

Innovative method for measuring the tractive effort of rail vehicles

Dr.-Ing. Frank Rick, Dr.-Ing. Robert Grimm, Dipl.-Ing. Gunter Venter

Deutsche Bahn AG
Research and Technology Centre
Verification and Testing, Traction, TZF 74
Germany, Völckerstraße 5, 80939 Munich
Tel.: +4989 1308 7509, Fax: +4989 1308 7762
email: Robert.Grimm@bku.db.de

Introduction

The tractive effort of a rail vehicle is a physical feature which is highly relevant in the acceptance procedure of a new vehicle as well as in the calculation of its life cycle cost. Consequently, generating reliable measurements of a rail vehicle's tractive force at reasonable cost is an important task in the Research and Technology Centre of the DB AG. A new method has been developed which holds a number of advantages over the previously used conventional methods. The practical application and reliability of this innovative method will be presented in this paper.

Conventional methods

Nowadays a number of tractive effort measuring methods exist. The selection of a method is quite dependent on the measuring task and the kind of vehicle. The following scenarios can be distinguished:

To identify the tractive effort in the rail-wheel-contact of a locomotive a coupling hook is used. The coupling hook is the link between locomotive and load. Thus the acting force between both bodies is transferred over this device. This force at the hook is then converted to the total force transmitted between wheel and rail. For that transformation the locomotive resistance as well as the resistance of the track (i.e. curve radius and gradient) must be known as input parameters. Apart from a special software-tool the assembly of this method is rather straightforward and in practice this method delivers very reliable results due to the accurate measurement of the tractive effort at the hook.

In case of trains without a hook e.g. InterCityExpress Trains (ICE) and commuter trains of the Deutsche Bahn AG the torque of shafts is directly measured (shaft method). The tractive effort of those railway vehicles can be determined by combining the information of the wheel diameter with the torque of the drive train gained with strain gauges. The measuring signal of the strain gauges is transferred from the rotatory part to the stationary part via inductive coupling of two coils. To transfer the signal over long cable lengths and to avoid EMC (electro-magnetic coupling) special precautions have been taken and a very sophisticated high frequency transmission method has been chosen. Because of continuously increasing travelling speed, high dynamics of vertical rail-wheel forces caused by track properties and the occurrence of damaging stick-slip-vibration in case of bad weather conditions, the system has to be very robust. Under all circumstances a perfect signal transmission has to be guaranteed leading to high effort in the set-up phase. To measure the total force every driven axle has to be equipped with a single measurement device. Consequently, the equipment of such trains takes a long time and is quite expensive, as for example the new ICE 3 has eight directly driven axles in case of single traction.

Innovative method

For all cases where only the total force of a vehicle is of importance, an innovative tractive effort method (patent pending) has been invented at the Research and Technology Centre Munich of the Deutsche Bahn.

Physically the tractive effort in the rail-wheel contact F_{ino} equals the the sum of all acting forces F_w (resistance) on a train.

$$F_{imo} = F_W \quad (1)$$

Thus when a train is in motion the tractive effort must be balanced by the resistant forces. In detail the resistant force F_W can be divided in an acceleration force F_{Wa} , an inclination force F_{Wn} , a curve force F_{Wb} and a running force F_{Wl} :

$$F_W^* = \sum_i (F_{Wa} + F_{Wn} + F_{Wb}) \quad (2)$$

$$F_W = F_W^* + F_{Wl} \quad (3)$$

In general every part of a vehicle has its own resistant force and especially during the beginning and end of curve drives and changes of gradient those forces can differ extremly. The following test drives have been carried out with an EMU class 425. As smallest part of the train a single coach has been chosen. The train consists of four coaches. According to equation (2) the resistant force of one coach has been calculated and finally the four coach forces summed up to F_W^* . Because the running resistance acts on the complete train the force F_{Wl} is added afterwards (eq. (3)). With the knowledge of the mass m of a coach and the actual acceleration a and inclination β the acceleration force

$$F_{Wa} = m \cdot (\rho + 1) \cdot a \quad (4)$$

and inclination force

$$F_{Wn} = m \cdot g \cdot \sin(\beta) \sim m \cdot g \cdot \beta, \beta \ll 1 \quad (5)$$

can be determined. The factor ρ represents an additional imaginary mass to take the acceleration of the rotatory mass into consideration. With a specially developed gyroscope the three dimensional acceleration and rotatory angle of a body can be measured precisely. The gyroscope has been placed in the coach running in front of the train, so that the momentary acceleration in driving direction and the gradient of the rail can be measured. To identify the total profile of the track, the coach position is saved together with the measured inclination. Thus the determination of the inclination resistance for the coaches running in the rear is possible.

