COMPUTER ANALYSIS OF CREEP OF ROAD VEHICLES

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Since majority of road accidents occur in cornering and overtaking, it should be studied what an effect the creep exerts on the occurrence of an accident in the motion of a cornering vehicle.

Notation

The following symbols are used in this paper:

g	gravity constant
a_t	non-dimensional tangential acceleration $(a)g$; or deceleration of the vehicle (where the sign of a is negative)
a_n	non-dimensional normal acceleration (a_n/g)
G	weight of vehicle
I	moment of inertia of vehicle resting on plane surface with respect to the axis normal to surface and intersecting gravity centre of vehicle
K	front-to-rear axle brake ratio
i	nearside-to-offside wheel brake ratio on same axle
l_k B_k	distances defining position of gravity centre of vehicle ($k = 1$ and 2)
F	force applied to vehicle
δ	creep angle of vehicle wheel
β	creep angle of gravity centre of vehicle
Θ	steer angle
R	concerning radius
C_p	air pressure in tyre
Y	dynamic wheel load
A	function characterizing tyre
C	function characterizing road

Subscripts

z	effect in radial direction
F	consequence of braking
f	consequence of rolling
l	consequence of air resistance
e	front axle
h	rear axle
k	external wheel
b	internal wheel.

Movement of the vehicle is defined by the forces acting on the vehicle by whose consideration the state of movement may be characterized. In case

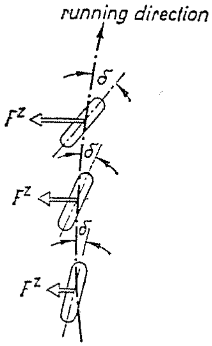

Fig. 1

where the vehicle also is affected by a sideways force, creep takes place which represents a risk to accident because drivers can keep their vehicle in a stable state up to a given angle of creep value. Under the effect of the sideways force the vehicle changes its direction of running, i.e., deviates from the desired track by a given angle. This happens because the force attacks the wheels in the form of a sideways force and the tyres can only withstand the sideways force applied to the vehicle if they are rolling askew related to the running direction (Fig. 1). The evaluation of the experiments and the measurement results revealed the sideways force which could be transferred by the tyre to be independent of the radius of cornering, and to depend only slightly on the running speed but mainly on the construction and grade of road, air pressure in the tyre, profile and design of the tyre, and wheel load [1].

Studies showed that the function defining the relation between tyre and road should conveniently be investigated, in addition to the sideways-force coefficient (sideways force/wheel load), brake and accelerating-force coefficients (brake force or accelerating force/wheel load), tyre pressure and creep angle in case of a particular tyre and road [3]. If this relation is familiar, the interaction between vehicle and road may be determined. The scheme of analysis is shown in Fig. 2.

To ease the understanding of the investigations and analyses, a particular system should be analyzed, determined by the vehicle and its environment, and the state of motion of the vehicle of the system is fairly difficult and uncertain, it seems to be convenient to build up a model of the actual system which includes the representation of parts of the system and their interconnection in a way that in case of certain neglects, the model functions as an actual system. If the behaviour of the vehicle as a subsystem is to be known, the series of the stages passed over by the subsystem should be realized. The change of state of the system is caused by the interactions between the parts which depend on the interconnections between these latter. The change

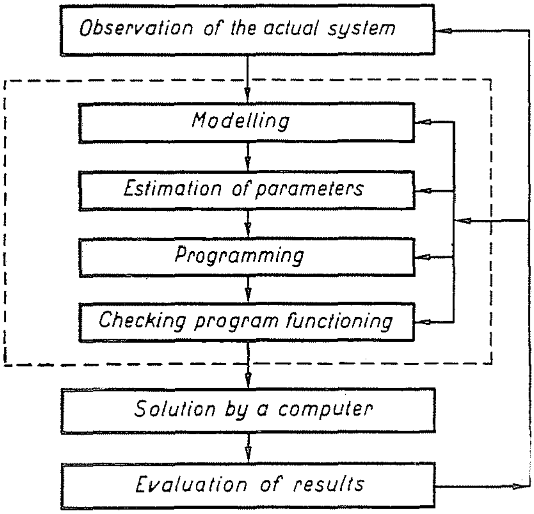

Fig. 2

of state, i.e., the event occurs at the end of the process of an elementary activity. Since the activities and events in the model can closely be simulated, the model has only to represent the events.

Functioning of the model is as follows. In a given situation from the list of events that going to take place is to be established. If such an event was found then the respective values should be changed in such a way as prescribed by the operation functions associated with the event. Then, the new event likely to take place and its time is to be found out in correspondence with the event and decision rules, and thereby, the list of events will be established. All these having been done for all of the events which ought to take place in the given situation, the state has been described and the description of the state representing the following situation can be begun.

