Wheel Power Management for AWD Vehicle Dynamics and Performance Optimization

Vehicle Dynamics Expo Open Forum

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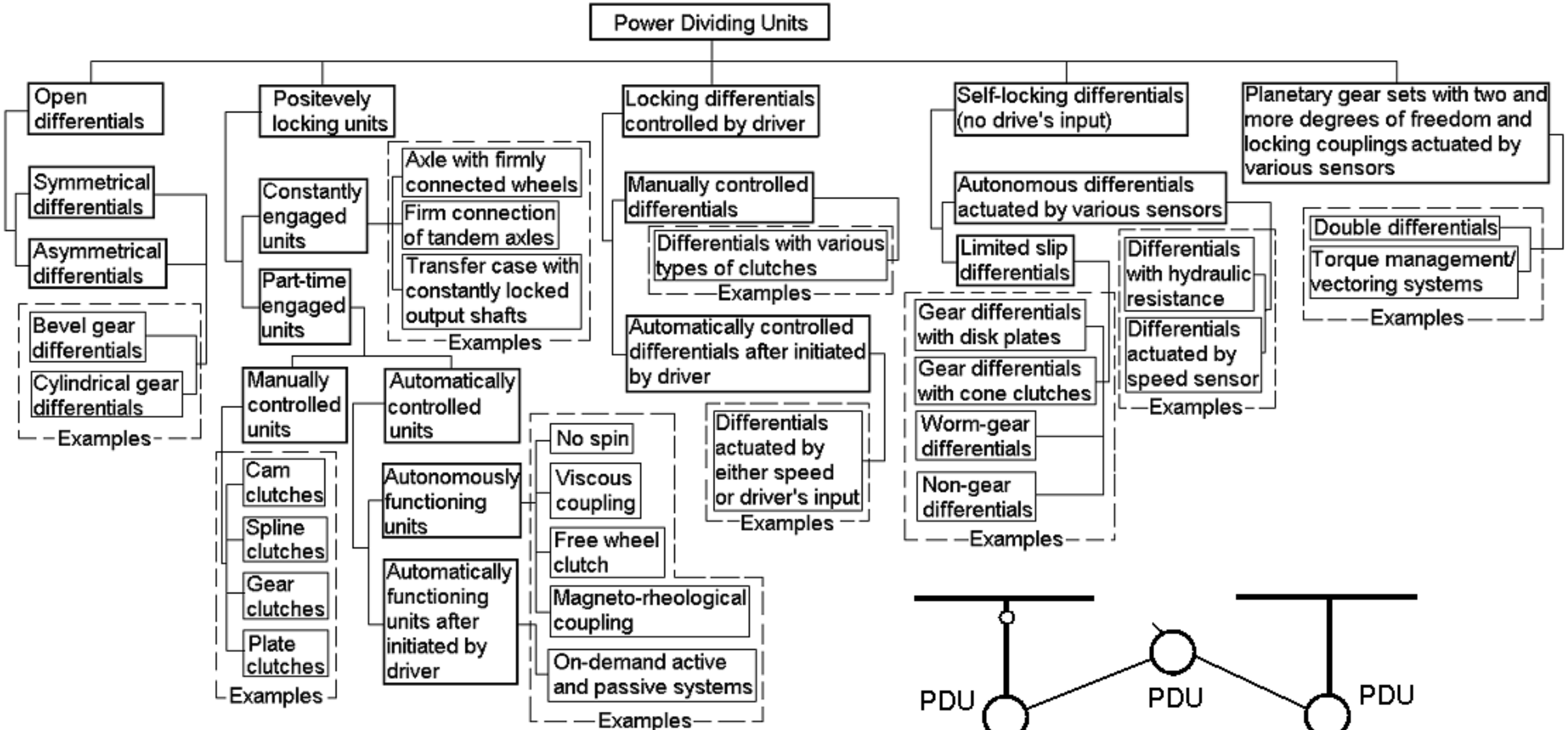
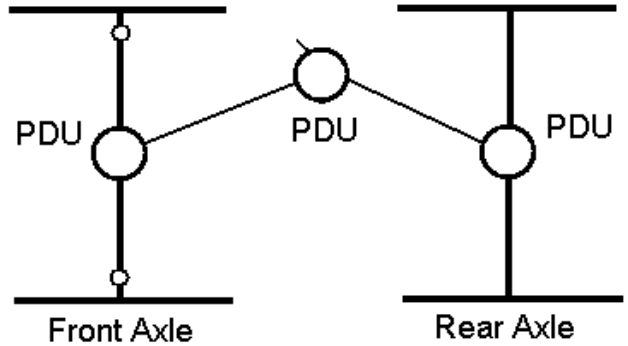
Vladimir V. Vantsevich, D.Sc., Professor
Director, M.Sc. in Mechatronic Systems Engineering Program
Associate Director, Automotive Engineering Institute
Lawrence Technological University,
Michigan, U.S.A.
vvantsevi@ltu.edu

OUTLINE

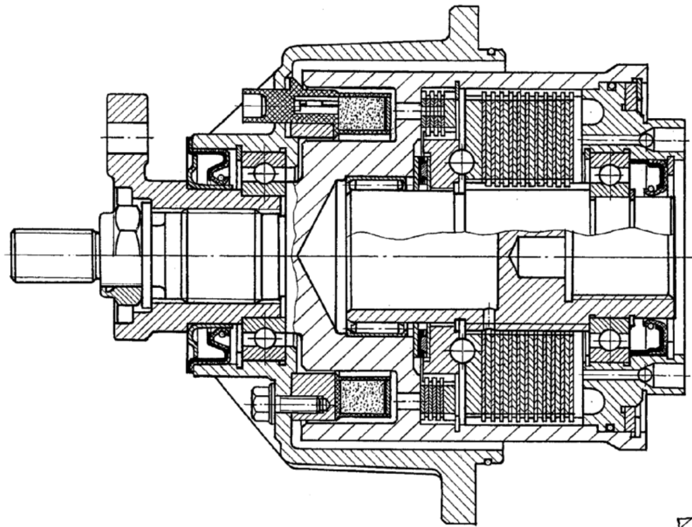
- Wheel Power Management Systems
- Tire Power Balance and Efficiency
- AWD Vehicle Power Balance and Energy/Fuel Efficiency
- Vehicle Lateral Dynamics and Wheel Power Distribution
- Vehicle Set up for Tire Power Balance Research
- AWD Vehicle Chassis Dynamometer with Individual Roll Control
- Conclusion

