FACULTY OF MECHANICAL AND CIVIL ENGINEERING
IN KRALJEVO
UNIVERSITY OF KRAGUJEVAC

XI TRIENNIAL
INTERNATIONAL CONFERENCE

HEAVY MACHINERY HM 2023

Proceedings

VRNJAČKA BANJA, SERBIA
June 21– June 24, 2023

FACULTY OF MECHANICAL AND CIVIL ENGINEERING IN KRALJEVO
UNIVERSITY OF KRAGUJEVAC
KRALJEVO – SERBIA

THE ELEVENTH TRIENNIAL INTERNATIONAL CONFERENCE

HEAVY MACHINERY
HM 2023

PROCEEDINGS

ORGANIZATION SUPPORTED BY:

Ministry of Science, Technological Development and Innovation, Republic of Serbia

Vrnjačka Banja, June 21–24, 2023

FACULTY OF MECHANICAL AND CIVIL ENGINEERING IN KRALJEVO
UNIVERSITY OF KRAGUJEVAC
KRALJEVO – SERBIA

PUBLISHER:

Faculty of Mechanical and Civil Engineering in Kraljevo

YEAR:

2023

EDITOR:

Prof. dr Mile Savković

PRINTOUT:

SATCIP DOO VRNJAČKA BANJA

TECHNICAL COMMITTEE

Doc. dr Aleksandra Petrović – Chairman
Bojan Beloica – Vice-chairman
Miloš Adamović
Goran Bošković
Vladimir Đorđević
Marina Ivanović
Marijana Janićijević
Aleksandar Jovanović
Stefan Mihajlović
Predrag Mladenović
Stefan Pajović
Anica Pantić
Nevena Petrović
Mladen Rasinac
Vladimir Sinđelić
Marko Todorović
Đorđe Novčić
Jovana Bojković
Tanja Miodragović
Jovana Perić
Slobodan Bukarica

No. of copies: 60

ISBN-978-86-82434-01-6

REVIEWS:

All papers have been reviewed by members of scientific committee

CONFERENCE CHAIRMAN

Prof. dr Mile Savković, FMCE Kraljevo, Serbia

INTERNATIONAL SCIENTIFIC PROGRAM COMMITTEE

CHAIRMAN

Prof. dr Radovan Bulatović, FMCE Kraljevo, Serbia

VICE-CHAIRMAN

Prof. dr Milan Bižić, FMCE Kraljevo, Serbia

MEMBERS

Prof. dr M. Alamoreanu, TU Bucharest, Romania
Prof. dr D. Atmadzhova, VTU "Todor Kableshkov", Sofia, Bulgaria
Prof. dr M. Banić, FME Niš, Serbia
Prof. dr M. Berg, Royal Institute of Technology-KTH, Sweden
Prof. dr G. Bogdanović, Faculty of Engineering Kragujevac, Serbia
Prof. dr H. Bogdevicius, Technical University, Vilnus, Lithuania
Prof. dr N. Bogojević, FMCE Kraljevo, Serbia
Prof. dr I. Božić, FME Belgrade, Serbia
Prof. dr S. Bikić, Faculty of Technical Sciences, Novi Sad, Serbia
Prof. dr M. Bjelić, FMCE Kraljevo, Serbia
Prof. dr M. Blagojević, Faculty of Engineering Kragujevac, Serbia
Prof. dr S. Bošnjak, FME Belgrade, Serbia
Prof. dr A. Bruja, TU Bucharest, Romania
Prof. dr S. Ćirić-Kostić, FMCE Kraljevo, Serbia
Prof. dr I. Despotović, FMCE Kraljevo, Serbia
Prof. dr M. V. Dragoi, Transilvania University of Brasov, Romania
Prof. dr B. Dragović, Faculty of Maritime Studies Kotor, Montenegro
Prof. dr Lj. Dubonjić, FMCE Kraljevo, Serbia
Prof. dr R. Durković, FME Podgorica, Montenegro
Prof. dr Z. Đinović, ACMIT, Wiener Neustadt, Austria
Prof. dr R. Đokić, Faculty of Technical Sciences, Novi Sad, Serbia
Prof. dr K. Ehmann, Northwestern University, Chicago, USA
Prof. dr I. Emeljanova, HGTUSA Harkov, Ukraine
Prof. dr O. Erić Cekić, FMCE Kraljevo, Serbia
Prof. dr V. Gašić, FME Belgrade, Serbia
Prof. dr D. Golubović, FME East Sarajevo, Bosnia and Herzegovina
Prof. dr P. Gvero, FME Banja Luka, Bosnia and Herzegovina
Prof. dr B. Jerman, FME Ljubljana, Slovenia
Prof. dr R. Karamarković, FMCE Kraljevo, Serbia
Prof. dr M. Karasahin, Demirel University, Istanbul, Turkey
Prof. dr I. Kiričenko, HNADU Kiev, Ukraine
Prof. dr K. Kocman, Technical University of Brno, Czech Republic
Prof. dr S. Kolaković, Faculty of Technical Sciences, Novi Sad, Serbia
Prof. dr M. Kolarević, FMCE Kraljevo, Serbia
Prof. dr M. Kostić, Northern Illinois University, DeKalb, USA
Prof. dr M. Krajišnik, FME East Sarajevo, Bosnia and Herzegovina
Prof. dr M. Králik, FME Bratislava, Slovakia
Prof. dr E. Kudrjavcev, MGSU, Moscow, Russia
Prof. dr Đ. Lađinović, Faculty of Technical Sciences, Novi Sad, Serbia
Prof. dr D. Marinković, TU Berlin, Germany
Prof. dr G. Marković, FMCE Kraljevo, Serbia
Prof. dr A. Milašinović, FME Banja Luka, Bosnia and Herzegovina
Prof. dr I. Milićević, Technical Faculty Čačak, Serbia
Prof. dr V. Milićević, FMCE Kraljevo, Serbia
Prof. dr Z. Miljković, FME Belgrade, Serbia

