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Research Article

Driven axle with dual final drive ratio

Srinivasan Ekambaram[#*] and Shoaib Hassan[!]

[#]RD I/CDV, Mercedes Benz R&D India
[!]RD I/TBC, Mercedes Benz R&D India

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Abstract

A new approach to design a driven axle with dual final drive ratio is reported in this paper. The design integrates an additional speed reduction. Objective of this design is to provide a better gear spread in an automobile which would result in improved fuel economy. The additional reduction stage is a planetary gear set comprising a ring gear, a sun gear and a plurality of planetary gears mounted on a carrier. The selectable speed reduction can provide choice of reduction which in combination with the reduction stages in the gear box/transmission, can at least double the gear spread that would otherwise have been available. Thereby it helps to have a better control on drive torque/traction force and engine speed to which results in improved fuel economy.

Keywords: *Dual ratio, Driven axle, gear spread, speed reduction, torque multiplication, fuel economy.*

1. Introduction

Drive train or power train of an automobile transfer's power from internal combustion engine to the wheels, and it typically comprises clutch, Gear box (also called transmission), at least one driven axle and propeller shaft(s) connecting output of the gear box to the driven axle(s). Such engines normally operate at a relatively high rotational speed which is inappropriate for starting, stopping, and slower travel. The power train reduces the higher engine speed to the slower wheel speed, increasing torque in the process.

Normally the speed reduction takes place at two places i.e. in the gear box/transmission and in final drive in the driven axle. The gear box adapts the output of the internal combustion engine to the drive wheels. The gear box incorporates multiple speed reduction ratios to enable user to change drive torque or traction force at the wheels and during the process the speed reduction in the final drive remains fixed. Having more gear reduction ratios in the gear box can be beneficial from fuel economy point of view as it enables the engine to run close to its optimum operating conditions (Kazuhiko, *et al*, 1991) besides this, these can also provide higher traction force when required under difficult conditions such as steep gradients. However, increasing the reduction ratios beyond a reasonable number in the gear box can make it bulky with attended problems. It would be advantageous to have one more selectable reduction stage elsewhere in the drive train which in combination with reduction ratios in the gear box can provide a wide range of reduction choices.

Vehicles having more than one driven axle generally incorporate an additional gear box commonly known as auxiliary gear box or transfer gear box or transfer case. The auxiliary gear box splits the power train in two or more – one for each driven axle. The auxiliary gear box often incorporates an additional reduction stage with an option to change the reduction. However, vehicles having only one driven axle are deprived of such additional reduction stage.

Speed reduction in final axle drive usually takes place by means of a pair of spiral bevel gears - either simple spiral bevel or hypoid spiral bevel (Bain Griffith, 1968), that provide the axle drive. The pair of spiral bevel gears is housed in axle housing along with differential assembly. Fig.1 illustrates a pair of bevel gears that could be a pair of spiral bevel gears or a pair of hypoid spiral bevel gears 100 as shown in Fig.1. The pair 100 comprises a pinion 102 and a crown gear (or crown wheel) 104. They provide useful function of changing direction of input drive from the propeller shaft by 90 degrees to drive the wheels and additionally provide a speed reduction beyond reduction achieved in the gear box.

Fig.1 Hypoid spiral bevel gear

*Corrresponding author **Srinivasan Ekambaram** is a Senior Product design Engineer and **Shoaib Hassan** is a Product design Engineer

Due to such as need to have a differential, ground clearance etc., it is practically difficult to incorporate a conventional gear train in addition to the pair of spiral bevel gears in the final axle drive that could provide an additional selectable reduction stage. Fig.2 illustrates a sectional view of a typical differential assembly that is an essential part of the final drive of a driven axle assembly and functions to split power between the two wheels while allowing them to have differential speeds. The crown gear 104 is usually mounted on the differential housing 202. The differential housing 202 in turn drives the bevel pinions 204 that are mounted on the differential housing 202. Side bevel gears 206 are in engagement with the bevel pinions 204 and are connected to two wheels on either side of the axle through respective drive shafts.

