Design and Modeling of Fluid Power Systems

ME 597/ABE 591 - Lecture 15

Dr. Monika Ivantysynova
MAHA Professor Fluid Power Systems

MAHA Fluid Power Research Center
Purdue University

Hydrostatic transmissions

- Hydrostatic transmission – basic principle

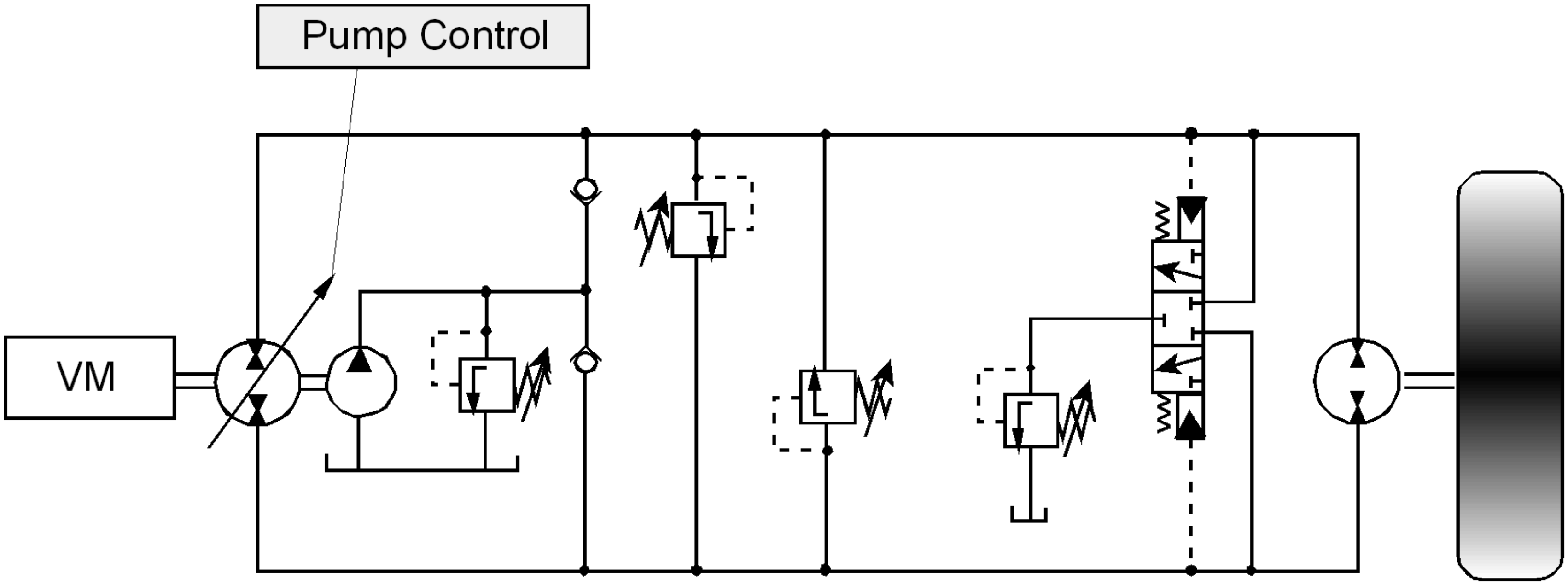
- Hydrostatic transmission – circuit solutions with additional functions

