NCAT – National Center for Advanced Technology

National Vehicle and Fuel Emissions Laboratory
Office of Transportation and Air Quality
U.S. Environmental Protection Agency

The following material was prepared by FEV Engine Technology under EPA Contract EP-C-12-014 and describes the test procedures performed by FEV on the 6T40 transmission. Use of any NCAT material provided below, included as part of the complete test data package, should reference the suggested citation provided.

SUGGESTED CITATION: *2013 GM 6T40 Transmission Mapping – Test Data Package.* Version 2019-06. Ann Arbor, MI: US EPA, National Vehicle and Fuel Emissions Laboratory, National Center for Advanced Technology, 2019.

Project: FEV Benchmarking (EP-C-12-014 WA 1-5) **Task:** Transmission Benchmarking - Task 2	**Project #:** P310798 **Date:** 4-30-2013
Client: U.S. EPA	
Subject/Objectives: Transmission benchmark of the GM 6T40 6-speed automatic transmission; FEV performed a transmission benchmark on the GM 6T40 consisting of shift map, no-load spin loss, loaded efficiency and torque converter efficiency measurements. For the tests a GM 6T40 transmission was removed from a 2013 Chevrolet Malibu 2.5L vehicle.	
Method/Solution: FEV completed the vehicle break-in period following the manufacturer's recommendations. The vehicle was driven for a minimum of 4000 miles over a combination of highway and city driving, as is typical for similar FEV benchmarking projects. After the break-in was completed, the shift map evaluation was performed on road and FEV's chassis dynamometer. The transmission was removed from the vehicle and installed on a customized transmission test stand. Adapters were machined in order to connect the transmission to the input drive motor and the absorber. The original transmission controller was deactivated to allow direct control of the shift solenoids. FEV's PWM controller was used to energize the shift solenoids in the appropriate sequence to select gears.	
Summary/Results: The GM 6T40 performed as expected for a 6-speed FWD planetary automatic transaxle. The maximum transmission efficiency measured was 94.5% (5th gear, 93°C) while the global average efficiency is 81.2% (over all speeds, all loads, all gears). The spin loss results are on a similar level with comparable FWD transmissions. The minimum spin loss was recorded in 2nd gear (5 bar, 93°C) with 2.58 Nm and the overall average was 8.34 Nm. In 4th gear, the measured losses were significantly higher than in the other gears which could be related to the powerflow and number of open clutch elements for this gear. Loaded efficiency and spin loss results follow expected trends with respect to input speed, input load, transmission oil temperature and main line pressure. During the torque converter efficiency tests it was found that the converter's K-factor is ~200 and the coupling point is reached at a speed ratio of ~ 0.9.	
Conclusions/Recommendations: The results of the tests conducted yielded results which were in-line with expectations for the FWD transaxle tested. For future benchmarking, FEV recommends a similar test plan to that conducted for this project (including shift map, torque converter, spin loss, and loaded efficiency) in order to gain the full understanding of the transmission efficiency and spin losses.	

Engine Technology

Analysis Report FEV P310798

FEV Benchmarking
2013 Chevrolet Malibu 2.5L GDI
Transmission Testing Final Report

EPA Contract EP-C-12-014 WA 1-5

Prepared for:

U.S. Environmental Protection Agency

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April 30, 2013

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2013 Chevrolet Malibu Vehicle Benchmarking Final Report

A Transmission Benchmarking

FEV, Inc. (FEV) was contracted by EPA under EP-C-12-014 WA 1-5 Task 2 to collect benchmarking data on the GM 6T40 transmission. The vehicle application for this transmission is the MY2013 Chevrolet Malibu 2.5L ECOTEC

This report provides a summary of the transmission benchmarking evaluation performed by FEV. An accompanying set of measured results and an overall project presentation are also provided which include the full set of tests conducted. The scope of work documented in this report contains the transmission test setup, the transmission controls investigation as well as bench and chassis dyno testing. The transmission benchmarking consisted of the following tests. Note that some points were excluded from the test matrix to eliminate operation at 'unreasonable' speed/load conditions which would not be realized under normal operation.

Test Plan:

- Instrument vehicle for shift map evaluation
  - Upshift map: On-road (test track)
  - Downshift map: Chassis dyno

- Remove transmission and install it on test bench
  - Design and fabricate adapters to mount transmission
  - Implement oil conditioning features for transmission temperature control
  - Reverse-engineer transmission controls and clutch schedule to:
    - Control clutches and brakes
    - Control torque converter
    - Control line pressure

- Transmission Test Plan
  - Loaded Efficiency

  - Gears 1 through 6
  - 500 – 5000 rpm input speed (with exceptions)
  - 25 – 250 Nm input load (with exceptions)
  - 37°C and 93°C transmission oil temperature
  - 10 bar main line pressure
- Spin Loss
  - Gears 1 through 6
  - 500 – 5000 rpm input speed (with exceptions)
  - 5 and 10 bar main line pressure
  - 37°C and 93°C transmission oil temperature
- Torque Converter Efficiency
  - 93°C transmission oil temperature
  - 10 bar main line pressure
  - 6th gear selected

B Scope of Work

B.1 Vehicle Break-In Procedure

FEV performed the mileage accumulation according to the manufacturer's break-in procedure outlined in the owner's manual. The typical break-in period for FEV test vehicles ends at 4,000 miles, and the baseline emission test was performed with 4,335 miles on the odometer.

B.2 Vehicle Instrumentation

Following the break-in mileage accumulation the vehicle was instrumented for shift map evaluation. All signals required for the planned tests were obtained from the vehicle's CAN bus. A detailed list of acquired CAN signals is outlined in section C.

B.3 Instrumented Chassis Dynamometer Testing

The shift map evaluation was performed with the dynamometer target coefficients and Estimated Test Weight (ETW) as follows:

A = 38.080 lbs.
B = 0.2259 lbs./mph
C = 0.01944 lbs./mph^2
ETW = 4,000 lbs.

