Continuously Variable Transmission
CVT belt
CVT assembly
Operating principles for CVTs

Adjustable-pitch drives
- Shafts pitch diameter is changed to change the speed ratio.
- Output shaft.
- Low speed-reduction.
- High speed-reduction.

Traction drives
- Input shaft.
- Plate.
- Output shaft.
- Wheel.
- Small track radius.
- Large track radius.
- Low reduction.
- High reduction.

Variable-stroke drives
- Input shaft.
- Crank.
- Eccentric.
- Control link.
- Drive link.
- Large stroke.
- Small stroke.
- Low reduction.
- High reduction.
Traction type belt

under varying degrees of spin and slip were made using the model by Treskawetz and Johnson [3] and Treskawetz [4] for the traction prediction of an elastic-plastic material. The traction prediction of the traction type belt was made using the model by Treskawetz and Johnson [3] and Treskawetz [4].

Treskawetz [4] suggests that there are basically three regions of operation for a traction driven contact. Fig. 3 shows these regions as a function of the aspect ratio of the contact and the dimensionless spin on the contact. At low spin values, (region I), the contact becomes a purely elastic driven contact. As the spin increases (region II), the traction efficiency is reduced, and the conventional analysis of Wadell's [1] and Magni [4] cannot be used. The analysis done by Treskawetz [4] and Treskawetz and Johnson [3] is used to predict the maximum traction coefficient from the simple slip traction curve.
Rubber type belt

Power Trac—the new CVT (Continuous Variable Transmission) belt from Gates—is a technologically advanced product that combines the best features of high-grade, lightweight synthetic and stainless steel materials.

Four unique design features allow Power Trac to handle high horsepower and last longer on CVT drives:

1. **High-modulus DuPont Kevlar tensile cords.** Surrounded by protective rubber/titanium oxide, these high-strength cords are extremely flexible, yet extremely strong.
2. **High modulus tensile cords.**
3. **Segmented trapezoidal belt design.**
4. **Specially compounded friction pads.** The pads maintain uniform friction with the pulleys and a low wear rate. They also allow for momentary high torque slip without damage to the pulleys.

Economical Design Simplicity
Dry system Power Trac CVT’s don’t require intricate multiple planetary gears, complicated oil bath housings or costly oil coolers. Low axial force pulleys also allow the use of simple, low-cost mechanical pulley controls. With fewer transmission components involved, Power Trac can reduce production costs by 10 to 20%.

Reduced Power Loss.
The axial force required of Power Trac pulleys is much less than what is required of pulleys in other types of CVT’s. This low axial force reduces system parasitic losses.

Improved Fuel Economy.
A Power Trac CVT’s large speed ratio range combined with its continuous shift capability and high mechanical efficiency results in fuel-economy similar to a manual transmission.

Power Trac works. We have proven that. The potential that awaits this belt is as limitless as the imaginations of the design engineers who will work with it. We have the belt. You have the knowledge. Together let us design the ultimate transmission of the future!
Chain type belt

Introduction
The Borg Warner Automotive, Inc. Morse® CVT chain belt is unique in design. Prototypes are manufactured by proven production methods at Borg Warner's chain plant in Ithaca, New York. Extensive development background with various customer applications in their own Continuously Variable Transmissions has been and are being carried out by Borg Warner's chain development engineering personnel. Borg Warner issued patents covering CVT Chain Belt include the following:

4,313,730 4,319,540
4,350,702 4,465,155
4,397,796 4,512,056
4,407,154 4,510,000
4,550,071

The Morse® Chain Belt: A Closer Look
The history of the Morse® chain belt goes back many years. It is based on our successful product lines of Hy-Lube® transmission chains and “silent” engine timing chains. We currently supply the majority of the market requirements for front-wheel drive automatic transmissions; four wheel drive transfer cases and a major portion of the engine timing drives in North America. This requires makings, processing and assembling over 35 million chain parts per day.

The extensive knowledge of manufacturing and application to the automotive environment of our straight chain product has been used to develop a friction drive chain belt for CVT uses.

The Morse® CVT belt consists of three basic parts: a load block, links and pins. Not these parts can be produced on existing high volume equipment currently being used to produce our toothed automotive chain.

