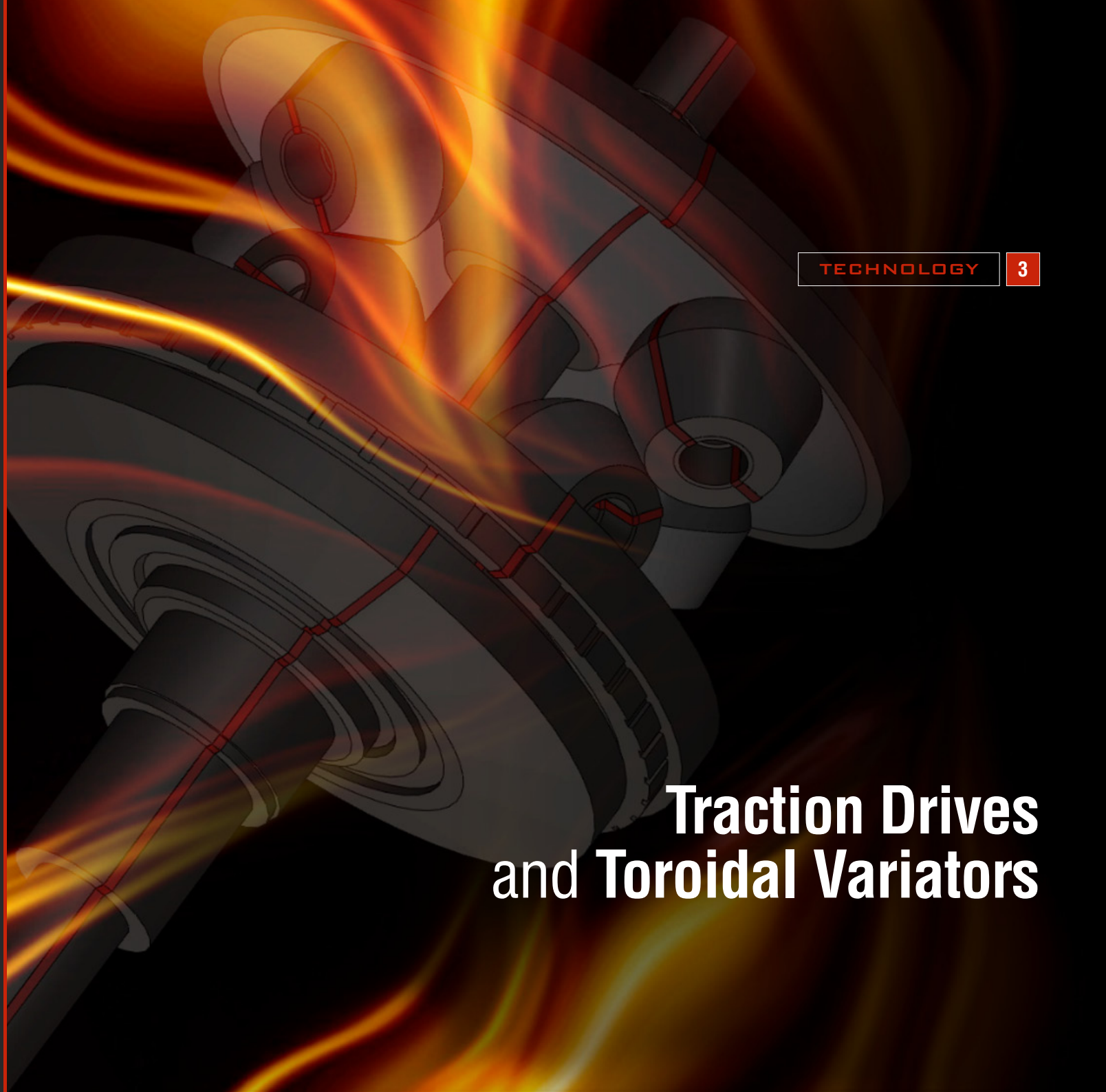
UTIMATE
TRANSMISSIONS

TECHNOLOGY 3



Traction Drives and Toroidal Variators

UTIMATE TRANSMISSIONS

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Traction Drive

A traction drive is a device for transmitting rotating power from one rotating shaft to another by a form of friction, as distinct from mechanical meshing as with gears.

There are two basic types of traction drives. One in which the ratio at which power is transferred remains the same (Fixed ratio traction drive) and one in which the ratio varies (variable ratio traction variators.)

These devices in the form of fixed ratio devices have been in use, and continue to be in use for a variety of transmissions ranging from jet engine reducers, to machine tools. They are often more reliable than geared systems and are extremely smooth and quiet. Fixed ratio drives are around the same physical size as a similar geared drive.

Many different variable ratio traction variators have been tried and used to operate as transmissions for automobile or other high speed or high power applications, where they are often referred to as CVT's.

