THE EXPERIMENTAL SUPPORT TO THE TRAILER BRAKING SYSTEM CERTIFICATION

Abstract

Certification of braking systems used in road vehicles is supposed to consist of a variety of identification, calculation and test procedures. They should be applied in the course of verification of the design and operational properties of a system as given by the manufacturer. According to the European type-approval based certification system, the following steps are to be applied:

(i) identification of the vehicle type and the fitted braking system type,
(ii) verification of the fulfillment of design requirements as prescribed by road safety regulations, standard etc.,
(iii) theoretical verification by means of calculations of the fulfillment of performance requirements as prescribed by road safety regulations, standards etc., and
(iv) experimental verification of the vehicle performance with respect to braking.

Specific issues of the trailer braking systems certification by applying the type-approval procedures are observed in this paper, particularly in the case of heavy trailers of O_3 and O_4 categories. Importance of prediction of braking performance, vehicle stability during braking and compatibility between towing vehicle and the trailer by means of calculation procedures is underlined and practical experience associated with the test results is discussed. Stochastic nature of braking is also demonstrated. Evidence is given to the need of practical verification of all design and calculation predictions of braking behaviour of a heavy trailer by means of the appropriate component or vehicle braking tests prior to the application for type-approval.

1. Vehicle quality and related certification systems

Manufacturers can provide customer satisfaction by ensuring high quality of vehicles, equipment and parts. Today's vehicle consumer is a sophisticated one and he expects good fits and long life from the vehicle. He wants lower cost, more functions and less complexity in the new vehicles. The customer makes final decision on whether or not a vehicle has quality, and that is why all the vehicle manufacturer efforts have to be customer driven. Customer satisfaction is the only global advantage or the only long-term advantage on the market-place. Customer does not care if the vehicle he buys is certified following type-approval or self-certification system and pursuant to what Regulations. He wants a good vehicle at a good price and he looks for quality.

Customers have preferences and opinions about the vehicle expressing them in imperfect, implicit or subjective way so that experts have to translate the "Voice of the Customer" into engineering criteria [8, 22, 27]. The technology used on the vehicle and its manufacture must serve a need, be affordable, have high reliability, and be cost competitive. Engineers are called upon to respond to increasing demands from different governmental and other regulations and standards [1, 13, 34, 35], changing expectations of customers, and a rapidly expanding array of new technologies. Not only a manufacturer is in charge of quality assurance management and thus the customer satisfaction issues, but governmental authorities also take responsibility for certain aspects of it. Quality of service represents today the total effect of service performance defining the rate of the customer satisfaction, according to the new quality characterization given by IEC/ISO 300 standard [12].

Certification system based on the type-approval concept or third-party certification as applied in Europe and some other parts of the world and strictly applied only to a sample of vehicle or component represents good example of how responsibility for customer satisfaction is shared between manufacturer and related governmental agencies. The only alternative procedure to type-approval system is self-certification as applied in the US. This certification system makes vehicle manufacturer to be the only responsible for the quality of its product.

Both certification systems are now looking for support from harmonized quality standards, and the initial assessment of Conformity of production procedure [3, 5, 9, 16, 17, 19] is based on the principle that manufacturer is registered to the quality assurance accreditation standards ISO 9002 or EN 29002, or QS9000, or similar [1, 10, 14, 18].

Certification system based upon the principle of so called "Type-approval" or "Third-party approval" as applied in many countries in Europe for many years makes the manufacturers of vehicles or components responsible for compliance of a "model" or representative sample ("of the type") of product in "the new" condition with the legal construction and performance requirements prescribed under national or international standards and regulations [16, 27]. "Type-approval pursuant to a Regulation" indicates an administrative procedure by which the competent authorities of one Contracting Party declare, after carrying out the required verifications, that a vehicle, equipment or parts submitted by the manufacturer as a prototype of the series production conform to the requirement of the given Regulation [5].

In addition to the manufacturers of vehicles, equipment and parts, such a certification system as shown in Figure 1 also involves national governmental agencies and national accredited technical services who are authorized to carry on the tests so as to verify that the compliance is provided with respect to relevant standards or regulations.

Type-approval may have the national or international scope depending on whether the relevant rules are concerned towards the national or international bases, like UN Economic Commission for Europe Regulations or European Union Directives, for example. In general, type-approval procedure comprises documentation audit and component test so as to verify that related documentation as well as the product it-self comply with prescribed design and performance requirements. Besides, the type-approval certification system compels manufacturers to demonstrate the existence of satisfactory arrangements and procedures for ensuring effective control so that vehicles, equipment or parts when in production conform to the approved type and thus providing the adequate "Conformity of Production".