The load block contacts the pulley face at the surface on the outside flanges. The surface at the bottom of the window contacts the links to provide the engaging flanges necessary to provide the friction drive. The chain links are attached to the load blocks and joined with two pins at each joint to form a horizontal tension chain. The two pins form a rocking joint which articulates with a sliding action rather than a sliding action as would occur with a snap pin. This reduces joint friction and increases efficiency.

The aperture in the link is shaped to align the pin with the link to provide even stress distribution and reduce bending of the pins during articulation. The tangential driving load from the load blocks is taken by the tabs at the top and bottom of the links which are arranged in an alternating pattern. The
Drive arrangement for chain belt

Drive chain: are retained by the sides of the sheaves during normal belt operation.

The links are steel thru hardened and tempered. The load blocks are a modified, tempered material and the pins are case hardened steel. All parts are processed to provide the proper finish and increased fatigue life. The Morse® chain belt will maintain its ability to function even after a remarkable amount of abuse.

Meeting Design Challenges For Optimum Performance

The efficiency of the belt is very good. The exact number varies with the equipment used (i.e. fast stand, pulley stiffness, hydraulic control, bearings, temperature and lubrication), but for a fast belt, two pulleys mounted on four support bearings properly lubricated, the efficiency is around 95%. The Morse® chain belt has always shown an efficiency equal to or higher than any of the “push” type belts we have tested.

The coefficient of friction of the belt in Dacron® is approximately μ = 0.09. The actual operating coefficient varies slightly from this value, but for initial calculations this value is accurate enough for most belt equations. For final design we use an empirically adjusted equation.

In general, the Morse® belt will operate satisfactorily in systems designed for push belts without alteration other than those required by belt length and shaft clearance considerations.

Control of noise has been a major challenge in the development of the belt. A pitch frequency noise is generated by the belt due to the contaction of the links as they wrap the pulleys. This causes a change in belt length and thus a change in belt tension as each pitch engages or disengages the pulleys. To eliminate the regularity of this tension variation, the belt is assembled with load blocks of different widths at the pulley faces.

A complex computer program is used to predict noise levels and optimize the belt pattern. Vibration noise levels are measured and modifications given to the computer to further refine the pattern and produce compatible “signatures”. Morse® is currently supplying two different belt widths: nominally 25mm and 30mm. The 25mm belt is intended for vehicles with engines up to 1.6 liters; the 30mm belt for engines up to 2.3 liters. Other belt widths, larger and smaller, are being developed. The available belt for any installation requires a detailed analysis of all of the transmission design parameters and predicted duty cycle requirements.

The capacity of a belt is determined by the maximum tension (i.e. clamping forces, torque, variable torque) developed in operation and the duty cycle life expectations. The "torque" capacity is therefore determined by the transmission design and application. For initial design considerations, maximum belt tension should be kept below the following values:

<table>
<thead>
<tr>
<th>Belt Width</th>
<th>Tension</th>
</tr>
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<tbody>
<tr>
<td>25 mm</td>
<td>680 kg</td>
</tr>
<tr>
<td>30 mm</td>
<td>910 kg</td>
</tr>
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</table>

Evaluating Your Design

To aid in design decisions we have developed several computer programs to predict the vehicle and transmission performance. Evaluation on preliminary designs or completed designs can be made along with recommendations for control parameters, loads, etc. All customer design information is treated with strict confidentiality.
Van Doorne

TRANSOMATIC

Fluid coupling which is now being studied for the American version of the new transmissions.

Lindquist said, "The requirements for an automatic transmission really go to the psychology of the drivers. Approximately 90% of European cars are manufactured with automatic transmissions. So the CVT transmissions is compared to the manual transmission in this usage."

"In the U.S., where over 90% of the cars are manufactured with automatic transmissions, a non-shifting transmission like ours would be compared with the automatic transmission. So the development is going on at our Transmission Div. in England, at Fiat and at van Doorne is directed towards a transmission with these characteristics.

Worldwide Interest

Currently, Borg-Warner is either working with or has demonstrated the Transmatic to the four major U.S. automakers, as well as a few European companies. One of these interests in Europe is Ford. The company wants to introduce the transmission in its car line up in the near future, and other automakers may follow within two or three years later.

In the meantime, the Transmatic transmission is further developing in the manual version of the CVT, as well as working with Ford on similar CVTs for vans, light-duty trucks and medium-duty trucks.