CVT's are an automatic transmission type most often applied to automobiles. Among these are;

a) Toroidal Variators
b) Belt and pulley
c) NuVinci planetary CVT
d) Cone on ring variators

It is in the area of Toroidal Variators that Ultimate transmission has focused its research and developed its technology.

The Toroidal Variators and the Belt and Pully Variators exhibit high efficiency and power density. Only the Toroidal Variators and the Belt and Pulley Variators have achieved commercial success in the automotive industry, and only the Toroidal Variator in the aerospace industry.

A special type of lubricant called a traction fluid is used in these transmissions. Under high pressure it transforms to a solid state and can transfer force from one metal part to another without the metal parts actually touching. Recent improvements in these fluids has greatly expanded the effectiveness and application of traction drives.

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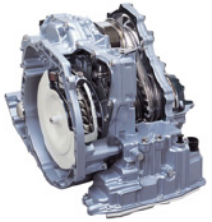

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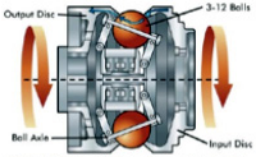

Figure 3: *NuVinci* CVP geometric configuration [3]

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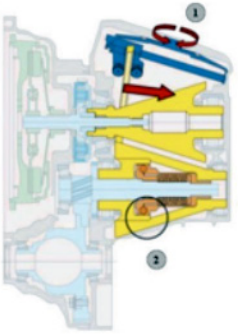

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For links to youtube showing the CVT concept go to:

Describing consumer perception of CVT's
www.youtube.com/watch?v=IFdmwnfaCg&feature= related

Italian NSK traction
http://www.youtube.com/watch?v=SHFe7qa0jfM&NR=1

Toroidal Variator

Single Roller Half Toroidal Variator – SHTV

The SHTV has been used in a number of machines including the Harrier Jump Jet and is generally acknowledged as being the most reliable, efficient and power dense form of mechanical CVT.

a. Two discs machined to the negative shape of the inside half of a toroid are clamped over (typically) two or three rollers that are held in place by a rotatable trunnion that supports a heavy thrust bearing.

   The discs are clamped onto the roller so that it contacts the discs with a very high force.

   The SHTV is typified by the large contact patches because of its ability to ensure that the contact velocities are well matched. However it suffers from the need of the thrust bearings to support the rollers.

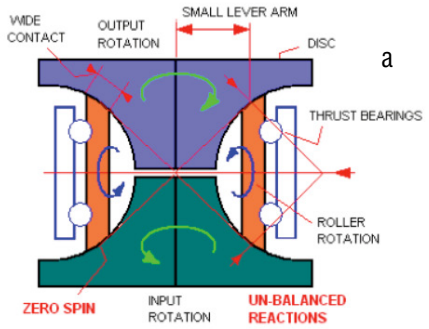
b. One of the discs performs the function of an input of power and rotates the roller which then turns the other disc (output disc).

   By rotating the trunnion it is possible to change the ratio in which the rollers turn and so act as a CVT or Continually Variable Transmission.

   These variators have been successfully employed in the automotive and aerospace industries where high expectations of power density and reliability are essential.

c. The T-IDG, worlds first traction drive integrated drive generator employing SHTV for application in large size aircraft. Manufactured by Kawasaki Heavy Industries, Ltd., and Shinko Electric Co., Ltd.

   This Variator is capable of rotating at 15,000 RPM.



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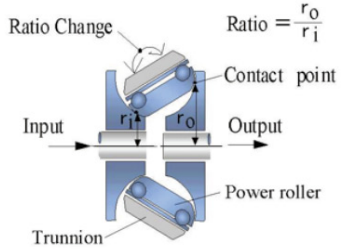

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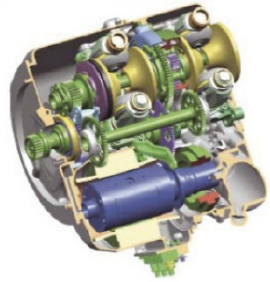

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Single Roller Full Toroidal Variator – SFTV

The SFTV has been used in mechanical transmissions for well over a Century. It demonstrates one of the simplest methods of creating a Constantly Varying Transmission.

a. Two discs machined with a toroidal shaped groove on their inside surface are clamped over a series of rollers. One disc performs the function of an input mechanism the other as an output mechanism. The rollers are free to rotate, on supporting shafts and transfer power from one disc to the other as they rotate . By moving the rollers within the toroidal cavity the Discs rotate at different relative speeds to each other.

b. Because the upper and lower parts of the toroid are used the device is referred to as a Full Toroidal Variator to distinguish it from a Half Toroidal Variator where only the inside (or half) of the toroid is used.

