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FAILURE ANALYSIS OF LIGHT COMMERCIAL VEHICLES' BRAKING SYSTEM

Abstract: *The description of the fault tree analysis is given in the introductory part of the paper, and it is pointed out the significance of the system for braking motor vehicles on the safety of people in traffic. A brief overview of the methodology of this method is then followed. The basic structure and the function of each subsystem during realization of given tasks are given in the part of the paper related to the brake system. Considering the example of the total failure of the brake system, it has been shown how to acquire a block-diagram of the observed system's reliability based on the formed fault tree. In order to be acquainted with the brake system from the aspect of failure occurrence and to record the largest possible number of potential failure modes of the constituent elements, the fault tree for the peak event "Reduction of the performance of the brake system" has been formed. In conclusion, the paper presents possible applications of the achieved results.*

Keywords: *Fault Tree Analysis, Light commercial vehicles, Braking system*

1. Introduction

The Fault Tree Analysis - FTA is one of the basic and most commonly used methods for analysing the safety and reliability of technical systems (Ericson, 1999; Bertsche, 2008). FTA is a deductive method, where for the defined top event, which represents a failure of the considered structural unit of a system the possible causes that lead to itare defined. The method can be applied both in the development phase and during the exploitation of the system. The obtained results and conclusions can be used for the design of products and production processes, control and testing, maintenance, etc. This method is especially convenient for the reliability and safety analysis of systems whose failures might cause catastrophic consequences for mankind and environment.

For all means of transportation, safety aspect isparticularly important. Increasing safety can be achieved by taking measures to prevent an accident (active safety) or, if necessary, by taking measures to minimize the consequences (passive safety) in the event of an accident. Based on the research conducted in Germany (Todorović, 1988), the percentage participation of the failure of motor vehicle's individual systems, as a cause in the total number of traffic accidents, was determined. The greatest influence on the active safety of the motor vehicles in traffic has a braking system.

2. The Fault tree analysis

Fault Tree Analysis method was developed

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in the early sixties of the 20th century in the United States. The conceptual designer of the method is H. A. Watson of the Bell Telephone Laboratories Company (Ericsson, 1981). From the mid-sixties of the last century to the present, the Fault Tree Analysis method has been widely applied to research reliability, safety and diagnostics of the failure of a large number of complex technical systems.

The methodology of the Fault Tree Analysis includes (Ćatić, 2005; Ćatić, 2014a):

1. Defining the technical system;
2. Determination of the limits and objectives of the technical system;
3. Defining a top event;
4. Systematic collection of the data related to the system and their analysis;
5. Forming a fault tree for a specified top event;
6. Checking and accepting a fault tree;
7. Qualitative and/or quantitative analysis;
8. Reviewing the results and checking their compatibility and matching the required results;
9. Adopting the results and
10. Presenting results and suggesting corrective measures.

3. Braking system of motor vehicles

An important part of the motor vehicle technology relates to braking. The ability of a vehicle to decelerate is one of the primary components of the preventive-active safety.

Speed of the motor vehicle in certain traffic conditions, as well as the maximum speed on the open road, depends on the efficiency of the braking devices and the possibility of stopping a motor vehicle in the shortest possible distance. Vehicle with better braking performances may develop in service a higher average speed. Therefore, the braking characteristics of the vehicle can be considered an important part of the overall dynamic characteristics of the vehicle.

The braking systems of modern motor vehicles and trailers must satisfy numerous quality requirements imposed by legal obligations from the point of view of traffic safety, then by the development of vehicles and their applications, technology development, development of new materials, economic constraints, competition, etc. (Todorović, 1988). The degree of satisfaction of all these requirements is a measure of the quality of the braking system. Generally speaking, the quality of the braking system can be expressed as the probability of meeting the target function in the given time and under given working conditions, or as the so-called effectiveness.

Braking system is a typical example of a complex system of motor vehicles, whose structure is determined by a complex objective function and certain current international and national regulations on the safety of vehicles in traffic. The main subsystems of the braking system are: service brake, secondary brake, parking brake and an additional brake or retarder.

The term "brake" in the names of individual subsystems has conditionally, i.e. adopted meaning. In this case, it involves the entire subsystem with the specific purpose (for service, auxiliary, parking or additional braking), not just brake as the executive mechanical device of the braking system, as well as each subsystem individually.

