July 2013. Vol. 4, No. 1 ISSN2305-8269
International Journal of Engineering and Applied Sciences

www.eaas-journal.org

ANALYSIS OF CAUSES AND MODES OF FAILURE OF AIR CONDITIONER AND DC ELECTRIC-VENTILATOR, AS PARTS OF AUTOMOTIVE AIR CONDITIONING SYSTEM

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ABSTRACT

Using the method of Fault Tree Analysis (FTA), in this paper, are analyzed the causes and modes of failure of air conditioners and automotive DC electro-ventilator, as part of automotive air conditioning system. Primarily, there was given a description of FTA method and of the importance of air conditioners and DC electro-ventilators in nowadays automotive industry. Secondly, based on a detailed analysis of the structure and functioning of the observed object, and other relevant data, are presented the FTA analysis of DC electro-ventilator. In this way, has been established a logical relation between the peak and the basic initiating events in the fault tree. In conclusion, the paper presents possible applications of the obtained results.

Key words: Fault Tree Analysis (FTA), DC electro-ventilator.

1. INTRODUCTION

Fault Tree Analysis (FTA) is one of the basic and the most common method for analyzing the safety and reliability of the technical systems. It is a deductive method at which, for a defined peak event, in the form of layoffs, are considering the structural system as a whole and determines the causal events that led up to it. The basis of FTA represents a translation of physical systems to the structural logic diagrams.

FTA method was developed in the early sixties of the 20th century in the United States. The creator of this method is Watson (H.A. Watson), from the company "Bell Telephone Laboratories". Over 1961 and 1962, he was developed and applied this method to the analysis of security systems for launch of rockets "Minuteman" for the purpose of the Air Force of the United States.
The first published papers, related to this subject, are the papers of Haasal, Shreder and Jackson (D.F. Haasal, R.J. Shreder and V.R. Jackson (1965)) from the "Boeing" company, presented at a symposium of the reliability at the State University of Washington in 1965. This year is also considered as the momentum when the FTA method got its present form. Therefore, in the literature from the subject area can be found that the formalization of the structural design of fault tree, Haasal made in 1965.

FTA method is used in the formation of logical – probabilistic graphical model of reliability. It allows the study of the causal connection between failures of different elements. Therefore, by using fault tree, it can be simultaneously analyzed the reliability and safety of operation and determined appropriate measures to improve these indicators at all stages of the product lifecycle.
In the early design stage, formation of the fault tree allows the identification of potential failure modes; determine their causes and the connection between them. With the development of the project, fault tree is gradually developed and configured to cover all the changes in the project. Based on the results of FTA analysis, can be identified the critical elements of mechanical systems which have restrictive effect on reliable and secure operation of the system.
Ranking of the critical components allows to the constructor to focusing attention on the elements that have the strongest impact on reliability. Therefore, he can easily take measures to minimize, or completely

eliminate the cause of failure. In addition, the results can be also used in the abbreviated test for reliability assessment.

2. FTA METHODOLOGY

At the beginning of the analysis of the reliability of technical systems using FTA, should be defined and determined limits and goals of the system. For practical reasons, there need to be listed all the assumptions related to the system which will be used in future work. Peak event in the fault tree, depending on the analyzed system, may be general (in the form of cancellation or proper operation of the system), or specific (if it involves only a state of the system or its components).
Careful selection of the peak event is very important for the success of the analysis. If the event is too general, the analysis becomes cumbersome and it cannot be controlled. Otherwise, if the event is too specific, the analysis does not set a good enough insight into the system.
Peak event must be fully defined so that causal events could clearly be recognized [5].

From the analyst is required that, before join to the formation of the fault tree, they must studied system very well, from the standpoint of structure, mode of operation and the relationship between the components. The basis for this is a collection of information contained in catalogs, maintenance manuals, user complaints, etc.
Only a full understanding of how the system and its components operate, as well as knowledge of their mutual relationships, allows the implementation of logical analysis that defines the necessary and sufficient conditions for the realization of peak events.

