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Zeroshift Automated Manual Transmission (AMT)

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ABSTRACT

Zeroshift technology allows a manual transmission to change gear in zero seconds. The Zeroshift Automated Manual Transmission (AMT) is easy to manufacture and allows a cost effective alternative to the traditional torque converter based automatic transmission. Zeroshift offers potential fuel economy improvements from driveline efficiency and the best possible vehicle acceleration. Compared to an existing AMT, Zeroshift offers an uninterrupted torque path from the engine to vehicle which allows for a seamless gearshift. This seminal paper provides an introduction to the technology together with test data from a demonstrator vehicle.

INTRODUCTION

The world is dominated by two forms of transmission, the Manual Transmission (MT) and the Automatic Transmission (AT). The MT has a single dry clutch operated by the driver, whilst the AT uses wet clutches that are automatically controlled. There are pros and cons in both transmissions.

The MT is the most efficient transmission available. This lends itself to providing good fuel economy for the vehicles it is employed in. The efficiency of the MT is dependent on the load applied. Over a representative drive cycle its efficiency can approach 97% [1]. The MT is very easy to manufacture having very few parts. It is reliable and easy to maintain.

It's main weakness is that it is less easy to drive than an AT especially in congested traffic as it requires the driver to operate the clutch for each gear shift. Gear shifts are sometimes not smooth which causes discomfort for passengers who will notice an interruption of engine torque to the wheels when the transmission is between gears. In severe situations, the interruption of torque can cause dynamic instability of the vehicle resulting in loss of control.

The AT has many advantages which include ease of driving and very smooth shift quality. The choice of gear is determined by a Transmission Control Unit (TCU) and this will ensure that the best gear is chosen for the vehicle road speed depending on whether the driver requires fuel economy or performance. Drivers are willing to pay a premium for this type of transmission even though performance and fuel economy are inferior to the MT.

A reduced performance and fuel economy is apparent because of the lower efficiency of the transmission. Not only are there parasitic losses for operation of the hydraulic pump, but large amounts of slip in the torque converter generates heat loss which warms the transmission fluid rather than providing torque to the wheels. In recent years a lock up clutch bypasses the torque converter for a large proportion of the journey which can improve the overall efficiency dramatically. The efficiency of an AT can be as high as 86% [1].

From a manufacturing point of view, the AT contains many parts and is more difficult to service if it develops a fault. In addition, some countries like India have few AT factories meaning that OEMs have to pay an import duty tax on each unit. This increases the purchase price of vehicles equipped with an AT. This reduces the penetration of a much desired transmission in a price sensitive market.

If a transmission could have the benefits of both the MT and AT and the weaknesses of neither, this would introduce a third option to segment the market. By automating the MT, a cheap and economic transmission is created. Traditionally, the AMT has had good fuel economy, inferior performance (compared to the MT) and

bad shift quality. Zeroshift corrects these latter two issues allowing simultaneously good fuel economy, performance and shift quality. The combination of these has not been seen in any other transmission, previously.

This paper is split into the following sections: Firstly, the concept of Zeroshift is introduced. Secondly, the benefits in terms of fuel economy, performance, shift quality and ease of manufacture are illustrated. Finally, the conversion of a Ford Mustang demonstrator vehicle is described.

ZEROSHIFT CONCEPT

The drive components that make up a Zeroshift hub assembly are very simple but very effective (Fig. 1). The system consists of 2 drive elements mounted on a common hub. Each element is double-faced where one face can only drive in one direction and the opposite face in the opposite. When paired back-to-back, they both provide either a direct-drive or a ramp face depending on drive direction configuration.

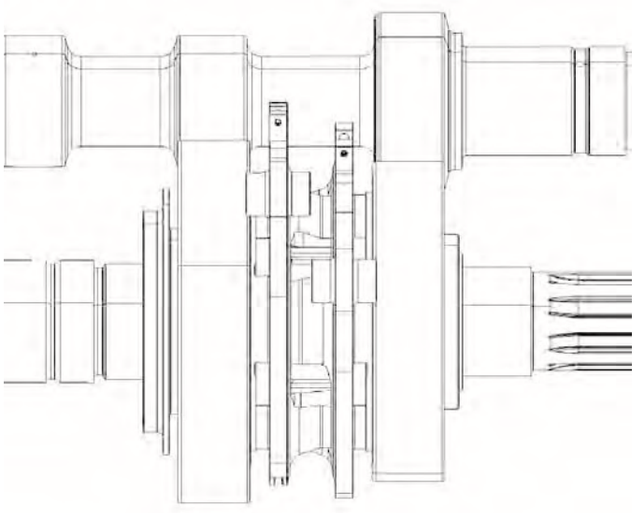

Figure 1 : Two Zeroshift Hubs

When initiating a shift from the neutral position, one drive ring is engaged with the dog faces on the gear and the second ring joins the first axially adjacent which provides drive in the opposite direction to oppose engine overrun and, more importantly, eliminate perceivable backlash. This ring is unloaded and is the ring to make the next shift and as such requires less shift force i.e. much less than synchroniser force.

