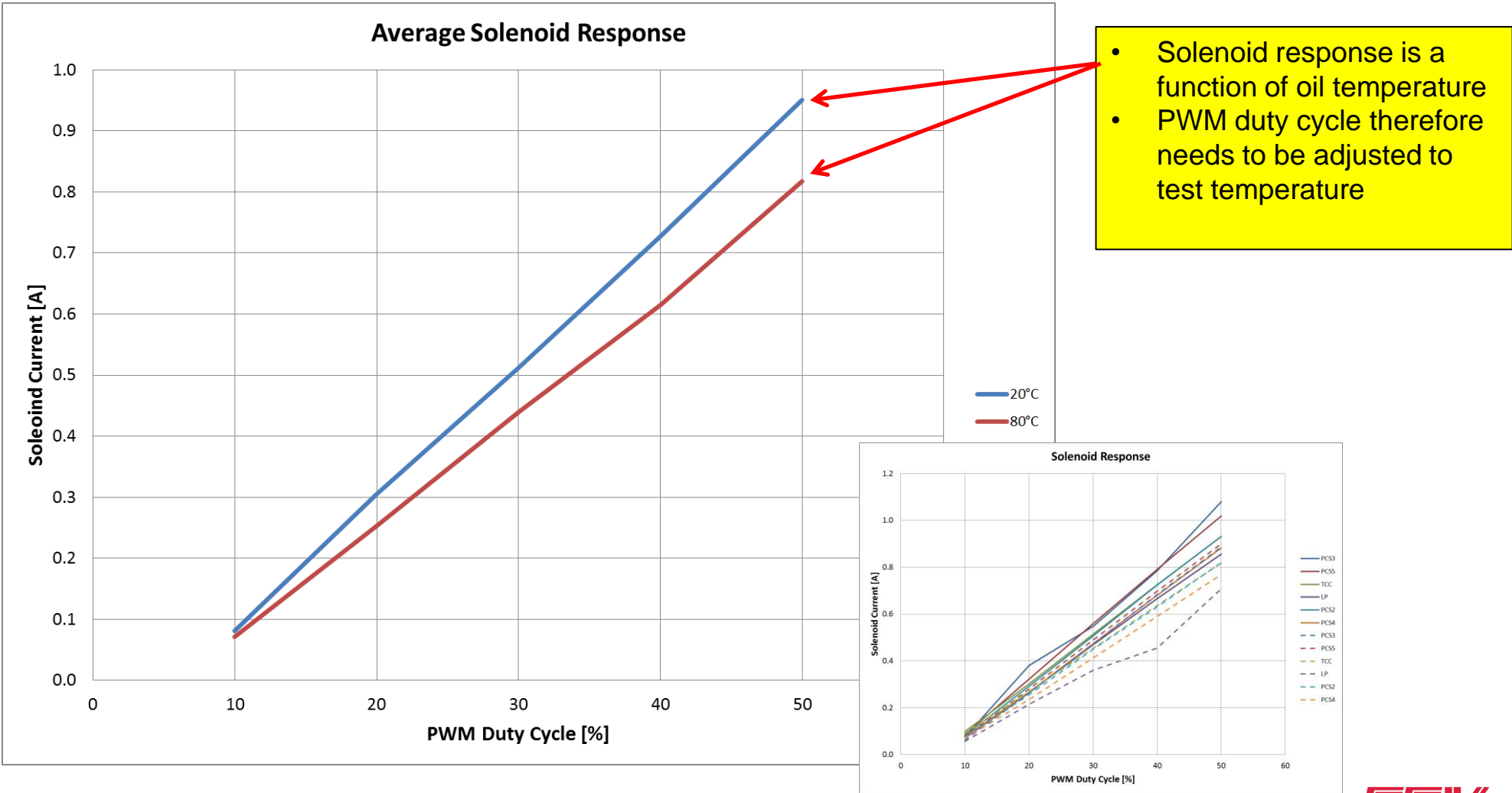
## 3. Transmission Test Setup

### ■ Gear Controls

- During transmission model changes, solenoids '2' and '5' have been modified
- GM solenoid schedule has not been updated in the service literature
- Additional time/effort required to determine the correct solenoid schedule in order to select all gears



# Chevrolet Malibu 6-Speed AT – Benchmark Transmission Testing – Test Setup



# Chevrolet Malibu 6-Speed AT – Benchmark Transmission Testing – Loaded Efficiency

Contract No. EP-C-12-014, Work Assignment 1-5  
April 30, 2013

## 2. Loaded Efficiency Measurements

- Gear 1 through 6
- Torque converter clutch locked for all tests
- Input loads(7):
  - 25 ... 250 Nm for gears 3 through 6
  - 25 ... 200 Nm for gear 2 (avoiding excessive torque on differential)
- 25 ... 150 Nm for gear 1 (avoiding excessive torque on differential)
- Input speeds(11):
  - 500 ... 5000 rpm for gear 1 through 4
  - 500 ... 4000 rpm for gear 5 (avoiding excessive vehicle speeds)
  - 500 ... 3000 rpm for gear 6 (avoiding excessive vehicle speeds)
- Transmission oil temperatures(2):
  - 37°C, 93°C
- Transmission line pressures(1):
  - Min-max (minimum pressure to hold highest test load w/o clutch slip)

# Chevrolet Malibu 6-Speed AT – Benchmark Transmission Testing – Loaded Efficiency

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Contract No. EP-C-12-014, Work Assignment 1-5  
April 30, 2013

## ■ Loaded Efficiency Test Summary

- Modified internal TCM to connect to each solenoid individually
- Fabricated harness to connect FEV PWM controller to 6T40 solenoids
- Had difficulties to properly select gears
  - Investigated and created new solenoid schedule since GM service information seemed to be outdated
  - Were not able to transmit significant loads in 1<sup>st</sup> gear
  - EPA agreed on limiting mechanical efforts and estimating the efficiency values for 1<sup>st</sup> gear
    - EPA agreed to approximation of loaded-efficiency values for 1<sup>st</sup> gear
- Had difficulties holding input torques > 150 Nm at 93°C oil temperature
  - EPA agreed to apply sufficient interpolation method to project high torque efficiency values

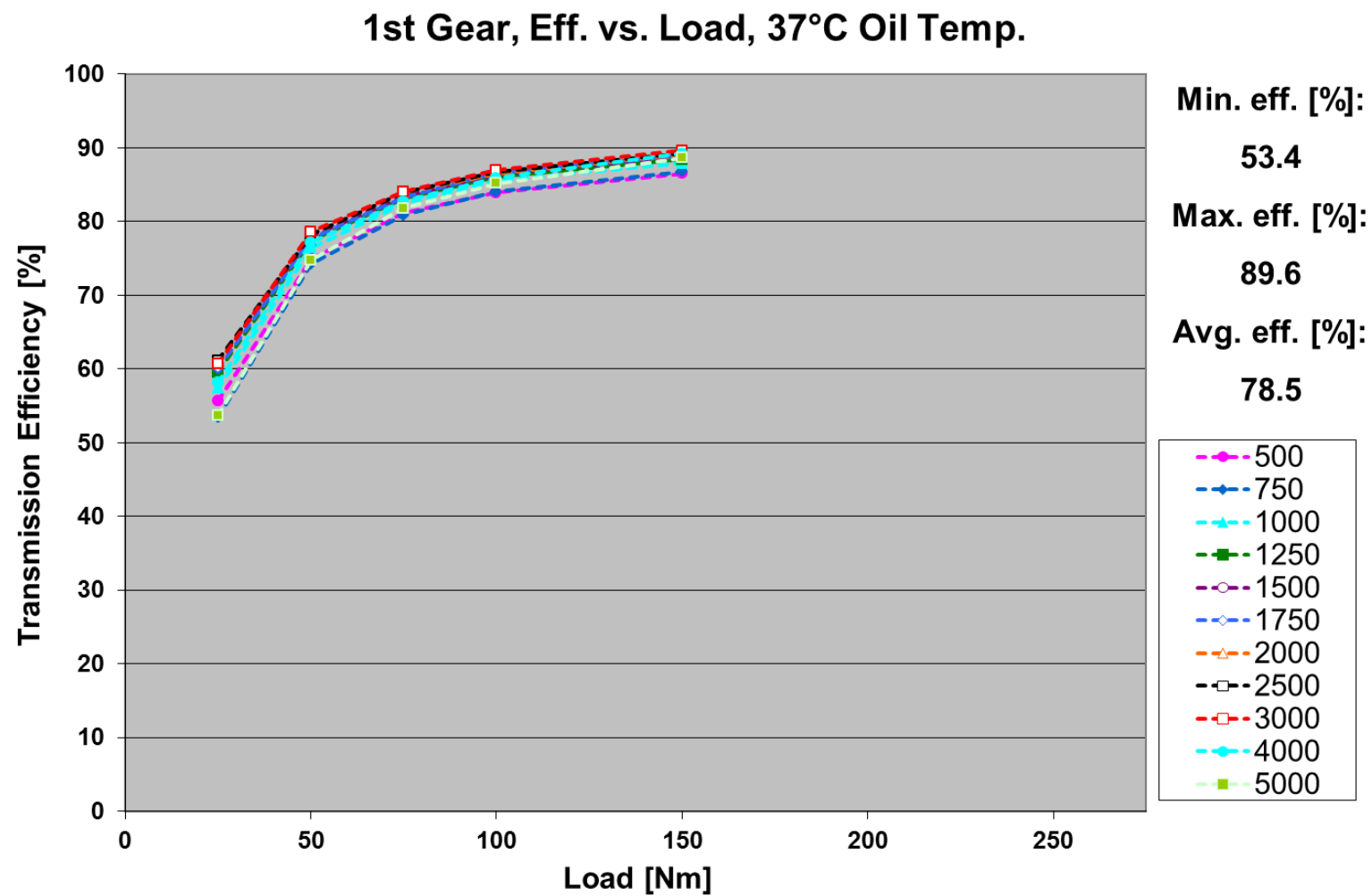
# Chevrolet Malibu 6-Speed AT – Benchmark Transmission Testing – Loaded Efficiency

Contract No. EP-C-12-014, Work Assignment 1-5  
April 30, 2013

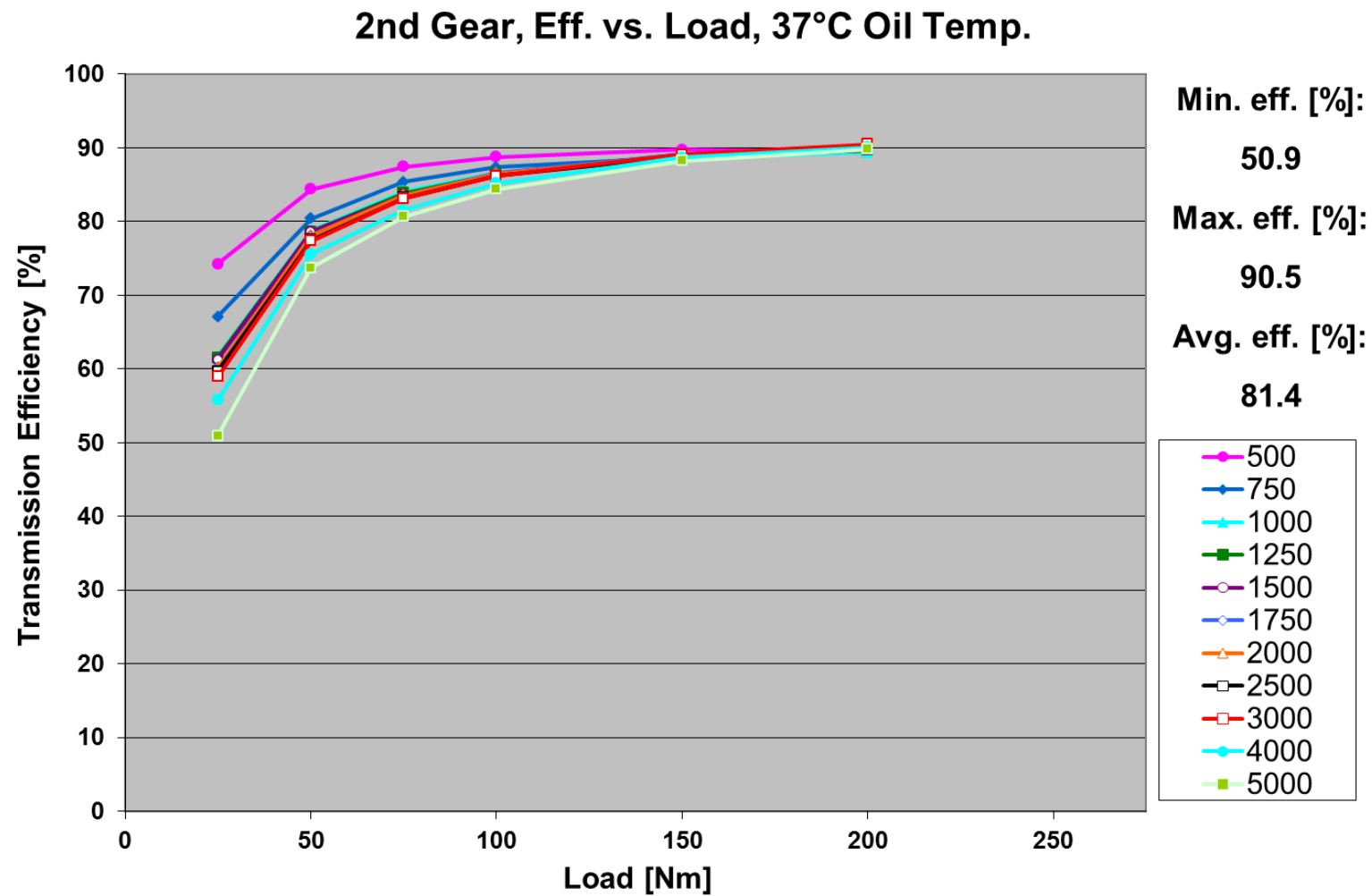
## ■ Efficiency Calculations for 1<sup>st</sup> Gear

- Calculated Power Loss and Mesh Loss for each gear:
  - $\text{Power Loss} = \text{Input Power} - \text{Output Power}$
  - $\text{Mesh Loss} = \text{Power Loss} - \text{Spin Loss}$
- Reviewed transmission design and service literature and found that the power flow for 1<sup>st</sup> and 2<sup>nd</sup> gear are very similar
- Assumed similar mesh losses for 1<sup>st</sup> and 2<sup>nd</sup> gear because of similar power flow through transmission
- Calculated efficiency for 1<sup>st</sup> gear:
  - $\text{Power Loss} = \text{Mesh Loss (2<sup>nd</sup> gear)} + \text{Spin Loss (1<sup>st</sup> gear)}$
  - $\text{Output Power} = \text{Input Power} - \text{Power Loss}$
  - $\text{Efficiency} = \text{Output Power} / \text{Input Power}$

