Out of gear!

TU/e technische universiteit eindhoven

Inaugural lecture
5 January 2001

prof. ir. N.J.J. Liebrand

out of gear!

/ department of mechanical engineering

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Given on 5 January 2001
at the Eindhoven University of Technology

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Dr. Hub van Doorne

Introduction

Mr Rector, ladies and gentlemen,

Four days ago - on 1 January 2001 - the "dr. Hub van Doorne memorial year" was closed. Exactly one year earlier, it was one hundred years ago that this great inventor and entrepreneur was born in this region.

On the occasion of this commemoration, the Van Doorne family has made a donation to this university.
In close consultation with the parties concerned and in the spirit of Mister Hub - as he is still reverently referred to in the province of Brabant - it was decided to use this donation for the financing of a special chair for a period of five years, with the assignment "to do research and teach in the field of variable transmission technology."

The result of this decision is standing in front of you.

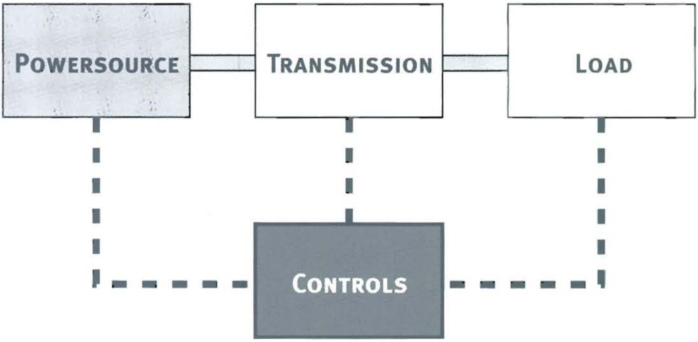
On the basis of the previous history, you might conclude that a new branch of science is created here in a rather arbitrary way.

I would like to use this inaugural lecture to convince you of the opposite, by explaining what this variable transmission technology is all about and what the international situation of its development is. But most of all by showing you which potential advantages of the transmission system are not yet utilised and in what way our research programme may contribute to the plucking of these as yet unharvested fruits.

The function of transmission

When we go back to the origin of the Continuously-Variable Transmission, to which I will further refer as CVT, the question, "what does transmission do?" must be answered first.
As the Latin verb "transmittere" (which means "to send on" or indeed "to transmit") already indicates, transmission sends something on. When applied in vehicles, it sends on torque and rotation velocity.
In the freshman's course at the faculty of Mechanical Engineering "Introduction Mechanical Engineering", the drivetrain is characterised by three components, power source - transmission - load. In the modern drivetrain concept this combination is always complemented by the controls of and between these components.

figure 1
drivetrain



Let us investigate this drivetrain a little closer.
Originally, human or animal power were the power sources that put the vehicle into motion. The transmission was a rope or a pole by means of which the traction was transmitted to the vehicle. The speed could be increased by taking bigger steps and, usually simultaneously, increasing the step frequency. A faster heartbeat is almost certainly the result.
During transport, nothing changed in the transmission; no gears were shifted, the coupling was never changed; at the most, the rope would go slack when the vehicle stopped or was driven downhill. The only requirements of the transmission were: sufficient strength of the rope or the pole, and the possibility of coupling and uncoupling in standstill. The latter was even deemed unnecessary in the slave era.
From the moment human beings (and later animals) were replaced - at first by a steam engine and later by an internal-combustion engine - the requirements for transmission become more and higher, and are still valid.

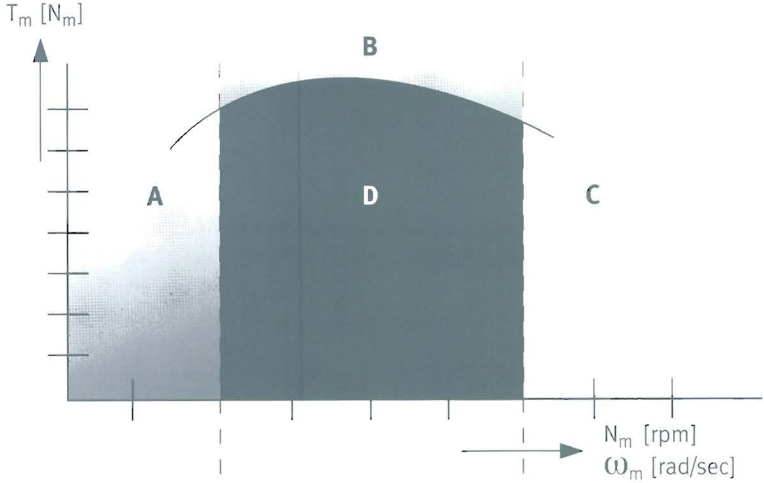
- A clutch was required to be able to drive away from standstill, because the combustion process inside the engine stopped below a few hundred revolutions per minute.
- A reverse mechanism was required, because the engine turned in one direction only, while the vehicle should be able to drive both forward and backward.
- An increasing number of ratios was required to drive the same car fast over better roads or slowly over rough or uphill roads.

I will explain the reason why a greater number of ratios was required by means of an example you all well know: cycling in the mountains!
When you go cycling in windless weather on a flat bituminous road without too many curves or traffic, so that you hardly need to speed up or slow down, you can do perfectly without a bicycle with gears.
It is different when you go to the mountains.
If you wish to maintain a constant velocity on your single-speed bicycle, you will have to increase the power you exert with your legs. As a consequence, your pulse will quicken, your temperature will rise and you will soon grow tired and lower your speed.
When used properly, the gears of a bike do nothing more than compromise between the desired speed and the pedalling power. Uphill you choose a low gear ratio. A single revolution of the pedals will carry

you less far, but on the other hand does not demand too much force. For cycling downhill, you hardly need any force at all. If, when cycling downhill, you keep using the gear ratio you have used uphill, you will have to rotate the pedals ever faster, until your legs will not be able to keep up. Shifting to another gear ratio re--enables drive, so that you can accelerate further.

