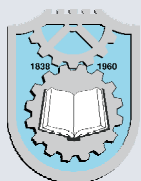


**International Congress  
Motor Vehicles & Motors 2014**

**VEHICLE AS A SAFETY FACTOR  
OF THE TRANSPORTATION ACTIVITY**

**Proceedings of Papers**



October 9<sup>th</sup> - 10<sup>th</sup>, 2014  
Kragujevac, Serbia

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Kragujevac, Serbia

*Publisher:* Faculty of Engineering, University of Kragujevac  
Serbia, 34000 Kragujevac, Sestre Janjić 6

*For Publisher:* Prof. dr Miroslav Živković - Dean

*Editors:* Dr Božidar Krstić, prof.  
Dr Dragan Taranović, assist. prof.

*Technical preparation:* Dr Dragan Taranović, assist. prof.

*Picture on the cover:* Nemanja Lazarević

*Print CD:* Faculty of Engineering, University of Kragujevac, Kragujevac  
ISBN 978-86-6335-010-6

*Year of publication:* 2014.

*Number of copies printed:* 200

CIP - Каталогизacija y публикацији  
Народна библиотека Србије, Београд

629.3(082)  
621.43(082)

INTERNATIONAL Congress Motor Vehicles &  
Motors (5th ; 2014 ; Kragujevac)  
Vehicle as a Safety Factor of the  
Transportation Activity : proceedings /  
International Congress Motor Vehicles &  
Motors 2014, [5], October 9th-10th, 2014,  
Kragujevac, Serbia ; [congress organizers  
Faculty of Engineering, University Kragujevac  
... [et al.] ; editors Božidar Krstić, Dragan  
Taranović]. - Kragujevac : Faculty of  
Engineering, 2014 (Kragujevac : Faculty of  
Engineering). - IX, 546 str. ; 30 cm

Tiraž 200. - Napomene i bibliografske  
reference uz tekst. - Bibliografija uz svaki rad.

ISBN 978-86-6335-010-6

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*Publishing of this book is supported by:*

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- European Union by the "*DIAUSS - Development and Improvement of Automotive and Urban Engineering Studies in Serbia*" Joint Project [JP 516729-2011] as part Tempus Program

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**MVM2014-031**

**Vanja Šušteršič<sup>1</sup>**  
**Jasna Glišović<sup>2</sup>**  
**Dušan Gordić<sup>3</sup>**

## **TRENDS IN DEVELOPMENT, DESIGN AND CALCULATION OF CVT**

**ABSTRACT:** Continuously variable transmissions (CVTs) are applied in an increasing number of vehicles. Large ratio coverage allows for reduced engine speeds, which adds to both highway driving comfort and reduced fuel consumption. It becomes increasingly important to further improve the performance in terms of efficiency, robustness and torque capacity of the CVT. This paper describes trends in development, design and calculation of push belt CVT.

It's foreseen that in not so distant future these power transmission will replace the classical transmission, especially in power transmission in road vehicles.

**KEYWORDS:** design, Continuously Variable Transmission (CVT), metal push belt

### **INTRODUCTION**

The main trends in the development of transmission are increase of operating machine efficiency, with reducing the dimensions, i.e. to achieve optimum ratio of capacity and compact design. These trends are reflected particularly in the automotive industry. There are numerous researches where these objectives are achieved by continuous change of transmission ratio or in other words by Continuously Variable Transmission (CVT) [3]. It has an advantage over conventional automatic transmissions, with respect to the large transmission ratio coverage and absence of comfort issues related to shifting events. This enables the engine to operate at more economic operating points. For this reason, CVT equipped cars are more economical than cars equipped with planetary gear automatic transmissions [1]. In addition to the aforementioned, the advantages of CVT transmissions are:

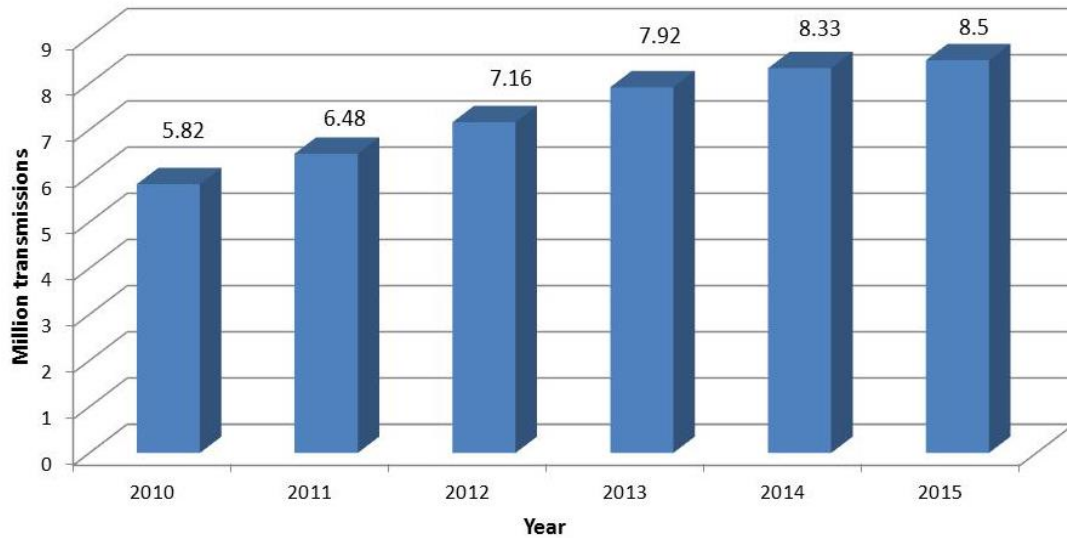
- CVT allows for the operation at the lowest possible speed and highest possible load, partially avoiding the low efficiency region of the engine map.
- A continuously variable transmission (CVT) transfers power through a range of speed/torque ratios from engine input to output, continuously without interruption.
- Contrast with either manual or conventional automatic transmissions that use discrete ratios and normally disengage when changing ratio.
- The CVT category includes infinitely variable transmissions (IVT) that give a zero output speed within the operating range.

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Figure 1 shows the Continuously variable transmission forecast for automobile production worldwide from 2010 to 2015 (in millions) [9].



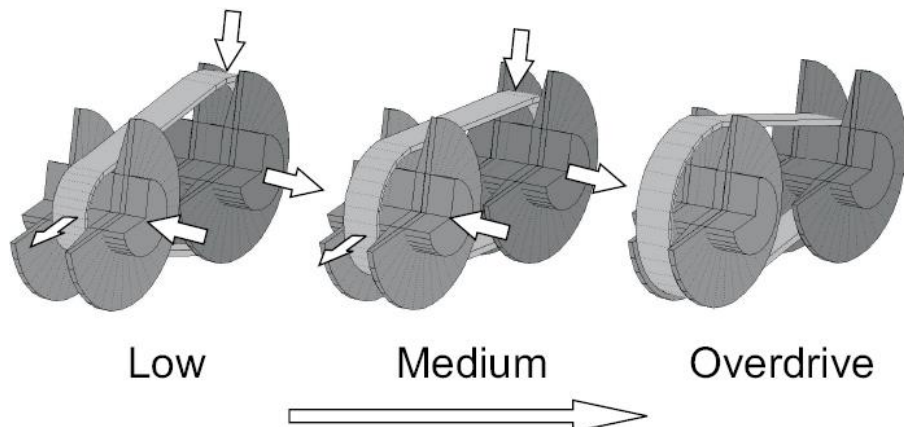
**Figure 1** CVT forecast for automobile production worldwide [8]

The timeline shows a continuously variable transmission forecast for automobile production worldwide from 2010 to 2015. In 2010, about 5.82 million cars and light vehicles produced worldwide were equipped with a continuously variable transmission. It is forecast that this number will increase to about 8.5 million automobiles produced worldwide in 2015. A continuously variable transmission (abbreviated as CVT) is a transmission that can change steplessly through an infinite number of effective gear ratios between maximum and minimum values. This is a contrast to other mechanical transmissions that offer a fixed number of gear ratios [9]. However, in the last couple of years, in North America, the CVT transmission has been slipping in popularity. Why? One reason is because they are usually more expensive than comparable, traditionally geared transmissions. Another is that they lose the shifting feel that consumers are used to experiencing in vehicles. Some may view this as a positive, but many apparently do not. In fact, auto companies like Nissan are putting a shifting feel back into their CVTs with software. Finally, there tends to be a torque limit with CVT transmissions which lowers vehicle performance in comparison to geared transmissions making them better suited to small engines.

New systems with increasing numbers of gears of up to 8 gears in the latest automatic gearbox decrease the advantage of the CVT with respect to the transmission ratio coverage and optimal engine operation (i.e. fuel economy). However, the increasing numbers of gears present additional costs and increased size of the transmissions. The push belt type CVT already has a large ratio coverage and unlimited number of gears.

## DESIGN OF CVT

This type of transmission consists of cone disks on which are enveloped by chain or belt. Power transmission is done through friction between the disc and chain/belt (Fig.2). Varying of transmission ratio is achieved by different position of disc on input and output shaft, i.e. by changing the diameter at which there is direct contact between chain and discs. Required pressure force between compressed elements of the chain and working surface is achieved by the hydraulics via a special hydro aggregates.