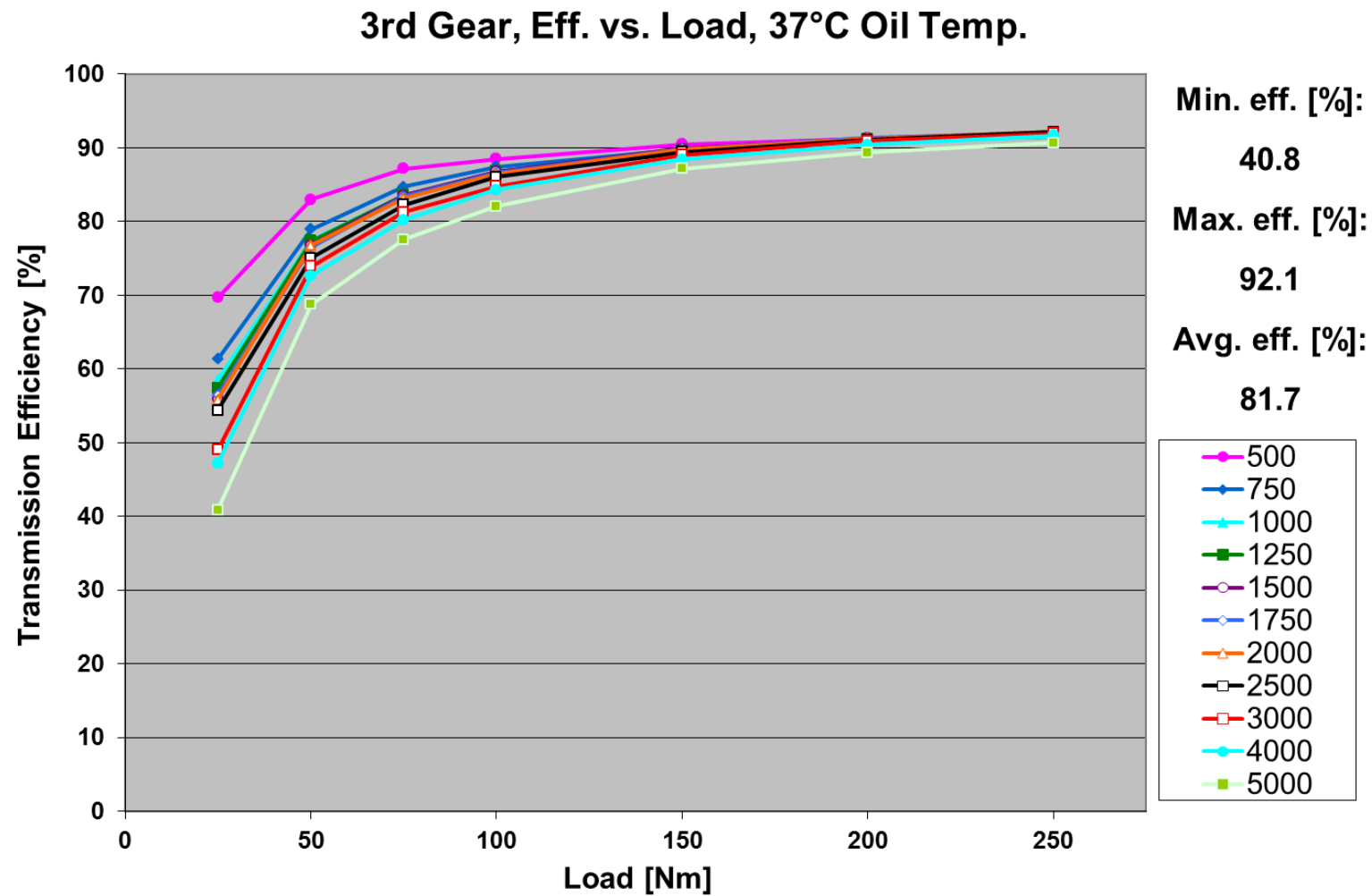
# Chevrolet Malibu 6-Speed AT – Benchmark Transmission Testing – Loaded Efficiency



# Chevrolet Malibu 6-Speed AT – Benchmark Transmission Testing – Loaded Efficiency

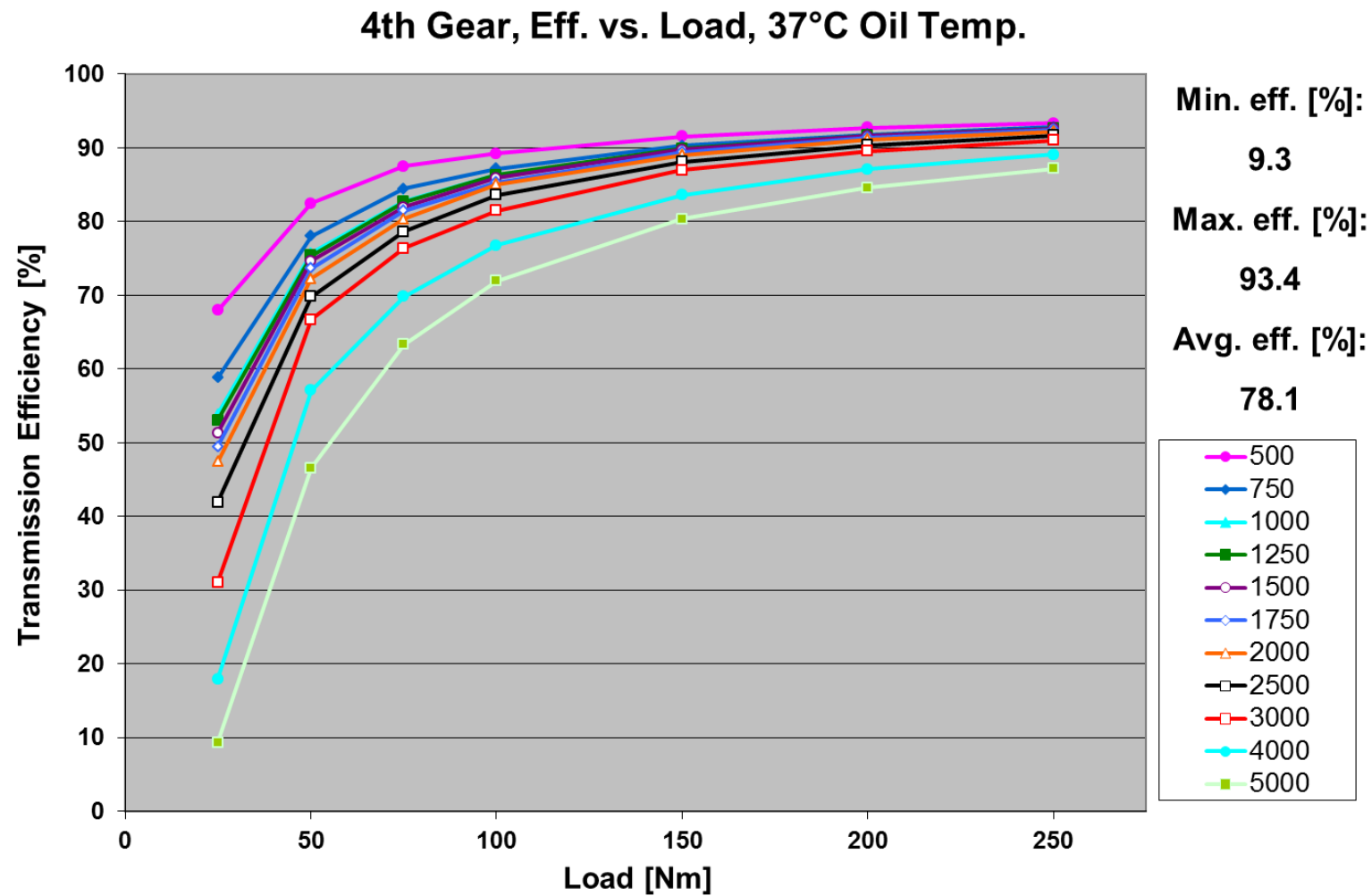


# Chevrolet Malibu 6-Speed AT – Benchmark Transmission Testing – Loaded Efficiency

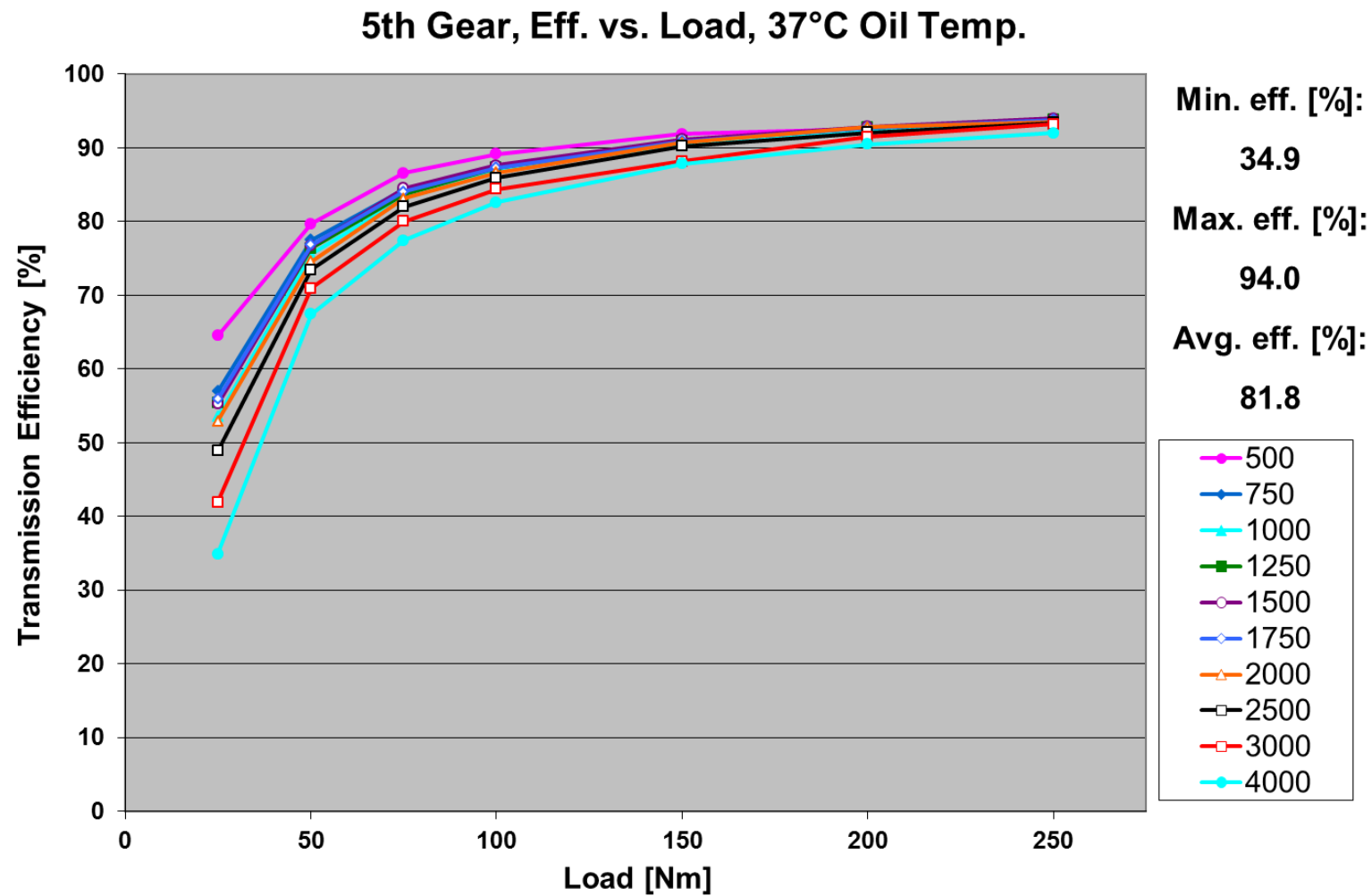




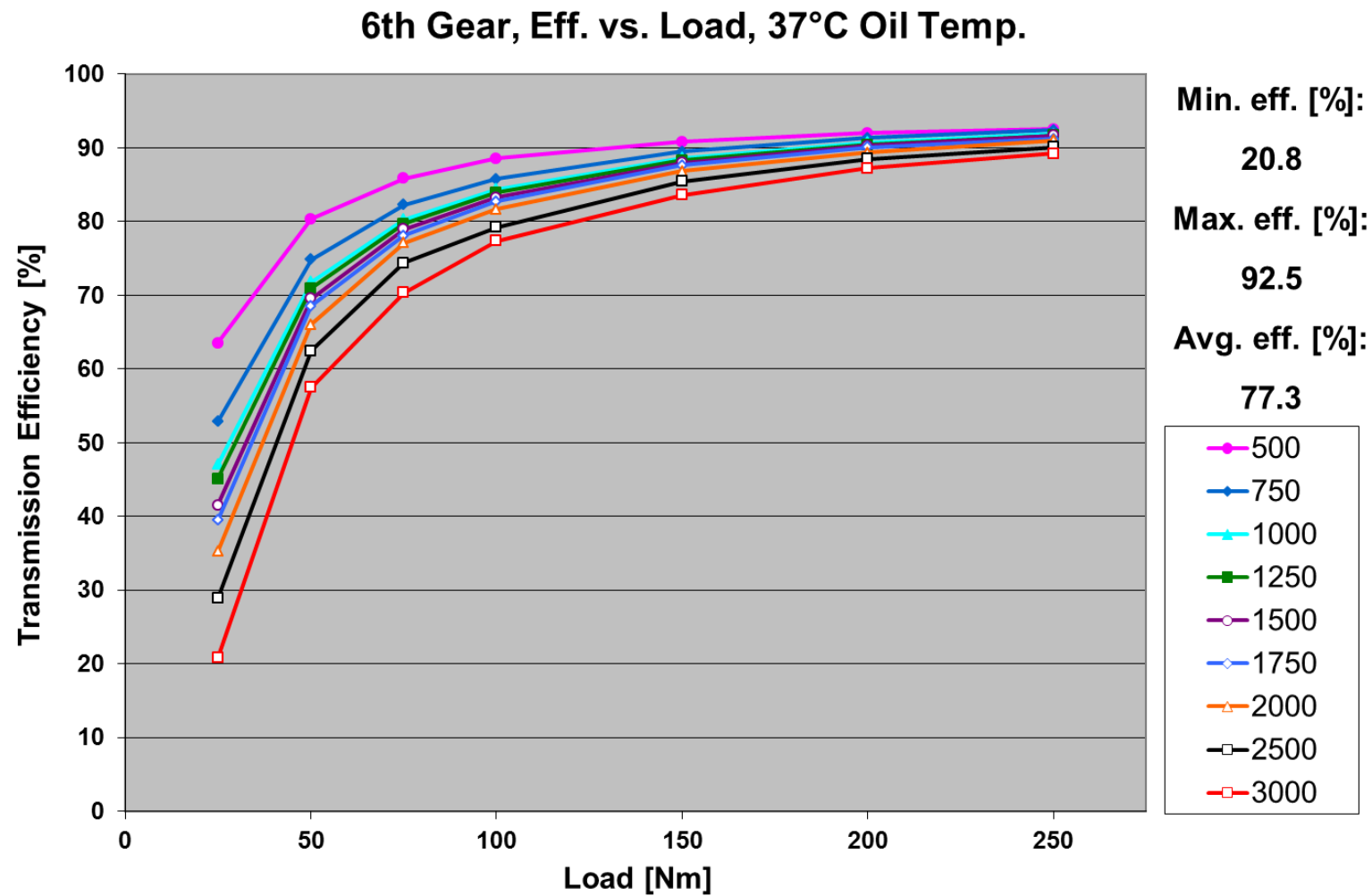
# Chevrolet Malibu 6-Speed AT – Benchmark Transmission Testing – Loaded Efficiency