In principle, the same story goes for vehicles with an internal-combustion engine.
The output shaft of the engine supplies torque (the pedalling power) and rotation speed (the pedalling frequency).

figure 2
max. engine torque



Just as the cyclist, the internal-combustion engine can only function properly within a limited operative range - in fig 2 this is area D. In area B, the valves will burn; in area C, the engine makes to many revolutions and in area A, the engine thunders or cuts out. This phenomenon occurs when the engine is not making enough revolutions. It is also the reason why a driving-off element, such as the clutch, is necessary. The clutch connects the turning engine with the non-rotating wheels by means of friction plates (again, transmission through friction...).

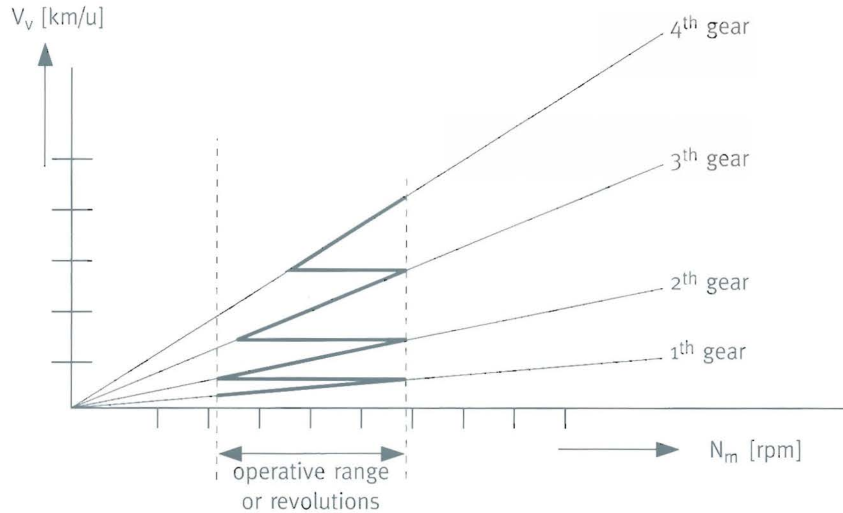


figure 3
variogram

On the horizontal axis of fig. 3, you see another representation of the limited range of revolutions of the engine. In case of gear-wheel transmission, this range of revolutions is translated, through for example the first gear, in a one to one relationship, in a speed range of the vehicle, as represented by the vertical axis of fig. 3. When we want to drive faster, we must apply the second gear and so on, exactly analogously to the earlier mentioned cyclist. To avoid that the engine cuts out, we must shift down. You may not always be aware of it, but this is the background to all the shifting you have to perform when driving in the city.

Historic perspective

Although we now understand that the variation in transmission ratios is essential for the driving characteristics of the vehicle - I primarily refer to road vehicles - this function was not yet present in the first automobiles. A robust clutch - generally in the form of a flat belt transmission - in combination with an engine with an operative range of minimally 200 and maximally 1000 rpm enabled velocities between 4 and 20 mph, without shifting.

The lack of more than one transmission ratio meant insufficient driving torque when the load increased.

Therefore soon, the number of steps increased, and already before 1900, the first four-step transmissions were built. These were mostly executed as flat-belt transmissions with multiple pulleys.
In the beginning of the 20th century, the belt transmissions were replaced by gear wheel transmissions, mostly for reasons of packaging volume and low force density. The gear wheels were assembled in a single box with the main shaft, the idler shaft, the clutch and the reverse mechanism. Regularly add a large quantity of oil, and the gearbox is born.
From this moment, developments were determined by the following factors:

- **Engine development**

The maximum power, torque as well as number of revolutions, increased, so that heavier gearboxes with more steps were needed, and the requirements to clutches, gear wheels and bearings increased.

- **The driver**

He desired more comfort and - especially in the United States - no longer wanted to perform complicated actions such as declutching - intermediate throttle - shifting - clutching.

- **The infrastructure of the road system**

It became possible to drive over longer distances at a higher speed and also to transport more people and goods. This had consequences for the life cycle demanded, because of the higher stress on the material over a longer period.

These external factors have entailed a number of - often very original - designs, of which only a small portion has reached the phase of mass production.

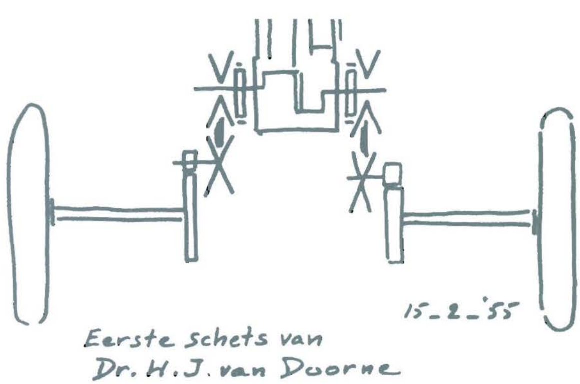
At the end of the fifties, the development of transmission was much smoother. Europe had generally opted for the manually shifted transmission because of the price, the low consumption and above all because of the sporty image. In America, on the other hand, the driver and, with him, the car industry had chosen the automatic transmission. The automatic shifting occurred while maintaining torque transfer by means of multiple planetary gear sets. The torque converter was generally used as clutch, because of the combination of easy shifting behaviour with torque multiplication during the driving off.

