



UNIVERSITÀ DEGLI STUDI
DI MILANO

The Hybrid transmissions and their feasibility in agriculture



Antoniotto Guidobono Cavalchini
University of Milano
Club of Bologna november 2010

The Hybrid transmissions and their feasibility in agriculture

Aim of this study is to verify if the Hybrid transmissions , day by day becoming more popular in the the car sector, or some principle of them, can be transferred in the agricultural tractors with advantages in terms of efficiency, manoeuvrability and ergonomics.



NO CLUTCH USE
WHEN SHUTTLING

HIGH OVERDRIVE DURING HAULAGE AND TRANSPORT

The hybrid cars

- *Very far from a tractor are the requirements of a car mainly of the Hybrid cars developed to be used in the urban traffic.*
- *In this case the main requirements to be satisfied are:*
 - *Less or zero pollution;*
 - *Less noise;*
 - *Better comfort in the use,*
 - *Less fuel consumption, or better efficiency*
 - *But this last point is not the priority.*



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HIGH OVERDRIVE DURING HAULAGE AND TRANSPORT

The agricultural tractors

In the case of the tractor the same targets should be reached but with different priorities:

*basically the **productivity** (both of the operator and of the machines) obtained with **low fuel consumption** and **costs** in general, or in other words improvement of the **efficiency**.*



The agricultural tractors transmissions

- Since the substitution of animal traction with mechanical means, the tractors have been used stepped transmissions in order to match the requirements of the different agricultural operations (speed, loads,..) with the characteristics of the engine (torque, power,..);
- Nevertheless to operate a conventional gear box means to interrupt the power flow i.e. a decrease in term of performances, manoeuvrability, and confort;
- To solve the problem many solutions have been proposed and applied especially in the last decades when: the day by day increasing power and cost of labour; the sophistication of the operated implements, and the ergonomic requirements justified large investment in new devices and therefore additional cost of the machines



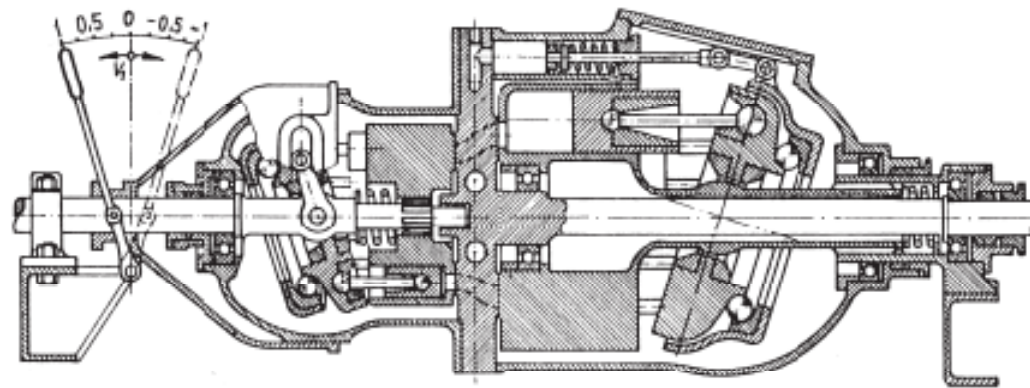
The agricultural tractors transmissions

- *In the late '60 appeared in the market the torque converter;*
- *Late '70 the simple power schift(Hi-lo, Dual Power,..);*
- *Mid '80 power schift with multiple ranges*
- *Late '80 full power schift;*
- *Late '90 power split CVT*



The technological development

- *If the commercial use of the new transmissions was the mentioned, nevertheless for that concerning the technological achievements we should look back in the long past.*
- *In 1907 Renault manufactured a passenger car equipped of an Hydrostatic -mechanical split gear box*



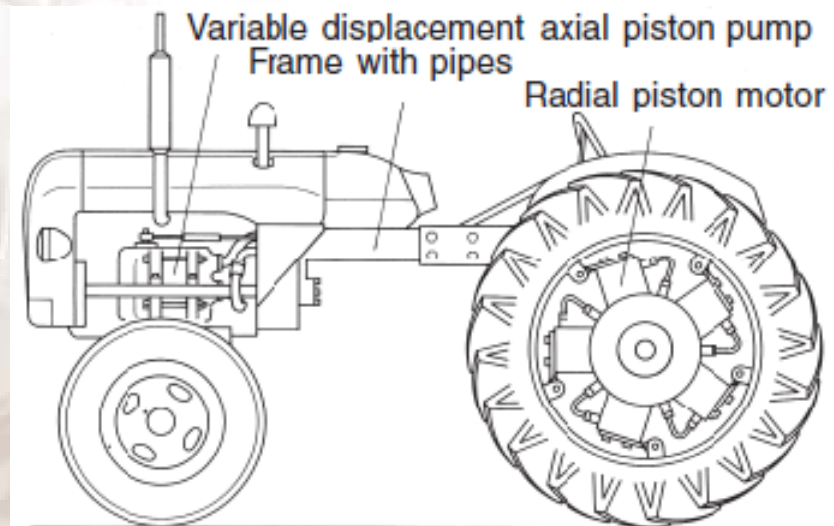
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HIGH OVERDRIVE DURING HAULAGE AND TRANSPORT

