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TRACTION DYNAMICS AND FUEL EFFICIENCY OF TRACTORS

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Power Balance of a Tractor and Its Components The overall and conditional traction efficiency of a tractor. Components of the traction efficiency of wheeled and tracked tractors. Constructive and operational factors influencing the efficient use of the engine's effective power. Traction Dynamics of Four-Wheel-Drive Tractors

One of the most effective ways to increase the cross-country ability of wheeled tractors is to make all of their wheels driving.

In this case, the total weight is used as the adhesion weight of the tractor, and the coefficient of weight utilization reaches its maximum value. Compared to 4×2 wheel configurations, the slippage of the driving wheels is significantly reduced.

The traction dynamics of 4×4 wheel-configuration tractors depend on the type of interaxle drive installed on the driving axles.

In tractor engineering, internal-type interaxle drives are used — locked (rigid) and differential types.

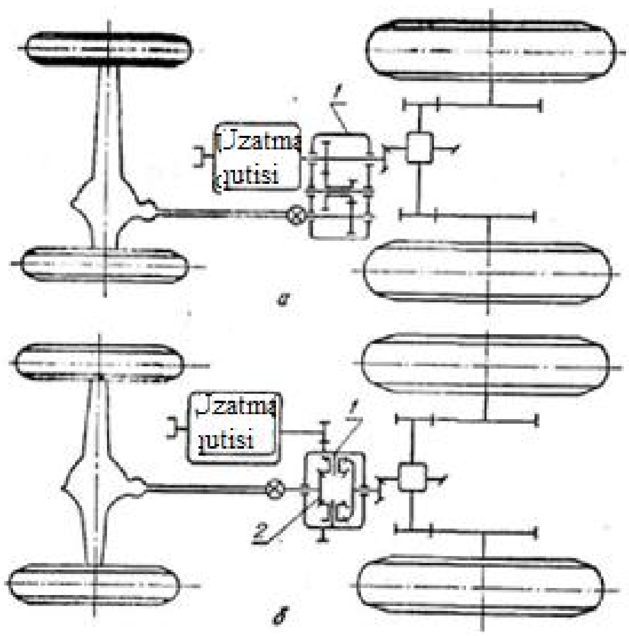

Figure 1. *Schemes of two types of interaxle drives for driving axles:*
(a) locked type; (b) differential type.

In **a** locked-type drive**,** the front and rear axles are rigidly connected kinematically through a transfer case. In a differential-type drive, the axles are connected through an interaxle differential.

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In locked-type drives, due to the uneven rotational speeds of the wheels, part of the power (a few percent) may circulate within the transmission, which reduces the tractor's efficiency and increases tire wear. Differential-type drives, on the other hand, prevent power circulation in the transmission. However, if the wheels on one axle encounter poor adhesion conditions (mud, snow, ice), while the other axle's wheels are on firm ground, the differential effect prevents the tractor from using the available traction fully. As a result, the tractor may stop or slow down.

Locked-type drives are widely used in agricultural tractors with four driving wheels. The kinematic and dynamic characteristics of tractors equipped with both types of interaxle drives are analyzed below.

Locked-Type Drive

Since the front and rear driving wheels are connected, and the tractor moves at the same linear speed while the rotational speeds of the wheels differ, a kinematic mismatch always occurs in the transmission of locked-type drives.

To determine the effect of this mismatch on the kinematics and dynamics of the tractor, let us consider a 4×4 wheel-configuration tractor with a locked-type interaxle drive moving in a straight line on a horizontal surface, where the rotational speed of the rear driving wheels is slightly higher than that of the front wheels.

For both axles to have equal linear speeds, one set of wheels must either slip or skid. The wheels with higher theoretical rotational speed are called leading wheels, and those with lower speed are lagging wheels. As is known, leading wheels always slip because they produce thrust, while lagging wheels may skid; in some cases, they may slip slightly less than the leading wheels.

When lagging wheels slip, S2<S1S_2 < S_1S2 <S1 (where subscript 1 refers to leading wheels and 2 to lagging wheels), they generate additional thrust. If these wheels skid, additional rolling resistance arises. If S2=0S_2 = 0S2 =0, the wheels roll without slipping or skidding.

The condition for equal linear velocities of both axles for a tractor with a locked-type interaxle drive can be expressed as follows:

Vm=VH2V_m = V_{H2}Vm =VH2

where VmV_mVm and VH2V_{H2}VH2 are the theoretical rotational velocities of the leading and lagging wheels, respectively. The kinematic mismatch between front and rear driving wheels is denoted as KnK_nKn :

Kn=VmVH2K_n = \frac{V_m}{V_{H2}}Kn =VH2 Vm

The theoretical rotational velocities of the leading and lagging wheels can be expressed as:

Optimal traction performance is achieved when the rotational speeds of the front and rear driving wheels are equal, i.e., Kn=1K_n = 1Kn =1. In this condition, both axles slip equally, and the traction capabilities of all wheels are fully utilized.