In and around the sixties, several important events happened that would influence future transmission developments and especially CVT. I will go into that below.

The breakthrough of CVT

In 1958, at the RAI automobile exhibition in Amsterdam, DAF launched the first commercially available CVT. Under the name Variomatic, this automatic transmission was applied in a small passenger car, the DAF 600. Inspired by American automatic transmissions, Hub van Doorne wanted his small passenger car to have an automatic gearbox as well. Taking his cue from driving systems as applied in workshop equipment, he chose the adjustable V-belt transmission [fig. 4].

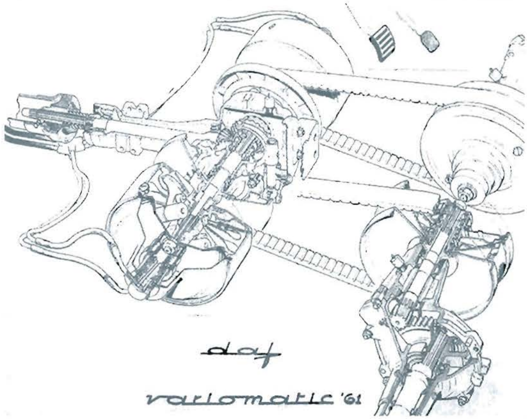
figure 4
first drawing
DAF variomatic



The splitting of the power of the engine to the wheels by means of two V-belts compensated the limited capacity of the V-belt. Without going into further details about this ingenious concept, I think it is important to state that the reason to choose CVT was exclusively the comfort of not having to shift. The desire for a simple technical solution led to the V-belt transmission [fig. 5].

figure 5

DAF Variomatic 1961



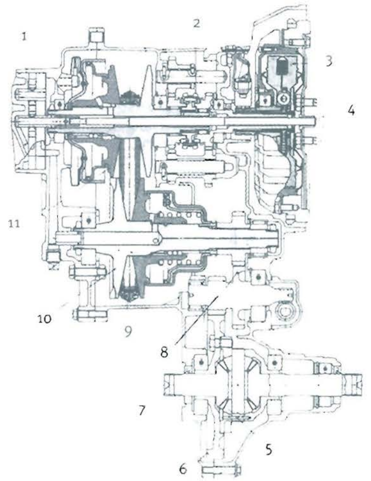
The possibilities to operate the engine with this transmission principle at its optimal operational point and to achieve low emission were known at that moment, but hardly relevant.

This changed radically because of two events with world-wide impact: In 1957, the Club of Rome published its first report about energy shortage and the effects of emission on the environment, and in 1973, the world was startled by the first oil crisis, that was followed by a second five years later.
Now, two elements came together: the technical availability of the - at that moment still flawed - CVT and a dawning awareness that emission and fuel consumption should be reduced drastically. But CVT was not yet ready to play its part in the race for cleaner and more economic vehicles that had just begun.

For that aim, the first design had too many drawbacks, which arose primarily from the rubber V-belt used.

Limited life cycle, large packaging volume, high internal losses and a limited capacity were obvious disadvantages. Apart from that, the interface of the design was too strictly aimed at application in the DAF passenger car, which severely restricted the possibilities of building this CVT into other cars.
These were all reasons to develop an alternative for the rubber V-belt. The history is well-known: after his retirement in 1965, Hub van Doorne started the development of a metal V-belt, at first in his shed in Deurne and after the first promising test results, in a corner of the DAF factory. The development went so successful that in 1972, "Van Doorne's Transmissie bv" was founded, with the aim to develop, produce and sell continuously-variable transmissions based on the metal V-belt.
After a long and laborious trajectory, in which very intensive test programmes were run in co-operation with car manufacturers Subaru, Ford and Fiat, the production of push belts was started in Tilburg in 1986. From 1987 onwards, the first transmatics, with VDT patent and know-how licences, were launched on the market, equipped with a push belt, which was also manufactured by VDT.

figure 6
Subaru-ECVT



1. oil pump
2. forward/reverse shift
3. em powder clutch
4. pump shaft
5. differential
6. final reduction
7. output shaft
8. reduction gears
9. push belt
10. secundairy pulleyset
11. primairy pulleyset

The most important differences between the Transmatic of the eighties and the Variomatic of the sixties were:

- The rubber V-belt was replaced by a metal push belt, which implied the switch from dry to wet friction.
- The clamping force exerted by the sheaves was generated hydraulically instead of by means of centrifugal forces, so that a hydraulic pressure control was required.
- An oil pump was added to the system to generate oil pressure, to move the sheaves axially, and to lubricate and cool the belt and the sheaves.

Although the introduction on the market was only modest and the Transmatic design still had a number of restrictions, this concept was of historic importance for the further development of the CVT technology, for the following reasons:

- The design showed that the metal push belt was indeed fit for transmission in high-power applications, and had a life cycle that was equal to that of the car itself.
- Tests of the CVT system with a standardly produced push belt in a 800 HP (600 Kw) Renault/Williams Formula One racing car on the Silverstone racetrack confirmed the potential for high torque transfer.
- The concept of the belt could relatively easily be scaled up for high-power applications, using practically the same manufacturing process.
- In combination with the still to be developed electronic clamping-force control, a further enhancement of CVT efficiency could be realised, by means of which the consumption figures were approximately 10 % lower than those of comparable conventional automatic transmissions.
- The car industry - first of all the Japanese - showed a strong renewed interest in CVT technology and started ambitious development programmes.
- Infected by the success of the push belt, alternative developments were undertaken, especially by the suppliers of the car industry, both for the belt and for the variator.