The instantaneous shift is by definition a torque hand-over from one gear to another. This creates a torque or energy spike in the driveline which is dissipated through a combination of engine and transmission management, clutch control and system compliance. The result is a continual delivery of torque and unaffected vehicle stability. The main benefits of Zeroshift are:

- fuel economy
- performance
- shift quality
- ease of manufacture

FUEL ECONOMY : The fuel economy of a vehicle is a function of many components including its powertrain. The two main components of the powertrain that determine fuel economy are the engine and transmission. It has been stated by more than one company that to reduce CO_2 it is twice as cost effective to develop the transmission rather than the engine [2]. Having developed such technologies, the additional manufacturing cost of engine technology is more than twice that of transmission technology for the same benefit in fuel economy [3]. It is therefore beneficial both in terms of development costs and manufacturing costs to first seek a fuel economy improvement via novel transmissions.

To date, the MT has shown better fuel economy as compared to AT [4]. The only technology that has demonstrated better fuel economy than the MT is the AMT. This fuel economy improvement is not due to the in gear efficiency of the transmission as it is no more efficient than the MT. But the gear shift schedule which is more favourable for an AMT than a MT, gives better fuel economy for AMT. In real driving with the AMT is in automated mode, an improvement in fuel economy over the MT can be achieved. It is unlikely that the driver will always be in the correct gear for all situations. At highway cruise, the AMT will be no better than the MT. It may be slightly worse if parasitic losses are present to operate a hydraulic pump continuously.

Zeroshift is an AMT which has no significant parasitic losses when in gear. A small amount of power is required during the gear shifting. There is no hydraulic actuation so there are no parasitic losses to operate a hydraulic pump. Both the gear actuation and clutch control can be electrically operated from the standard 12V vehicle electrical system.

If we compare the fuel economy of the manual, automatic, and simulated Zeroshift transmission derivatives, Table- I shows that the Zeroshift is no worse than the manual and considerably better than the automatic.

PERFORMANCE : Compared to a MT, the Zeroshift concept allows gear shifts to take place in zero seconds. This has an immediate performance benefit as the vehicle is never coasting in neutral. Every gearshift which would normally take a test driver at least 0.5 s to

complete is performed in 0 s with Zeroshift technology as illustrated in Fig. 2.

Popular Car in India	City fuel economy (km/l)	Highway fuel economy (km/l)
Manual	12.1	16.2
Automatic	9.0	13.7
Zeroshift (simulated)	12.1	16.2

Table- I : Fuel Economy

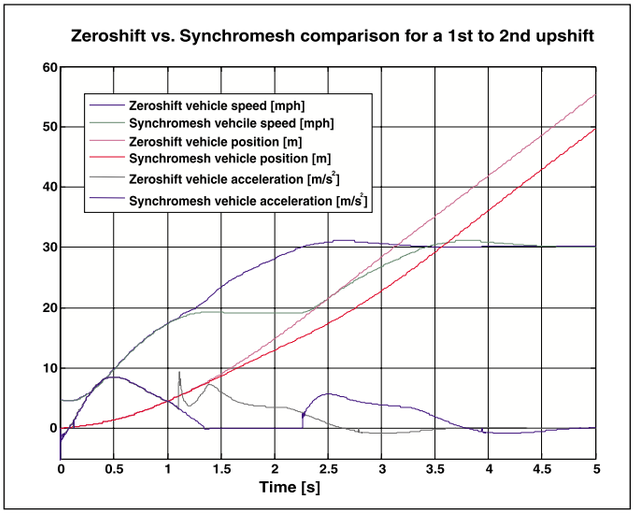

Figure 2 : Zeroshift Compared to Manual Gear Shift

On the above Indian Popular car, it is necessary to perform two gear shifts during a 0-100 km/h acceleration starting in 1st gear and ending in 3rd gear. The Zeroshift technology enables the acceleration to be completed 1 s quicker than a human. If we compare the accleration of the manual, automatic, and simulated Zeroshift transmission derivatives as given in Table- II and it shows that the Zeroshift is the clear winner.