- Advanced transmission concepts

- Power Split drive technology

Hydrostatic transmission

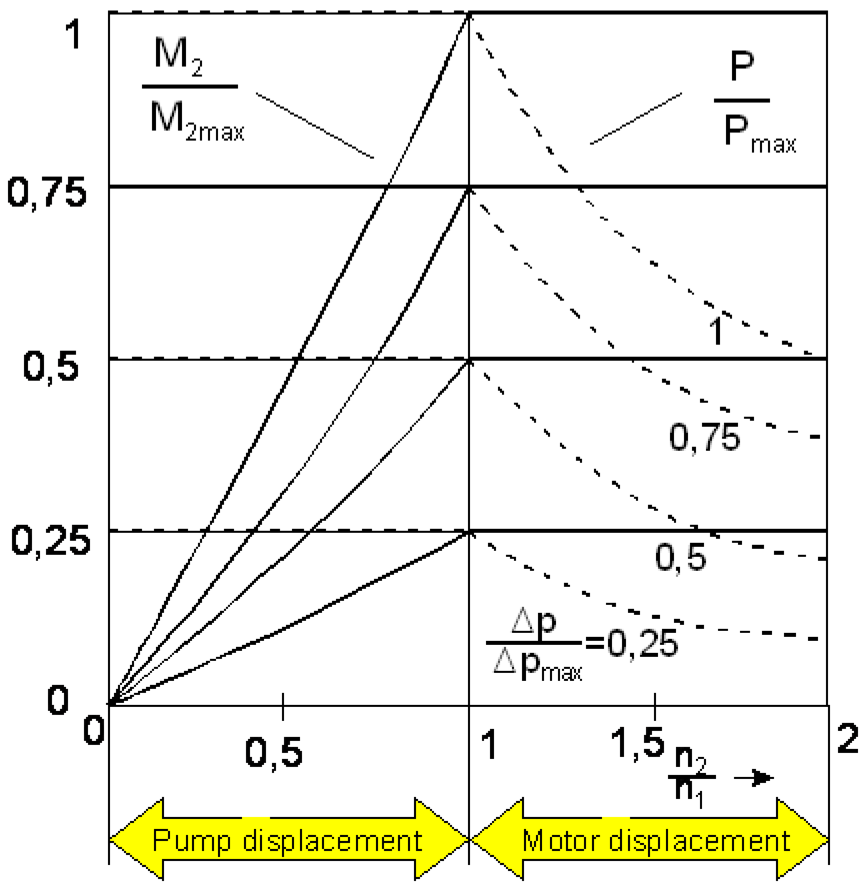
Basic Circuit Design

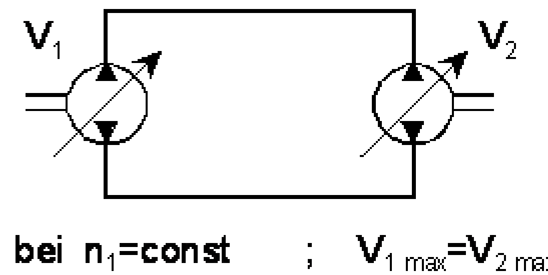


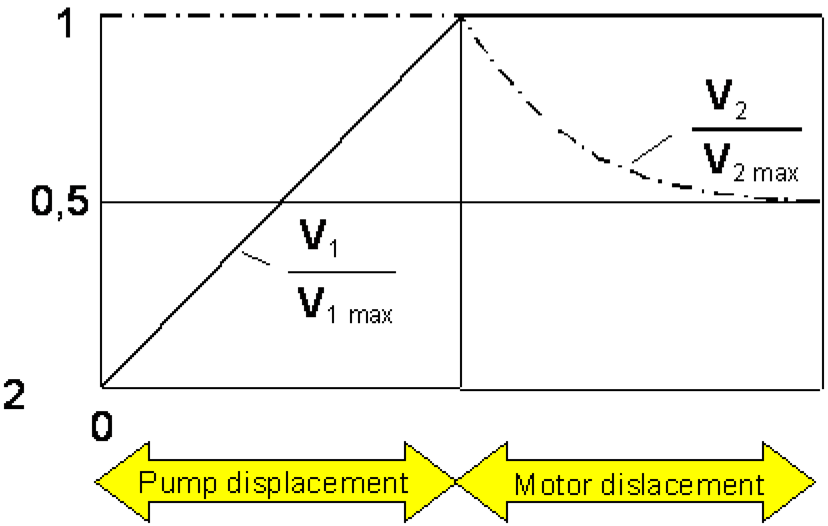
Hydrostatic transmission

Two variable units –controlled in sequence

M… torque P… power V… displacement

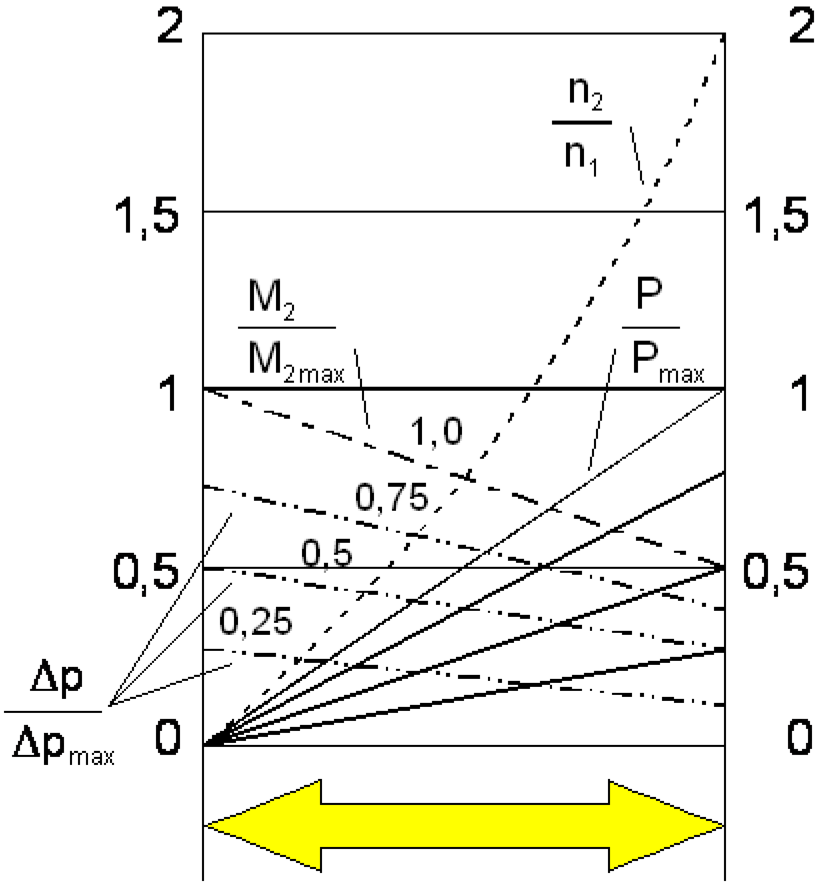


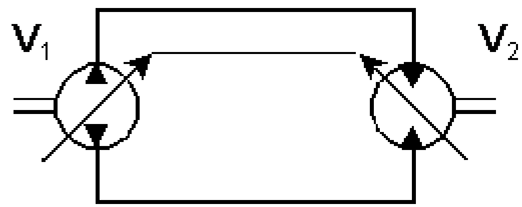




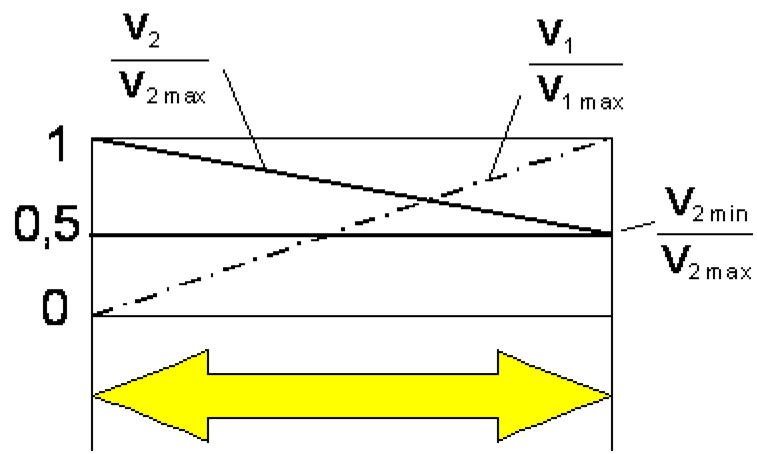
Hydrostatic transmission