Every vehicle, equipment or part approved under given Regulation must be so manufactured as to conform to the type approved by meeting the requirements of conformity and the said Regulation. The approval authority reserve the right to monitor production and must verify that, beside the above mentioned satisfactory arrangements, there are documented control plans and to carry out at specified intervals those tests or associated checks in accordance to the specifications given in the said Regulation, necessary to verify continued conformity with the approved type. However, the type-approval certification system allows manufacturers to prepare a sample vehicle or component prior to the compliance ("type-approval") or conformity tests. It means that the compliance of a product from the production line with the requirements of the given Regulation is verified into two steps: first, using a prototype sample prior to putting the series production on the market and second, applying the COP for the series production. Besides, manufacturers share the responsibility for quality of their products with their government.

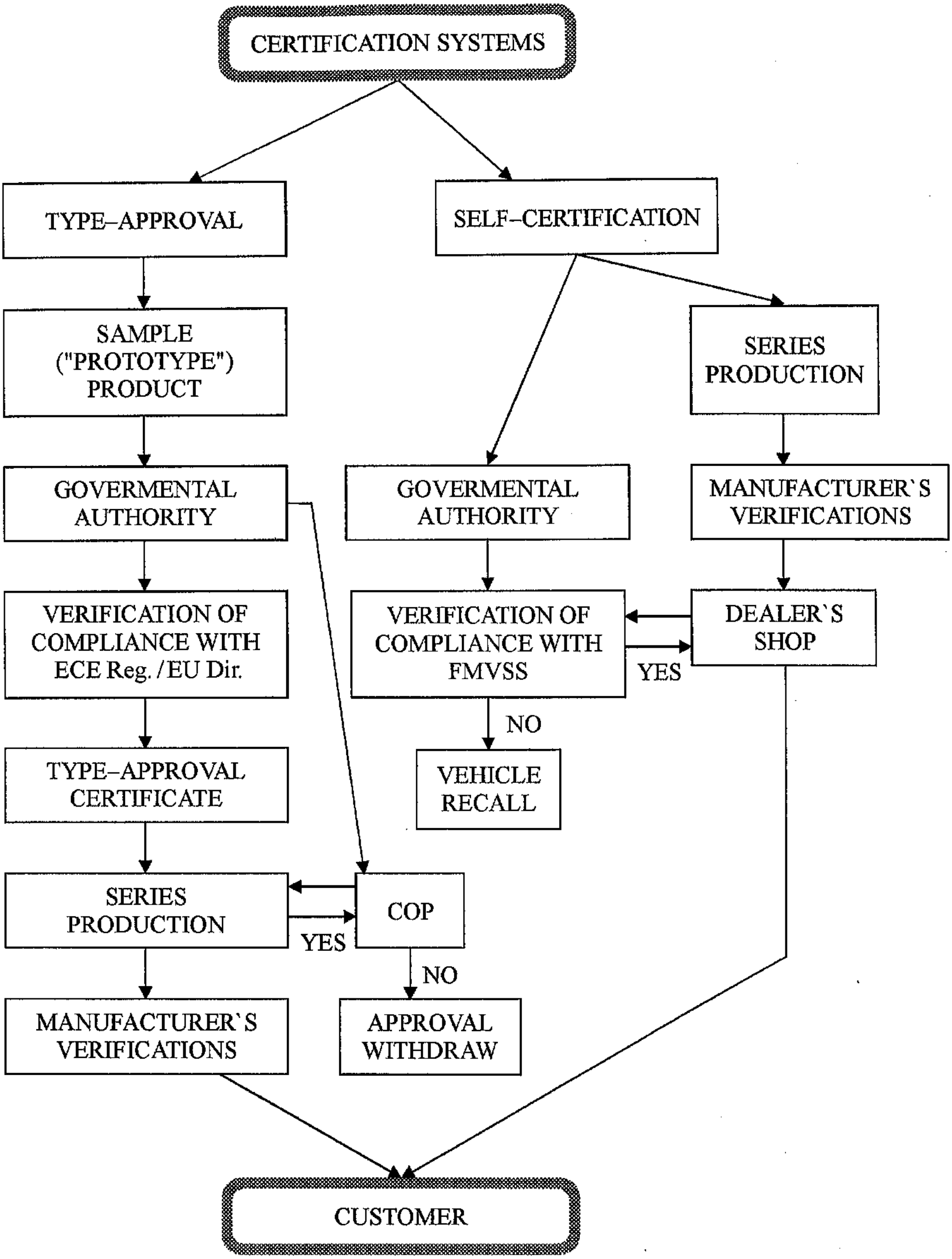

Figure 1. Two certification systems

The only alternative procedure generally known, and particularly applied in the US, is the self-certification system. By this system, the manufacturer declare that all applicable safety standards (like FMVSS in US, for example) have been satisfied or certify, without any preliminary administrative control, that each product put on the market from the series production conforms to the given Regulation. Manufacturers must check the compliance of every vehicle or component with the requirements of applicable safety standards by carrying out their own certification testing, while the frequency of such verifications depends upon the manufacturer's quality management. The competent administrative authorities, like NHTSA as the federal authority in the US, is authorized to audit the compliance of a given vehicle or component by random sampling at the market, i.e. by purchasing a new vehicle from a dealer's shop and submitting it to an independent technical service for compliance testing of the self-certified products against the relevant safety standard. In the case of self-certification system, there is no any administratively driven compliance and Conformity of production check prior to the series production, and the manufacturer does not share with the government any responsibility for the quality of its products.