Service brake takes over performing the most important tasks of the braking system, i.e. braking with the maximum deceleration (in case of emergency) and all mild, short braking under normal moving conditions. The auxiliary or emergency brake is introduced solely to increase the security of the vehicle in traffic, i.e. in order to achieve higher reliability of the braking system. Its mission is to provide an opportunity for braking the vehicle in case if there is a failure in the service brake subsystem.

Parking brake has a task to provide permanent braking-holding the vehicle in place, so-called the parking brake. In addition, it is used for starting the vehicle on

a hill. If this brake is designed so that it can be also activated during the movement of vehicles, which is commonly the case, the parking brake can take over tasks of the secondary-emergency brake. In this case, the emergency and parking brake are one same subsystem.

Additional brake or retarder has a task to provide slightly, prolonged braking while vehicle moving on longer downs, with the goal of moving vehicles approximately with constant speed. Mandatory presence of the additional brake is prescribed only for vehicles with greater total mass.

Subsystems of the braking system are structurally design basically in the same way, and they include the same functional components: command, transmission mechanism and brakes.

The command pedal/lever serves to activate the appropriate brake system subsystem. The transmission mechanism has the task of transferring the received impulse from the command to the executive organs - the brake and in this way to provide the necessary slowdown or braking of the vehicle. Effective performance of this task significantly affects the overall performance of the vehicle in terms of braking. The brakes are the executive organs of the braking system, through which their tasks are realized. Therefore, their importance within the braking system is particularly pronounced. Basically, brakes are friction mechanisms that convert the kinetic energy of the vehicle into heat.

4. Fault tree of the braking system

In order to successfully complete the braking task of motor vehicles, at least two basic conditions must be met:

- the braking system should operate properly and
- the conditions of adhesion between the tire and the ground should enable the vehicle to slow down.

In addition to the above, there are other factors that determine the execution of a braking task, such as driver response, traffic conditions, etc. However, the first two conditions are characteristic of the two basic types of braking system's failure that determines the reliability of the system that is, the reliability of the execution of the braking task:

- internal failures, i.e. failures due to malfunction of the constituent elements of the system, and
- external failures or failure of adhesion, which are associated with the phenomenon in contact between the tire and the ground.

In most cases, these two types of cancellations may be regarded as mutually independent. Furthermore, only internal failures of the braking system, which result in complete or partial non-performance of the braking mission, is considered.

In order to get to know the braking system of light commercial vehicles better from the aspect of failure, an analysis of this system was made using the FTA method. Forming of the fault tree is done by using the symbols for events, logic gates and transmission (Ćatić, 2014a). A number of different symbols are used for events that indicate whether it is a complex or basic initiating events. The rectangle is used for complex events. Among the symbols used for basic events most commonly used is the circuit, which signifies the state of an element of the system conditioned by its characteristics, and rhombus, which indicates an undeveloped event. Logical symbols in the fault tree signify mutual conditionality and correlation of lower and higher levels events. For example, the "OR" logic gate produces output if one or more input events have happened. In contrast, "AND" logic gate produces output only if all input events occur.

If a "Complete failure of the braking system of the motor vehicle" is adopted for a topevent in the fault tree, the fault tree is

shown in Figure 1.

