

SYSTEMATIZATION OF PLANETARY GEAR SET CONFIGURATIONS WHICH ARE IMPLEMENTED IN AUTOMATIC TRANSMISSIONS

SISTEMATIZACIJA KONFIGURACIJA PLANETARNIH PRENOSNIKA IMPLEMENTIRANIH U AUTOMATSKIM MENJAČIMA



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Apstract: Most common planetary gear sets which are implemented in numerous automatic transmission systems are presented in this paper. Automatic transmissions in which these gear sets are implemented were also briefly mentioned. Alongside these topics, cutting edge automatic transmission systems alongside their schematics were also presented. Current industry developments and future of automatic transmission systems were also briefly analyzed.

Key words: Automatic transmission, Ravigneaux gear set, Lepelletier gear set, Simpson gear set

1. INTRODUCTION

The history of modern automatic transmission systems starts during 1950-s when most manufacturers started to implement these devices in passenger vehicles, [1]. Since then, several companies in automotive industry developed better systems, which found application in numerous passenger and commercial vehicles. Although manual transmission systems still represent biggest part of the automotive transmission market, customers in certain parts of the world (NAFTA region) nowadays can't imagine a vehicle without automatic transmission systems, [1]. Main advantage of these systems is perceived in the automatic gear shifting which in return provides

Abstrakt: Najčešći planetarni prenosnici koji se primenjuju u brojnim automatskim menjačima su opisani u okviru ovog rada. Automatski menjači u kojima su ovi prenosnici napomenuti su takođe kratko opisani. Pored ovih tema, predstavljeni su i najsavremeniji automatski menjači kao i njihove šeme. Trenutni trendovi u industriji i budućnost automatskih menjača je takođe ukratko analizirana.

Ključne reči: Automatski menjači, Ravigneaux prenosnik, Lepelletier prenosnik, Simpson prenosnik

safer and better driving experience for the customer. Automatic transmissions also possess certain drawbacks which are mainly perceived through somewhat higher fuel consumption, more complex and expensive system with increasingly complex and expensive maintenance procedures [1, 2].

These disadvantages are meaningful because they are contradictory with the goals of the automotive industry which are mainly focused on the production of cheaper, efficient and reliable passenger vehicles.

On the market, one can find numerous devices which enable automatic gear shifting. Biggest part of the market certainly represent gear based automatic transmissions (AT).

Besides systems based on this principle, automotive companies also implement Continuous Vehicle Transmission systems (CVT), and Dual Clutch Transmission systems (DCT), [1].

Within the scope of this paper, numerous planetary gear sets which are implemented within automatic transmission systems used in passenger vehicles were represented. Automatic transmission systems from renowned manufacturers were also presented.

2. SIMPSON PLANETARY GEAR SET

The planetary mechanism which set foundation for modern automatic transmission systems is Simpson planetary gear set (Figure 1.). This simple system is similar to the two stage planetary speed reducer which implements two standard planetary gear sets. Main difference between these two is that this gear configuration has one sun gear. Simpson gear set also has two sets of planets which are mounted on two planet carriers. Each set of planets is meshed with ring gears (two ring gears in total). This simple system enables three forward speeds, one rear speed, and one neutral, [2].

Simpson planetary gear set is not implemented in modern transmission systems, and one can hardly find great number of the details about this gear set in recent technical literature. On the other side, standard planetary gear set mechanism which represents integral part of Simpson gear set represents vital part of practically every modern gear based automatic transmission system.

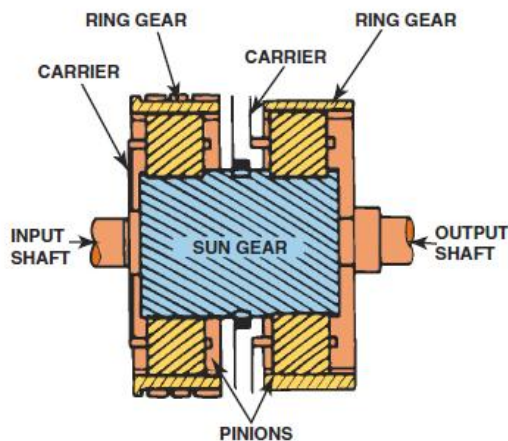


Figure 1. Simpson planetary mechanism, [2]

3. RAVIGNEAUX PLANETARY GEAR SET

Ravigneaux mechanism represents modern and compact planetary gear set construction. It was patented by the Pol Ravigneaux in the first part of the XX century, and since then it was implemented in numerous transmission systems developed by the ZF, Daimler, Aisin etc., [3, 4, 5].