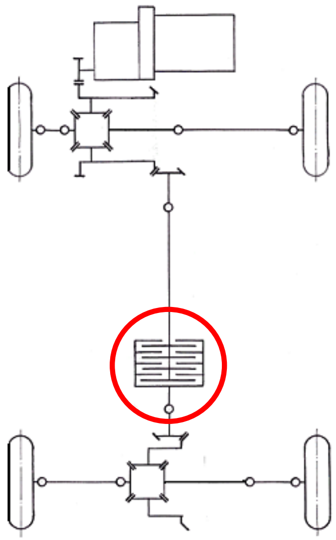
WHEEL POWER MANAGEMENT SYSTEMS

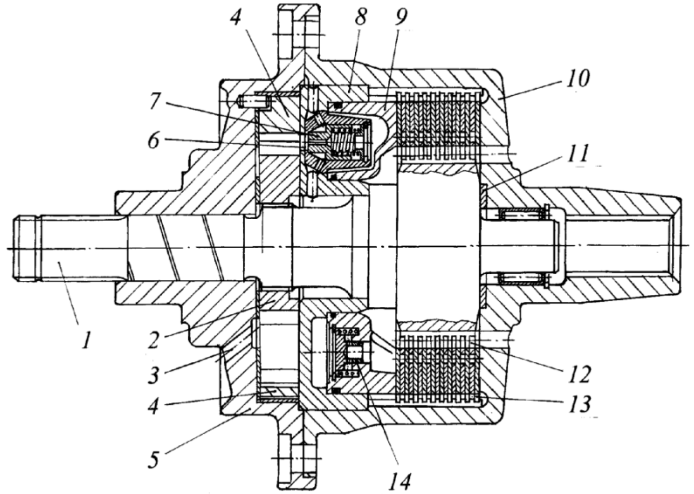


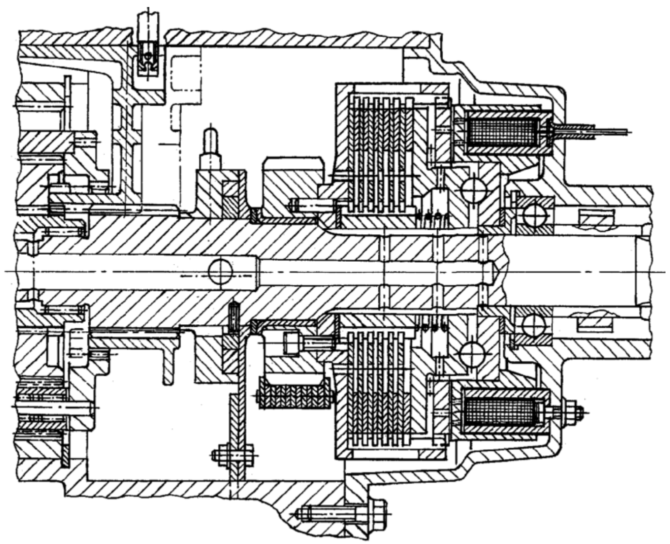


WHEEL POWER MANAGEMENT SYSTEMS



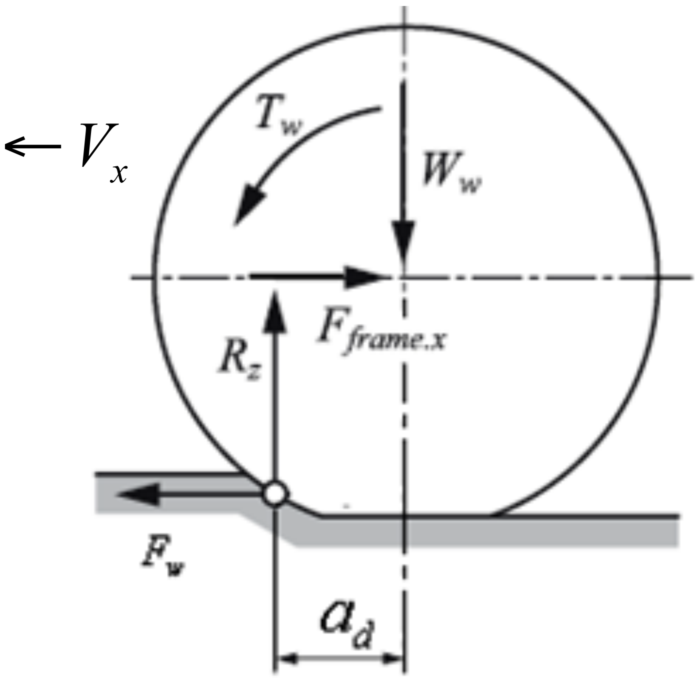






TIRE POWER BALANCE

Output Power ← Power Losses ← Input Power

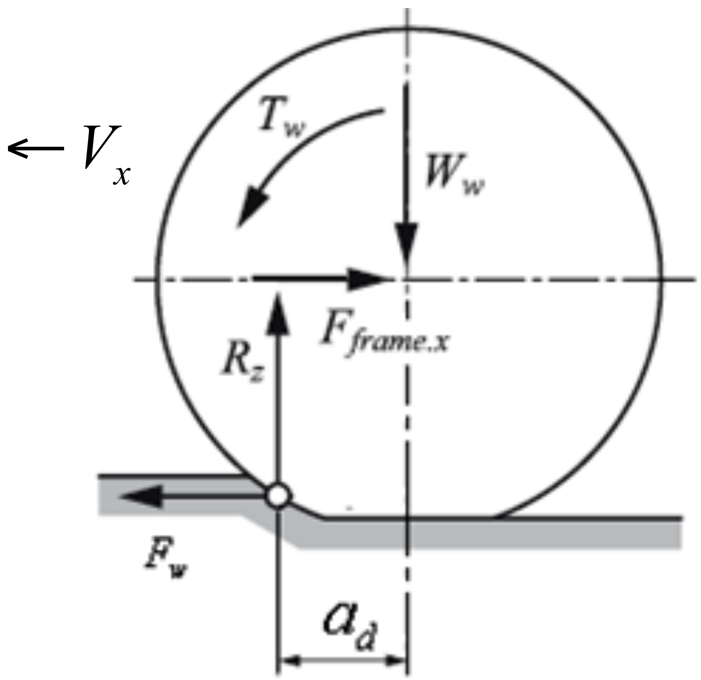


Steady motion

- <u>Input Power</u> comes from driveline system
- <u>Output Power</u> goes to vehicle chassis