Both certification systems contribute significantly to the quality of new products from series production. They both also provide to manufacturers the means for improvements in different aspects of product liability. Although both certification systems offer certain benefits, they also have some deficiencies. It is almost impossible to presume their effectiveness because in the case of type-approval certification system only a prototype passes complete verification, while in the case of self-certification the same apply to the product from the series production on the random bases, i.e. upon audit of compliance realized by an appropriate agency.

The existence of two different certification systems still do not give appropriate answers to the questions, problems and burdens associated with the approval process in various countries. It is obvious that existence of two certification systems makes extra burden which would not add any new value to the product but does add cost to the customer by means of building administrative and technical barriers to trading of those vehicles and their equipment that are marketed under small series by duplicating of effort presently required in selling products in the USA, Europe, Japan, and in Third World countries [4].

2. ECE Type-approval and Braking Regulation No. 13

Since 1958, when a number of Contracting Parties, i.e. countries within United Nation's Economic Commission for Europe, signed the so called "1958 Agreement" concerning the adoption of uniform conditions of approval and reciprocal recognition of approval for motor vehicle equipment and parts [19], an enormous work has been done to develop different safety Regulations that are annexed to this Agreement. At present, 99 ECE Regulations have been adopted and a large number of new Regulations is still under development [5, 16, 17, 19, 27, 35].

Type-approval is accomplished by the complex association of administrative and technical procedures and it comprises:

(a) verification of design and related manufacturing documentation together with a sample of the product (vehicles, equipment, parts) for compliance with design requirements,

(b) application of the prescribed approval tests for experimental verification of a sample of the product for compliance with the performance requirements, and

(c) audit of the quality control system for COP purposes to provide that a product from the series production complies with both design and performance requirements.

In addition to performance of vehicles and their trailers, ECE Regulations deal with prescribing design and/or performance requirements for type-approval of various vehicle systems, equipment and parts.

Braking of road vehicles and their trailers has an evident safety related importance. That is why braking regulation that brings the famous designation "ECE Reg. 13" is practically the first "vehicle performance" regulation introduced by the Group of Experts on Braking and Running Gear of the Working Party 29 under Inland Transportation Committee of the UN ECE for Europe. ECE Regulation No. 13, having the official title "Uniform provisions concerning the approval of vehicles with regard to braking" was first published in May 1969; the first revision was issued in December 1973.

The next revision is dated February 1979; this includes the 03 series of amendments. Following the 04 series of amendments dated August 1981, the 05 series of amendments dated February 1985 and the 06 series of amendments dated January 1990, another revision, i.e. a consolidated version was attempted during 1990. Since that time, the 07, 08 and 09 series of amendments have been published in June 1993, April 1994 and September 1995, respectively.
ECE Regulation No. 13 specifies construction and performance requirements for the approval of braking equipment of power-driven (motor) vehicles and trailers. The ECE vehicle categories were first defined in Reg. 13. However, because of their wider applicability in a number of ECE Regulations, they have been transferred to the so-called "Consolidated Resolution on the Construction of Vehicles (R.E.3)". Trailers are classified in four categories, with respect to their maximum weight:

O1 - trailers with maximum weight not exceeding 750 kg;

O2 - trailers with maximum weight above 750 kg, but not exceeding 3,5 t;

O3 - trailers with maximum weight above 3,5 t, but not exceeding 10 t; and

O4 - trailers with maximum weight above 10t.

Motorcycles and 3-wheelers were before included in Reg. 13, but in 1990 they were transferred into a new ECE Regulation No. 78. Reg. 13 is based on the separate or individual approval of motor vehicles and trailers and that is why the only vehicle combination prescriptions reports to the parking braking systems of towing vehicles.

3. Experimental support to the trailer braking system certification

One of the basic principles of the type-approval certification system of a vehicle is that the accredited technical or administrative authority undertakes a number of compliance checks to verify that the vehicle type in question fulfills prescribed construction and performance requirements. Such verification is usually realized in three steps:

(i) documentation audit with respect to the relevant data as declared by the manufacturer that are compared to the requirements or prescribed values,

(ii) verification of compliance of the practical status of design and other features of the submitted vehicle sample with manufacturer's declarations as defined by the above mentioned documentation also provided by the manufacturer, and

(iii) application of the prescribed type-approval tests so as to enable experimental verification of compliance of the vehicle performance with prescribed performance requirements.

