

Thermal imaging on the force transmission of tires on winter tracks under laboratory conditions.

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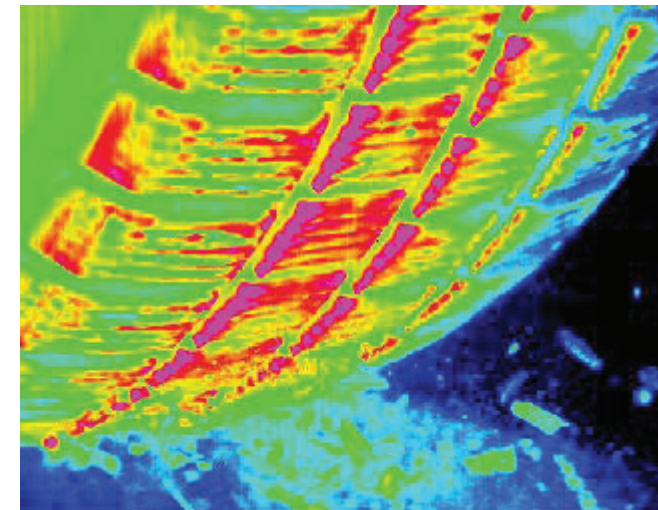
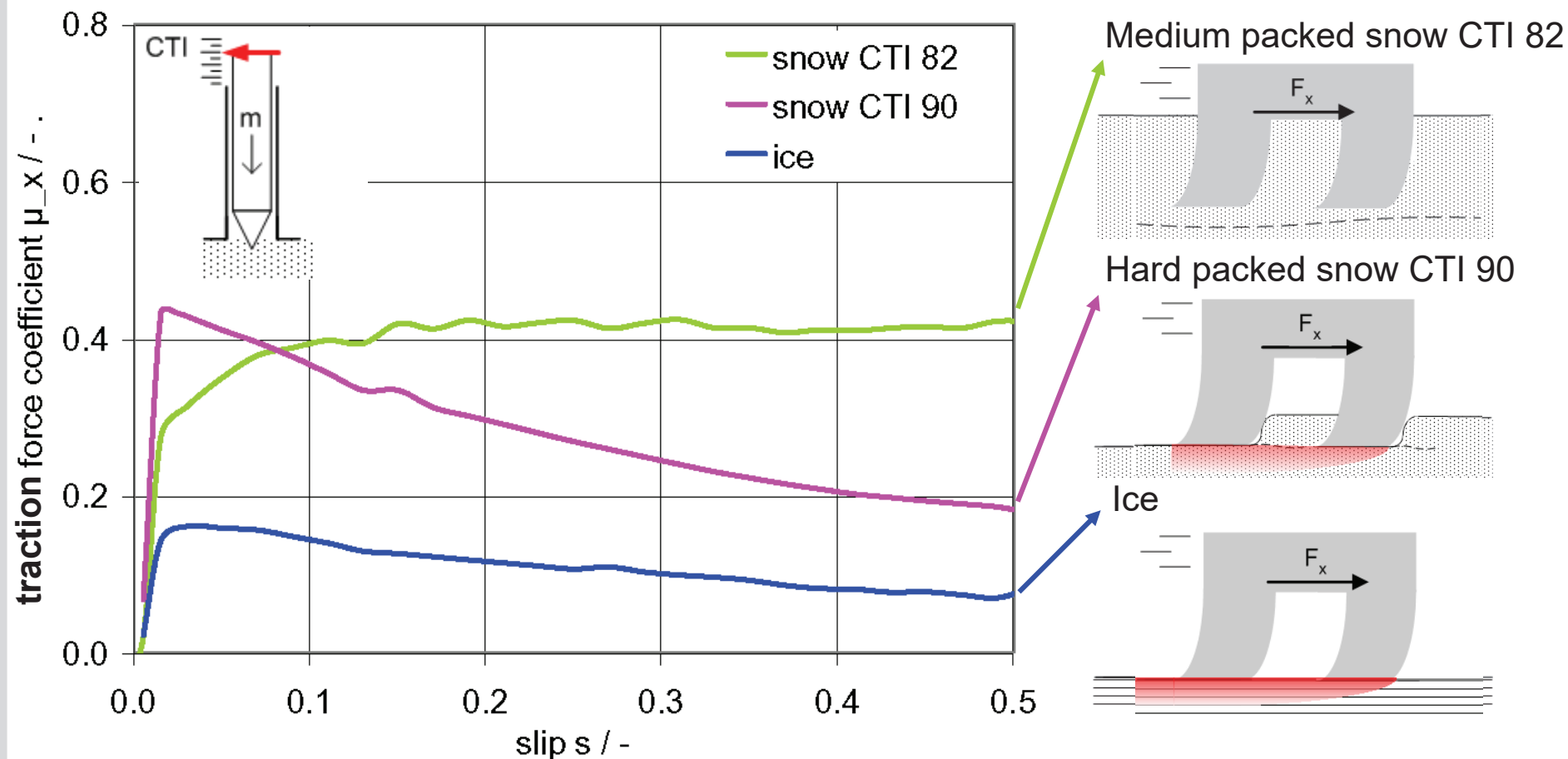