The methodology of reliability analysis of technical systems using the fault tree includes:
1. Defining the technical system,
2. Definition of limits and objectives of technical systems,
3. Definition of peak events,
4. Systematic data collection and analysis,
5. Forming event tree for the identified peak event,
6. Review and adoption of the event tree,
7. Qualitative and/or quantitative analysis,
8. Discuss the results and check for completeness and conformity with the requirements,
9. Adoption of the results, and
10. Presentation of results and proposal of corrective measures.

In the early stages of design, function block diagram (Figure 1), can serve as the basis for the formation of the fault tree.

In addition, functional analysis of the structural units of technical systems and the development of a functional block diagram is implemented as follows [4]:

• Identify the components of the system and describes how their work
• allocate all the elements of the lowest structural levels and describes their basic functions,
• Identify all inputs and outputs of the system and summarized their relationship with other systems and
• Constructs a functional block diagram of a system that shows how the components are connected to each other, clearly defined external system connections.

The most commonly used symbols for the formation of the fault tree are given in Table 1 [2]. Power of the fault tree symbolism lies in the fact that the symbols for the events, associated with logic gates, can be easily translated into algebraic expressions.
For events are using a number of different symbols that indicate whether it is a complex or basic initiating events. For complex events is used the rectangle.
Of the symbols of basic events is commonly used circuit, which indicates the state of the system elements, conditioned on its characteristics, and the diamond, which means undeveloped event.
Number of diamond symbols in the event tree shows the depth of the analysis. The logical symbols in the tree of events marked influence and connection between events of lower and higher levels.

The symbols for transmission, in the form of triangles with identification mark (letter) within them, allow the formation of complex tree failures in the form of the parent trees and a number of sub-trees. In addition, if there are parts of the fault tree, which are identical, the use of these symbols avoids unnecessary duplication of parts of the tree, and thus achieves a saving in space and visibility of the tree.
When the fault tree is completed, it is systematically analyzed in order to understand the logic of relations between events, and to better understand the different states of the system.