C Methodology/Tools

C.1 Vehicle Instrumentation

For the shift map evaluation, the vehicle's CAN bus was tapped to obtain the following signals:

- Engine Speed [rpm]
- Vehicle Speed [km/h]
- Vehicle Speed [mph]
- Accelerator pedal Position [%]
- Commanded Gear

C.2 Transmission Preparation

For the appropriate determination of the transmission performance, the test rig was set up to measure the following parameters:

- Transmission Input Shaft Torque [Nm]
- Transmission Input Shaft Speed [rpm]
- Transmission Output Shaft Torque Left [Nm]
- Transmission Output Shaft Torque Right [Nm]
- Transmission Output Shaft Speed [rpm]
- Main Line Pressure [bar]
- Oil Sump Temperature [°C]

The input and output torque values were acquired from in-line torque meters as outlined in Figure 1. Since all but the torque converter efficiency tests were conducted with the torque converter clutch locked, the transmission input speed was obtained from encoder installed in the drive motor of the setup. The output speed was acquired from the encoder installed in the absorbing dynamometer.

The main line pressure was read on a service port on the outside of the transmission case using a pressure transducer.

The transmission oil sump temperature was obtained from a K-Type thermocouple located in the transmission drain plug.

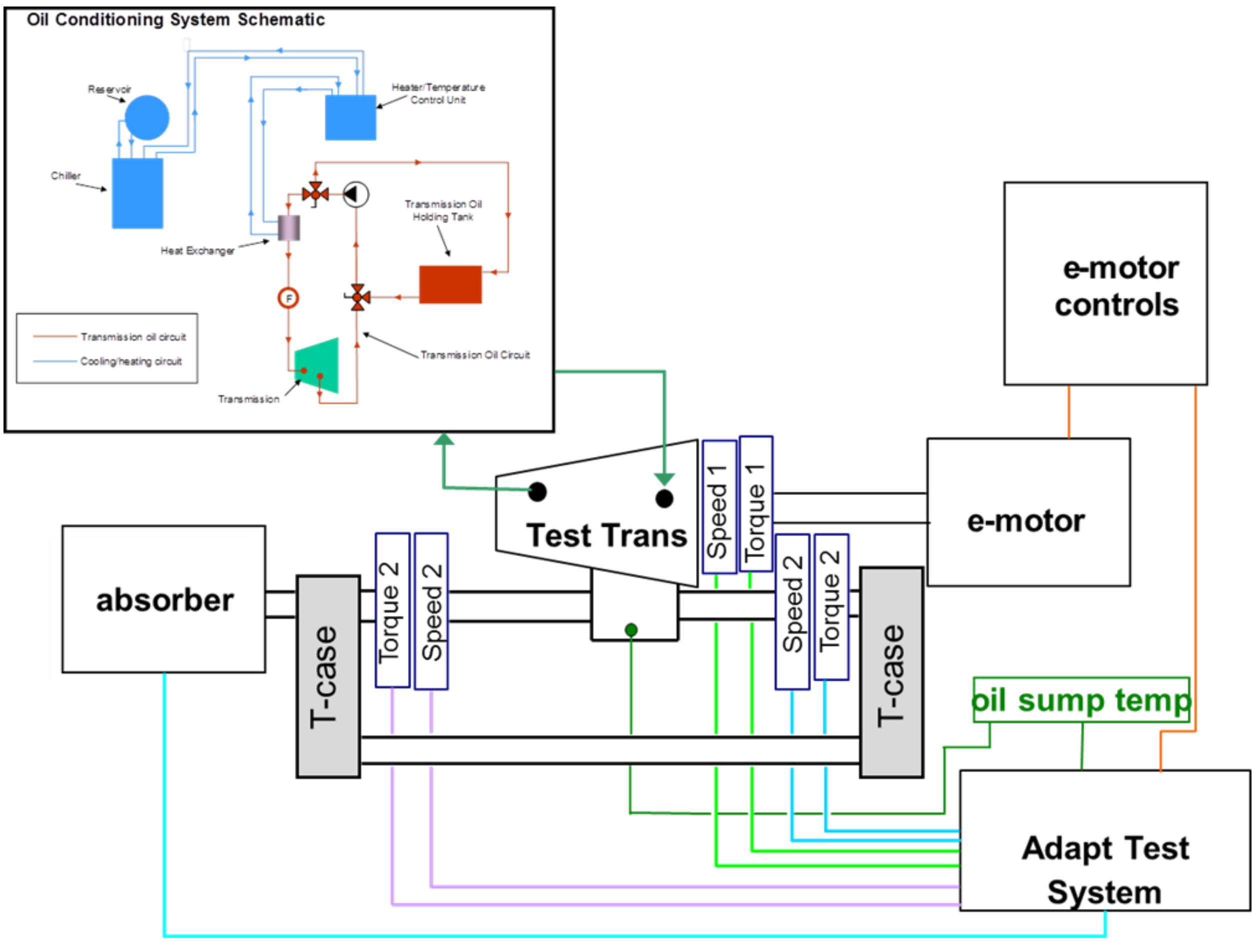

Figure 1: **Test Transmission Setup Schematic**

D Boundary Conditions

The boundary conditions for the transmission tests were outlined in section A.

In order to control the transmission temperature, an additional oil circuit was connected to the transmission. Using the original oil fill opening and an added drain hole, conditioned oil can be circulated (through an external oil pump) to adjust the temperature of the transmission. As shown in Figure 1, this oil conditioning circuit is equipped with a heat exchanger, an external oil pump and an oil filter.

In order to not disturb the natural oil flow inside the transmission during measurements, the auxiliary oil conditioning circuit was only used when not recording data.

Additionally, the OEM ATF cooler ports were used to connect to an oil/coolant heat exchanger to increase the temperature control of the transmission.

E Analysis Results

E.1 Vehicle Shift Map Evaluation

During the only full vehicle test in this section of the project, the upshift and downshift map were recorded for the 2013 Chevrolet Malibu with GM 6T40 transmission.

The upshift map was recorded on a test track while the downshift map was conducted on FEV's chassis dyno. Both experiments included the following accelerator pedal positions.