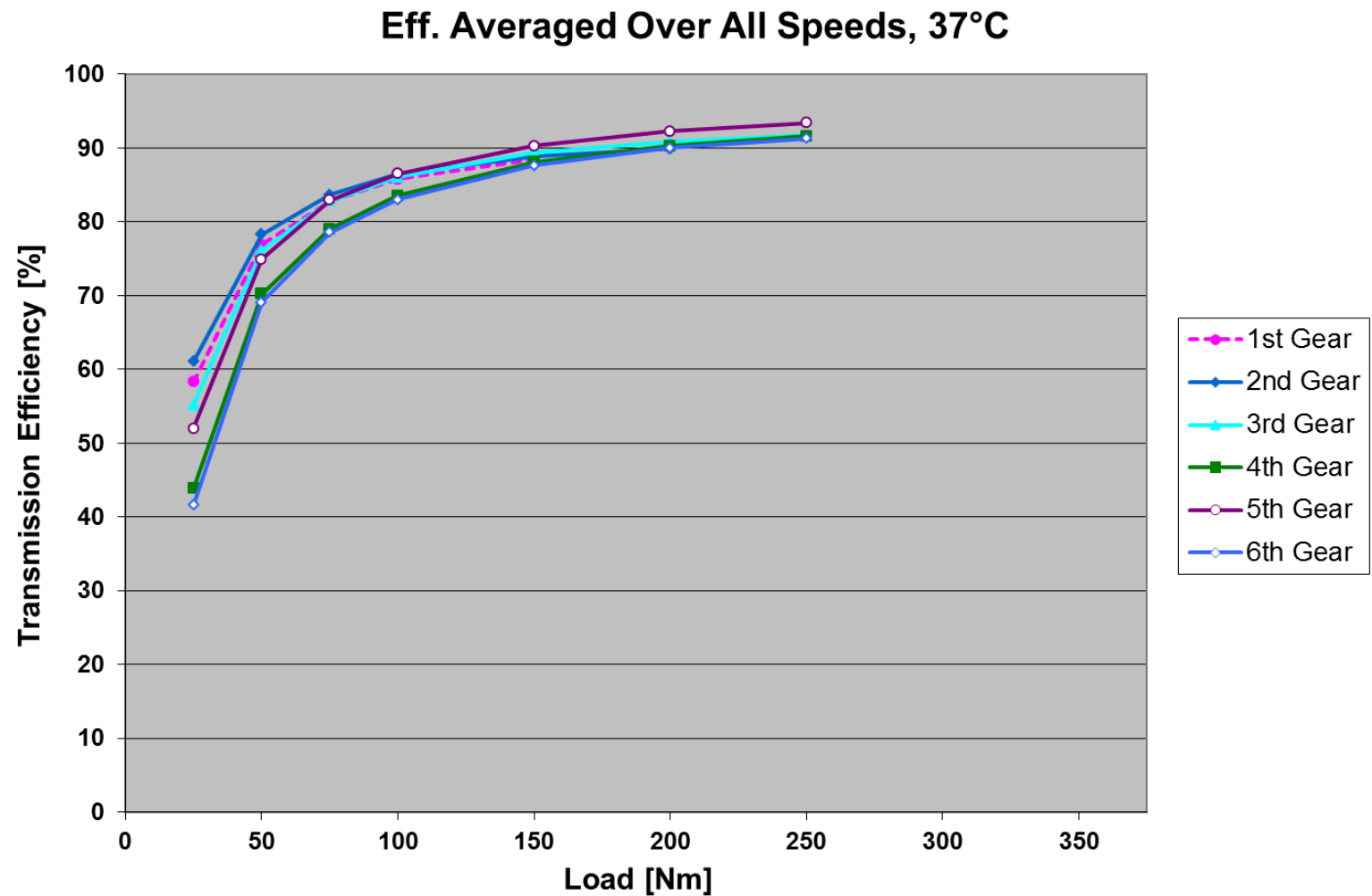
# Chevrolet Malibu 6-Speed AT – Benchmark Transmission Testing – Loaded Efficiency



# Chevrolet Malibu 6-Speed AT – Benchmark Transmission Testing – Loaded Efficiency



# Chevrolet Malibu 6-Speed AT – Benchmark Transmission Testing – Loaded Efficiency



# Chevrolet Malibu 6-Speed AT – Benchmark Transmission Testing – Loaded Efficiency

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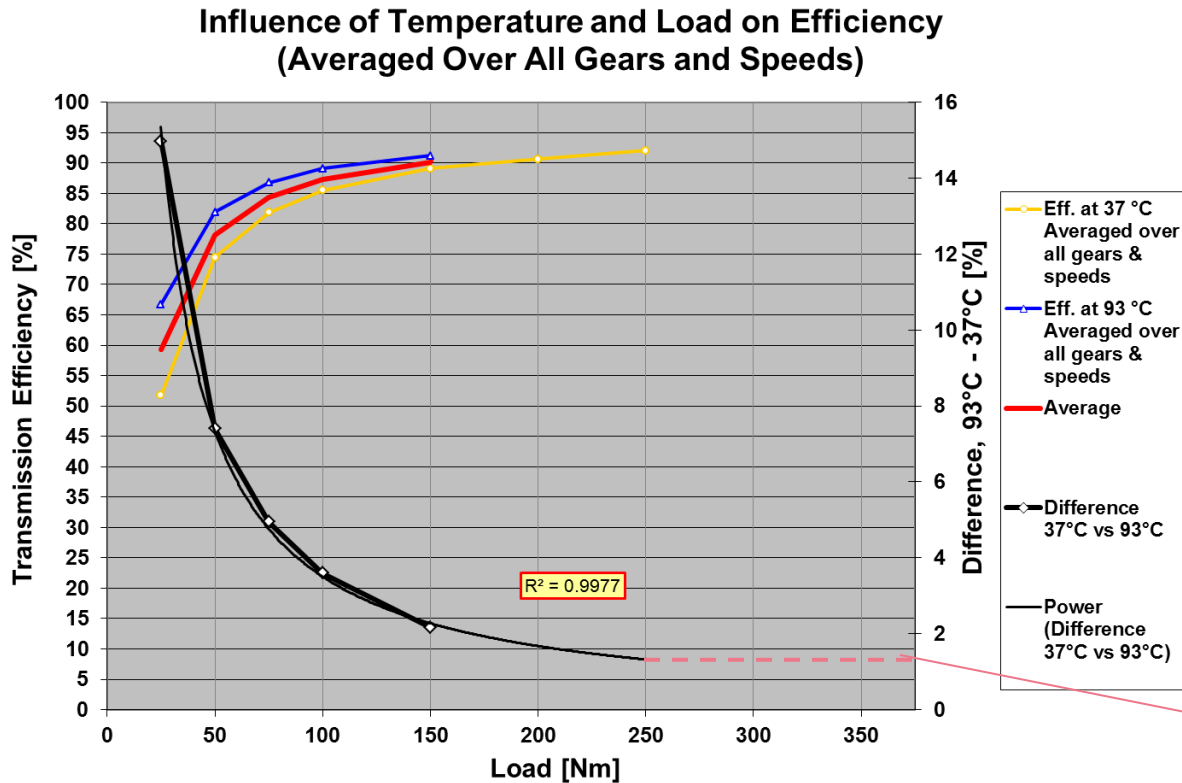
Contract No. EP-C-12-014, Work Assignment 1-5  
April 30, 2013

## ■ Efficiency Calculations for Input Loads above 150 Nm

- The absolute difference between the efficiency values for 37°C and 93°C was plotted against input shaft torque
- The trend of the difference can be represented by a power-law equation (next slide)
- Extending the found power-law-curve allowed for predicting the hot/cold difference in efficiency for high input shaft loads
- The predicted efficiency differences were then added to the acquired 37°C efficiency data to gain the values for 93°C

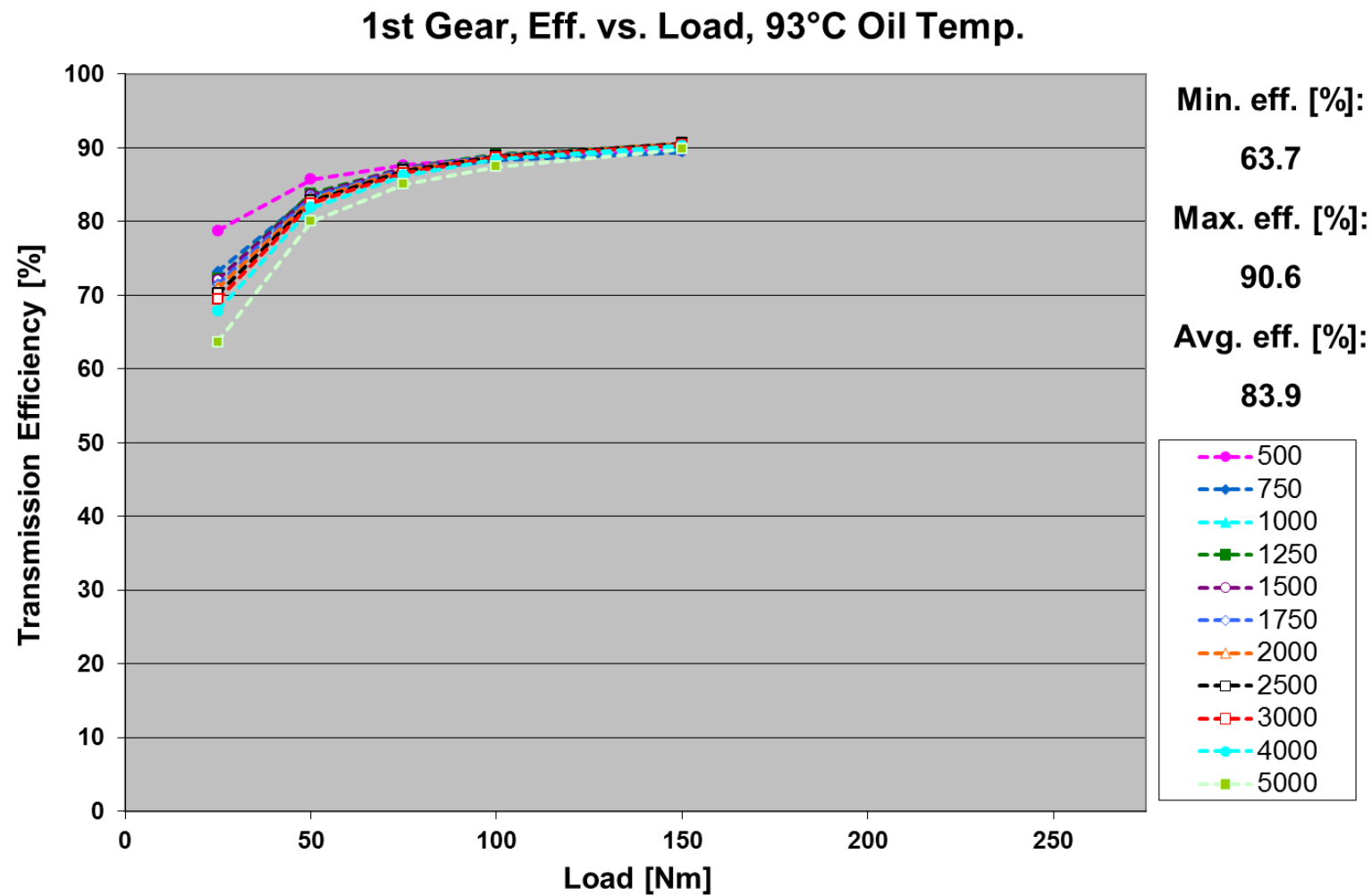
# Chevrolet Malibu 6-Speed AT – Benchmark Transmission Testing – Loaded Efficiency

Contract No. EP-C-12-014, Work Assignment 1-5  
April 30, 2013



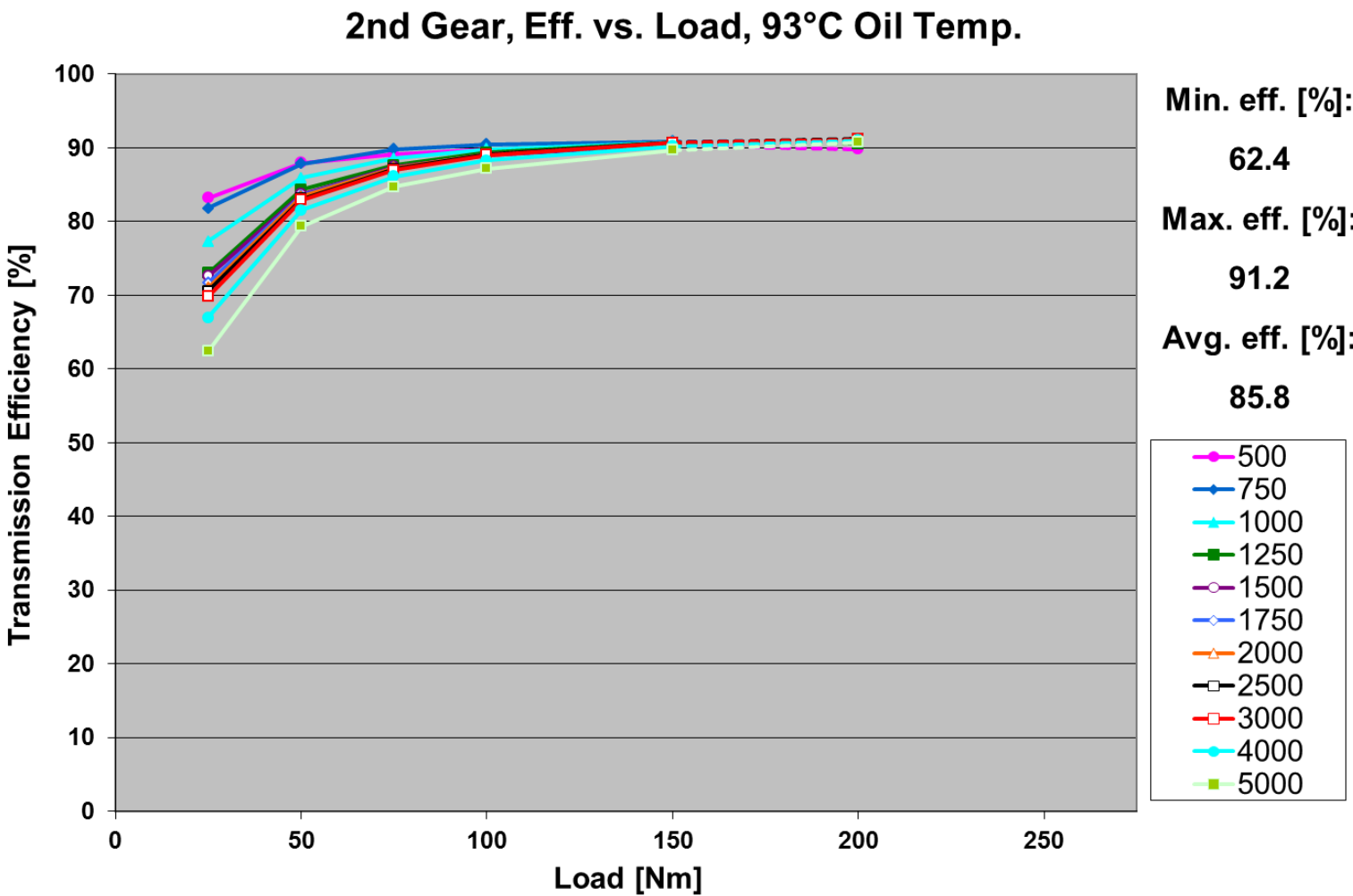
- The efficiency difference vs. input torque was represented with a power-law equation
- The extended power-law-curve enabled to estimate efficiency difference values for input torque above 150 Nm
- This relationship holds true for other automatic FWD transmissions as well as for all speeds and gears
- Example: Estimated difference in efficiency between 37°C and 93°C at 250 Nm = ~1.3%
- Resulting values can be added to 'cold efficiency' to gain 'hot efficiency'