ORGANIZING COMMITTEE

CHAIRMAN:

Prof. dr Goran Marković, FMCE Kraljevo

VICE-CHAIRMAN:

Doc. dr Miljan Marašević, FMCE Kraljevo, Serbia

MEMBERS:

Doc. dr M. Bošković, FMCE Kraljevo, Serbia
Doc. dr V. Grković, FMCE Kraljevo, Serbia
Doc. dr V. Mandić, FMCE Kraljevo, Serbia
Doc. dr A. Nikolić, FMCE Kraljevo, Serbia
Doc. dr M. Nikolić, FMCE Kraljevo, Serbia
Doc. dr A. Petrović, FMCE Kraljevo, Serbia
Doc. dr B. Sredojević, FMCE Kraljevo, Serbia
Dr N. Pavlović, FMCE Kraljevo, Serbia
Doc. dr N. Stojić, FMCE Kraljevo, Serbia

PLENARY SESSION

SESSION A: EARTH-MOVING AND TRANSPORTATION MACHINERY

SESSION B: RAILWAY ENGINEERING

SESSION C: PRODUCTION TECHNOLOGIES

SESSION D: AUTOMATIC CONTROL AND FLUID TECHNIQUE

SESSION E: APPLIED MECHANICS

SESSION F: THERMAL TECHNIQUE AND ENVIRONMENT PROTECTION

SESSION G: CIVIL ENGINEERING

Continuously Variable Transmission for Construction Machines to increase efficiency and productivity

Jasna Glišović[1*], Vanja Šušteršič[1], Jovanka Lukić[1], SašaVasiljević[2]
[1]Faculty of Engineering/Department for Motor Vehicles and Motors, University of Kragujevac, Kragujevac (Serbia)
[2]High Technical School of Professional Studies, Kragujevac (Serbia)

According to estimates, by 2050 two-thirds of the world's population will live in large cities. This trend also comes with disadvantages: fuel emissions, fine dust and noise impact the environment and residents. Ideally, the construction site of the future should not only be environmental neutral, but it should also operate safely and efficiently. Mobile machines used in construction, mining, forestry and agriculture are engineered to withstand extreme working environments while allowing operators to control equipment safely, comfortably and efficiently. Power transmissions make it possible to move extremely heavy loads by applying a multiple increase in torque. However, transmissions must also allow vehicles to move with loads at speeds appropriate to the situation. Careful selection of transmissions can provide an optimal solution: towing or pushing loads at low speeds and operating at higher speeds when needed. Very few mobile construction machines made today are equipped with purely manual transmissions; instead, they are more likely to be equipped with variable-speed transmissions or other automated transmission types. Continuous variable transmission is characterized by: an infinite number of ratios improving vehicle performance and engine optimization, and increasing work efficiency; automatic shifting with smooth forward/reverse shuttling, increasing productivity and drive comfort; maximize fuel savings versus current technologies, allowing cost savings. An objective comparative analysis of various design solutions of continuously variable transmission for modern construction machines and assessment of the most likely trend of the future development of this class of heavy machines was carried out in the paper.

Keywords: CVT, Construction Machines, performance, productivity, design ring

1. INTRODUCTION

Mobile machines used in construction, mining, forestry and agriculture are engineered to withstand extreme working environments, while allowing operators to control equipment safely, comfortably and efficiently. These machines must also be productive and efficient when moving materials. The two main powertrain components used on off-road vehicles that can meet these basic requirements are forward/reverse transmissions and powershift transmissions.

Power transmissions make it possible to move extremely heavy loads by applying a multiple increase in torque. However, transmissions must also allow vehicles to move with loads at speeds appropriate to the situation. Careful selection of the gearbox and its gear ratios can provide an optimal solution: towing or pushing the load at low speeds and working at higher speeds when necessary. Transmissions are designed according to the purpose and tasks of the machine in which they are installed to achieve these goals. Very few mobile construction machines made today are equipped with purely manual transmissions; instead, they are more likely to be equipped with variable-speed transmissions or other automated transmission types. There have been radical changes in the operation and control of hydraulic systems; the use of hybrid drive systems (Figure 1) and great energy savings are some new technological trends in the field of construction machinery [1,2].

The construction industry is faced with massive changes, caused by volatile markets, economic uncertainties, and governmental regulations, demanding high flexibility and fast development cycles. Until recently, hydrostatic-mechanical power split CVT (Continuously Variable Transmission) drivelines have not found a place in construction machinery. The majority of these vehicles still use hydrodynamic powershift transmissions, full-hydrostatic transmissions or mechanical direct-shift transmissions. Hydrostatic drive lines are widely used in construction machinery possessing lower engine power. The upper power range is dominated by hydrodynamic powershift transmissions.

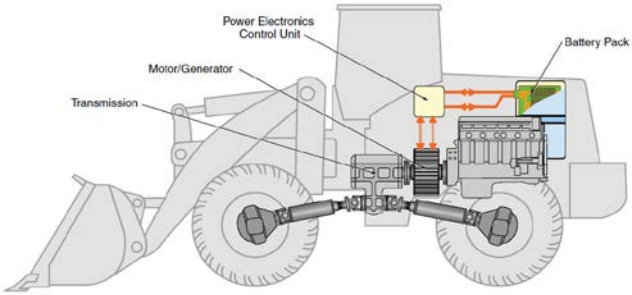

Figure 1: Hybrid machines like this loader use an electric motor between the engine and the transmission, which reduces the fuel consumption and emissions of construction machinery. [3]

2. DEVELOPMENT TREND OF CONSTRUCTION MACHINERY TRANSMISSIONS

In some machines, such as dozers and wheel loaders, it is useful to have the same number of forward and reverse gears. These types of machines usually repeat the same task throughout their workday, such as digging a pile of soil, then carrying it to a dump truck and dumping the load, and then returning to the pile again. To accommodate this cyclical workload, manufacturers typically use an auxiliary gearbox either before the main

*Corresponding author: 6 Sestre Janjic Str., Kragujevac, jaca@kg.ac.rs

standard gearbox, or integral with it. The auxiliary transmission uses two multi-plate couplings. Figure 2 shows a forward/reverse gearbox.