The construction of the typical Ravigneaux planetary mechanism is somewhat more complex if

compared to the standard planetary mechanisms. Ravigneaux planetary mechanism can exist in numerous configurations, but seven link configuration certainly found most applications in the real automatic transmission systems, [6].

Although complicated eight link and nine link configurations didn't find too much practical usage, they were also briefly described within this paper.

Seven link Ravigneaux gear set (Figure 2.) consists of two sun gears (1, 2), two planets (5, 6) and one ring gear (4). Complexity of this planetary gear set comes from the fact that two planets are meshed together, and are mounted on the one planet carrier (3). Automatic transmission systems which are solely based on this gear set can achieve four forward speeds, [1, 6].

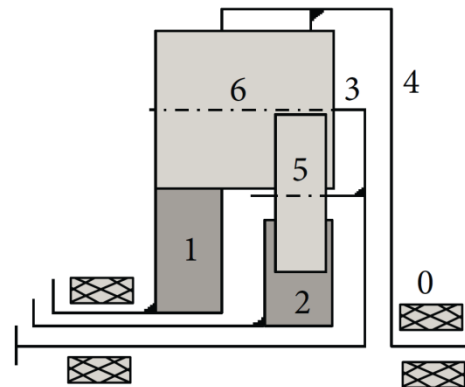


Figure 2. Seven link Ravigneaux planetary mechanism, [6]

One of the first transmission systems which was based on the seven link Ravigneaux gear set is ZF HP 14 (Figure 3.), [1, 6]. It is based on just one Ravigneaux planetary gear set, and this transmission which debuted in 1984. offered offered four forward speeds, one rear speed, and a neutral one, [1].

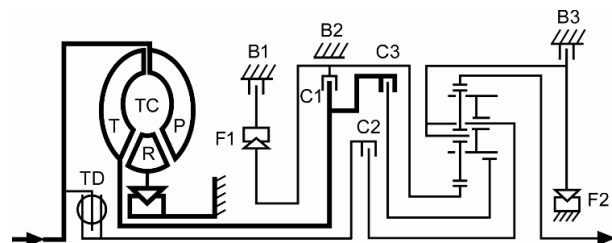


Figure 3. ZF HP 14 gearbox diagram, [1]

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ight link Ravigneaux planetary gear set (Figure 4.) is somewhat more complex mechanism than the widely known seven link one. The main difference between these two configurations can be observed in one additional ring gear (7), [6].

If compared to the seven link configuration, this additional ring gear results in different gear sizes. Alongside seven link Ravigneaux planetary mechanism, it was also presented in one of the initial patents [4].

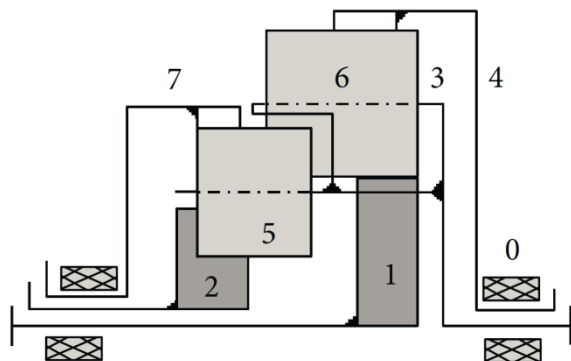


Figure 4. Eight link Ravigneaux planetary mechanism, [6]

Nine link planetary mechanism (Figure 5.) is significantly different if compared to the previously mentioned Ravigneaux gear sets. This mechanism consists of the three sun gears (1, 2 and 8), three planets (5, 6 and 6¹), and two ring gears (4 and 7), [6]. This configuration requires highly complicated planet carrier (3), on which three different planetary gears are mounted on two spider shafts. Thanks to the increased complexity of this planetary gear set, its application in automatic transmissions is highly limited.

