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Zeroshift. A seamless Automated Manual Transmission (AMT) with no torque interrupt

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Zeroshift

ABSTRACT

Zeroshift technology allows a manual transmission to change gear in zero time. 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 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 to 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.

Its 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 to account for to operate the hydraulic pump, but large amounts of slip in the torque converter generates heat loss which warms the transmission fluid rather than provide 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. Over a representative drive cycle the efficiency of an AT can be as high as 86% [1].

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. Traditionally, the AMT has matched the MT for fuel economy but has suffered from 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 previously been seen in any other transmission.

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 Zeroshift concept is to remove the synchromesh components within a manual transmission and replace them with Zeroshift rings, Figure 1. Synchronisation is performed externally with the assistance of torque intervention performed by the engine control unit and an automated clutch (standard equipment in an AMT).

The Zeroshift rings act as a pair and represent a dog engagement type transmission. The unacceptable backlash found in dog engagement transmissions is eliminated by splitting the dog into two halves. The first Zeroshift ring is engaged to take up drive whilst the

second Zeroshift ring is brought in afterwards to take up the backlash.

Each ring is double-faced where one face can only drive in one direction and the opposite face in the other direction. When paired back-to-back they provide either a direct-drive or a ramp face depending on the vehicle drive direction.

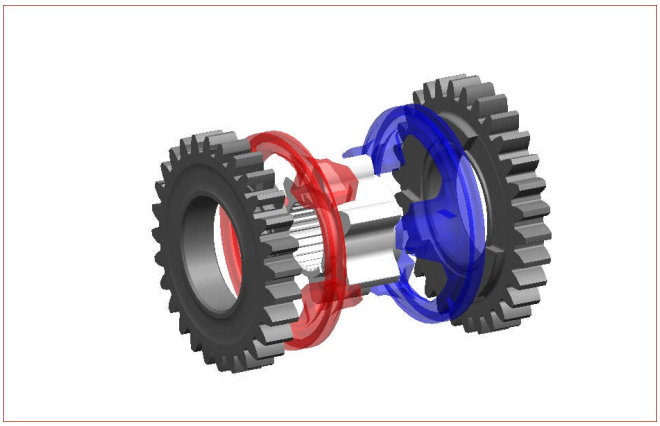

Figure 1. Two Zeroshift rings between two gears.

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 (in the order of 1/25th).

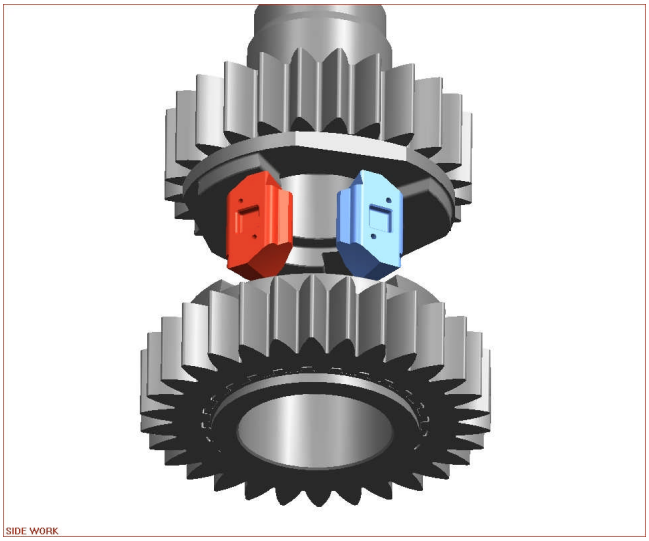

Figure 2. Neutral position.

It is easier to see the actions of these rings if we look at an exploded view, Figure 2. Each pair of rings has three pairs of “bullets”. Here we see just one pair of bullets for illustration purposes. On one side of the bullet is a retention angle to take up the drive whilst on the opposite side is a ramp face to disengage drive.