Two variable units – simultaneously controlled



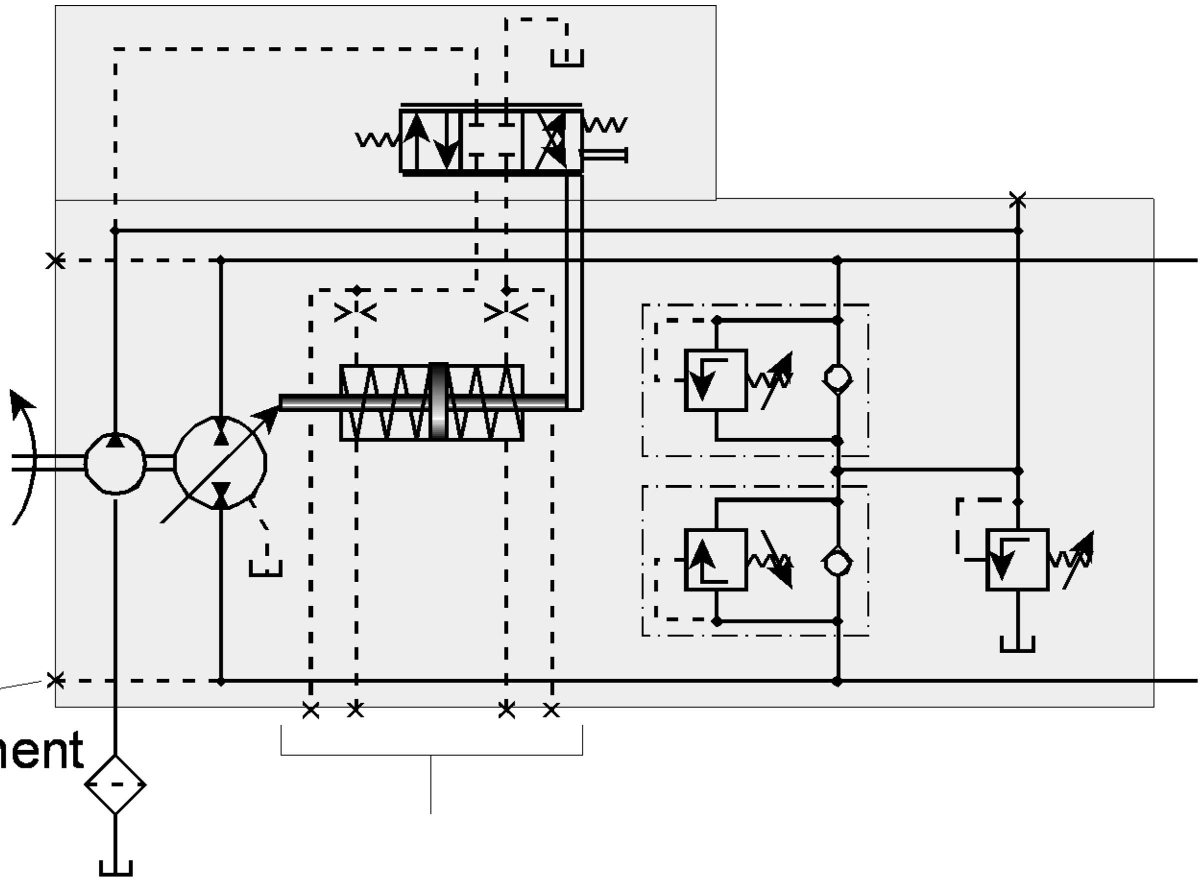


n_1=const ; $V_{1\,max}=V_{2\,max}$



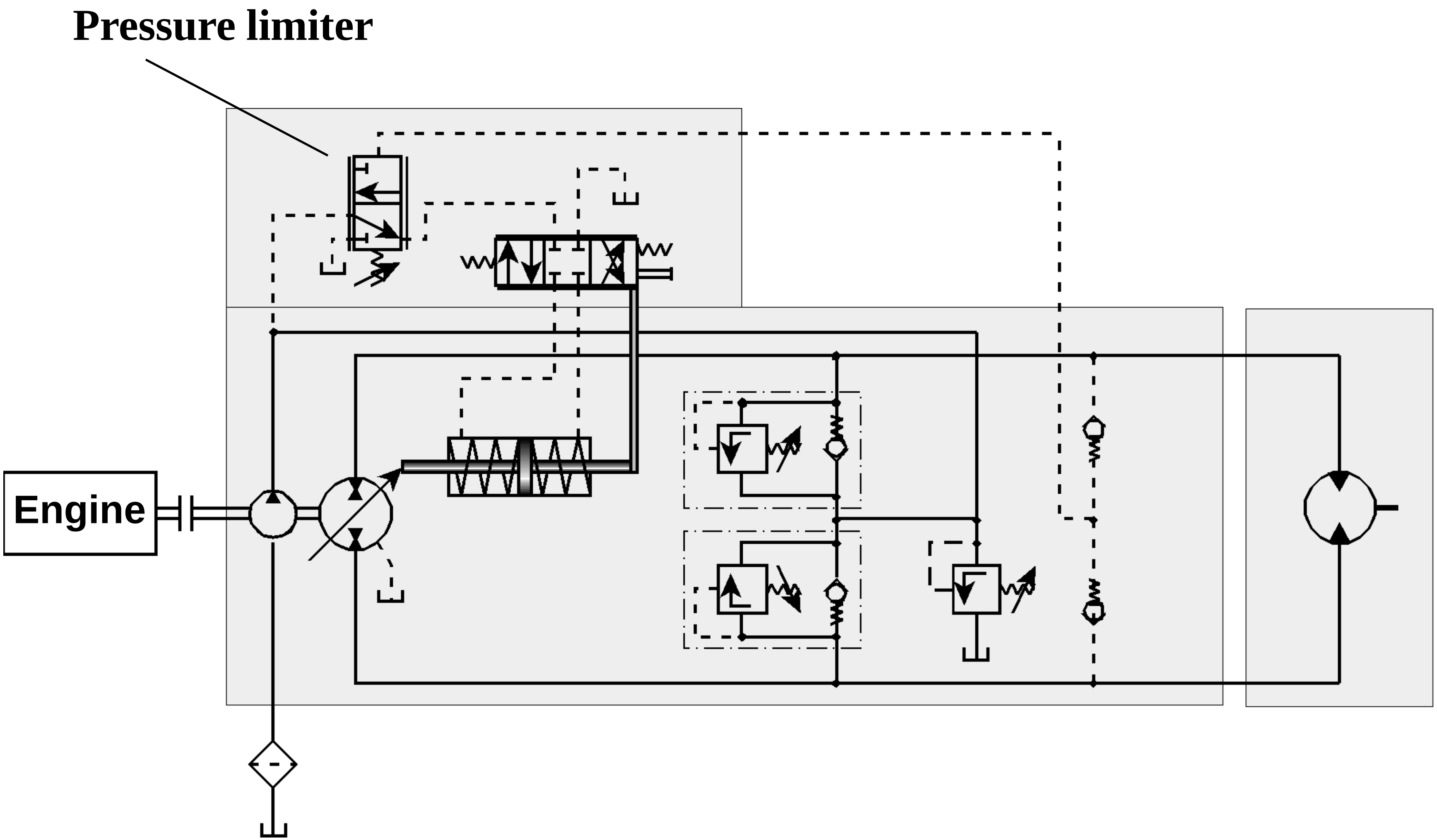
Hydrostatic transmission

Pump control – manually, with mechanical feedback



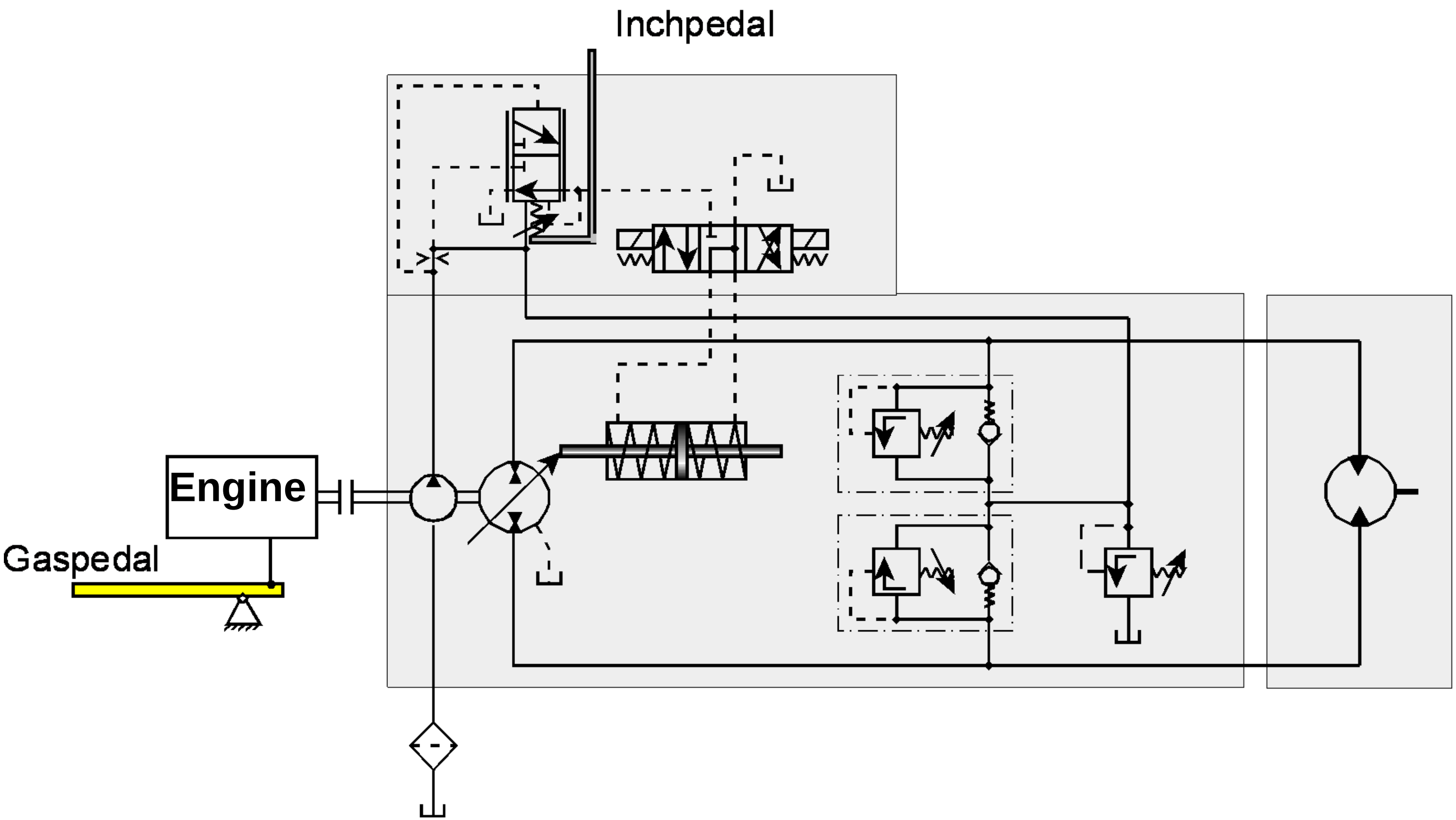
Pressure Measurement

Hydrostatic transmission



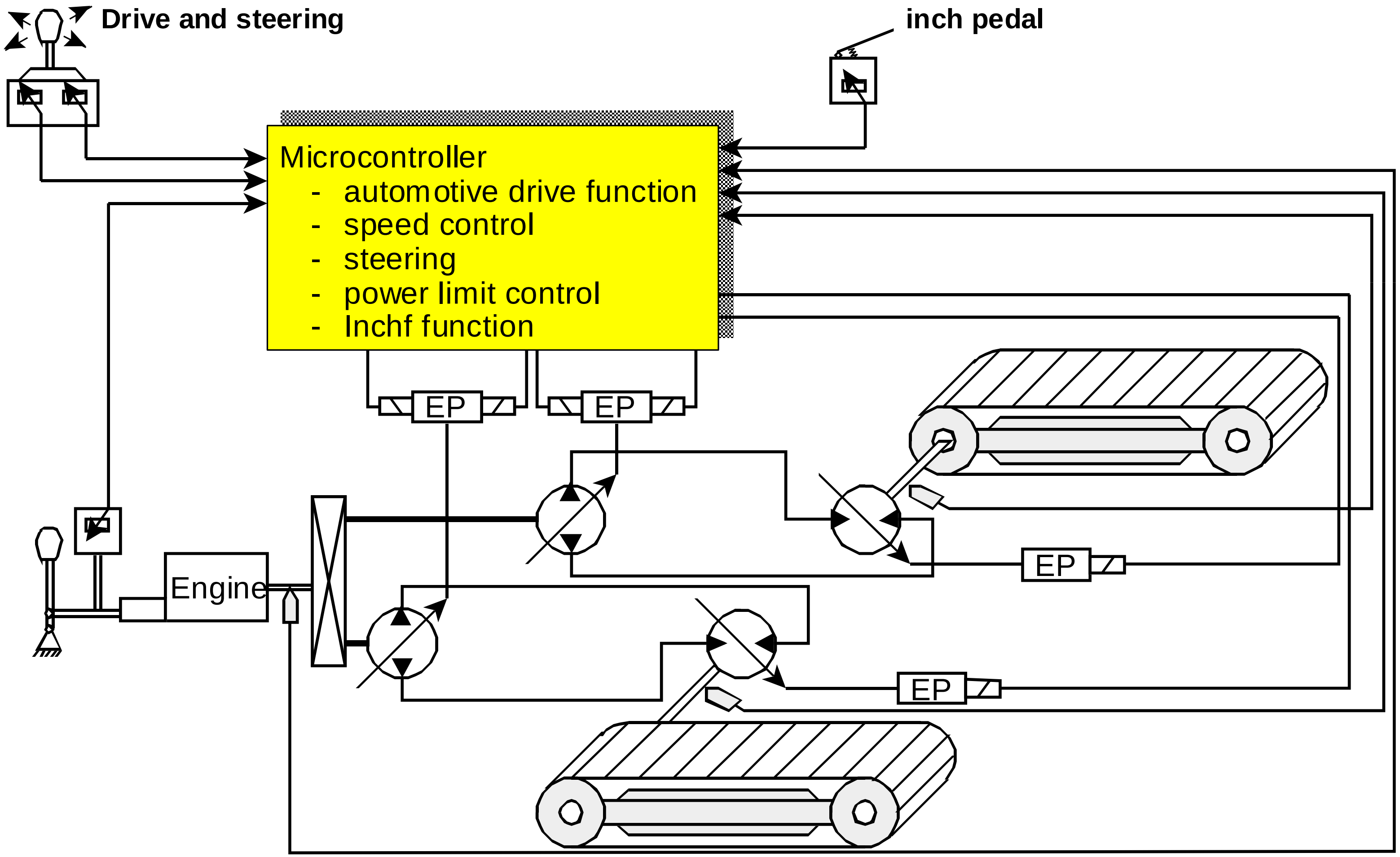
Hydrostatic transmission

"Automotive" control

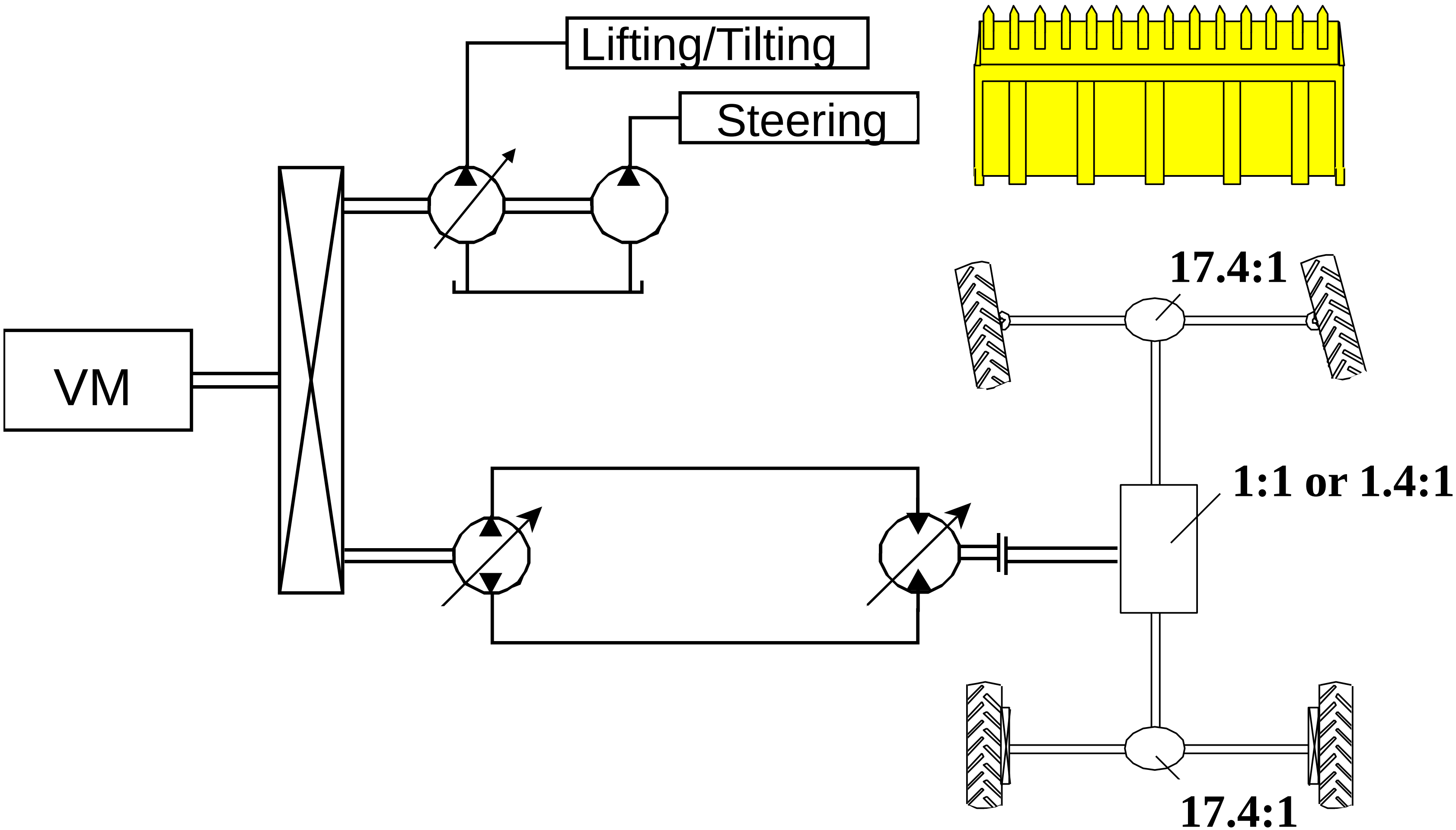


Hydrostatic transmission

With electrohydraulic controlled displacement units



Example Wheel loader



Wheel loader Transmission Design

Example

Design the hydrostatic transmission for a given wheel loader and calculate the traction force- speed characteristic for the entire speed range.
The following parameters and requirements are given:

Engine speed:	2200 rpm
Engine power:	90 kW
Vehicle mass:	10 t
Bucket volume:	1 m^3
Density soil:	2kg/dm^3
Dynamic roll radius:	0.617 m

Coefficient of rolling resistance (soil): 0.08
Coefficient of rolling resistance (asphalt): 0.015