# Chevrolet Malibu 6-Speed AT – Benchmark Transmission Testing – Loaded Efficiency



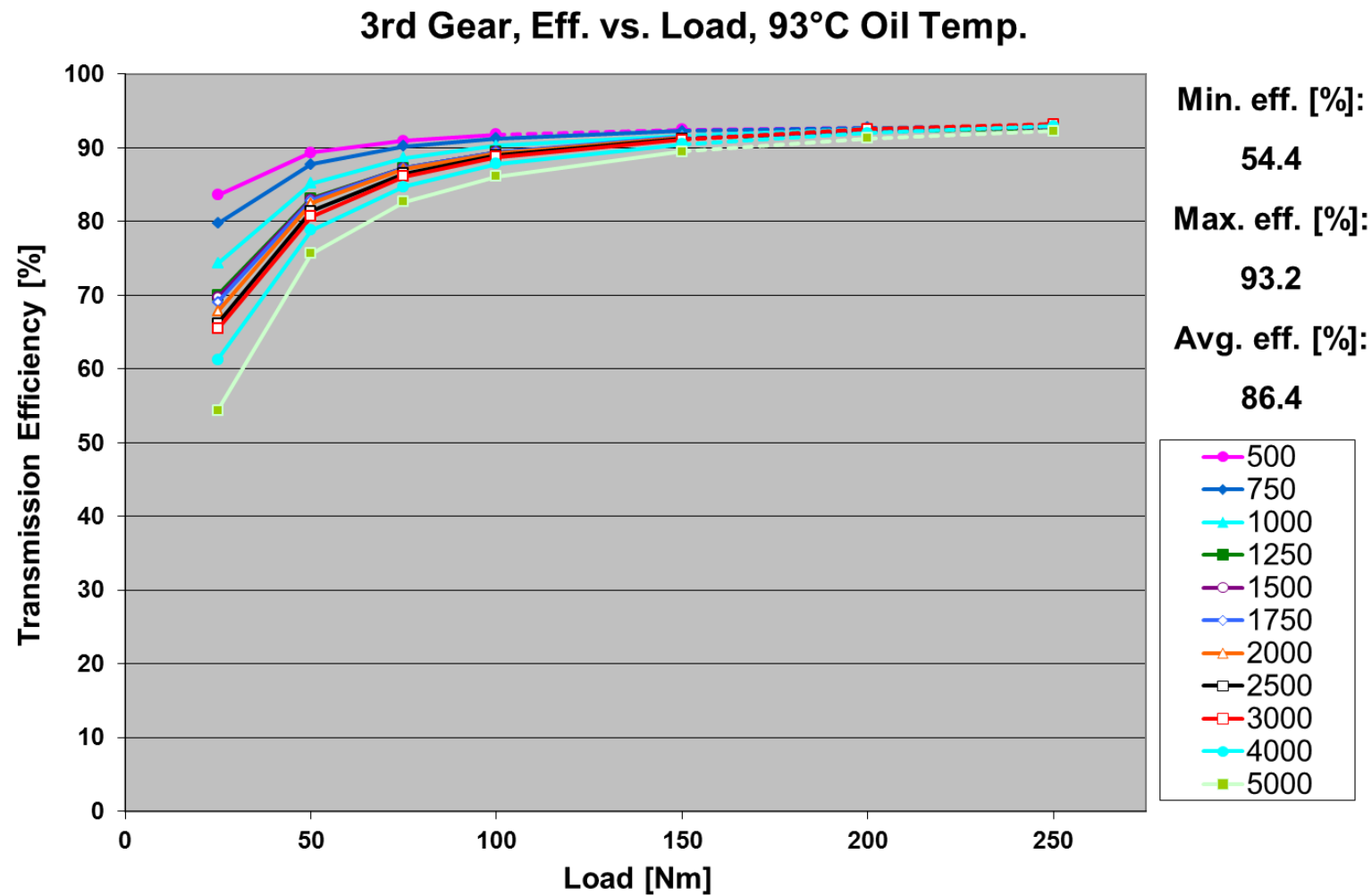
# Chevrolet Malibu 6-Speed AT – Benchmark Transmission Testing – Loaded Efficiency

The found procedure has been applied to all measured 93°C efficiency data to extend results to 250 Nm input torque

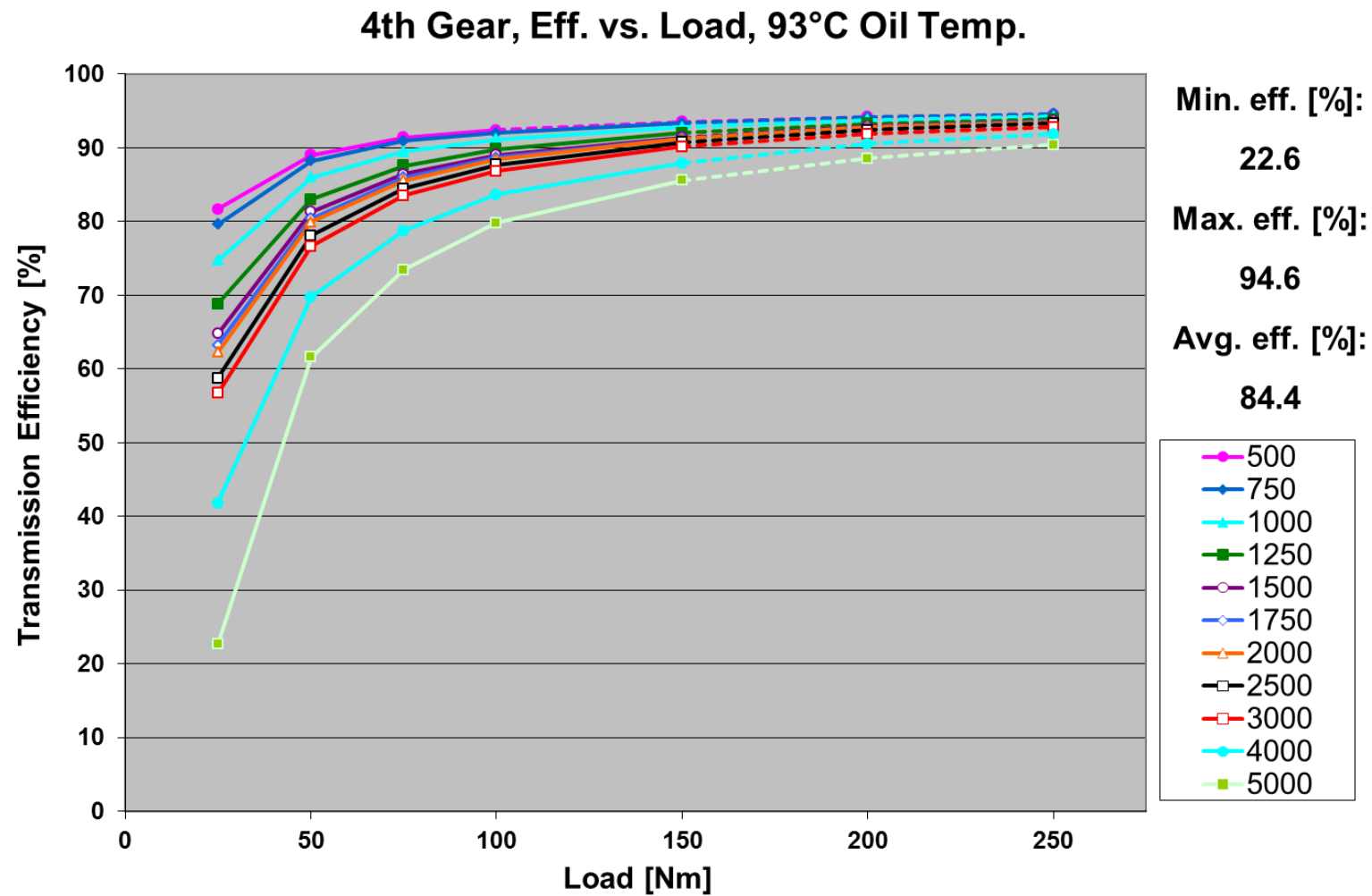




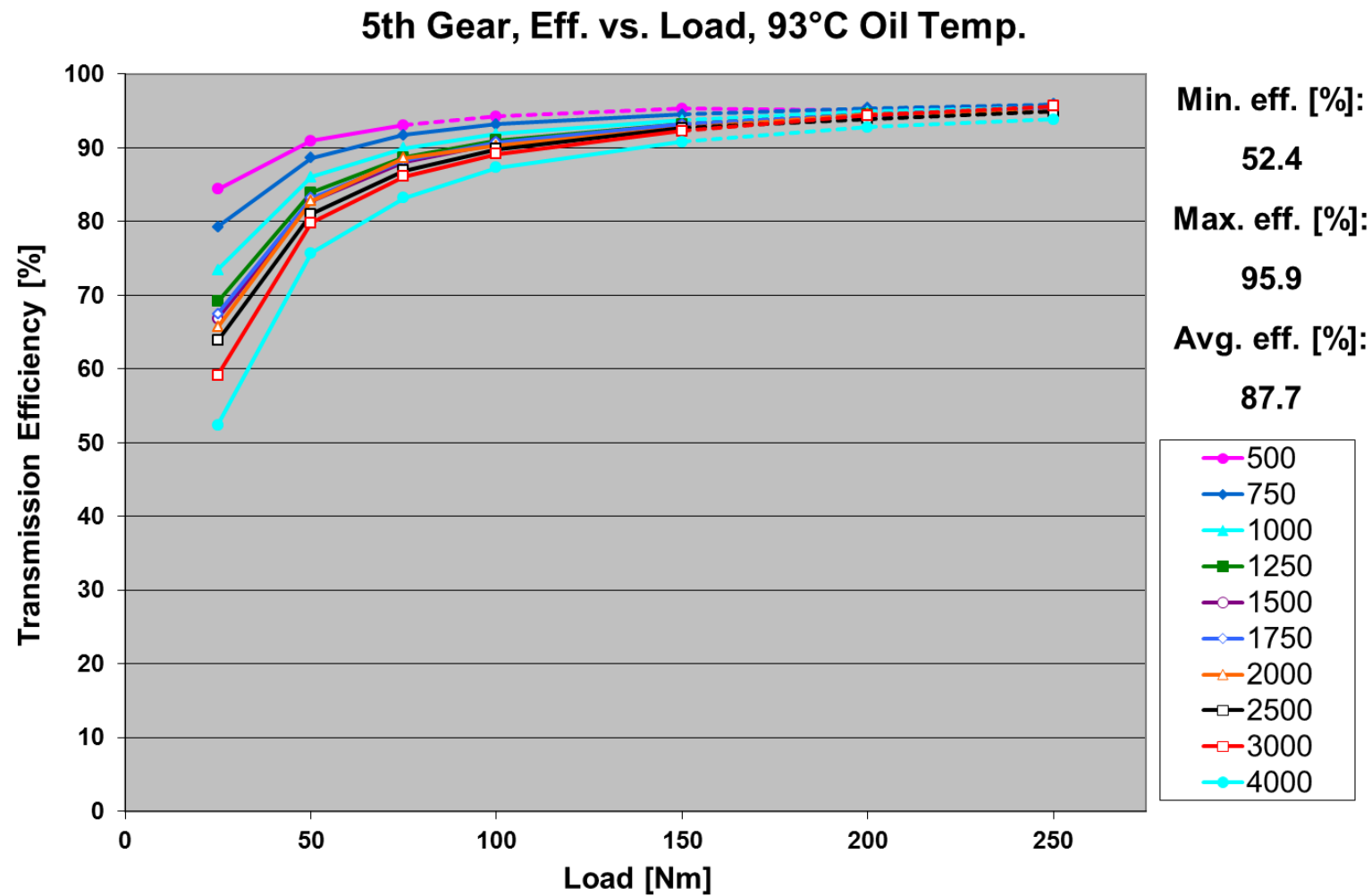
# Chevrolet Malibu 6-Speed AT – Benchmark Transmission Testing – Loaded Efficiency



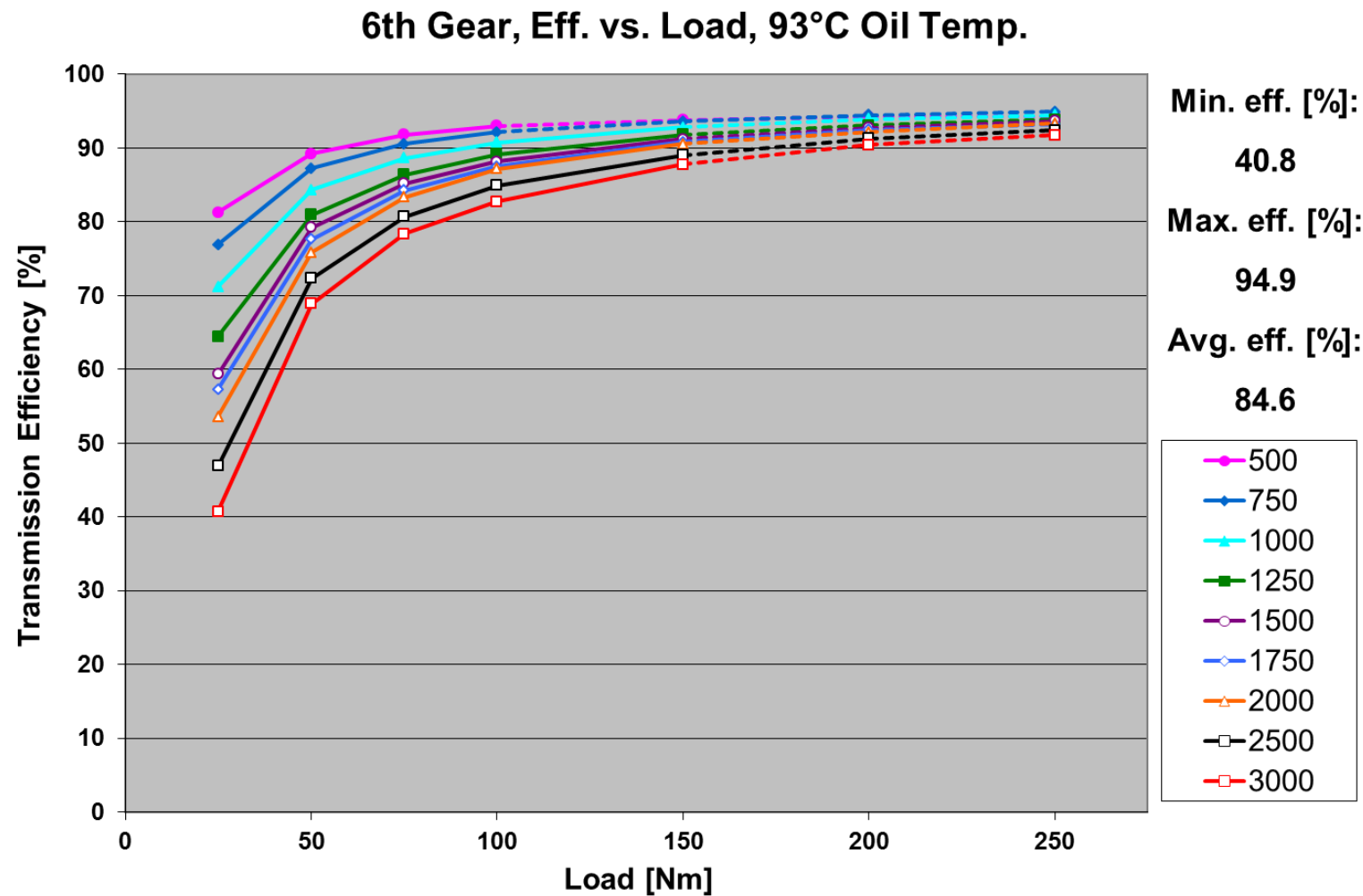
# Chevrolet Malibu 6-Speed AT – Benchmark Transmission Testing – Loaded Efficiency