Current plans are to manufacture and assemble all the Transomatics in Europe, but production could start in the U.S. if there is sufficient demand.

Asked about possible future fuel savings with the Transmatic, Lindquist said, "Some special prototypes with a high ratio of T/L allow reducing the engine at less than normal (rpm). One of the largest auto manufacturers in Europe measured a 20% improvement with such units.

However, Borg-Warner engineers said its engineering tests indicated that an efficient CVT could achieve a 14-20% improvement in fuel economy compared to conventional automatic transmissions, but this depends on the driver, the engine and the application.

Lindquist said that the Transmatic will be smoother than most of the current locking automatic transmissions, adding that smoothness is one of the greatest advantages of this transmission.

Future Possibilities

Looking into the future, Lindquist concluded, "One of the biggest changes occurring in automotive worldwide is the move towards electronics to control all sorts of functions. As we get closer to the optimum control, which means that the engine performs with optimum fuel economy, optimum emissions and most pleasing driveability, we cannot today see the engine and transmission being one."

"We are beginning to see the engine's use as an electric motor for some applications."

The two men handling the CVT are J.F.D. Hamstra Pk (left), managing director of van Doorne's Transmatic BV; and Terry R. Lindquist, vice-president/engineering of the Transmission Equipment Group of Borg-Warner Corp.
Main parts for CVT

Small car belt has steel loops made up of 10 seamless 0.2-mm bands with diameters varying to give 0.01-mm interference fits. Larger belt at rear for medium truck is of similar construction.

Unusual flexibility enables steel belt to wrap around small 30.5-mm pulley radius, making possible wide ratio spread. It transmits torque between pulleys by thrust, not tension.

A typical CVT steel “belt,” this one made by the Morse Chain Div. of Borg-Warner, is made of hundreds of metal blocks guided by steel bands. This belt operates under compression as opposed to rubber belts which operate under tension.

Controlled. Control of the Van Doorne CVT is basically hydraulic, using a valve body similar to that in a conventional automatic transmission, but most companies are feverishly developing electronic control systems.

Electrifying The CVT

Subaru’s ECVT (Electro-Continuously Variable Transmission) uses an 8 bit microprocessor developed by Mitsubishi Electric to control its magnetic particle clutch. The computer senses engine rpm, vehicle speed, throttle position and transmission selector lever position.

If the gas pedal is floored with the selector in ‘D,’ the car will start in the lowest speed ratio and hold that ratio until engine revs reach 4000 rpm. Then the CVT begins to change ratio.

This is all normal CVT operation. What is unusual is the ‘D’s’ or “Drive sporty” (or “Drive on slope”) selector position. This position can be selected for engine braking or for a sportier transmission “program.” In the “D’s” mode, engine speed is generally kept above 3000 rpm.

Another unusual feature of the Su-
Mechanism of transmission
This diagram shows how the ratio spread of Subaru’s ECVT compares to that of a conventional five-speed manual gearbox. Note, also, how the operational area of the ‘Ds’ range is limited to the upper portion of the ‘D’ range.
Engine performance

Fig. 1  Engine performance map
DESIGN STUDY OF STEEL V-BELT CVT FOR ELECTRIC VEHICLES

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FIGURE 1. CVT DRIVETRAIN SCHEMATIC
Layout for CVT

FIGURE 17. CVT LONGITUDINAL CROSS SECTION
Block and belt for electric vehicle
# Efficiency of belts

<table>
<thead>
<tr>
<th>Belt</th>
<th>Efficiency, percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>90 91 92 93 94 95 96 97 98 99</td>
</tr>
<tr>
<td>D</td>
<td>94.0 95.5 97.0</td>
</tr>
<tr>
<td>E</td>
<td>94.0 95.5 97.0</td>
</tr>
<tr>
<td>F (1 3/8)</td>
<td>92.0 94.9 96.0</td>
</tr>
<tr>
<td>G (1 1/4)</td>
<td>92.0 94.6 96.0</td>
</tr>
<tr>
<td>H (1 1/2)</td>
<td>90.5 93.0 94.2</td>
</tr>
</tbody>
</table>

*Average for each belt (95.0% average for all tests).*

*Based on 190 test data points.*