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Motivation

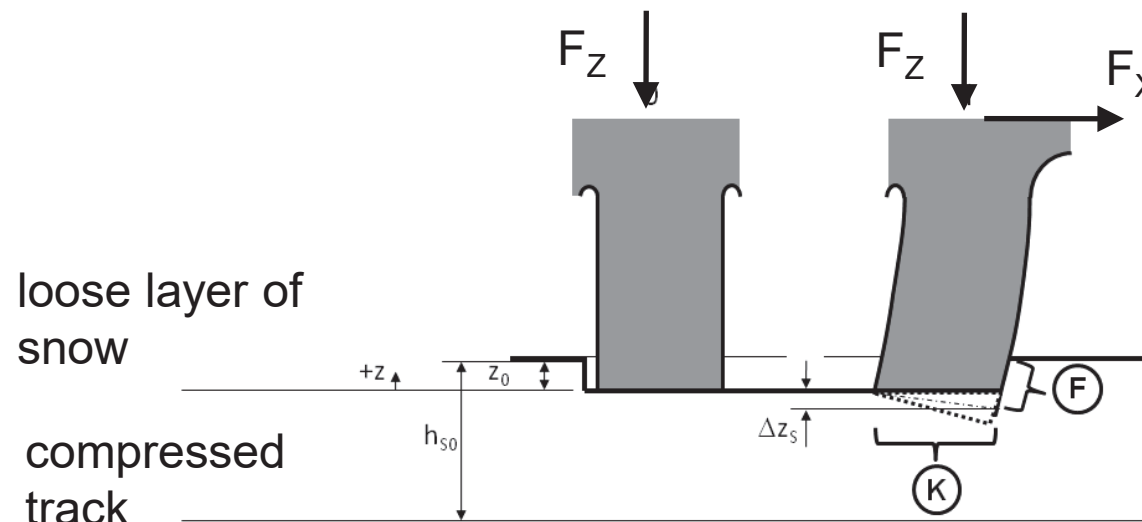


On tracks with low hardness, high traction forces can be transmitted under high slip. Distinctive force maximum on hard packed snow and ice.