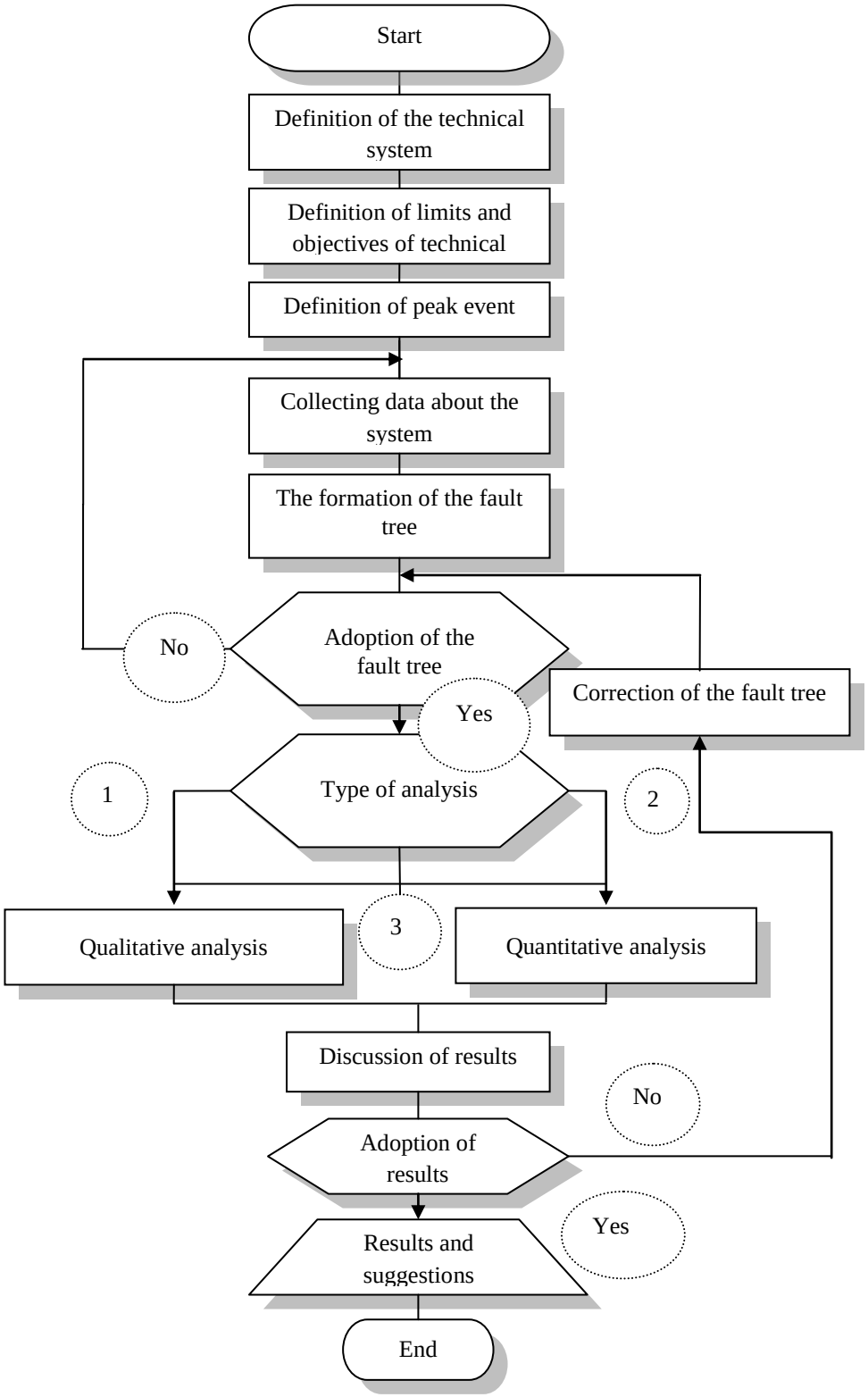


Figure 1: Block diagram of the methodology of reliability analysis of technical systems (fault tree)

If it is a fault tree, the analysis should focus on the failures whose probability of occurrence is greatest. If the fault tree does not reflect the real situation or all significant events are not covered, or there is no logical connection between base and peak events, then is needed to perform further data collection system and modification of the fault tree. To eliminate subjectivity in the evaluation of the fault tree, it is necessary to include the people who are familiar with the method used and with the object of research and who were not directly involved in the development of the tree.
Upon approval of the fault tree, depending on the ultimate goal of this method can be performed qualitative and/or quantitative analysis.

Qualitative analysis of the fault tree is a broad term. Besides establishing and logical analysis of the fault tree, it means determining a set of minimum cross-section of events, common cause analysis and other analysis [1].
Determination of minimum cross-section set of events forms the basis for most of the fault tree analysis of quantitative nature. The intersection of the event is a basic event, or a combination of basic events, whose occurrence leads to the peak event.
At the *fault tree*, such cross-section is called "disjunctive set", because it leads to failure, and at the *proper operation tree*, "component set" (path, trail) because it allows the successful operation of the system [6].
Minimum cross-section of events is the intersection of basic events that cannot be reduced, but still leads to the peak event. Similarly, a set of minimum cross-section of the event is such a set, which consisting of all minimal cross sections of the event for a one tree that can be reduced [3].

From the procedures of quantitative event tree analysis, in practice is commonly used: ranking (comparison) of the base events according to the structural importance, ranking of basic events according to the importance in terms of probability of occurrence, and determination of the probability of occurrence of events, according to the probability of basic event.
Structural importance of the basic events in the fault tree is determined by the number of its occurrence in the minimum cross-section of events, and by the number of members in these sections. It is important to note that this measure does not depend on the probability of occurrence of the event. The importance of basic events in terms of the probability of occurrence is determined by measuring the impact of changes in the probability of its occurrence on the probability of occurrence of the peak of the event.
If the results of the qualitative and/or quantitative analyzes are not complete, or they are caused by the existence of principal errors by changing event tree, it is necessary to correct event tree in order to eliminate identified deficiencies.
Based on the obtained and adopted results, through the event tree, arising proposals for corrective measures, in order to eliminate deficiencies or suggestions of alternative solutions. There may also become decisions about the control of the production process or about taking risks.