- 2.5 %
- 5%
- 7.5%
- 10%
- 15%
- 20%
- 30%
- 40%
- 60%

- 80%
- 100%

The upshift map evaluation was performed per the following procedure:

- Vehicle at still stand
- Transmission shifted to “D” (normal mode)
- Recording started
- Desired accelerator pedal position applied
- Recording stopped after terminal vehicle speed was reached for the given pedal position (note, maximum vehicle speed limited to 180 km/h)

The downshift map was conducted after the following procedure:

- Vehicle accelerated to 90 mph on the chassis dyno
- Desired accelerator pedal position applied
- Recording started
- While accelerator pedal position held constant, chassis dyno was slowed down from 90 mph to 0 mph within 30 seconds
- Recording stopped once minimal vehicle speed was reached

After analyzing the acquired data, the shift map for the GM 6T40 transmission was created and is shown in Figure 2.

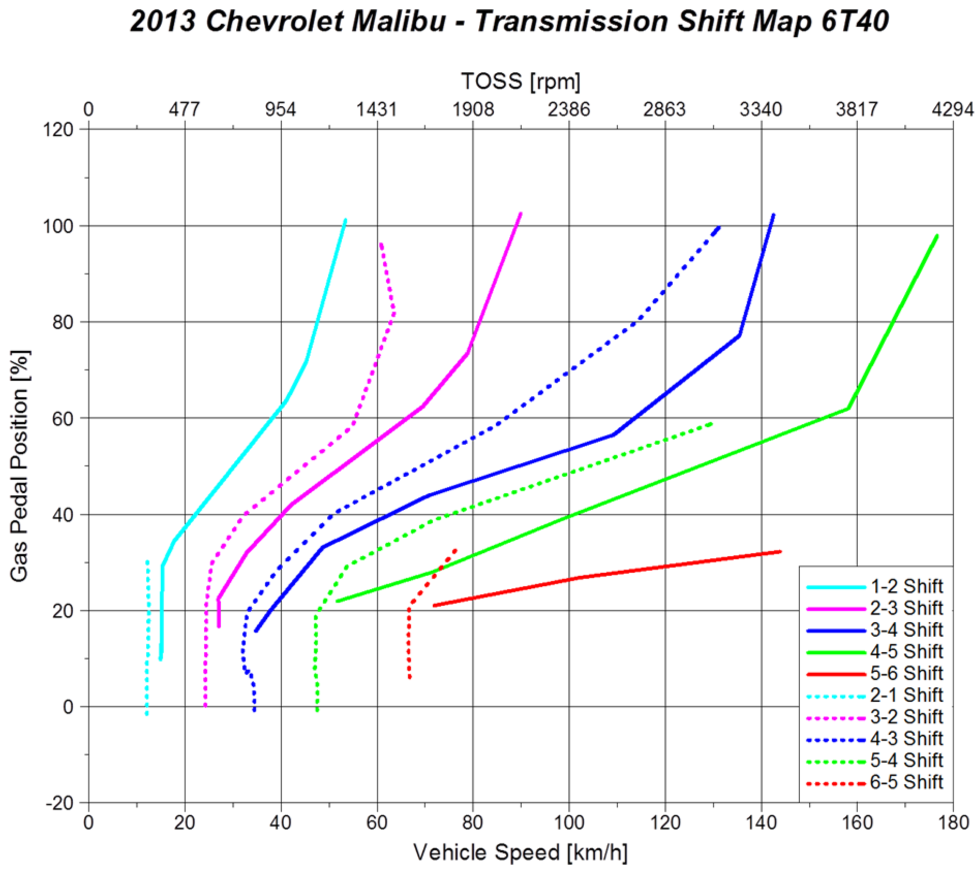

Figure 2: **Transmission Shift Map 6T40**

The plot shows gear shift events as a function of accelerator pedal position (y-axis) and vehicle speed (x-axis). Solid lines indicate an upshift while dashed lines represent a downshift event. For example, the transmission shifts from gear 1 to gear 2 at 17 km/h when 20% accelerator pedal is applied and at 40 km/h when 60% accelerator pedal is applied.

E.2 Transmission Bench Testing

After the vehicle tests were completed, the transmission was removed from the car and installed in FEV's transmission test cell. Figure 3 shows the 6T40 transmission installed on the test bench.