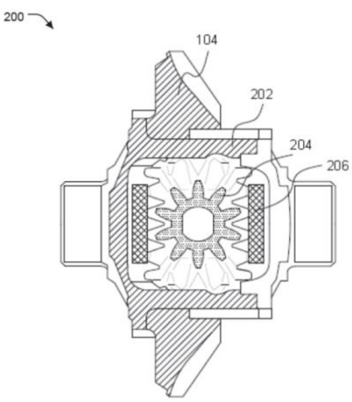

Fig.2 Sectional view of a differential assembly

1.1 Planetary gear train

Requirement of an additional speed reduction stage in the final drive can be possibly met by a planetary gear train (Oliver K. Kelley, 1959), on account of their compactness and ability to provide a varying and high reduction ratio.

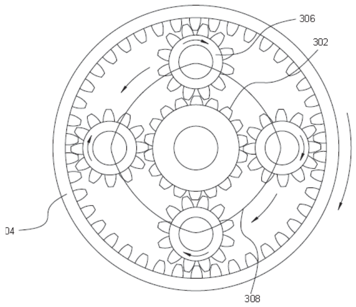

Fig.3 Planetary gear arrangement

Fig.3 illustrates schematic arrangement of a typical planetary gear arrangement incorporating a sun gear 302, a ring gear 304 configured with internal gear teeth, plurality of planetary gears 306 in engagement with the sun gear 302 and the ring gear 304. The planetary gears 306 are carried on a planetary carrier (or carrier) 308. The arrangement incorporates three concentrically rotating members namely the sun gear 302, ring gear 304 and carrier 308 either of which can function as input or output in different combinations. The third member can be held stationary or locked with any other member.

The formulas below give the reduction ratios in different conditions, where Na, Ns and Nc indicate the number of teeth in the ring gear, the sun gear and the carrier respectively, and ωa, ωs and ωc indicate the speeds of the ring gear, the sun gear and the carrier respectively

a. When the carrier is held fixed, ωc=0, and

$$\omega s \ / \ \omega a = - Na \ / \ Ns$$

b. When the ring gear is held fixed, ωa=0, and

$$\omega s \ / \ \omega c = 1 + Na \ / \ Ns$$

c. When the sun gear is held fixed, ωs = 0, and

$$\omega a, \ / \ \omega c = 1 + Ns \ / \ Na,$$

Based on above formulas, and considering order of number of teeth each of the gears is likely to have on account of difference in their sizes, Table 1 below indicates laws of planetary gear operation (Jack Erjavec, *et al*, 2015), showing result of different combinations in respect of speed reduction and direction of speed

Table 1 Laws of planetary gear operation

	Sun gear	Carrier	Ring gear	Speed	Direction
1	Input	Output	Held	Maximum reduction	Same as input
2	Held	Output	Input	Minimum reduction	Same as input
3	Output	Input	Held	Maximum increase	Same as input
4	Held	Input	Output	Minimum increase	Same as input
5	Input	Held	Output	Reduction	Reverse of input
6	Output	Held	Input	Increase	Reverse of input
7	When any two members are locked together, speed and direction of output is same as input.				
8	When no member is held or locked together, no output can occur and results in neutral condition.				

German patent DE1430610 discloses a hydraulic arrangement in combination with a planetary gear set and a plurality of friction engaging elements to hold or lock one or more elements of the planetary gear set to provide different gear speed ratios in an automatic gear transmission. The construction involves utilizing a sun gear, planetary gears and a ring gear to establish different reduction ratios in different configurations. The friction engaging means with help of the hydraulic arrangement are used to switch between different configurations to achieve different ratios. However, the prior art reference limits use of such an arrangement in the gear box that does not involve integrating the planetary gear set within the axle housing.

It would be advantageous if such a planetary gear set and hydraulically actuated friction engaging elements could be integrated between differential assembly such as 200 and crown gear such as 104 and housed within the axle housing to provide an additional selectable speed reduction stage. Such an arrangement can in combination reduction ratios provided by the gear box, result in better gear spread resulting in fuel economy.

There is therefore a need for a design integrating planetary gear set, hydraulically actuated friction engaging elements, differential assembly and crown gear for accommodating within an axle housing to provide an additional reduction stage.