Obviously, the type-approval certification system comprises audit and verification of data declared by the manufacturer and their realization on the vehicle for compliance checks with respect to the prescribed requirements.
Trailer braking system certification according to the type-approval principle as recognized in Europe by the countries applying "58 Agreement" within the United Nations Economic Commission for Europe or by the Member states of the European Union, i.e. with respect to ECE Reg. 13 or EU Directive 71/320 comprises the following mandatory braking system performance tests:

(i) Cold brake performance test or so called Type "O" test, with (a) cold brakes - brake temperature less than 100°C, (b) unladen and laden vehicles, (c) an initial vehicle speed of 60 km/h and (d) control line pressure not exceeding 6,5 bar. Minimum required performance must be more than 50% of maximum trailer weight for full trailers and more than 45% for semi-trailers.

(ii) Brake heating or brake fade test realized in several phases, and in particular:
(a) Type "I" test by continuous braking or laden vehicle drag test at constant vehicle speed of 40 km/h, where the energy output must be equivalent to that obtained with the fully laden vehicle on 1,7 km long 7% down-slope road;
(b) Type "II" test for long descents in the case of laden trailers of O4 category or laden vehicle drag test at constant vehicle speed of 30 km/h, where the energy output must be equivalent to that obtained with the fully laden vehicle on 6 km long 6% down-slope road;
(c) Type "III" test by repeated brake applications in the case of laden trailers of O4 category with initial vehicle speed of 60 km/h, 20 repeated brake applications under brake cycle duration of 20 seconds, where control line pressure should provide trailer deceleration of 3 m/s^2 at first application; the final vehicle speed at each brake application should be calculated with respect to the specific formulae.

(iii) Hot effectiveness tests that are similar to cold performance test except that temperature levels are different due to the fact that hot effectiveness tests are realized immediately after fade tests were accomplished.

(iv) Automatic brake tests in the case of the total pressure loss in air supply line for trailers of O3 and O4 categories, with an initial vehicle speed of 40 km/h, and when brake force must not be less than 13,5% of the trailer maximum axle weight.

(v) Parking or hill-holding test, where parking braking system must keep the vehicle stationary on 18% up&down hill gradient.

(vi) Anti-lock braking system tests following a specific procedure as defined in Annex 13 of ECE Regulation No. 13.

One should take into consideration that successful realization of the type-approval activities is rather difficult task, and that is why there is significant engineering responsibility in different phases of the design, development, fabrication and servicing of a vehicle. This responsibility is particular having that vehicle depends on a hierarchy: subsystems, subsubsystems, assemblies, subassemblies and components. Each of these can be designed and manufactured separately, and then assembled into a whole that serves given purpose. A large and complex problem is thus portioned into many smaller, manageable problems. However, effects on interactions among the many parts of the overall system must be taken into account during the engineering process [8], and particularly within the type-approval and COP. Because of all of that, there are cases in practice that during the type-approval procedure one or more compliance checks does not give results that may be accepted. Braking systems for road vehicles may be very complex. Beside that, their performance depend on a number of influencing factors, and majority of them are having stochastic nature. One may get evidence for it in a number of available reference [7, 15, 28-33].

Speaking in general, there are two possible situation with this respect: (i) an unsatisfactory test result has occurred during the type-approval procedure and therefore the cause for it must be identified; and (ii) the test authority discovers that there is a significant deviation in particulars as defined by the manufacturer when compared to those observed during the type-approval procedure.

The first of two cases may occur following the compliance checks in different phases of the type-approval procedure: audit of the documentation as supplied by the manufacturer, or comparison of the documentation dealing with the vehicle constructions as supplied with the practical realization of it on the vehicle sample, and/or comparison of the approval test results with the performance prescribed by the regulation.

Such a situation may refer to a vehicle as a whole but also to some of its components. This may be caused by the fact that not only vehicles but also their systems, like braking system, are complex technical systems, composed by a number of subsystems, subsubsystems and components. Because of that it is possible that (a) characteristics of the components that are mounted on the vehicle does not comply to the reference, or (b) the fit of a couple of components that are used to compose the system is not the appropriate one, or (c) that all necessary adjustments were not made in the way they should be done, etc. Of course, it is always possible provide additional tuning or other necessary adaptations so as to provide that the test result will become satisfactory for the subsequent application of the compliance check. Some typical examples for that are explained in [7].

The second of two cases as given above would be more feasible. As already explained, this case deals with the compliance checks as applied during the type-approval procedure showing the significant deviation of particulars given in the documentation in comparison to those obtained during the type-approval. This may be illustrated by a number of examples. It is important to understand that such an experience should be taken for the bases of the vehicle manufacturers strategic orientation towards a need to substantial application of own tests prior to the type-approval application. It would be the only way to increase the probability that all the declared particulars as contained in the type-approval documentation are real and not based on the uncertain predictions.