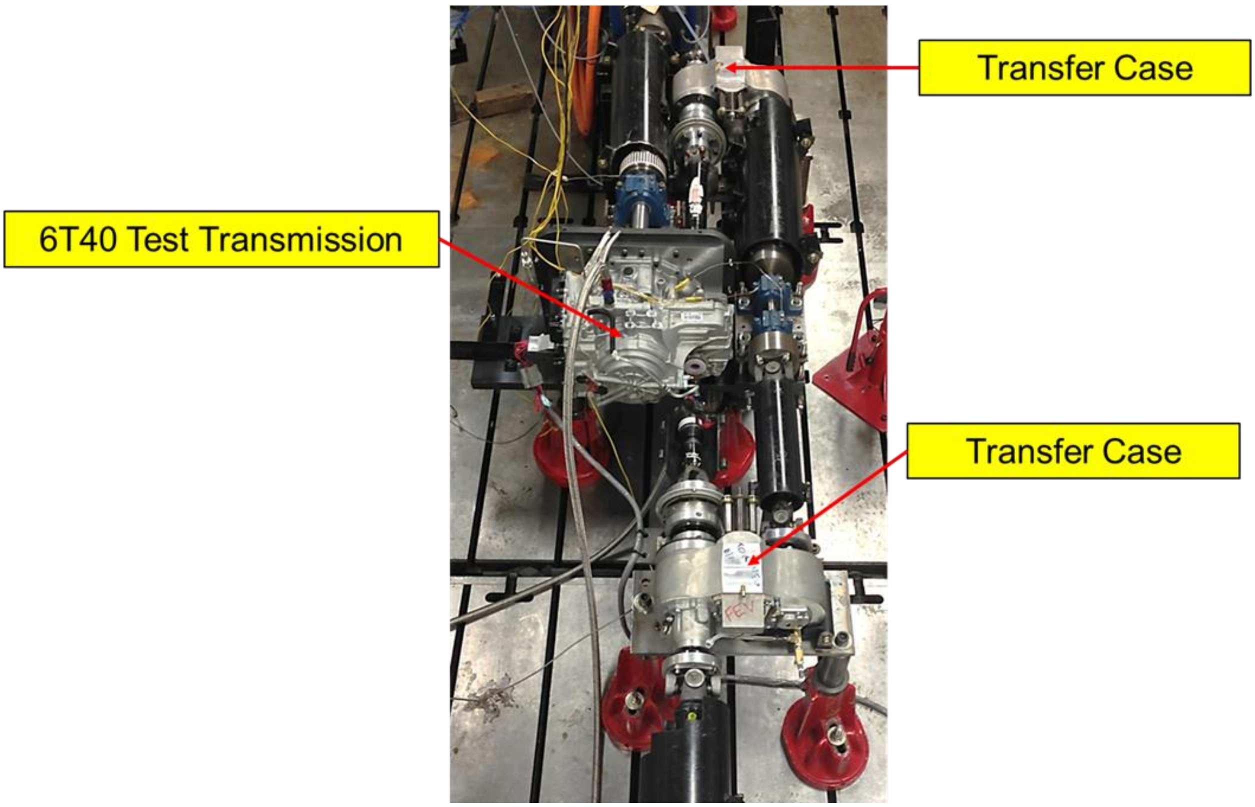

Figure 3: Transmission Bench Test Setup

The transmission was mounted in such a way that the input shaft could be connected to an electric drive motor (top end of picture) and the output shafts could be connected to an absorber (bottom end of picture). Two (2) transfer cases (ratio 1:1) were used on the transmission output shafts to redirect the power flow in a way that a single absorber could be used to develop the target input torque.

For the installation, a custom adapter plate was fabricated incorporating the key features of the bell housing (piloting dowels and faster locations) to mount the transmission on the test stand. Further, a custom input drive adapter was made that connected the input drive motor to the flexplate/ torque converter assembly.

In addition, an auxiliary oil conditioning loop was installed in order to control the transmission oil temperature throughout the test. For this, the original oil fill opening was used as the auxiliary circuit return and an FEV-added port in the sump used as suction. Figure 4 shows the location of feed and return port on the transmission. The auxiliary oil conditioning circuit was used only during temperature adjustment phases and was shut off during data acquisition phases in order to not disturb the natural oil flow within the transmission.

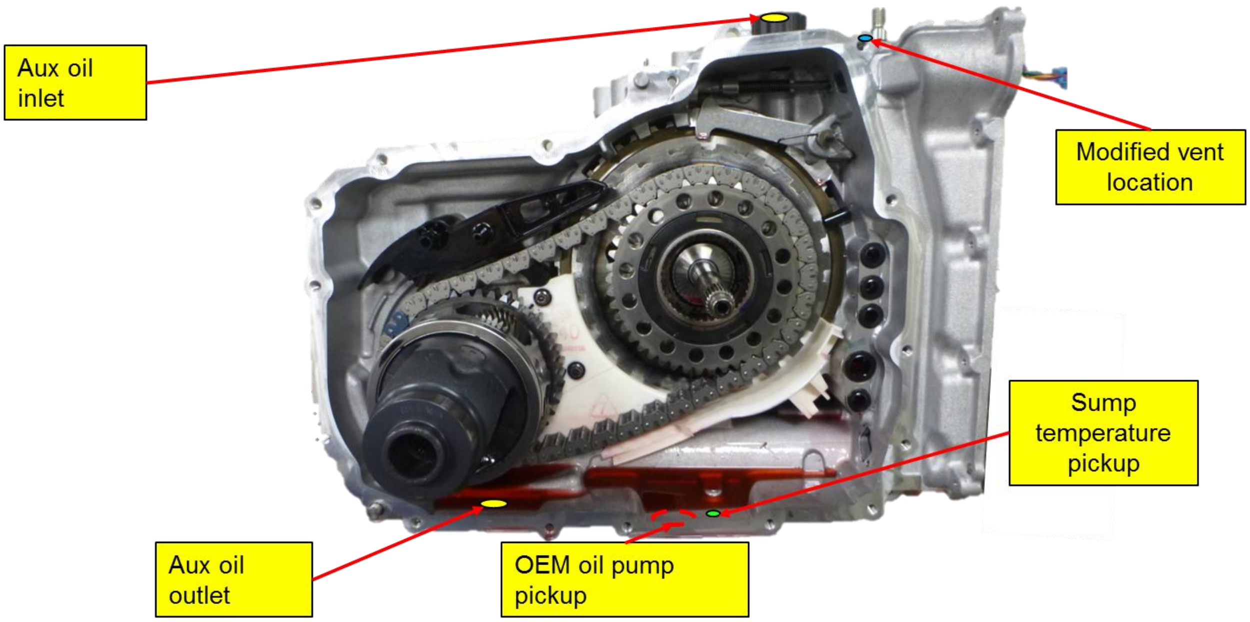

Figure 4: Oil Conditioning Ports 6T40

The transmission sump temperature was measured through a thermocouple installed in the drain plug.

For controlling the transmission's solenoids in the test cell, the TCM was been disabled and all controls were extracted/extended to FEV's controller. FEV's controller has been used successfully in the past to command electric current to transmission solenoids in order to select gears. Manufacturer's information usually gives sufficient details about the solenoid and clutch schedule but the information material available for the 6T40 was proven incorrect which resulted in additional debug/research work to determine the correct shift solenoid schedule.

Despite the efforts of reverse-engineering the GM shift logic, no valid logic was found to securely select first gear under any significant torque. The solenoid settings determined for 1st worked sufficiently for measuring spin losses but not for applying significant loads. In agreement with the EPA WAM, a procedure to estimate the efficiency values for first gear was developed.

Another limitation found during the tests was that no input shaft loads greater than 150 Nm could be transmitted at 93°C oil temperature (likely due to torque converter slip as it happened at the same input torque for all selected gears). The EPA WAM agreed to use FEV's estimation approach for high torques at 93°C to avoid further effort to debug (and/or possibly mechanically locking) the torque converter operation. From various options, a power curve fitting method was selected to extrapolate the existing measurement data to fill in the matrix at the higher torques. Any calculated results are presented using dashed lines to distinguish those results from measured points.

E.2.1 Loaded Efficiency

As outlined in section A, the GM 6T40 was tested at an array of input shaft speeds and input shaft loads to determine the mechanical efficiency of the transmission. An overview of the results for 37°C and 93°C is shown in Figure 5.