The auxiliary gearbox for forward/reverse movement (reverser) is a set of two hydraulic multi-plate couplings, the first of which, when activated, rotates the gears of the gearbox in the direction of forward movement (clockwise), and when the second is activated, the transmission is achieved in the reverse direction (counter-clockwise). This arrangement can increase the cycle speed of the machine by allowing quick changes between forward and reverse without the need to change the mechanical gear ratio. Although these changes can be made while moving, it is still recommended to stop the vehicle before making the change of direction. In these types of transmissions, the input power is usually delivered to the auxiliary transmission via a torque converter that can mitigate the rapid changes in direction and shock loads on the other power transmission elements of the machine.

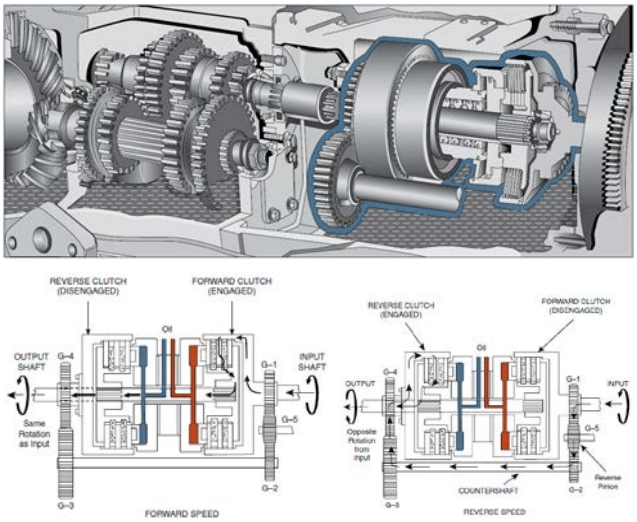

Figure 2: Forward/reverse auxiliary gearbox with two multi-plate couplings [3]

Automated manual transmissions (AMTs) are quickly becoming a presence in the heavy-duty truck market for a number of reasons, primarily fuel economy. These gearboxes are able to optimize the gear change points, resulting in savings of around 5-7% in fuel consumption. This increases the thermal efficiency of the vehicle's engine, meaning that more of the fuel is used to do useful work. By saving fuel, they also reduce the production of carbon dioxide, which contributes to the greenhouse gas effect and thus global warming. These gearboxes, however, also offer other benefits: they reduce driver fatigue, as they no longer have to constantly change a gear, which in turn allows the driver to pay more attention to the road and his surroundings, improving traffic safety. The simplicity of driving vehicles equipped with these transmissions also solves another problem in the trucking industry: the availability of trained drivers to operate construction machines and trucks.

The add-on AMT transmission with dual countershafts uses an auxiliary part to multiply the available gear ratios. The auxiliary is essentially a second gear box bolted to the rear of the main gearbox, so the output of the main gearbox becomes the input for the auxiliary. The auxiliary part can achieve two, three or even four different gear ratios that are used to multiply the available gear ratios of the five-speed main gearbox, resulting in transmissions that have 9, 10, 13, 15 and 18 gear ratios. The auxiliary part can deliver very high torque (high gear ratios) for off-road work, or it can achieve close values of gear ratios to achieve high fuel economy when driving on the highway. Figure 3 shows the power flow for a 10-speed auxiliary transmission.

The range change gear is a large gear on the countershaft auxiliary, and power from the main transmission can be transmitted directly through the range gear (low range), or it can be directly transmitted to the mainshaft auxiliary (high range or direct). In low range, the range synchronizer is moved rearward by a shift fork powered by an air piston. The synchronizer slip clutch engages the range gear engagement teeth, locking them to the mainshaft auxiliary. The output from the main shaft of the main gearbox is connected to the auxiliary part of the drive gear. Power flows from the auxiliary part of the drive gear to the countershaft and back to the range change gear, as shown in Figure 3a.

In high range, the range synchronizer moves forward and locks the auxiliary drive gear directly to the auxiliary main shaft, and power flows straight through the auxiliary, as shown in Figure 3b. The range change system allows the main gear torque to be multiplied by two.

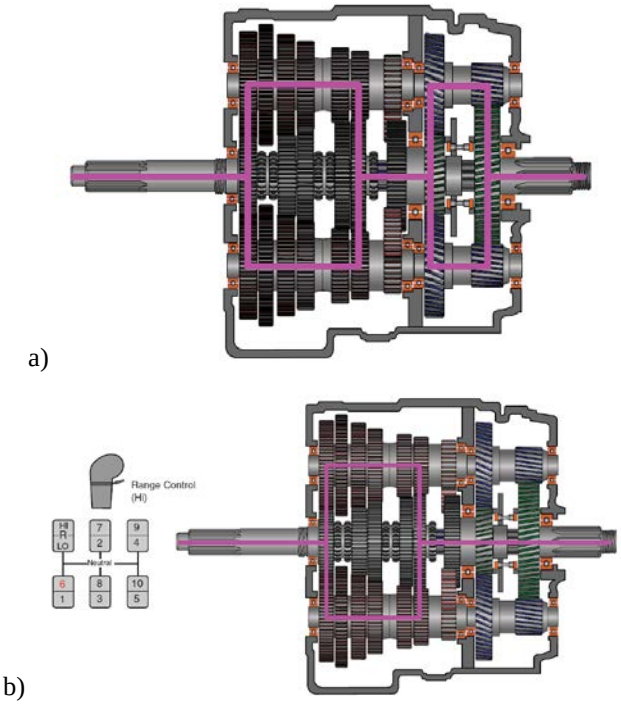

Figure 3: a) Auxiliary gearbox in low range. b) In the high range, the power flows straight through the auxiliary section unchanged [3]