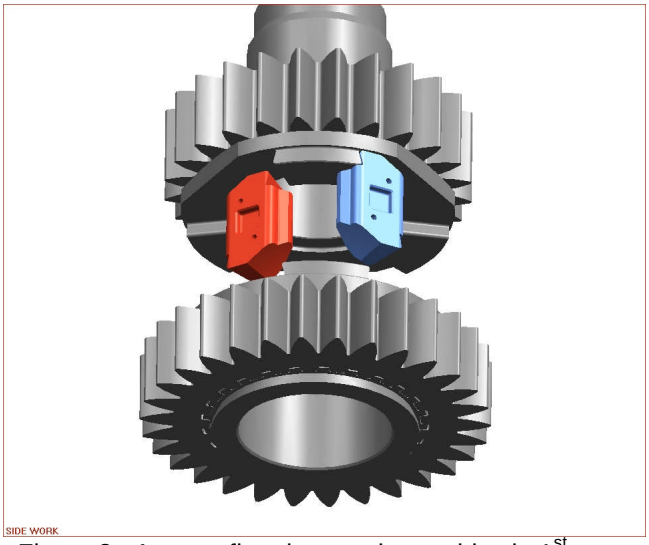

Figure 3. Actuate first ring to take up drive in 1st gear.

The unique feature of Zeroshift is that it is able to change gear in zero time, just like a digital switch. We can see in Figure 3 how by shifting the blue ring and its bullets with a shift fork, drive is taken up on the 1st gear (top of diagram). Backlash is taken up by shifting the red ring, Figure 4.

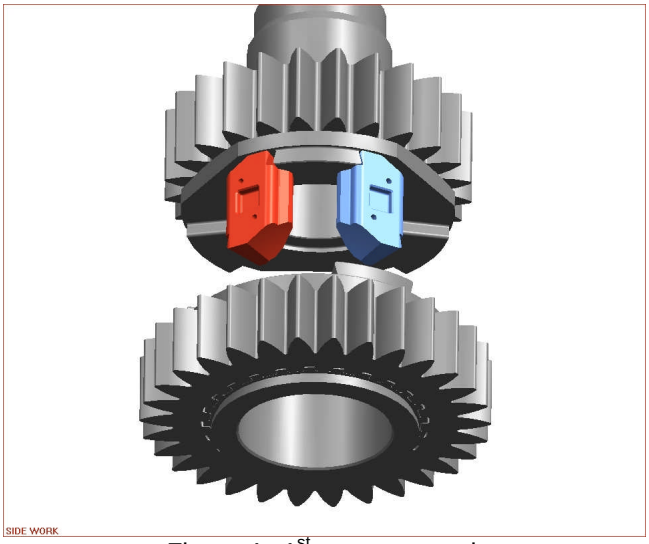

Figure 4. 1st gear engaged.

To perform a Zeroshift gearshift, whilst still driving in 1st gear on the blue ring, the unloaded red ring may be moved to the 2nd gear (bottom of diagram), Figure 5.

As 2nd gear is rotating faster, it overruns 1st gear and takes up drive on the red ring allowing the engine torque to be handed over. At no time is the engine torque interrupted from being transferred to the vehicle’s wheels.

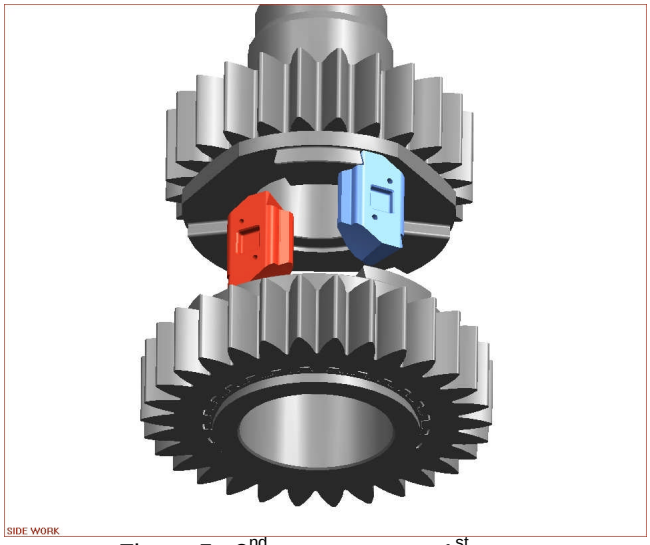

Figure 5. 2nd gear overruns 1st gear.

The gearshift is complete when the original blue ring is no longer loaded on 1st gear and is able to be actuated over to 2nd gear to take up backlash, Figure 6.