Depending on the method of grouping underlying causes of peak events, as well as on the methods of defining the sub-peak events, there are three possibilities for the formation of event tree. In the first case, intermediate events in the event tree, are the states of the corresponding structural units (hardware-structural approach).
In the second case, the events that described the way on which the event has occurred at the exit of logic gates are those, which are common to several elements regardless of the structural background (functional approach).
The third option is a combination of the previous two.
The first method of forming event tree is suitable for obtaining the reliability block diagram of the considered system and for analyzes of the modes and effects of failure (FMEA) of its elements.
Another method can be used in the analysis of common cause basic events. In all cases, the basic events are the same.

3. FTA OF AIR CONDITIONER AND ELECTRIC-VENTILATOR (FAN)

The main objective of the formation of the fault tree of automotive air conditioner is a detailed analysis of potential failures, and modes of failure, of recording elements of these systems.
Cancellation of these systems may occur or due to some internal clients or external failure. External failures may occur due to failure of some external elements that are not part of the cooling system.
At the other side, internal failure of the air conditioner may occur due to: loss of function of electric motors - electric fans, compressors, valves, low or high pressure valves, expansion valves, condensers, evaporators or coolant reservoir. Compressor, as subassembly of the air conditioning system, consists of electric motors, pistons or snail (depending on type) and valves.

The compressor may lose the function for a number of reasons, most often due to prolonged usage or hidden defects. In any case, the repair is not possible, but only replacement. The reason for failure can be cancellation of the electric motors, bad leaks or insufficient pressure created due to the large piston gap between the piston rings and cylinder. The cause of the broken pipe is an error that can occur for many reasons: because of the poor quality of the pipe (copper or aluminum), impossible or fluid circulation and aging pipes... Cancellations as a condenser or evaporator leakage occurs due to mechanical failures. In case of cancellation of valve repair is not possible, replaced with a new one.

Fault tree for car air conditioners is given in Figure 2.

3.1. Fault Tree for Electric Motor of Air Conditioner

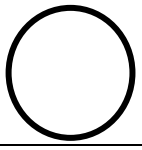
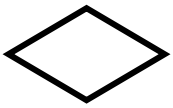
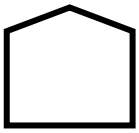
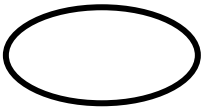
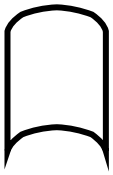
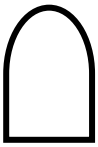
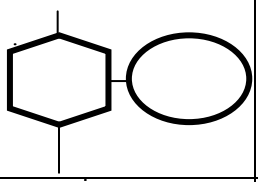
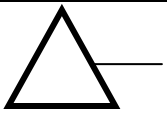
Most essential subsystem of the electric fan is a collector electric motor. Cancellation of the electric motor at electric fan can cause catastrophic failure of internal combustion engine.
With electric motors – electric fans in the system of cooling the liquid at the combustion engines, and automobile air conditioners may appear full or partial cancellations. (Figure 3)
Failures that lead to a reduction of torque commonly referred to as dismissal of friction. Failures can occur due to friction wear of the friction surfaces, material inhomogeneity, surface dirt or grease, etc.
Total failures occur when the electric motor cannot achieve starting torque, because of: rolling bearing cancellation, joint failure of collector wires, collector worn brushes or deformation of parts assembly.

In the case of partial failure, performance of electric motor are significantly deteriorated. This is manifested by reducing the torque, generated below the prescribed requirements.
Electric motor with brushes, for cooling the coolant combustion engines and air-conditioning system is irreparable. For this product, for its purpose and according its required quality, is not foreseen repair during operation. This means that, during the planned service life, it must achieved working characteristics provided by the technical requirements. Production trend in the collector electric motor, is that it must satsfy the 1000 ppm, that means that at million produced engines can only be a one failure.