CVT in the year 2000

In the year 2000, the CVT landscape offers promising prospects, both for the car manufacturers, the drivers, the suppliers of CVT components and definitely also for research institutes and universities.
Let us look at all these parties separately:

- **The car manufacturer**

Nearly all car manufacturers have introduced CVT into their production or development programmes. In this respect, Japan is clearly the frontrunner. There we see both the first CVTs for high-power applications, the first designs with torque converter, the first tiptronic applications and the first hybrid concepts in combination with CVT.
The United States, home of automatic transmission, lags somewhat behind Japan for two reasons. The push belt was in the first place developed for small passenger cars and therefore did not have enough capacity for the more powerful engine of the American car. Moreover, the low fuel price was no incentive to purchase more economic transmission.
Europe may be the cradle of CVT, but the European car manufacturer is still very conservative about investments in CVT mass production, because automatic transmission, with its not particularly sporty image and high purchase price, is not yet popular in Europe.

- **The car driver**

At this moment, the car driver can choose between some ten automobile brands that offer CVT in their programme. It is interesting that one of the driver's prime reasons to purchase CVT is the low fuel consumption. In Japan, CVT is even called 'green transmission'.

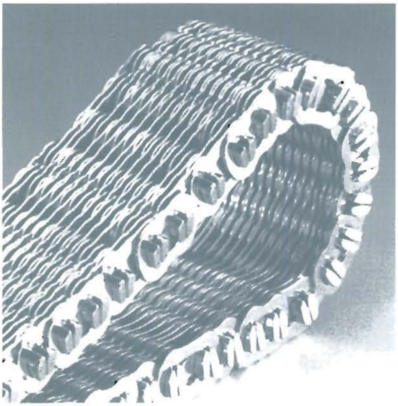
Incidentally, it should be stressed that transmission plays only a minor part in the purchase considerations for a new car. It is limited to the question, in the case of manual transmission, of how many gears the car has, and in the case of an automatic, of how much more it will cost.

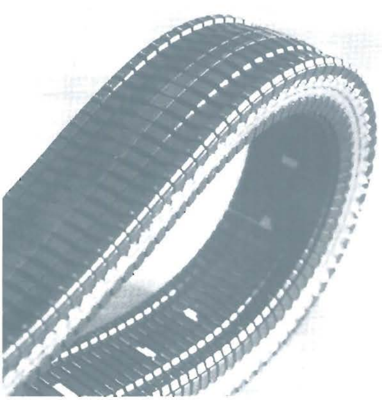
• The supplier

The success of the push belt CVT has induced a number of suppliers to develop alternatives, both for the belt and for the variator. In 1999, a CVT on the basis of a drive chain [fig. 7a] and on the basis of a synthetic belt [fig. 7b] were introduced on the market, the latter as dry friction transmission.

figure 7a
Luk chain (left)

figure 7b
Bando pullbelt (right)





• CVT research at universities and research institutes

Continuously and in many places, universities and research institutes have been involved in CVT design and research, both on the level of the components and on system level.
During the second CVT World Congress, that was held last year at this university, in 2 days 42 lectures on CVT were given, 21 of which were presented by universities and research institutes. In many cases, co-operation projects between universities and the industry were involved; a cross-fertilisation that proves to be very fruitful for this research field.

Some examples of this are:

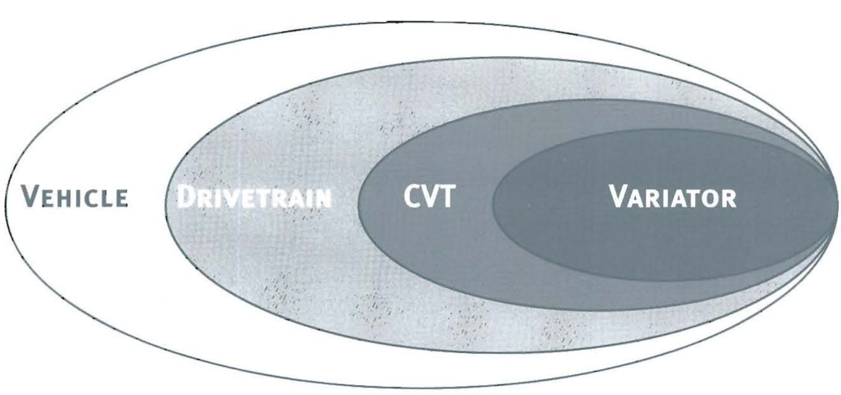
- The development of a synthetic belt by Bando Chemicals in co-operation with the Doshida University of Kyoto, Japan
- Several CVT research projects by Honda and Toyota, also in co-operation with the Doshida University
- Co-operation between General Motors and the University of California-Davis
- Research into the behaviour of the push belt by the University of Bath, England, the University of Palermo, Italy and the University of Gotenborg, Sweden
- Research into and further development of the PIV chain by the Technical University of Hannover and Dresden, in co-operation with LuK
- Joint development of hybrid drives by VW with the ETH/Zurich and the Technical University of Hannover and Chemnitz

In mentioning research at universities, I have reached our own university and the research programme this chair wishes to dedicate itself to. Before going into the research questions to which we will direct our efforts in the future, first it is important to analyse the current CVT systems more thoroughly, in order to determine the research objectives from there.