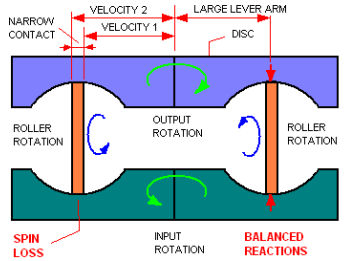
   A special transmission fluid, called a Traction Fluid allows very high torques to pass from the rollers to the discs without any metal to metal contact occurring.

   The SFTV is typified by a mismatch of the surface velocities at the contact patches but no need for thrust bearings.

   Because the rollers can be moved during the transfer of power without interruption the generic term for this type of transmission is Continuously Variable Transmission or CVT.

c. Typically with both the SFTV and the SHTV the toroids are arranged in pairs so that they can be clamped without the need for any thrust bearing.

   The input and output discs rotate in different directions and when high input rotations (6,000+) are required. This necessitates an additional lay shaft for inputting or removing power.



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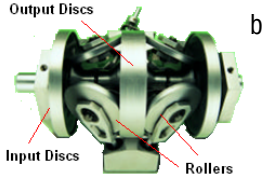

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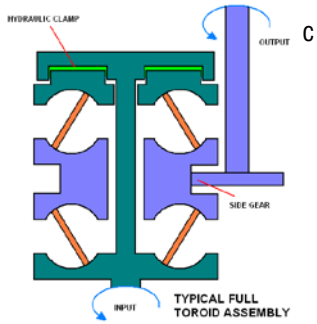
Full Toroidal Variator using Two Cavities holding Three Rollers



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Toroidal Variator

Double Roller Full Toroidal Variator – DFTV

The DFTV developed by Ultimate Transmissions takes the best of the SHTV (well matched surface velocities) and the best of the SFTV (no thrust bearings and simple controls) and elegantly combines them into one mechanism. The result is a transmission that can deliver extremely high efficiency and power density

a. The Double Roller Full Toroidal Variator or DFTV uses two rollers rolling on each other in place of the traditional single roller.

   This design reduces the differential velocities or “spin” at the contact points between the discs and rollers. This eliminates most of the energy losses experienced with a single roller design. The result is a mechanism that is significantly more efficient than the single roller design, of either a Half or Full Toroidal design.

   By eliminating the spin at the contacts, the contacts themselves can become much larger and can support higher loads allowing the Power Density to significantly increase when compared to the Single Roller design of either a Half or Full Toroidal Variator.

The double rollers contact the inside of the toroidal cavity in the same place as do the contact points in a single roller design. This means that there are no unbalanced thrust reactions as there are in a Single Roller Half Toroidal Variator (SHTV).

b. Because the input and output discs rotate in the same direction for a DFTV, while they operate in reverse directions for the SFTV and SHTV it is not necessary to arrange a working CVT with the two cavities.

   A single cavity can be arranged using a hydrostatic bearing clamp and a coaxial design with no need for secondary layshafts.

With a Single roller design the rubbing speeds of the seals in this type of design become typically three times as high making a hydrostatic bearing impossible to use when input rotational speeds are typical of an IC engine.

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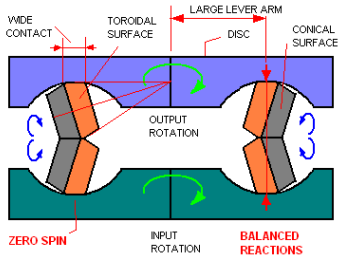

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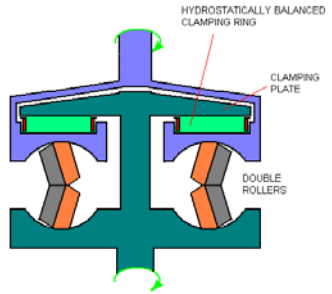


Applications of Toroidal Variators

The NSK - Nissan – SHTV

A joint development program was undertaken by Nissan and NSK starting early last century. This program developed special Traction Fluids for efficient shear transfer without metal to metal contact and low defect steel to reduce fatigue failure in the rollers and discs.

a. The result was the Nissan Extroid or what NSK called the PowerToros. This was a double cavity Half Toroidal arrangement with two rollers per cavity. It was fitted into the Nissan Cedric and Nissan Gloria sedans, from 1999 to 2006.

   It had a maximum torque capacity of 430Nm. c.

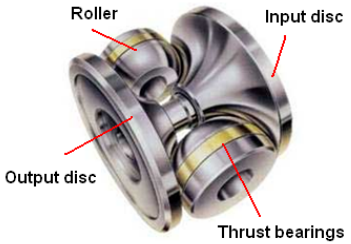
b. These components formed the basis of its construction. A double input with a central pair of output discs and the four rollers mounted on their thrust bearings supported on rotatable trunnions.

   The Rollers are mounted on Trunnions that are free to rotate allowing ratio change.