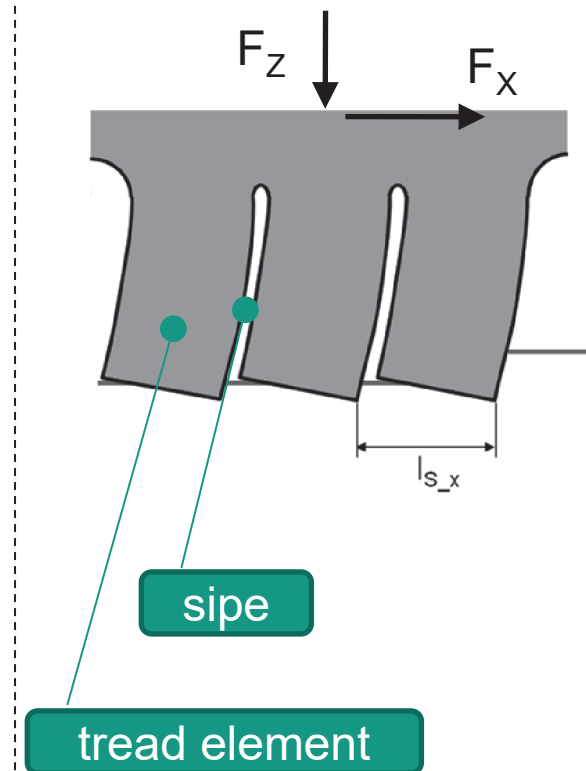
Theory

Force transmission at a tread element

Phases of Deformation



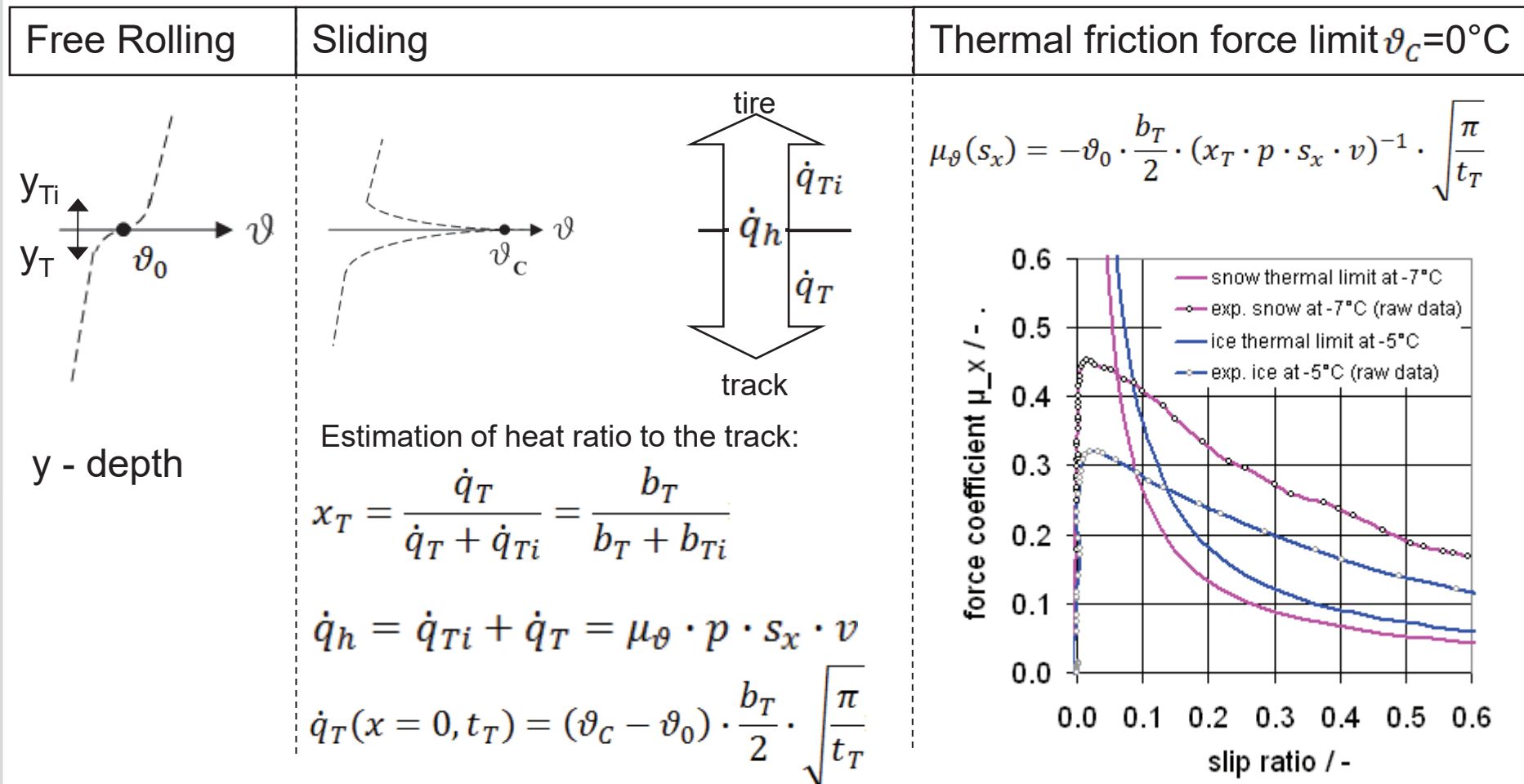
Form Closure



Tangential forces are transmitted via active surfaces of form closure (F) and friction (K). Both depend on the stiffness of track and tire and the resulting deformation.

Theory

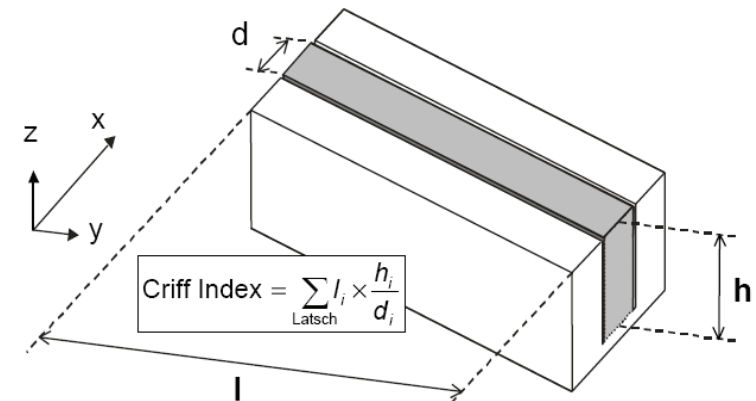
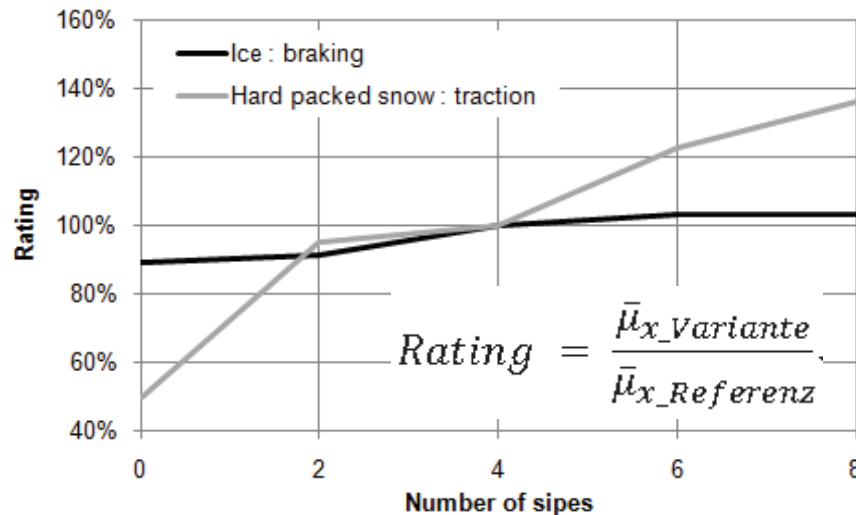
Thermal friction force limit



Contact temperature of 0°C reduces transmittable friction forces. Estimation of heat ratio to the track leads to the thermal friction force limit. Measured maximum of tangential forces is close to the thermal friction force limit.

Experiment Tested tires

Sipe influence on transmittable tire forces



Definition des CRIFF-Index
nach Strache et. al., VDI Berichte 1912, Düsseldorf 2005.

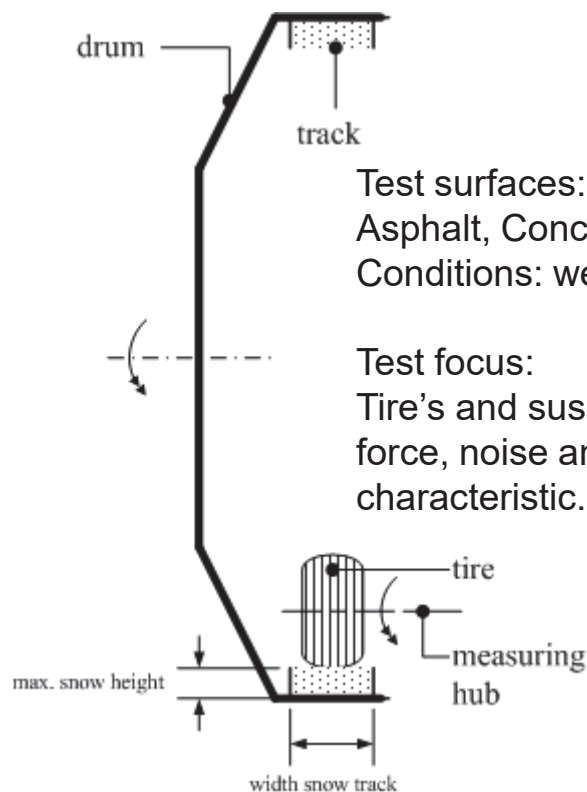
	without Sipes	with 4 Sipes
		
VOID / %	31,8	31,8
CRIFF / 1000	0,22	4,16
Spec. Footprint Stiffness Longitudinal in N/cm³:	21,38	8,39

Results of laboratory tests show, that sipes increase transmittable tangential forces on snow and ice. 2 tires have been picked out for a closer discussion of sipe influence on transmitted mechanical and thermal power.