- <u>Power Losses</u> occur due to tire/soil deflections

TIRE POWER BALANCE

Output Power ← Power Losses ← Input Power



Input Power comes from driveline system:

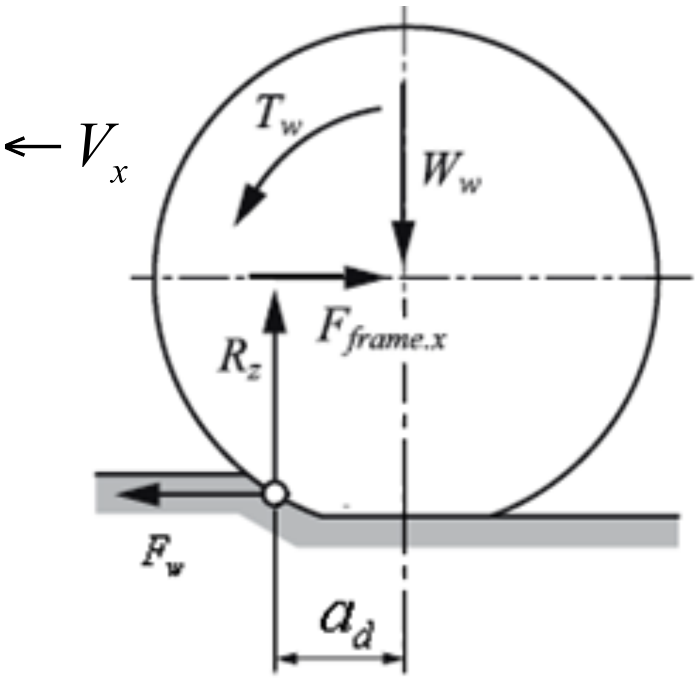
$$P_w^{in} = T_w \omega_w$$

Output Power goes to vehicle chassis:

$$P_w^{out} = F_{frame.x} V_x = F_w V_x = F_w \omega_w r_w$$

TIRE POWER BALANCE

Output Power ← Power Losses ← Input Power

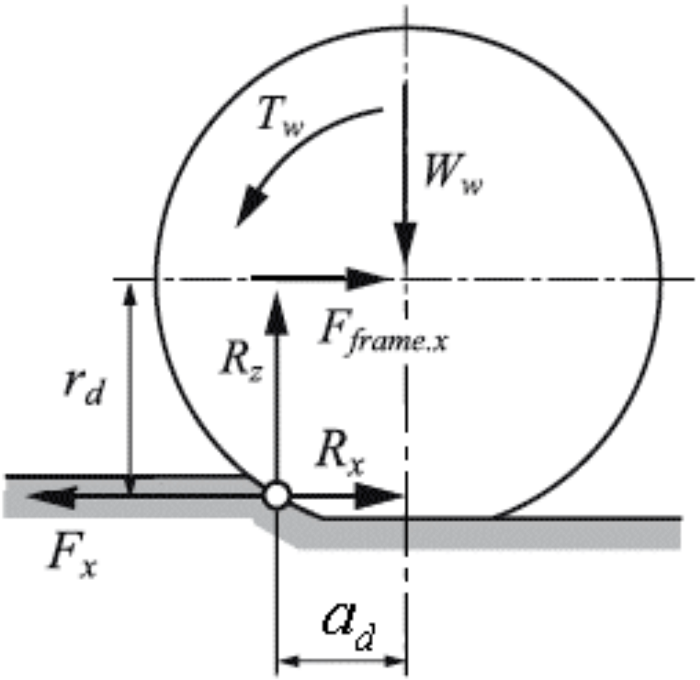


Power Losses due to tire and soil deflections:

- Normal Deflections
- Longitudinal Deflections

TIRE POWER BALANCE

Output Power ← **Power Losses** ← Input Power



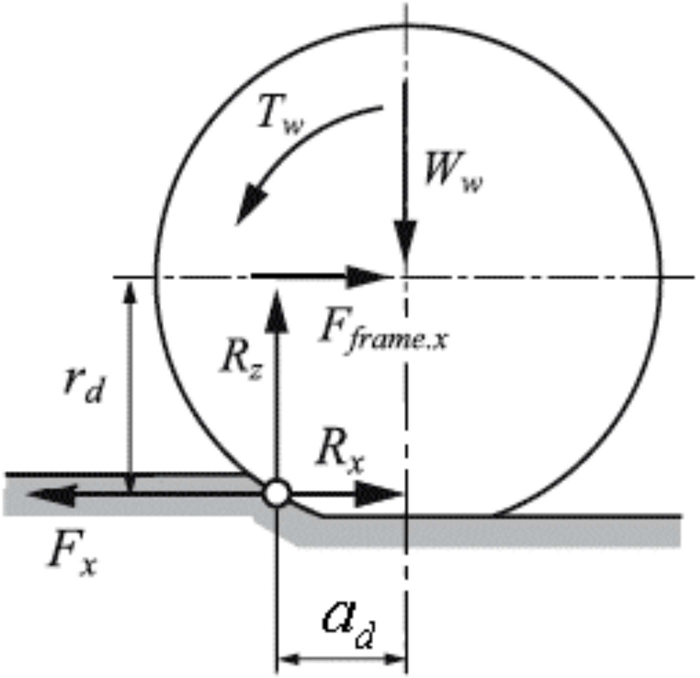
Normal Deflections

Rolling Resistance Power Loss

$$P_f = R_x V_x = R_z f V_x$$

TIRE POWER BALANCE

Output Power ← Power Losses ← Input Power



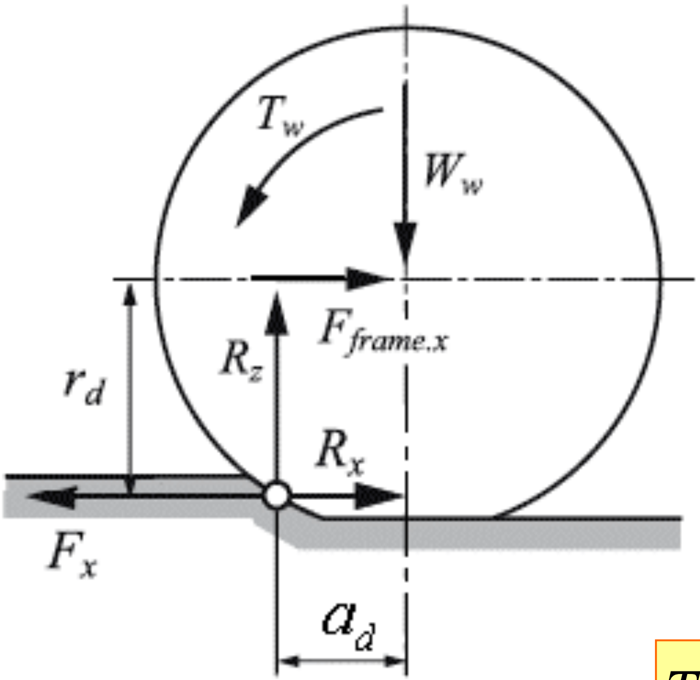
Longitudinal Deflections

Slip Power Loss

$$P_\delta = F_x V_\delta = F_x (V_t - V_x)$$
$$= F_x \omega_w (r_w^0 - r_w)$$

TIRE POWER BALANCE

Output Power ← Power Losses ← Input Power



- Input Power comes from driveline system
- Rolling Resistance Power Loss occurs
- Slip Power Loss occurs
- Output Power goes to vehicle chassis

$$P_w^{in} = P_f + P_\delta + P_w^{out}$$

$$T_w\omega_w = R_x\omega_w r_w + F_x\omega_w\left(r_w^0 - r_w\right) + F_w\omega_w r_w$$

TIRE ENERGY EFFICIENCY

Driving Mode

$$P_w^{in} = P_f + P_\delta + P_w^{out}$$

- Tractive Energy Efficiency

$$\eta_w^t = \frac{P_w^{out}}{P_w^{in}} = \frac{F_w V_x}{F_x V_t} = \frac{F_w}{F_x}\frac{V_x}{V_t} = \eta_{fw}\eta_{\delta w}$$

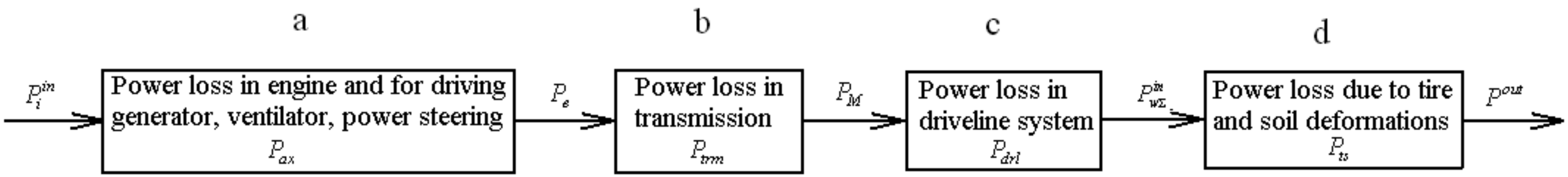
- Rolling Resistance Efficiency

$$\eta_{fw} = \frac{F_w}{F_x} = \frac{F_x - R_x}{F_x} = 1 - \frac{R_x}{F_x}$$

- Slip Efficiency

$$\eta_{\delta w} = \frac{V_x}{V_t} = \frac{V_t - V_\delta}{V_t} = 1 - \frac{V_\delta}{V_t} = 1 - s_\delta$$

POWER BALANCE OF VEHICLE



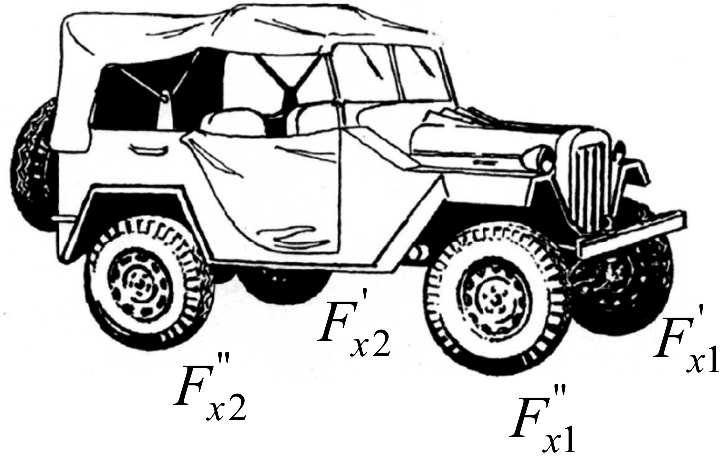
$$P_i^{in} = P_{ax} + P_{trm} + P_{drl} + P_{ts} + P^{out}$$