   Each individual trunnion is connected to a hydraulic piston that allows a very small tangential movement of the trunnion to be controlled. This movement causes the rollers to steer to different ratios. A very complicated mechanical arrangement is required but it is one that does not require a great deal of hydraulic power. *These images are from a technical paper written by NSK.*

The ratio change in an Extroid Transmission is initiated by moving the rollers slightly forward or backward in the cavity so that they are subject to a rotating force and “steered” to a new ratio. Extremely complicated electro hydraulic control systems are required to ensure the ratio change is stable.

The Hydraulic pressure is required to move the roller The stepper motor is required to monitor its position.



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Applications of Toroidal Variators

c. This type of ratio control is indirect and it is never possible to arrive at a precise ratio as the final resting place of the rollers is the result of a dynamic “nudging” action not the direct rotation of the trunnion.

d. The extroid and Nissan received numerous awards from the engineering community for excellence in innovation for this transmission

Over is a promotional description of the Extroid.

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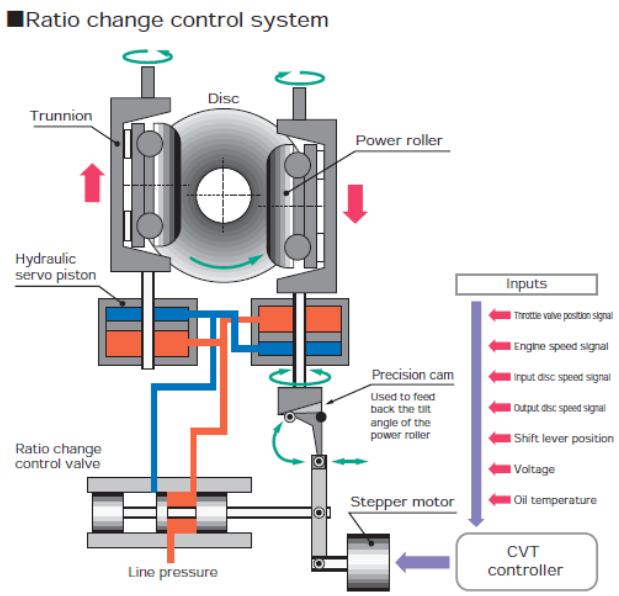

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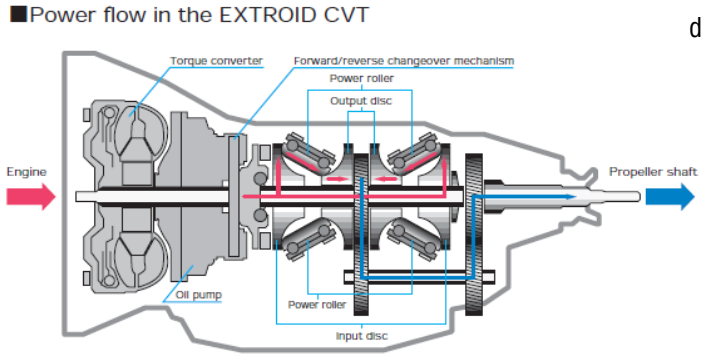


Applications of Toroidal Variators

EXTROID CVT

Only CVTs are capable of delivering such smooth, powerful driving performance combined with remarkably low fuel consumption. Nissan has wanted to exploit this superior transmission performance in rear-wheel-drive cars powered by large engines, in addition to applying CVTs to front-wheel-drive vehicles fitted with small engines. To accomplish that goal, Nissan has now developed the EXTROID CVT that can be used even on rear-wheel-drive cars fitted with powerful engines displacing more than 3.0 liters. Using a combination of discs and power rollers to transmit drive torque and execute ratio changes, this all-new type of CVT is the world's first CVT to be successfully implemented on rear-wheel-drive production vehicles equipped with high-torque engines.

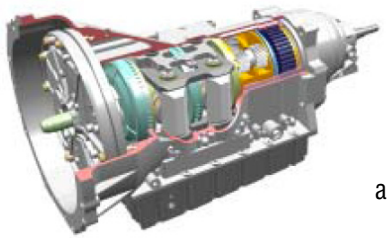
Applications of Toroidal Variators

a. NSK have continued the development work and are now proposing a Power Split transmission that has increased the torque capacity and reduced the physical size of the transmission so it can compete with a 6 speed automatic.

   The Extroid Transmissions have only been incorporated in High Power Luxury Rear Wheel Drive automobiles because of cost, size, and proportional shape (long and thin).

   The design life of an Extroid Transmission is over 400,000 kms. and they have proven to be an extremely reliable transmission provided they are maintained properly using the specified Traction fluid.

Nissan is the only motor vehicle company to adopt them for passenger vehicles. However for most of Nissans CVT range they use Belt type CVT's specifically Jatco. The Belt CVT's are more compact and suit the architecture of front wheel drive cars better than the long shape of the Half Toroidal Variator.



