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Study of technical reasons for fire-burning vehicles

Yuri Lazarev[1], *Albert* Bashkarev[1], *Olga* Makovetskaya-Abramova[1*], and *Shihseid* Amirseyidov[2]

[1]Peter the Great St. Petersburg Polytechnic University, 29, Polytechnicheskaya, 195251, Saint Petersburg, Russian Federation

[2]Vladimir State University named after Alexander and Nikolay Stoletovs, Gorkogo, 87, 2600000, Vladimir, Russian Federation

Abstract. The article presents the authors′ methodology for studying technical ignition causes of cars, with the establishment of the initial fire based on the signs and nature of temperature damage. What is more, subsequent development of the main scenario of fire occurrence is introduced. Modern control system is becoming larger and more complicated day by day and probability of system outage increases with it, so people urgently need to personalize the system of failure diagnostics to conduct real-time monitoring and malfunction diagnosis in production system and take necessary steps to improve its overall reliability and maintainability. According to the presented method of fire research, determination of the ignition causes is carried out by the method of successive elimination. Based on the functional features of the researchable object (a motor vehicle), established by expertise as an initial fire, the ignition of flammable liquid because of leakage from the fuel system, thermal development of the processes accompanying the emergency operation mode of the power grid could be possible ignition causes of the car. The authors pay special attention to the fire hazard of the electric system of a vehicle, which is determined by the fact that its individual elements can serve as a source of burning in case of an emergency in some functional chain. Establishment of initial fire causes increased complexity in connection with relatively small size of cars (especially light cars), fleetness of fires in vehicles and in case of failure to take recovery measures for burning in the initial stage and its development for the entire volume of the car. The results of applying the methodology were positively evaluated by independent expert companies.

1 Introduction

Explosion protection, that is a matter of concern of researchers and government authorities all over the world is extremely important for testing and certifying explosion-proof electrical equipment required for their compliance assessment, taking into account

* Corresponding author: makovetsk_ov@spbstu.ru

unexpected explosion hazard because of potentially explosive atmosphere which risk must be minimized in order to ensure industrial hygiene and safety of workers, prevent material losses and reduce environmental pollution [2].

An important aspect in determining the causes of fire break-out is to identify the initial flash after on-site investigations. The most probable sources of ignition can be determined based on the information obtained as the result of thermal and dynamic effects and compared with the results obtained during the course of sample laboratory tests and with possible scenarios of event generation. The research group must carefully consider all the elements of thermal, mechanical, electrical, radiative, chemical effects which could have an impact on the initial flash.

Computer software for fire modelling will also be used to test possible scenarios with geometrical modeling, combustible / flammable properties of real case elements, as well as location of the fire ignition, whereafter, dynamics and propagation directions of the simulated fire must be compliant with the case under consideration [3].

A car fire may occur by virtue of the carrying explosive cargo. A considerable part of the transport of hazardous materials is carried out on public roads. That is why, the safety of such transport is becoming more crucial. Each accident connected with hazardous materials has a negative influence on the immediate road users and the environment, considering that its operating range is mostly not local. The implication is that in case of such accident, its consequences must be reduced to a minimum. This can be possible only if the mechanism for spreading the accident impact in the presence of hazardous materials is known [4].

