INCREASE OF THE ENERGY EFFICIENCY OF PASSENGER CARS USING DIFFERENT TYPES OF TRANSMISSIONS

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INTRODUCTION

Vehicle fuel economy (FE) norms are being implemented world over to conserve energy and for reduction in carbon dioxide emissions. The European Union standards are based on fleet averaged carbon dioxide emissions, while the Japan standards are based on vehicle weight. The EU has already set the standards applicable for the model year 2012 and Japan for the year 2015. The US and Japan standards are mandatory. The EU standards are voluntary in nature so far but become mandatory from the year 2012. [1, 2]

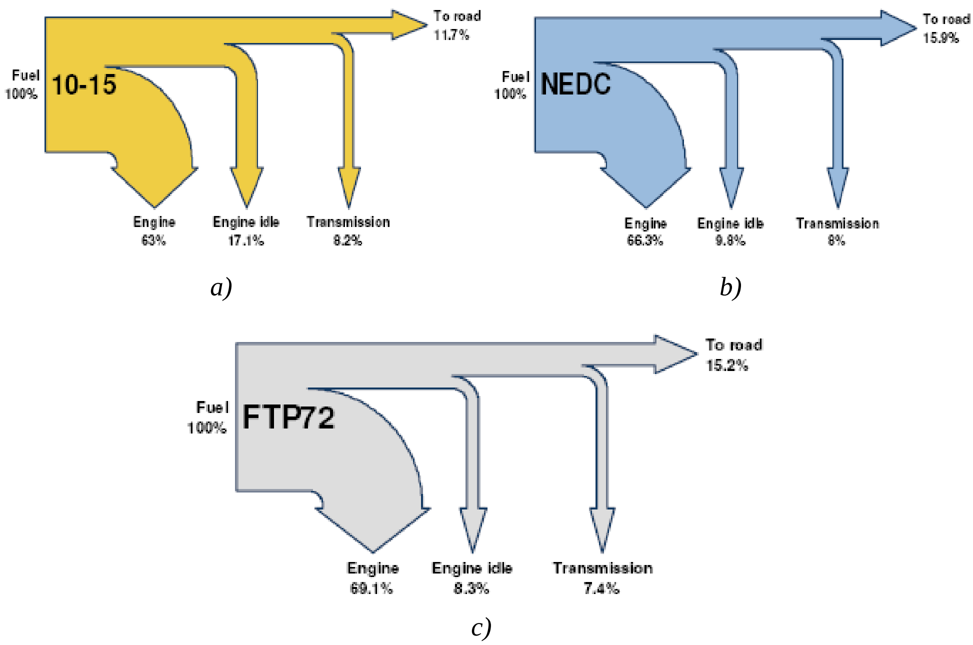

Figure 1: *Calculation results of energy losses for*
a) the Japanese 10-15, b) the European NEDC cycle and c) the US FTP72 cycle [3]

On the Figure 1 is shown energy lost in the transmission and other parts of the driveline. The new technologies, such as automated, manual transmission and continuously variable transmission, are being developed to reduce these losses. Also, in recent years, power

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transmission systems are using more number gears going to 6-, 7- and 8- gear transmissions and continuously variable transmission (CVT) to reduce fuel consumption and emission of CO_2. The new transmission designs lead to a fuel consumption reduction in the New European Driving Cycle (NECD) of 6 to 8%. In parallel, there is also an increase in acceleration from 0 to 100 km/h of 4 to 10%.

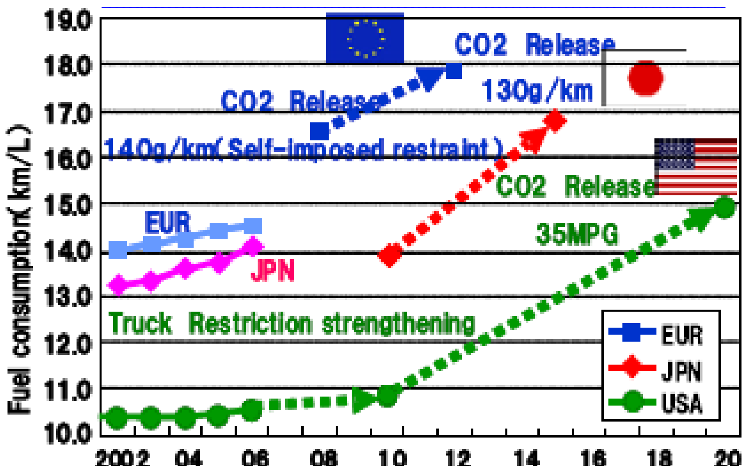

Figure 2: *Fuel economy target (EU, JPN, US) [4]*

On the Figure 2 is shown fuel economy target and CO_2 reduction for EU, Japan and US.