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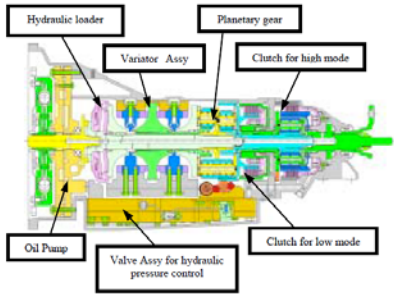


Link to Youtube clips describing Half Toroids and Nissan:

http://www.youtube.com/watch?v=PByIAAtdxvY&list=QL&playnext=1 (failed thrust bearing)

http://www.youtube.com/watch?v=bFJ6WpLXpbA (general technology incl Dr. Machida of NSK)

http://www.youtube.com/watch?v=889nZAtcyYM

http://www.youtube.com/watch?v=MyAq-RZyTBo&feature=related

Applications of Toroidal Variators

The Torotrak – SFTV

The Torotrak system has evolved from work done by the British government shortly after the second world war. One of the individuals involved was Forbes Perry a British engineer who was the motivating force behind this work and developed the Perbury Variator in parallel with this work.

British Leyland assumed responsibility for this technology when it was nationalized in the eighties. It continued to work on its development until it (Leyland) was broken up in the mid nineties.

A group of Leyland employees bought the Toroidal variator business and patents from Leyland, floated the company Torotrak (Development)LLC and have spent over ten years perfecting the technology using the (in excess of 60 million pounds) capital generated in this float.

Torotrak is a technology company who license, or form joint ventures with manufacturing companies who become the actual makers of completed products.

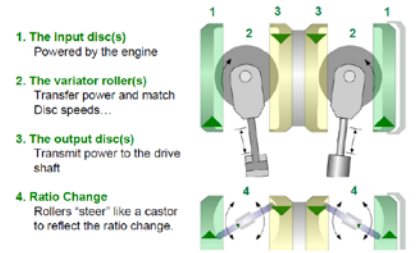
The recent rapid advances in Traction fluids and high purity steels enabled Torotrak to complete the work started so long ago by people like Perbury.

a. The rollers are supported on pistons that resist the reaction forces on them, developed when the system is transferring power. By managing the hydraulic pressure within the pistons it is possible to allow the rollers to move forward or backward within the toroidal cavity. This movement offsets the roller axis of rotation from the centre of the main rotation axis and the rollers are “steered” to a new ratio position.

b. The control system in a Torotrak design relies on a connection to the rollers using a ball ended yoke that can be moved in s tangential direction that causes the rollers to move (steer) to different ratios .

   Each roller is connected to a hydraulic ram which actuates a lever . This results in a complicated mechanism with many parts and requires a high power hydraulic actuation system.

   The hydraulic rams are located in a sump system below the variator that also contains the hydraulic controls.



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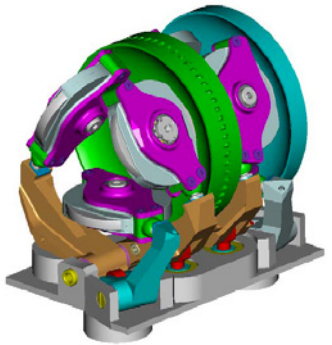

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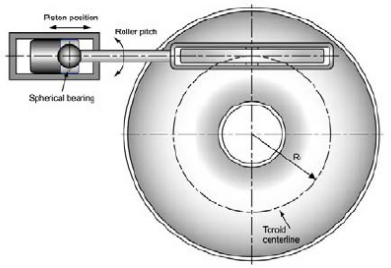
Applications of Toroidal Variators

c. This method of control is similar to that used by Nissan but with an important difference.

   The pistons that support the rollers are angled slightly to the rotational plane of the discs and as the rollers are displaced they are forced into a new stable position and do not need to return to the centre as is the case with the Nissan method of control. Torotrak call this the castor angle.

d. Torotrak describe this method of control as torque control to distinguish it from ratio control. They claim that this gives them a particular advantage when the CVT is applied to automotive transmissions.

   However this method of control consumes a great deal of energy because the rollers are moved a reasonable distance against the full torque reaction Force.



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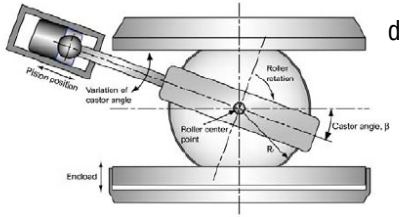

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Ultimate Transmissions use direct ratio control or torque to control ratio and claim that the torque control system used by Torotrak actually makes incorporation into an automotive transmission more difficult. This is particularly the case when the CVT is applied to an IVT transmission which relies on precise, preferably direct ratio control when adopting a geared neutral state.

The castor angle arrangement is an extremely elegant solution when analyzed on paper but because it is not possible to directly control it requires feedback controls that can lead to vibration or hunting in unexpected conditions.

Torotrak have spent a great deal of effort to remove the uncertainties associated with unstable roller control particularly when associated with the “knife edge” state called geared neutral in an IVT. Nissan is also working in this area with similar uncertainties.