Several off-road vehicles manufacturers are developing or have developed dual clutch transmissions. Figure 4 shows a dual clutch transmission for mid-range trucks. Dual-clutch transmissions save fuel by shifting gears without interrupting torque transmission and shifting much faster than a conventional automatic transmission. Changeover speeds are reduced from 100 to 200 milliseconds to as little as 6 to 12 milliseconds. Because

dual clutch transmissions have two separate power input paths, a solid input shaft and a hollow input shaft, the transmission control unit can select the next gear while still in the previous gear. To change ranges, the transmission simply switches the input clutch to drive a different input shaft, making it much faster.

With the primary input shaft connected to the output shaft, the transmission can achieve sixth gear by shifting to the secondary input clutch and driving the primary input shaft through the secondary input shaft and intermediate shaft. All those transmission ratios go through a planetary gear set. This achieves six forward transmission ratios in the low range with a planetary gear system. The same six ratios are repeated in high range when the planetary gear system allows the power flow to pass through the transmission unchanged. This makes a total of 12 forward gear ratios.

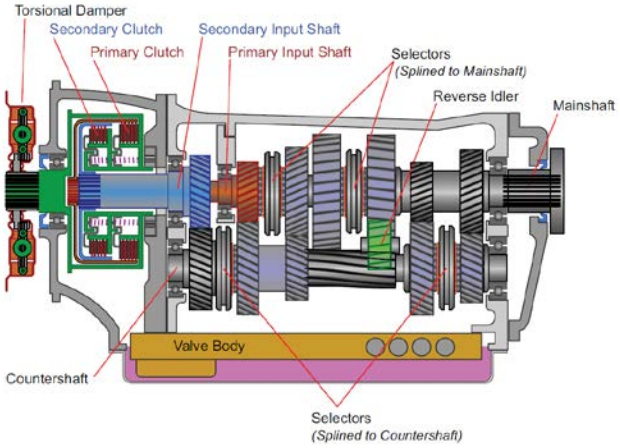

Figure 4: Double clutch transmission with synchro mesh on the main shaft and intermediate shaft [3]

Powershift is a type of transmission developed to allow the operator to shift gears up or down and change direction in motion and under load without loss of acceleration or torque and without using the clutch foot control. More specifically, a powershift transmission transfers torque from the engine's flywheel or torque converter and changes speed, torque and direction of rotation through various gear ratios. Then those changes are transmitted to the rest of the power train, which may include a differential, a set of drive shafts, etc. (Figure 5).

The ability of powershift transmissions to change gears without interrupting the power flow is achieved by means of hydraulic multi-plate clutches that engage and disengage series of gears and are operated by a hydraulic system.

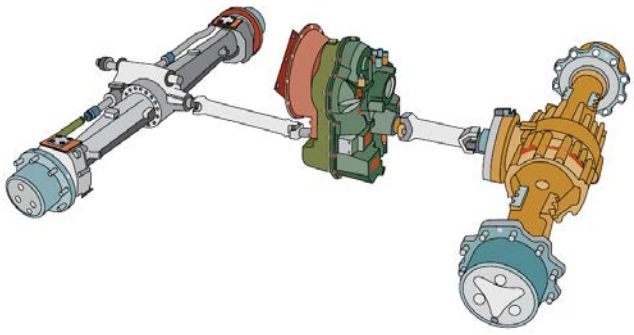

Figure 5: Typical example of a power transmission with a powershift gearbox [3]

There are two main types of powershift transmissions: intermediate shaft and planetary. These names refer to the type of gear arrangement used to transmit torque through the transmission. Both types have permanently toothed gears, meaning that each of the gears inside the transmission is always meshed with another gear. When one or more gears are hydraulically coupled to the shaft, torque is transmitted through the gearbox. In a countershaft transmission, the hydraulic couplings operate counter-rotating shafts by meshing gears. This type of power transmission is commonly found in small to medium wheel loaders, graders, trucks and other machines that have a range of 75-300 kW.

In a planetary power transmission, hydraulic couplings actuate sets of planetary gears to transmit power. Planetary powershift transmissions can be found in any type or size of machine, from less than 75 kW to 750 kW or more.

The powershift intermediate shaft transmission used in the John Deere 872D grader serves as a good example of how this type of transmission is incorporated into the machine's power transmission (Figure 6).

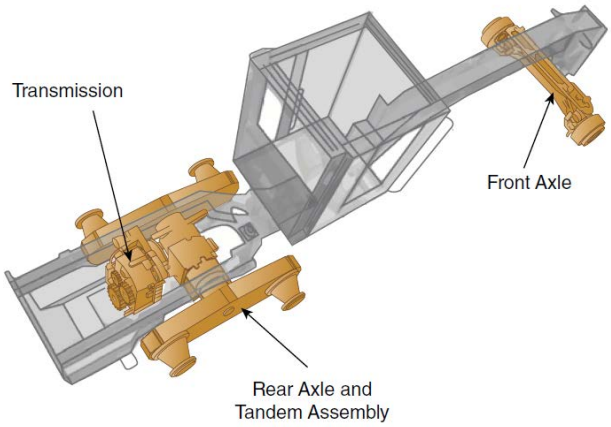

Figure 6: Layout of the elements of the powershift transmission with an intermediate shaft in the grader transmission [3]

Several construction machinery manufacturers offer continuously variable transmissions (CVTs) as standard or optional equipment. A CVT is a transmission in which the transmission ratios are continuously and almost infinitely variable. This type of transmission provides several advantages to the operator. The biggest advantage is that the engine can run at the best rpm in terms of fuel economy and engine efficiency.