EFFECT OF TRANSMISSION TECHNOLOGY ON FUEL ECONOMY

Knowing that, engine performance map shows relationship between fuel consumption, engine torque and speed, it is demonstrated that the best engine fuel efficiency is obtained when it operates in medium to low speed range and at high loads. Engine specific fuel consumption (mass of fuel consumed per kilowatt-hour) increases as the operating point moves away from the best efficiency point. For example, if a vehicle has been designed for a 5-gear transmission and it is operated in 4^{th} gear at constant speed of 100 km/h the specific fuel consumption of the engine may typically increase by nearly 15% as the engine would be operating at higher engine speed and lower torque [1]. The highest possible gear is therefore, selected to keep the engine speed low and torque high. If more gears are available than it is more likely that the engine would operate close to the best efficiency point at all the vehicle speeds. A larger number of gears say, 5 to 6 in comparison to 4 forward gear ratios also results in better fuel economy and CO_2 reduction.

A reduction in fuel consumption is approximately half as expensive when achieved with investment in the drive train compared to sophisticated engine concepts. The transmission affects fuel consumption in two ways. One factor is its own transmission losses; the other is providing suitable ratios for fuel – efficient utilisation of engine power. Geared transmissions are still the most efficient, although there is now a significant factor of continuously variable transmission. But the main factor affecting consumption is still the driver. This main factor affecting reducing fuel consumption includes the follows:

- Improving the efficiency of the internal combustion engine, particularly by reducing part-load consumption.
- Appropriate engine performance characteristics, i.e. the vehicle must be neither over-powered nor under powered.
- Reducing driving resistance, for example rolling resistance and drag.
- Reducing the power draw of accessories such as servo pumps, air conditioning, etc.
- Improving the efficiency of the transmission. This relates principally to continuously variable transmission.
- Traffic management system to reduce stationary periods.
- Improved driving. Intelligent control system, which protect the driver against his own misjudgement. There are many factors involved in determining how far "usurping" of control can go [5].

A drive train components supplier has to deliver these fuel economy improvements while enhancing comfort. Coming from traditional components such as the self-adjusting clutch, dual mass flywheel and clutch release system, these components have been optimised over the years and they continue to evolve and are becoming more efficient, reliable and comfortable.

Effect of number of gear ratios and other changes in power transmission on vehicle fuel economy are given in Table 1. Also, in Table 1 is given how different types of transmission could influence on the reduction of CO_2. In further text, it would be explained each of the transmission technology improvements mentioned in Table 1.

Automatic gear transmission is another technology that influences fuel economy. As automatic transmission has been developed, more forward speeds have been added to improve fuel efficiency, performance and improve a vehicle's market position. Increasing the number of available ratio provides the opportunity to operate an engine at more optimized condition over a wider variety of vehicle speeds and load condition.

Automated shift manual transmission (AMT) operates similarly to a manual transmission except that it does not require clutch actuation or shifting by the driver. Automatic shifting is controlled electronically (shift-by-wire) and performed by a hydraulic system or electric motor. In addition, technologies can be employed to make the shifting process smoother than conventional manual transmissions. This system can deliver a 15% improvement in fuel economy compared to conventional automatic transmission [6]. Figure 3 shows the possible savings resulting from automating manual transmission such as the parallel shift gearbox or by means of mild hybridisation.

Continuously variable transmission (CVT) is unique in that it does not use gears to provide ratio for operation [7]. Instead, the most common CVT design use two V-shaped pulleys connected by a metal belt. Each pulley is split in half and a hydraulic actuator moves the pulley halves together or apart. This causes the belt to ride on either a larger or smaller diameter section of the pulley which changes the effective ratio of the input to the output shafts. Ideally, a continuously variable transmission (CVT) provides best means to implement the strategy of engine operation near best efficiency point at all the vehicle speeds (Figure 4).

Elimination of hydraulic torque converter improves fuel economy as the fluid slippage increases energy losses. With hydraulic torque converter the engine idling speed is to be kept at higher levels compared to manual transmission increasing vehicle fuel consumption.