The technological development

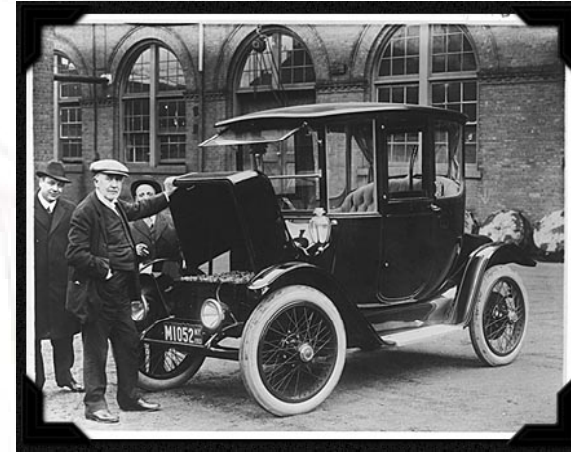
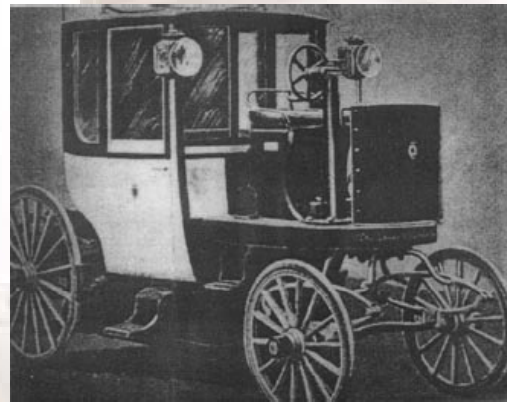
In 1954 the Silsoe Institute presented an Hydrostatic CVT Tractor

In 1970 another full Hydrostatic tractor was developed by Cemoter a branch of CNR



The technological development

While at the beginning of the 20th century in USA the electric vehicles were more popular than the car operated by ICE



In 1921 the Owen presented this Touring car Equipped of an electromechanical Transmission.



For different reasons the electrical transmission was proposed in the naval propulsion during the '70 and now, jointly with hybrid solutions, it is again in discussion for pleasure boats.



The technological development

Concerning electrically driven agricultural machines we can also mention:

The Tema Tractor driven by batteries (1985)



The self propelled frame for orchard operations driven by batteries (1988)

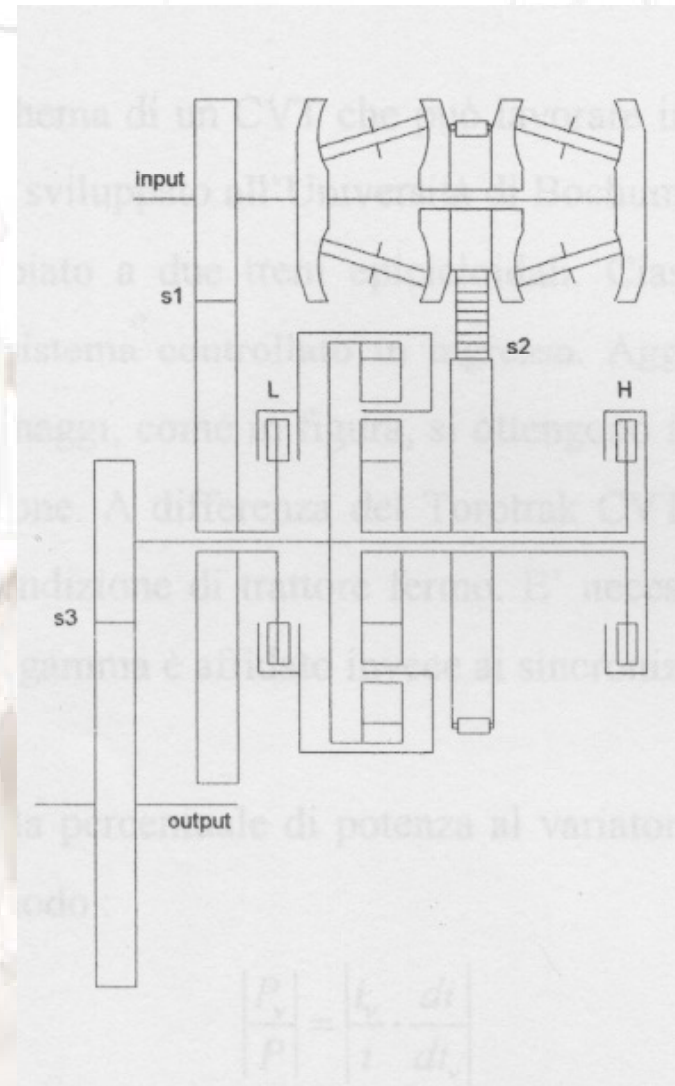


The tractors for green houses driven by batteries, or by net (1990)

