INTRODUCTION

After more than a century of research and development, the internal combustion (IC) engine is nearing both perfection and obsolescence: engineers continue to explore the outer limits of IC efficiency and performance, but advancements in fuel economy and emissions have effectively stalled. While many IC vehicles meet Low Emissions Vehicle standards, these will give way to new, stricter government regulations in the very near future. With limited room for improvement, automobile manufacturers have begun full-scale development of alternative power vehicles. Still, manufacturers are loath to scrap a century of development and billions or possibly even trillions of dollars in IC infrastructure, especially for technologies with no history of commercial success. Thus, the ideal interim solution is to further optimize the overall efficiency of IC vehicles.

One potential solution to this fuel economy dilemma is the continuously variable transmission (CVT), an old idea that has only recently become a bastion of hope to automakers. CVTs could potentially allow IC vehicles to meet the first wave of new fuel regulations while development of hybrid electric and fuel cell vehicles continues. Rather than selecting one of four or five gears, a CVT constantly changes its gear ratio to optimize engine efficiency with a perfectly smooth torque-speed curve. This improves both gas mileage and acceleration compared to traditional transmissions.
The fundamental theory behind CVTs has undeniable potential, but lax fuel regulations and booming sales in recent years have given manufacturers a sense of complacency: if consumers are buying millions of cars with conventional transmissions, why spend billions to develop and manufacture CVTs?

Although CVTs have been used in automobiles for decades, limited torque capabilities and questionable reliability have inhibited their growth. Today, however, ongoing CVT research has led to ever-more robust transmissions, and thus ever-more-diverse automotive applications. As CVT development continues, manufacturing costs will be further reduced and performance will continue to increase, which will in turn increase the demand for further development. This cycle of improvement will ultimately give CVTs a solid foundation in the world’s automotive infrastructure.
CVT THEORY & DESIGN

Today’s automobiles almost exclusively use either a conventional manual or automatic transmission with “multiple planetary gear sets that use integral clutches and bands to achieve discrete gear ratios”. A typical automatic uses four or five such gears, while a manual normally employs five or six. The continuously variable transmission replaces discrete gear ratios with infinitely adjustable gearing through one of several basic CVT designs.

Push Belt

This most common type of CVT uses segmented steel blocks stacked on a steel ribbon, as shown in Figure (1). This belt transmits power between two conical pulleys, or sheaves, one fixed and one movable. With a belt drive:

![Figure (1) – Metal Push Belt CVT From [3]](image)

In essence, a sensor reads the engine output and then electronically increases or decreases the distance between pulleys, and thus the tension of the drive belt. The continuously changing distance between the pulleys—their ratio to one another—is analogous to shifting gears. Push-belt CVTs were first developed decades ago, but new advances in belt design have recently drawn the attention of automakers worldwide.
**Toroidal Traction-Drive**

These transmissions use the high shear strength of viscous fluids to transmit torque between an input torus and an output torus. As the movable torus slides linearly, the angle of a roller changes relative to shaft position, as seen in Figure (2). This results in a change in gear ratio.

![Figure (2) - Toroidal CVT](image)

*From [3]*

**Variable Diameter Elastomer Belt**

This type of CVT, as represented in Figure (2), uses a flat, flexible belt mounted on movable supports. These supports can change radius and thus gear ratio. However, the supports separate at high gear ratios to form a discontinuous gear path, as seen in Figure (3). This can lead to the problems with creep and slip that have plagued CVTs for years.
This inherent flaw has directed research and development toward push belt CVTs.

**Other CVT Varieties**

Several other types of CVTs have been developed over the course of automotive history, but these have become less prominent than push belt and toroidal CVTs. A nutating traction drive uses a pivoting, conical shaft to change “gears” in a CVT. As the cones change angle, the inlet radius decreases while the outlet radius increases, or vice versa, resulting in an infinitely variable gear ratio. A variable geometry CVT uses adjustable planetary gear-sets to change gear ratios, but this is more akin to a flexible traditional transmission than a conventional CVT.