Max vehicle speed (on road): 40 km/h
Max traction force: 25 kN

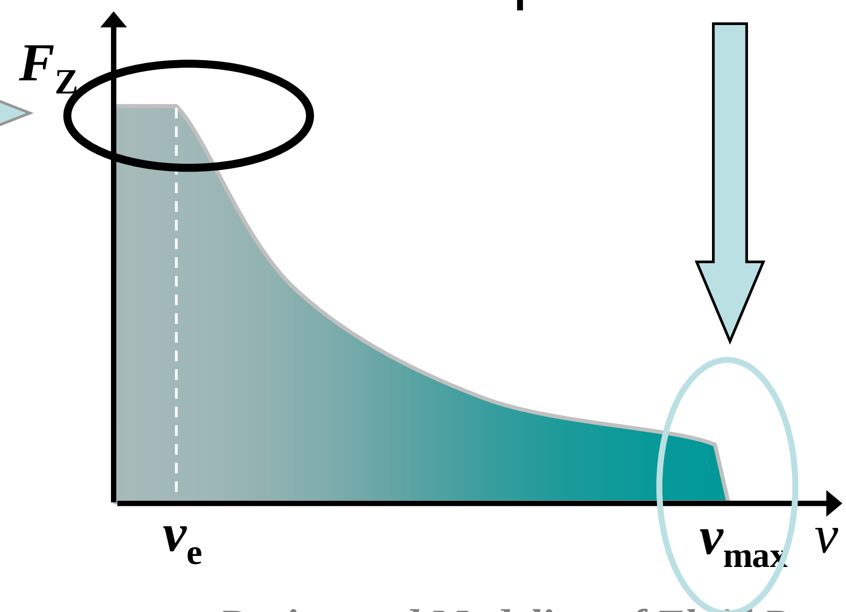
Axial piston machines

Selected pump and motor sizes

Max. Displacement Volume	Max. Speed	Max. Pressure (contin.)	Max. Pressure	Theoretical flow rate @1000 rpm	Power @ 100 bar, 1000 rpm	Displacement charge pump	Mass variable pump	Torque @ 350 bar Fixed displ. motor	Mass fixed displ motor	Displacement Volume ß=7°	Max. Speed @ ß=7°	Mass variable motor
cm^3	min^{-1}	bar	bar	l/min	kW	cm^3	kg	Nm	kg	cm^3	min^{-1}	kg
33,3	3800	350	420	33,3	5,6	12,3	45	176	30	12,5	5000	51
51,6	3500	350	420	51,6	8,6	12,3	55	272	35	19,5	4400	61
69,8	3200	350	420	69,8	11,6	18,0	63	373	40	26,4	4000	69
89,0	2900	350	420	89,0	14,8	18,0	78	472	47	33,6	3700	84
118,7	2700	350	420	118,7	19,8	18,8	124	624	70	44,7	3350	139
165,8	2400	350	420	165,8	27,6	32,8	164	883	124	62,6	3000	179
227,3	1890	350	420	227,3	37,9	32,8	212	1202	152	85,9	2200	227
333,7	1670	350	420	333,7	55,6	65,5	270	1760	197	126,0	1900	285

Trends & New Requirements

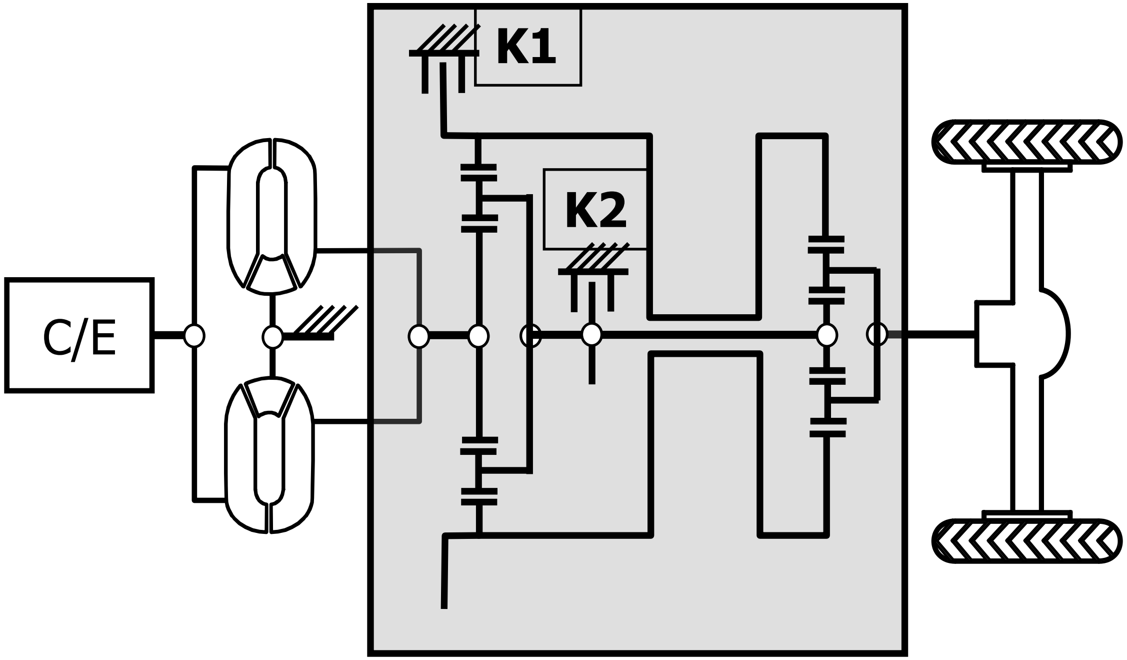
- High traction force & high max. speed
- Continuously variable transmission (CVT)
- Reduction of fuel consumption
- Cost effective