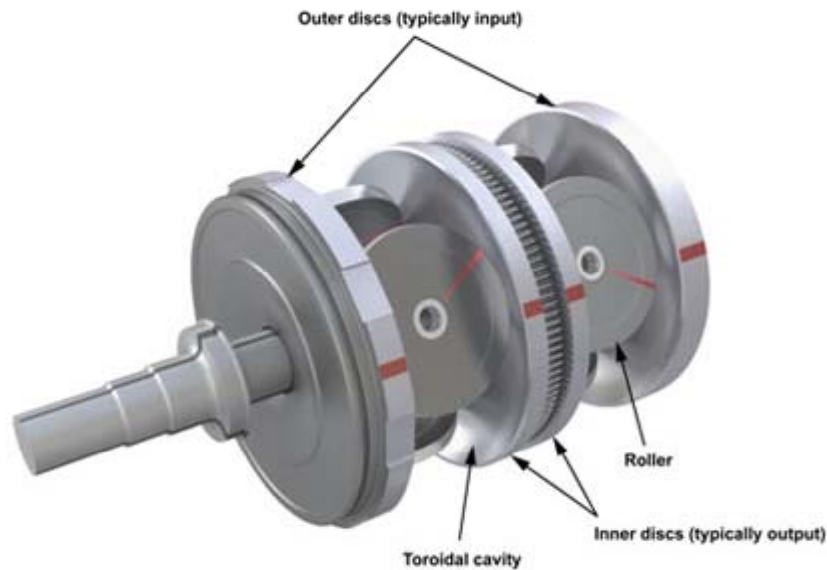


The CVT solutions

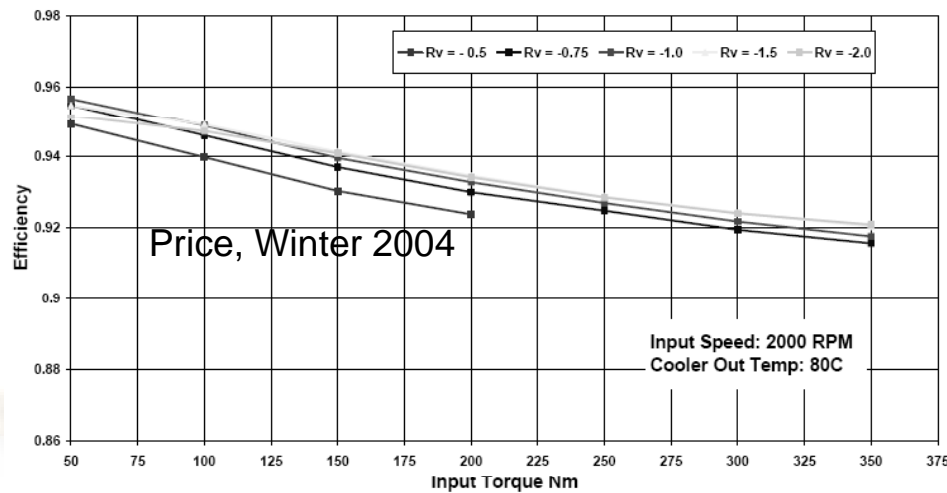
Generally speaking about CVT we recall the hydro-mech split solution well known for the Fendt Vario models, but there are many other different solutions as the toroidals (half, or full) which recently have been proposed as Hybrid (flywheel kers) solution for cars & Buses and introduced also in the market of agricultural tractors.



Carraro Torotrak VAryT



FULL TOROIDAL
Variator Efficiency vs. Input Torque



Advantages: compact design, suitable for medium torque; but drops in efficiency at high loads and high speed reductions; better efficiency for half toroidal solution (according to Renius, 2005), average $\eta = 85\%$ (Hirohisa et al, 1999)



NO CLUTCH USE
WHEN STOPPING

HIGH OVERDRIVE DURING HAULAGE AND TRANSPORT

The CVT solutions

The Hydrostatic-mechanical split transmissions is the most common solution in agr. tractor.

CAN MAINTAIN CONSTANT
BAR FINDER LEVELS TO
ULL-THROUGH TROUGH
SPOTS IN THE FIELD

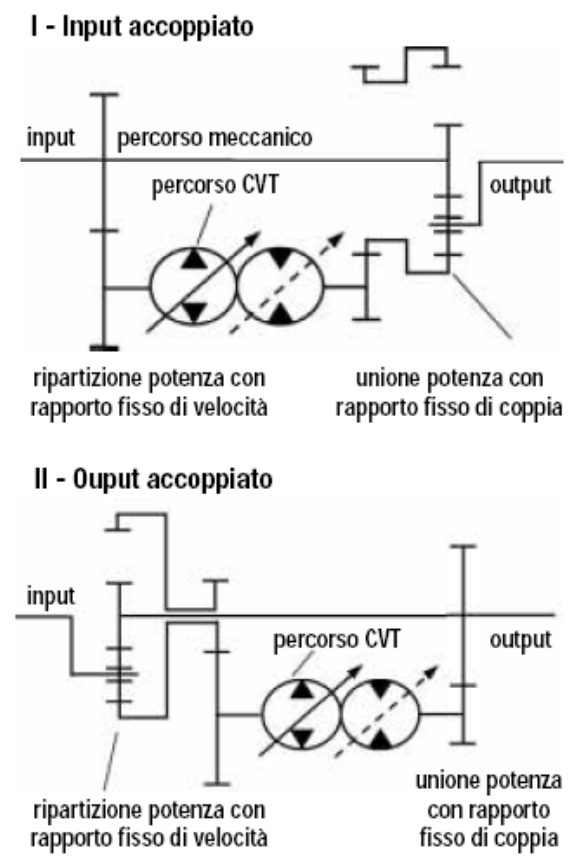
Two main solutions,
according the
classification
by Kress (1968):

