A COMPARATIVE STUDY OF METHODS USED FOR TESTING TOWED VEHICLES

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Abstract

This research is aimed at designing and testing a mathematical model which can be used to determine the stresses on vehicles moving on different terrain types. Vehicles towed across terrain are exposed to forces originating from the towing vehicle and from the ground-vehicle relationship. The latter comprises dynamic forces due to soil unevenness and forces due to rolling resistance. The impact of the ground on the vehicle depends on the geometrical features of the terrain and mechanical properties of the soil. The activating force affecting the moving vehicle is related to the effective profile, and the damping effect is the result of the friction among soil particles. A complex mathematical model will be developed using analytical mathematical models and the numerical results of field experiments on a test field. The activating function derived from the model will be tested on a purpose-designed test bench. For certain problems of forces acting on moving vehicles, the formula describing terrain conditions enables us to carry out a more exact analysis of certain forces which have been hidden so far.

Keywords

effective profile, ground–vehicle relationship, micro- and macro-obstacles, purpose-designed test field, terrain conditions, test bench

1. Background

In the past few decades, several accelerated fatigue testing methods have been developed for vehicles travelling on terrain, but compared with long-term operational tests under real conditions ([4] Kiss P.,), bench durability tests – even at identical running times – are frequently found to result in different failure modes. The reasons for the discrepancies have not yet been established. It may be concluded from a survey of published research that no method of testing has been devised which is capable of modelling real terrain and real soil ([3] Kiss P. Laib L.).

Many test systems have been designed to model extreme terrain conditions. These are aimed at gathering the most possible information, in the least possible time, on vehicle faults associated with motion across terrain. The structure can be modified according to the analysis of the faults, and the process is repeated until the required performance is achieved under the test conditions.

2. Objectives

This research is focused on modelling the ground – vehicle relationship. Specifically, the aim is to describe the activating forces ([2] Komándi, Gy.) to which the vehicle is subject by consequence of the terrain profile, i.e. micro- and macro obstacles, and the inhomogeneity and mechanical properties of the soil. The mathematical model will permit the determination of loads arising from the ground-vehicle relationship in various terrain conditions. The model, by means of a purpose-built test bench, will permit a towed vehicle to be subjected to loads simulating any of the extreme terrain and soil conditions which the vehicle might encounter in reality. The model may be used to address all problems involving the relationship between the soil and the towed vehicle.

Existing terrain modelling procedures are restricted to a very small number of profile variations and lead to a narrow range of outcomes. Since the failures during the tests arise only from the particular terrain modelled, modifications lead to a construction which withstands only the test conditions. Real terrain conditions generate a much wider range of activation forces, and machinery developed with previous test methods does not necessarily fit its intended purpose. A satisfactory model of terrain profile is one which takes into account the unlimited variations of activating frequencies, thus reflecting real-life conditions.

3. A comparison of different test methods: field durability and rolling test bench

A durability test was performed on a towed vehicle (header trailer). It involved durability tests on two identical vehicles, one running under real conditions, and the other on a rolling test bench. The two methods led to different failure modes. Under real conditions, large amplitude swings caused the lampholders at the end of the long frame structure to break off. The much more intensive rolling test bench test caused cracks at the king pin and the rear axle welds. In both cases, the structure had to be strengthened.

The comparative tests prove that the rolling test bench does not simulate the forces occurring under real conditions.

4. Frequently used test methods and their limitations

The testing of towed vehicles is generally performed by means of four different procedures. The field durability test (I) involves running under real terrain conditions for a period equal to the lifetime. This method gives a good approach to real loads on the vehicle structure, but is very time-consuming and is difficult to extend to all possible terrain conditions

Figure 1. Field durability test

The next method involves a purpose-designed test field (II). This has the advantage of shortening of the time to failure. An artificial obstacle field, however, can only include a very small number of terrain obstacles, is difficult to convert, and carries the great disadvantage of damaging the tractive structure together with the towed vehicle.

The most commonly-employed test method uses a rolling test bench (III). The towed device is fixed to the end of a drawbar and it wheels are set into rotation by eccentric rollers. The eccentricity and the rotation induces vibration in the structure, thus modelling vibrational accelerations from field obstacles. This is a much lower cost test and leads to failure in a short time. Further

advantages are that the amplitude and intensity of vibrations can be altered by adjusting the eccentricity and speed of rotation, and that it permits comparative tests, because the conditions can be repeated. The method has several drawbacks, however. The most severe is that it does not model real conditions. It is not capable of simulating many of the activating forces to which vehicles ([1] Fekete A.) moving on terrain are exposed. A vehicle traverses combinations of micro- and macro-obstacles on real terrain, and is therefore subject to activating forces which vary suddenly, dynamically and within wide limits. The eccentricity on a rolling test bench is much smaller in scale than the natural variation of terrain profile, and so only to a very small extent models the dynamic effects of gravitational forces acting on the axles when a vehicle traverses large terrain obstacles. The real activating forces are closer to impulse loads than constant-intensity and constant-amplitude vibrations. A further major defect of the rolling test bench is that it does not simulate the large dynamic forces generated by braking and acceleration.

