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Marek BRZEŻAŃSKI
Przemysław MĘŻYK

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Heat balance of the military vehicle

In modern combat vehicles there are very often used observation devices with the capability of operating in the infrared. They allow detecting heat emission. It is very important to reduce such situation on the battlefield; therefore generated heat masking or reducing systems are used. The article presents the heat balance of the military vehicle, impact of heat amount on detectability and solutions reducing or changing the thermal image which impedes recognition.

Key words: *heat balance, thermal energy storage, emission of heat, thermal image, IR device*

1. Introduction

The detection and proper identification of equipment on the modern battlefield is one of the basic military tasks. Over the past few years many solutions, which allow detection of a gathering of enemy forces based on weapon recognition including conveyance, have been developed. Recently most of the land, water and air vehicles use combustion engines which, during operation, emit a large amount of heat to the environment. This difficult to avoid feature is commonly used as an uncover factor. In military vehicles the heat emission issue is very important from the crew point of view. Effective reduction of heat emission is in many cases a condition for the survival of the crew of a combat vehicle on the battlefield. Optical devices which use infrared are currently standard equipment of observation and scouting units. They allow for quick detection and recognition not only of moving vehicles but also hidden, whose engines are switched off. Nowadays, we can find many different solutions that allow us to observe heat emission. Besides standard devices which present infrared images, image forming systems called fusion technology that rely on a combination of an image in visible light and image recorded in infrared are also used.

2. Heat balance of the military vehicle

Military land vehicles are usually propelled by piston or turbine internal combustion engines. Their characteristic feature is the very large stream of heat emitted along with the exhaust. A rough analysis proves that this stream depending on the type of engine, constitutes about 30% to 40% of total heat value emitted in the combustion process of the engine and that energy is compared to energy needed to move a vehicle. The second in terms of size heat flux dispersed in the vicinity of the vehicle is heat transferred in the cooling system and heat from other exchangers like oil coolers or air conditioning cooling systems. Therefore mentioned heat sources are the basic targets for detection systems on a battlefield. A simple technique using the infrared spectrum is becoming increasingly important during the operation of detection, identification and on the next step tracking and destroying a target. A typical view of a vehicles column, taking by standard observing systems using IR is presented in Fig. 1. From picture analysis it is possible to define a type and destination of the vehicle and operating state specifying temporary load of the engine.

Fig. 1. Combat vehicles' column in infrared image [9]

More complex recognition method, like the fusion technology mentioned earlier, allows for a thorough estimation of equipment, which visualize whether the device was used before so that it possible to evaluate e.g. the engine's thermal state relative to other systems of the vehicle, or the barrel's temperature after shot. The effects of this method are presented in Fig. 2, which allow for unambiguous analysis of the recorded image which has top priority in battlefield conditions.

Fig. 2. Comparing images (from left side) in visible light, in infrared and using fusion technology [1]

Factors affecting the thermal image of a military vehicle can be analysed by creating heat balance. This is a complex issue, because it is necessary to take into account a lot of factors. Employing literature [2] and [3] the following heat balance can be prepared for a combat vehicle, which includes the most important factors affecting heat emission outside the vehicle:

$$Q_u + Q_a + Q_s + Q_l = Q_n + Q_{ch} + Q_j + Q_w + Q_o \pm Q_f \quad (1)$$

where: Q_u – heat flux changed in the engine to mechanical energy, Q_a – heat flux provided from fire module (combustion of explosives), Q_s – heat flux provided from the sunlight, Q_l – heat flux secreted by people, Q_n – heat loss flux in power transmission system, Q_{ch} – heat loss flux in cooling system, Q_j – heat loss flux in traction system, Q_w – heat loss flux in exhaust system, Q_o – heat flux penetrated through vehicle's walls, Q_f – heat flux related with ventilation and air conditioning system.

In the above heat balance it is correct to assume that thermal efficiency of energy conversion systems is constant, all mechanical systems of the vehicle have a fixed thermal state, and ambient temperature is constant.