Table 1: *Effect of Transmission Technology on Fuel Economy and CO_2 Reduction of Passenger Cars [8]*

Transmission Technology Improvement/Change	**Fuel Economy* [%]**	**Reduction CO_2 [%]**
Use of 5-gear automatic instead of 4 -gear automatic transmission (aggressive shift logic)	1 - 2	2.5
Use of 6-gear automatic instead of 4 -gear automatic transmission	3 - 5	4.5 – 6.5
AMT (automated shift manual transmission) instead of 4 -gear automatic transmission	7 - 9	9.5 - 14.5
CVT in small FWD instead of 4 -gear automatic transmission	3 - 8	6
Elimination of torque converter	2 - 3	0.5

*NAS report 2002, NESCCAF report 2004

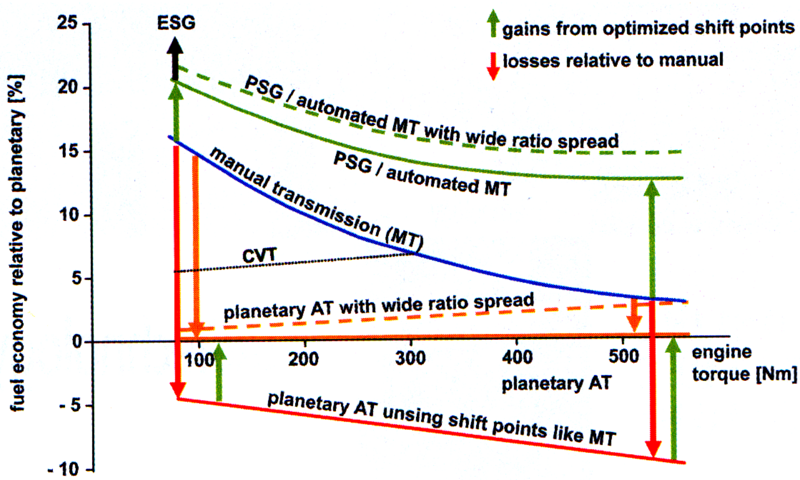

Figure 3: *Differences in fuel consumption for several transmission concepts [5]*

- PSG – parallel shift gearbox,
- ESG – electronic shift gearbox,
- AT – automatic transmission,
- AMT – automated manual ttransmission

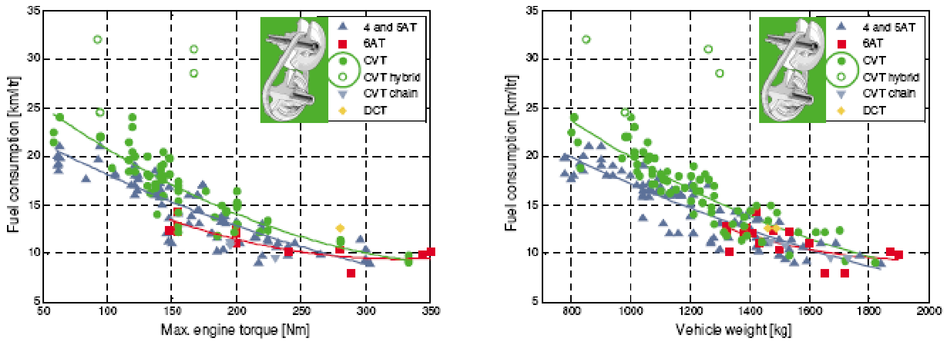

Figure 4: *Fuel consumption of FWD vehicles with several transmission types as currently available on the Japanese market (OEM data of European applications on the Japanese market) [3]*

ENERGY EFFICIENCY OF DIFFERENT TYPE OF TRANSMISSION

The increase of energy efficiency is resulted by the reduction of fuel consumption which is different in order to transmission (automatic or manual). The energy efficiency of automatic transmission has increased with the introduction of the torque converter lock-up clutch, which practically eliminates fluid losses when engaged. Modern automatic transmissions also minimize energy usage and complexity, by minimizing the amount of shifting logic that is done hydraulically. Typically, control of the transmission has been transferred to computerized control systems which do not use fluid pressure for shift logic or actuation of clutching mechanisms.

Hydraulic automatic transmissions are almost always less energy efficient than manual transmissions due mainly to viscous and pumping losses; both in the torque converter and the hydraulic actuators. A relatively small amount of energy is required to pressurize the hydraulic control system, which uses fluid pressure to determine the correct shifting patterns and operate the various automatic clutch mechanisms.

