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Analysis and choice of the launching process optimal sequence for an anti-tank guided missile

Miodrag Kobilarev, PhD (Eng)[1)]

This paper describes an analysis and a choice of an optimal sequence of events that take part during the launching and initial flight of an anti-tank guided missile which a gunner can fire either from his shoulder or a tripod. The influence of modern tactical and technical demands upon that sequence is underlined. A detailed analysis of events is done according to their type and duration with respect to the gunner security, regular rocket flight and its combat efficiency against a target. In order to verify the designed sequence of events, the signals registred during the rocket flight research experiments are analyzed as well.

Key words: **anti-tank rocket, guided missile, rocket launching, flight experiments, thrust vector control system, signal analysis.**

Notation and symbols

D_{nn} – rocket angular position signal from gyroscope
K_{1n}, K_{2n} – command signals
k – command coefficient
V_n – vertical signal from gyroscope
U_{TB} – thermal battery voltage
t_{TB} – thermal battery workable regime rising time
t_{V_1}, t_{V_2} – rocket rotation periods
t_{pk} – time from the moment of trigger activation to the moment of "umbilical" connection breaking up
t_{DK_1} – the first command calculation delay time
t_p – command signal exceeding time
t_{DUVP} – thrust vector control system command execution delay time
t_{DMRM} – sustainer rocket motor ignition delay time
t_{DK} – the first command execution delay time
DAS – digital acquisition system
ERA – explosive reactive armour
ICG – impulsive command generator
LB – lithium battery
LT – launching tube
ATGM – anti-tank guided missile
PTL – pyrotechnic lock
BRM – booster rocket motor
SRM – sustainer rocket motor
WAL – wide angle lens
TB – thermal battery
THCW – tandem hollow charge warhead
TBL – test before launching
TTD – tactical and technical demand
UFC – ultra fast camera
NAL – narrow angle lens
CLU – command & launch unit
TVC – thrust vector control

Introduction

THE complexity of tactical guided rocket systems depends on type, distance, velocity, protection and maneuverbility of a target as well as on a type of the platform form which a rocket is to be launched. In that sense, the most complex systems are air-to-air rockets and relatively simple systems are those that belong to the class of portable ATGMs. The subject of this paper will be an analysis of the launching and initial flight sequence of a modern lightweight, portable ATGM with low muzzle speed and maximum range up to 1000 m and which can be launched either from the gunner shoulder or from a tripod.

The term ATGM launching comprises all of the activities, done by the gunner, from the moment when he acquires and identifies the target, till the moment when the rocket leaves the launching tube.

The launching sequence is composed of a group of events in the launcher and the missile initiated by the gunner. These events are executed automatically while the rocket is still in the launching tube.

The initial phase of flight means the time period necessary for the rocket to pass the distance from the launching tube muzzle to its minimum range, which is usually determined with respect to the security zone protecting the gunner from THCW fragments.

The launching sequence and the initial phase of flight have a great importance for launch security, regular rocket flight and its efficiency against a target.

The launching sequence and the initial phase of flight are to be tested both during the laboratory and practical provings. The laboratory tests comprise the launcher function checks, as well as the adequacy of rocket subsystems and programs taking part in the launching process.

1) Militar Technical Institute (VTI), Katanićeva 15, 11000 Beograd

The practical tests comprise the flame influence measurements and the overpressure influence measurements.

Flame and overpressure, generated by the rocket motor burning products, can damage the launching post or harm the gunner, during both open and close space firings. The practical tests of the initial flight phase also include the rocket initial flight parameters determination such as space position, axial and angular velocity and acceleration, etc.

During the tests, the following equipment is usually used:

- Digital acquisition system, directly connected to the measuring points on the launcher or on the communication link between the launcher and the rocket, where the signals to be measured are available;
- Doppler radar, for the rocket velocity and acceleration measurements;
- Ultra speed cameras and a high-speed TV system, which have to record the rocket launching and flight. From their shots, one can determine rocket axial and rotational velocity and acceleration, rocket space position, booster and sustainer rocket motor moments of ignition and burning times, check out some subsystems operation and measure the process duration (for example, the rocket stabilizing fins opening and its duration).