The fourth method is the shaker rig (IV), on which the vehicle is set into vibration by computer-controlled hydraulic activators. This is the method used to test off-road vehicles, because it best models the forces acting on a vehicle traversing terrain. It is very costly, however, and the outcome very much depends on how well the program simulates the terrain conditions. To be able to test devices towed on terrain, the forces arising from the terrain profile and the traction characteristics would have to be determined and modelled.

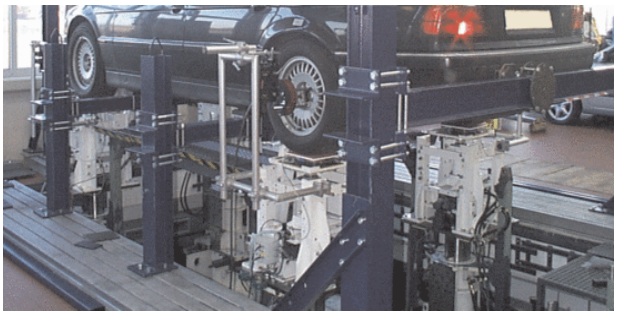

Figure 2. A test bench in operation

5. Different terrain types with different mechanical properties

The interaction of vehicles with obstacles is the subject of terrain-vehicle interaction theory. These obstacles are categorised by height: macro-obstacles are larger than 250 mm, and micro-obstacles are smaller than this. Macro-obstacles divide into step-, trench- and barrier obstacles. The first and most important criterion for determining the mobility of a vehicle is whether the geometrical design of the vehicle permits it to cross the obstacle. Important design criteria for the test field are that the towed structure crosses the terrain obstacle without sliding off or falling over, and does not collide in any direction. The vehicle stoppage condition for a terrain obstacle may be described by a track curve obtained by approximation via the VSE function. To calculate the accelerations generated as the vehicle traverses terrain, a differential equation of dynamic balance may be written for each degree of freedom of the vehicle model.

$$\overline{M}\ddot{y} + \overline{K}\dot{y} + \overline{S}y = \overline{sx}(t) + \overline{k\dot{y}}(t) \qquad (1)$$

Vibrational accelerations are set up by macro-obstacles corresponding to the terrain relief and by micro-obstacles – those smaller than 250 mm – covering the surface of the soil. Investigation of the micro-obstacles and their effect on the structure is a much more complex task, because the corresponding profile types can only be described by statistical functions. The mathematical relations describing surface unevenness of the terrain are called stochastically distributed processes. Stochastic processes are a physically related group of events or forms with identical statistical parameters. To ensure that the model as far as possible approximates real conditions, the terrain profile curves describing the micro-obstacles should be recorded on the type of terrain used by the vehicles. Test fields should be constructed with micro-obstacles whose distribution of size and density corresponds to real conditions.

Different soil types have different mechanical properties. These properties are to a large degree influenced by the inhomogeneity and moisture content of the soil and the ambient temperature The inhomogeneity derives from the mixture of different soil types, vegetation and other foreign matter. Vehicles traversing the terrain often contact the surface vegetation rather than the soil itself, and this also has differing mechanical properties. The inhomogeneity thus considerably affects the soil's mechanical properties. The adhesion of the soil depends on its moisture contact, which is expressed by the moisture uptake ability of the soil, pF. The temperature also influences the state of the soil and thus indirectly the moisture content. All of these factors greatly influence the mobility, and hence the lifetime, of a vehicle moving on the terrain. They must be taken into consideration in the construction and use of test fields, especially for comparative tests.

6. Tested vehicles (header trailers)

For a proper description of forces acting on towed vehicles it is not sufficient to provide theoretical equations of motion and activating functions. There are some forces generated by terrain conditions which can only be described by measurement. These have to be recorded via measurements on a suitable towed vehicle – in this case, a header trailer. Any vehicle, however, may only be tested on terrain conditions for which it was designed, i.e. those it will traverse when in use.