2. Working

Referring to Fig.4 wherein an exemplary representation of proposed planetary gear set 400 to achieve an additional stage of speed reduction in final drive is shown. It is to be understood that the representation in Fig.4 is a simplified layout of the disclosed arrangement for ease of understanding and explanation and does not in any way show the arrangement of constituent parts in an actual assembly. The planetary gear set 400 can include a ring gear 402, a plurality of planetary gears 404, and a sun gear 406. The planetary gears 404 can be mounted on a carrier 408. The ring gear 402 can be connected to the input from the crown wheel (not shown here). The carrier 408 can provide the output from the planetary gear set 400. The ring gear 402, the carrier 408 and the sun gear 406 can rotate concentrically, and constitute three elements of the planetary gear set 400. The sun gear 406 can be either held stationary or locked with carrier 408 for achieving different reduction ratios.

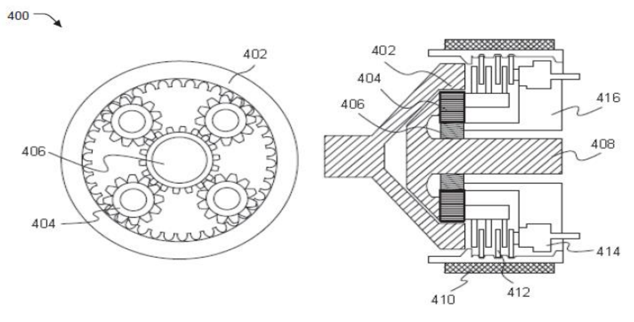

Fig.4 Proposed planetary gear train arrangement

Fig.4 also shows means for holding the sun gear 406 stationary or for locking the sun gear 406 with the carrier 408. The means can respectively be a band 410 configured around the circumference of a drum 416 connected to the carrier 408 and a clutch arrangement 412 configured between the drum 416 and the sun gear 406. Both the clutch 412 and the band 410 can be hydraulically actuated such as one or more clutch pistons 414. The actuation means can be integrated with Transmission Control Unit (TCU). The band 410 and the clutch 412 can be configured on a drum 416 connected to the carrier.

In an embodiment, locking of the sun gear 406 and the carrier 408 can result in all three elements of the planetary gear set 400 rotating at same speed thus providing a 1:1 ratio. On the other hand, holding the sun gear 406 stationary can result in a speed reduction depending on number of teeth in the sun gear 406 and the ring gear 402. Thus, the disclosed arrangement of the planetary gear set 400 and holding/locking arrangement can provide a selectable reduction stage. The disclosed selectable reduction stage can, in its first selection, provide 1:1 speed ratio thus giving an overall reduction in the drive train that is same as reductions available in the gear box/transmission. On the other hand, second of the selection can provide a reduction of (1+ Ns / Na), Ns and Na being number of teeth in the sun gear 406 and the ring gear 402 respectively.

In an exemplary embodiment, number of teeth in the planetary gears 404 and the sun gear 406 can be kept as 15, and therefore the ring gear shall have 45 teeth. The selectable reduction in which case shall be (1+ 15 / 45) = 4/3 or 1.33. It is however possible to provide different combinations of teeth and have different reduction depending on requirement of the power train.

Table 2 lists typical values of gear ratios and axle drive ratio in an automobile indicating presently available gear spread:

Table 2 Typical values of gear ratios and axle drive ratio in an automobile

Transmission Ratio A	Axle Drive Ratio B	Overall Ratio A X B
5.321	2.12 (FIXED)	11.281
4.165		8.830
3.126		6.627
2.896		6.640
1		2.120

In above example, introduction of an additional reduction stage can provide an option to enhance the axle drive ratio depending on requirement. For example, when a higher traction effort is required in conditions such as steep slope, the sun gear 406 can be held by means of the band 410 to provide an additional reduction. On the other hand, when the requirement of the higher traction effort ceases, to affect fuel economy the sun gear 406 can be released from held position by deactivating the band 410 and locked with the carrier 408 by means of the clutch 412.