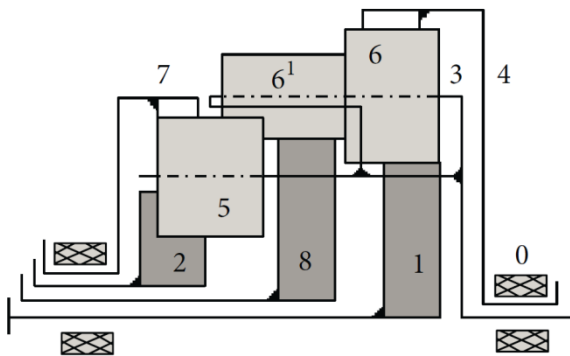


Figure 5. Nine link Ravigneaux planetary mechanism, [6]

Although Ravigneaux planetary gear set represented revolution in design of automatic transmissions in the last decade of the XX century, technical possibilities of said gear set couldn't fulfill increasing needs of the automotive industry.

Thanks to the combination with standard planetary gear sets, Ravigneaux mechanisms are still widely implemented in numerous automatic transmissions in the form of the Lepelletier concept. Some

companies went even one step further and significantly modified common Ravigneaux configurations in order to meet the needs for cutting edge automatic transmissions.

4. LEPELLETIER GEAR SET

This concept was patented by Pierre Lepelletier in 1992., [7]. This planetary gear set (Figure 6.), as presented in the initial patent combines standard gear set and previously described seven link Ravigneaux planetary gear set. Standard gear set is mounted at the front, while seven link Ravigneaux planetary gear set is mounted at the rear, [1]. Thanks to the compactness, Lepelletier mechanisms are widely implemented in numerous modern automatic transmission systems.

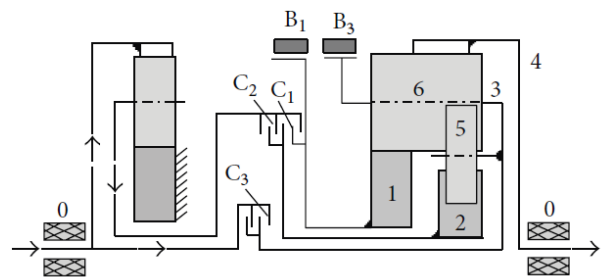


Figure 6. Six speed Lepelletier concept, [6]

First six speed automatic transmission system in the world was solely based on Lepelletier concept. This transmission (Figure 7.) has been brought to the market in 2001. by the ZF under the name ZF 6 HP 26, [1]. This was also one of the first commercially available automatic transmission systems which offered two overdrive speeds.

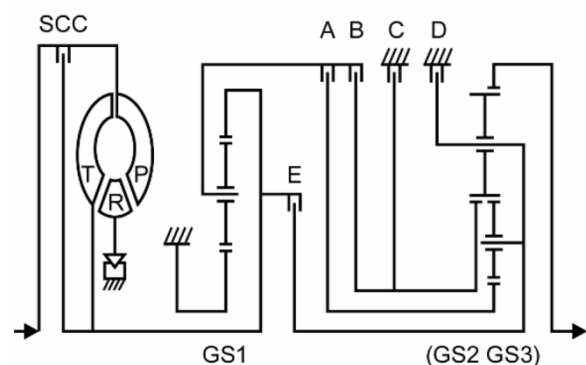


Figure 7. Gearbox diagram of ZF 6 HP 26 automatic transmission, [1]

In 2006. Japanese company Aisin debuted world first commercially available 8-speed automatic rear wheel/all-wheel drive transmission for passenger

vehicles, [1]. This transmission was used for the first time in the Lexus LS460, under the code name Toyota AA80E or Aisin TL80-SN (Figure 8.), [8].

Surprisingly, this transmission is based on the initial Lepelletier concept used in ZF 6 HP 26, but thanks to the sophisticated clutching sequence patented by the Aisin, this transmission achieved 8 different forward speeds (2 overdrive speeds), [8]. Gearbox diagram of this transmission is presented on the Figure 8.