Possible failures of electric motor are: mechanical connection interruption, power failure, reducing the time allowed under the appearance of vibrations...
The mechanical connection is achieved by linking the electric motor to the "konfuzor" by screws or rivets. This used bolts, that are welded to the engine mounts, can be broken due the waken material, welding defects in material (hidden defect) or an increased clearance in brackets confusion.
Ties that can also cause cancellation is failure of the pins that connects the motor and the propeller. Now is mainly used elastic pins, whose possible cancellation comes due to defects in material (hidden defects) or larger hole on the shaft.
Breaking of the propeller can be caused due to refraction screws or pins, and also due to contact, for example, with a part of the combustion engine (belt and so on.) or other foreign body. This cancellation leads to the destruction of electric motors, like the previous two.
Interruption of power supply is primarly caused by cable (+) and (-) which can be oxidized at the ends or falling off.

Cancellation of an alternator is a serious problem that can even lead to car's ignition. This fix it, so it will not necessary cause the immediate stopping of the vehicle.
Reduced torque (in case of electric motor with brushes) can be caused by: failure of the bearings, worn brushes, collector and cold weld wire, and forming parts of the assembly.
The appearance of the vibration is a failure that occur very rarely, only if there is damage on electric motor and impellers (propeller), leading to a drastic reduction in the life of an electric motor. These errors are very rare during the service life of electric motors and have a lower probability of failure compared to the brush wear and bearing cancellation.
Wear (deterioration) of brushes is the most complex problem, because it may be due to several reasons: poor materials or brush collector, collector of poor treatment, lack of heat dissipation due to the brush design brush holders to prevent it. As a result of temperature increase, above the allowed, due to failure (lock) beds, cold solder or worn brushes, it is possible deformation of some parts of electric motor.
An important characteristic of every material is also the intensity of wear. From this material properties depend on the life of EM [2].

Table 1 : Symbols for events, logic gates and transmission

The symbol name	Graphical representation	Description
Peak or intermediate event		The rectangle indicates the event at the exit of logic gates (peak or indirect), which occurs as a result of a logical combination of input events. It contains a description of the event.
Basic primary (original) event		The circle indicates the basic initiating event that requires further development. Independent event that is only used as input to the logic gate. Represents the end of the tree at that point.
Basic secondary (undeveloped) event		Diamond indicates an event that has not been developed to their own designs because of lack of necessary information, or the significance of small consequence, or avoiding parallel analysis.
Normally expected event		"Lodge" means the expected event, whose occurrence is normally expected during normal operation of the technical system, in the projected operating conditions, and can cause a peak event.
Conditional event		"Oval" describes a conditional event that is defined in the form of specific conditions or limitations. Usually used in conjunction with logic gates.
"Or" gates		Logic gate produces output if it does one or more of the input events. (Output event gate 'or' happens if there is a least one input event). Graphic symbol contains an identification sign "+" or "OR".
"And" gate		Logic gate that produces output only if all input events occur. (Output event gate "and" happens then and only then when it happens all the input events). Graphic symbol contains an identification mark "." Or "AND".
Blocking gateway		Input event in blocking logic gate leading to the realization of the output event only if it is satisfied a conditional event.
Transfer "in"		Indicates that the tree is further developed in the event of the appropriate transfer "in" (marked the same identification with a capital letter).
Transfer "from"		Indicates that this part of the event tree must be connected to the appropriate transfer "from" (marked the same identification with a capital letter).