Experiment

Test equipment

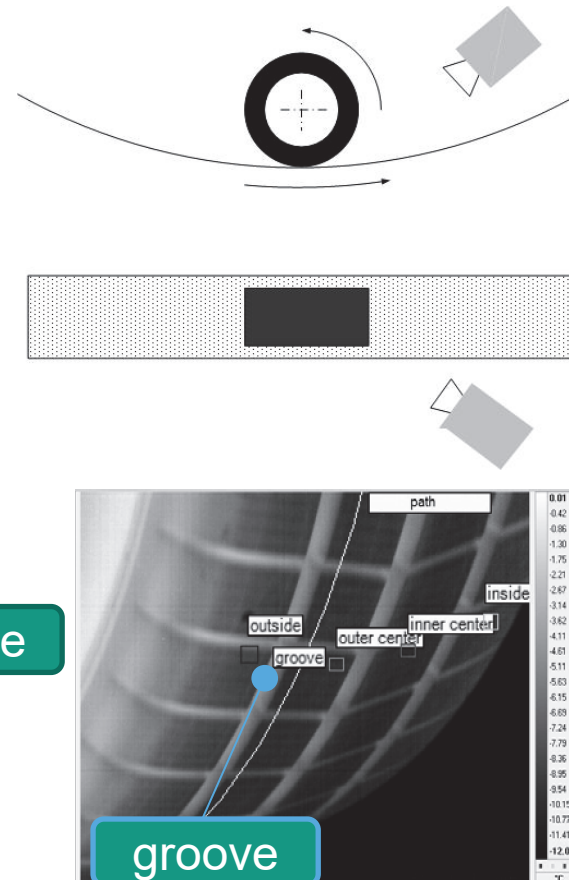
Inner Drum Test Rig



Test surfaces:
Asphalt, Concrete, Safety-Walk
Conditions: wet, icy, snow

Test focus:
Tire's and suspension's
force, noise and live time
characteristic.

High-Speed Thermo Camera



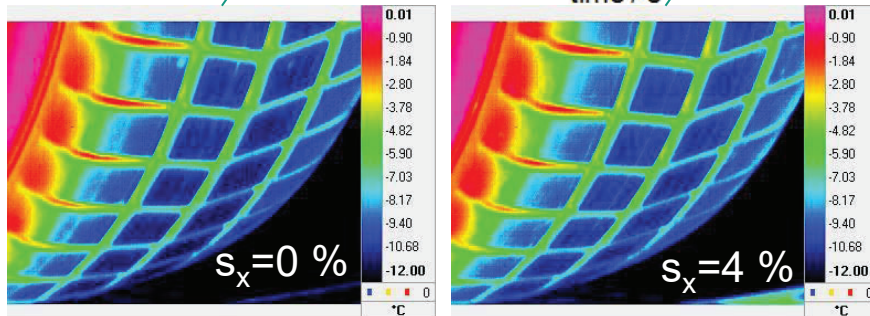
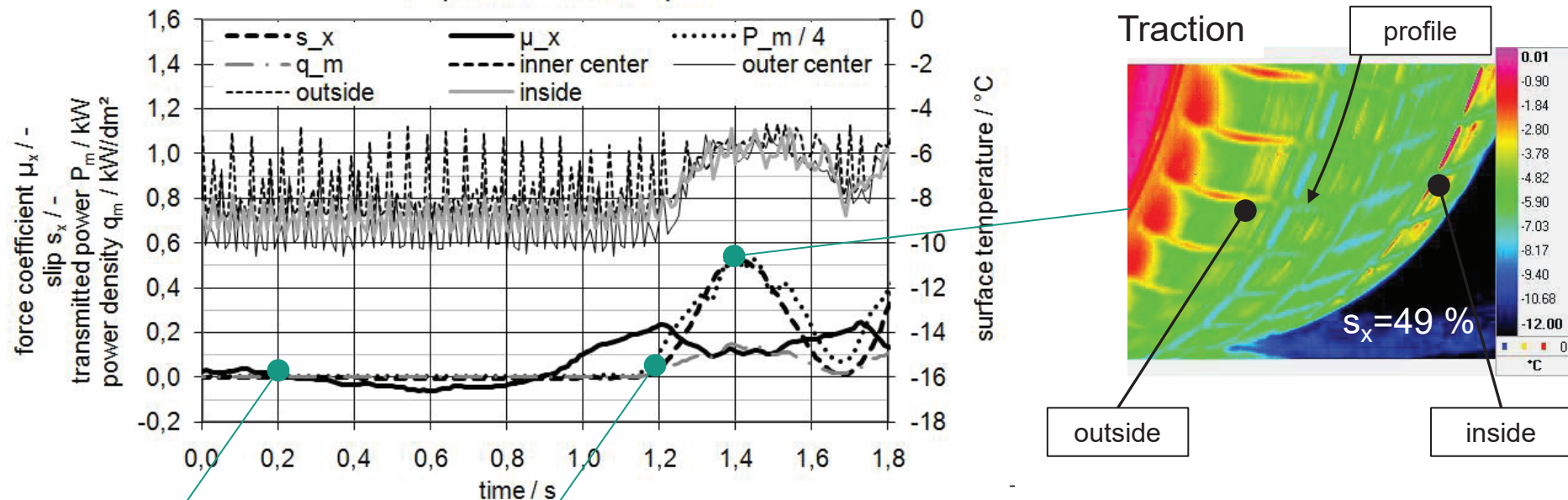
inside