Go to *http://www.torotrak.com/content/50/ratio-and-torque-control.aspx* for Torotrak’s explanation of torque and ratio control. It must be born in mind that a Torotrak variator is unsuitable for application of stable ratio control as it is always indirect.

Torotrak has published a number of academic and commercial papers on how they believe they can overcome this particular problem. Go to technical papers in the same web page as above.

They have demonstrated the IVT system in a Ford Explorer with what appears to be strong evidence of success.

Applications of Toroidal Variators

e. The diagram (right) illustrates the transmission used in these tests. There is no clutch between the IC engine and the transmission.

The issue of safety of geared neutral in a Torque controlled variator is highlighted in a paper prepared by Torotrak in 2002 entitled “Delivery of IVT for a 5 litre SUV : Addressing the Concerns of Geared Neutral” by Chris Brockbank and Dr Hubert Heuman.

The pressure produced by the control system required to change the state of the vehicle from geared neutral to forward motion is less than one bar. Any small stickage of the servo pistons could cause the vehicle to move backward instead of forward when executing this maneuver. For all sorts of reasons this type of control is dangerous, no matter how many academic papers on the subject are written.

Torotrak predicted the following fuel savings for an IVT of this sort

Table 1: Measured fuel economy benefits of Series III IVT compared to 4 AT

Drive cycles	Series III
Metro-Highway (combined cycle)	20 % improvement
EPA FTP75 (city cycle)	23 % improvement
HWFET (highway cycle)	16 % improvement

Extract above from SAE paper 2003-01-0971 “Powertrain Efficiency Optimization of the Torotrak Infinitely variable Transmission (IVT)” Matthew Burke, Graham Briffet, John Fuller,Hubert Heumann & Jonathan Newell.

In spite of some very convincing PR by Torotrak they been unable to interest mainstream automotive companies in adopting their technology.

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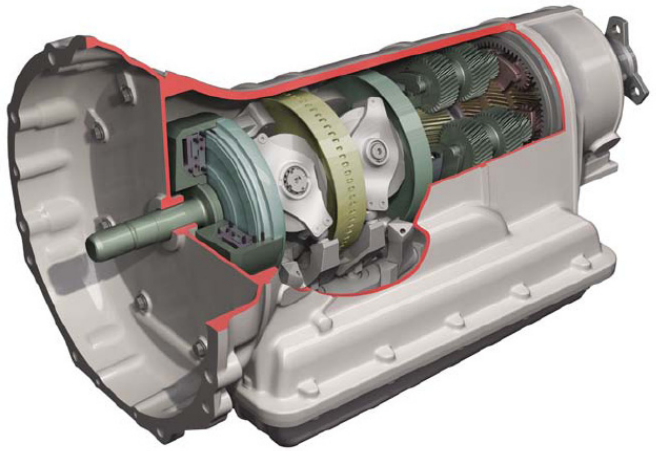

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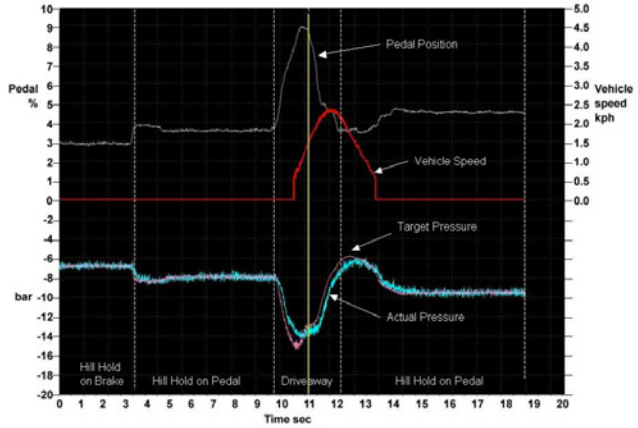


Figure 7 – Control System Accuracy

From Figure 7, the level of control of vehicle speed and the accuracy of the reaction pressure control can be observed.

As a measure of the capability of the Geared Neutral IVT with respect to control, kerb climbing and balance testing on a 25% incline at the maximum weight of the vehicle (Gross Vehicle Weight - GVW) resulted in throttle control resolution to 1/10th of a wheel revolution.