4. Examples of critical issues requiring experimental verification

The complexity of such a situation shall be illustrated by means of a number of practical examples from the type-approval experience with different vehicle types gained at the Faculty of Mechanical Engineering, University of Belgrade, for a time period of more than 10 years. Those examples are related to some critical issues in the trailer braking system type-approval process.

4.1. The first critical issue relates to the condition of brake under type-approval tests. Normally, it is assumed that only brakes that are bedded-in are capable of providing required performance and reliability characteristics. However, the procedure of bedding the brakes is not standardized, and there is a lot of evidence [6] that the way of applying the bedding procedure and its kind and type may significantly affect the result of type-approval checks.

4.2. The second critical issue deals with verification of cold brake performance, but the same may also be demonstrated in the case of hot brake performance. It is particularly interesting to point out that trailers braking system type-approval does not follow the same procedures like in the case of other vehicle categories. Trailers braking systems type-approval consists of the separate brake and/or axle certification procedure to which the whole vehicle type-approval is then associated, assuming that brakes and/or axles used on the vehicle are already type-approved. One of the most specific procedures that may be used for this purpose is brake inertia dynamometer testing of a given brake, following prescriptions given in Annex 11 of the ECE Regulation No. 13. In addition to the bedding-in procedure, first part of the test is designed so as to enable threshold value of the braking torque or deceleration over control line pressure to be determined. In the second part of the test heating procedure is applied and the fade and recovery characteristics of the tested brake are observed.

The requirements laid down in Annex 11 of the Regulation impose to the tested brake to be capable of producing the deceleration exceeding 5.0 m/s^2 when the applied control line pressure does not exceed 6,5 bar. The possible situation is demonstrated by means of a graph shown in Figure 2, where line "A" designates the acceptable character of deceleration flow for given pressure values. On the other hand, line "B" in the same figure has the character which is not to be accepted.

It may be seen that the difference between two characters is not high, but it may be easily demonstrated that such a situation may occur, for example, in the case where two different friction materials are intended to be used in the same brake. The same may also be obtained in the case that particulars as declared by the vehicle manufacturer, following which the line "A" is drawn, does not comply to the test results obtained under type-approval to which the line "B" may correspond.