outside

groove

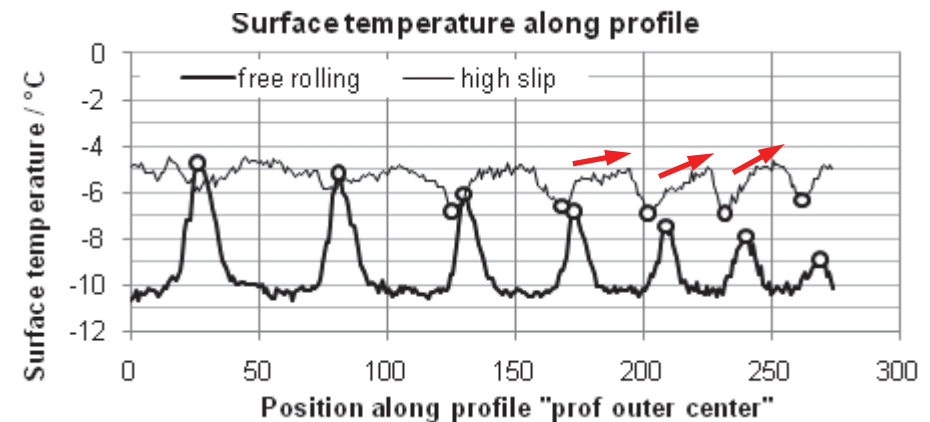
Measurement of tire's force characteristic on snow and ice at the inner drum test rig is combined with the measurement of tire's surface temperature.

Traction of tire without sipes on hard packed snow



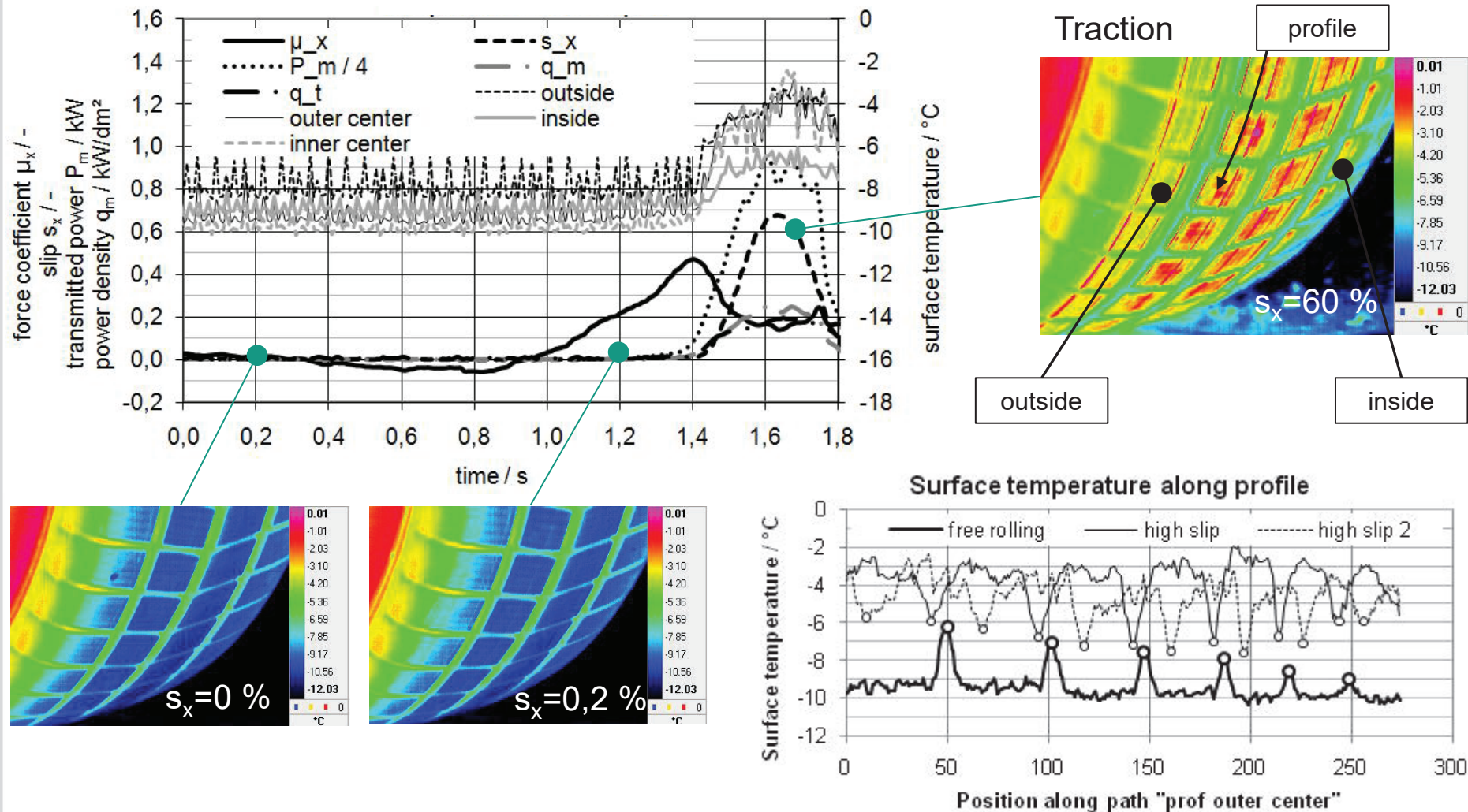
$$P_m = s_x \cdot \mu_x \cdot v \cdot F_Z$$

$$\dot{q}_m = s_x \cdot \mu_x \cdot v \cdot p_i \cdot (1 + VOID)$$



Temperature of groove higher than tire's surface temperature due to rolling resistance. Traction force increases up to it's maximum combined with a low slip increase. Only with the start of sliding the friction heat leads to an increase of surface temperature.