# Chevrolet Malibu 6-Speed AT – Benchmark Transmission Testing – Loaded Efficiency

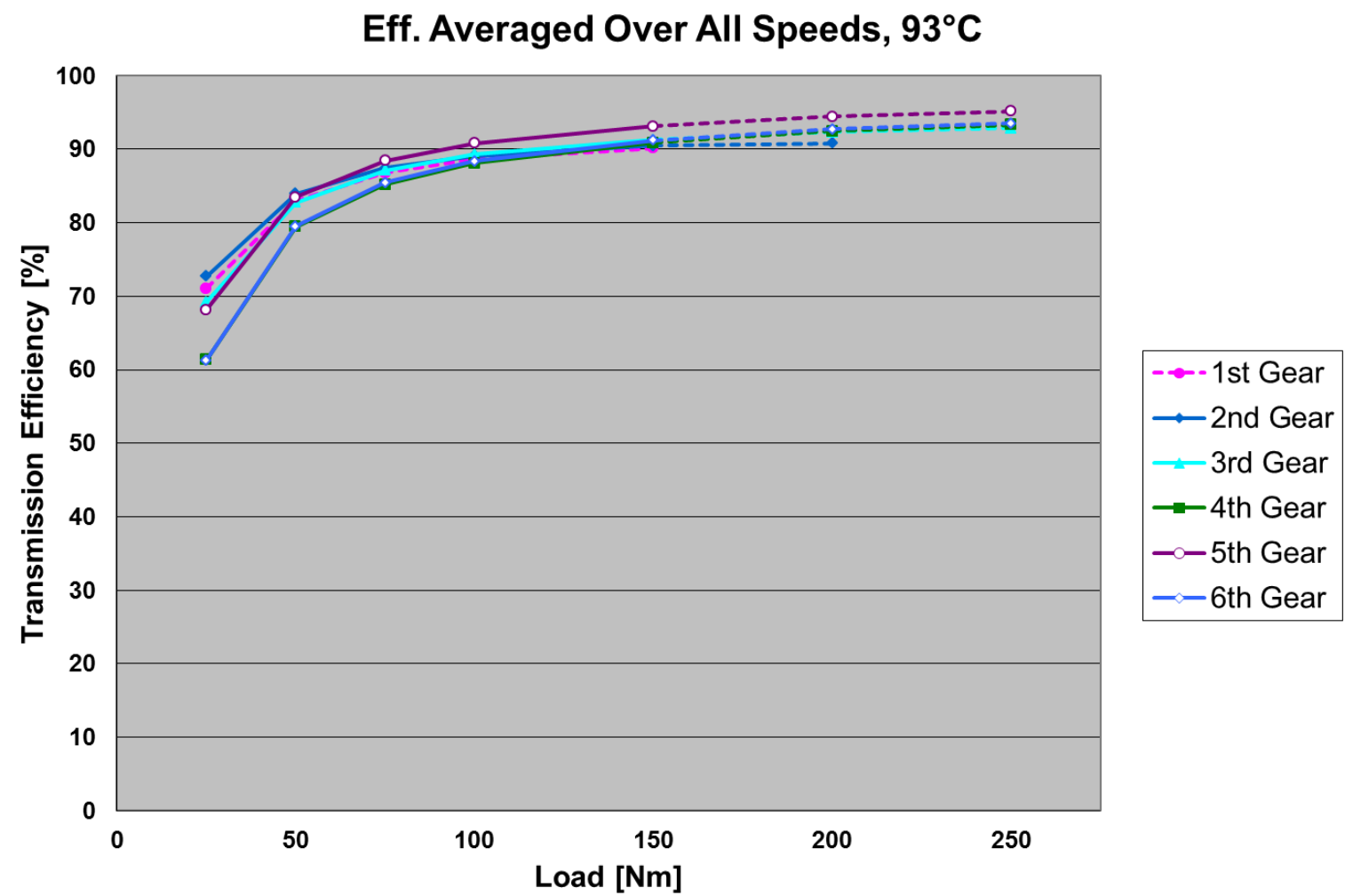


# Chevrolet Malibu 6-Speed AT – Benchmark Transmission Testing – Loaded Efficiency

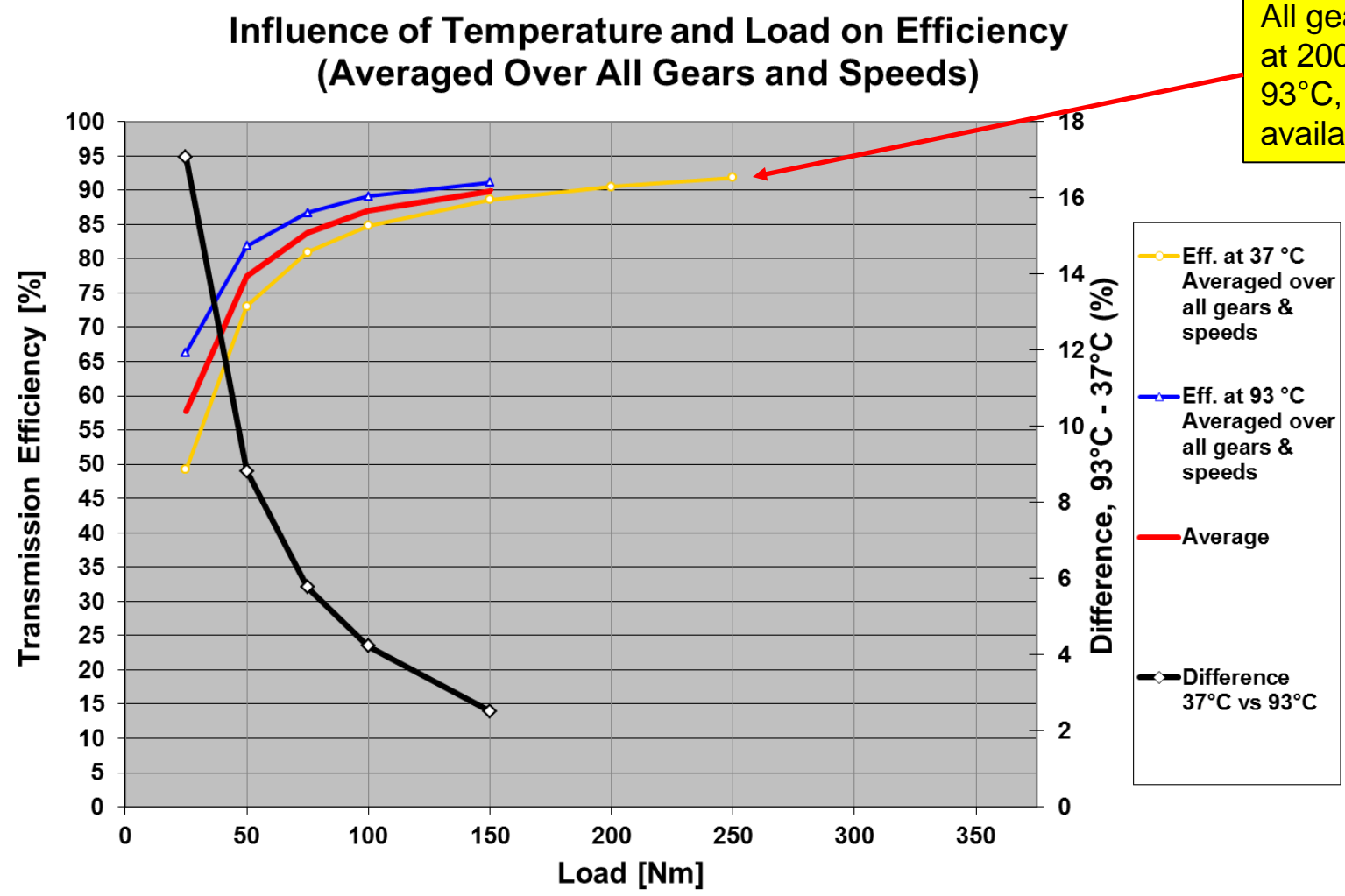


# Chevrolet Malibu 6-Speed AT – Benchmark Transmission Testing – Loaded Efficiency

Contract No. EP-C-12-014, Work Assignment 1-5  
April 30, 2013

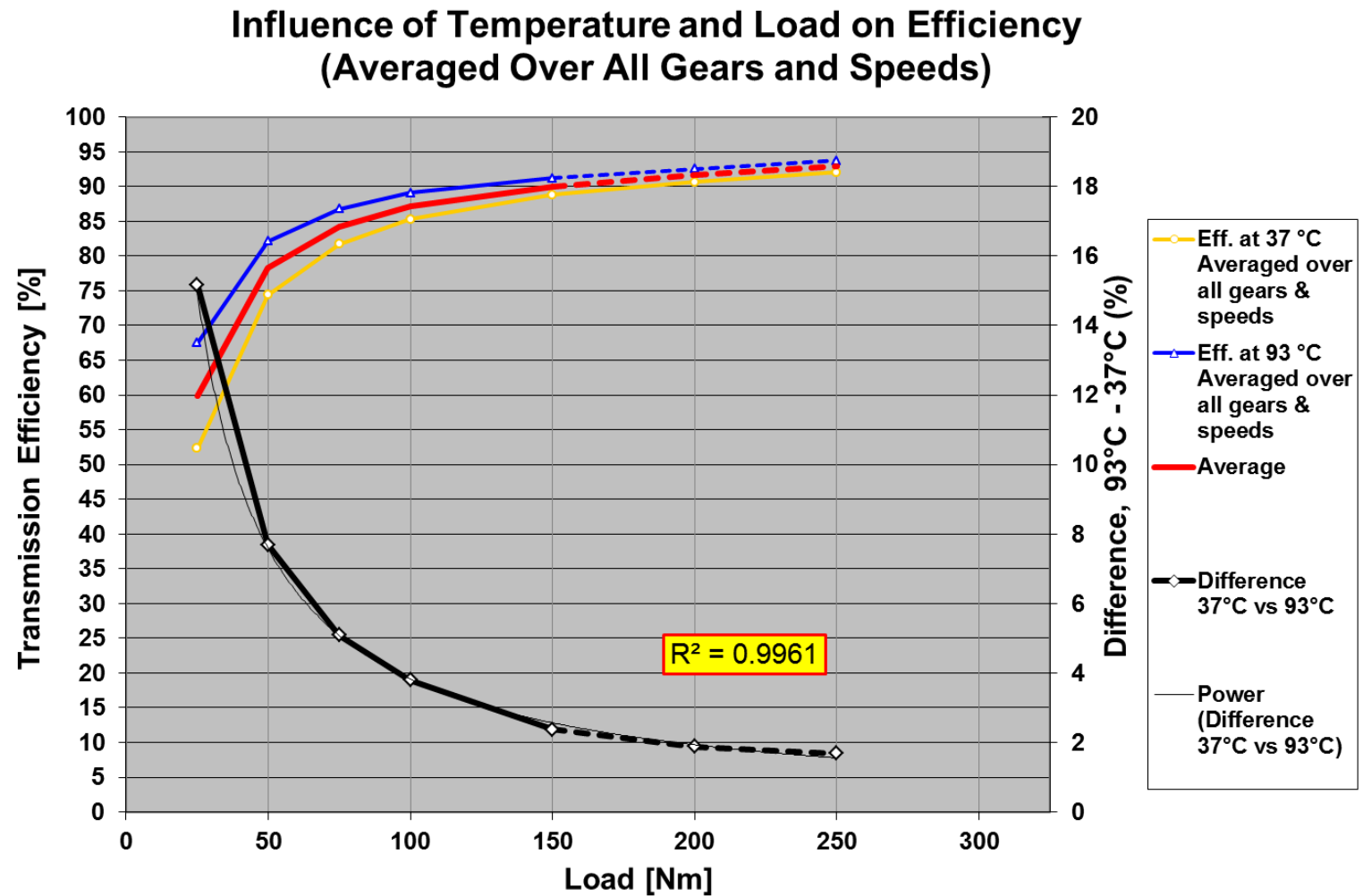


# Chevrolet Malibu 6-Speed AT – Benchmark Transmission Testing – Loaded Efficiency



All gears exhibited slip at 200Nm and 250Nm at 93°C, so only 37°C data available above 150Nm

# Chevrolet Malibu 6-Speed AT – Benchmark Transmission Testing – Loaded Efficiency



# Chevrolet Malibu 6-Speed AT – Benchmark

## Transmission Testing – Spin Loss

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Contract No. EP-C-12-014, Work Assignment 1-5  
April 30, 2013

### 3. Spin Loss Measurements

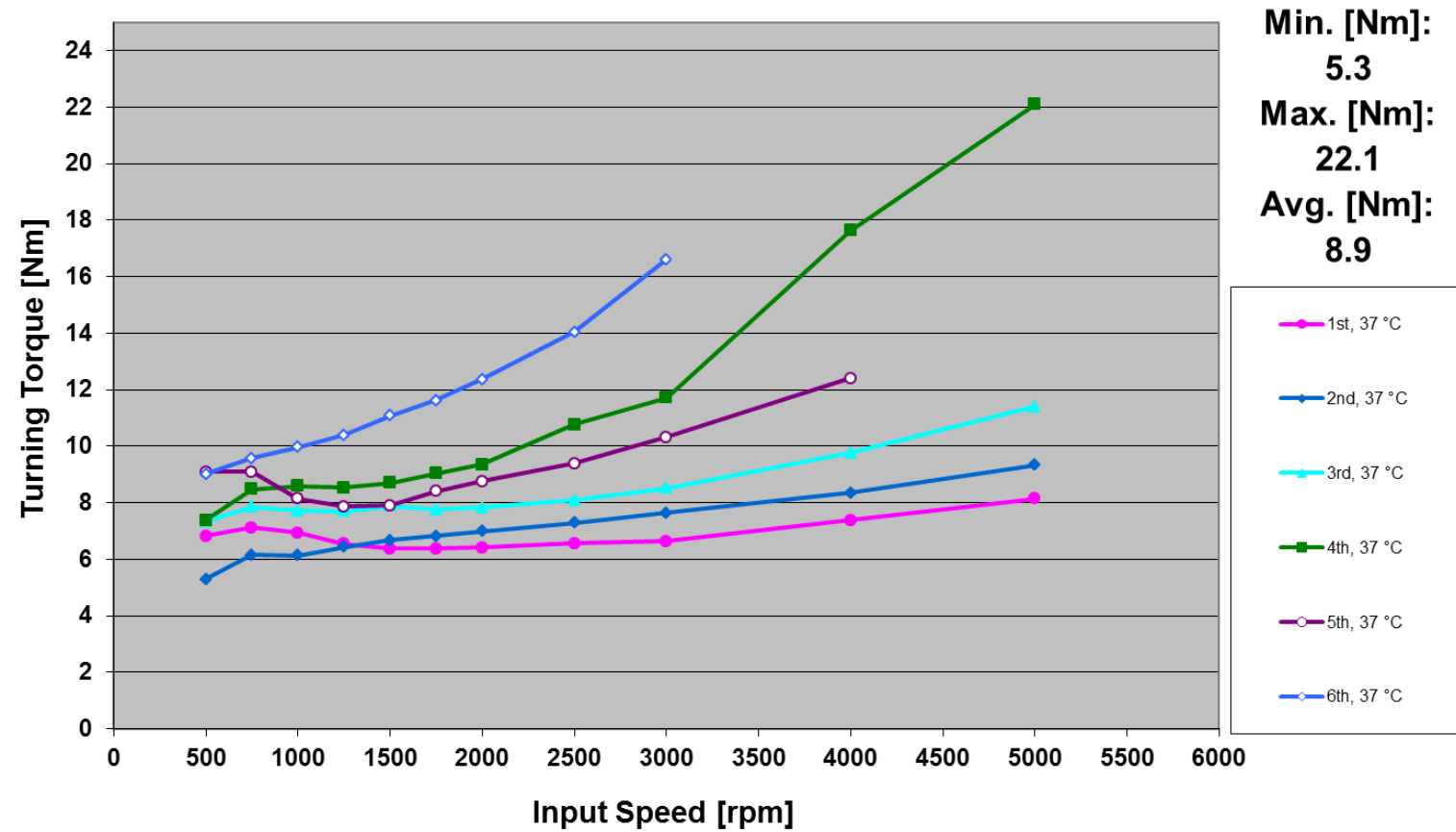
- Gear 1 through 6
- Torque converter clutch locked for all tests
- Input speeds(11):
  - 500 ... 5000 rpm for gear 1 through 4
  - 500 ... 4000 rpm for gear 5 (avoiding excessive vehicle speeds)
  - 500 ... 3000 rpm for gear 6 (avoiding excessive vehicle speeds)
- Transmission oil temperatures(2):
  - 37°C, 93°C
- Transmission line pressures(2):
  - Max-min (highest of the 'low' line pressures for all gears)
  - Min-max (minimum of the 'high' line pressures required to hold highest input torque without slip)