Analysis of the influence of tactical and technical demands upon the ATGM launching sequence

In general, up-to-date ATGMs have to fulfill the following TTDs:

1. Frontal armour piercing for destructing modern tanks, including those equiped with explosive reactive armour;
2. Possibility of close space launching for the purposes of urban anti-tank combat;
3. High level of guidance and control system protection from various disturbances;
4. Ability for night and low visibility action.

The first TTD influences the mass and design of the missile through a needed warhead calibre as well as its distance from the missile top (STAND OFF). The ability of frontal efficiency against tanks equiped with ERA causes tandem hollow charge warhead implementation and adequate fuses arming and synchronization of which are more complex than in the case of a single warhead. The sequence of fuse arming begins during the phase of the missile launching and is in connection with the key processes taking part in the launching and in the initial flight phase.

The second TTD requests a low muzzle velocity of the missile (about 20 m/s) which, by the total impulse, depends upon the booster rocket motor propellant mass. That mass must not exceed the mass which produces (in the close space) an overpressure able to endanger the gunner.

The low muzzle velocity complicates the launching process and the initial flight phase from several points of view:

- There is a need for the missile to be controlable as early as possible because it is relatively unstable during the first phase of its flight. Such a need demands the ignition of SRM to be initiated at a minimum acceptable distance from the launching post and the thrust vector control system implementated at the SRM nozzles exit planes, because the aerodynamical control devices are rather uneffective at low flight velocities [2,3].
- The missile launch acceleration is low (about 100 m/s^2) and must not exceed the value of acceleration provoqued by missile transport or manipulation, e.g., by an accidental drop. For that reason, the missile launching acceleration cannot be used any more as an animation for starting fuse arming, and some other fuse designs, in comparison with existing ones, must be created.
- The gunner can be exposed to warhead fragments if the SRM ignition device breaks down. To avoid such situation, the warhead fuses must not be armed before the missile reaches the minimum distance from the launching post, determined by the gunner security zone radius.

To satisfy the third TTD, the synchronization of the flare emitter and the coordinator must be done at adequate frequences during the rocket flight and in the impulse working regime of the flare emitter [4]. The synchronization has to be made before launching and must be maintatined all the time till the rocket impact upon the target.

For that purpose, an active source of direct current voltage must be used to deliver electric power to the launcher and to the missile electronics. That source has to be of repeated usage capable to be applied in every attempt of the missile launching. So a lithium battery is used as an active direct current source because it is active and has the working and shelf life longer than 10 years. A thermal battery is not convenient because it is passive and dispensable.

The coordinator is usually realized by CCD cameras connected with the image processing processor in order to determine the coordinates of the missile (flare emitter) in the pixell coordinate system and by the implementation of an algorithm for the coordinator protection from interferences [4]. The processor within the coordinator is powerful enough to enable realization of the robust algorithm for the missile guidance and control, as well as realization of the launching sequence control. Furthermore, the processor enables the ATGM periodical testings and the operator training activities.

The fourth TTD influences the control and launching unit design in the sense of the night sight unit conection with ease, an operation which the gunner has to perform before the missile launching.

Sequence of events during the missile launching

The sequence of events during the missile launching begins when the gunner, aiming at the target, pulls the LB switch on (event 1) and enables the electrical supply to the CLU and to the flare emitter electronics in the missile. In that way, the synchronization of the flare emitter and the coordinator, begins at the working frequency. The LB and the CLU reach their operating modes 10 ms and 300 ms respectively after event 1, and those are event 2 and event 3 (Table 1).

When the CLU reaches its operational mode, a program (TBL) within the coordinator proccesor is activated in order to control the launching sequence. The TBL consists of two parts:

- TBL 1 is a test before the trigger pressing and it has to stop the launching sequence if the CLU is out of order or the flare emitter is not synchronized with the coordinator.
- TBL 2 is a test before the launching which has to stop the BRM ignition if the TB in the rocket did not achieve its operational mode or if the PTL, locking the missile in the launching tube, was not unlocked.

The synchronization between the flare emitter and the CCD cameras within the coordinator (event 5) begins at the same time when the TBL is activated and must be completed before the triggering button is pressed. If the gunner presses the triggering button before the synchronization is completed (event 6), TBL 1 will not pass (event 7) due to which the sequence of the missile launching will be stopped till event 7 is done. In that case, the gunner has to press the triggering button again (event 8).