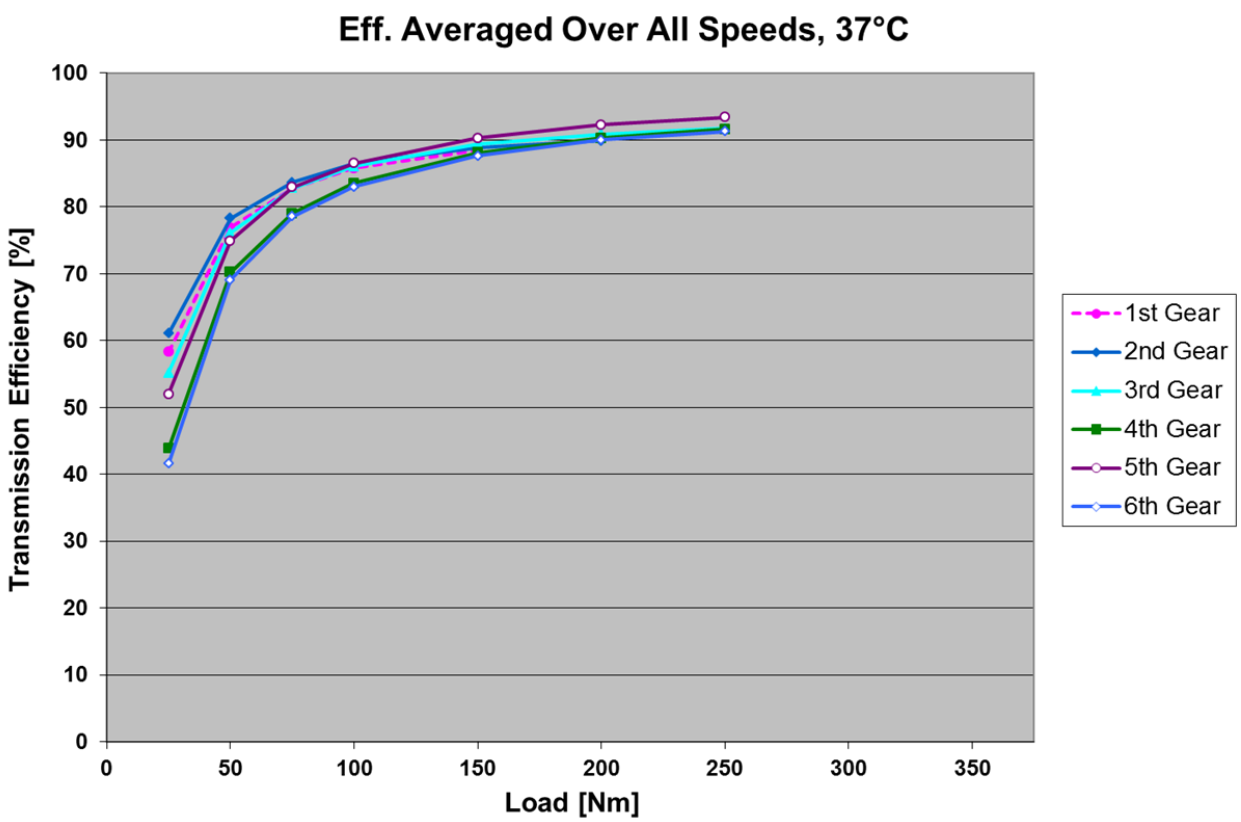

Figure 5: Loaded Efficiency Results 6T40 at 37°C

Plotted is the average transmission efficiency (= output power / input power *100) for each gear over input shaft load. The values shown represent the average of all input shaft speeds per load. The trend of the obtained results matches with the expectations for a front-wheel-drive automatic transmission. The efficiency levels range well within the anticipated range of modern front-wheel-drive automatic transmissions.

The dashed line for first gear indicates that the data was not measured but calculated. Since the power flow in first gear is very similar to the power flow in second gear, it was assumed that the mesh losses are equal in first and second gear. The measured spin losses of first gear were added to the mesh losses of second gear to calculate the efficiency values of first gear.

The results of the loaded efficiency tests at 93°C are shown in Figure 6.