Determining the ignition cause of cars is a hard task, especially during an auto-technical expert review. Knowledge of the ignition or flash temperatures, melting points of materials, is obligatory during a fire inspection of cars. Most commonly, fires [5-7] occur in the engine compartment, because it is the hottest area of the car. In a short period of time, such a fire can cause significant damage. Primary failures usually occur within 15 minutes after the fire, which makes it almost impossible to carry out an expertise. Determining the ignition cause in the engine compartment is complicated by a large amount of highly-flammable objects and liquids that transmit the flames to each other. If an electrical wire overheats, its vinyl shell melts and ignites the nearest wire, whereafter, a short circuit occurs and the metal of the wire begins to melt with the formation of characteristic beadings at the ends, similar to the beadings on an electric welding electrode. Then the fire is transmitted to other combustible materials. In this case, the wiring harness will be a kind of wick that can ignite other flammable items. Now let us assume that a widespread fire in the engine compartment caused the fuel pipe to ignite. Then the secondary fire will be more intense than the primary one and this may mislead the expert, as the short circuit will be recognized as secondary. The article [8] is dedicated to the analysis and modeling of the consequences of an explosion in the presence of a truck transporting cylinders materials with flammable gas. Consequence modelling includes graphical depiction or calculation and evaluation of numeric values which describe in the best possible way the physical results of protective covering loss scenarios which contain flammable / explosive / toxic materials in terms of their impact on surrounding assets or people. Modern software has been used to model and simulate the accident scenario.

Fire hazard testing of vehicle must be carried out by means of special robots. The article [9] is dedicated to the development of technologies required to simplification and safe performance of inspections in hazardous areas.

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2 Materials and methods

Laboratory tests have shown that the ignition of ethylene glycol occurs along with the liquid spillage. When hot antifreeze mixture hits the exhaust manifold, the water begins to boil and evaporate, whereafter, the remaining oily ethylene glycol ignites even at a temperature of 120° centigrade. In real conditions, this means that even an accidental spark can ignite ethylene glycol vapors. Ethylene glycol burns with a steady, strong flame after ignition. It can ignite other materials in the engine compartment. The burning temperature of ethylene glycol is about 700° centigrade. It is more than enough for melting aluminum radiators, air conditioner pump casing or even valve covers. Such fires have the form of arson because melting of aluminum radiators occurs from top to bottom and has a V-shaped appearance. Ignition of antifreeze is almost impossible when the engine is cold, which is very important for an independent expertise of ignition causes of cars, that immediately excludes this version. Polyurethane foam is a standard material for interior decoration of a modern car. It is contained in seat cushions, door casing, consoles and armrests. Polyurethane foam burns as well as petrol if you set it on fire. The interior of an ordinary car burns down in approximately 5-10 minutes.

The ignition of the antifreeze. Such fires are most common for end-of-life vehicles. Nowadays many motor cars and trucks risk to take fire because of antifreeze leaking on hot surfaces of the exhaust manifold and the engine block itself [10-13]. Antifreeze appears to be a non-flammable liquid for many experts, so the real cause of ignition may be ignored.

Petrol fires. Such fires occur because of various fault conditions of fuel line, fuel injection system and gasoline tank**.** Especially for modern cars, where the electric fuel pump is located directly in the gasoline tank. An interesting feature of the safety system of most of these pumps is that they must receive a pressure pulse of the fuel back leak, otherwise the system immediately switches off. That is, if the fuel-supply line is damaged, the pressure will drop. Unfortunately, small fuel leaks will not affect this system in any way, and if the fuel line ignites, petrol will flow continuously to the place of ignition.

Self-ignition of petrol vapors can occur at a temperature of 430° centigrade but in the presence of a spark, petrol ignites at temperatures up to 42° below zero, as the spark itself can have a temperature of 1900° centigrade.

The ignition of oil. Sometimes when refilling oil, careless drivers spill it on the engine, whereafter it falls on the collector. Like any oil product, the oil can take fire at a temperature of 450° centigrade. Such fires are not rare. However, the seat of fire may lead to an improper conclusion about the fuel ignition. Such liquids as brake fluid or power steering one can burn only when the flame is open but their afflux into the fire zone often leads to flame increase, so there is a chance to make an altered judgement about the seat of fire under the hood.

Short circuit of electric wiring. Looking for a place of a short circuit is a very meticulous work and it can take a lot of time. If the fuse panel is unbroken, then its inspection can show the line of development of internal wiring fires, although the separation of the wires of the burned braid may take a long time. It should also be mentioned that many wires do not have fuses because of their length. These wires become brittle when they overheat. If the short circuit was on the ground wire, fault location can be detected by traces of melting of the wiring.