Popular Car in India	0-100 (km/h) acceleration time (s)
Manual	16.4
Automatic	21.2
Zeroshift (simulated)	15.4

Table- II : 0-100 km/h Acceleration Time

SHIFT QUALITY : Transmission shift quality is measured in many ways, some objectively and others subjectively. The longitudinal acceleration of a vehicle which can be measured both objectively and subjectively. Objectively, a vehicle may be instrumented to measure longitudinal acceleration which will show the deceleration and acceleration experienced during a gear shift. It can be seen from Fig. 3 that during a standard upshift in a MT there is a torque interrupt to the wheels. This is shown in the Fig. 3 by the reduction in longitudinal acceleration during the shift. Subjectively, this is experienced by the vehicle's occupants not only by observing the pitching of the front of the vehicle but also by head nod. In its mildest form, this is merely a discomfort to the occupants. In its severest form, this can lead to instability of the car, especially during cornering. The AT is less prone to this phenomenon as the torque variation during a gear shift is less undulating.

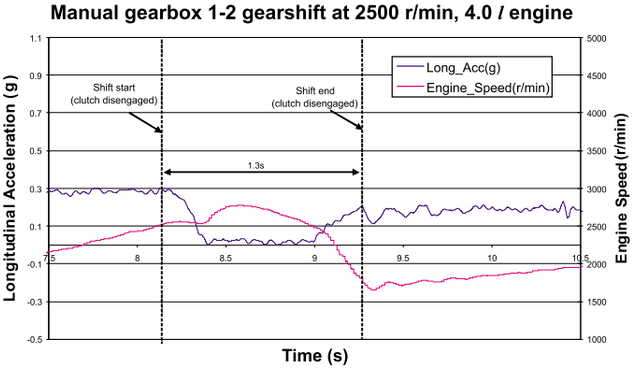

Figure 3 : Manual Transmission with Torque Interrupt

It can be seen from Fig. 4 that during a standard upshift in a vehicle fitted with Zeroshift there is no torque interrupt to the wheels. This is shown in the Fig. 4 by the consistently flat longitudinal acceleration during the shift. Subjectively, the shift is unobserved by the vehicle's occupants as there is no pitching of the vehicle and stability is maintained.

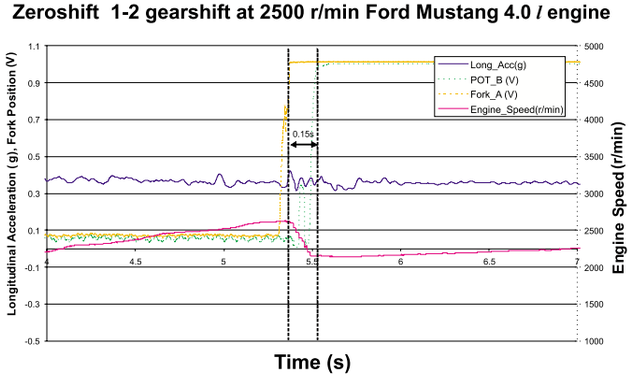

Figure 4 : Zeroshift Transmission with no Torque Interrupt

EASE OF MANUFACTURE : The materials used for all components are as per industry standard and require no unusual treatments. Manufacturing methods too are standard including forging, sintering, stamping and casting with defined final finishing. The comparative cost to which

Zeroshift components replace standard components i.e. synchronisers is reduced purely on a lesser part count. The only additional cost is in shift actuation. This is consistent with AMT but less than AT. Manufacturing plants have minimal line disruption when replacing just the hub assemblies.

A Zeroshift hub assembly can be packaged within an existing synchroniser envelope and in some instances be less – an inherent vehicle packaging advantage with ever increasing engine torques and hence gear-widths. For the full vehicle torque range, independent fork control is employed meaning 2 actuators per hub are needed but with the shift forces being much less than that of equivalent synchroniser the actuator sizes are much smaller than that of AMTs.

ZEROSHIFT CONVERSION

A Ford Mustang has been converted to demonstrate the Zeroshift concept, Fig. 5. The existing Tremec T5 transmission has been converted. The synchromesh has been removed and replaced with Zeroshift hubs. The hubs are independently actuated using solenoids. Solenoids can be employed because of the low force (much less than synchromesh) as it is the unloaded forks that are actuated.

Figure 5 : Zeroshift Demonstrator Vehicle

To complement the conversion, a fly-by-wire clutch control unit automatically regulates a speed difference during the shift event across the clutch, allowing the energy spike to be monitored and conditioned to suit the driving conditions.

CONCLUSION

The Zeroshift conversion of an existing manual transmission has been demonstrated. This has the following benefits:

- Automated gear shift
- Improved fuel economy compared with torque converter automatic transmission
- Improved acceleration performance compared with manual transmission
- Improved shift quality compared with manual transmission
- Easy to manufacture

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