The selection of research objectives

figure 8
schematic drivetrain

Let us take a closer look at the drivetrain of the vehicle, with the help of the following schematic presentation [fig. 8].



The vehicle

There are many kinds of vehicles, dependent on their function. We will limit ourselves to road vehicles and furthermore - for practical reasons - to passenger cars. This is not to say that the results of the CVT research are not valid for trucks, coaches and motor cycles, but in our laboratories, you will find primarily passenger cars.

The drivetrain

As I have mentioned earlier, the drivetrain is characterised by a power source, the transmission, the load and the controls. For our research, a thorough knowledge of the power source, the load and the controls will be necessary, but our research will not concentrate itself on these areas. Still, the contributions of and the co-operation with my fellow professors Mr. Baert of Internal-Combustion Engines, Messrs. Steinbuch and Van Campen of Controls and Dynamics and Mr. Pauwelussen of Vehicle Dynamics at the Technical University of Delft will be essential to advance CVT development.

The Continuously-Variable Transmission

Dependent on the form of energy in which the torque is led through the transmission, CVT can be divided in three main groups; the electric, the hydraulic and the mechanical CVT [fig. 9].

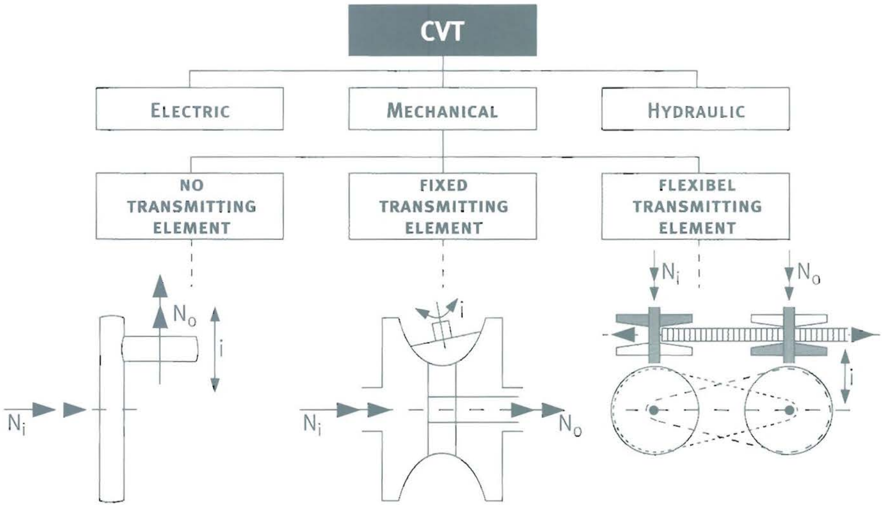


figure 9
CVT sub division

All these types will be discussed in my lectures, but the CVT research programme will mainly be limited to the mechanical CVT. Or, to put a finer point to it, to the CVT on the basis of a mechanical variator.

The variator

The variator - the heart of the CVT system - is executed in three basic versions:

- The variator without transmitting element:

This is the archetype of the stepless variator. Because of the very limited torque transfer, this version cannot be applied in automobiles. Therefore, there will be no research on this variator.

- Variator with fixed transmitting element:

This exists in many versions, of which the toroidal version is now being tried out on the Japanese market.
The most important research questions about this system are the life cycle of the lubricant and the wear-resistance of the hardened contact surfaces. On system level, there is need for well-founded comparative research in the characteristics of toroidal CVT in comparison to belt or chain CVT.
Since research on toriodal systems is especially advanced in Japan, we will first intensify our contacts with Professor Tanaka of the Yokohama National University, to bring the knowledge of this type of CVT up to date, but also to avoid doing research that is already being performed.

- Variator with a flexible transmitting element:

This concept is generally accepted as the standard for small and medium-sized automobiles up to 350 Nm. The concept will still have to prove itself - especially in comparison with the toroidal systems - for torque transfer above 350 Nm.
Since it is generally expected that the breakthrough of CVT systems will be based on this variator with flexible transmitting element, our research will concentrate itself on this. Two directions can be distinguished:
- Fundamental research in the operation and the improvement of the variator with flexible transmitting element.
- Research in and the design of new CVT concepts based on this variator.

For both these directions, I will further specify the research programme.

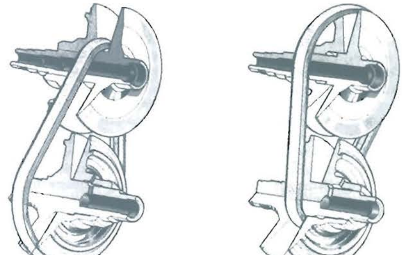
The research programme

The variator research

As stated earlier, the function of the variator is the transmitting of torque and rotational speed, with the possibility of varying the ratio between input and output speed.

In the case of the variator with flexible transmitting element, this is achieved by changing the radius of the transmitting element by means of an axial displacement of the pulley sheaves [fig. 10].

figuur 10
variator with flexible transmitting element



The torque is transmitted because the pushing force of the driving pulley transfers a frictional force to the transmitting element. Then, according to the same principle, this transmitting element transfers the force to the driven pulley. The present variator design is about thirty years old. The most important development during this time has been the scaling up to high-power applications and the introduction of the electronic controls of the clamping force.