Construction machines using a hydrostatic transmission are highly efficient under lower working speed condition, but less capable at higher transport velocities. To increase overall efficiency, the powertrain design can combine a hydrostatic transmission with a dual-clutch transmission (DCT). Unlike other mechanical gearboxes, the DCT avoids the interruption of torque transmission in the process of shifting without sacrificing more transmission efficiency. However, there are some problems of unstable torque transmission during the shifting process, and an excessive torque drop occurring at the end of the gear shift, which result in a poor drive comfort. A novel structure that combines the HST with a dual-clutch transmission is presented in Figure 7. [4]

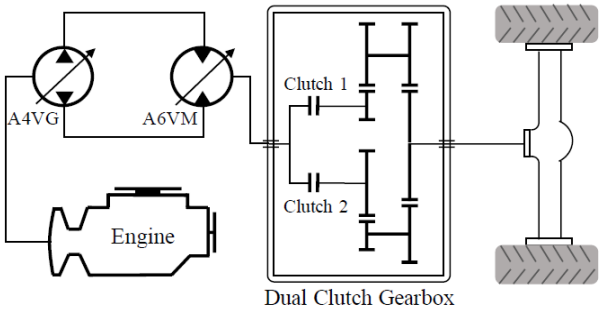

Figure 7: HST+DCT drivetrain [4]

3. IMPROVEMENT OF FUEL EFFICIENCY AND PRODUCTIVITY OF CONSTRUCTION MACHINES

Fuel economy has also been a growing trend over the past decade. However, the additional cost of more complex technologies must be compensated by the savings in fuel cost over a time period of 2-3 years. The transmission’s efficiency highly contributes to the vehicle’s fuel consumption. [5]

Despite the development of emission-free construction machinery, diesel vehicles will continue to dominate the global market for a long time to come. But they too must meet requirements for lower fuel consumption and CO_2 emissions. This is where most manufacturers come in with its solutions for reducing emissions and saving energy that also work to increase efficiency and productivity. Today’s technology is not advanced enough to operate large construction machinery by purely electric means. To meet the demands of tomorrow's construction sites, modern working machines must reduce fuel consumption and give off minimal emissions, while also remaining efficient, convenient, productive, and easy to use.

The proven and tested fully automatic powershift transmission system (Figure 8) has today been optimized for different off-highway machinery types and offers the innovative feature of six instead of four or five gears. The noise-optimized transmission allows even more comfortable and easier handling, high shifting quality and flexibility. Moreover, the operating costs can be further reduced due to various features like converter lock-up, engine de-rating, operating mode selection and much more. For example, the ZF-ERGOPOWER provides additional possibilities for connecting an electronic driveline management, thus enabling vehicle-specific controls (Figure 9). Easy shifting and shift quality by the electronic device is a derivate from the passenger car application with automatic transmissions. Efficiency and safety features are our main targets for the improvement of these transmission ranges.

Whether its wheel loaders, dumpers, graders, forest applications or material handling - in its customized EFFICIENCY PACKAGE (Figure 9), ZF unites its expertise in transmission, axle and software development to offer more than the sum of the advantages of individual applications. System components such as ZF axles and transmissions are optimized for compatibility and enable greater efficiency and easy handling. In light of calls for sustainability, fuel savings of up to 15% are already possible with hydrodynamic technology.

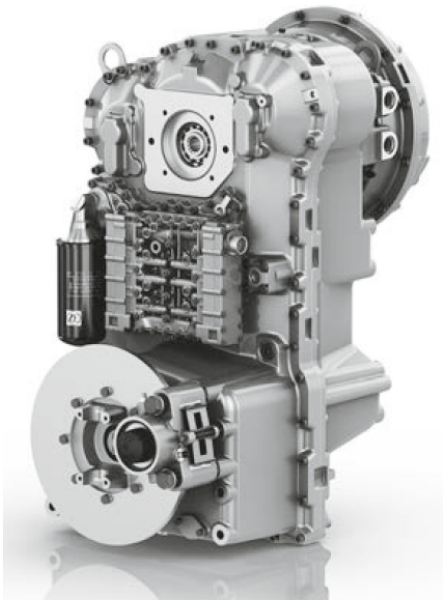

Figure 8: ZF fully automated or manual powershift transmission

Figure 9: ZF ERGOPOWER with efficiency package

CVTs have found applications in machinery that operates at relatively low power, but their applications in the automotive industry have gone through many setbacks and it is only in recent decades that the CVT vehicle market share has become significant. The status of CVT technologies today is the result of intensive research and development by researchers and engineers both in the academic community and in the automotive and construction equipment industry. [6]

An increasing number of machinery manufacturers follow a rising demand for continuously variable transmissions in the construction and agricultural machinery market [8]. Hydrostatic technology is more and more displacing hydrodynamic (torque converter) transmissions especially in construction machinery systems. A trend towards lower engine speeds and the demand for engine stabilization by a constant speed concept are the future challenges. The continuously variable meets both requirements.

Movement sequences flow easier using continuously variable transmissions. Therefore, construction machines can be controlled more precisely. With gear shifting, the drop in power associated with the change of gear does not occur. This ensures more constant engine speeds. The driver profits from the continuously variable technology as well, since manual gear shifting is no longer needed and he can completely concentrate on his work.

