

Development of a Compact Torque Vectoring Axle for Primary or Secondary Axles

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ABSTRACT

There has been a recent demand for torque vectoring axles in premium sedans and high end sports vehicles. The improved handling and active safety resulting from this product is desirable in all vehicles. As the cost of these units is driven down, the applications should proliferate to lower cost vehicles. This paper is to introduce a torque vectoring axle assembly designed for low cost manufacturing methods to allow this proliferation.

INTRODUCTION

Premium sedans and sports vehicles have had all wheel drive for a number of years. Recently there has been a demand for the ability to vector torque from side to side as well as controlling the torque distribution between the front and rear axles. Brake based systems have existed for several years where one or more wheels are braked to create a yaw moment thereby influencing the yaw rate of the vehicle. Being able to shift the torque from one side to the other is generally viewed as a more proactive and productive means to influence the yaw rate of the vehicle than creating the yaw moment by utilizing the vehicle braking system. This paper describes a cost effective approach to accomplish the vectoring of torque side to side.

AXLE DESIGN

The axle design consists of three primary components. Two of these components are the end cap assemblies which are functionally identical. The end cap assemblies have the function of transferring torque from one axle half shaft to the other axle half shaft. The third component is the center section which contains the hypoid ring and pinion and the axle differential which, along with the normal differential function of dividing the input torque between the two axle half shafts, also has the function of dynamically transferring torque from the active end cap assembly to the opposite axle half shaft.

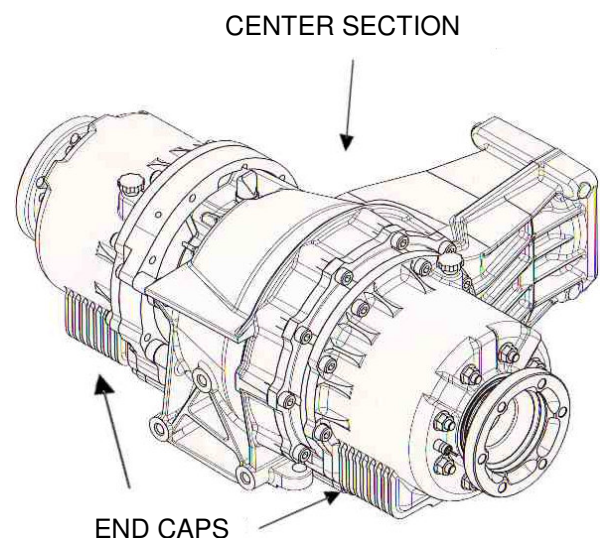


Figure 1: Axle Assembly

CENTER SECTION

The center section of the axle assembly contains the hypoid gearset as is conventionally found in the axle assembly of a rear wheel drive vehicle. Also in the center section is the differential gearset. This differential gearset may be a conventional bevel gear or a 50:50 planetary differential. The planetary design has functional benefits but is normally a more expensive option. In a torque vectoring axle, the differential is used to dynamically deliver torque when the axle assembly is actively vectoring torque. Conventional bevel gear differentials are designed to permit speed differences rather than designed to transmit torque in a dynamic manner. The gears are normally designed with contact ratios less than one. This results in an uneven driving speed being transmitted through the gearset as driven during a vectoring event. This can be somewhat mitigated by the side gears and pinions having odd numbers of teeth. This axle design is compatible with a conventional differential design but will run more efficiently with a planetary design.

In addition to the rolling smoothness of the differential gears, friction is an important consideration to improve the effectiveness of the torque vectoring. The separating loads of the side gears can be high enough to cause a loss of up to 40% of the torque being transmitted through the differential. These losses are substantially reduced by the use of a needle thrust bearing behind the side gear or almost eliminated by the use of a planetary differential.

END CAP ASSEMBLY

The end cap assembly consists of the double planetary gearset and the activation clutch.