It is seen immediately that even in case of investigation of systems coniisting of relatively small number of parts how labourious it is to obtain the cutput, therefore, the idea of computer simulation seems to be fully justified.

Since evaluation of the tracking error of the vehicles due to creep established that most of the drivers percepting the dangerous situation in conerning try to diminish the uncertainty by braking, therefore the analysis was carried out for such a situation.

The state of motion of the vehicle is determined by the forces occurring in concerning. These forces are represented in the Cartesian co-ordinate system with its origin at the centre of gravity of the vehicle (Fig. 3).

The equilibrium equations of the vehicle are determined by the equilibrium conditions of the forces and moment related to the centre of gravity

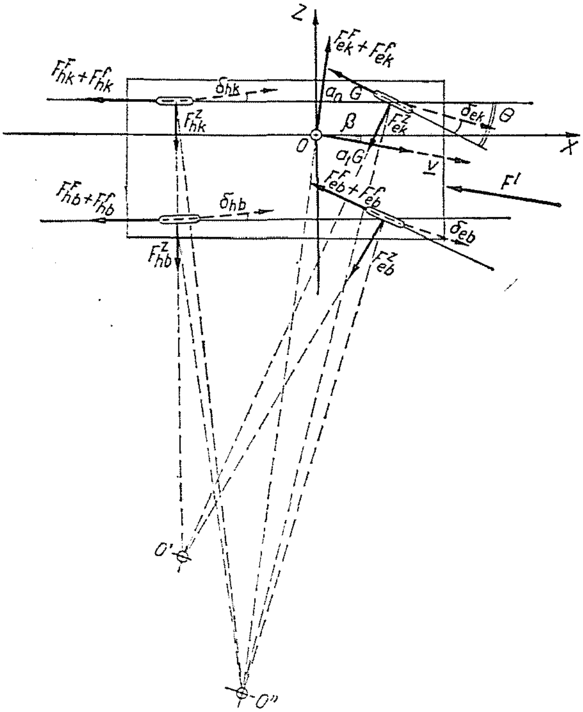

Fig. 3

investigated with different parameters, and likely to give information on the range of stability of the vehicle [1].

Since the effect of creep is investigated, only actual braking processes are dealt with where the slip remains below a given value [2]. If the brake system functions correctly, the braking force available on the axles will be shared between the wheels of the rear and front axles according to a pair of values to be characterized by intervals, to be considered for increasing the accuracy of the determination of the state of motion. Taking into account that in case of up-to-date motor cars, often a brake force controller device is applied, with a familiar characteristic curve, the functions determining the equilibrium equations will take the following forms:

$$\eta_1(F^z, F^F, \beta, \Theta, F^1 F^f, G, a_t, a_n K) = 0 \tag{1}$$

$$\eta_2(F^F, F^z, \beta, \Theta, F^1 F^f, G, a_t, a_n, K) = 0 \tag{2}$$

$$\eta_3(F^z, F^F, \beta, \Theta, F^1 F^f, I, a_t, R, K, i, B, 1) = 0 \tag{3}$$

which determine

— the equilibrium of forces with respect to the x-axis,

- the equilibrium of the forces with respect to the y-axis, and
- the equilibrium of the torque with respect to the axis which is perpendicular at the origin to the plane x, y, respectively.

In the equations of motion more of unknown variables are involved than is allowed for the definite solution of the equations, therefore, solutions need the introduction of the function of the coefficient of the lateral force and angle of creep

$$\eta_4(F^z, F^F, \mathbf{M}, c_p, A, C)\, \xi_4 = 0 \tag{4}$$

and to apply the trial-and-error method.

In the first step β and Θ are assumed to be small angles, and the angles of creeping of the wheels determined accordingly. Then, by replacing these values in the equations one obtains exacter data for the creep angles of steering and gravity centre of the vehicle. Iteration is done up to the desired exactitude.

The values calculated in this way determine the characteristics of the state of motion of the vehicle.

Assessment of the effects of the variable parameters and great many calculations as well as iterations needed induced to work out a computer program which allows a rapid evaluation.

The program has been established so that to each event a subroutine corresponds which involves the operation functions corresponding to the respective event and the rules for the decisions. Hereupon, only the central organizing program ought to be established for controlling. Application of a computer markedly affects the programming theory approach on the shape and logics of the vehicle model.

Since in Hungary the number of the Zhiguli (Lada, VAZ 2101)-type motor cars rises year by year, it seemed to be convenient to report on actual calculation results for this type. The input of the program has been determined by laboratory measurements carried out by the Department of Motor Vehicles of the Faculty of Transport Engineering, Technical University, Budapest.