# Chevrolet Malibu 6-Speed AT – Benchmark Transmission Testing – Spin Loss

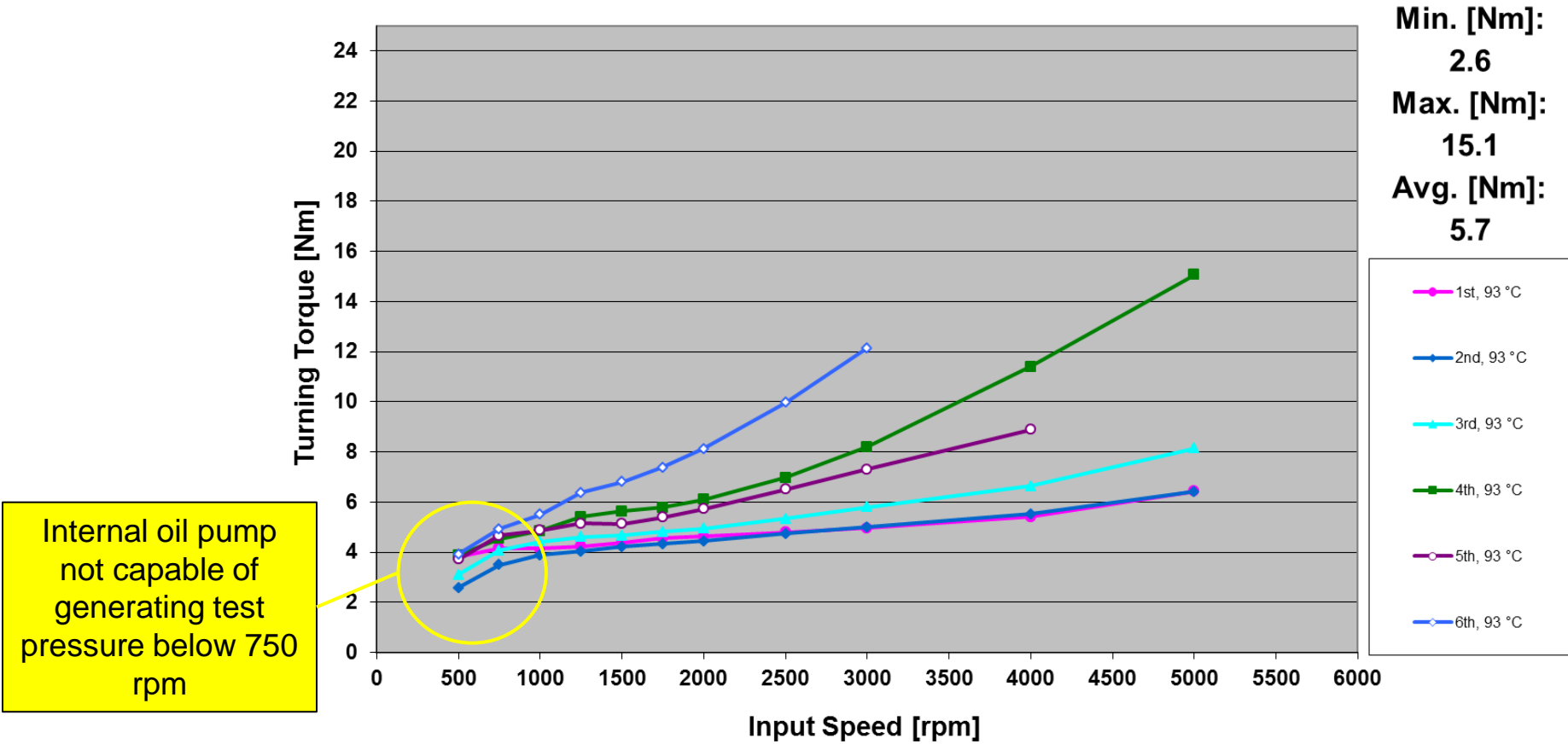
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April 30, 2013

Spin Loss Results, 37 °C Sump Temp, 5 Bar



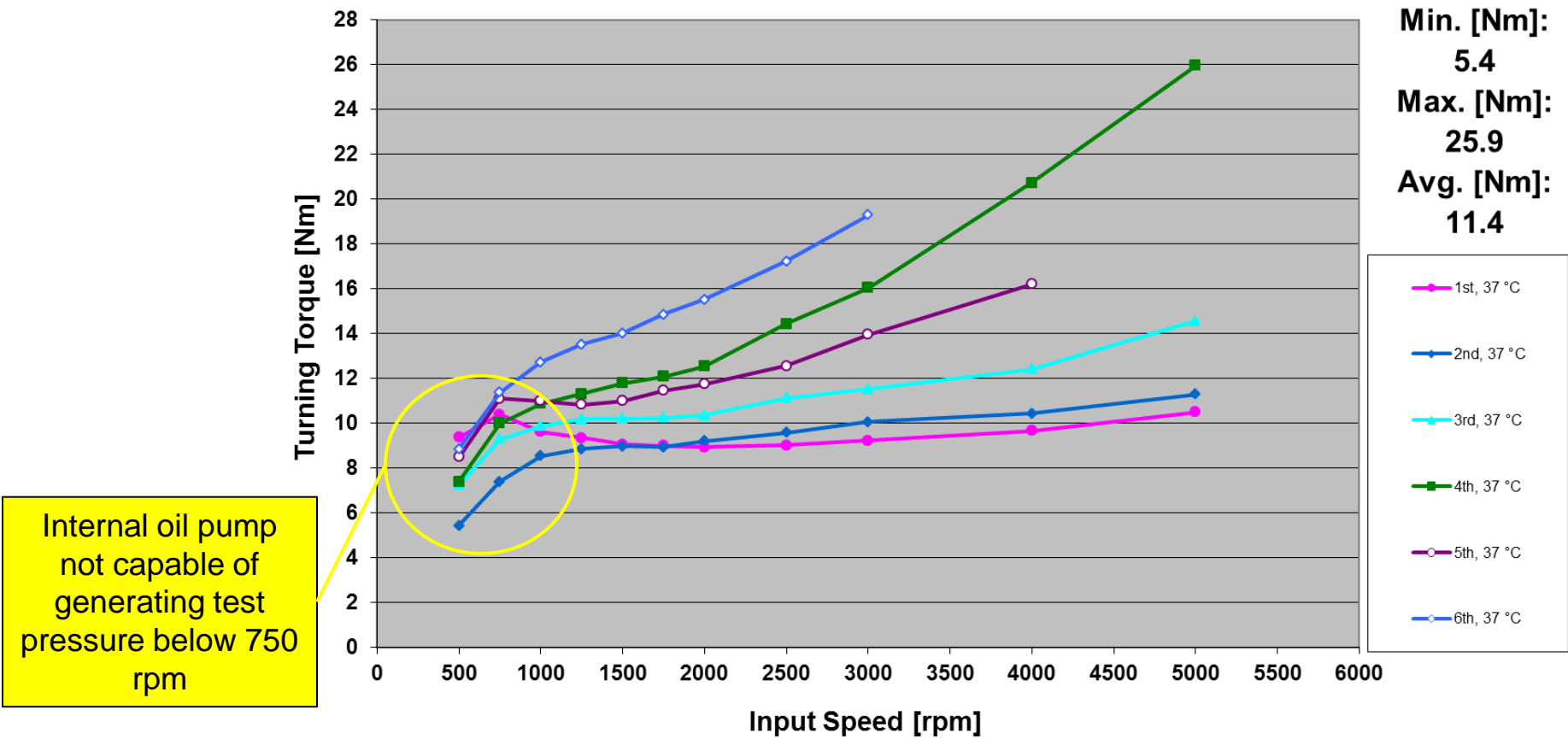
# Chevrolet Malibu 6-Speed AT – Benchmark Transmission Testing – Spin Loss

Spin Loss Results, 93 °C Sump Temp, 5 Bar



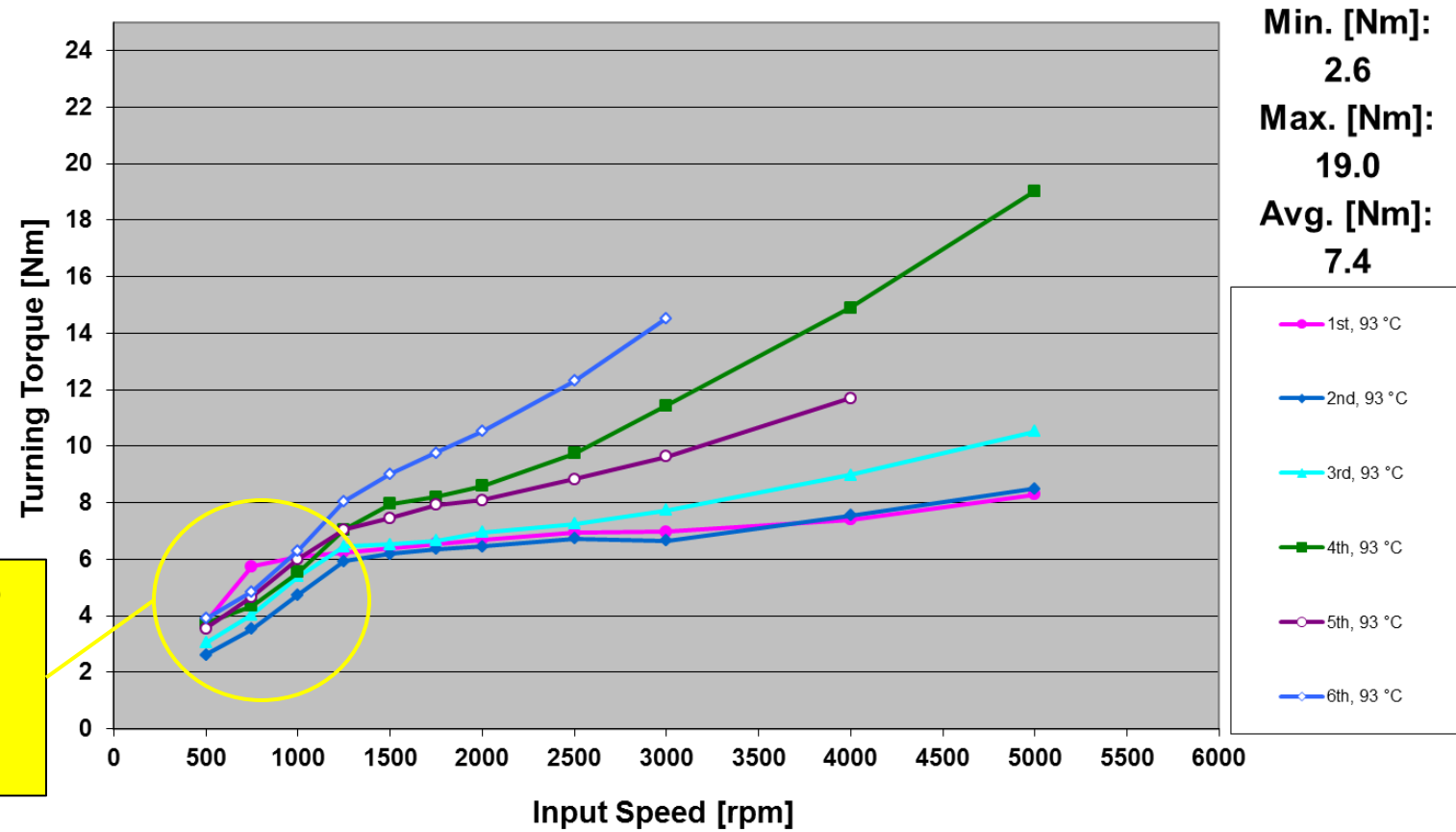
# Chevrolet Malibu 6-Speed AT – Benchmark Transmission Testing – Spin Loss

Spin Loss Results, 37 °C Sump Temp, 10 Bar



# Chevrolet Malibu 6-Speed AT – Benchmark Transmission Testing – Spin Loss

Spin Loss Results, 93 °C Sump Temp, 10 Bar



Internal oil pump  
not capable of  
generating test  
pressure below  
1500 rpm

# Chevrolet Malibu 6-Speed AT – Benchmark Transmission Testing – Spin Loss

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Contract No. EP-C-12-014, Work Assignment 1-5  
April 30, 2013

- Spin loss results are within the expected range for FWD automatic transmissions
- Noticeably higher values for 4<sup>th</sup> gear throughout the test
  - Higher losses in 4<sup>th</sup> likely due to the power flow and open clutch elements associated with this gear (which also appears to be the default – unpowered – gear state of this transmission)
- Some low speed points show lower losses because the speed/ temperature combination did not always allow for generating the full test oil pressure (as marked on associated figures)

# Chevrolet Malibu 6-Speed AT – Benchmark

## Transmission Testing – Torque Converter Testing

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Contract No. EP-C-12-014, Work Assignment 1-5  
April 30, 2013



### 4. Torque Converter Efficiency Measurements

- Gear = 6
- Input speed = 2000 rpm (constant)
- Achieve different torque converter speed ratios (0 .... 1)
- Transmission oil temperature = 93°C
- Transmission line pressures(1):
  - Min-max (minimum pressure to hold highest test load without clutch slip); same as used for loaded efficiency testing = 10 bar

# Chevrolet Malibu 6-Speed AT – Benchmark Transmission Testing – Torque Converter Testing

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Contract No. EP-C-12-014, Work Assignment 1-5  
April 30, 2013