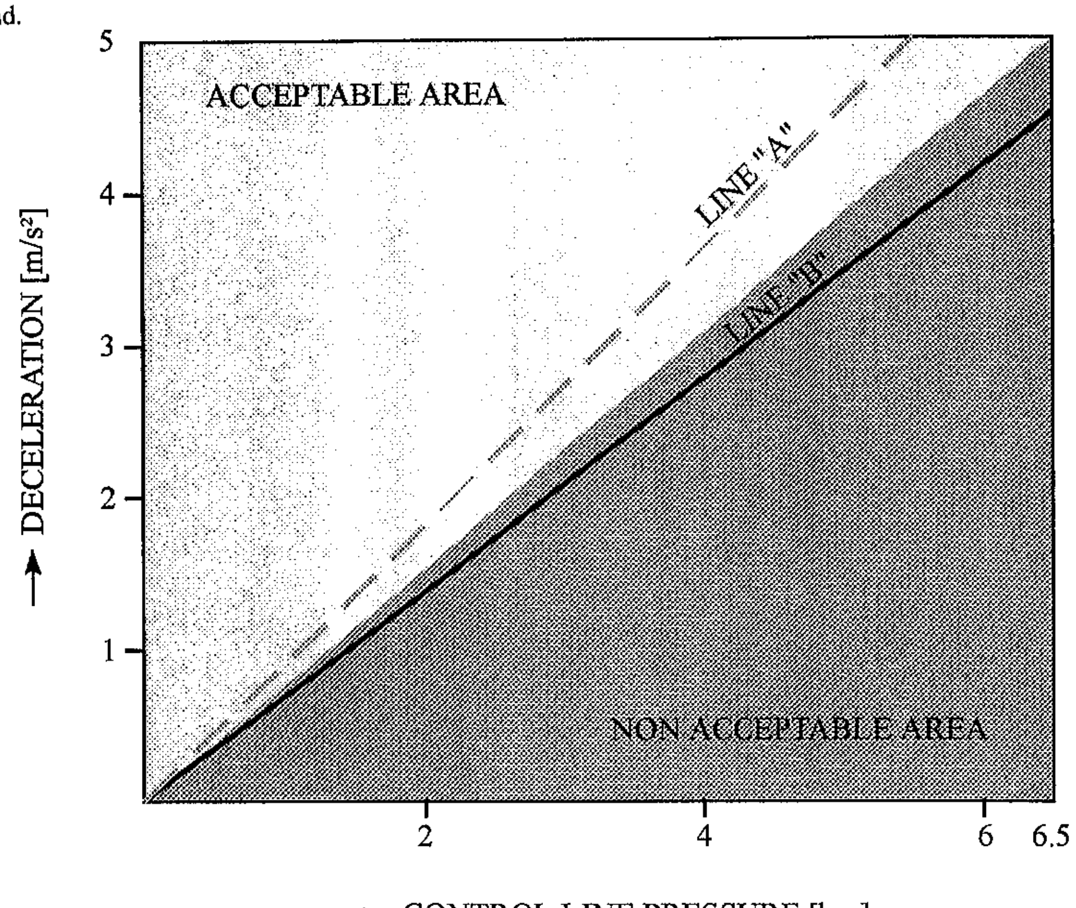

Figure 2. Evaluation of threshold torque over line pressure

4.3. The third critical issue relates to the so called "compatibility bands", prescribed to deal with the compatibility between motor vehicle and its trailer. ECE limits are shown in Figure 3, and its is prescribed that the line representing braking ratio over control line pressure should lie between the upper and the lower limits. However, example given in Figure 3a shows that although the line corresponding to nominal values as declared by the manufacturer lies within prescribed area, it is possible to change this situation under test conditions. Such an unexpected decrease in braking ratio may be caused by the total losses in the braking system control associated to the losses in transmission and brakes. If that would be the case, there will be a new line that will not satisfy the requirement because it will cross the lower limit line. In Figure 3a two lines of that kind are shown to illustrate the influence of possible total losses of 25% and 50%, respectively.

Figure 3b shows that the similar problem may occur if the real value of braking force distribution become higher than declared for about 20% - if that would be the case, the line representing braking ratio over control line pressure will be above the upper limit.