The motor car was in the state of ready to start and during the measurements only the driver was in the car. The wheels were fitted with radial cord tyres and the results refer to dry bituminous road surfaces.

In connection with the computer work, also the rate of convergence of the applied trial-and-error method has been studied. According to the results the desired accuracy was reached already at the third step of trial.

The plot of the creep angles of each wheel of the vehicle versus speed is seen in Fig. 4.

The curves designated by I represent the creep angles of each wheel in cornering in a curve of 50 m radius and those designated by II belong to a curve of 150 m radius. The numerals 1, 2, 3 and 4 mark the wheels of the vehicle according to Fig. 4.

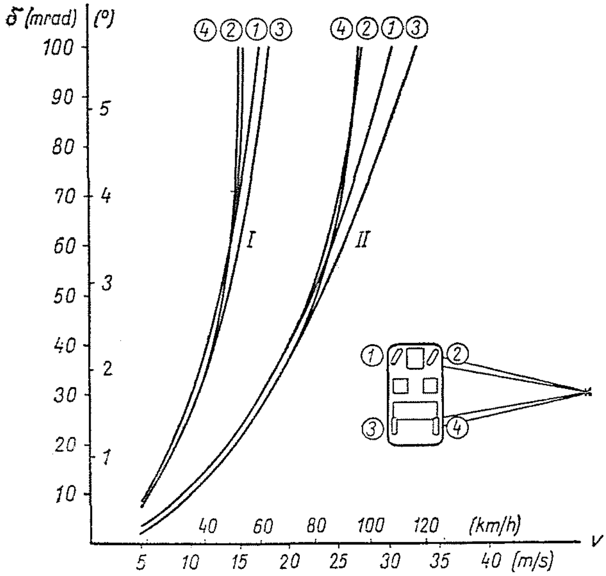

Fig. 4

The Zhiguli-type motor car belongs to the category of under-steered vehicles. As long as the creep angle of the vehicle is small (at most 55 mrad, i.e., 3,15° or so) the creep of the front wheels is seen to be greater than that of the rear wheels, i.e., the motor car is understeered. The definite under-steer persists up to a speed of 14 m/sec in a cornering of 50 m radius, then the creep of tyres increases to 60 mrad (i.e., 3,43°). In concerning of 50 m radius, over the speed of 14 m/sec, the sideways force acting on the motor vehicle due to the centripetal force changes the wheel loads to such a degree that the creep of the internal wheels (No 2 and 4) gradually increases due to the decrease in their loads.

Analyses of the actual investigations have shown that above a creep angle of 80 mrad (4,58°) a driver of average driving abilities cannot manoeuvre his car.

Evaluation of computer outputs enables to follow and evaluate wheel creep phenomena invisible for the naked eye, sensorily imperceptible and inaccessible but for very complicated instruments. According to diagram I, at a speed of 15 m/sec in offside cornering, the creep of the offside rear wheel (No 4) becomes already greater than that of the front wheels and reaches the 80 mrad (4,58°) value, while the creep angle of the near-side rear wheel remains only 63 mrad (3,6°). The results point out that the definite behaviour of the motor vehicle (under- or over-steered) changes in such a situation. The driver may easily correct the under-steer or over-steer of the motor car by steering, as long as its behaviour is definite, i.e., as long as the creep value does not exceed 45 mrad (2,57°). At a creep of a value between 45 and 80 mrad (2,57° and 4,58°), the vehicle is difficult to keep under controls, i.e., in the desired direction by steering, and over 80 mrad (4,58°) a driver of average driving abilities can little manoeuvre the motor vehicle.

The results hint to the particular sensitivity of the creep angle to the change of speed. Thus, in a dangerous situation, when the creep of the wheel is significant, it seems to be more efficient to diminish the speed in order to decrease the creep angle than to increase the cornering radius.

Incorporating the statically measurable car characteristics into the program enables to predict the expectable behaviour of the motor vehicle in cornering.

Provided computations show the vehicle to become unmanoeuvrable already in the range of low speeds, the method allows to improve brake-force ratio already in the design stage.

In knowledge of the motor vehicle and cornering, the program lends itself to define in accident investigations the running speed of the vehicle before the accident took place. In case of a given motor-vehicle stock and commercial speed envisaged, the program is suitable for computing cornering conditions on planned roads and the maximum running speeds of safety to be prescribed for curves on existing roads.

Summary

The paper deals with a problem which is significant with respect to the road traffic safety, i.e., with the creep of vehicles, and proposes a method for the computerized investigation of the phenomenon difficult to measure, for the rest. In the paper the essential of the investigation procedure is concisely summarized and its results reported on.

Multiplication of accidents on public roads calls the attention of specialists both to the prevention and to a rapid and reliable analysis of traffic accidents.

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