*Planetary input
coupled*

*ZF Same Deutz Fahr,
John Deere, Case NH,..
generally with 4 mech.
ranges*

*Planetary external
coupled*

*Fendt coupled with
2 mech ranges*



The CVT hydro-mech. solutions

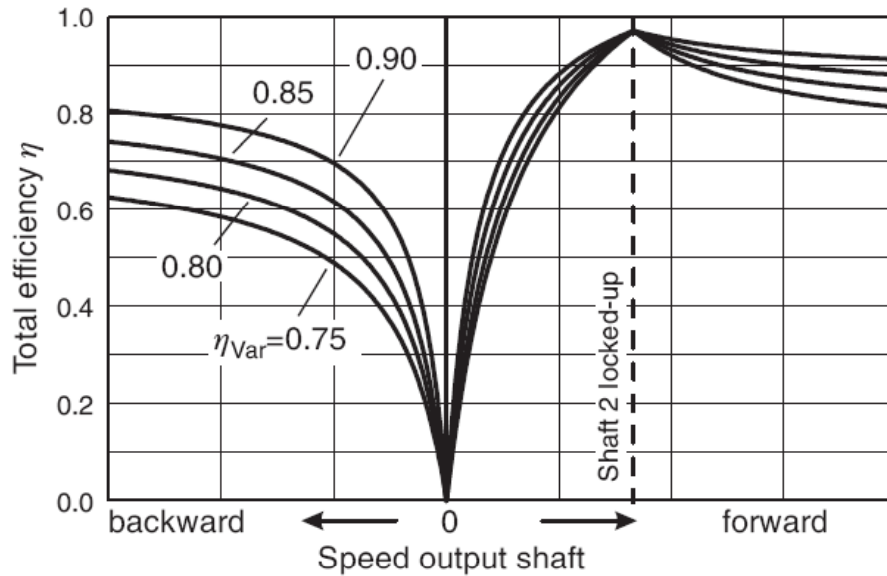


Fig. 32 Influence of the variator efficiency on the overall efficiencies for the structure from Fig. 30.

Input coupled

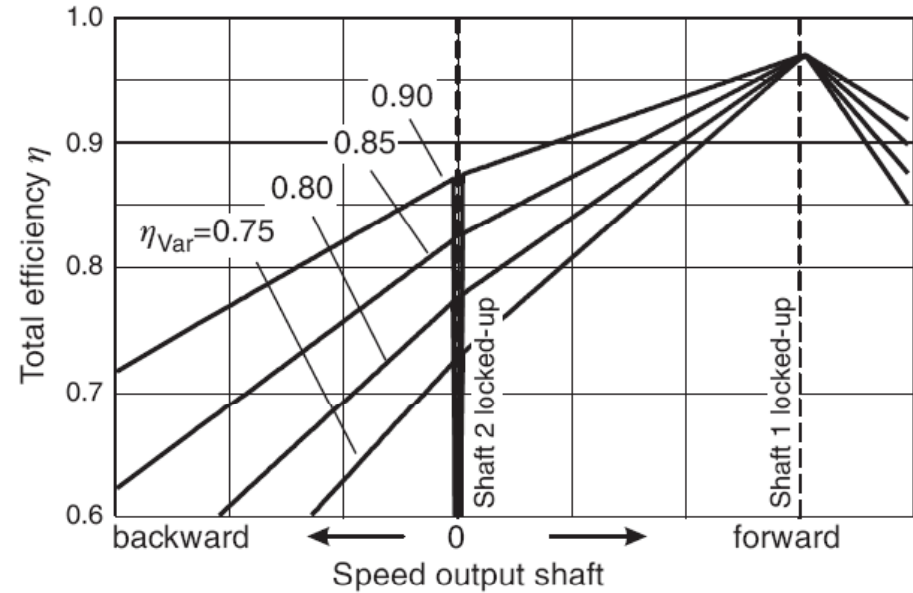


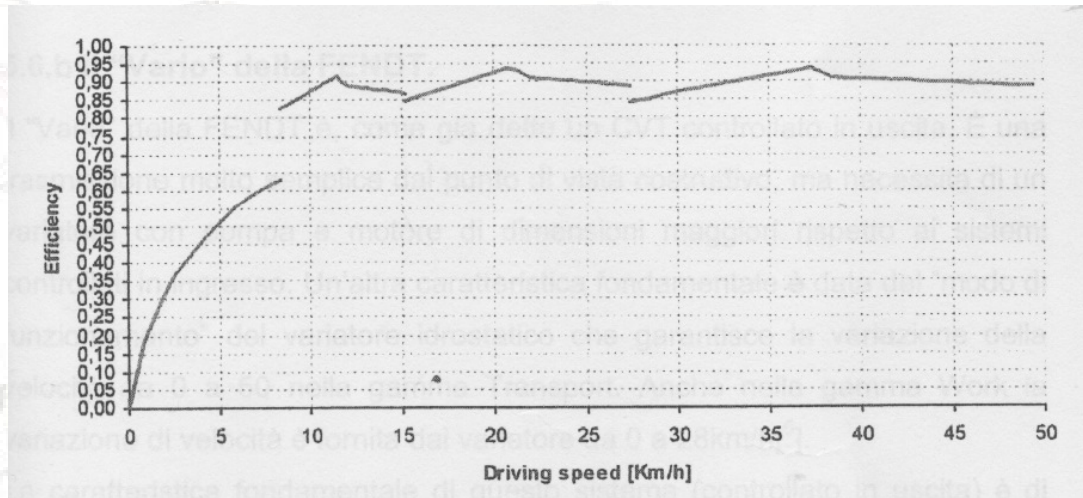
Fig. 33 Influence of the variator efficiency on the overall efficiencies for the structure from Fig. 31.