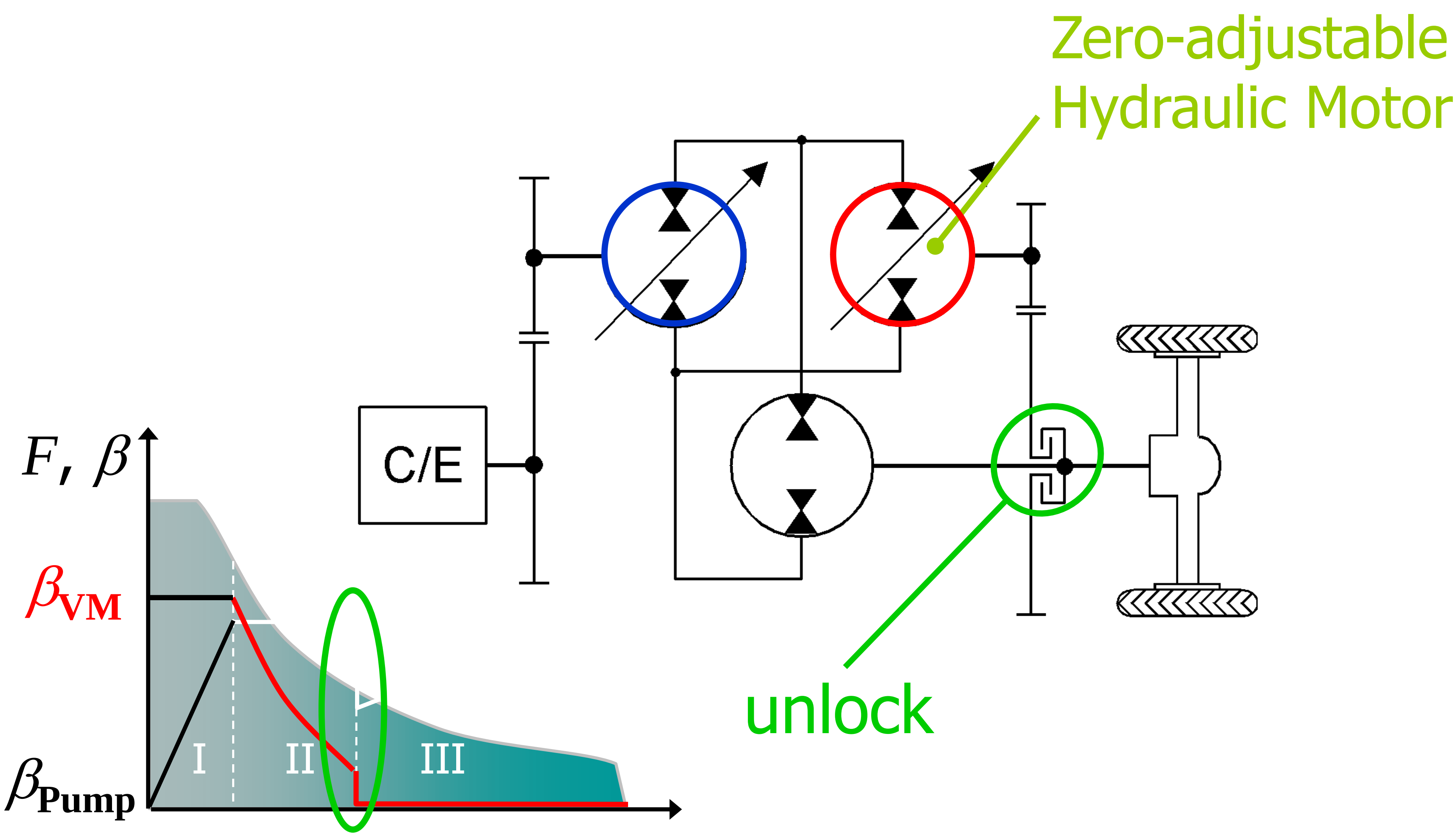
Transmissions - today

Power Shift Gearbox with hydro dynamic torque converter

- state of the art solution
- complex, multi-stage gear system
- high number of clutches
- low starting efficiency
- interrupted power flow

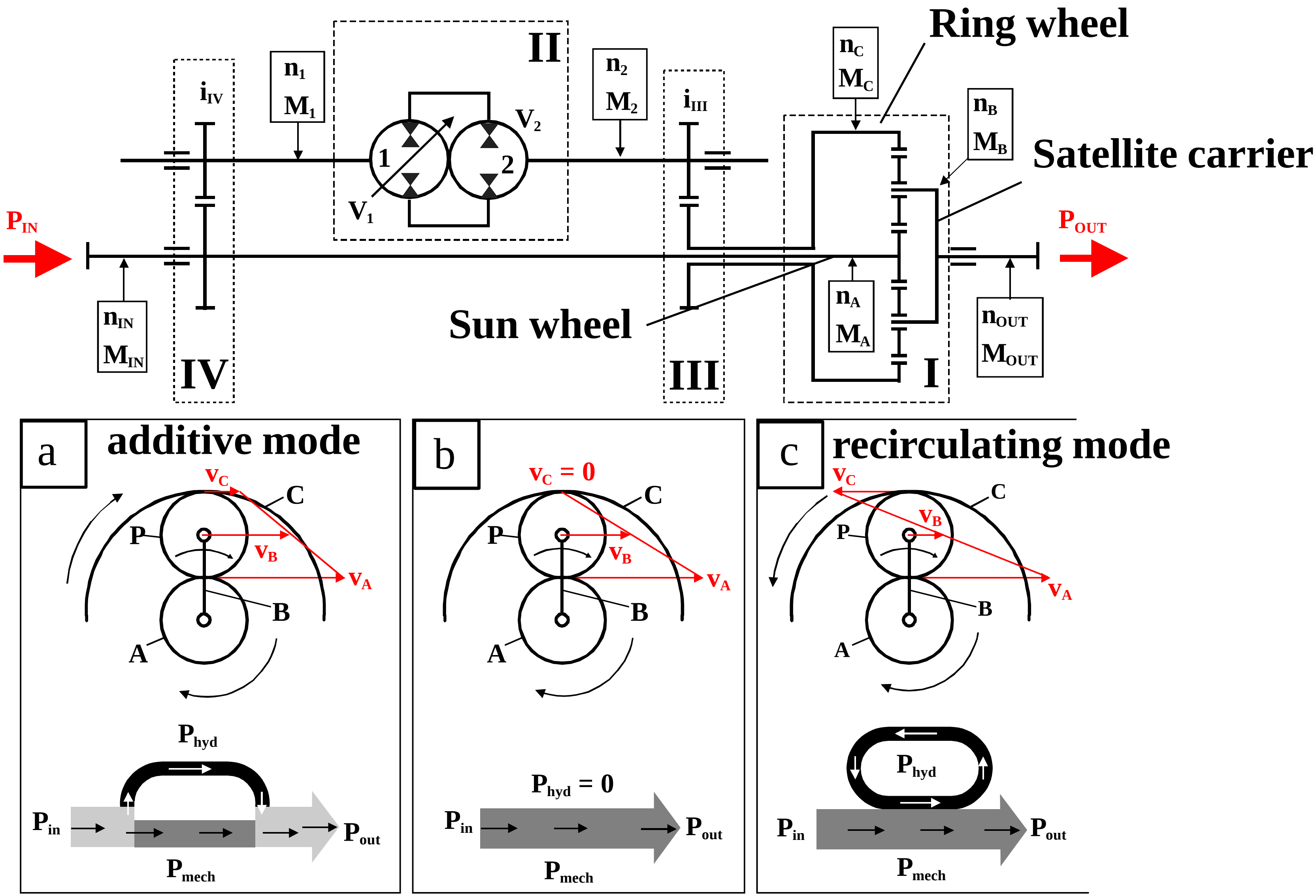


Multiple Motor Concept



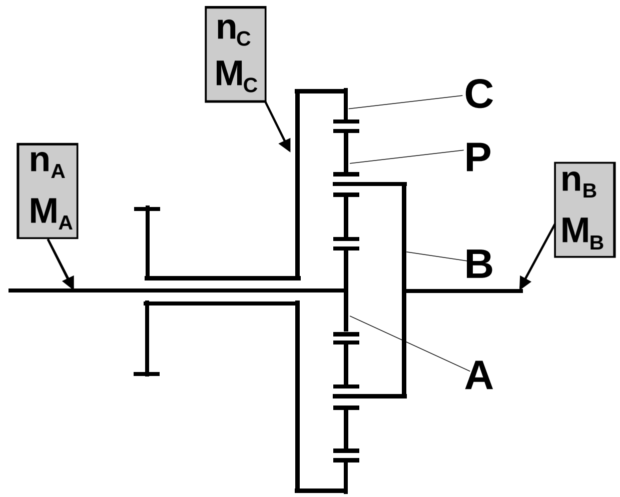
Power Split Drive

Basic structure



Planetary Gear

Three wheel planetary gear train



Willis equation:

$$n_A - i_{0AC} \cdot n_C - \left(1 - i_{0AC}\right) \cdot n_B = 0$$

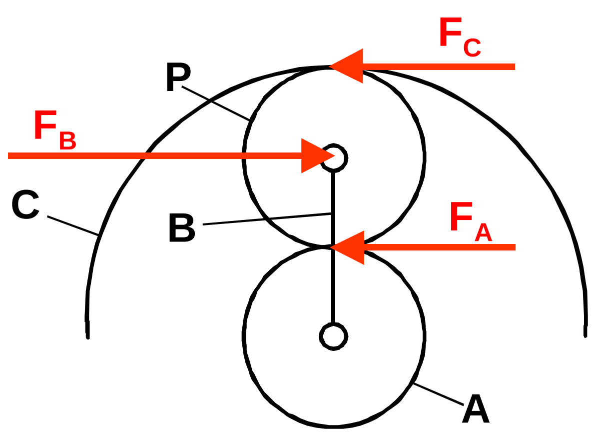
A - Sun Wheel

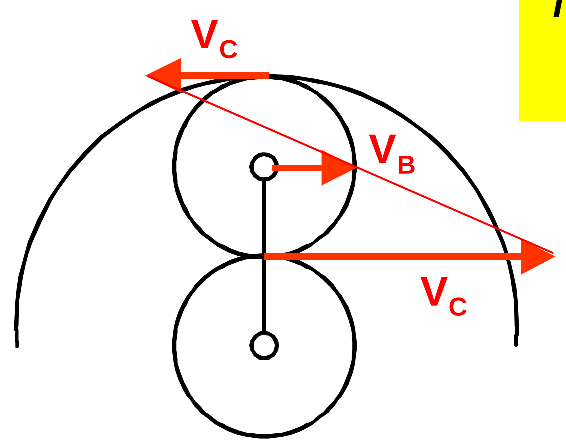
B – Satellite Carrier

C - Ring Wheel

P - Satellite

$$i_{0AC} = -\frac{z_C}{z_A}$$



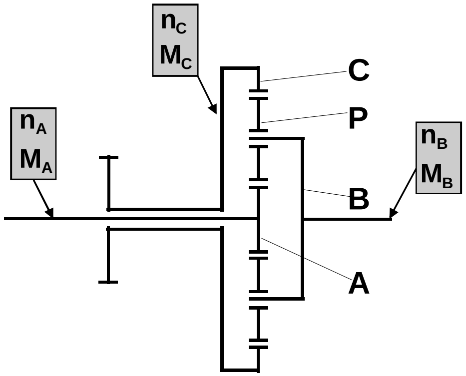


When satellite carrier B is block
$n_B = 0$

Negative planetary gear, the standing gear ratio i_{0AC} is negative

Planetary Gear

negative standing gear ratio i_{0AC}



A - Sun Wheel

B – Satellite Carrier

C - Ring Wheel

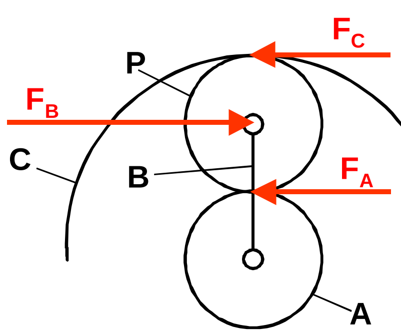
P - Satellite

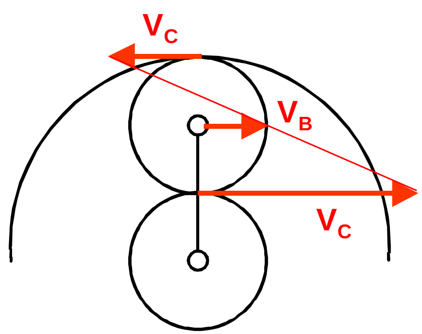
Speed of individual wheels:

$$n_A = i_{0AC} \cdot n_C + (1 - i_{0AC}) \cdot n_B$$

$$n_B = \frac{n_A - i_{0AC} \cdot n_C}{1 - i_{0AC}}$$

$$n_C = \frac{n_A - (1 - i_{0AC}) \cdot n_B}{i_{0AC}}$$



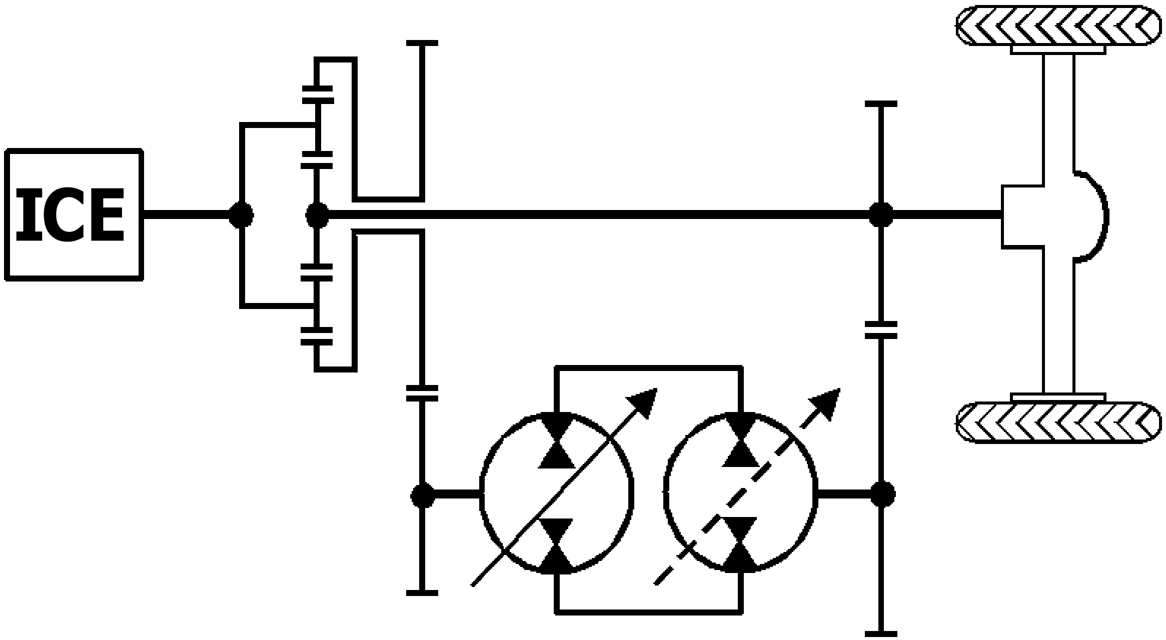


$$i_{0AC} = -\frac{z_C}{z_A}$$

Directions of rotation of sun wheel A and ring wheel C are different, when the satellite carrier B is blocked!

Power Split Drive

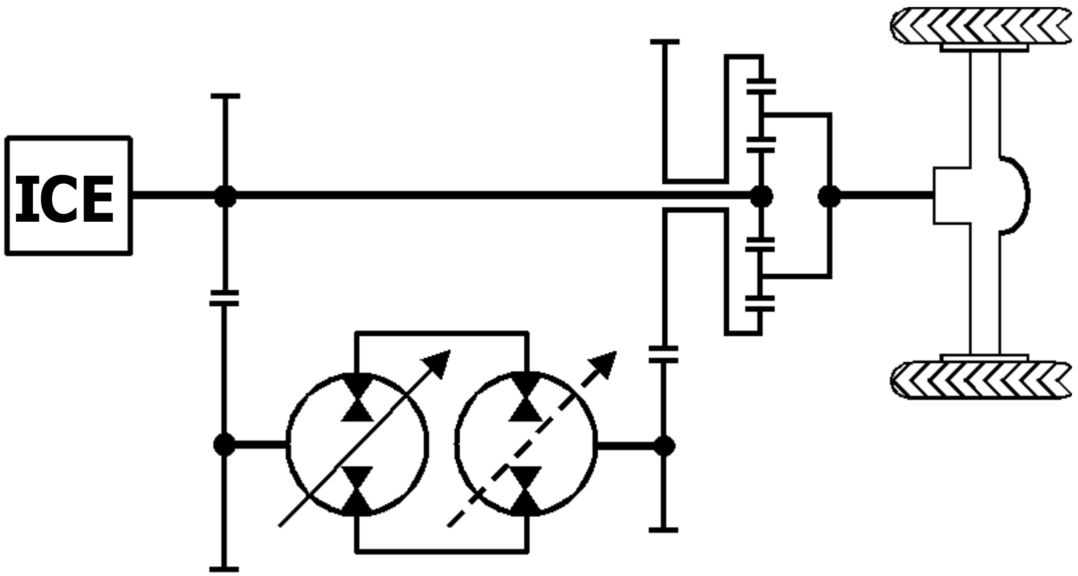
Output coupled System



Fendt, Germany, developed a transmission system for agricultural tractors, which is in series production since 1996