Table 3 lists values of overall reduction ratios that would be available on the vehicle having gear ratios and axle drive ratio indicated in table 1, when the same is incorporated with disclosed additional reduction stage:

Table 3 Gear spread on providing an additional reduction stage

Axle Drive Ratio B	Transmission Ratio A	Overall Ratio A x B
4.12 (Overall axle drive ratio including planetary reduction)	5.321	21.923
	4.165	17.160
	3.126	12.879
	2.896	11.932
	1	4.120
2.12 (Axle drive ratio with 1:1 planetary ratio)	5.321	11.281
	4.165	8.830
	3.126	6.627
	2.896	6.640
	1	2.120

Fig.5 illustrates an exemplary representation 500 of arrangement of the planetary gear set 400 within the crown wheel 104 in accordance with an embodiment of the present design. Set of bevel gears comprising pinion 102 and crown wheel 104 provides the normal final drive reduction ratio after the input is received by the pinion 102. As shown, the planetary gear set 400 can be housed within the crown wheel 104. The ring gear 402 can be configured to receive the input for the planetary gear set 400 by fixing within the crown wheel 102. The planetary gears 404 mounted on the carrier 408 (not shown here) and the sun gear 406 can be configured within the ring gear 402. The planetary carrier 408 (not shown here) can be the output of the planetary gear set 400 and connected to the differential assembly 502. Thus the planetary gear set 400 is housed within the crown wheel 104 without need of much extra space to house them.

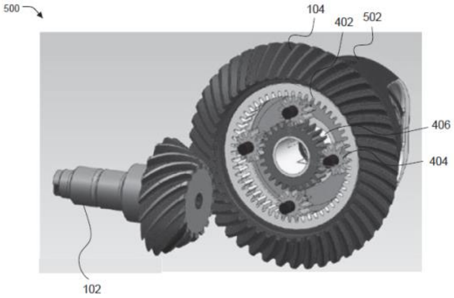

Fig.5 Planetary gear set within the crown wheel

Fig.6 illustrates an exemplary sectional view 600 of the reduction stage integrated between the crown wheel 104 and differential assembly 502 in accordance with an embodiment of the present design. A differential, as is known in art, splits the drive power between left and right drive shafts and allows the left and the right drive shafts to rotate at differential speeds. As shown, the differential assembly 502 can include a differential housing 602 that can be configured to receive output from the planetary gear set 400 by direct connection to the carrier 408 and house a pair of bevel side gears 604 and plurality of differential bevel pinions604 in engagement with the side bevel gears 604. The side gears 604 can incorporate splines to receive drive shafts configured to transfer power to left and right wheels. Fig.6 also shows sectional view of the planetary gear set 400 comprising the ring gear 402, the planetary gears 404, the sun gear 406 and the carrier 408 all arranged within the crown wheel 104. Also shown is the clutch 412 that can lock the sun gear 406 with the carrier 408.

Thus the disclosed arrangement of an additional reduction stage between the set of bevel gears (crown and pinion set) and differential assembly 502 in the final drive of a driven axle by using planetary gear set 400 can provide dual final drive ratios. The first of the two ratios is achieved when the sun gear 406 and the carrier 408 are locked by means of the clutch 412 to provide 1:1 ratio from the additional reduction stage and the final drive ratio in this case will be same as reduction provided by the set of bevel gears. The second of the two ratios is achieved when the sun gear 406 is held by means of the band 410 and the final drive ratio in this case shall be increased on account of additional reduction in the planetary gear set 400.

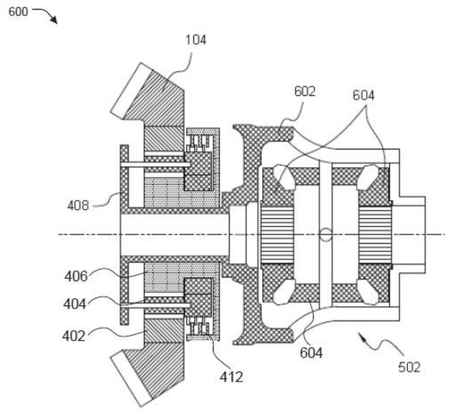

Fig.6 Sectional view of the proposed reduction stage

Conclusions

The paper discusses a final drive for a driven axle that integrates an additional speed reduction stage. The additional reduction stage can be integrated between the crown wheel and differential assembly, and therefore can incorporate a selectable speed reduction stage.

Selectable speed reduction can provide choice of reduction which in combination with the reduction stages in the gear box/transmission, can at least double the gear spread that would otherwise have been available, thereby enabling better control on drive torque/traction force and engine speed with resultant fuel economy.

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