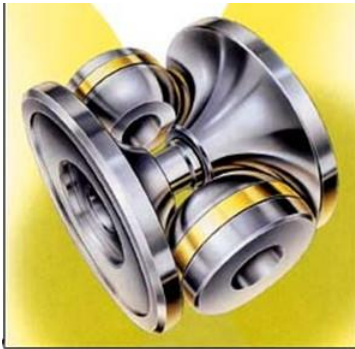
**Figure 2** The working principle of the V-belt CVT [1]

The CVT appears in several forms. The most common types of CVT are (Fig. 3):

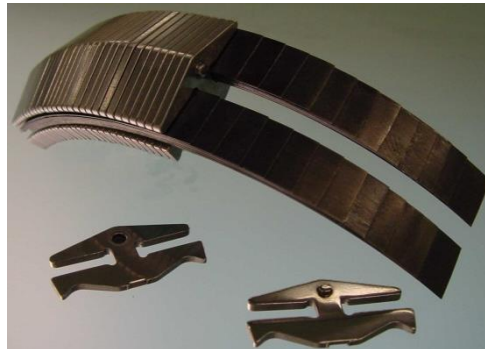
- Toroidal CVT,
- Belt CVT and
- Chain CVT.

The most important belt CVT are:

- Dry belt (rubber V-belts, but they are not well suited for automotive applications, because of their limited torque capacity, but therefore needs less clamping force and can be much smaller and lighter),
- Chain (consist of pins and segments. The pins are typically crowned to enhance the chain-pulley contact. Most CVT chains only have rolling contacts between the pins and have static contacts between the pins and the segments) and
- Push belt (consists of blocks and bands. The maximum engine torque can vary between different types, but is roughly somewhere in the 150-350 Nm) [1].



*Toroidal CVT*



*Belt CVT*



*Chain CVT*

**Figure 3** Types of CVT

## ***Metal push belt CVT***

In most common CVT system, there are two V-belt pulleys that are split perpendicular to their axes of rotation, with a V-belt running between them. The gear ratio is changed by moving the two sheaves of one pulley closer together and the two sheaves of the other pulley farther apart. Due to the V-shaped cross section of the belt, this causes the belt to ride higher on one pulley and lower on the other. Doing this changes the effective diameters of the pulleys, which in turn changes the overall gear ratio. The distance between the pulleys does not change, and neither does the length of the belt, so changing the gear ratio means both pulleys must be adjusted (one bigger, the other smaller) simultaneously in order to maintain the proper amount of tension on the belt.

In a metal V-belt CVT, torque is transmitted from the driver to the driven pulley by the pushing action of belt elements. Since there is friction between bands and belt elements, the bands, like flat rubber belts, also participate in torque transmission. Hence, there is a combined push–pull action in the belt that enables torque transmission in a metal V-belt CVT system (Table 1).

**Table 1** Differences of pull and push type of CVT

	<b>Dry-pulling type</b>	<b>Wet-pushing type</b>
Torque transfer path	Driving pulley-Belt-Driven pulley	Driving pulley-Block-Belt-Block-Driven pulley
Function of block	Reinforcement of belt	Torque transfer
Belt friction coefficient	Two times of wet types	Less than dry type
Adoption	Light passenger car	Ordinary passenger car

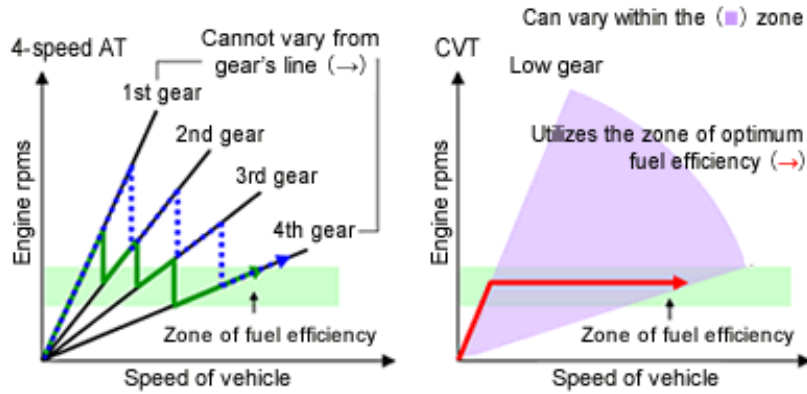
## **Efficiency and fuel economy of CVT**

A continuously variable transmission seeks to overcome this by offering an infinite number of gear ratios between the transmission's upper and lower limit ratio. There are several ways to reduce fuel consumption in vehicles that use CVT and to increase efficiency. We will mention some of them:

- Optimizing the activation ways,
- Increasing the efficiency level of hydraulic pump and by providing greater pressure,
- Optimizing of the engine and CVT operation,
- Better lubrication and cooling,
- Reducing the clamping force,

- The use of new materials.