The running-wheeled towed structure (header trailer) is subjected to a variety of forces as it moves across the ground. Braking and acceleration exert forces on the vehicle via the drawbar. The header trailer's own braking system sets up braking forces at its wheels. The weight and the inertial force act at the centre of mass of the structure, as does the centrifugal force during turning. There is a force arise originating from rolling resistance in the vehicle's ground-vehicle relationship and dynamic forces originating from soil unevenness (micro- and macro-obstacles). The magnitude and intensity of these forces influence the vehicle's lifetime. Those which can only be determined by measurement are the dynamic forces arising from braking and soil unevenness.

7. Modelling real terrain obstacles

When designing the test field, the most important consideration is that it should approach the size and distribution of real terrain obstacles. In order to determine this distribution, terrain profiles ([5] Richard Chan Lee.) must be measured under real conditions.

There is an unlimited number of possible combinations of soil and terrain conditions in nature, and so the number of variations must somehow be restricted. Firstly, obstacles which would be impassable by virtue of the trailers' geometry are excluded. Secondly, the most relevant terrain conditions are those which the vehicle is likely to encounter during use. It is also important to exclude terrain profile combinations which are known from experience to make only a small contribution to reduction of the vehicle's lifetime. Another design consideration for the test field

is the need for a higher frequency of terrain obstacles than that measured in real conditions, owing to the geometrical dimensions of the test field and the limitations of time available for testing.

There are several other circumstances to be taken into account in the design of the test field. The mechanical properties, vegetation and moisture content of the test field soil must not differ substantially from the real conditions. Then there are the damage which macro- and micro-obstacles may cause to the tractive vehicle and the need to prevent health hazards to the person driving it.

Given these boundary conditions, the optimum form is the „merry go round" test field. This configuration permits the tractive vehicle to travel on a different path than the towed vehicle and therefore be spared many of the stresses acting on the towed vehicle.

Figure 3. Merry-go-round test field

8. Developing a new model

The mathematical description of the external forces arising as the towed vehicle moves across terrain comprises the dynamic relationships presented above and the measured forces ascribable to terrain unevenness and traction. The measured and calculated forces are combined into a complex mathematical model for the towed vehicle. Activations functions are then derived from the model and used to simulate, on a purpose-built test bench, the forces which act on the vehicle under real conditions. The magnitude and intensity of the forces depend on the velocity of travel and weight of the vehicle, the accelerations occurring during operation, the geometry of the terrain and the vehicle and the mechanical properties of the soil type.

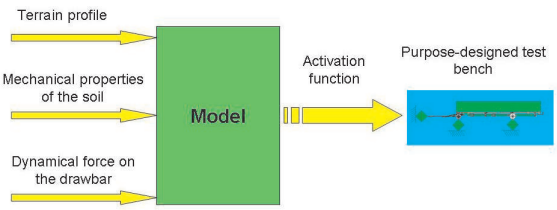

Figure 4. Modelling terrain conditions

The activation forces given by the model must meet certain boundary conditions. First of all, the maximum force acting on the structure may not exceed the force required for the immediate failure of the vehicle, i.e. no terrain profile may be formed which the vehicle cannot traverse without failure. Neither may the intensity of the activating forces exceed the critical sudden-failure value. Another boundary condition is that the minimum activating force must be greater than that which the tyre absorbs through its damping properties, because such activating forces have a negligible effect on vehicle lifetime.

By building a test bench to simulate an arbitrary combination of terrain conditions, it will be possible to generate activating forces equivalent to those occurring under real conditions. The test bench will permit different vehicle constructions to be compared.

The goodness of the model is most effectively determined by a comparative test. Under identical conditions, two identical towed vehicles should display the same failure mode. The comparative test will involve a durability test of one vehicle in the field, and of another on the purpose built test bench. If both tests provide similar results, the model may be considered satisfactory.

9. Expected results

1. A mathematical model which describes forces acting on vehicles traversing terrain, and which permits forces equivalent to real forces to be modelled.
2. The ability to test the effects of various terrain conditions on the vehicle structure without the use of test fields.
3. The possibility of simulating terrain conditions which in reality occur only under extreme conditions, enabling greater safety to be designed into vehicle structures.
4. Incorporation into the model of how the damping properties of various soil types compare to the properties of hard road surfaces.
5. The characterisation, via the model, of the mechanical processes which occur as a pneumatic tyre traverses the soil, thus providing better insight into the tyre-soil interaction.
6. The determination of the effects of different soil types and terrain profiles on vehicle structures.
7. Production of extreme terrain effects independently of environmental effects on the vehicle.
8. Validatability. Every test may be repeated at any time, implying applicability to proving procedures.
9. Considerable reduction in the duration and cost of vehicle testing.

10. Nomenclature

$\overline{M}$	mass matrix
$\overline{y}$	displacement vector
$\overline{K}$	damping matrix
$\overline{x}$	activating vector
$\overline{S}$	stiffness matrix

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