However, in practice, achieving perfectly equal rotational speeds is extremely difficult because the wheel radii differ from their nominal sizes due to several factors:

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- manufacturing tolerances,
- tread wear,
- tire pressure differences,
- variations in normal ground reactions during operation, etc.

Even when the tractor's front and rear wheels are designed with identical radii, these factors prevent their actual rotational speeds from being equal.

Skidding of the lagging wheels severely reduces the tractor's traction efficiency, because in this state only two wheels remain effectively driving — the skidding ones become driven wheels. Additionally, skidding lagging wheels produce an extra resistance force Rk2R_{k2}Rk2 to the rolling of the.

This resistance can vary from zero (when there is no slip) up to Rk2=f2U2R_{k2} = f_2 U_2Rk2 =f2 U2 (in the case of full skidding).
Part of the useful traction force Rk1R_{k1}Rk1 from the soil reaction on the leading wheels is transmitted through the tractor frame to the lagging wheels and is spent overcoming the resistance Rk2R_{k2}Rk2 .

Thus, the power associated with Rk2R_{k2}Rk2 circulates in a closed loop — from the skidding wheels, through the transmission to the rear driving wheels, and back through the tractor frame to the skidding wheels again.

Since this circulating power is useless (loss), some sources call it "parasitic power." Such power circulation is more pronounced on hard surfaces or when the tractor moves without load (idling). Therefore, under such conditions, engaging the second driving axle may cause negative rather than positive effects.

When both driving axles operate on relatively soft soil with sufficient load, no power circulation occurs during straight-line movement.

Differential-Type Drive
In tractors with differential-type interaxle drives, the distribution of traction loads between the front and rear axles depends on how the interaxle differential distributes the torque. A change in the tangential force on the wheels of one axle leads to a change in the tangential traction force on the other axle.

For instance, if the wheels on one axle encounter poor adhesion and their tangential traction force decreases, the tangential force on the other axle also decreases — even if its wheels are on firm ground. As a result, the total traction force of the tractor decreases. The principal disadvantage of the differential-type drive is that the tractor's tractive effort depends on the axle whose wheels have poorer adhesion conditions.

Freewheel Clutch (Overrunning Clutch) in Locked-Type Drives
To eliminate kinematic mismatch in tractors with locked-type drives, it is recommended to use an interaxle freewheel clutch**.**

The operating principle of such a clutch is shown in**.**
The driving element (drum 1) is connected to the tractor's transmission, while the driven element (profiled disc 2) is connected to the additional axle.
Their directions of rotation are shown schematically by the arrows. When the driving drum 1 rotates faster than the disc 2, the rollers 3 between them wedge, locking the clutch and causing both axles to rotate together.
If, during operation, the driven disc's rotational speed exceeds that of the drum (due to excessive front-wheel slip), the clutch disengages, allowing the axles to rotate independently.

When using an interaxle freewheel clutch, the transmission ratio is selected so that the main driving axle (usually the rear) rotates slightly faster (by a few percent) than the auxiliary (front) axle.

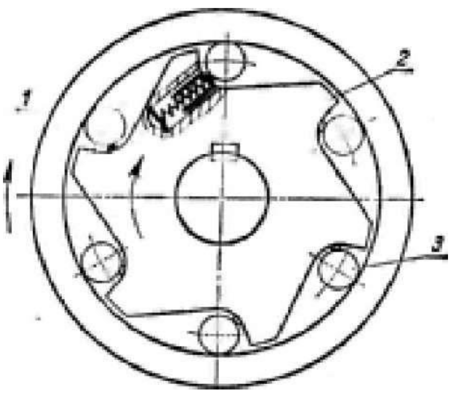

Figure 2. *Schematic diagram of an interaxle freewheel clutch.*

With this configuration, the front wheels rotate slightly faster due to the thrust transmitted through the tractor frame, causing the clutch to disengage and the torque to be transmitted only to the rear axle.The front axle is automatically re-engaged when the tractor's forward speed decreases because of rear-wheel slippage — once the rotational speeds of the clutch's driving and driven elements become equal. When the rear-wheel slip exceeds approximately **4–6%**, the front axle is automatically engaged. Thus, the interaxle freewheel clutch automates the engagement and disengagement of the front axle, preventing the formation of circulating (loss) power.

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