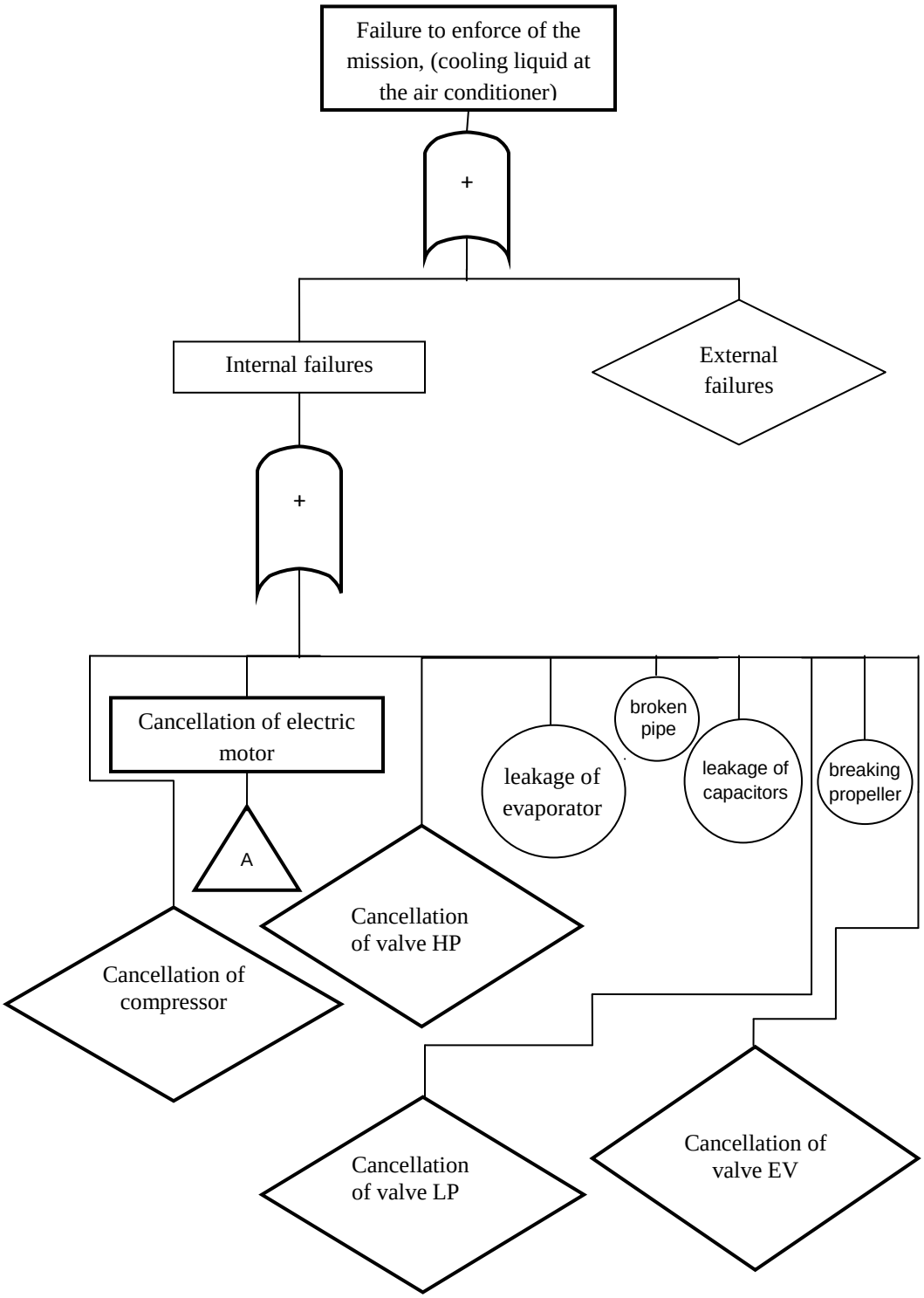


Figure 2 : Fault tree for for the peak event "Failure to enforce of the mission- cooling liquid at the air conditioner".