Table 1. Sequence of events during the missile launching*

Number of event	Event	Time from the trigger pressing (ms)	Time from the reference event (ms)	Number of the reference event
1	LB switched "on"		0	1
2	LB achieves its operational mode		10	1
3	CLU achieves its operational mode		300	1
4	TBL activated		300	1
5	Synchronization of the flare emitter and the coordinator begins		300	1
6	Flare emitter sinchronized with the coordinator		600	1
7	TBL 1 satisfied		600	1
8	Trigger pressed	0	600	1
9	TB activated	5		
10	Gyroscope starting activated	5		
11	Gyroscope locked–off	505	500	10
12	TB achieves its operational voltage	805	800	9
13	PTL activated	815		
14	PTL locket–off	865	50	13
15	TBL 2 satisfied	870		
16	BRM ignited	890		
17	"Umbilical" connection disconnected	900		
18	SRM ignition delay activated	900		
19	THCW fuse arming activated	900		
20	THCW fuse first degree of safe removed	950	50	19

*The times are referred to the ambient temperature of +20°C

The maximum time for the missile launching preparation from event 1 to event 8 does not exceed 600 ms. If the gunner decides to abandon a firing attempt, he has to set the LB switch into the "off" position. The LB capacity permits several firing attempts when the complete sequence of events from 1 to 8 is to be repeated.

When the triggering button is pressed, the TB electrical igniters, (event 9), and the igniters of gas generator for gyroscope running (event 10), are simultaneously activated. The gyroscope unlocking and running (event 11) is about 500 ms long and the TB reaches it operational voltage (event 12) for about 800 ms after the trigger is pressed. There is no feedback information if the gyroscope is unlocked and accelerated because it is difficult to built in an adequate sensor without risking the gyroscope reliable operation. When the PTL electrical igniter is activated (event 13), the process of missile unlocking from the launching tube starts and lasts about 50 ms (event 14). If TBL 2 is satisfied (event 15), the BRM is ignited (event 16), and the rocket starts its motion along the launching tube. From the moment when the gunner presses the trigger (event 8) till the moment when the missile starts its motion, about 900 ms have to pass. The maximum shortening of that time is obtained by the fact that the CLU becomes operational and the synchronization between the flare emitter and the coordinator is completed during the process of the launching preparation. So the time necessary for the missile launching is radically shortened and depends only upon the time necessary for TB, PTL and BRM to reach their operational modes.

When a missile starts its motion, the "umbilical" connector is disconnected, so there is no more connection between the missile and the launcher. The "umbilical" connector enables the launching sequence performance and it is controlled by the CLU. After launching, the only connection between a missile and a launching tube is via microcable link because the microcable is connected to the launching tube by a specially designed connector. Using the microcable, the missile sends signals about its angular position towards the CLU. On the basis of these signals, theCLU generates the command signals and sends them towards the missile [5].

The "umbilical" connector disconnection (event 17), initiates the activation of the SPM ignition delay (event 18), and the start of the THCW fuse arming (event 19). For the execution of these events, the main role have the signals from the gyroscope which give the information about the missile proper flight and rotation. The sensitive part of the gyroscope is of special design to enable the generation of one impulse per every 45 degrees of an angular position or eight impulses per every missile round. The impulse corresponding to the vertical position differs from other impulses due to the opposite polarity.

The SRM ignition happens at the distance determined by the gunner safety and will be described in the following chapter of this paper.

In general, the THCW fuse has two levels of protection before arming. For the first level of protection elimination it is necessary that the "umbilical" connector is disconnected, (event 17), and that the rocket achieves initial axial acceleration of 100 m/s^2, which happens and finishes while the rocket is still moving along the launching tube.

The second level of protection elimination happens just before the missile reaches its minimum range, under the conditions described in the next chapter.

Sequence of events during the initial flight phase

The sequence of events taking part during the initial passive rocket flight from the moment when it leaves the launching tube till it reaches the minimum distance, is shown in Table 2. Trusted by the BRM, the rocket slides along the launching tube for about 80 ms. When it leaves the tube (event 21), the stabilizing fins open up (event 22), and the sliding skaters are rejected. The duration of fins opening is about 40 ms. The fins are built-in with a small angle of attack of about 1.5° to give the axial rotation of the missile about 4 to 12 rounds per second during the flight.