Power Split Drive

Input coupled System

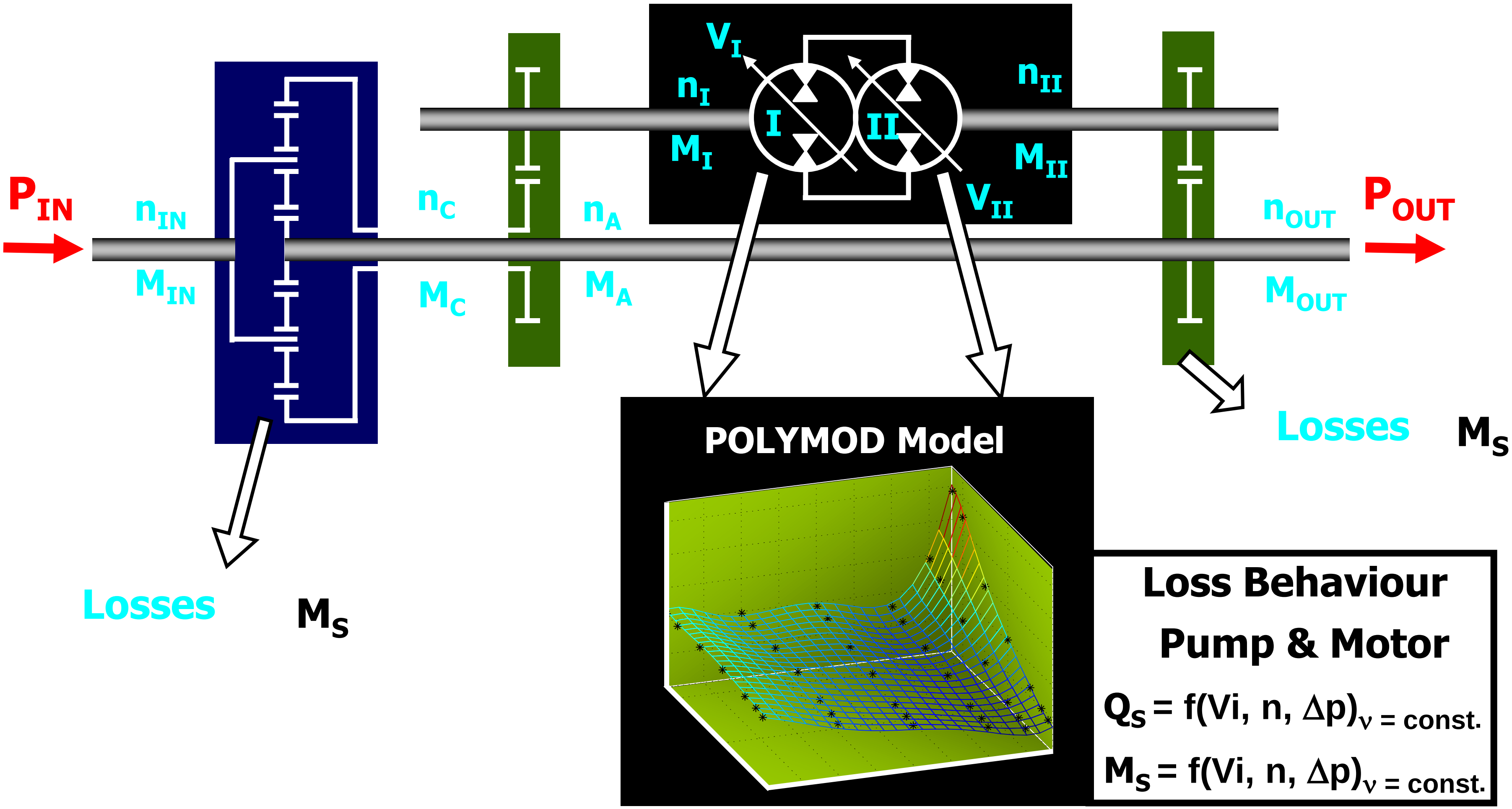


Sundstrand Corporation - Responder transmission
New development by John Deere

PSDD toolbox for Simulink

Best Efficiency ?

POLYMOD allows Precise Loss Models



Loss Behaviour

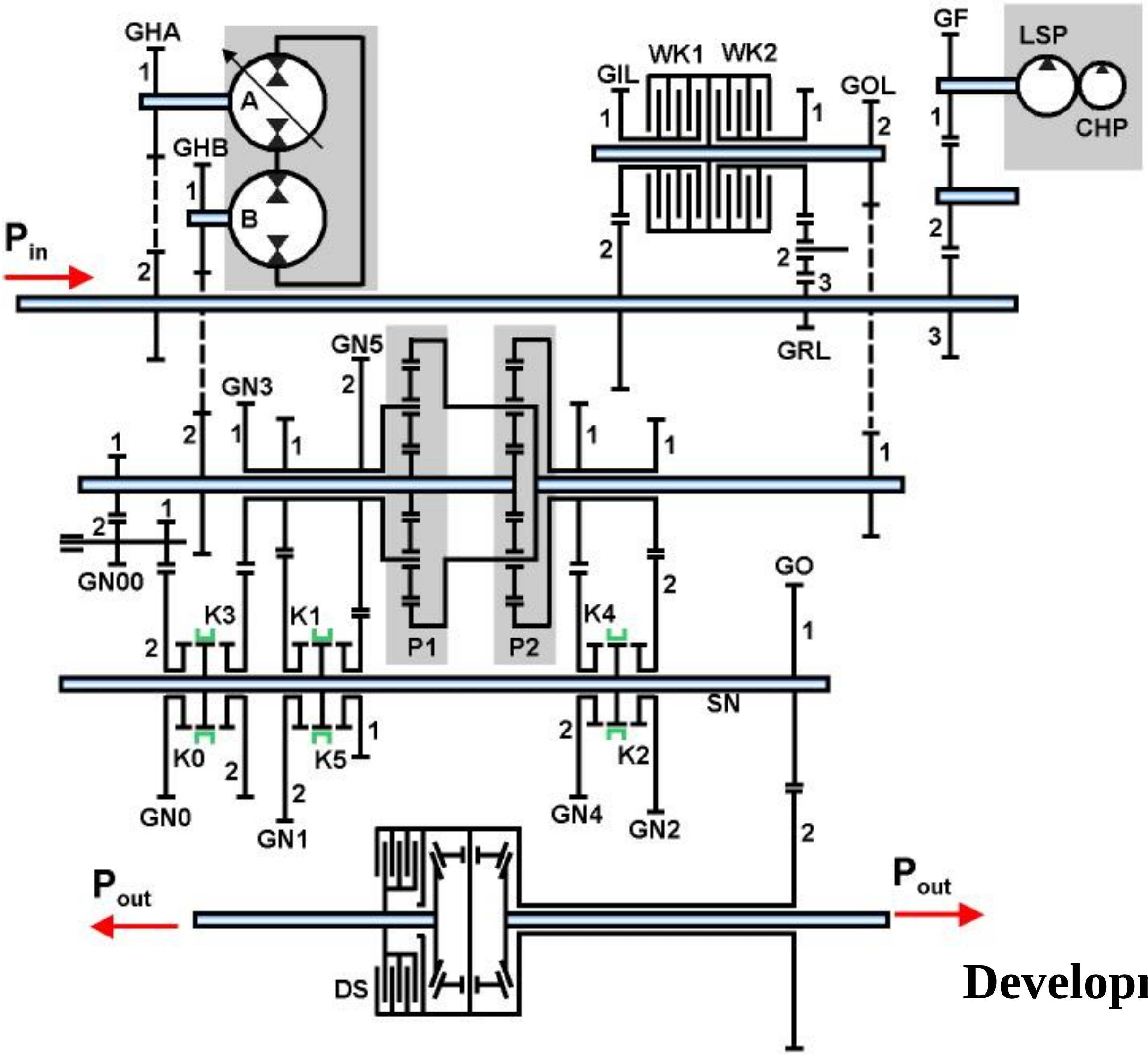
Pump & Motor

$Q_S = f(Vi, n, \Delta p)_{\nu = const.}$

$M_S = f(Vi, n, \Delta p)_{\nu = const.}$

Power Split Drive

System Example



Development by Claas