Tire power management is associated with

$$P_{ts} = P_{f\Sigma} + P_{\delta\Sigma}$$

VEHICLE SLIP EFFICIENCY

$$\eta_\delta = \frac{P_{w\Sigma}^{in} - P_{\delta\Sigma}}{P_{w\Sigma}^{in}} = 1 - \frac{P_{\delta\Sigma}}{P_{w\Sigma}^{in}}$$



$$P_{w\Sigma}^{in} = \sum_{i=1}^{2} P_{wi}^{in\,'('')} = \sum_{i=1}^{2} F_{xi}^{'('')} V_{ti}^{'('')}$$

$$P_{\delta\Sigma} = \sum_{i=1}^{2} P_{\delta i}^{'('')} = \sum_{i=1}^{2} F_{xi}^{'('')} V_{ti}^{'('')} s_{\delta i}^{'('')}$$

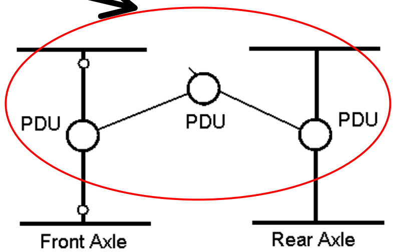
Substituting $V_{ti}^{'('')} = V_x / (1 - s_{\delta i}^{'('')})$ into the above formulas, we obtain…

VEHICLE SLIP EFFICIENCY

$$\eta_\delta = \frac{F_{x\Sigma}}{F_{x\Sigma} + \sum_{i=1}^{2}\left(F'_{xi}s'_{\delta i}/(1-s'_{\delta i}) + F''_{xi}s''_{\delta i}/(1-s''_{\delta i})\right)}$$

here, the total circumferential force is

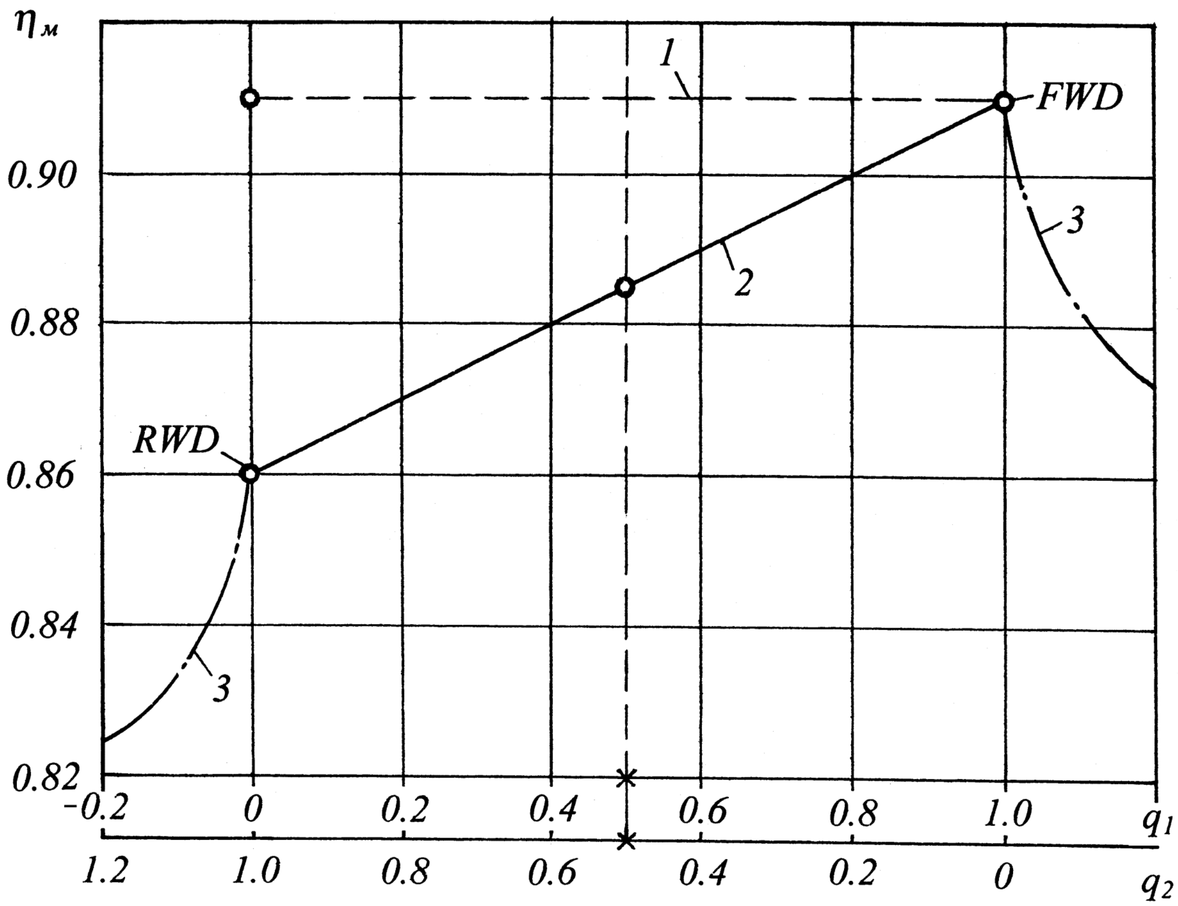
$$F_{x\Sigma} = \sum_{i=1}^{2}(F'_{xi} + F''_{xi}) = \sum_{i=1}^{2} R'^{('')}_{xi} + \sum_{j=1}^{sum} F_j$$