Table 2. Sequence of events during the initial flight phase*

Number of event	Event	Time from the moment when the missile leaves the launching tube (ms)	Time from the reference event (ms)	Number of the reference event (ms)	Distance from the launcher muzzle (m)
21	Missile left the launching tube	0	80	17	
22	Stabilizing fins opened-up	40			0
23	Rocket entered into the WAL field of view	60			1
24	The first command calculated	100	40	23	
25	SRM ignited	170	250	17	3
26	The first command possible	190	270	17	
27	The second level of THCW fuse protection elimination starts	475			45
28	Missile reaches the minimum distance	500	580	17	50
29	The THCW fuse armed	500	25	27	50
30	Missile entered into the "guidance tunnel" (NAL)	500	580	17	50

*The times are referred to the ambient temperature of +20°C

When a missile enters the field of view of the CCD camera with the wide-angle lens (event 23), it is possible to calculate the first flight control command (event 24). This camera is placed within the CLU coordinator and tracks the missile up to the minimum distance, when the CCD camera with the narrow-angle lens takes over at the command obtained from the CLU processor. The first flight control command can be executed only when the SRM begins to work, because until then, the TVC system is out of operation. The SRM ignition (event 25) happens at the distance where the gunner is safe, about 3 m away from the launcher muzzle. For the SRM to be ignited 230 ms are necessary to pass from the moment of the "umbilical" connector disconnection and the rocket must make one round when the gyroscope generates eight impulses. The SRM ignition is possible only when both conditions, mentioned above, are satisfied, no matter what is the order of events.

The TVC system is activated 20 ms after the SRM is ignited, when the execution of the first command is possible (event 26). The delay of 20 ms is introduced in order to secure the first command execution not until the SRM reaches its operational mode.

For the second level of the THCW fuse protection elimination (event 27), it is necessary for the rocket to make 4 rounds and to fly about 45 m away from the launcher muzzle. The first information is given by a gyroscope, generating 32 impulses, and the second one is given by a contacting foil on the microcable coil which is torn by the microcable in unwinding. When both of the conditions mentioned above are satisfied, the THCW fuse can be armed at the missile minimum distance (event 28) and (event 29).

When the missile reaches the minimum range, it enters into a "guidance tunnel" of 1 m in diameter (event 30), and flies to the target, executing, all the time, commands generated by the CLU and sent via microcable. The gunner's task is to guide a missile aiming at the target through the sighting equipment.

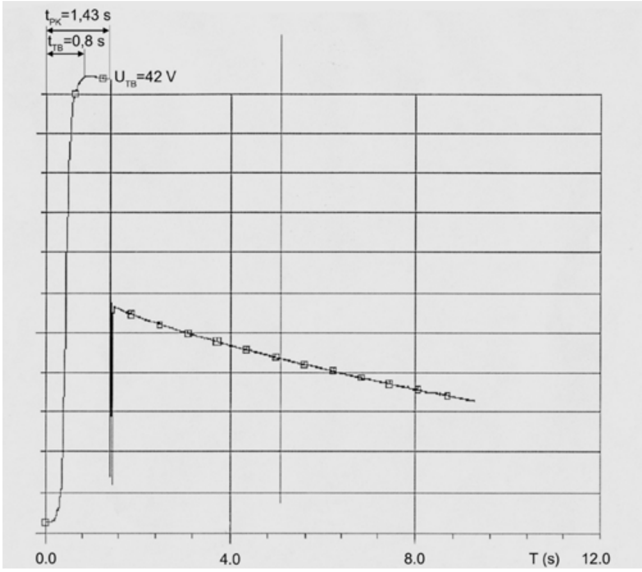
Signal analysis and discussion

For the designed sequence of events verification and control purposes, the analysis of the rocket flight results is made and presented in Table 3 [5].