Figure 3a

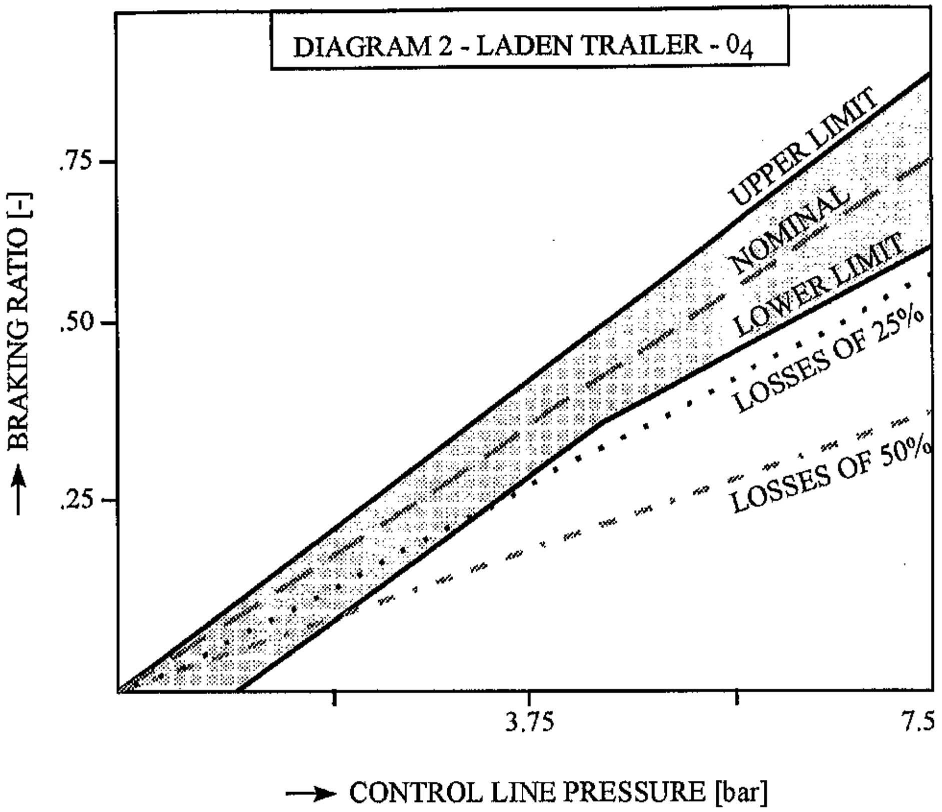

Figure 3b

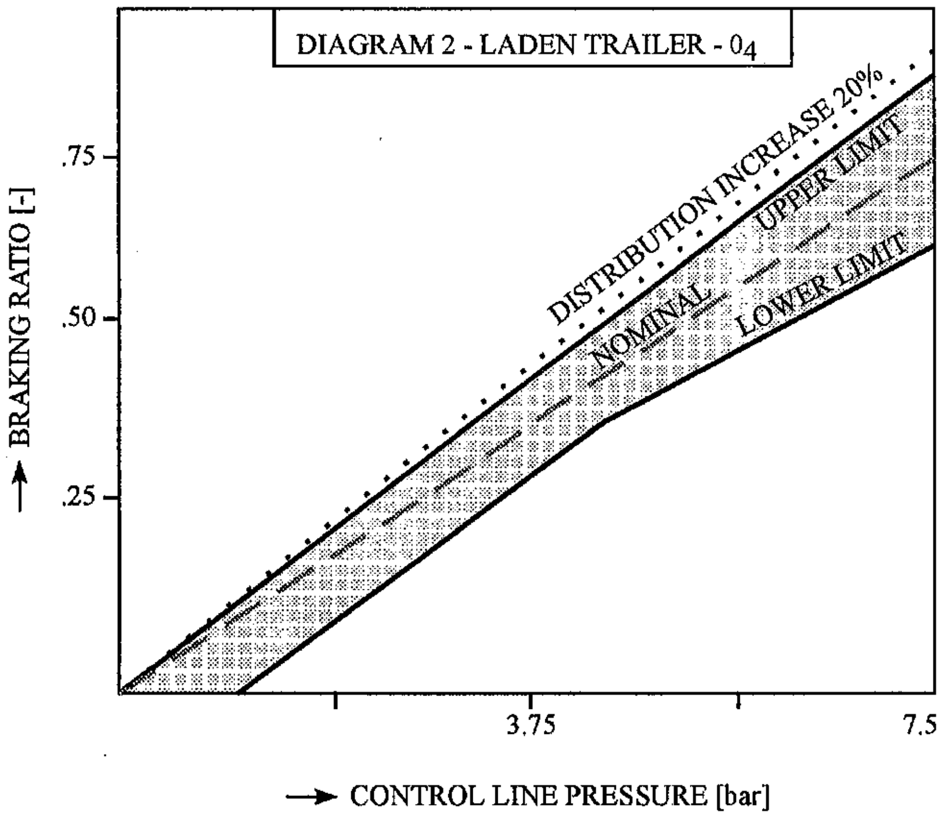

Figure 3. Compatibility bands

Figure 4a

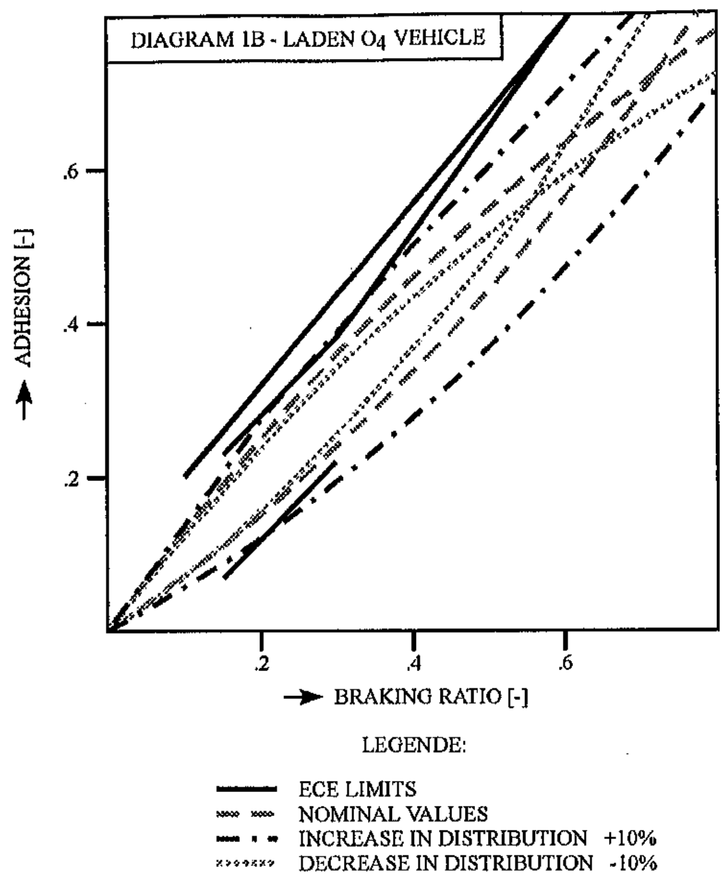

Figure 4b

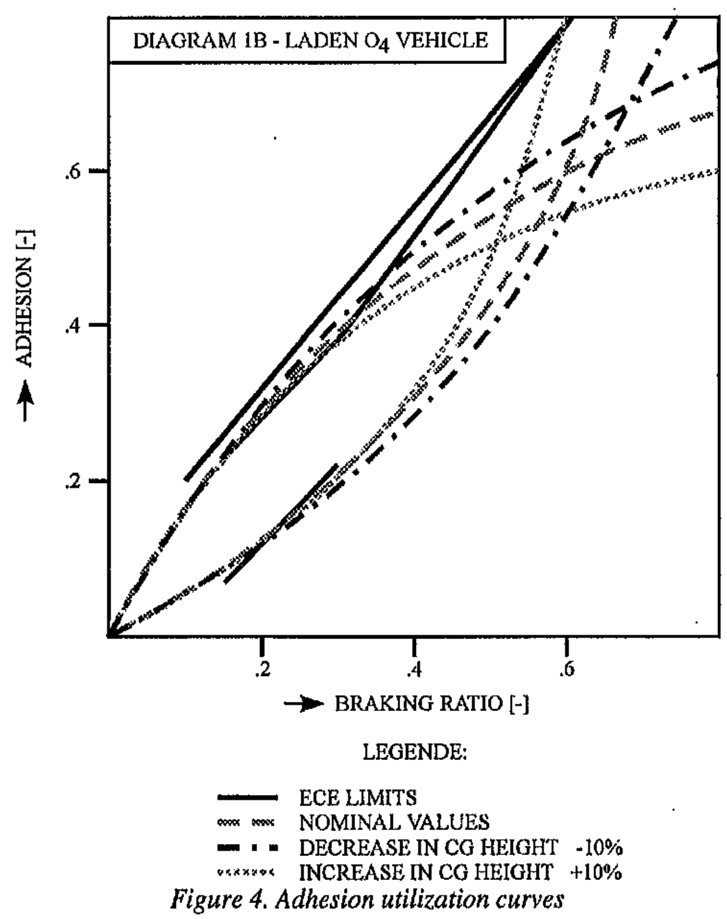

Figure 4. Adhesion utilization curves

4.4. The forth critical issue deals with the adhesion utilization curves, as shown in Figure 4. Stability of a vehicle during braking is supposed to be maintained if the adhesion utilization curves calculated and plotted for front and rear axle of a vehicle satisfy conditions prescribed for a given vehicle categories in Annex 10 of ECE Reg. 13. In the case of trailers of category O_4, such requirement are the same as for vehicles other than M1/N1 categories. Diagram in Figure 4a shows the influence of deviation in braking force distribution factor. It is well known from experience that such deviations are possible and realistic and that they may be produced by deviations in friction or brake factor, internal and external mechanical brake losses, and a number of other design parameters. The diagram shows deviation in adhesion utilization curves caused by the increase in the brake force distribution factor for 10% and the decrease in the brake force distribution factor also for 10%.

In Figure 4b similar variations are shown. In this case the change in position of the center of gravity is analyzed. The diagram shows what possible impact may be given to the increase in the center of gravity (CG) height for 10% and to the decrease of the same quantity also for 10%.

5. Conclusion

Certification of trailer braking systems should provide verification of fulfillment of all relevant design requirements associated with theoretical and experimental performance evaluation. Laboratory and road tests should be combined in such a way to enable the best quality versus cost effectiveness ratio. The above illustrated critical issues show that the time for "cut-and-try" engineering has already elapsed and that more sophisticated methods must be applied. "High-tech" is required to provide this. That is why the technology is now attaining the unimagined height.