Output coupled

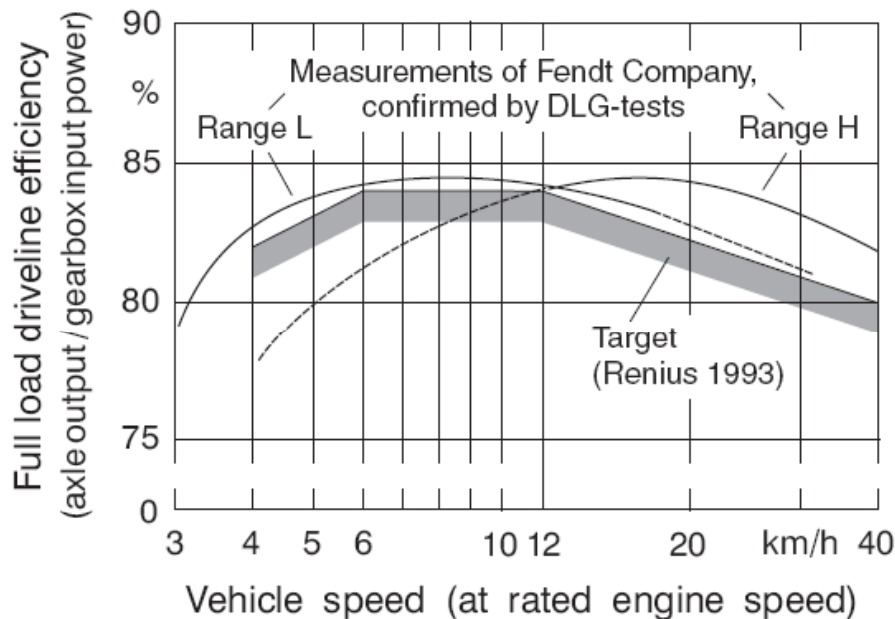
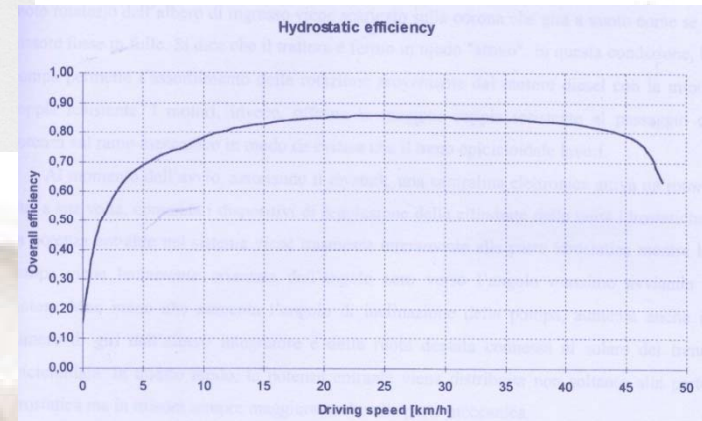
Renius 2005



The Hydro-mech. CVT Efficiency



The SameDF CVT efficiency. To the reported data should added the axis losses. The 4 ranges allow to keep a low % of the Hydrostatic power which η decreases at low & high speed



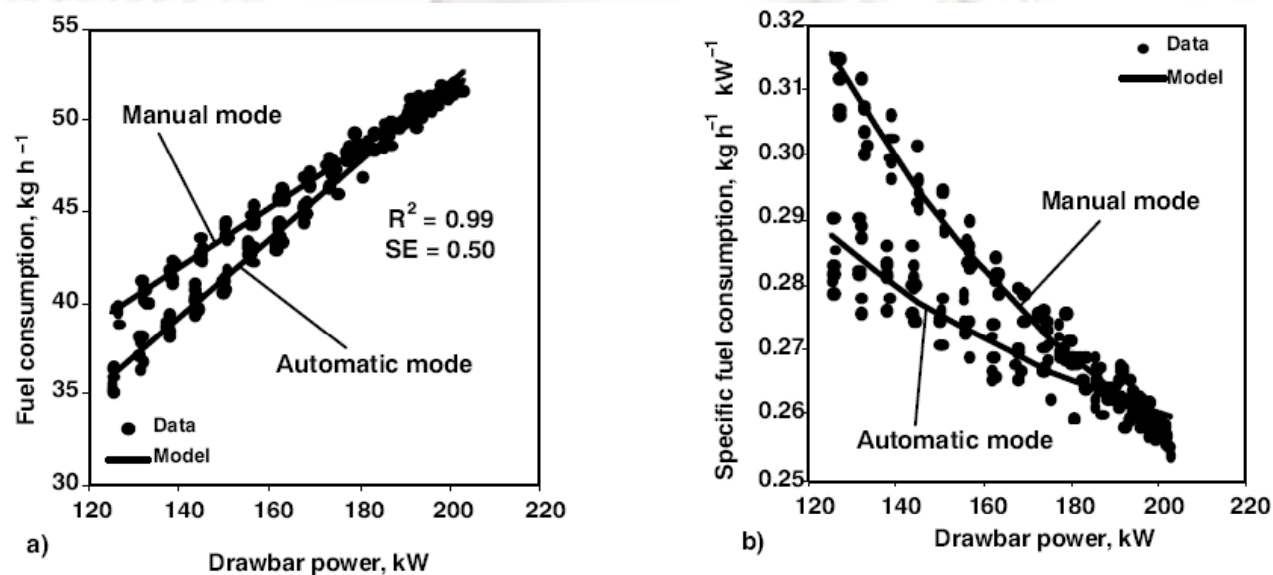
The Fendt CVT total efficiency

The grey line shows the target performances for a CVT calculated by Renius (1993)



The Hydro mechanical CVT

The following diagrams highlight the benefits of the CVTs on the general efficiency of the whole tractor system thanks to the possibility to control loads and speed of the ICE which is directed to operate at the most efficient condition



Tests by
Coffman et
al. 2010

Figure 3. Hourly (a) and specific (b) fuel consumption response to drawbar power for a John Deere 8530 IVT tractor with the transmission in automatic and manual mode.