The curve resistance can be calculated after the well known formula according to Röckl. Test drives have demonstrated that in case of very small curves the formula is not sufficiently precise enough. Therefore the test drives have been carried out on a straight track, in order to neglect the curve resistance.

The missing running resistance is identified with the following method: the train is accelerated on a straight and quite even track up to maximum speed and then the tractive effort demand is taken away. According to eq. (6) the train decelerates to standstill due to the acting of the resistances F_{Wa} and F_{Wl} . Taking also the influence of the gradient into consideration the result is:

$$F_{Wl} = -F_{Wa} - F_{Wn} \quad (6)$$

Measurements

In recent months this innovative method has been tested on different locomotives. In order to compare the innovative force F_{imo} with a reference force in the test phase, either the converted coupling hook force or the shaft torques were also measured. The results were very promising, so that in May 2001 test drives on an EMU train class 425 of the Deutsche Bahn AG were carried out between Gütersloh-Neubeckum and Ansbach-Dombühl. The ten-axle train has eight directly driven wheelsets. Four asynchronous motors are fed over one DC-link voltage by one converter (group drive) and controlled by a traction controller. With the knowledge of the input parameters of the voltage, current and rotor speed of a motor the flux and torque is calculated by Siemens AG. Kindly Siemens made the following controller-signals available: total force gained of all calculated motor torques and besides the tractive effort demand and speeds of every wheelset.

Test drive on dry rails

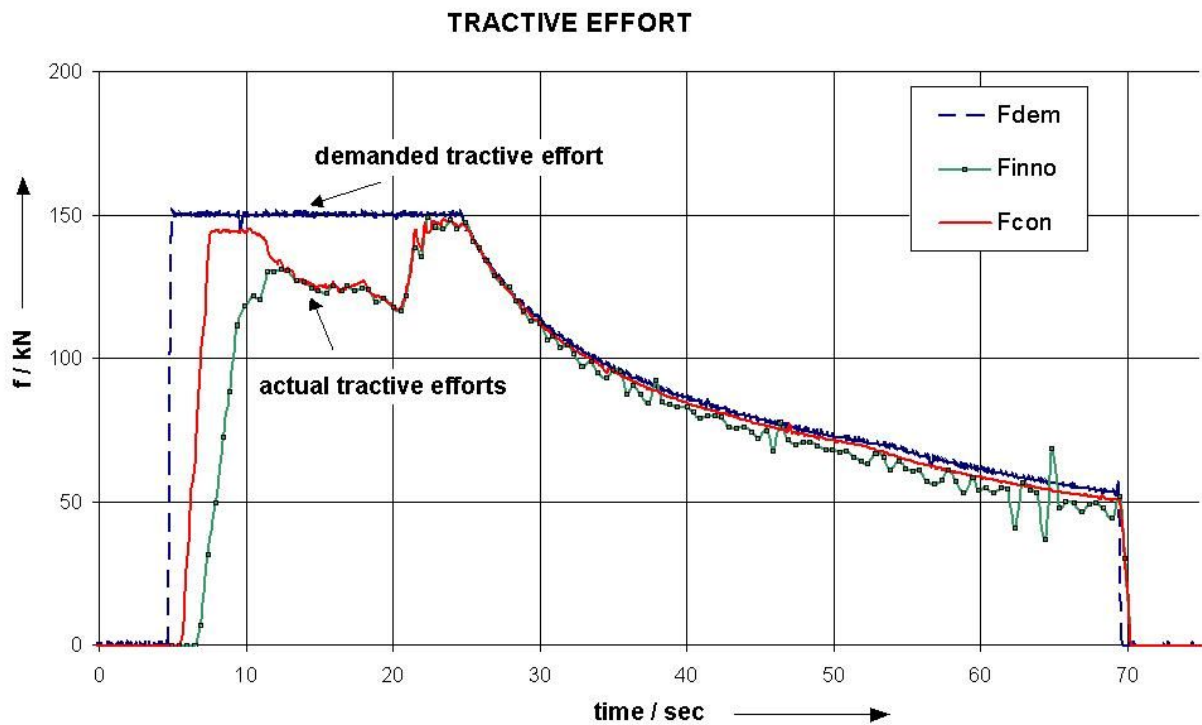
Figure 1 and 2 show the results of a test drive from standstill on almost dry rails up to a velocity of $v = 140$ km/h. After $t = 5$ s the driver demands maximum force F_{dem} . In case of good weather