Manual transmissions use a mechanical clutch to transmit torque, rather than a torque converter, therefore avoiding the primary source of loss in an automatic transmission. Manual transmissions also avoid the power requirement of the hydraulic control system, by relying on the human muscle power of the vehicle operator to disengage the clutch and actuate the gear levers, and the mental power of the operator to make appropriate gear ratio selections. Therefore, the manual transmission requires very little engine power to function, with the main power consumption due to drag from the gear train being immersed in the lubricating oil of the gearbox.

The on road acceleration of an automatic transmission can occasionally exceed that of an otherwise identical vehicle equipped with a manual transmission in turbocharged diesel applications. Turbo-boost is normally lost between gear changes in a manual whereas in an automatic the accelerator pedal can remain fully depressed. This however is still largely dependent upon the number and optimal spacing of gear ratios for each unit, and whether or not the elimination of spool down/accelerator lift off represent a significant enough gain to counter the slightly higher power consumption of the automatic transmission itself.

CONCLUSIONS

This paper presents the effect of different transmissions on fuel consumption which affect energy efficiency and emission of CO_2. A reduction in fuel consumption is approximately half as expensive when achieved with investment in the drive train compared to sophisticated engine concepts, however the effect of different transmission is about 8%. Some of the transmission technology improvements affect the fuel economy by small but important percentage such as use of 5-gear or 6-gear automatic instead of 4 -gear automatic transmission; use of CVT in small FWD instead of 4 -gear automatic; elimination of torque converter; use of AMT (automated shift manual transmission) instead of 4 -gear automatic etc. To conclude, it is shown that hydraulic automatic transmissions are almost always less energy efficient than manual transmissions due mainly to viscous and pumping losses; both in the torque converter and the hydraulic actuators.

After price, reliability and fuel efficiency are primary decision factors for car buyers. When buying a new car, drivers want to have confidence that their cars are reliable and long lasting, with excellent fuel efficiency and low CO_2 emissions. The comparison reviews investigating fuel consumption and acceleration characteristics of passenger cars with different type transmission concepts show the significant advantages offered by new transmission concepts currently being launched as volume production models. Therefore, these new transmission make a considerable contribution towards reducing fuel consumption and assist the automotive industry in significantly reducing fleet consumption and exhaust emissions. At the same time, they offer the vehicle driver greater performance and increased driving comfort.

REFERENCES

[1] B. P. Pundir: „Fuel Economy of Indian Passenger Vehicles - Status of Technology and Potential FE Improvements“, Greenpeace India Society, 2008

[2] F. An, A. Sauer: „Comparison of Passenger Vehicle Fuel Economy and Greenhouse Gas Emission Standards Around the World“, Pew Center on Global Climate Change, 2004

[3] F. Van der Sluis at all: „Fuel Consumption Potential of the Pushbelt CVT“, FISITA, 2006

[4] T. Shibayama, H. Yada, Y. Morita, M. Fujikawa: “Introduction of the latest hydraulic control system for automatic transmission”, Proceedings of the 7th JFPS International Symposium on Fluid Power, Toyama, 2008, pp.137-142

[5] G. Lechner, H. Naunheimer: “Automotive transmission - Fundamentals, Selection, Design and Application”, Springer, 1999

[6] P. Gutzmer: “Global Trends in Transmission Development”, Auto Technology 2, pp. 70-71, 2004

[7] M. Terruso, G. Virzi’ Mariotti: “Prediction of Driving Performance of a Hybrid Vehicle with CVT transmission”, Mobility and Vehicle Mechanics, vol. 35, num. 3, pp. 25-42, September 2009.

[8] EPA Staff Technical Report: Cost Effectiveness Estimates of Technologies Used to Reduce Light-duty Vehicle Carbon Dioxide Emission, EPA, United State Environmental Protection Agency, 2008

[9] John B. Heywood**:** More Sustainable Transportation: The Role of Energy Efficient Vehicle Technologies, A report for OECD for the International Transport Forum, Leipzig, Germany, 2008

[10] REGULATION (EC) No 443/2009 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 April 2009 setting emission performance standards for new passenger cars as part of the Community's integrated approach to reduce CO_2 emissions from light-duty vehicles

[11] Jovičić N., Šušteršič V, Gordić D., Babić M.: "Computer Aided Engineering in Modeling of Hydrodynamic Coupling", Mobility Vehicle and Motors, vol. 30, Number 2&3, pp. 41-51 September 2005