The Hybrid transmissions in ag. Tractors

Speaking about Hybrid transmission, we think about the electro mechanical cars powered by an ICE, although before was mentioned the flywheel(kers) which also is considered an Hybrid solution. Here is reported a table by Renius (2005) in which this option is yet considered

Table 5 Relevant CVT principles for tractor drives.

| | pros`s | con`s | comments |
|---|---------------------------------------|--|---|
| Mechanical by friction "direct" | High efficiency, low noise level | No start from zero, low shift speeds, power limits (chains) | Push type CVT: Japanese cars Pull type CVT: Audi-LuK chain CVT (2000) Toroid Nissan (1999) |
| Mechanical power split | Start from zero, low noise level | Efficiency can be lower than with "direct" | Prototypes known under the name "geared neutral" |
| Hydrostatic "direct" | Long experience, high shuttle comfort | Low efficiency high noise level | Popular for small tractors and crawlers |
| Hydrostatic power split | High efficiency | Noise, limited flexibility, shift can be complicated, high R&D costs | CLAAS "HM-8" (1996) Fendt "Vario" (1996) "Steyr S-Matic" (2000) ZF "Eccom 1.5" (2001) J. Deere/USA (2001) |
| Electrical "direct" with Diesel engine | Low noise level, high shuttle comfort | Expensive, low efficiency | Several research activities on units and systems. |
| Electrical "direct" with fuel cells | Low noise level, high shuttle comfort | Very expensive, extra motor for PTO, high R&D costs | Long term potential, commercial use 2022? |
| Electrical power split with Diesel engine | High efficiency low noise level | Expensive, high R&D costs | Several research activities on units and systems. Commercial use 2012? |

The major Types of Hybrid configuration on the market

Toyota Coaster bus; TNO WW Beetle; Chevy Volt,...

Honda Insight integrated by a pull Type chain CVT; Smart,...

Toyota Prius, Mercedes S, Ford Escape,...

| System | Drive power & electric power | Ratio of engine and motor operation (conceptual diagram) | Comparison of Effects | | | | | |
|-------------------------------------|------------------------------|--|--------------------------|-----------------|-----------------------------------|------------------|---------------------|------------------------|
| | | | Fuel economy improvement | | | | Driving performance | |
| | | | Idling stop | Energy recovery | High-efficiency operation control | Total efficiency | Acceleration | Continuous high output |
| Series hybrid system | | | ○ | ⊙ | ○ | ○ | △ | △ |
| Parallel hybrid system | | | ○ | ○ | △ | ○ | ○ | △ |
| Series/parallel hybrid system (THS) | | | ⊙ | ⊙ | ⊙ | ⊙ | ○ | ○ |

→ Drive power - - - - - electric power ■ Engine ■ Motor ⊙ Excellent ○ Superior △ Somewhat unfavorable

The hybrid solution on the tractors

Of the presented mayor types of Hybrid configuration:

- *The Series Hybrid, based on a full electric traction, is not suitable due to the dimension of the electric motor and to the overall efficiency;*
- *On the contrary the two other configurations, the parallel and the Series/parallel could be examined: The two are more similar to the CVT examined where the extra mechanical transmission is a small %: this permit to limit the cost of the systems.*



The hybrid solution on the tractors

- *But which could be the real advantages compared to the Hydro-mech. CVT ?*
- *Less noise and less pollution?*
- *Less vibrations?*
- *Surely not a considerable improvement in efficiency*



The Hybrid solution on the tractors

Conclusions

The efficiency of the electric components is higher than of the hydrostatic machines, but also in this case not in all operating conditions. In addition the dimensions are much more significant, creating problems in the traditional agricultural tractors architecture, although important modifications of it should be expected.

Another problem we should take in consideration is the large investments required to develop such new configurations, taking in account that: The transmission represents the 25-30%, or more, of the total value of a tractor and that the investment required could raise up tens and tens millions of €.