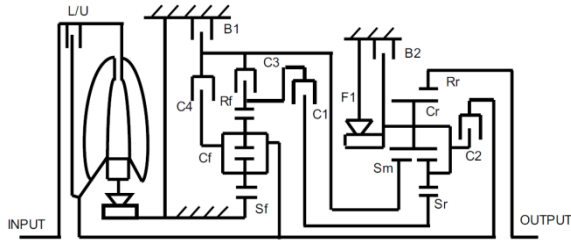


Figure 8. Gearbox diagram of Toyota AA80E/Aisin TL80-SN automatic transmission, [8]

5. OTHER MODERN AUTOMATIC TRANSMISSION SYSTEMS

Recent developments in the industry point out that the major automatic transmission companies such as Daimler and ZF abandoned Ravigneaux and Lepelletier concepts. These companies in their recent products for front longitudinally placed engines, 9G-Tronic (Daimler), 8HP (ZF) indicate that they shifted their focus to the simple planetary gear sets, [9, 10]. For front transversally positioned engines Daimler uses DCT transmission systems, while ZF developed world first (2013.) nine speed automatic transmission, ZF 9HP [11, 12]. One year earlier Aisin debuted world first eight speed front wheel drive automatic transmission, Aisin AWF8F35, [13].

First seven speed automatic transmission was debuted by the Daimler in 2003., [1]. This transmission was code named as W7A 700 (Figure 9.), while in marketing material it was also known as 7G-Tronic, [1, 14]. Currently, Daimler also offers improved version of this automatic transmission known as the 7G-Tronic Plus, [14]. Improved version has same gear train, with improvements visible in the aspect of materials, electrohydraulic control, etc., [14].

Gear train of this transmission combines modified Ravigneaux gear set and two simple planetary gear sets, [1]. This modified Ravigneaux gear set is also known under the name of inverse Ravigneaux gear set, [1]. Inverse gear set has one sun gear, two planetary gears and two ring gears, compared to the two suns, two planets and one ring gear at the seven

link Ravigneaux gear set. This transmission can achieve 7 forward speeds (2 overdrive), one neutral, and two rear speeds, [1].

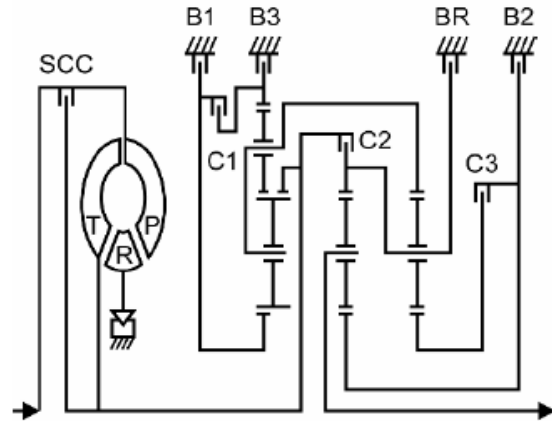


Figure 9. Daimler W7A 700 automatic transmission, [1]

In 2013. Daimler debuted nine speed automatic transmission code named W9A 700 (Figure 10.) or publicly known as the 9G-Tronic, [9]. This is rear wheel/all-wheel drive automatic transmission, which consists of four simple planetary gear sets, [9]. It enables nine forward speeds (three in overdrive), and one rear speed, [9].

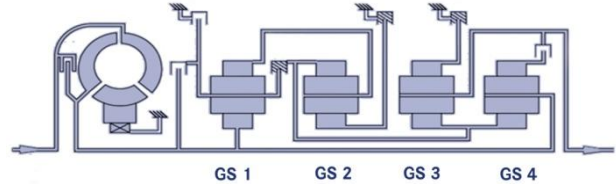


Figure 10. Gear train of 9G-Tronic automatic transmission, [9]

In 2009. ZF debuted its rear/all-wheel drive ZF 8HP automatic transmission (Figure 11.), [10]. As it was earlier mentioned, this automatic transmission is based on the four simple planetary gear sets, [10]. It can achieve eight forward speeds (two in overdrive), and one rear speed, [10].

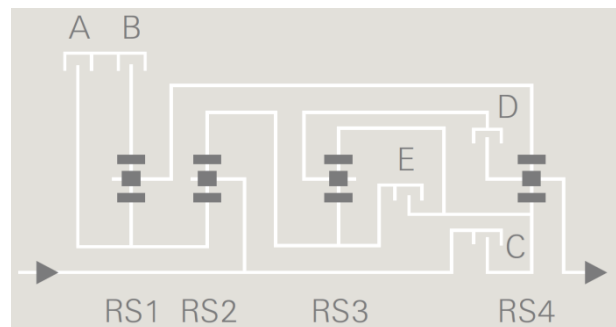


Figure 11. Gear train of ZF 8 HP automatic transmission, [10]

Next step in development of automatic transmissions in the ZF was compact nine speed ZF 9HP (Figure 12.), [11]. It was primarily developed for front transversely positioned engines, and front-wheel/all-wheel drive cars. This transmission to the certain extent consists of four simple planetary gear sets. In order to achieve compactness, planetary gear sets are nested in the unconventional way which demands certain modifications in the construction of the simple planetary gear sets, [11].