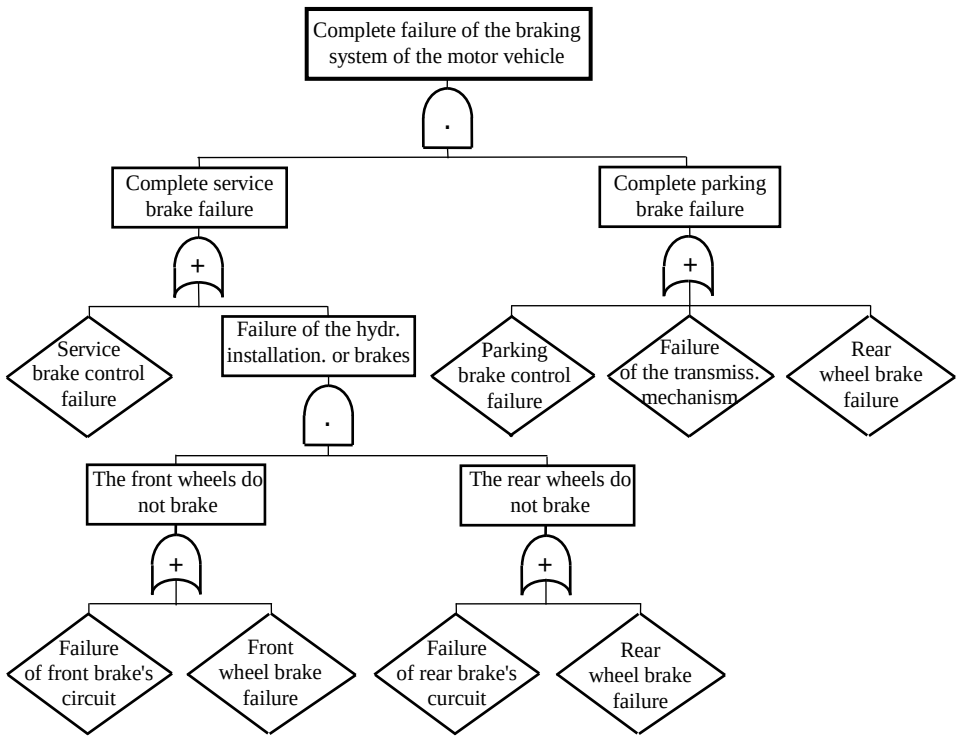

Figure 1. Fault tree for a top event "Complete failure of the brake system of the motor vehicle"

The fault tree (Figure 1) is significant because it simply comes to the block diagram of the reliability of the motor vehicle's braking system. Thus, based on the presence of the "AND" gate (corresponding to the parallel link of the components) and "OR" gate (corresponding to the sequential link of the components), the block diagram of reliability is obtained, which is shown in Figure 2. When forming a block diagram of reliability, it is taken into account that the rear wheel brakes are executive bodies both for service and parking brakes.

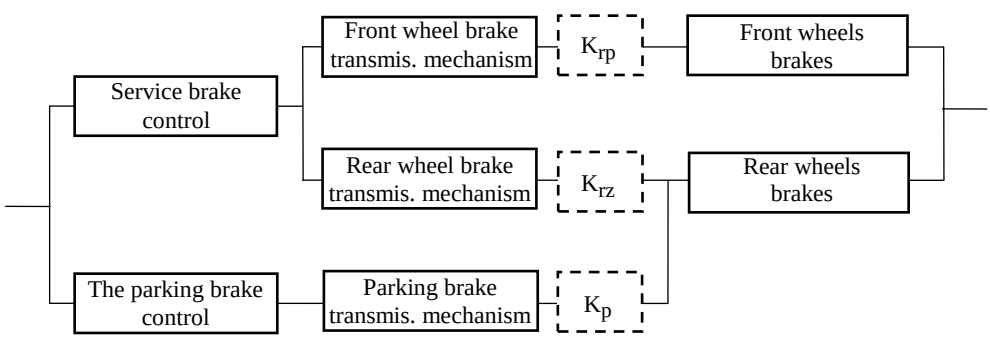

Figure 2. Block diagram of reliability of motor vehicle's braking system

In the case of a braking system of motor vehicles, the failure of one of the circuits (brake lines) or the entire service brake subsystem reduces the performance. Therefore, in the block diagram of reliability, which is shown in Figure 3, the fictional elements Krp, Krz and Kp are included, which symbolize the existence of quasi-parallel connections. Due to the complexity of the structure, a complete failure of the braking system is rare. The majority of failure modes of constituent elements lead to partial failure of this system. In order to carry out detailed analysis of the failure of the braking system elements, the fault tree is formed for the top event "Reducing the performance of the braking system of the motor vehicle", as shown in Figure 3. If the brake system performance parameters go outside the boundaries, this is assumed to be the top event in the fault tree. In Figure 3, only the indirect event "Failure of hydraulic installation" is only developed to basic events. The remaining parts of the fault tree marked with symbols for transmission were given as part of a comprehensive analysis of the criticality of the elements of the braking system for light commercial vehicles in the reference (Ćatić, 2005).