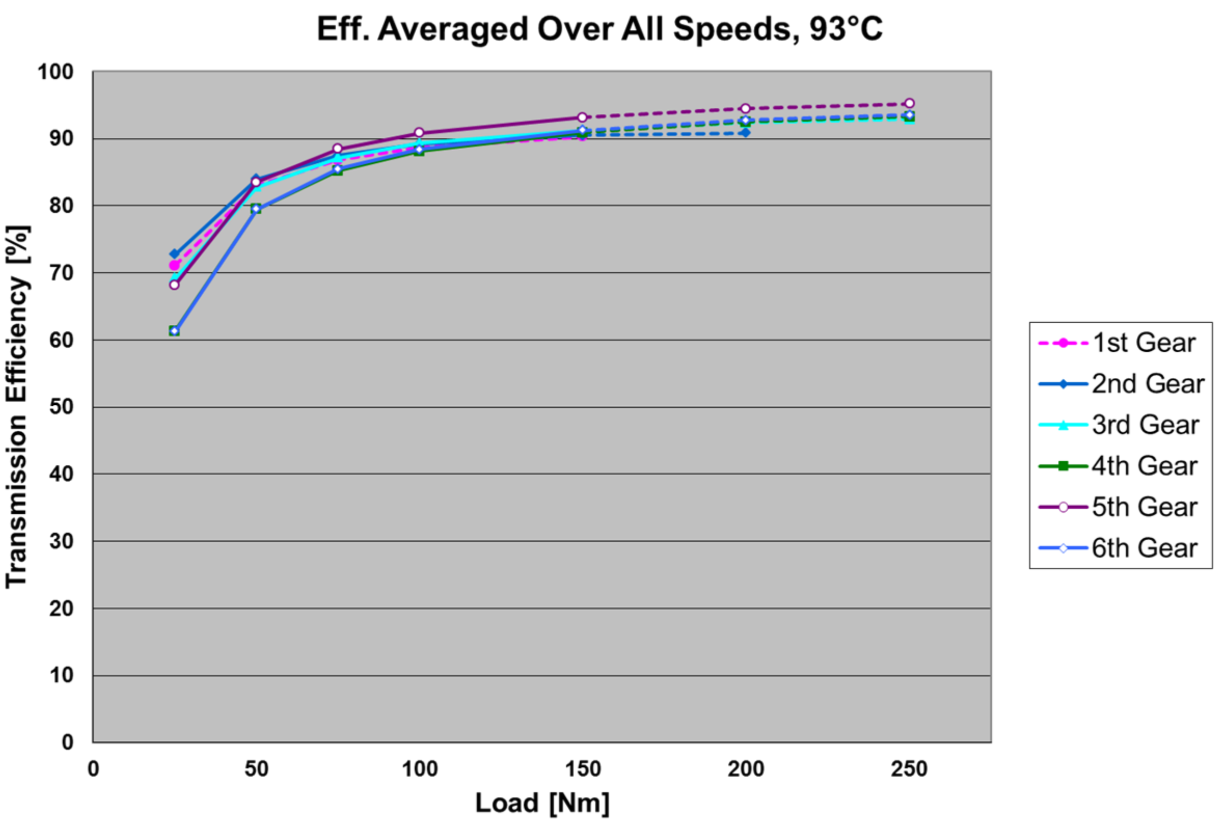

Figure 6: **Loaded Efficiency Results 6T40 at 93°C**

Similar to the results at 37°C, the measured data meets the expectations for an automatic transmission of this class.

The break-down of the efficiency values of each gear is presented in full detail in the document 6T40_Loaded_Efficiency_Results.xls.

E.2.2 Spin Loss

Following the loaded efficiency measurements, the transmission spin losses were evaluated. During these tests, the transmission was driven with the torque converter clutch locked and the output shafts spinning freely. Detailed test conditions can be reviewed in section A of this report.

Shown in Figure 7 are the results of the spin loss tests at 37°C and 10 bar main line pressure. Plotted are the spin losses in Nm over input shaft speed in rpm.

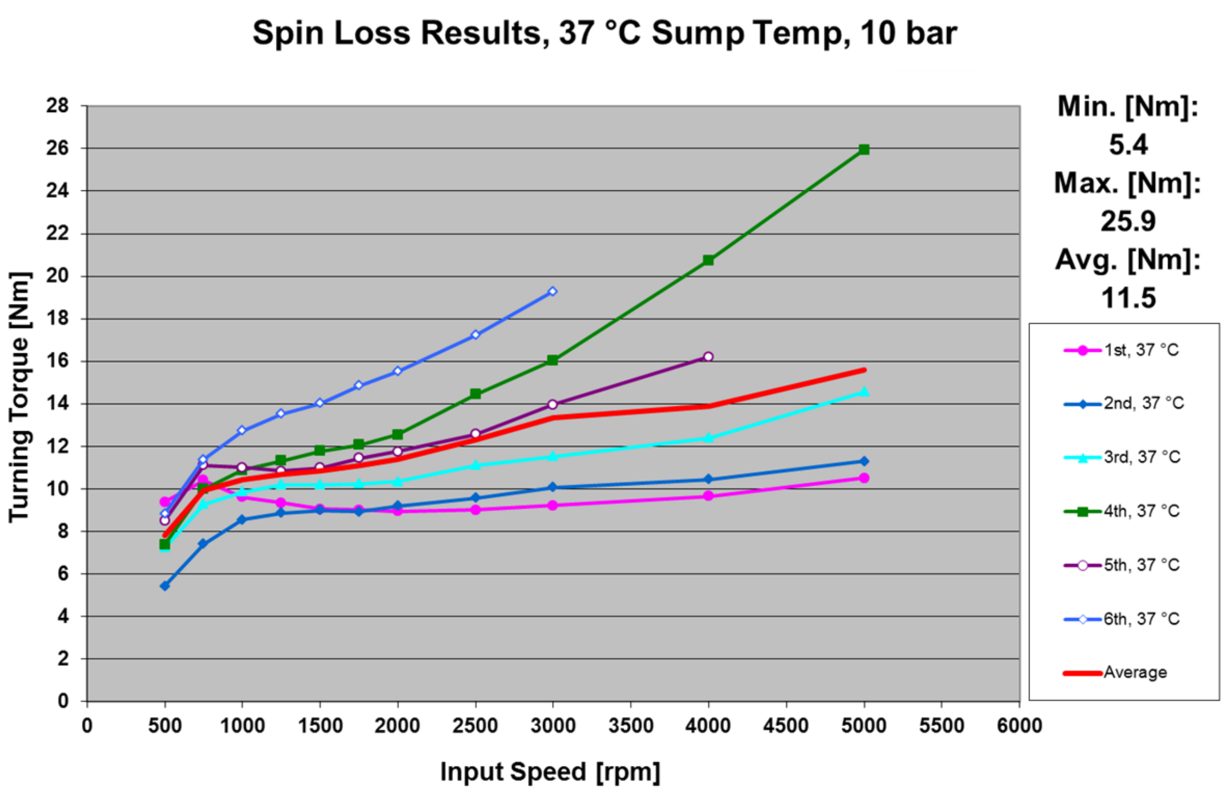

Figure 7: **Spin Loss Results 6T40 at 37°C, 10 bar**

The results represent expected values that lie within the range of current front-wheel-drive automatic transmissions (although the losses in fourth gear seem high relative to 5th gear). It is assumed that the higher spin losses in fourth gear are due to the powerflow and open clutch elements associated with this gear (which also appears to be the default – unpowered – gear state of this transmission).

It should be noted that at speeds below 1000 rpm the internal mechanical oil pump was not capable of generating the test oil pressure of 10 bar and therefore the spin losses appear to be lower in this range.

The results of the spin loss tests at 93°C oil temperature are shown in Figure 8. The general characteristic and 'stacking' of gears matches the observations at 37°C although at a lower overall level (compare average spin losses of 11.5 Nm at 37°C to 7.4 Nm at 93°C); this reduction in spin losses with increasing oil temperature is as expected.