Comparing the fuel efficiency of CVT with AT is fairly complex because a number of factors play a part. However, if we look at the most important factors in fuel economy, which are mechanical efficiency and ratio flexibility, i.e. the ability to seamlessly change ratio between the minimum and maximum value of gear ratios, CVT's typically are more efficient than traditional automatic transmissions (Fig.4).



**Figure 4** Fuel economy comparisons [9]

## CALCULATION OF CVT

The highest ratio is selected to achieve maximum speed, and it's used to reduce fuel consumption on the open road. Using the given strength can be determined by the maximum speed. The transmission ratio is shown in the equation 1, and the lowest and largest ratio in the equation 2 and 3:

$$i = \frac{R_{max}}{R_{min}}, \quad (1)$$

$$i_{min} = \frac{F_a \cdot d_t}{2 \cdot M_m \cdot \eta_s \cdot i_{dif}} \quad (2)$$

$$i_{max} = \frac{\pi \cdot n_m \cdot d_t}{60 \cdot v_{max} \cdot i_{dif}} \quad (3)$$

where:

$F_a$  – drag force ascent,

$d_t$  – wheel diameter,

$M_m$  – torque,

$i_{dif}$  – differential gear ratio.

Length of belt can be written as:

$$l = R_{min} \cdot \beta_{min} + R_{max} \cdot \beta_{max} + 2\sqrt{[a^2 - (R_{max} - R_{min})^2]} \quad (4)$$

where:

$$\beta_{min} = 180 - 2\alpha$$

$$\beta_{max} = 180 + 2\alpha$$

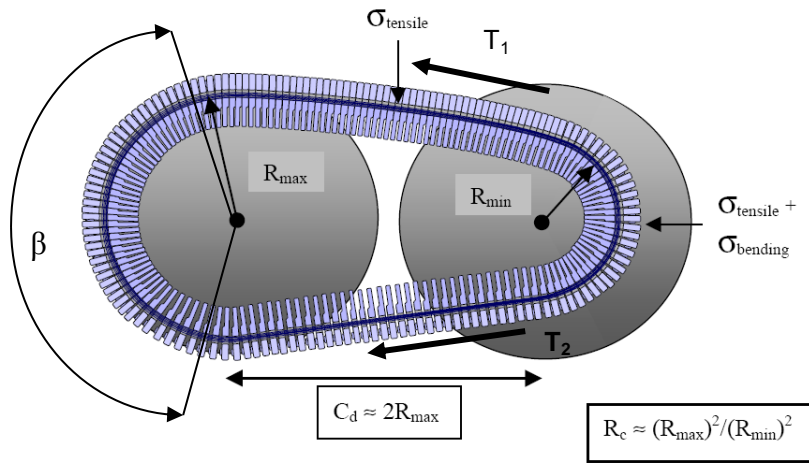
$$\sin\alpha = \frac{R_{max} - R_{min}}{a}.$$

Load on the shaft (Fig. 5) can be calculated using equation (5):

$$T_v^2 = T_1^2 + T_2^2 - 2 \cdot T_1 \cdot T_2 \cdot \cos\beta_{min} \quad (5)$$

where:

$T_1$ ,  $T_2$  - loading forces in the belt.



**Figure 5** Push belt loading [4]

3D model of the CVT is done in the programming software, CATIA V5R18 and is shown in Figure 6.



**Figure 6** 3D model of push belt CVT

## CONCLUSIONS

CVT transmissions are used in almost all types of vehicles that are produced, regardless of whether the engine has 4, 6 or 8 cylinders. Belt that is used today in most CVT has a high quality and can resist very high torques. These transmissions are very reliable, as long as the maintenance is performed properly and when the transmission fluid is used as recommended by the manufacturer. These transmissions are particularly interesting for application in our market, because this type of power transmission is still a little used, since vehicles with manual transmission are mainly used in our market, though CVT offers:

- Higher fuel economy,
- Driving comfort,
- The maximum power,
- Continuous uniform acceleration.

The power transmission with belt is analysed in this paper. The basic equations for calculating gear ratios and geometric parameters, as well as the 3D model of such transmission are presented.

## ACKNOWLEDGMENTS

This paper is part of the research included in the project: *"The research of vehicle's safety as part of the cybernetic system: the driver-vehicle-environment"*, TR 35041, supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia. The authors would like to thank the Ministry for the financing of this project.

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ISBN 978-86-6335-010-6



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