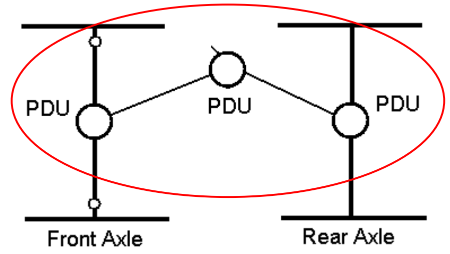


Conclusion:

Slip efficiency of multi-wheel drive vehicles depends on
(i) both the total circumferential force and
(ii) its distribution among the drive wheels

MECHANICAL POWER LOSSES IN POWER MANAGEMENT SYSTEM





$$\eta_M = \frac{1}{\sum_{i=1}^{p_1} \frac{q_i}{\eta_{Mi}^{pos}} + \sum_{i=1}^{p_2} q_i \eta_{Mi}^{neg}}$$

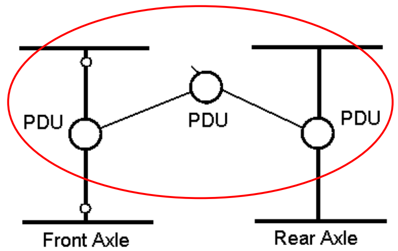
$$q_i = \frac{P_{wi}^{in}}{P_{w\Sigma}^{in}} = \frac{P_{wi}^{in}}{\sum_{i=1}^{n} P_{wi}^{in}}$$

,

VEHICLE FUEL EFFICIENCY

$$Q_s = \frac{Q_h}{V_x} = \frac{g_e P_e}{V_x} \quad gram/km$$

$$P_e = P_{trm} + P_{drl} + P_{\delta\Sigma} + P_{f\Sigma} + P^{out}$$



$$P_{drl} = P^{in}_{w\Sigma}(1-\eta_M)/\eta_M$$

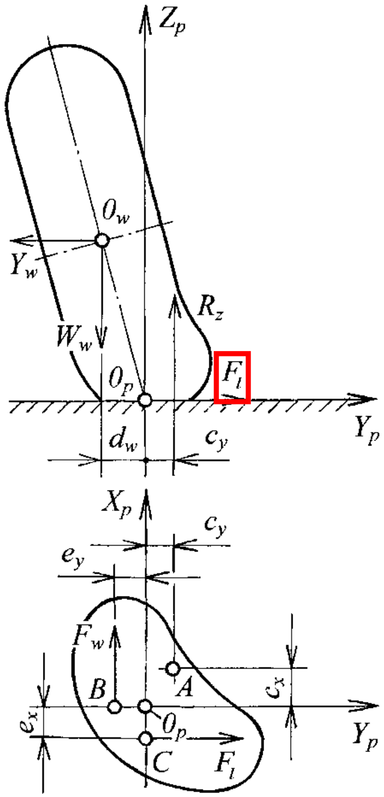
$$P_{\delta\Sigma} = P^{in}_{w\Sigma}\left(1-\eta_\delta\right)$$

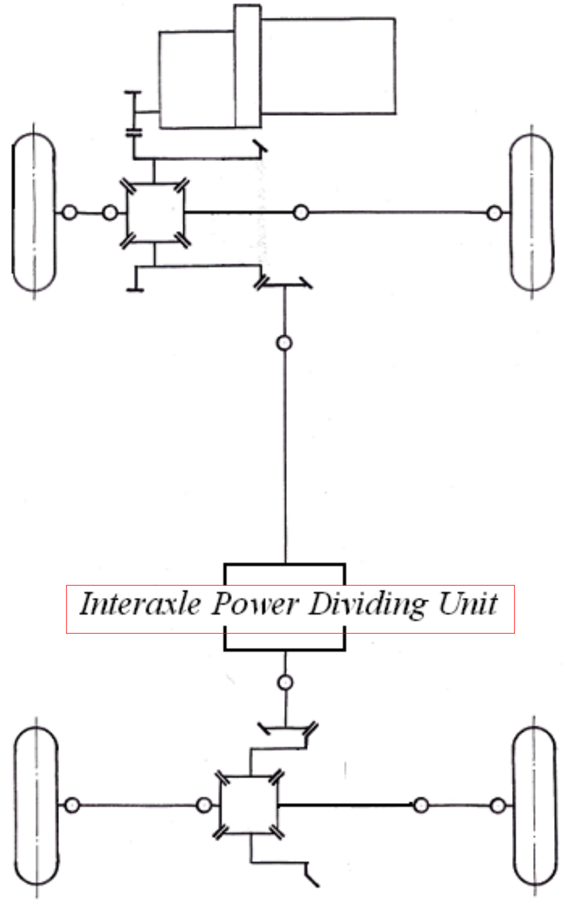
$$P^{in}_{w\Sigma} = \sum_{i=1}^{n} T^{'(")}_{wi}\omega^{'(")}_{wi} = \sum_{i=1}^{n} F^{'(")}_{xi}V^{'(")}_{ti}$$

$$Q_s = \frac{g_e}{V_x}\left[P_{trm} + \sum_{i=1}^{n} T^{'(")}_{wi}\omega^{'(")}_{wi}(1-\eta_M)/\eta_M + \sum_{i=1}^{n} T^{'(")}_{wi}\omega^{'(")}_{i}\left(1-\eta_\delta\right) + P_{f\Sigma} + P^{out}\right]$$