conditions the installed power and maximum force can be conveyed to the track, represented by the tractive effort F_{dem} . The force F_{con} (controller) is calculated by Siemens while the force F_{inno} is identified with the new method. After $t = 12$ s there is a close correspondance between both actual forces. With increasing speed both forces differ slightly. It is to point out that both forces have a remaining uncertainty because they are not measured directly. Nevertheless their difference over the whole period (apart from the beginning) is less than 7 %. This demonstrates the practical appliance of this method.

The reduction of adhesion between wheel and rail due to wetness results in a difference between maximum possible force F_{dem} and actual forces. The slip controller detects the beginning slipping of the wheelsets and temporarily reduces the torque. To judge the development of tractive effort the differential speed

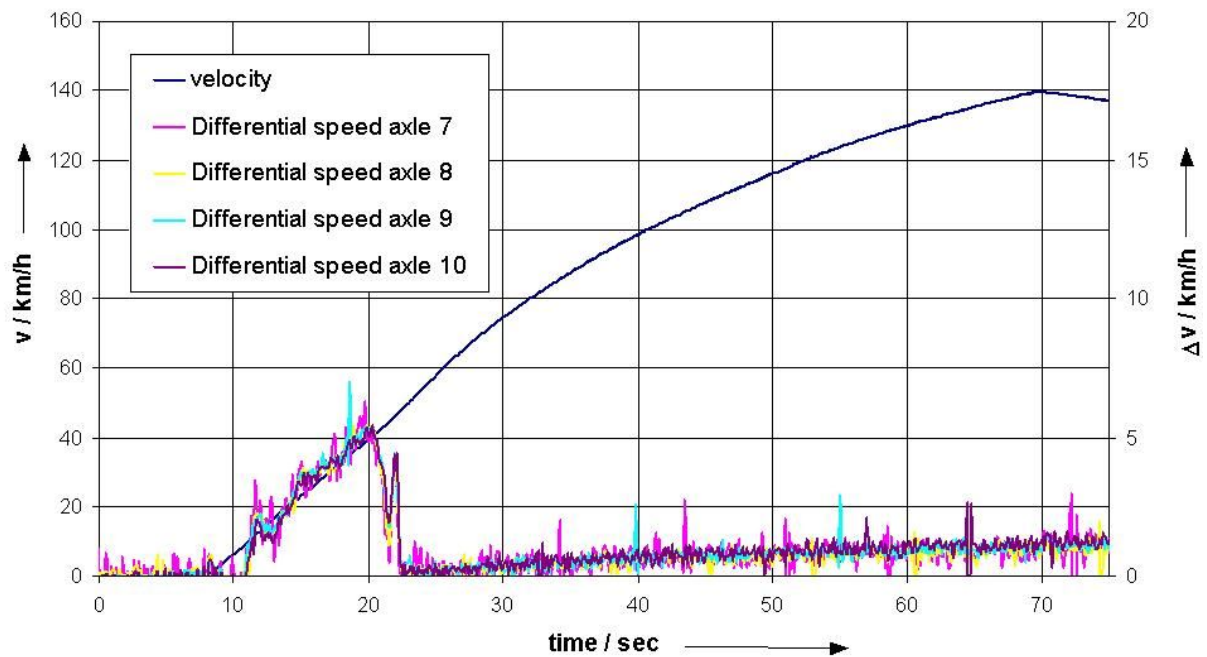
$$\Delta v = v_U - v \quad (7)$$

as the difference between rotatory speed v_U and driving speed v is of great importance. Therefore in figure 2 the speeds at axle 7 to 10 are shown. The increase of differential speed corresponds with the decrease of tractive effort. After the detection of higher adhesion the differential speed is reduced to almost zero, which is a hint for dry tracks. Because of the group control the axle speeds related to one converter show almost no variation. The difference in the beginning of the actual forces F_{inno} and F_{con} is the result of different acting points. The force F_{con} acts on the rotor shaft and has to accelerate the rotatory and translatory masses. According to eq. (3) the force F_{inno} occurs at that moment when the train starts to move. Consequently there must be a delay and difference at the beginning.