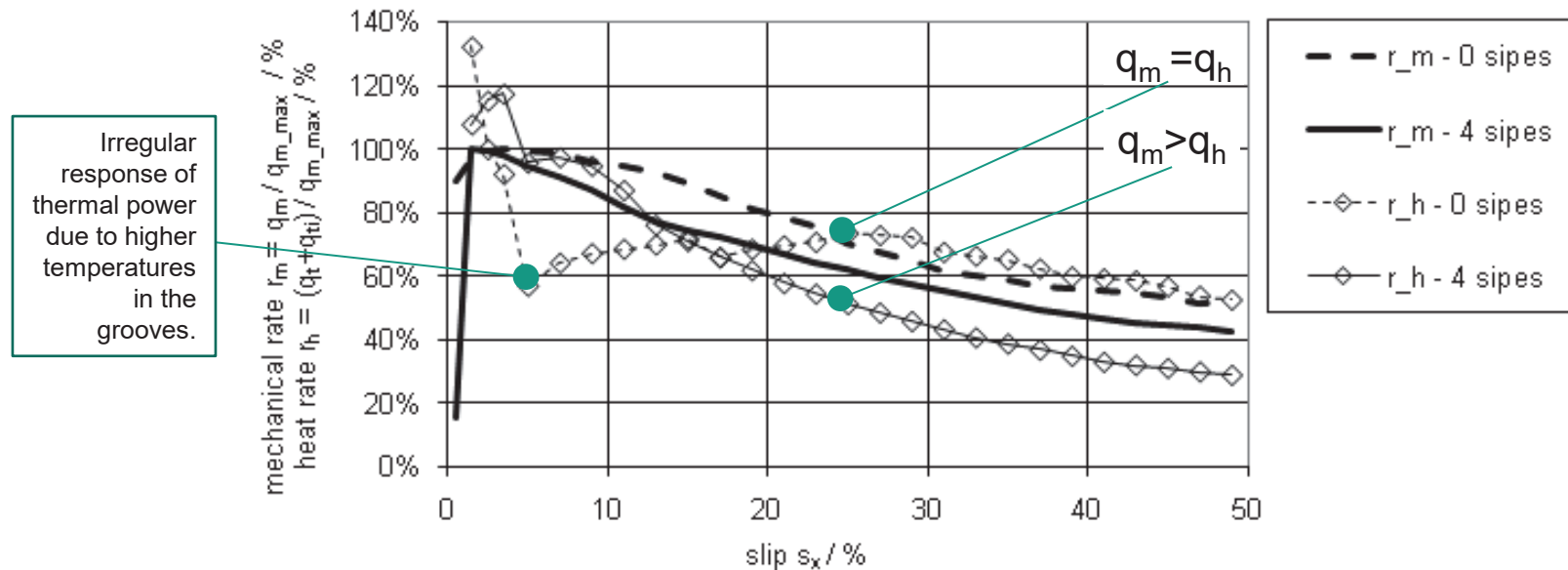
Traction of tire with 4 sipes on hard packed snow



Tire with sipes can transmit higher traction forces on snow. Friction heat of sliding siped tire leads to a higher increase of surface temperature compared to tire without sipes.

Traction of tire with and without sipes on snow

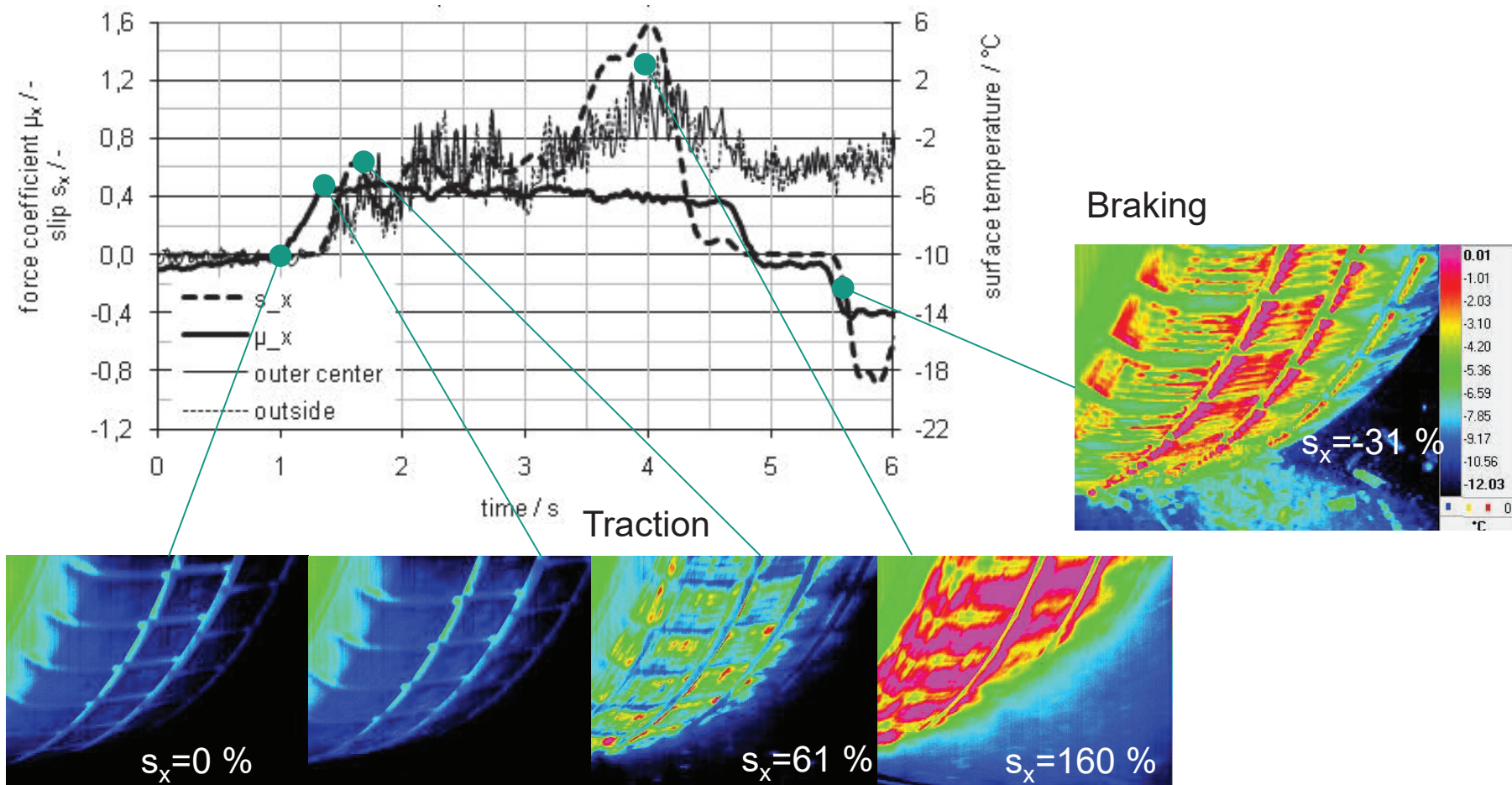
Comparison of transmitted thermal and mechanical rate