VEHICLE LATERAL DYNAMICS

$$F_l = F_l^{inertia} + F_l^{drawbar} + F_l^{suspension} + F_l^{w} + F_l^{a}$$

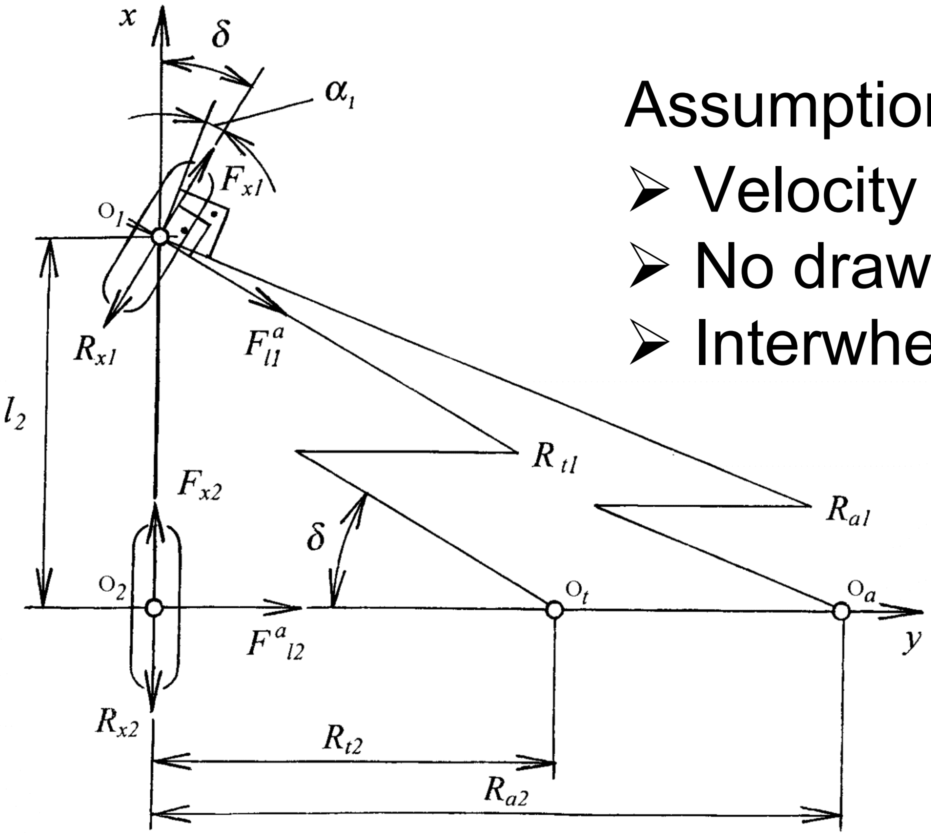




VEHICLE LATERAL DYNAMICS

$$F_l = F_l^{inertia} + F_l^{drawbar} + F_l^{suspension} + F_l^{w} + F_l^{a}$$

Interaxle PDU



Assumptions:

- Velocity is small (no inertia forces)
- No draw bar pull
- Interwheel differentials are open

$$\Sigma M_{01} = 0 \qquad \Sigma M_{02} = 0$$

$$F_{l2}^a = 0$$

$$F_{l1}^a = (R_{x1} - F_{x1}) \tan \delta$$

VEHICLE LATERAL DYNAMICS

Analyze Results

➢ Interaxle PDUs do not make any impact on the rear tire lateral force and rear tire side-slip angle:

$$F_{l2}^{a} = 0$$

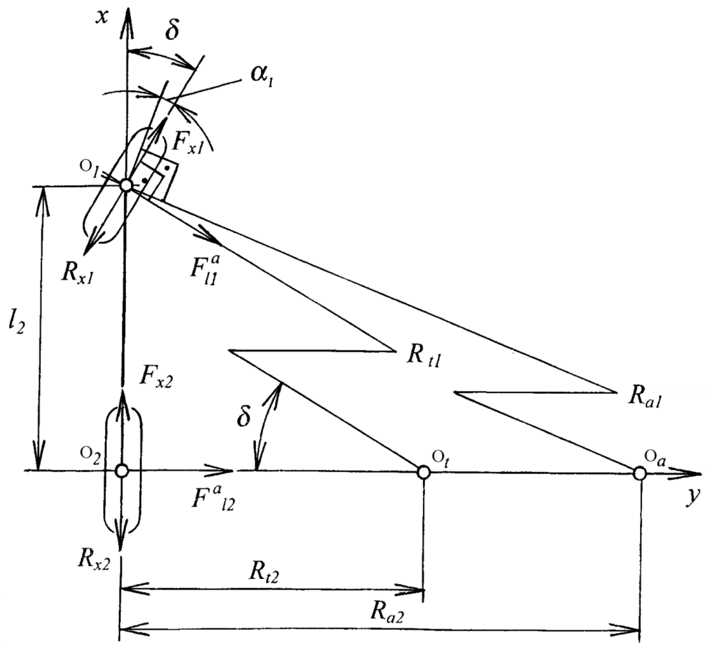
➢ Interaxle PDUs do make an impact on the front tire lateral force and front tire side-slip angle:

$$F_{l1}^{a} = (R_{x1} - F_{x1}) \tan \delta$$

➢ By changing the front tire circumferential force F_{x1} , interaxle PDUs impact both the magnitude and direction (sense) of force F_{l1}^{a}

VEHICLE LATERAL DYNAMICS

$$F_{l1}^{a} = (R_{x1} - F_{x1}) \tan \delta$$



1. When $F_{x1} = R_{x1}$, the front lateral force is zero. No impact on vehicle turnability.

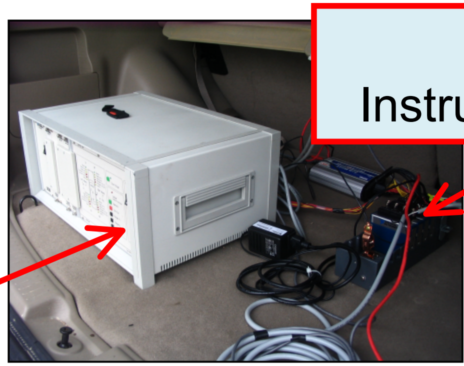
2. When $0 < F_{x1} < R_{x1}$, the front lateral force contributes understeering.