Over the years, a lot has changed in both the demands made on transmission and variator but also in the opportunities offered by new materials, calculation techniques, simulations and testing methods. I consider it the task of this chair to make use of these new opportunities, but also to extent them for the benefit of future variator designs. I will give a few examples of this:

- Research concerning the application of new materials within the variator. Possibilities are for instance ceramic materials, fibre re-enforced materials, aluminium, etc.
- Research into the realisation of completely new techniques to initiate the clamping force between the pulley sheaves, for example by means of electric motor instead of hydraulics.
- Research into the modelling of the slip behaviour of the variator in relation to efficiency, life cycle, shifting behaviour, etc., followed by simulation calculations and experimental verification.
- The maintaining of the hydraulically generated clamping force, but without need for a continually working fluid pump. Such a design could reduce the pump losses considerably and advance the efficiency of the transmission.

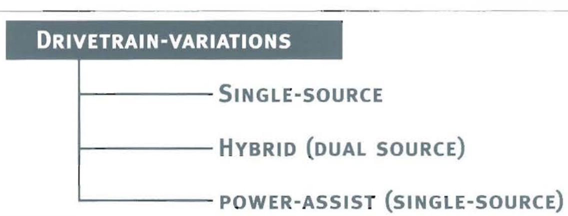
The number of research questions is of course much larger then mentioned here, but they do give a representative image of the versatility of the research field and especially of the necessity to co-operate with other disciplines within and without of the faculty, to lay the foundations for a variator that can function as the cornerstone for future CVT systems.

New CVT concepts

With the variator as the building block, a large number of system concepts can be developed. For these, I want to use the following classification of drivetrain versions [fig. 11].

figure 11

drivetrain variations



- **Single-source drivetrain:**

The single-source drivetrain is characterised by a single power source in the CVT drivetrain. The design versions that are in production at this moment are determined by:

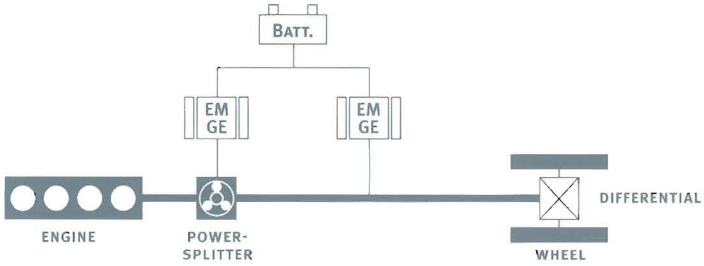
  - The nature and the position of the engine (Diesel, Otto, longitudinal, transversal).
  - Two-wheel or four-wheel drive and the position of the differential.
  - Position of the components within the CVT.
  - Selection of the components.

Apart from that, in research laboratories, concepts are being investigated that split the torque to be transmitted over two paths (power split or torque split), or that use the variator twice to achieve a larger ratio range (i2, dual mode)
Although research done on the basis of these concepts is very interesting and we will treat several of these concepts in class, we will not add another single-source CVT version of our own.

- **Hybrid drivetrain:**

A hybrid drivetrain operates with two engines that can be used independently over a long period of time. One of these is an internal-combustion engine and the other an electric engine, which is fed from a battery or from a generator driven by the internal-combustion engine. Impulse for the development of hybrid drivetrains is the idea to create a Zero-Emission Vehicle for city use, which does not have the disadvantages of an electric car outside the city.

There are many developments in hybrid systems, and recently, several concept cars have been presented, among which some have already reached the stage of production. I refer to, amongst others, the concepts of Toyota and Nissan [fig. 12 and 13]. About both these vehicles, the manufacturers claim that a fuel saving of 40% to 50% can be realised, in comparison to a conventional drivetrain.



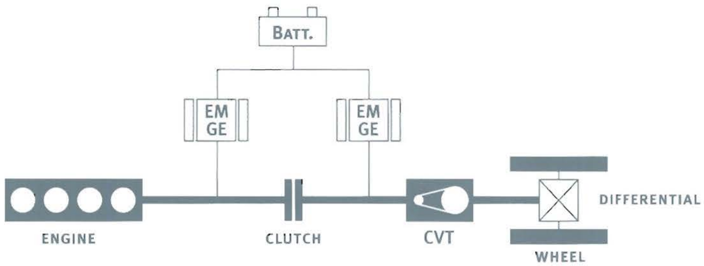


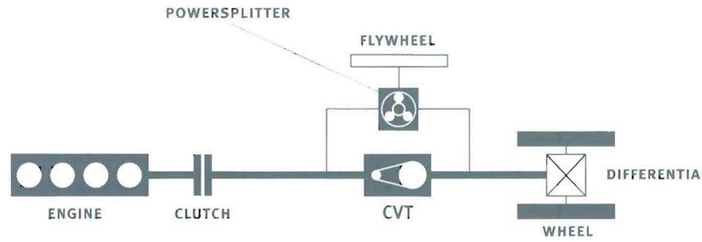
figure 12
Toyota Prius hybrid driveline (top)

figure 13
Nissan Tino hybrid driveline

Because there is a large variety of realisations of hybrid concepts, it is difficult to say which role CVT will play in these developments.
But it is certain that first a complete drivetrain needs to be specified, modelled and simulated, and that the CVT version will be derived from this as a subsidiary sub-design.
This means that our research programme will only react to hybrid system developments. The initiative must come from designers of integrated drivetrain concepts

Power-assist drivetrain:

The power-assist drivetrain is based on one main engine - almost always an internal-combustion engine - and a second power source that can be employed at moments of peak load. This power-assist source can be a flywheel [fig. 14] or a small electric engine with a generator [fig. 15].