	Power density	Rate
Transmitted <u>mech.</u> power density	$\dot{q}_m = s_x \cdot \mu_x \cdot v \cdot p_i \cdot (1 + VOID)$	$r_m = \frac{\dot{q}_m}{\dot{q}_{m_max}} = \frac{\mu_x(s_x)}{\mu_{x_max}}$
Highest transmittable <u>mech.</u> power density	$\dot{q}_{m_max} = s_x \cdot \mu_{x_max} \cdot v \cdot p_i \cdot (1 + VOID)$	
<u>Thermal</u> (~ Friction) power density	$\dot{q}_h = \dot{q}_{Ti} + \dot{q}_T$ $\dot{q}_T(x=0, t_T) = (\vartheta_c - \vartheta_0) \cdot \frac{b_T}{2} \cdot \sqrt{\frac{\pi}{t_T}} \quad t_T = \frac{l_x}{v}$ $\dot{q}_{Ti}(x=0, t_{Ti}) = (\vartheta_c - \vartheta_0) \cdot \frac{b_{Ti}}{2} \cdot \sqrt{\frac{\pi}{t_{Ti}}} \quad t_{Ti} = \frac{l_x}{s_x \cdot v}$	$r_h = \frac{\dot{q}_T + \dot{q}_{Ti}(s_x)}{\dot{q}_{m_max}} = \frac{\dot{q}_h(s_x)}{\dot{q}_{m_max}}$

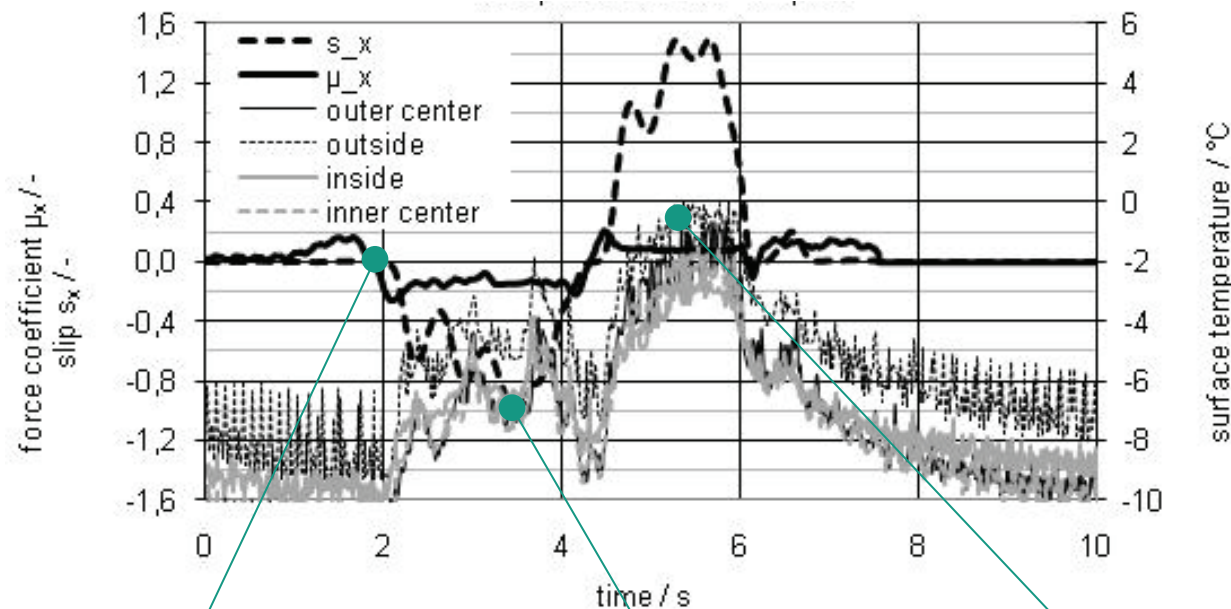
For tire without sipes the mechanical power is transferred almost into friction heat. For tire with sipes a portion of the mechanical power results from sliding resistance due to digging force.