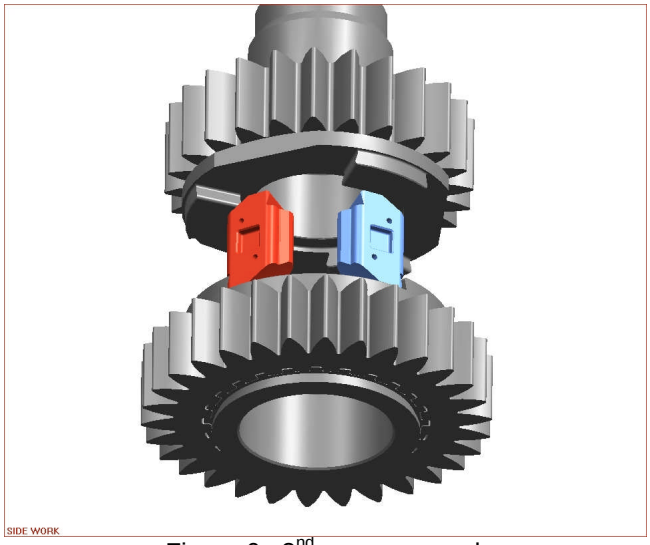

Figure 6. 2nd gear engaged.

Such a concept has wide application not only because of improved acceleration performance but also fuel economy and shift quality.

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 managed by dissipation 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.

ZEROSHIFT BENEFITS

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 and manufacturing costs to first seek a fuel economy improvement via transmission technology.

To date, the MT has provided better fuel economy than the AT [4]. A technology that has demonstrated on occasions, even better fuel economy than the MT is the AMT. This fuel economy is not due to the in gear efficiency of the transmission as it is no more efficient than the MT but due to the gear shift schedule. On a drive cycle an AMT is able to shift to a taller gear earlier whilst the MT has to stick with a mandatory gear schedule. In real driving with the AMT in automated mode, an improvement in fuel economy over the MT can be achieved for the same reason. It is unlikely that the driver will always be in the best 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.

It is difficult to compare different transmission types including Continuously Variable Transmission (CVT) and Dual Clutch Technology (DCT) across different vehicles as results can be misleading. By looking at the published data we can take an average of the current vehicles in production [4]. If we look at the relative fuel economy of each transmission type compared to an MT, we find the results of Table 1.

Transmission	Fuel economy compared to MT
4 or 5 speed AT	-11%
6 or 7 speed AT	-5%
CVT	-7%
DCT	-4%
MT	0%
Zeroshift (simulated)	2%

Table 1. Fuel economy of various transmissions compared to MT.

The worst fuel economy belongs to the 4 or 5 speed AT with on average 11% worse fuel economy. The best is Zeroshift which is 2% better than the MT.

PERFORMANCE

Compared to an MT the Zeroshift concept allows gear shifts to take place in zero time. This has an immediate performance benefit as the vehicle is never coasting in neutral. Each gearshift which would normally take a test driver approximately 0.5 seconds to complete is performed in 0 seconds with Zeroshift technology, Figure 7. For most (non-test) drivers, the gearshift would be greater than 1 second.

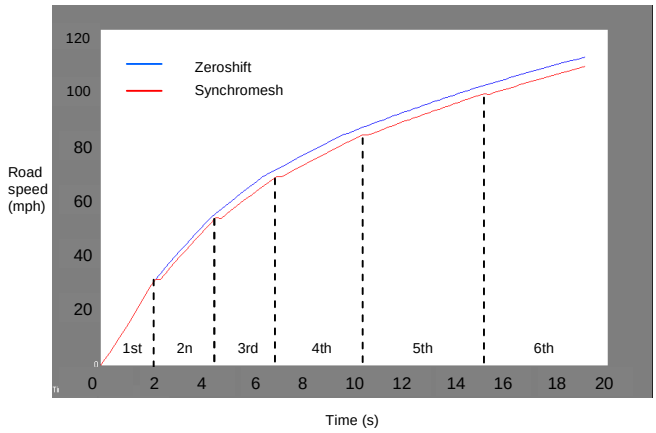

Figure 7. Zeroshift compared to manual gear shift.

For the average automobile equipped with a MT it is necessary to perform one gear shift during a 0 – 62 mph (0 – 100 kph) acceleration starting in 1st gear and ending in 2nd gear. The Zeroshift technology enables the acceleration to be completed approximately 0.5 seconds quicker than a test driver.