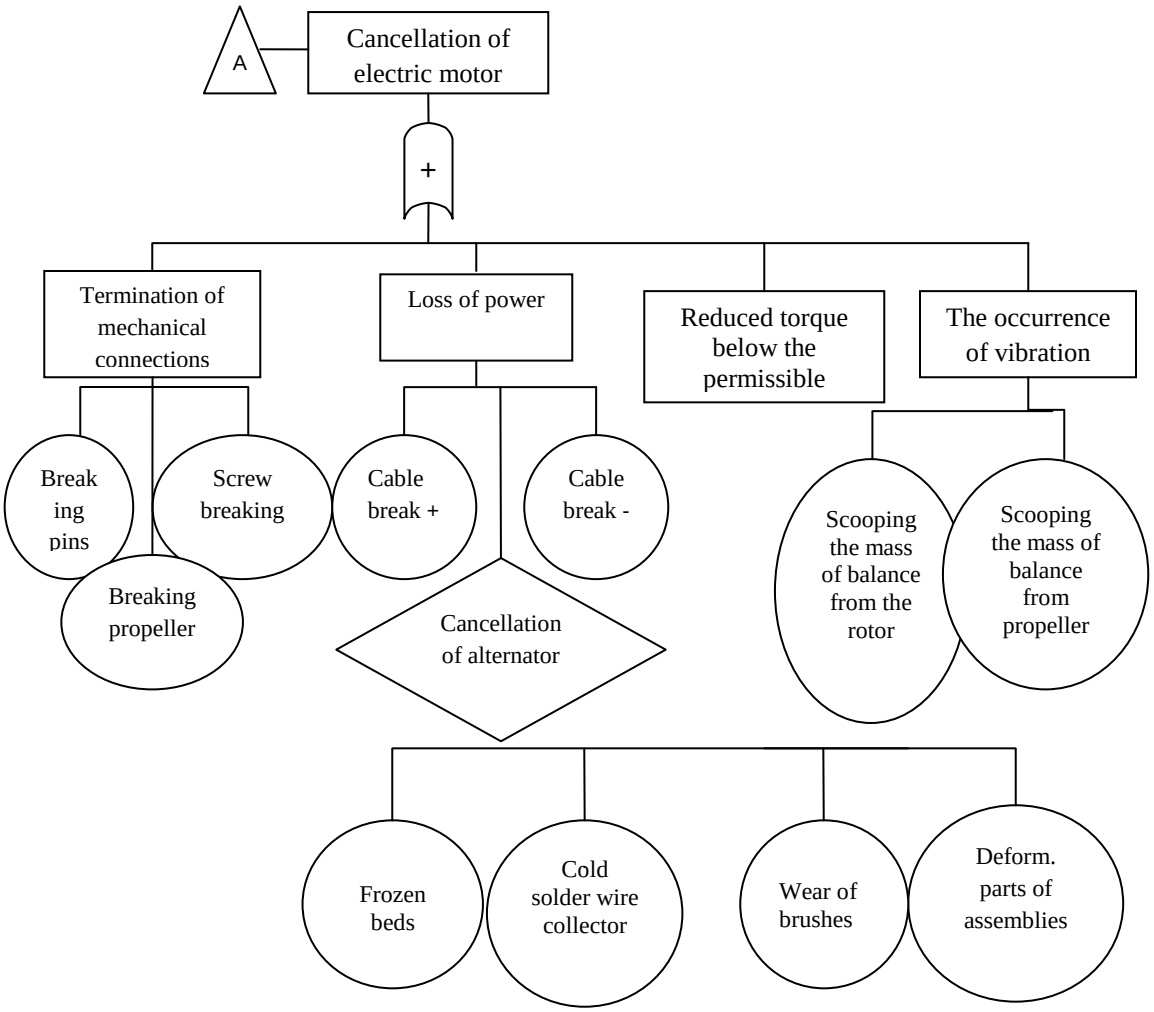


Figure 3: Independently subtree for "cancellation of electric motor" at vehicles

4. CONCLUSION

In accordance to above note it can be concluded:

The most important aims of fault tree of car cooling system, with special attention on electro motor, as key substructure:

- systematic identification of all possible causes combinations which lead to unwonted event;
- determinate of factor which most seriously effect on certain reliability measurement and application need for measurement improvement;

With fault tree analysis of the basic events for collector EM it can be concluded in which direction collector EM development need to go – increasing of working time, and except invest in development and material quality control improvement, parts and subparts, new equipment for production, this product does not charge – input price increasing for raw materials (material and parts).

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