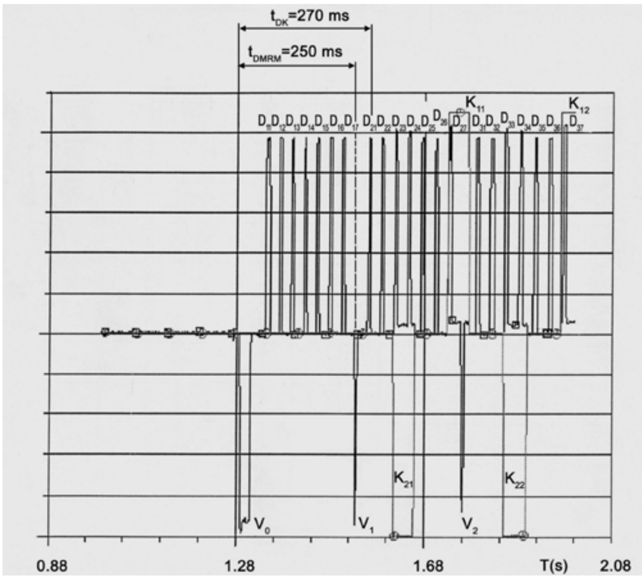
Table 3. Review of the characteristic signals terms related to the ATGM system

Ordinal number	Signal term	Notation
1	Positive command signal for the first pair of interceptors of the TVC system	K_{1n}
2	Positive command signal for the second pair of interceptors of the TVC system	K_{2n}
3	Bipolar command signals sent through the microcable to the missile	$K_{1n} + K_{2n}$
4	Bipolar gyroscope signal sent through the microcable to the CLU	$V_n + D_{nn}$
5	Positive signal of the vertical position in the CLU	V_n
6	Positive signal of every 45° of the missile angular position in the CLU	D_{nn}
7	Thermal battery voltage	U_{TB}
8	BRM ignition voltage	U_{SRM}

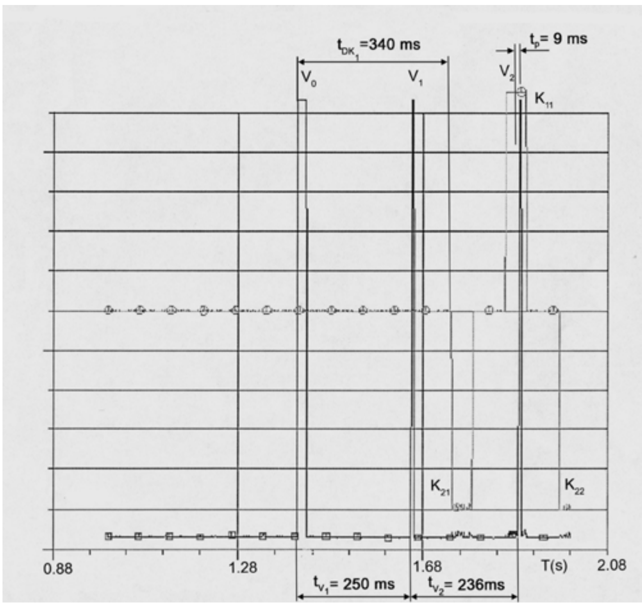
The signals were registred by the digital acquisition system connected to the communication link CLU-missile (microcable interface on the CLU side), TB exit port, BRM igniter and CLU measuring points. Some of these signals, important for the following analysis, are presented in Fig.1 [5].



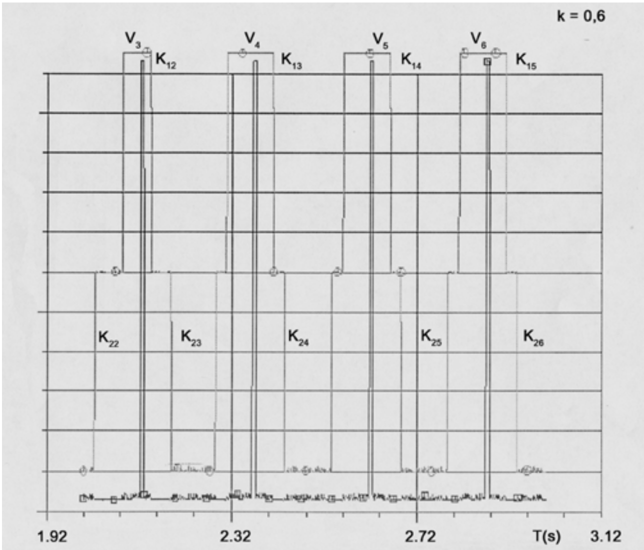
a)



b)



c)



d)