The biggest and the easiest to detect source of heat emission from contemporary combat vehicles is the heat stream from the propulsion unit. Only part of the thermal energy released from fuel combustion is processed on the mechanical energy used to move a vehicle, while most of the heat is emitted to the environment in the form of hot exhaust gases, heat transferred from exchanger of cooling system and in the form of radiation. Of course thermal energy converted to the mechanical energy is also consequently discharged into the environment, but it disperses considerably in power transmission system and it has less importance from the viewpoint of detection of a combat vehicle on the battlefield. In this aspect the most important is the heat stream from exhaust gases and from heat exchangers. The most important factors that will occur on a vehicle are listed here. Some of them could be written down in detail. For example heat stream from engine (Q_u) will have below form [2]:

$$Q_u = Q_p - Q_n - Q_r \quad (2)$$

where: Q_p – heat flux delivered to engine, Q_n – heat loss flux of incomplete combustion, Q_r – rest of balance includes other less significant errors and losses that are not included in other items of balance.

Heat flux Q_{ch} and Q_w should also be included but these factors occur in the main equation of balance, so they are omitted here. Military vehicles are designed for special tasks and it is hard to foresee all situations or factors influencing on the final heat balance. Therefore in the main equation (1) of heat balance it is worth to including additional factor Q_d which will be a sum of all heat profits and losses not included in main heat balance.

The final form of the equation is:

$$Q_u + Q_a + Q_s + Q_l = Q_n + Q_{ch} + Q_j + Q_w + Q_o \pm Q_f \pm Q_d \quad (3)$$

By analysing individual items of heat balance we can tell that reduction of heat emission from such a complicated construction as military vehicle is not so easy. It is necessary to carry out works aimed at hindering detection of heat emission from a vehicle. IR image of tank is presented in Fig. 3. The recognized tank has become a very easy target, which can be destroyed by a weapon with low power of destruction, because the thermal image allows identification of the most vulnerable, not protected points, areas or components of the vehicle. For example, mentioned above areas are the power transmission system and exhaust pipes presented in Fig. 3.

Fig. 3. Tank image in IR [7]

3. Reduction of heat emission and dispersion of heat stream

It is well known that total stoppage of heat emission from such a complicated mechanical construction as the military vehicle is impossible. Very important are the steps directed to reduce the biggest heat streams which are detected first from a long distance by standard IR detectors. Research therefore are carried out is on the possibility of temporary restriction of heat emission, heat storage and dispersion of heat stream.

In the Research and Development Centre for Mechanical Appliances "OBRUM" in Gliwice, the solutions that allow reducing heat emissions have been elaborated. One of them is a cooling system for multitask combat platform (Fig. 4.), which was designed for air streams from radial fans mixed with exhaust gases. Thanks to this exhaust gases are diluted and their temperature is reduced [4].

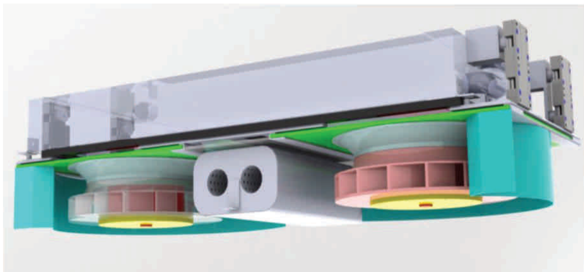

Fig. 4. Cooling system from Multitask Combat Platform (MCP) [5]

The above system has been used in combat platform called ANDERS (Fig. 5) thanks to this, the infrared thermal image is much weaker, and moreover dispersion of heat causes a blurring of thermal view and that make identification more difficult from long distance.

In special cases of protection of "big value" equipment like e.g. bombers masking methods are used, using the newest advanced technology in the field of optoelectronics and digital techniques. The first attempts of this kind were used in military aviation. The result of this was the "invisible" bomber Northrop B-2 Spirit. In the time when it was designed, new technology called Stealth had been used, that had begun in '60s of XX century [10].

Fig. 5. MCP „ANDERS" [OBRUM Ltd.]

This type of masking includes solutions which reduce visibility of the object for different detection systems like radars, sonars and all systems working by use of infrared spectrum [10]. Nowadays guidelines of Stealth technology are used more and more often in the design of military constructions. In OBRUM, concept works in that area were also carried out and as the effect of these works vehicle called "PL-01 Concept" was presented at the MSPO exhibition in 2013.

Fig. 6. „PL-01 Concept" vehicle on MSPO exhibition in 2013 [OBRUM Ltd.]

The method of forming of vehicle's thermal image taken by IR detection system exists as a separate issue. This kind of solution called ADAPTIV was developed in BAE Systems Company. It allows for hiding the vehicle from thermal vision detectors. This solution transforms heat emission and generates an environment temperature (Fig. 7) [8].