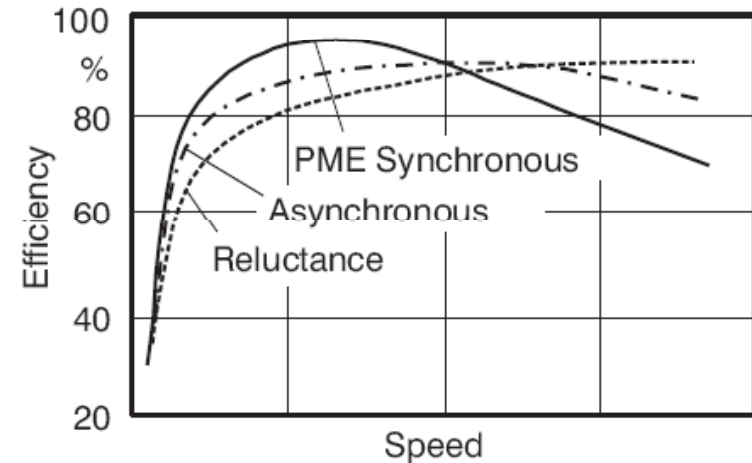


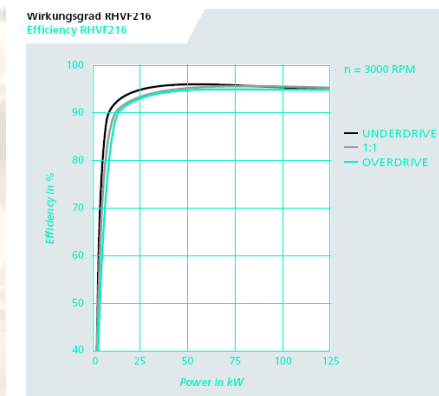
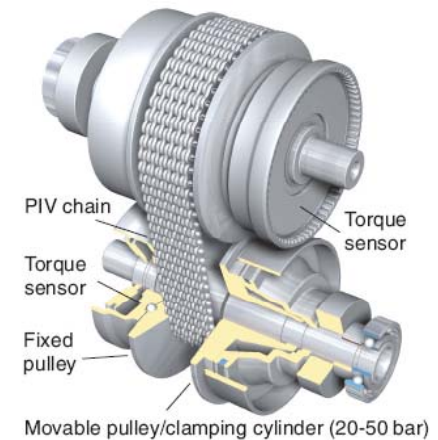
Fig. 24 Typical efficiencies for three concepts of electrical machines (Tarasinski 2004).

The Hybrid transmissions and their feasibility in agriculture

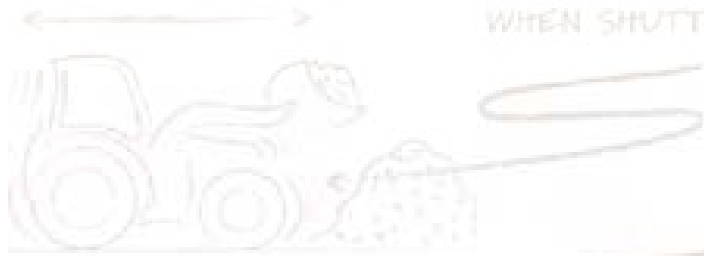
Conclusions

On the contrary, other points and possibilities of the agr. transmission should be investigated and improved:

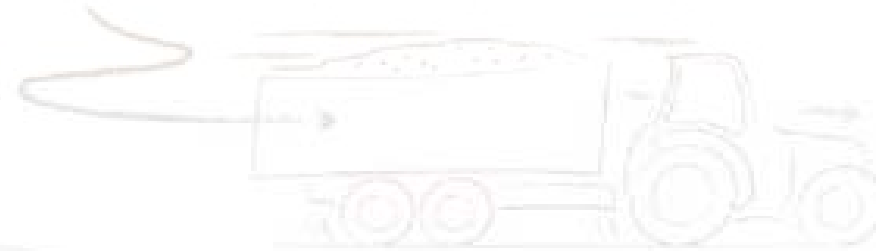
- The use of toroidal and pull belts solutions, characterized by high efficiency and simplicity in particular the last;
- The improvement of the mechanical part of the transmission. At this regard I was shocked by the results of the interesting works done by Molari (2008-2009) who highlined great losses in a full power schift and the important improvements achievable by design accuracies;
- The simple introduction of the stop&go system ;
- The introduction of the Kers System



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HIGH OVERDRIVE DURING HAULAGE AND TRANSPORT



ACCURATE POSITION CONTROL

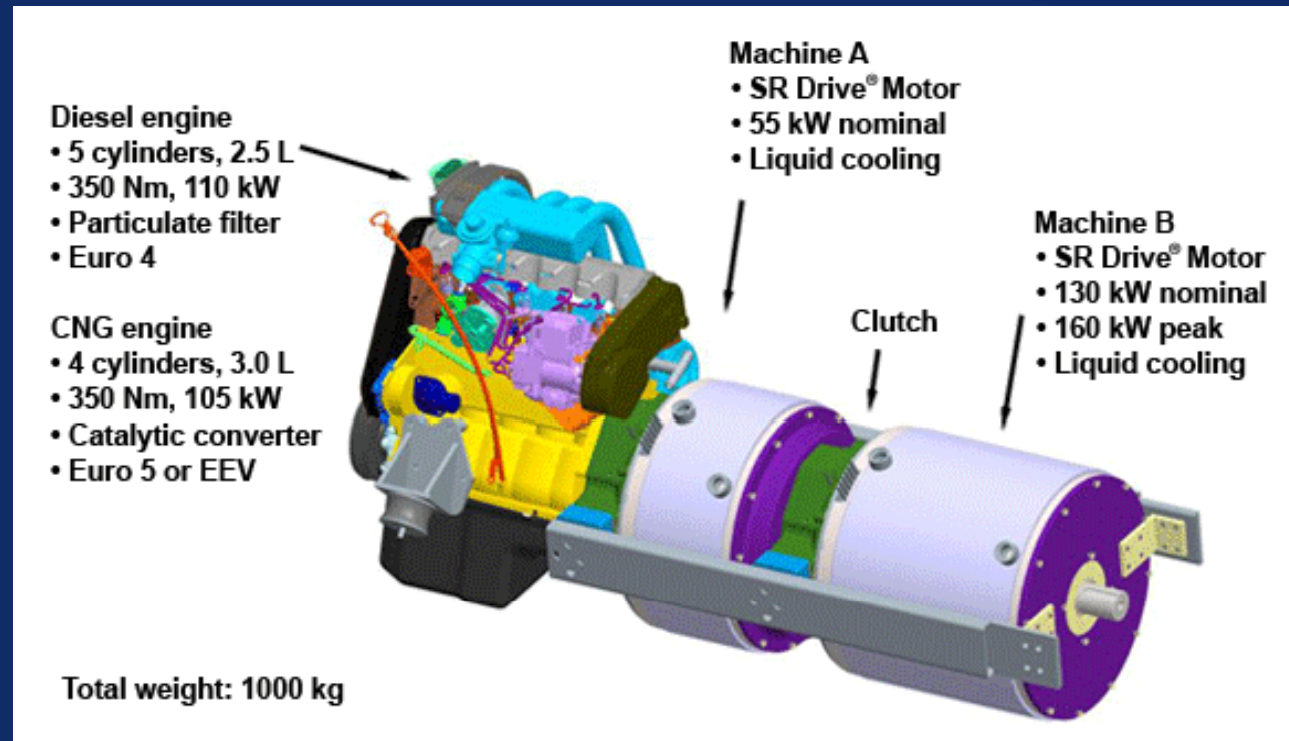
CAN MAINTAIN CONSTANT
BANK POWER LEVELS TO
FILL THROUGHOUT TOUGH
SPOTS IN THE FIELD