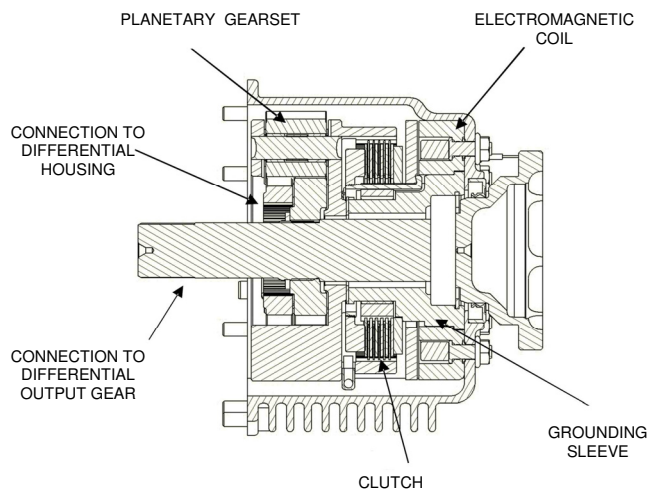


Figure 2: End Cap Assembly

The planetary gearset uses a common pinion meshing with two different sun gears. The cost to produce a single gear is substantially less than a stepped gear or two gears joined together to rotate as one. It also eliminates any possibility of index error between two stepped pinions. The two sun gears are connected to the differential housing and side gear respectively. As the axle assembly has two end cap assemblies, one end cap assembly is used for shifting torque from the right rear wheel to the left rear wheel and the other works in the opposite direction.

As shown in figure 3, the two sun gears have 30 and 33 teeth respectively. Therefore the effective ratio of the double planetary is 33/30 or 1.10. If the carrier was at zero rotational speed, the 30 tooth member would be rotating at 1.1 times the speed of the 33 tooth member. As the 33 tooth sun gear is splined to its respective output shaft and the 30 tooth sun gear is splined to the differential housing, this unique case will force the opposite differential side gear along with the opposite output shaft to rotate at a speed 10% faster than the differential housing. Therefore the overall speed difference would be 20% from side to side. This is sufficient to insure that torque can be transferred from one side to the other irrespective of the turning circle of the vehicle.

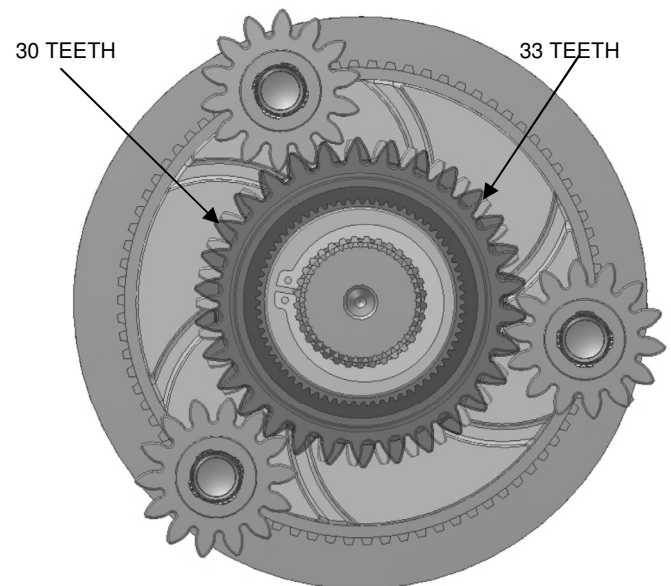


Figure 3: End Cap Gearing

The design of these gears is a balance of tradeoffs. Keeping unit cost low drives the design to using a single pinion. A single pinion can be made nearly net shape from a forging or even from a high density powdered metal. The single pinion forces profile modifications from a standard gear tooth form on the sun gears. Excessive modification to the profile will lead to thin teeth on one sun gear and all thick teeth on the other. Excessive modification can also contribute to high frictional losses at the tooth interface. The sensitivity of this gearing configuration is illustrated in Figure 4 which shows the case where one sun is held stationary and the other sun is driven with the carrier free to rotate. Although this is not a standard method of operation, it illustrates the importance of generating a smooth tooth flank on the sun gears as well as the pinion gears. Other methods of increasing the profile overlap or contact ratio are possible such as using a helical pinion with helical sun gears. Helical gears are typically more costly to manufacture than net shape powdered metal pinion gears.

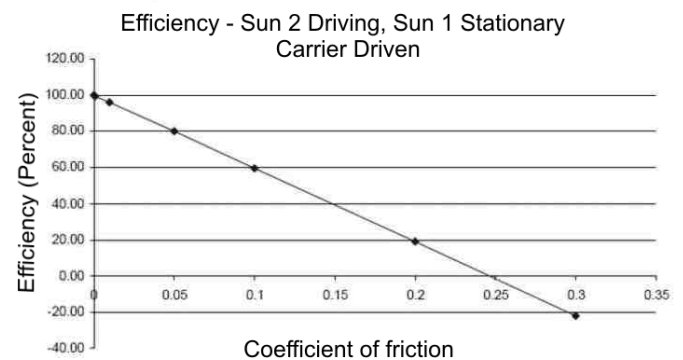


Figure 4: Sensitivity to Friction