Figure 10: ZF cPOWER CVT Technology [7,10,11]

To meet the increasing demands for reductions in fuel consumption and higher productivity with regard to sustainability, ZF has equipped its work machinery with fully power-split CVT technology. The new ZF cPOWER (Figure 10) offers full power-split and perfectly combines hydrostatical and mechanical advantages throughout the whole range. It benefits from the high degree of hydrostatical efficiency at low speeds and at the same time from the great mechanical efficiency at high speeds. Reduced fuel consumption of more than 25% and an increase of productivity of more than 20% are possible. The high tech CVT is 100% assembly-compatible with ZF-ERGOPOWER transmissions. The application of an elaborate hydraulic transmission-control unit and transmission-integrated on-board electronic unit optimally completes driving functions.

But not only in wheel loaders does ZF's cPOWER transmission help reduce fuel and increase productivity. In the Diesel-engine-powered lift truck market, a trend towards lower engine speeds and the demand for engine stabilization by a constant speed concept are the future challenges. The continuously variable cPOWER meets both requirements.

As for forestry equipment, ZF is already supplying the cPOWER transmission design for the Skidder application. In addition, this transmission system is also the ideal driveline solution for the forwarder application. The installation of the cPOWER in these vehicles guarantees a maximum in traction, excellent driving comfort and easy handling.

The entire driving range, forwards and backwards, uses cPOWER stepless control. Regardless of driving speed, lower engine speeds provide greater efficiency and optimum comfort. The result is fuel savings of up to 25% compared to standard ERGOPOWER drives. If cPOWER is combined with the ZF EFFICIENCY PACKAGE, the fuel savings increase by a further 5%. The newly developed EFFICIENCY PACKAGE and the cPOWER CVT technology enable ZF to tailor its solutions to customer needs and market demand. The developers have succeeded in reducing emissions and fuel consumption while increasing efficiency and productivity, without compromising on comfort. (Figure 11).

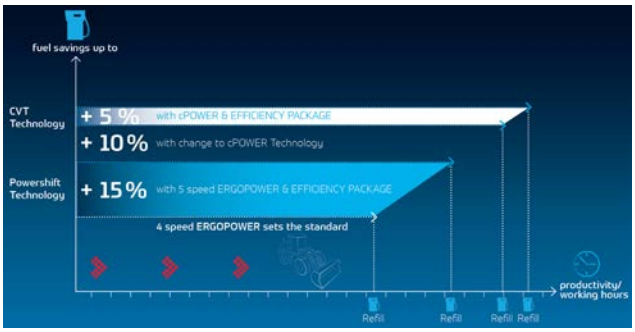

Figure 11: Efficiency package-less fuel and higher productivity [10]

Figure 12 shows the efficiency curves for a two-range CVT in comparison to a 4-speed torque converter power shift transmission. Because CVT is fully power split in the 1st and 2nd range, the efficiency remains stable through the entire vehicle speed range. The hydrostatic module transmits a higher percentage of power at lower vehicle speeds. At these low speeds, where high torque is needed, the power losses of CVT are much lower than a torque converter transmission. At higher speeds, power is transmitted mechanically, allowing the CVT efficiency to remain high while a hydrostatic transmission would lose efficiency rapidly. The first range of CVT covers vehicle speeds of up to 10 km/h allowing highest possible efficiency during productive work. The high and constant efficiency allows more flexibility for OEMs to optimize their power packaging and working hydraulics according to their own operation strategies.

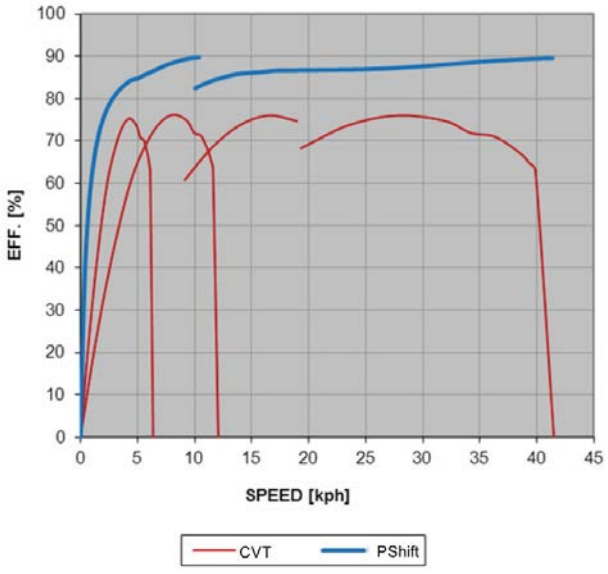

Figure 12: Comparison of Efficiency of CVT and Torque Convertor Power Transmission [4]

CVTCORP, the world leader in the design and development of mechanical continuously variable transmissions (mCVTs) for high-powered off-highway vehicles and his partner Bonfiglioli, a worldwide designer, manufacturer and distributor of a complete range of geared motors, drive systems, planetary gearboxes and inverters, presented a ECGenius line of products. ECGenius is a

high-power, efficient and cost-effective CVT dedicated to telehandler vehicles but also suitable for other equipment. The patented technology at the core of this product is the result of over 15 years of development and enables OEM’s downsize engine while providing unmatched operational ease, and overall vehicle performance improvements in the 20-30% range. Torque and power are transferred seamlessly through 6 actuated rollers, thanks to the elastohydrodynamic lubrication which prevents metal to metal contact while ensuring the correct torque transfer without slippage (Figure 13). Traction drive toroidal architecture offers smooth, seamless shifting with no steps through an infinite number of effective forward speeds. The innovative transmission design with advanced control and clutch reduces the number of mechanical components, therefore reducing mechanical and viscous losses. Seamless shifting allows the engine to operate at its optimal operating point. [9]