High technology providing high quality is called "Integrated Engineering" and defined as a new concept integrating the ideas, methodologies and tools of Simultaneous Engineering and Total Quality Management, where tools are connected with a complete Information Management System and based upon the Computer Aided and Computer Integrated Techniques [23], that emphasize modelling and analysis. More often, this new philosophy of providing quality is called "Systems Engineering" [2, 8, 11, 20-26].

However, no amount of analysis in the design can substitute entirely for laboratory and track testing. This phase should (a) verify that the vehicle as a whole satisfies all its system-level requirements, and trace all shortcomings to their source, (b) measure all significant as-built vehicle characteristics, especially those for which good models do not exist and (c) validate and/or calibrate models used in the vehicle development so that the effect of future modifications can be predicted with confidence [21].

Besides external requirements from the customer's direct needs, manufacturers have to face with government or supra-governmental regulations, and that is why the manufacturer may not act "à posteriori". He will not be allowed to wait for the customer or the governmental authority to bring the judgment on the product after its life cycle was ended, or type-approval certification gave unsatisfactory result. Otherwise significant delay is to be made in undertaking necessary corrections to the product and to align its performance and operation to the requirements. So what manufacturer needs? He needs an "à priori" approach, based upon updated engineering techniques to understand all critical points in the design and manufacture of a product and to include them in all phases of the life cycle of a product.

Quality is the only overall "performance" of a product by which manufacturers can meet the needs of customer. The requirement for quality is to develop, design, produce and service products that work better, look better, last longer, are lighter, cost less, spare energy, are safer, do not disturb the environment [2].

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