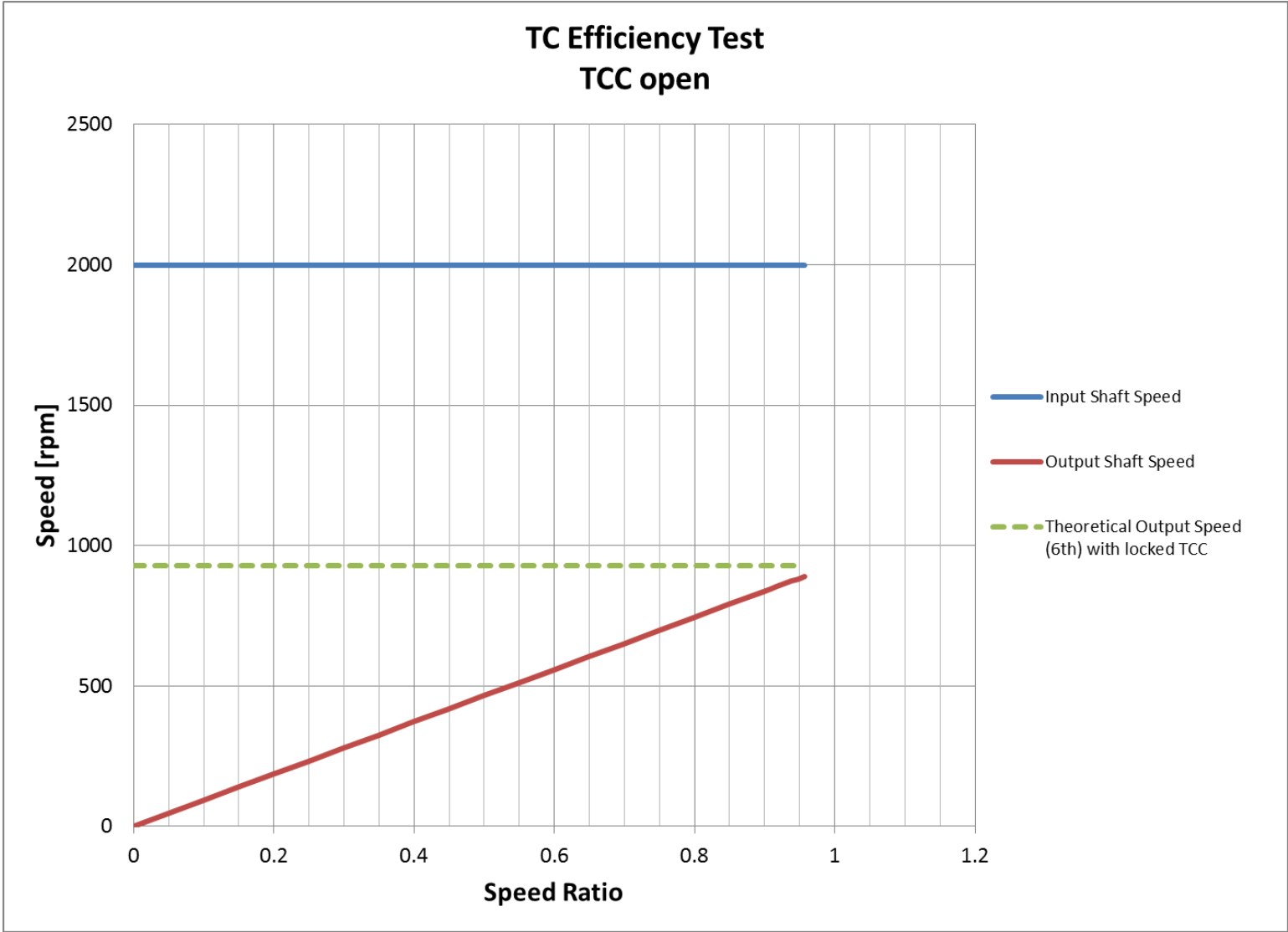


## Method for Calculating Torque Converter Efficiency

- Torque converter efficiency = TC-Turbine Power / TC-Pump Power
- 1. Input shaft of transmission was spun constantly at 2,000 rpm at 93°C and 10 bar main line pressure (in 6<sup>th</sup> gear in this study)
- 2. Torque converter clutch was open throughout test
- 3. Input (= *pump torque*) and output torque values were recorded while controlling (lowering) output shaft speed to force the torque converter into the desired speed ratios
  - i. As the output shaft speed is decreased, the output shaft torque increases unproportionally as a result of the growing (torque multiplying) effect of the torque converter
  - ii. Naturally, the input shaft torque increases also, which results from the added resistance on the output shaft; this also adds to the increasing output torque

# Chevrolet Malibu 6-Speed AT – Benchmark Transmission Testing – Torque Converter Testing

Contract No. EP-C-12-014, Work Assignment 1-5  
April 30, 2013





# Chevrolet Malibu 6-Speed AT – Benchmark Transmission Testing – Torque Converter Testing

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Contract No. EP-C-12-014, Work Assignment 1-5  
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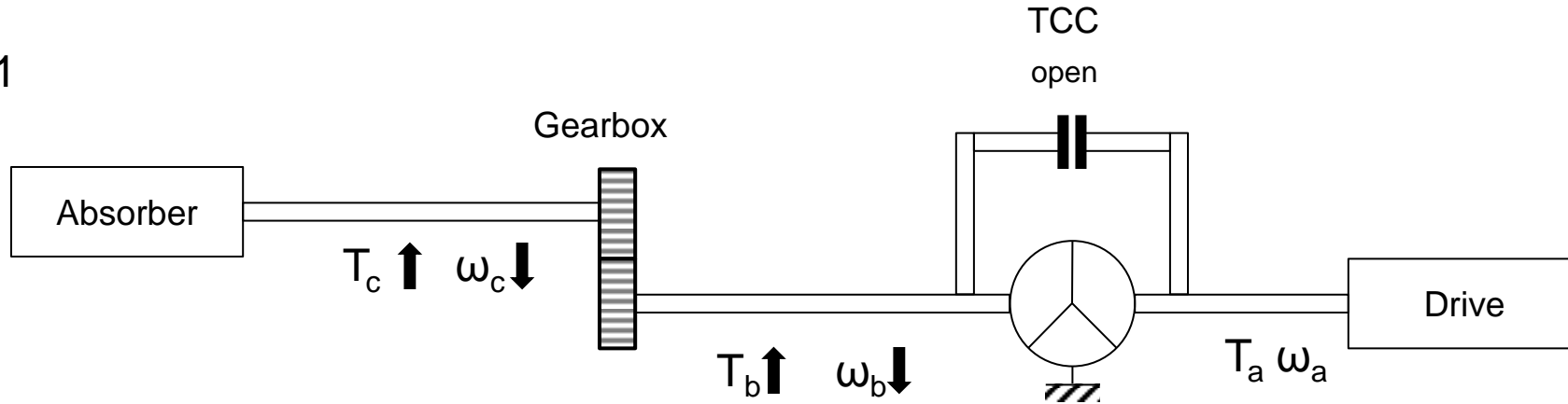
## Method for Calculating Torque Converter Efficiency

4. To find the values for turbine power, repeat the tests with locked torque converter clutch and otherwise equal boundary conditions
  - i. Adjust speed and load to match the recorded values (on the output) of the 'TCC open' test
  - ii. Since the TCC is closed and therefore pump power = turbine power the values for turbine torque can be read on the transmission input torque meter

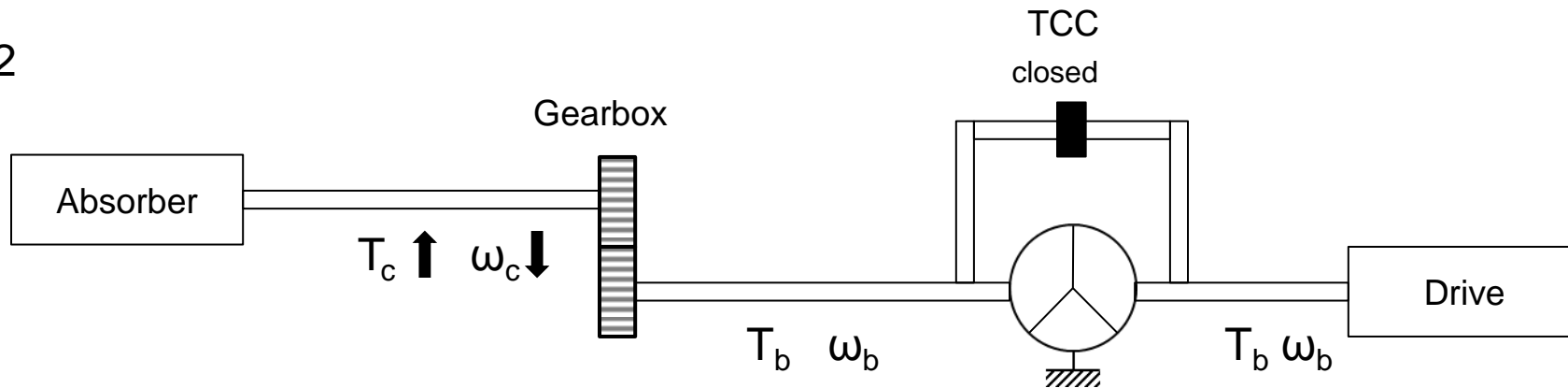
# Chevrolet Malibu 6-Speed AT – Benchmark Transmission Testing – Torque Converter Testing

Contract No. EP-C-12-014, Work Assignment 1-5  
April 30, 2013

# 1



# 2



# Chevrolet Malibu 6-Speed AT – Benchmark Transmission Testing – Torque Converter Testing

Contract No. EP-C-12-014, Work Assignment 1-5  
April 30, 2013

## Torque Converter Efficiency Testing # 1

- Recorded values for 6<sup>th</sup> gear shown in table
  - 6<sup>th</sup> gear ratio (incl. FD): 2.156:1
  - Input shaft speed: 2000 rpm
  - Line pressure: 10 bar
  - TCC open

Speed ratio	Output Speed [rpm]	Output Torque [Nm]
0.00	0	323
0.10	93	312
0.15	139	310
0.20	186	309
0.25	232	305
0.30	278	312
0.35	325	302
0.40	371	295
0.45	417	290
0.50	464	281
0.55	510	272
0.60	557	262
0.65	603	254
0.70	649	243
0.75	696	230
0.80	742	213
0.85	789	183
0.90	835	138
0.91	844	123
0.92	853	108
0.93	863	93
0.94	872	75
0.95	881	55
0.96	891	35

# Chevrolet Malibu 6-Speed AT – Benchmark Transmission Testing – Torque Converter Testing

Contract No. EP-C-12-014, Work Assignment 1-5  
April 30, 2013

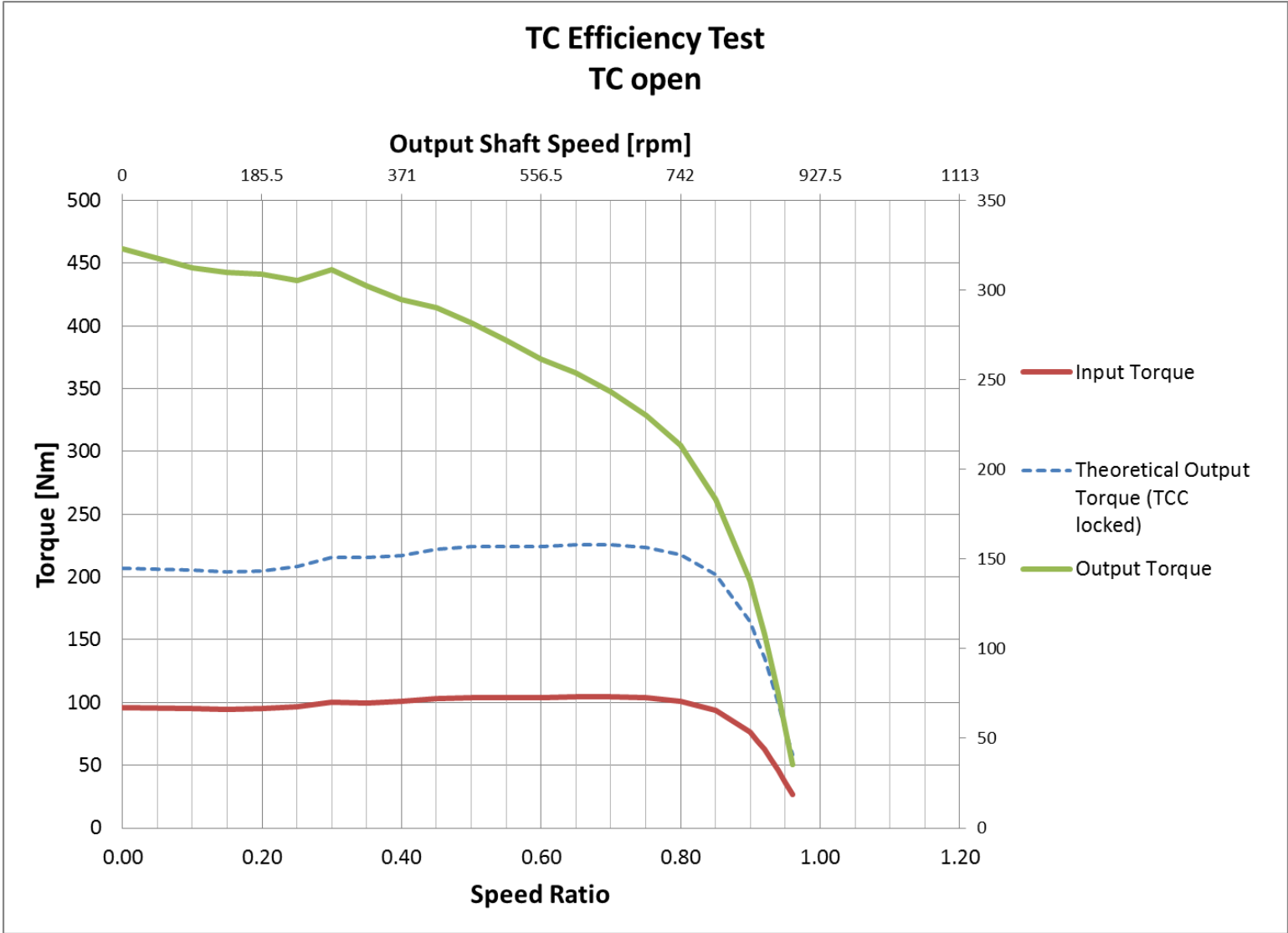
## Torque Converter Efficiency Testing # 2

- Recorded values for 6<sup>th</sup> gear shown in table
  - 6<sup>th</sup> gear ratio (incl. FD): 2.156
  - Line pressure: 10 bar
  - TCC closed

Input Speed [rpm]	Output Speed [rpm]	Output Torque [Nm]
0	0	323
200	93	312
300	139	310
400	186	309
500	232	305
600	278	312
700	325	302
800	371	295
900	417	290
1000	464	281
1100	510	272
1200	557	262
1300	603	254
1400	649	243
1500	696	230
1600	742	213
1700	789	183
1800	835	138
1820	844	123
1840	853	108
1860	863	93
1880	872	75
1900	881	55
1920	891	35