Traction and braking of tire with 4 sipes on medium packed snow



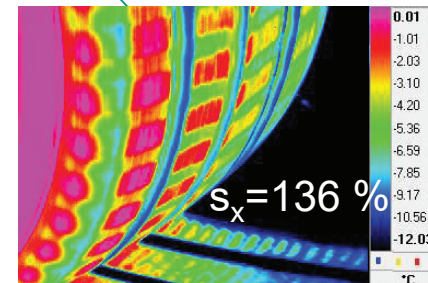
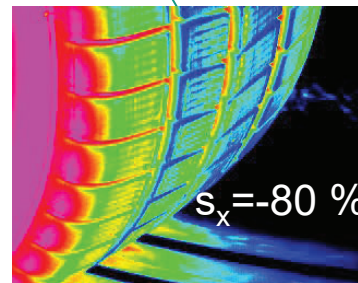
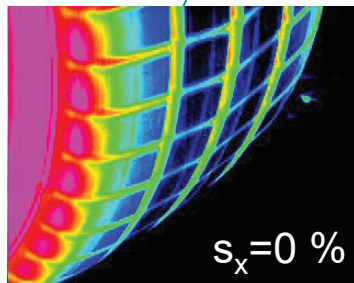
On medium packed snow tire digs into the snow via the active surfaces of form closure. The maximum force coefficient stays at 0,4 even with increasing slip. Surface temperature increase above 0°C does not influence transmitted tangential forces. Reasons: Digging force plays a major role.

Braking and traction of tire with 4 sipes on ice



Braking

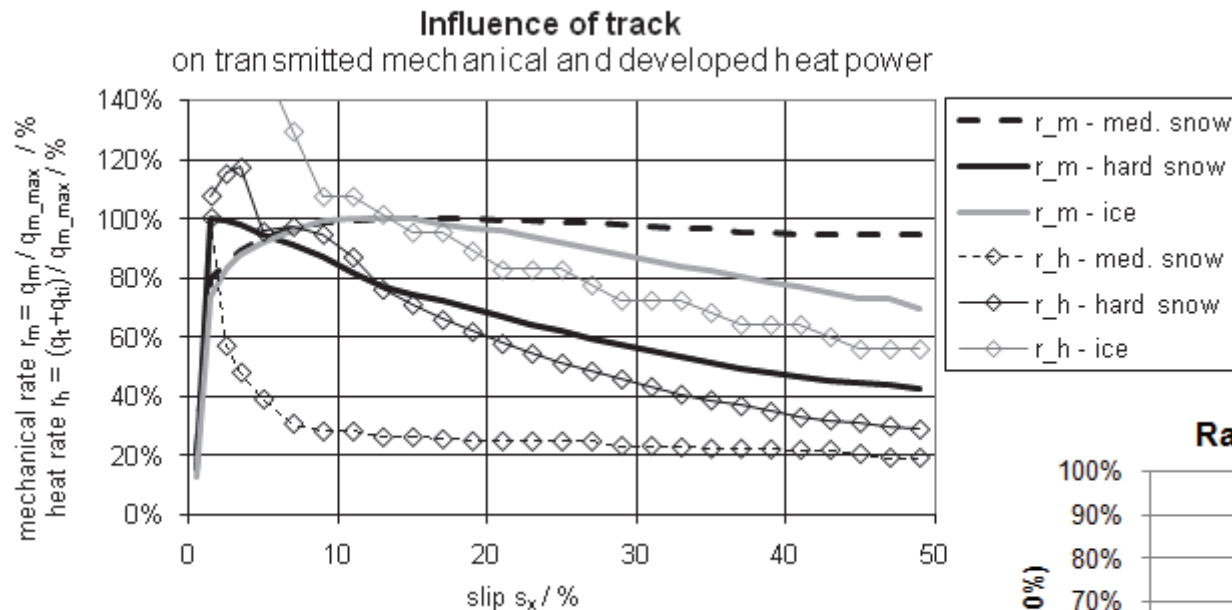
Traction



On ice maximum force coefficient is low. Leading edges of the tread elements cannot dig into the track (ice = high stiffness). When tire slides, force coefficient decreases.

Traction of tire with sipes on snow and ice

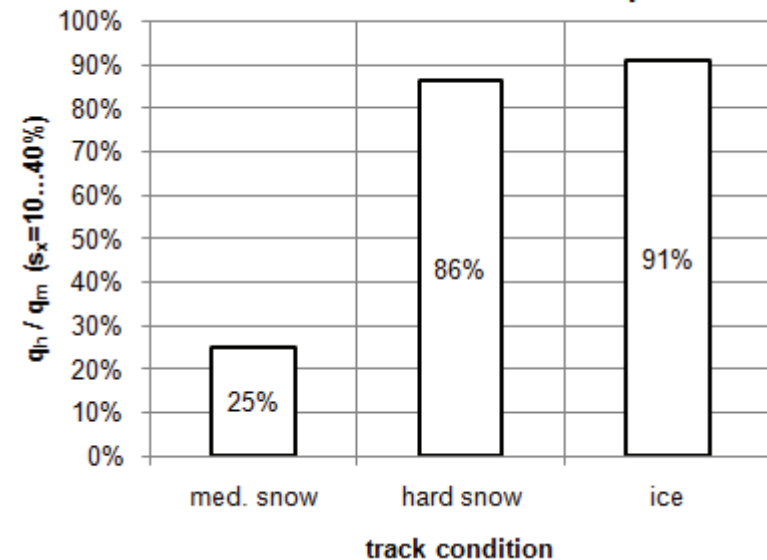
Comparison of transmitted heat and mechanical rate



$$r_m = \frac{\dot{q}_m}{\dot{q}_{m_max}} = \frac{\mu_x(s_x)}{\mu_{x_max}}$$

$$r_h = \frac{\dot{q}_T + \dot{q}_{Ti}(s_x)}{\dot{q}_{m_max}} = \frac{\dot{q}_h(s_x)}{\dot{q}_{m_max}}$$

Rate of friction heat on total power



Rate of friction heat during sliding increases with increase of track stiffness.

Conclusion

- Active surfaces of form closure and friction can be determined at a deformed tread element for snow traction.
- The theoretical limit for thermal friction force is close to measured maximum of tangential forces and is one reason, why tangential forces drop while slip increases.
- Thermo graphical analyses show that main temperature increase occur when tire slides.
- Tires with sipes transmit a higher portion of tangential force via form closure. On medium packed snow tire digs into the snow.
- Rate of friction heat during sliding increases with increase of track stiffness.