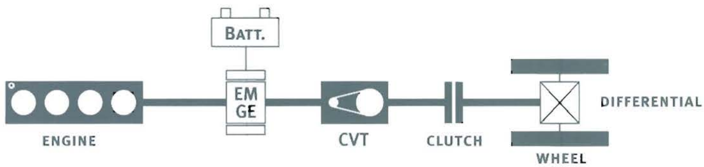


figure 14
Zero Inertia power assist driveline (top)

figure 15
Honda power assist driveline

In the next few years, we will concentrate our research efforts on the power-assist drivetrain concept, for the following reasons:

- Power-assist improves the driving behaviour of CVT by quickening the vehicle response to changes in the throttle position.
- Power-assist can further reduce fuel consumption by shaving the power peaks, which results in an optimal operation of the engine against relatively low extra expenses.
- Power-assist enables a go-no go operation of the engine.
- Power-assist offers possibilities for recuperation of braking energy.
- Power-assist projects fall in seamlessly with current research programmes within the faculty and also with research performed in co-operation with TNO (the Netherlands Organisation for Applied Scientific Research) and PD&E (Product Design & Engineering, Helmond).

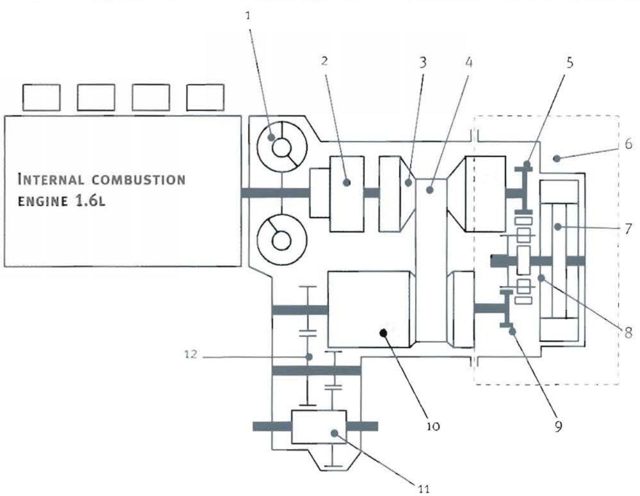
I will now go into both types of power-assist, the flywheel and the starter-generator.

- **CVT in combination with flywheel**

The design of a CVT with flywheel has gained international fame under the name of "Zero Inertia", and has won national and international

awards. In this project, which is realised in co-operation with TNO and VDT, and with financial support of the Dutch Ministry of Economic Affairs, three chairs within the faculty of Mechanical Engineering work intensively together.
The heart of this concept is a variator coupled to a flywheel by means of a planetary gear set (fig. 16).

figure 16
Zero Inertia
configuration



1. torque convertor
2. DNR-Set
3. primary pulley
4. pushbelt
5. primary gear
6. flywheel unit
7. flywheel
8. planetary gear set
9. carrier gear
10. secundary pulley
11. differential
12. final drive

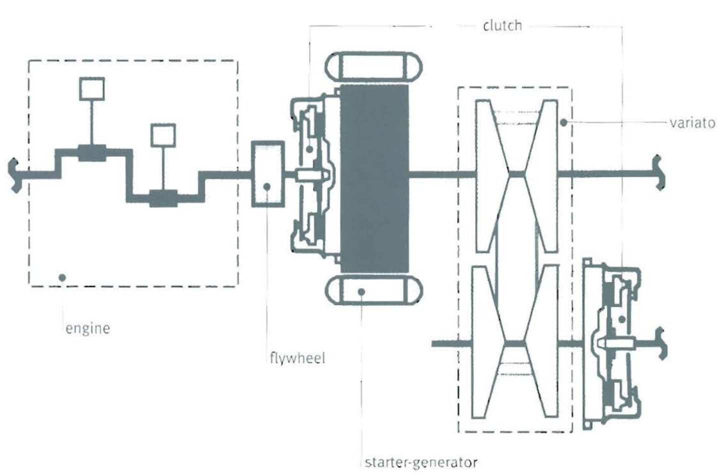
It operates in the following manner:
At the moment the driver gives throttle, the engine will rev up. Normally, no vehicle acceleration occurs as yet, because the rotating parts must first be accelerated. In the experience of the driver, it seems as if the vehicle fails to react - in case of kick-down - as if slight braking occurs.
When the driver shifts down, the flywheel ensures that part of the kinetic energy is transferred to the vehicle, so that it accelerates immediately. Another part of this energy is used to rev up the engine. As soon as a new stationary driving situation is reached, the revolutions of the steel flywheel will be build up at a steady rate until the former energy content, necessary for the next fast vehicle acceleration, is reached.
With this concept, based on proven technology, a reduction of fuel consumption of 15% is reached through a low rpm. adjustment

of the internal-combustion engine. At this time, driving tests and measurements of fuel consumption are in process. After that, the flywheel transmission will be tested in a driving configuration in which the engine will be driven under go-no go conditions and the flywheel will take over the function of the starter engine. With this addition, a further 10 % saving of fuel can be realised on the normative driving cycle. In the course of this year, Roëll van Druten, Alex Serrarens en Bas Vroemen will obtain their doctorate with a dissertation on this subject.