3 Results

The materials of the independent expert review are presented below. Inspection of the engine room of the burnt-out car Mazda CX-7 allowed to establish that the supreme thermal

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damages are on the left side of the engine (in the direction of the car). The fuse panel, car battery, rubber hoses and radiator were completely burnt out (see Fig.1).

Fig. 1. General view of the burnt engine compartment.

Fig. 2. Part of the electrical wiring of the motor harness.

When investigating the electrical wiring, it was found that there are no traces of a short circuit (see Fig. 2). There is no complete isolation. Metal of the conductors (copper) is brittle, fragile and dark red in color for a long distance. Some of the thin wires were burnt off in the middle part of the harness. Above mentioned characteristics are typical for copper wire that has been exposed to high temperatures for a long time. Most of the connecting devices at the ends of the conductors are in condition with a good crimp of the conductors and a push fit in the clips. Physiography of the surfaces of reflowings and adjoined sections of connectors is common to reflowings formed as a result of strong long-term heating It should be emphasized that all these types of reflowings have some common features which are typical for copper conductors. They are: significant changes in the cross-section along the length; extended reflow zone; arbitrary forms of reflowings; fusion of individual wires in the vein among themselves. These characteristics are typical for copper conductors fused as a result of thermal influence rather than short-circuit currents [5]. There are also no traces of a short circuit on the control wiring that comes from the generator and car battery (see Fig.3, Fig. 4). The temperature of the gas environment in emplacement of a power cable significantly exceeds the melting temperature of the cable insulation (120°-140° centigrade) in the event of a fire in the engine room of a car.

Fig. 3. A part of battery wiring on the side of the terminal post (+).

Fig. 4. A part of electrical wiring that comes from the generator.

The second wire on the side of the terminal post (-) that comes from the car battery also has no traces of a short circuit. Color and brittleness of the copper wires of the veins in two zones are indicative of metal damage of the conductors as a result of long-term thermal influence. As the wires of the copper conductor core have slightly changed their properties in the partitioning area, and the cores themselves are not fused together, it can be affirmed

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that such heating could occur from external thermal influences. The generator has no external damage or traces of a short circuit. As the study showed, the generator at the time of the fire was in good order, there were no traces of a short circuit on the wiring harnesses which come from the generator. Therefore, high temperature of the fire in the engine room could be the only cause of such damage.

Considering the fact that ignition of this car occurred at the time of its movement, rather than at the time of engine start (i.e. at the time when the starter does not work), the experts exclude the possibility of break in the power cable insulation from heavy current that appears at start of faulty starter. There was no damage to the elements or violation of integrity of their connections during the inspection of the exhaust system. No defects were found when investigating the still-standing parts of the fuel system.

4 Discussions

Thus, the cause of the fire as a result of the ignition of a flammable liquid because of a leakage from the fuel system and a burst of exhaust gases is unlikely.

A fire in the engine compartment of a car can be a result of simultaneous action of several factors, as follows:

1. Presence of the ignition source.
2. Presence of combustible material at the emplacement of the ignition source.
3. Sufficient igniting capability of the source to ignite this combustible material.
4. Equipment of the combustible material for ignition.

In our case highly heated surfaces are the ignition sources.

Combustible materials in the car engine room are following:

1. Petrol, engine oil, automatic transmission fluid and other process fluids (electrolytic solution, antifreeze, power steering fluid).
2. Rubber hoses.
3. Electrical wire insulation plastic.
4. Plastic wiring accessory (relay housing, fuse panel housing, accumulator jar, etc.).
5. Foreign objects forgotten in the repair work on the engine change.

Igniting capability of the collector is determined by the temperature of its surface and the duration of thermal influence. Since the collector heats up when the engine is running and its temperature depends on the duration of the engine running, its igniting capability increases with the duration of the engine running. Combustible material on the surface of the collector can ignite after some time, when the temperature of the collector surface becomes equal to the self-ignition temperature of this material.