3. When $F_{x1} < 0$, the front lateral force dramatically increases. This results in increased understeering.

4. When $F_{x1} > R_{x1}$, the front lateral force changes its direction and contributes oversteering. This results in $R_a < R_t$.

VEHICLE SET UP FOR TIRE POWER BALANCE RESEARCH

$$P_w^{in} = P_f + P_\delta + P_w^{out}$$

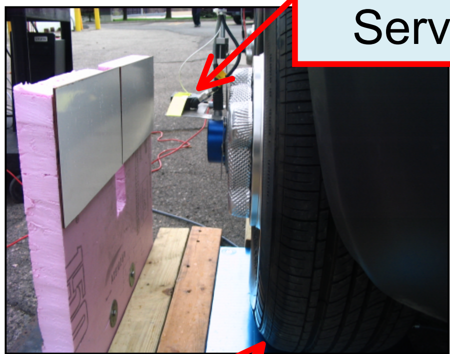


National Instruments cRIO-9104

Computer Control Unit

Kistler Instrument Piezoelectric Wheel Transducers and Control Unit

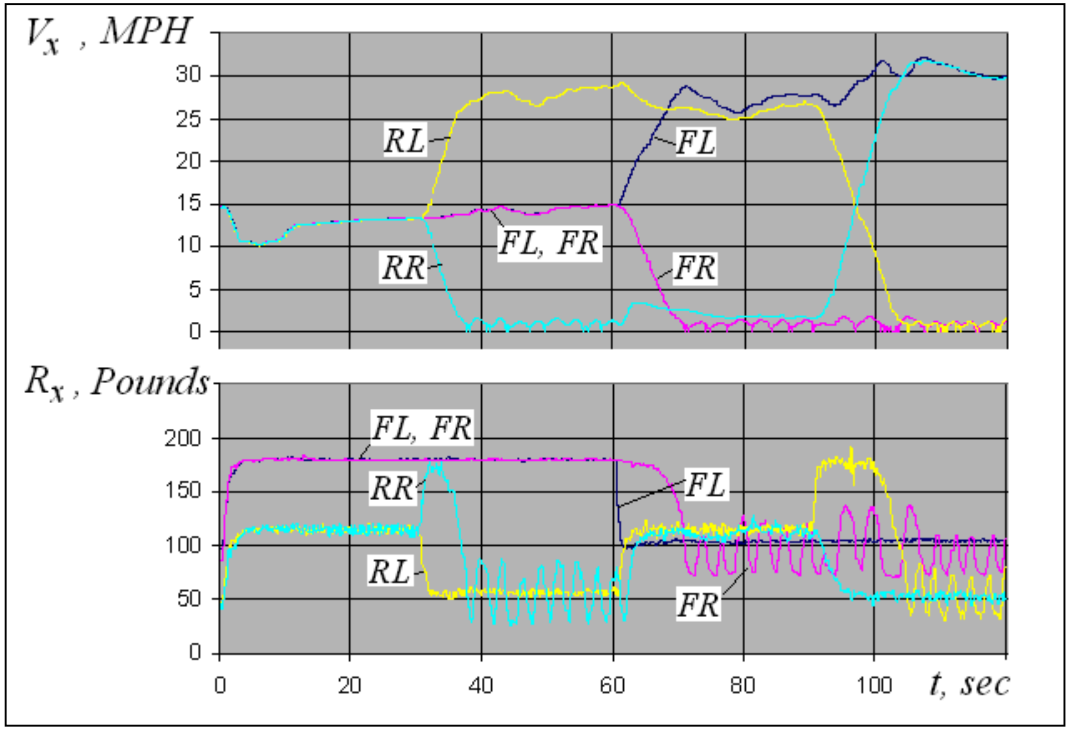
Stress Analysis Services Laser



Kistler Instrument Sensor Plate and BioWare Software

George Thomas
Jesse Paldan
Gerald Murphy
Mark Schmidt

AWD VEHICLE CHASSIS DYNAMOMETER WITH INDIVIDUAL ROLL CONTROL

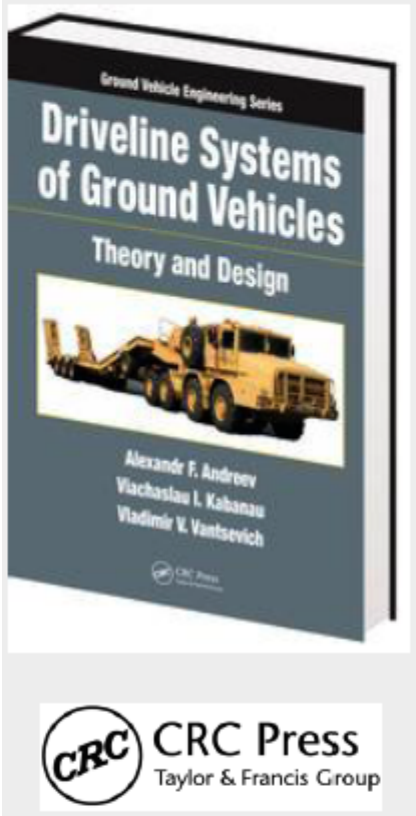


CONCLUSION

1. Wheel power management systems influence AWD vehicle dynamics and fuel consumption by impacting
   - Tire slip power and mechanical power losses which depend on power distribution between the driving wheels
   - Front tire lateral forces which depend on power distribution between the drive axles

2. Analytical methods were presented for mechanical and slip power losses and lateral forces evaluation in AWD vehicles

3. Vehicle set up and AWD chassis dynamometer were developed for experimental research of wheel power distributions and wheel power management systems



THANK YOU

Vladimir V. Vantsevich
vvantsevich@ltu.edu

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Founding Director of the Master of Science in Mechatronic Systems Engineering Program & Founding Associate Director of the Automotive Engineering Institute, Lawrence Technological University, Southfield, Michigan, USA
Email: Vantsevich@LTU.edu

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