- **CVT with starter generator**

Because of the increasing number of power consuming car accessories - for instance for air-conditioning, local heating of the windshield, the mirror or the chair, the servo engines for window and chair movement - it seems likely that the present 12V voltage supply will be increased to the level of 42V within a few years. This offers new possibilities for the use of a more powerful starter generator as power-assist for shaving power peaks, but also to lead the kinetic energy of the vehicle through the CVT and the generator back to the battery during the braking process. A possible configuration for such a drivetrain is given in fig. 17

figure 17
CVT with starter generator



Here we enter a fascinating area, in which mechanical engineering, dynamics, controls and product design need each other to realise a substantial reduction of consumption and emission. In this respect, CVT has important advantages over the stepped transmission for the regaining of braking energy. Within the Netherlands, TU/e, TNO, PD&E and VDT have, in good co-operation, started preliminary investigations for the realisation of a demonstration model that should lead to further research and industrial activities. For the moment, I will not go into this further.

Recapitulation

Ladies and gentlemen, I have tried to explain to you the function of vehicle transmission, the historical development of the drivetrain - especially of CVT - and our future research programme.
It is the aim of this research programme to contribute to the further development of the continuously-variable transmission, with as central themes the reduction of emission and fuel consumption. In doing so, our research at this university will make a contribution to one of the most pressing problems of the day: the improvement of the environment with the simultaneous preservation of the individual mobility.

Now that the course of our research has been plotted, I think a few critical remarks are called for.

- Firstly, I want to remark that every course need to be checked regularly. A sounding board, made up of people from the industry and of colleagues from this and other universities could be helpful to increase the technical and social relevance of the research and avoid costly duplications.
- Critical feedback from colleagues, especially from those participating in multidisciplinary projects, could only increase the quality of the research. I challenge them to push back the frontiers of CVT technology by contributing their expertise.
- The co-operation in a research programme with colleagues from the industry is exciting, but can also be tricky. There is a delicate balance between the advantages of synergy and cost-cutting and the disadvantages of the sharing of unique knowledge or even the danger of information leaks. In my opinion, the open sharing of information on

the basis of mutual trust is a condition for reaching positive research results for both parties.

- Good and efficient research needs a good infrastructure. By that I mean organisation, manning, laboratories, documentation, an adequate network, etc. A clearly defined long-range research plan demands a long-range financing plan - whatever the source of the funding - to guarantee the continuity of the research.
- You all know that the number of new technology students is declining sharply. For the faculty of Mechanical Engineering, we are talking about 60% less students over a period of 10 years. Judging by the number of final students for CVT in the first year of the existence of the CVT chair, I conclude that students are very enthusiastic about Automotive Engineering in general and especially about CVT.

I sincerely hope that this is not just a fad, but that this interest will continue and that this field will attribute to the broadening and deepening of the study programme of the faculty of Mechanical Engineering.

Furthermore, I think it feasible that, with an enthusiastic group of staff members and students, we will succeed in reaching the objectives for the reduction of emission and fuel consumption. As a result of that, the use of CVT technology will quickly increase, shifting will become superfluous and you and me will literally be OUT OF GEAR.

Conclusion

Ladies and Gentlemen, while preparing this inaugural lecture, I have studied many books and publications about drivetrains, about transmissions and about CVT. In all languages, I have come across the words "Van Doorne's push belt" or "Van Doorne's CVT"
What was originally a family name is now the international designation for a technical principle, developed and originally produced in this region.
It is therefore not surprising that the first chair completely oriented on the CVT technology is established at the Eindhoven University of Technology.
This would not have been possible without the support of the three parties involved, the Van Doorne family, the university and Van Doorne's Transmissie.
I would like to thank everybody for their efforts to create this chair and for the trust they have put in me through this appointment.

It is now 34 years ago that I left this university to step, with my Masters Degree, into the world of industry.
A lot has happened since then. I have met a lot of people in the world of Mechanical Engineering, of Automotive Technology and of CVT. But also, and even more often, I have met people from other fields, with other professions or other interests. Some of them are no longer alive, others I have lost sight of, but many of them have contributed to my development and formation, both inside and outside of my expertise.
To everybody who has contributed to the fact that I can give this lecture here today, my sincere thanks.

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Curriculum Vitae

Nort Liebrand was born in Gennep on 6 September 1942. After he had obtained his HBS (former Dutch High School) certificate, he studied mechanical engineering at the Eindhoven University of Technology, at which he graduated in 1966 under supervision of Prof. Ir. W. v.d. Hoek, with the specialities design and construction. After having completed his military service as an officer with the Inspection Technical Department, he started his career at Philips Electrologica, where he worked on the development of peripheral equipment for computer systems, at first in Eindhoven and later in Bremen. After a few years, he switched to Philips Medical Systems, where he was responsible for the development of equipment for X-ray diagnostics, especially for the manipulation of the X-ray in relation to the patient and vice versa.

In 1981, he took up office with "Bosch Verpakkingsmachines b.v." (Bosch Packaging Equipment) in Weert, where he had responsibility over the development of and application of new packaging equipment.

In 1986, he switched to "Van Doorne's Transmissie b.v." in Tilburg where he was vice-president, with the responsibility over the development and the testing of the continuously variable transmission, the push belt and the development of new production processes. In this position, he gave the keynote speech on the first CVT World Congress in Yokohama, Japan, in 1996.

During this period, he also was a member of the visitation committee Mechanical Engineering for the evaluation of the education on the institutes for mechanical engineering, and mechanical engineering as applied in medical technology and maritime technology in the Netherlands and mechanical engineering/electrotechnology and aviation and space technology in Flanders.

In 1996, he succeeded Ir. Paul de Bruin as president of VDT.

As from 1 January 2000, he is appointed as part-time professor at the faculty of Mechanical Engineering of the Eindhoven University of Technology, with the assignment to teach and do research in the field of the continuously variable transmission systems. Apart from that, he is still committed to VDT as general consultant.

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