Fig. 7. Thermal masking method ADAPTIV from BAE Systems [8]

The system creates an opportunity of changing the thermal image of the vehicle and as a result, we can get a thermal imitation shape of something different e.g. a car or an animal [8]. This method also allows generation of a text on the side of the vehicle, what is useful for communication between the own forces (Fig. 8).

Fig. 8. Frame from advertisement movie, showing generated by ADAPTIV [8]

The system is built from hexagonal shape elements, mounted on the sides of the vehicle. The elements can heat up or cool down very quickly [8].

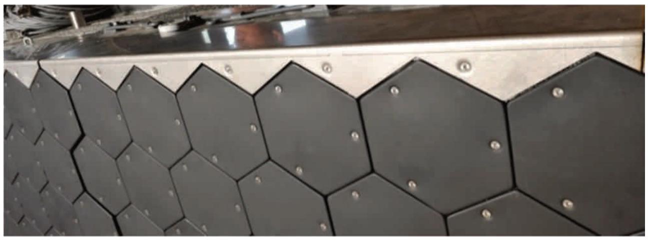

Fig. 9. Side of the vehicle with mounted elements of ADAPTIV [8]

4. Conception of heat management in combat vehicle

The total elimination of heat emission from the vehicle to the environment is impossible, but there are potential uses of these heat streams to active protection a combat vehicle by accumulating and forming emitted heat. One of the ways to use this method can be momentary stopping or reduction of heat emission by using heat storage. It is a thermally isolated vessel which contains an agent able to store heat. The shape of heat storage is usually cylindrical but it can be different and depend on free space in the vehicle's chassis. In first generation storages, thermal energy from exhaust system or cooling system was absorbed to a special phase-changeable substance. Because of problems with durability of this kind storages, which was a result of large chemical activity of used substances, so currently used heat storages use coolant which absorbs the engine heat. Periodically an accumulating agent can absorb a part of the emitted heat from an exhaust or cooling systems. Additionally, in certain cases, heat can be converted to cold e.g. in ice water installations. In this way, it is possible to periodically cool down selected elements of a vehicle and change its thermal image. In a dangerous situation when vehicle can be detected, exhaust gases can be quickly directed to heat exchangers in which the part of the heat is absorbed by coolant in heat storage. A properly planned heat control strategy of the military vehicle equipped in heat storage offers a wide variety of applications of stored heat. Opportune arrangement of heat storage's elements in different places of the vehicle's chassis can change the thermal image of the vehicle which is scanned by IR detection devices. Momentary storage of heat significantly weakens the heat emission. The thermal image is blurred which makes identification very difficult. Heat storage used in the vehicle can have additional functions. The most important is the possibility to help start up a cold engine which is a big advantage in a combat vehicle [6]. In an emergency situation coolant from heat storage can be used to extinguish a fire and provide an additional protection layer. Beside additional volume of coolant inside heat storage can protect the cooling system from overload, resulting of combat vehicle's engine use or can be a system taking heat in case of damage to the cooling system. Additionally, storage heat can be used to warm up the crew area and also to maintain a hydraulic or transmission oil temperature. Besides the mentioned advantages, very important features of heat storage is capability of effective energy recovery, which is used to improve overall engine efficiency and use exhaust gases energy, which is usually irrevocably lost in conventional systems.

5. Summary

Heat management in a contemporary combat vehicle is very important, taking into account equipment's reliability and combat tasks. Presently, detecting devices working in infrared spectre had a significant impact on action tactics. Vehicles, which are not equipped with thermal covers (Fig. 3.) are tracked very quickly and destroyed by e.g. anti-tank missile equipped with IR detectors. An irrevocably lost heat, which emission is danger for the vehicle, can be reasonably used to different conditions of the vehicles work. Presented on the combat vehicle example issues related to the heat balance and various proposals for the heat use, show that necessary and purposeful is research in this field.

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Nomenclature

IR infrared
MCP multitask combat platform

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Przemysław Mężyk, MEng. – Research and Development Centre for Mechanical Appliances OBRUM Ltd. in Gliwice.

e-mail: *Przemyslaw.Mezyk@obrum.gliwice.pl*

Marek Brzeżański, DSc., DEng. – Institute of Automobiles and Internal Combustion Engines at Cracow University of Technology

e-mail: *MBrzez@usk.pk.edu.pl*