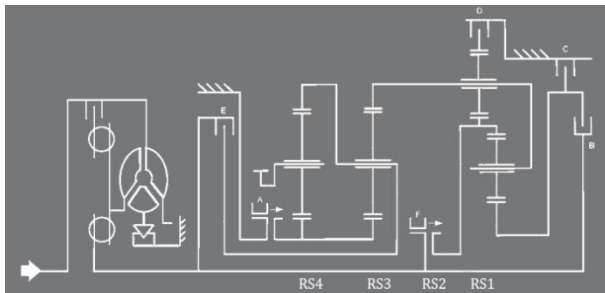


Figure 12. Gear train of ZF 9 HP automatic transmission, [11]

Major US automotive manufacturers also actively work on the development of automatic transmissions. In their passenger vehicles General Motors offers GM 8L90 eight speed automatic transmission which is based on four simple planetary gear sets, [15].

6. FUTURE OF GEAR BASED AUTOMATIC TRANSMISSIONS

Currently every major car manufacturer in the world offers passenger vehicles with automatic transmission systems. They are the only commercially available and applicable systems on the market which can handle high torques (up to 1000 Nm) and simultaneously offer automatic shifting for high number of speeds.

Comparable systems such as CVT can't sustain high torque, but thanks to their compactness they find application primarily in the light duty passenger vehicles, [1]. This type of transmission is primarily used by the Japanese car manufacturers.

Currently, automotive industry works on development of DCT systems, which represent BMW also followed this design principle in its BMW i3 which also has just one fixed gear ratio, [20].

viable alternative to the automatic transmissions, [1]. Although cutting edge commercially available DCT systems don't offer same number of speeds as automatic transmissions, their main advantage over conventional automatic systems is observed in higher efficiency and faster speed shifting, [1]. Generally, Volkswagen is considered as the worldwide leader in DCT transmissions, since this system is available for all their models, which is not the case for the other major automotive manufacturers, [16]. Volkswagen branded DCT transmissions under the name DSG, [16]. Volkswagen developed six and seven speed DSG transmissions, [16]. Other automotive companies also work on development of DCT transmissions. Daimler uses their own 7G-DCT system for compact vehicles with front transversally positioned engines, [17]. This transmission is also implemented in the 4MATIC all wheel drive for compact models, [18].

Automatic transmissions to the certain extent find application in the hybrid passenger vehicles which are due to their complexity mostly present in the luxury segment of the market. Existing automatic transmission systems are modified to the certain extent in order to meet the needs for parallel hybrid passenger vehicles. This type of hybrid vehicles is based on the principle that power from the electric and typical petrol/diesel engine is combined at the gear box, [1]. One of the prime examples of this concept is BMW Active transmission which is based on the existing ZF 6 HP 26 automatic transmission, [1]. Newer ZF 8HP automatic transmission is designed with the intent of hybrid modularity, [6]. Innovations present in this transmission enabled the production of plug in hybrid Mercedes Benz S class Hybrid and BMW ActiveHybrid 3, 5, and 7, [12].

Although automatic transmissions are widely implemented in the automotive industry, electric vehicle segment is probably the only part of the said industry where their application is highly limited. Commercially available electric passenger vehicles from Tesla Motors, BMW, etc. don't have any type of standard transmissions which are present in typical petrol/diesel and hybrid passenger vehicles, [19, 20]. Tesla Model S as one of the most popular electric vehicles on the market has just one pair of gears with one fixed gear ratio, [19].

7. CONCLUSION

In the past few years, development of automatic transmissions sped up. Manufacturers based recent developments primarily on Ravigneaux/Lepelletier planetary mechanisms. Cutting edge automatic transmissions indicate that simple planetary gear sets will probably rule the industry in the coming years.

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