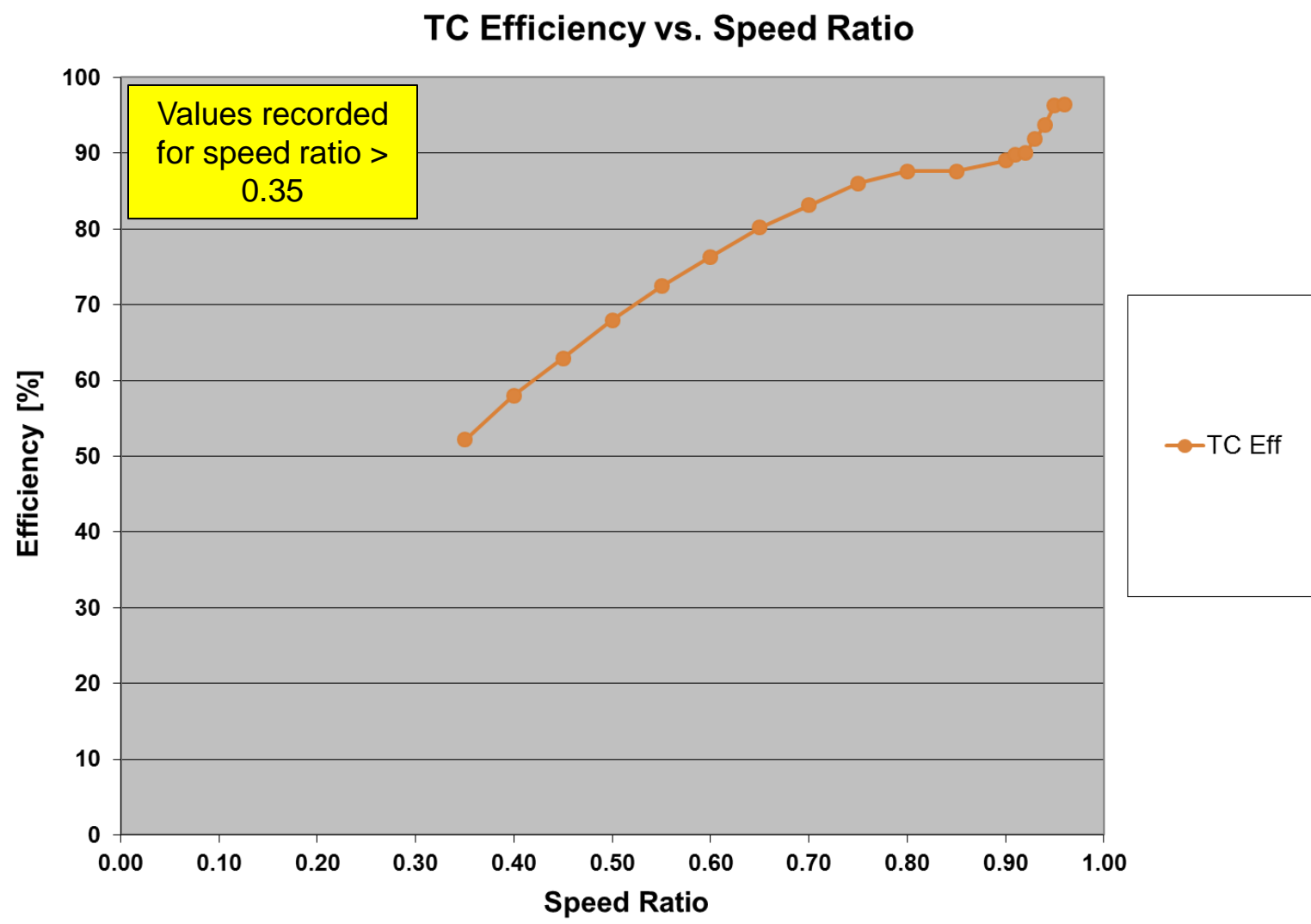
Too low of input speed to generate 10 bar oil pressure to securely transmit desired loads

# Chevrolet Malibu 6-Speed AT – Benchmark Transmission Testing – Torque Converter Testing



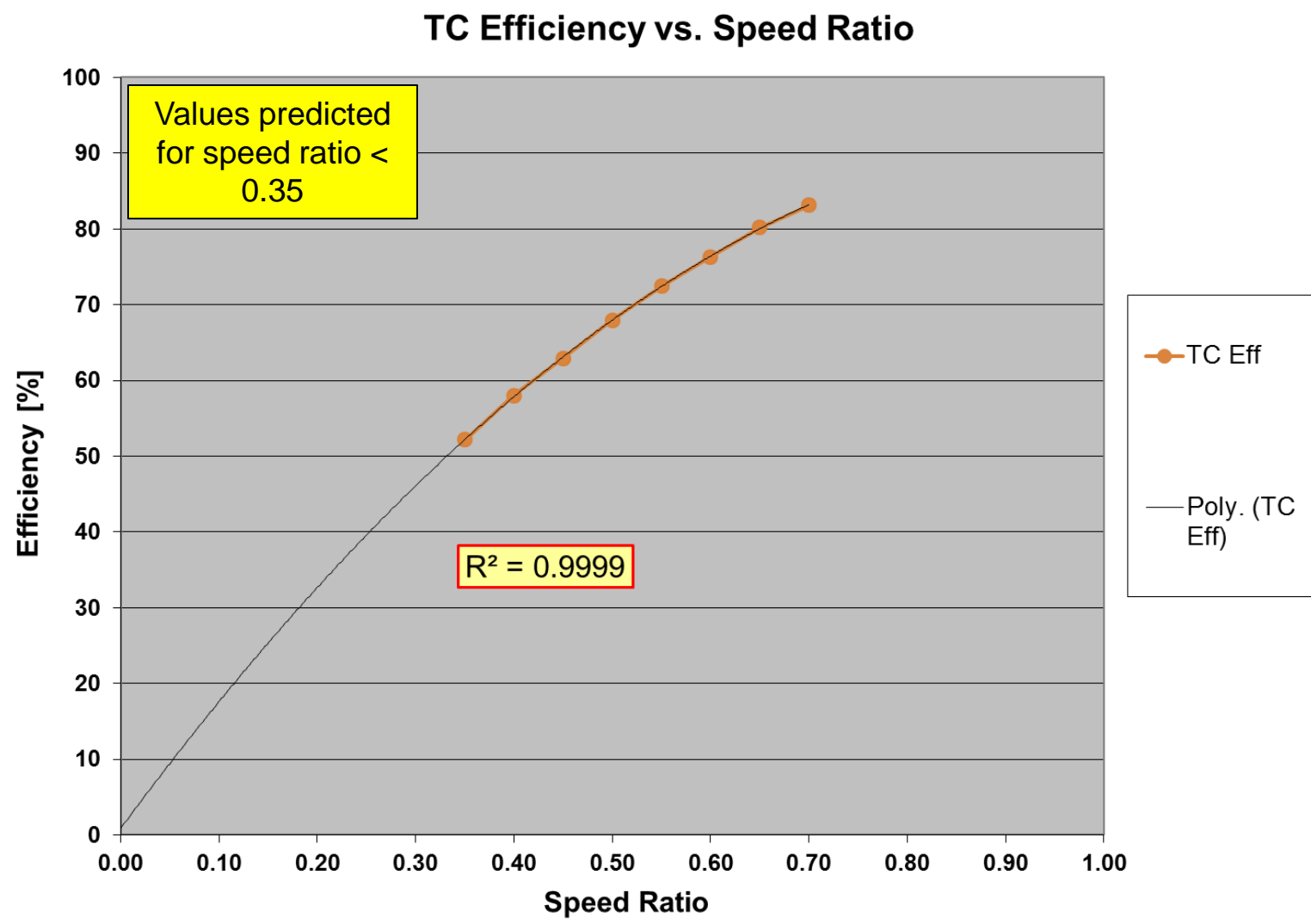
# Chevrolet Malibu 6-Speed AT – Benchmark

## Transmission Testing – Torque Converter Testing

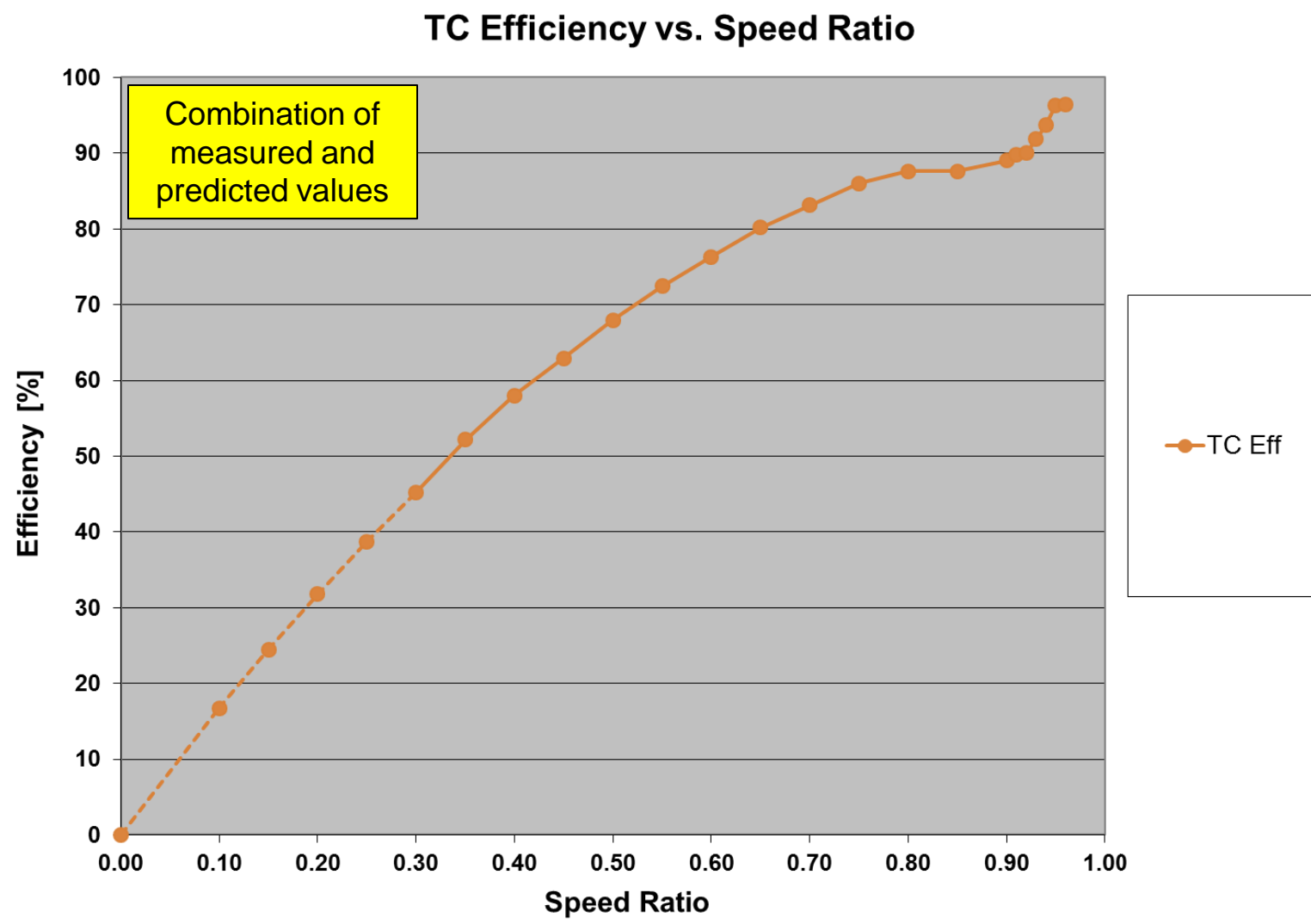


# Chevrolet Malibu 6-Speed AT – Benchmark

## Transmission Testing – Torque Converter Testing

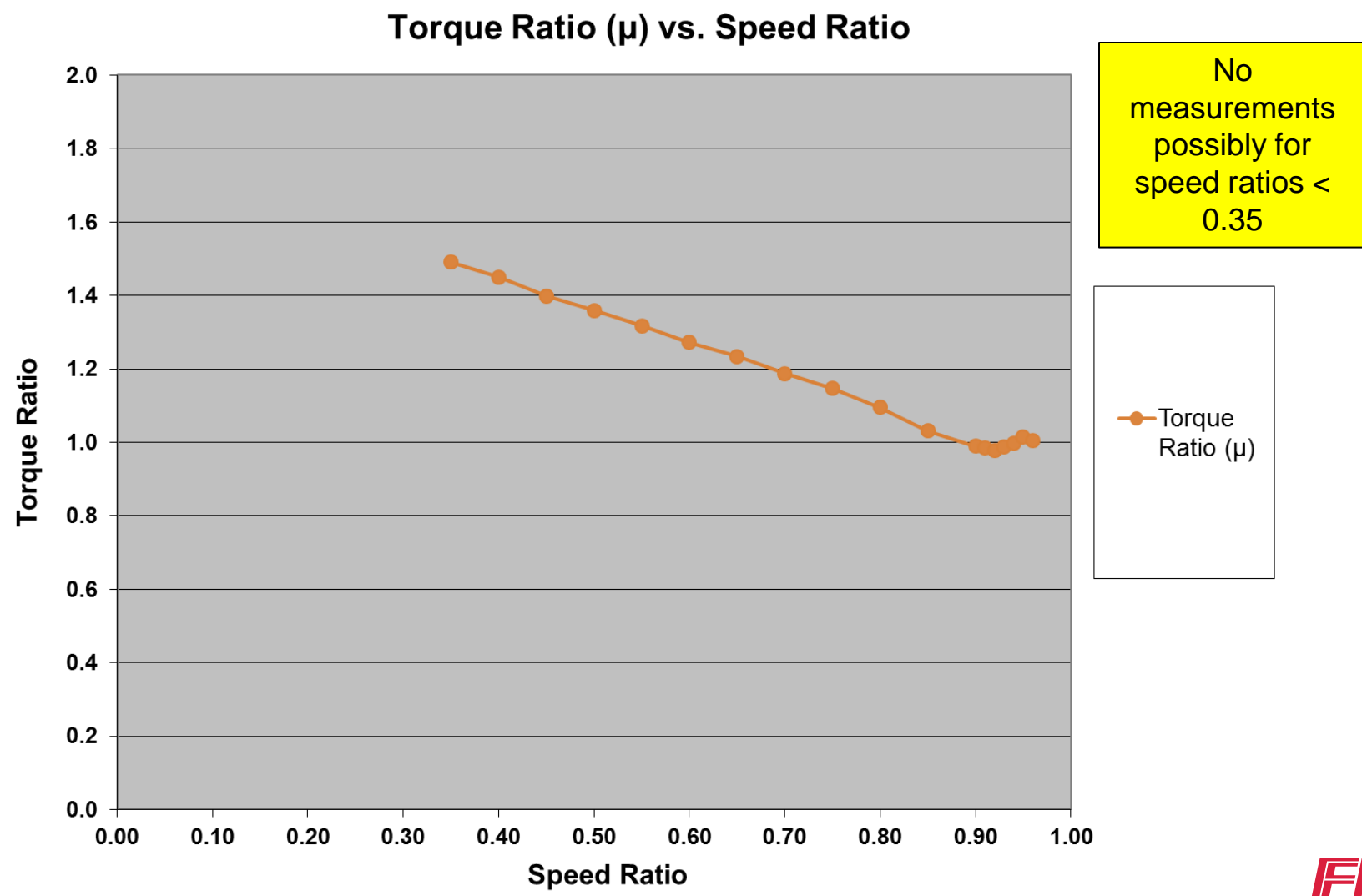


# Chevrolet Malibu 6-Speed AT – Benchmark Transmission Testing – Torque Converter Testing





# Chevrolet Malibu 6-Speed AT – Benchmark Transmission Testing – Torque Converter Testing



# Chevrolet Malibu 6-Speed AT – Benchmark

## Transmission Testing – Torque Converter Testing