Test drive from standstill on almost dry rails; tractive effort

VELOCITY AND DIFFERENTIAL SPEEDS

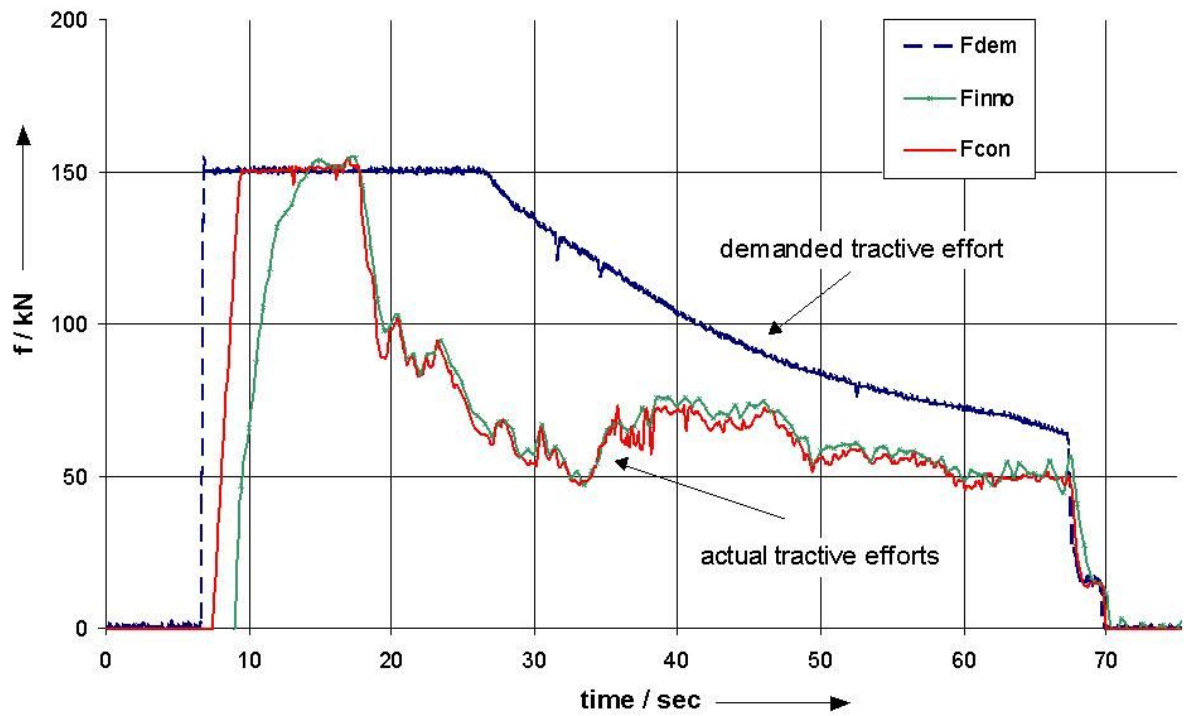


Test drive from standstill on almost dry rails; velocity and differential speeds

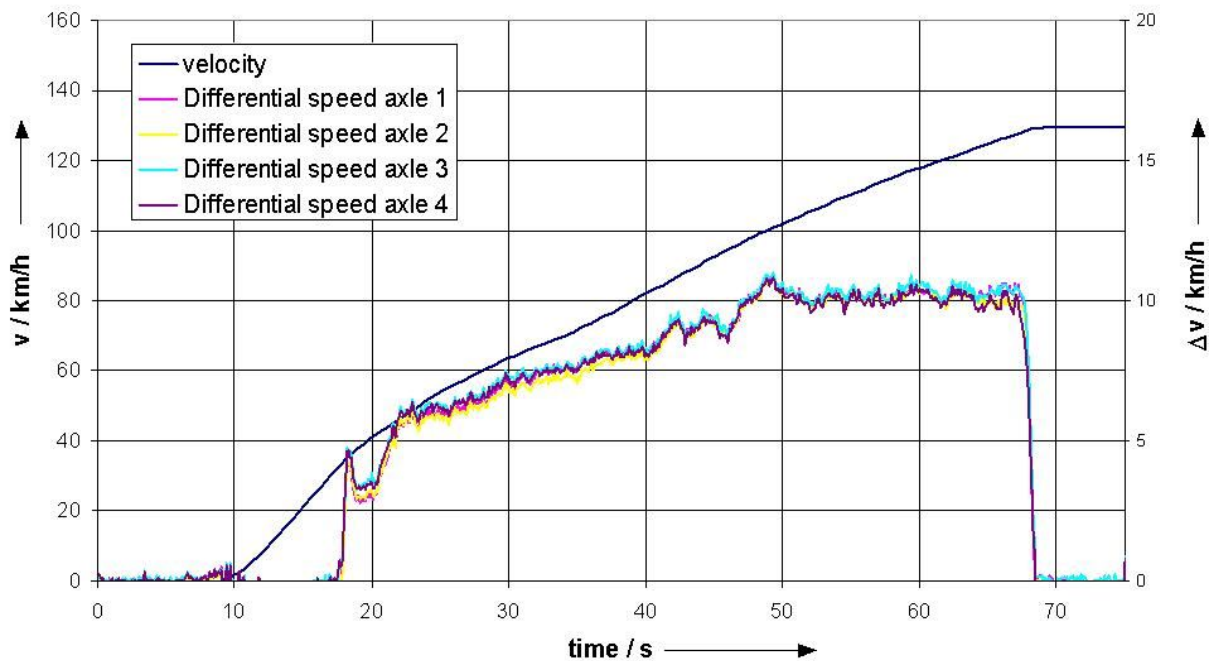
Test drive on watered rails

During the following test drive the friction between wheel and rail was reduced deliberately. Water mixed with soap was spread on the upper surface of each wheel of the forward running wheelset (driven) within one bogie. Four wheelsets were watered directly, while the other wheelsets run over the remaining water film. Regarding the forces in figure 3 and 4 the reduction of adhesion is represented by the great difference between demanded and actual forces over a long period. The slip controller is active as the high differential speeds reveal. The new innovative method follows apart from the initial difference the dynamic change of the actual force F_{con} .

TRACTIVE EFFORT



VELOCITY AND DIFFERENTIAL SPEEDS



Conclusion

In this paper a new method for identifying the actual tractive effort of a vehicle has been presented. The first test results showed good correspondance with the reference force gained from a conventional method. The innovative method therefore is an excellent alternative for all future measurements where only the overall tractive effort is to be determined. When applied to new high-speed trains with a number of distributed drive trains, it holds the additional advantage of reduced setting up effort as it is not necessary to equip every axle with strain gauges and separate transmission systems. A considerable reduction of effort can be gained with the new innovative system because only a gyroscope, a velocity signal and a measurement PC are necessary. In consequence a fast installation at low costs is now possible. Because the system is installed inside a vehicle, possible damaging vibrations and oscillations do not occur.

This system does not permit the identification of excitation of stick-slip-vibration, as it is often required. It is however possible to equip one axle with strain gauges in order to investigate the oscillation tendency of the drive train. The total tractive effort of the whole train can then be identified with the gyroscope.