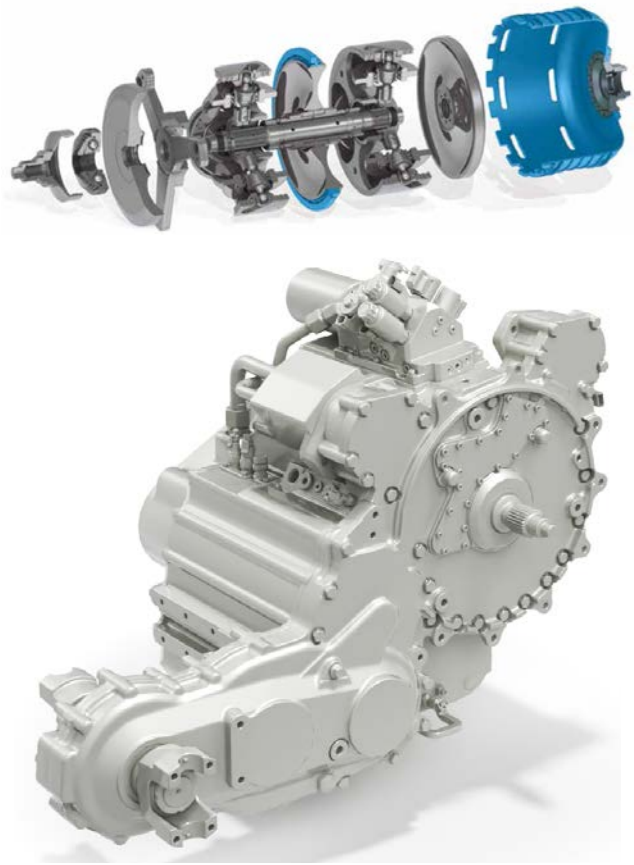

Figure 13: Bonfiglioli Continuously Variable Transmission [9]

4. ELECTRIC POWER TRANSMISSION

The trend towards electromobility is not confined to passenger cars. Electric power transmissions in the field of motor vehicles have found a wider application in special heavy-duty vehicles (so-called dumpers) used for transporting loose loads (ore and tailings) in day mines. The main advantages of the electric power transmission on motor vehicles consist in the fact that it is possible to continuously change the power parameters without its interruption from the source to the drive wheels, simple transmission of power over longer distances with simple electrical conductors, less driver fatigue and the possibility of using the transmission for efficient braking. However, the main disadvantage of this type of power transmission is the heavy weight of its basic components. On vehicles equipped with electric transmissions, the mechanical energy given off by the internal combustion engine is converted into electrical energy in the generator, and this energy is converted into mechanical energy in the electric motors.

Until now, two basic systems of electric power transmission on motor vehicles have been developed: with direct current and with alternating current. In a DC system, the mechanical energy of the internal combustion engine is converted into electrical energy (in a DC generator), and electrical into mechanical energy (in DC motors). In an alternating current system, the mechanical energy of the internal combustion engine is converted into electricity in an alternating current generator. A rectifier is installed between this generator and the direct current electric motors, in which the alternating current is rectified into direct current. As seen in the system, DC electric motors are used, which can be regulated very easily in a wide range of angular speed and torque.

Manufacturers use a wide variety of configurations for AC electric drive systems to drive machinery. In most systems, the flywheel of the diesel engine directly drives the generator, but one machine uses a gearbox located between the flywheel and the generator. The output shaft of the gearbox transmits the torque to the input shaft of the generator. Figure 14 shows the gear drive of the generator. For this machine, the engine speed is tripled to increase the generator speed to 5,400 rpm when the engine is running at 1,800 rpm. The gearbox also drives the machine's hydraulic pump.

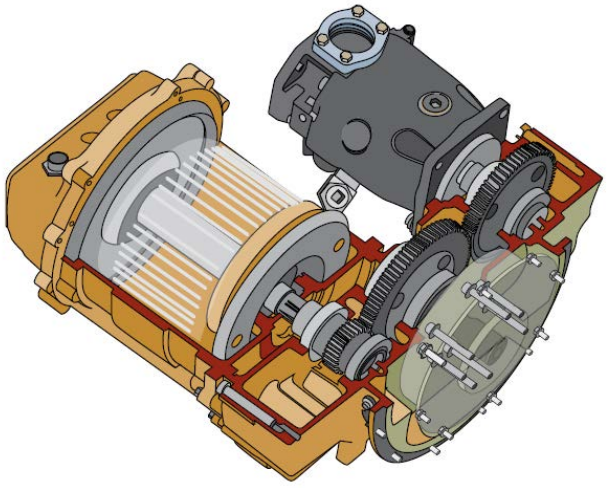

Figure 14: Generator-electric motor gearbox type [3]

The main differences between the systems are the type and number of generators, as well as the type and number of drive motors and how they are controlled. Almost all machines use one generator to power one or more electric motors. There are, however, machines that use two generators.

Electronic controls can precisely control the inverter output to the AC motors to match the operator's speed and direction requirements, while the motor-driven generator rotates at a constant number of revolutions (Figure 15).

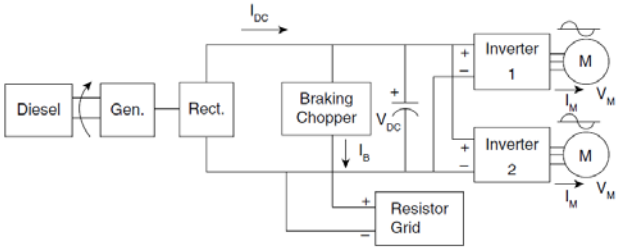

Figure 15: Block diagram of the electrical power transmission system [3].