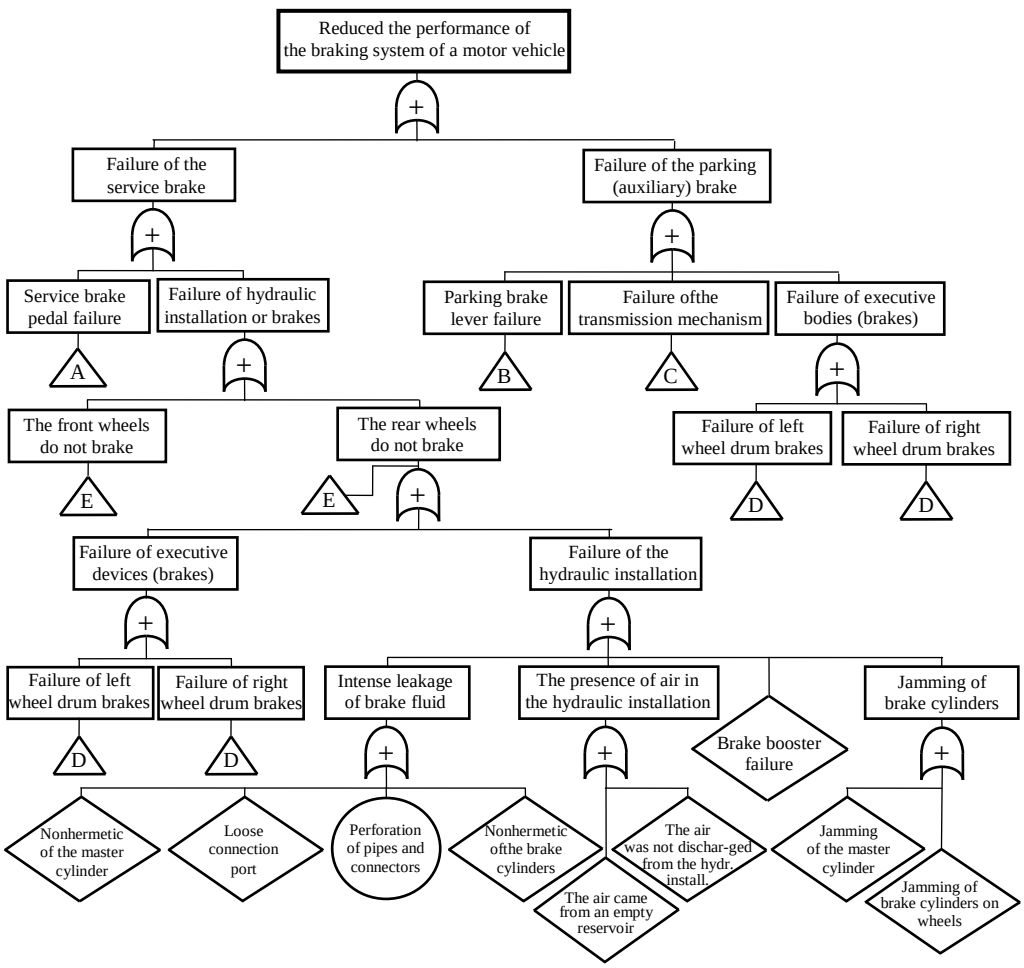

Figure 3. Fault tree for a top event "Reducing the performance of the braking system of MV"

In order to simplify the structure of the fault tree of commercial vehicle's brake system, it has been assumed that an indirect event marked with E ("The front wheels do not brake") has the same development up to basic events as the "The rear wheels do not brake" event. Furthermore, the braking force regulator located in the hydraulic installation of the rear wheels is disconnected from the analysis.

In the fault tree shown in Figure 3, the drum brake failure is an indirect event, which leads to the occurrence of an undesired top event. Since drum brakes of the same type are used on the front and rear wheels of the vehicles under consideration, and in addition, the rear wheel brakes are common for both the service and parking brake, the indirect event "Failure of drum brake" occurs six times in total. Based on this, it can be concluded that the reliability of the braking system depends on the reliability of the drum brakes. In the paper (Ćatić, 2014b) a detailed analysis of the criticality of the elements of the drum brake was performed.

5. Conclusion

The application of the FTA method enables a detailed comprehension of the considered machine system from the point of failure. Developing a top event in a fault tree to basic primary and secondary events, provides a qualitative and quantitative analysis. By forming a fault tree for a sufficiently general top event, most of the system failures can be recorded, which can be used as the basis for the Failure Mode and Effects Analysis - FMEA. Causal defining the state of the system that leads to failure can be used for maintenance purposes, for the diagnosis of the cause of the failure.

The complexity of the approach and the scope of the outputs ranked FTA method in the group of unavoidable methods in the program of quality assurance of technical systems.

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