As before, it is difficult to compare different transmission types as results can be misleading. By looking at the published data we can take an average of the current vehicles in production [4]. If we look at the relative acceleration of each transmission type compared to an MT, we find the results of Table 2.

The worst acceleration performance belongs to the 4 or 5 speed AT with on average 12% worse performance. The best is Zeroshift which is 5% better than the MT.

Transmission	Acceleration performance compared to MT
4 or 5 speed AT	-12%
6 or 7 speed AT	-5%
CVT	-3%
DCT	1%
MT	0%
Zeroshift (simulated)	5%

Table 2. Acceleration of various transmissions compared to MT.

SHIFT QUALITY

Transmission shift quality is measured in many ways, some objectively and others subjectively. We consider here 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 Figure 8 that during a standard upshift in a MT there is a torque interrupt to the wheels. This is shown in the figure 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 what is known as 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.

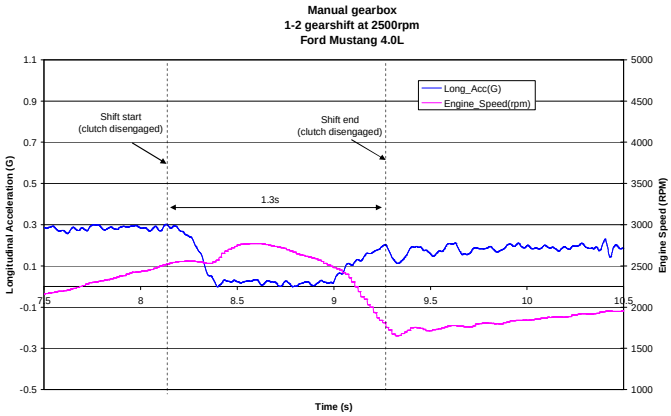

Figure 8. Manual transmission with torque interrupt.

It can be seen from Figure 9 that during a standard upshift in a vehicle fitted with Zeroshift there is no torque interrupt to the wheels. This is shown in the figure 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.

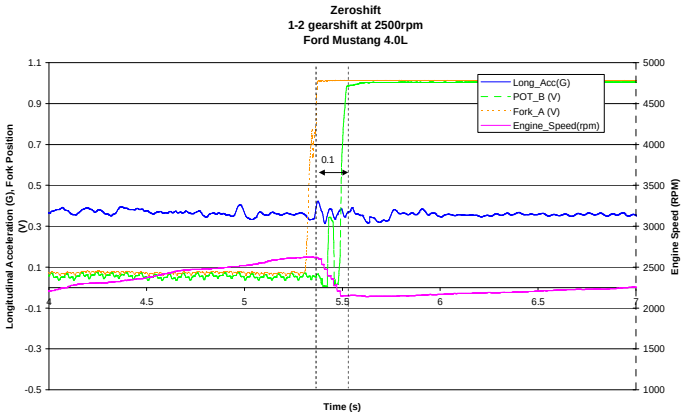

Figure 9. Zeroshift transmission with no torque interrupt.

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.

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 using 2 actuators per hub, but with the shift forces being much less than those of equivalent synchronisers, the actuator sizes are much smaller than that of AMTs.

It is difficult to compare different transmission types as results can be misleading because of volumes. By comparing the theoretical cost of producing current transmissions at similar volumes at a Greenfield site the following estimated data is provided in Table 3 [4].

Transmission	Production costs compared to MT
6 speed AT	170%
CVT	170%
DCT	180%
5 speed MT	100%
6 speed MT	110%
Zeroshift (5 speed AMT)	125%

Table 3. Production costs of various transmissions compared to 5 speed MT.

The most expensive transmission to produce is the DCT which is estimated at costing 80% more to produce than the 5 speed MT. The least expensive automated transmission is Zeroshift which is an AMT and is estimated at costing only 25% more to produce than the 5 speed MT.

CONVERSION

A Ford Mustang has been converted to demonstrate the Zeroshift concept, and provided the experimental data for this paper, Figure 10. The existing Tremec T5 transmission has been converted. The synchromesh has been replaced with Zeroshift rings. The rings are independently actuated using solenoids.

Figure 10. Zeroshift demonstrator vehicle.

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

CONCLUSIONS

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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