Thanks for your attention



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Nidec Hybrid Bus



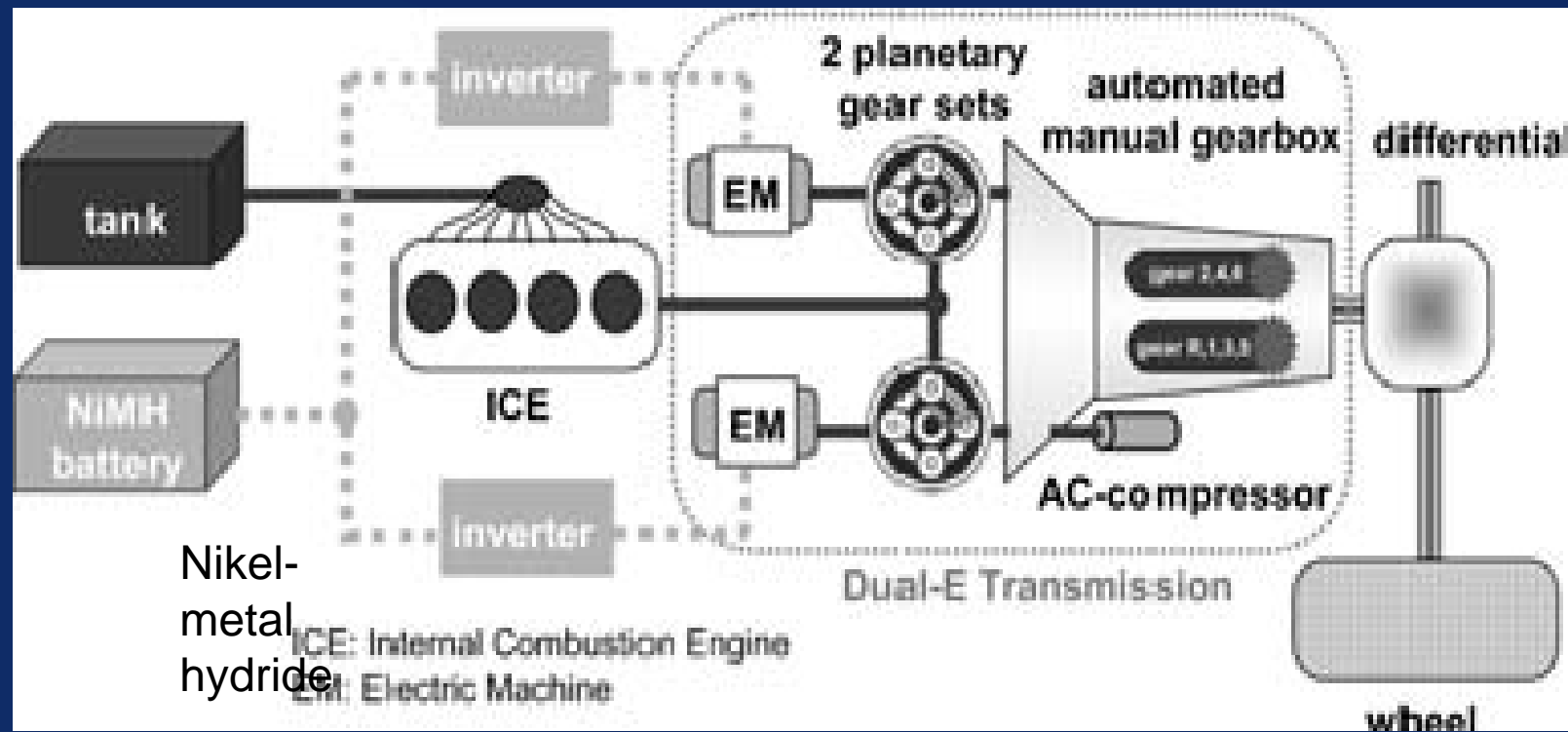


Fig. 3 Schematic representation of the Dual-E Transmission

by: M Schulz

(IMechE 2004)