E-mobility solutions for compact vehicles such as loaders, site dumpers or telehandlers are the first to enter the construction equipment market, especially in urban or emission-regulated areas. ZF starts volume production of new electrified driveline for compact wheel loader (Figure 16). The 48V system is the basis of a modular platform which can be scaled up to 650V and can cover compact vehicle loaders from 4 to 8 tones. Electric motor enables hybrid drive as well as purely electric driving, boost function, and zero-emission operation of equipment. Electric motor acts as retarder or recuperator, which reduces brake wear and thus maintenance costs.

Figure 16: Generator-electric motor gearbox type [10]

5. CONCLUSION

The industry of construction machinery and construction site vehicles is more and more focused on topics like reduced fuel consumption, driver comfort or environmental compatibility. Less fuel consumption, reduced wear and emission, increased efficiency, extended service intervals, easier and better handling, and more automation are all topics in the focus of engineers in this field.

By advancing the CVT powersplit technology known from agricultural machinery, the construction machines transmission provides significant consumption benefits and productivity increases with a level of efficiency previously inconceivable.

Leading manufacturers are also committed to the advancement of alternative drives – not only on the road, but also for off-road applications, so the first hybrid drive for construction machinery is already developed. An electric motor supports the conventional drive and prevents high power peaks. This significantly lowers fuel consumption and reduces the load on the drive. By integrating a hybrid module with the proven powershift transmission, the logical step toward the future was undertaken.

Ideally, the future of construction should not only be climate neutral, but it should also operate safely and efficiently. To ensure this, leading manufacturers are already developing future-oriented system solutions for smart construction sites. Based on all the activities in the passenger car and commercial vehicle segment, a broad portfolio of Know-How and products can be re-used for Off-Highway vehicle applications. Radar-based environment perception is just one example to ensure safe vehicle operation.

ACKNOWLEDGEMENTS

The Ministry for education, science and technological development of the Government of the Republic of Serbia supported the research presented in the article (grant number TR35041).

REFERENCES

[1] D. Janošević, “Projektovanje mobilnih mašina”, Univerzitet u Nišu, Mašinski fakultet, Niš, (2006)

[2] A.F. Andreev, V.I. Kabanau, V.V. Vantsevich, “Driveline Systems of Ground Vehicles. Theory and Design”, CRC Press, Taylor & Francis Group, Boca Raton, US, (2010)

[3] O.C. Duffy, S.A. Heard, G. Wright, “Fundamentals of Mobile Heavy Equipment”, Jones & Bartlett Learning, Burlington, USA, (2019)

[4] Y. Xiang, R. Li, C. Brach, X. Liu and M. Geimer, “A Novel Algorithm for Hydrostatic-Mechanical Mobile Machines with a Dual-Clutch Transmission”, Energies, Vol. 15, 2095, (2022)

[5] J. Legner, W. Rebholz, R. Morrison, “ZF cPower – Hydrostatic-Mechanical Powersplit Transmission for Construction and Forest Machinery”, 10th International Fluid Power Conference (10. IFK) March 8 - 10, Vol. 3, pp. 45-5, (2016)

[6] Y. Zhang and C. Mi, “Automotive Power Transmission Systems”, John Wiley & Sons Ltd, Hoboken, USA, (2018)

[7] HL975A CVT Wheel Loader - Hyundai Construction Equipment, Product Catalog, https://www.hyundai-ce.eu/en/products/loaders/wheel-loaders/hl975a-cvt

[8] The New Cat 966K XE Wheel Loader with advanced powertrain, Product Catalog, https://www.cat.com/en_IN/news/machine-press-releases/the-new-cat-sup-174sup966kxeefficientcomfortablesustainable.html

[9] Bonfiglioli Continuously Variable Transmissions, Product Catalog, https://www.dropbox.com/home/HM2023?preview=Bonfiglioli_LateralVertical.pdf

[10] ZF Construction Machinery Systems, From Less to Zero, Product Catalog, https://www.zf.com/products/media/industrial/construction/downloads_1/new/Construction_Machinery_Systems.pdf

[11] Doosan DL420CVT-5 Wheel Loader, Product Catalog, https://www.lloyd.ltd.uk/wp-content/uploads/2021/03/EN_DL420CVT-5_Brochure_D4600130_01-2019_LowRes.pdf

SUPPORTED BY:

The Ministry of Science, Technological Development and Innovation of the Republic of Serbia

The Serbian Chamber of Engineers

TeamCAD d.o.o. Zemun-Belgrade

Banim reklame d.o.o. Kraljevo

BRANDING BUSINESSES

Radijator Inženjering d.o.o. Kraljevo

Messer Tehnogas AD Belgrade

CIP - Каталогизација у публикацији Народна библиотека Србије, Београд

621(082)
621.86/.87(082)
629.3/.4(082)
622.6(082)
681.5(082)

INTERNATIONAL Triennial Conference Heavy Machinery (11 ; 2023 ; Vrnjačka Banja)
Proceedings / The Eleventh International triennial conference Heavy machinery
HM 2023, 21 – 24 June 2023, Vrnjačka Banja, Serbia ; [editor Mile Savković]. - Kraljevo : Faculty of Mechanical and Civil Engineering, 2023 (Vrnjačka Banja : SaTCIP). - 1 knj. (razl. pag.) : ilustr. ; 30 cm

Tiraž 60. - Str. 5: Preface / Mile Savković. - Bibliografija uz svaki rad.

ISBN 978-86-82434-01-6

a) Машиноградња -- Зборници b) Транспортна средства -- Зборници
v) Производно машинство -- Зборници g) Шинска возила -- Зборници
d) Аутоматско управљање -- Зборници

COBISS.SR-ID 120402697

Faculty of Mechanical
and Civil Engineering in Kraljevo
University of Kragujevac
Serbia, 36000 Kraljevo, Dositejeva 19
Phone/fax +381 36 383 269, 383 377

E-mail: office@mfkv.kg.ac.rs
www.mfkv.kg.ac.rs