The main fire scenario is following:

1. When the engine is running, the temperature increases and remains the same for a long time on the exhaust manifold in relation to its design features. This temperature is sufficient to ignite an object made of plastic or rubber. The surface temperature of the collector can vary, depending on the mode of operation of the engine. The collector can be the source of ignition, considering the fact that the exhaust gases behind the exhaust valves in an internal combustion engine can have a temperature from 100° to 750° centigrade while working in peak operations.
2. The conductor surface is covered with a layer of insulation made of polyethylene, so when the conductor is heated ignition insulation is possible rather than rubber or petrol. The exhaust manifold is the source of ignition, so the conductor insulator or a foreign object can be the source of combustion.
3. Igniting capability of an electric spark is not enough to ignite rubber and plastic. Witnesses of fire must notice signs of the fire before the motor stoppage. These signs are:

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engine failures, spontaneous switching on and switching over various vehicle systems and indicators on the control panel in the passenger compartment.

4. Being under the action of the air flow, hot combustion products will deviate to the upper part of the engine, concentrate in the emplacement of the plastic case of the air duct, wiring harness that comes from under the motor hood to the passenger compartment. The motor hood places an upper limit on the spread of hot burning products. Primary ignition of electric wiring and plastic under the motor hood leads to depressurization and ignition of the fuel system elements of the car, followed by vast petrol burning.

5 Conclusion

Analysis of the causes of fire on motor vehicles shows that the most common initial fires are electrical equipment failures and flammable liquids because of leaks from the fuel system. Fire hazard of the vehicle electrical system is determined by the fact that its individual elements can be a combustion source of burning in case of emergency operation in some function circuit. First of all, potential hazard of emergency operation is determined by the fact that in many places the electrical network wires are installed in packages of body structures where the distance from combustible construction materials is strictly defined and cannot be increased. Operating elements and wire insulation are often in direct contact with rough (with sharp edges) unfixed metal parts which are subject to constant vibration and friction. This may result in damage of an insulation layer. In case of a short circuit of unprotected parts of the circuit (ignition system, generator system, etc.) the electrical system itself has a sufficient supply of energy that can cause heating and melting of the metal core of the wire of this circuit, ignition of its insulation and combustible materials. The most intense temperature condition in the engine compartment is created in the area of the exhaust gas tract from the collector to the muffler exhaust pipe. The temperature of exhaust gases along the length of the exhaust line is 800-830° centigrade, the surface temperature along the length of the exhaust line is lower and can reach 710-770° centigrade. According to the reference data [14-15], when the initial burning occurs in the engine compartment of a parked motor car, the flame spreads to the interior of the car in 8-10 minutes In another 1-2 minutes the interior takes fire totally. Hereafter, the car is on fire. After that, leakproofness of the fuel system is broken and the leaking fuel burns. If a fire occurs from the model ignition source located in the back seat of a car with open windows, the glazing is destroyed approximately in 6 minutes. Visible lighting up of the interior, engine and luggage compartments ends in 30 minutes. There is only a flameless glowing ember of seats, tires, decorative and structural materials in 45 minutes. Thermal efficiency on nodes and components located in the engine room is recorded during the inspection of the engine compartment. Special attention should be paid to the carburetors, fuel injectors, oil fuel pumps, gas-pipes, exhaust system, electrical equipment and wiring harnesses. If it is necessary, this equipment should be removed for further investigation. It is imperative to establish the presence of car battery and battery switch and the fact of being the electrical equipment of the car under voltage at the time of thermal influence.

Vehicle fires can be caused by defective or worn-out components, low-quality repair, age or ordinary wear and tear and lack of proper maintenance operation. Study of the vehicle's maintenance history will provide important information in addition to the investigation of the burnt-out car. The technology of identification and analysis of the infrared spectrum, as well as the fault diagnosis technology, which allow to follow and analyze the parameters of important equipment in real time, are of interest [16].

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