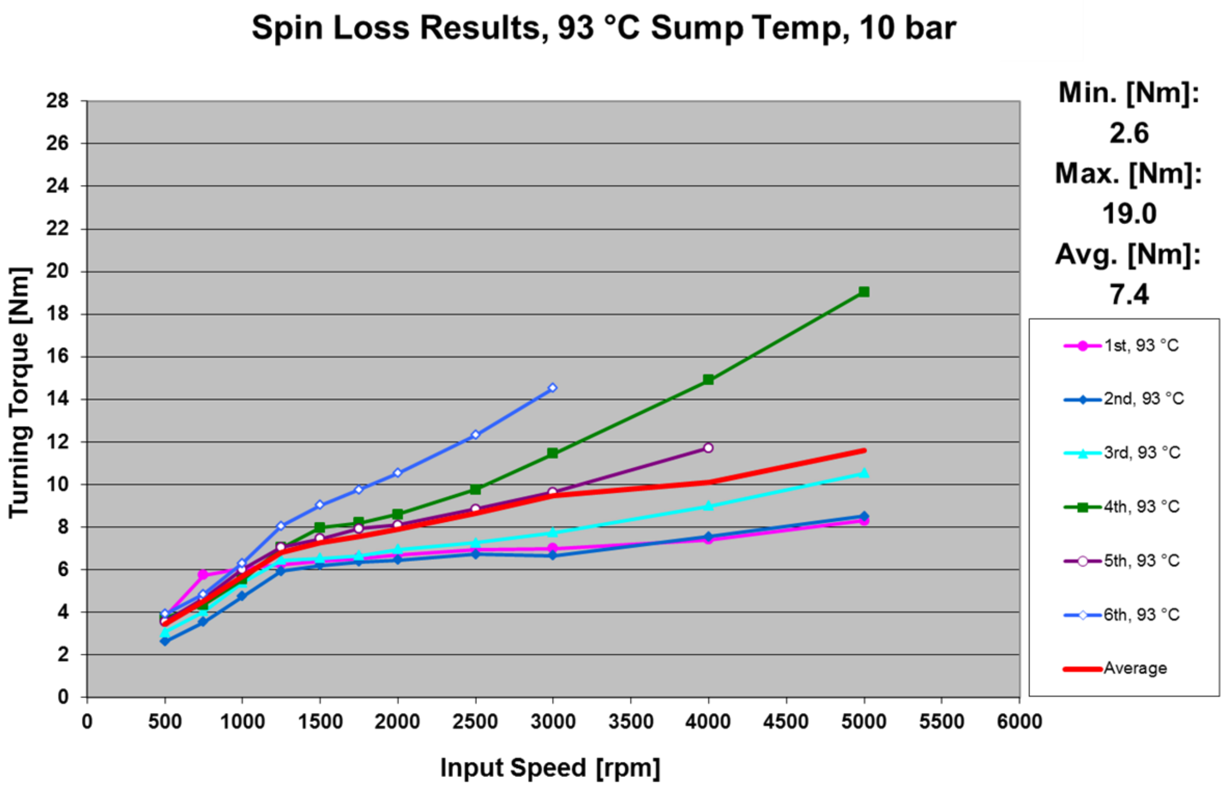

Figure 8: **Spin Loss Results 6T40 at 93C, 10 bar**

Due to the lower viscosity of the transmission oil at 93°C the transmission oil pump is not capable of generating the required test oil pressure of 10 bar below input speeds of 1500 rpm. Therefore the results at input speeds slower than 1500 rpm seem disproportionally lower.

The full data set of spin loss results is presented in the document 6T40_Spin_Loss_Results.xls.

E.2.3 Torque Converter Efficiency

During the torque converter efficiency study various tests were performed in order to determine pump and turbine power of the torque converter. The transmission was spun at

2000 rpm input speed in sixth gear, 93°C oil sump temperature and 10 bar main line pressure to observe its behavior while decreasing output speed (with TCC open). The same test was repeated with locked torque converter clutch while matching the torque and speeds recorded on the output (determined during in the first test), in order to back-out the associated gearbox losses. Figure 9 shows the procedure in a schematic form.

Test #1 was performed to determine the torque converter pump power for defined operating points (T_a, ω_a). Test #2 was set up to find the correlating turbine power (T_b, ω_b) to test #1. In order to determine the turbine power, the torque converter clutch was closed and the scenario downstream of the torque converter was reproduced to match test #1. With this setup, the turbine power equals the pump power which can be obtained from the input torque meter and the drive dyno speed sensor.