Applications of Toroidal Variators

Link to Youtube clips describing Full toroidal variators using Single rollers.

http://www.youtube.com/watch?v=FarSNO1V_pw (SFTV Explaination)

http://www.youtube.com/watch?v=MzCA0xPFB7I (CVT Explaination)

http://www.youtube.com/watch?v=9jaiLclL5gY&feature=related (more general on toroidal variators)

http://www.youtube.com/watch?v=gkqcWNB-B7c&feature=related (Single cavity manually controlled IVT)

http://www.youtube.com/user/torotrakplc (Video of how a Torotrak Full Toroidal Variator works in detail)

http://www.youtube.com/watch?v=kwUF9JCh0gQ&feature=related (Simplified Torotrak configured as an IVT or split power transmission in a rear wheel drive vehicle, Is simplified single stage IVT.)

http://www.youtube.com/watch?v=37-OLKE-QDo&feature=related Torotrak explained diagrammatically.

http://www.youtube.com/watch?v=6G5D3hjOvpc A talk video on Torotrak shortly after Toyota pulled out of its license agreement with them citing unacceptable vibrations, as the reason. It decribes much of the history.

http://www.youtube.com/watch?v=h5bR0Z9EaEw A video on the Infinitrak single toroidal arrangement using a form of traction epicylic arrangement and manual controls.

http://www.youtube.com/watch?v=IPXz2fQsi_o Video without sound of 4 x 4 fitted with Torotrak IVT system going up and down hills

http://www.youtube.com/watch?v=4PcIt0FPvWQ Interview of Chris Brokman (Torotrak) on Flywheel based Hybrids.

http://www.youtube.com/watch?v=8VYPsrOyIdw Belt drive (Dodge) CVT explained.

http://www.youtube.com/watch?v=hw3OdRedhnk Video on operation of Allison automatic transmission – likens it to a CVT

http://www.youtube.com/watch?v=JXrHDjcQIIU&feature=related The ZF 8 speed automatic explained.

http://www.youtube.com/watch?v=Ui4BB7gfRIw&feature=related IVT in OPE

The reluctance is founded on four basic factors

1. The Torotrak systems are larger than other alternatives such as Double Clutch transmissions or DCTs
2. They are more expensive to produce
3. They are less efficient than other CVTs and DCTs.
4. They have been demonstrated as part of an IVT system however the uncertainties about the "safety" of geared neutral when using an indirect ratio control inhibits take up in the passenger vehicle market.

However Torotrak's IVT technology is being taken up by Allison Transmissions for application to medium sized commercial vehicles. In these applications the drawback of size and cost is less of an issue when weighed up against the huge ratio spread IVT can offer.

The geared neutral issue is manageable when dealing with operators who are professional drivers and are used to operating a vehicle within its stated limits.

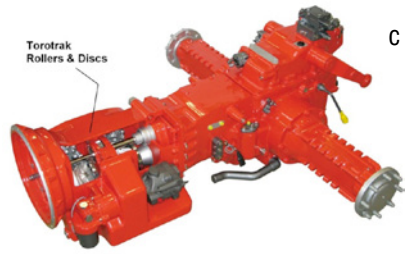
The durability of a Torotrak system can be established with greater certainty particularly when designing for in excess of one million kilometers.

Details of this agreement can be found at http://www.greencarcongress.com/2009/03/allison-transmi.html

c. Torotrak have also found success with small tractors with this Carraro transmission incorporating the variator.

d. The Infinitrak outdoor power equipment transmission using a Torotrak manually controlled Variator and an epicyclical Traction Roller to achieve geared neutral

e. Torotrak are also applying the Variator to flywheel based Mechanical Hybrids in association with Jaguar Land Rover and the Flybus project. This Torotrak Variator connects a Flybrid Systems LLC flywheel to the driveline of an automobile.



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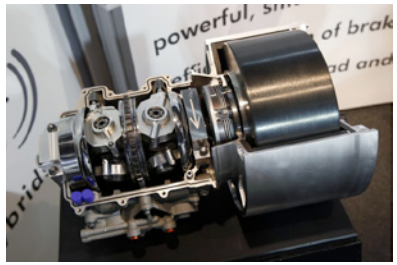


e

Applications of Toroidal Variators

The Perbury – SFTV

The Perbury variator was one of the earliest attempts to commercialize the Single Roller Full Toroidal Variator or SFTV, after high performance Tractions Fluids began to be introduced in the seventies.

The early design was based on a single cavity and required a large thrust bearing structure to support the thrust loads. The thrust bearing system also served as an epicyclical Traction roller creating an IVT outcome.

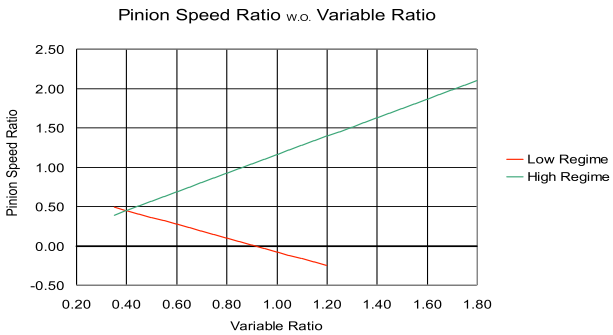
a. Schematic section through a single cavity Perbury Variator.