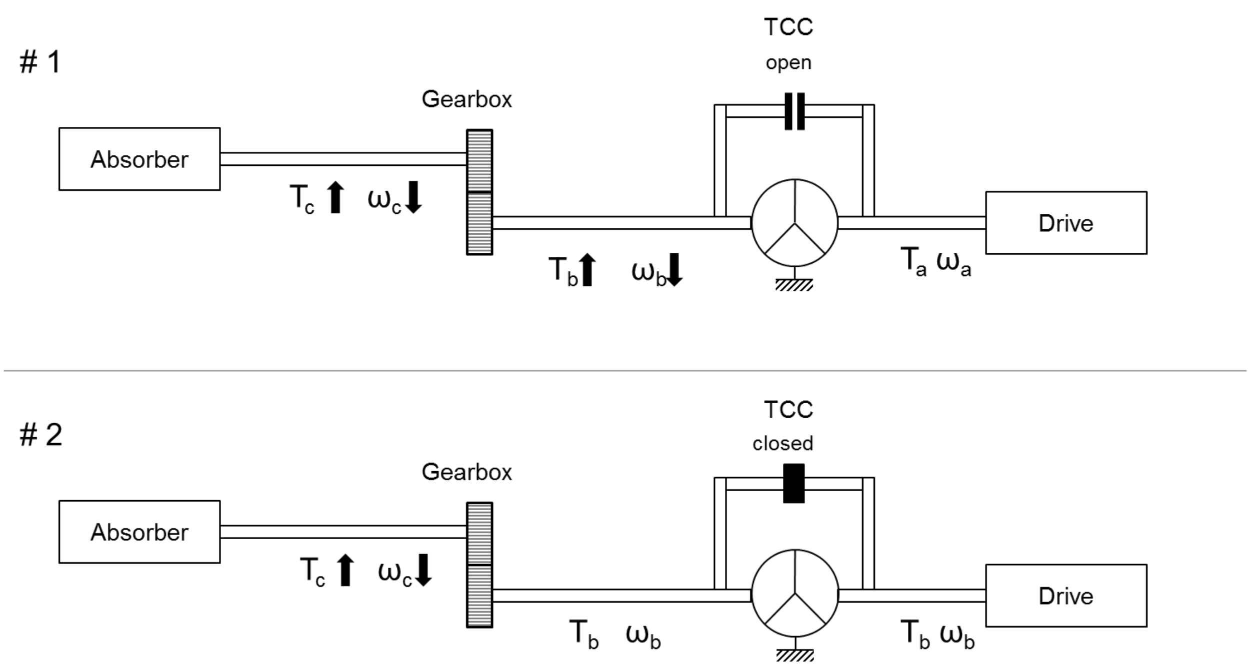

Figure 9: **Torque Converter Efficiency Evaluation Procedure**

The results of the two (2) tests were combined to calculate torque converter efficiency, K-factor as well as torque ratio.

Since reproducing the output power values from the first test required a high level of oil pressure, not all points could be recreated. Especially at speed ratios below 0.35 where the equivalent input speed was too low to generate the line pressure needed to securely transmit the accompanying loads. For these lower speed points, the data was extrapolated via curve fitting. This approach closely matches (for the lower speeds) what would have been obtained using a fixed efficiency for the gearbox over these points. FEV chose to use the outlined approach for higher speed ratios in order to obtain more precise results in the area where the torque converter characteristics are not as easily predicted.

In Figure 10 the results of the torque converter efficiency study are presented.

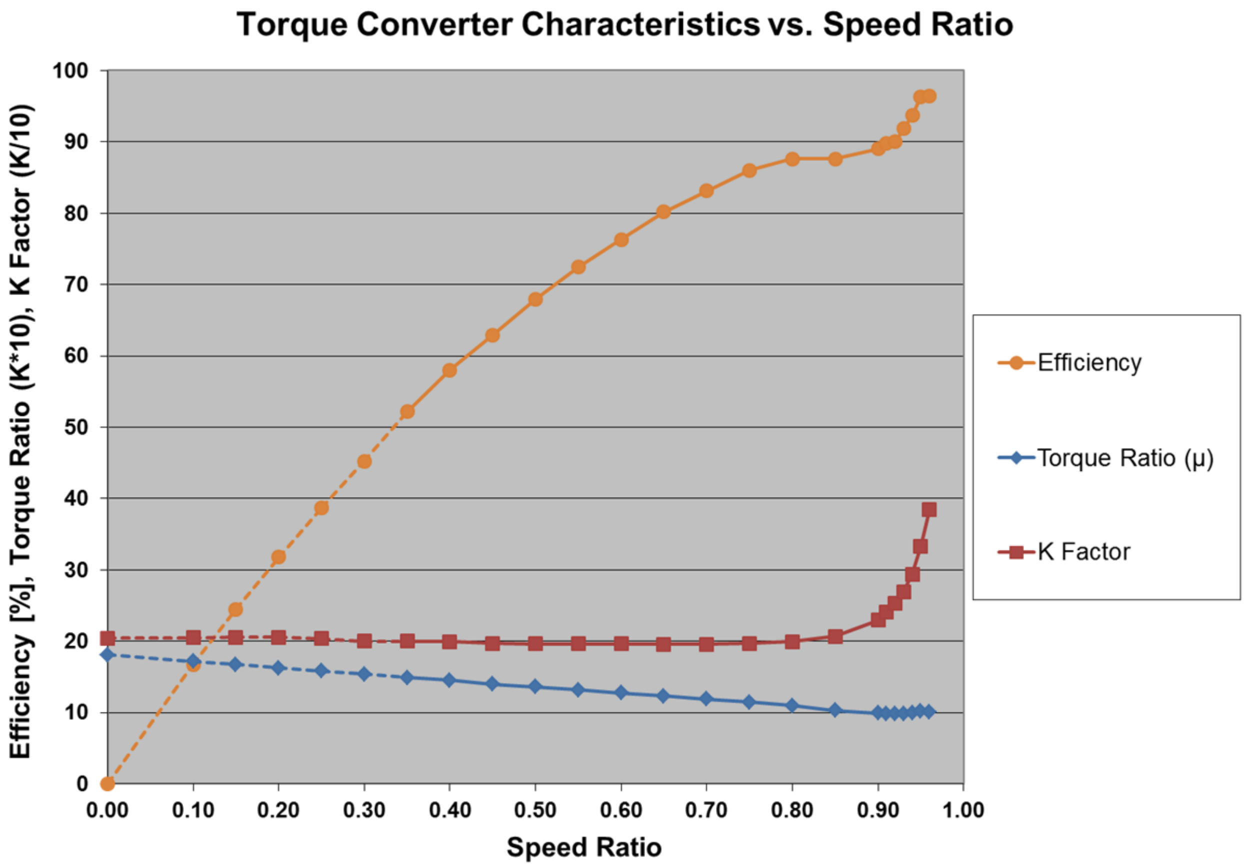

Figure 10: Torque Converter Characteristics 6T40

The torque converter efficiency is displayed by the orange line and shows that the coupling point lies at ~0.9 speed ratio. The K-factor is represented by the red line indicates that this torque converter has a K-factor of ~200. The conversion factor μ is shown as the blue line. As with previous data outlined in this report, segments of the results presented based on calculation are shown with dashed lines.

The full data set of the torque converter test is presented in the document 6T40_Torque_Converter_Test_Results.xls.

F Summary

Benchmarking the GM6T40 transmission yielded expected results and trends. Though this transmission uses a chain drive for the differential (rather than a gear set as is typical in many transmissions); the measurement results show this transmission performs similarly to comparable 6-speed front-wheel-drive automatic transmission in this class.

The trends observed during testing match the expectations when comparing losses and efficiency at low oil temperature to those at high temperature. Higher oil temperatures yield lower losses and therefore higher efficiency values. Reviewing the spin loss data with respect to line pressure, the expected trend of increased input torque with increasing pressure is evident.

The torque converter tests for the 6T40 transmission show the expected characteristics of modern torque converters.