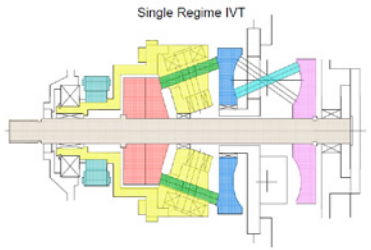
   A single cavity containing three rollers was balanced against a set of rollers that served as a thrust bearing. These rollers were captured by a frame that formed the output from the variator.

   This unusual arrangement served as a crude form of IVT with forward and reverse gear and geared neutral.

b. A number of prototype transmissions were produced and incorporated in smaller vehicles to demonstrate the concept.

c. The Perbury company was quick to realize the potential of the application of the variator to the Infinitely Variable Transmission concept using a high and low regime and geared neutral. (see below)





a

b

Applications of Toroidal Variators

e. They concluded that this application would yield huge increases in efficiency over a Honda Insight hybrid.

This information from Perbury was presented at Bath University in 2006

The Ultimate Transmission DFTV runs at more than 6% greater efficiency than the Perbury which would increase these numbers substantially.

e

MPG (US) Predictions for Perbury IVT

Drive Cycle	Pub[d] Data	NREL Test	Honda Simulation Results: Hybrid	Folsom CVT	Manual	Auto	Perbury	Perbury Increase: %	%	MPG (UK) Perbury
FTP	65.6	64.1	63.3	60.8	59.6	57.3	75.8	20.3	27.2	91.0
HWFET	89.9	79.0	84.8	76.6	79.0	81.1	101.9	20.2	29.0	122.4
US06	n/a	52.3	54.8	48.5	46.1	51.7	60.4	10.2	31.0	72.5
SC03	n/a	62.7	55.5	56.1	54.2	52.9	68.8	24.0	26.9	82.6
MPG at a constant 60 MPH							90.3			108.5
65 MPH							83.1			99.8
Official Combined MPG										94.8

Applications of Toroidal Variators

CVTCorp – SFTV

CVT Corp is a Canadian company specializing in Power Generation based on Diesel Engines.

By coupling the Diesel Engine to the genset through a Toroidal based CVT they achieve large fuel savings particularly when the electrical load is continuously varying or is mismatched to the genset.

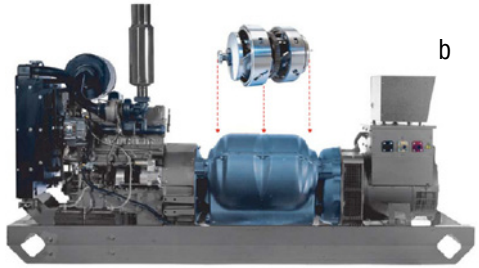
a. The Variator used by them is a very simple design adopting the same basic arrangement adopted by Torotrak of a Double cavity with three rollers per cavity and a ramp loading device to create the clamping force.

   Because energy generation is a static operation size and weight are not as important as they are with an automotive application and the CVTCorp variators are much larger than their Torotrak or Nissan counterpart.

The roller control method is much less sophisticated than that used in an automotive application because the speed of ratio response can be much slower and the only output parameter of the CVT is a constant output RPM of either 1,500RPM (for 50Hz) or 1,800RPM (for 60 Hz) hydraulic controls.

b. The CVT is simply placed between the diesel power plant and the generator as shown is this CVTCorp image.

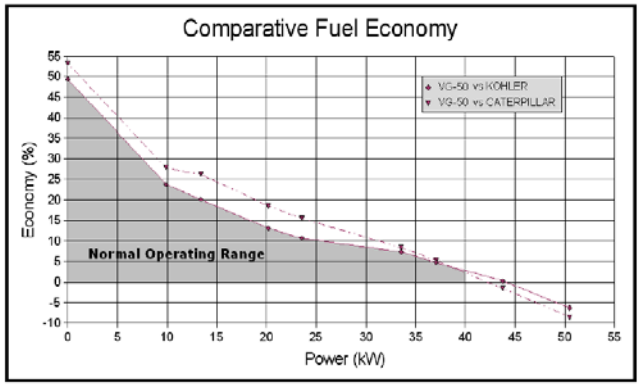
a



b

Applications of Toroidal Variators

CVTCorp has carried out a number of real time case studies on generator sets being used to power jack pumps pumping oil. Because this application runs in a cyclical manner the savings are very clear.



The variable speed generator offered fuel savings of up to 54% compared to fixed speed Gensets which constantly operate at 1500 or 1800 RPM.

Figure 7: Fuel economy when using CVT Corp's VG-50 as compared to fixed speed Gensets

The theoretical fuel savings are set out in this diagram.

The Double Roller Full Toroidal Variator could be used in this application with a ratio spread of around 3:1. At this ratio it will remain well over 6 % more efficient than the SFTV and at 1:1 as much as 8% more efficient.

Link to Youtube clips describing cvtcorp:

http://www.youtube.comwatch?v=4C3j7LG0S98

www.ultimatetransmissions.com.au