Figure 1. Registrated signals: a) U_{TB} ; b) $V_n + D_{nn}$ and $K_{1n} + K_{2n}$, c) V_n and $K_{1n} + K_{2n}$, d) V_n and $K_{1n} + K_{2n}$

In Fig.1 the following signals are shown: U_{TB}, V_n, $K_{1n} + K_{2n}$ and $V_n + D_{nn}$ and they give the key information about the missile launching phase after the trigger button activation. When the trigger button is pressed, at the moment $t = 0$, the DAS is started as well as the TB and gyroscope igniters. The time needed for the TB to reach its working voltage is denoted as t_{TB} in Fig.1a and is 800 ms. The feed-back information about the gyroscope running and unlocking does not exist, as mentioned earlier. This time is measured in the laboratory and is about 500 ms at 20^{o}C.

The drop of U_{TB} voltage, at the moment t_{pk} (Fig.1a), gives us information about "umbilical" connector disconnection and serves for the U_{TB} measurement. In Fig.1a, t_{pk} is longer than its optimum value, $t_{pk} = t_{TB} + 0.1 = 0.9$ s .

The commands execution is blocked up to time t_{DK} (Fig.1b), which corresponds to the sum of the SRM ignition delay time and the SRM working mode delay time (20 ms), so we have: $t_{DK} = t_{DMRM} + 0.02$.

The time t_{DMRM} is measured from a film obtained by the ultra speed camera during the rocket flight tests. From the moment t_{DK} all of the commands, generated by ICG, are executed by the TVC system.

Prior to launch, the missile is locked in the launching tube in the direction of the vertical line V_0 directed to the earth (Fig.1c), as marked on the gyroscope housing. The symbol V_1, in Fig.1c, denotes a signal of the second vertical position, given by the gyroscope. The time t_{V_1} corresponds to the first rotation period measured from the moment t_{pk} and V_0 when the missile started its motion and began to rotate. The time t_{V_2} corresponds to the second rotation period, etc. The initial rotation is obtained by the BRM with two inclined nozzles.

The first command signal sent to the missile, after the time t_{DK}, is K_{21} during the second rotation when the missile has an angular position rotated for 180^{o} in reference to V_1 (Fig.1c), [6,7]. The first command execution delay time, from the moment of the "umbilical" connector disconnection, is $t_{DK_1} = 340$ ms (Fig.1c).

The second command signal K_{11} is sent to the missile at the beginning of the third rotation, with the signal symmetry exelling for $t_p = 9$ ms relative to the front edge of the vertical line V_2 (Fig.1c). All of the command signals are generated with the time excel t_p in order to compensate for the TVC system time delay during the commands execution, which is $t_{DUVP} = t_p = 9$ ms [6].

Fig.1d represents the bipolar phase modulated impulses of the command signals $K_{1n} + K_{2n}$, generated by the ICG. During each missile rotation, the ICG generates a pair of command signals. The command signals K_{1n} are executed by the first pair of interceptors and the command signals K_{2n} are executed by the second pair of interceptors in the TVC system. With a direction and command coefficient of $k = 0.6$, as shown in Fig.1d, the missile is flying along the horizontal trajectory.

Conclusion

TTDs have important influence upon the launching sequence of modern ATGMs.

Maximum preparation time for the missile launching does not exceed 0.6 s. If the gunner is to postpone the firing he has to turn off the LB switch. The LB capacity is high enough to permit a few launching attempts when launching procedure and sequence of launching events are to be repeated.

From the moment when the gunner presses a trigger till the moment when the missile starts its motion along the launching tube, 0.9 seconds have to pass. The maximum reduction of this time is achieved by the fact that the CLU exile on to the operational mode, as well as the synchronization between the flare emitter and the coordinator, are completed during the launching preparation. In that way, the time needed for the rocket launching is shortened and depends only upon the time necessary for TB, PTL and BRM to achieve their operational modes.

When the missile starts its motion, the "umbilical" connection is disconnected and there is no more electrical relation between the rocket and the launcher. The "umbilical" connector disconnection initiates the activation of SRM ignition delay line as well as the beginning of the THCW fuse arming sequence. For the execution of these events, the signals from gyroscope have a key role giving the information about the missile proper flight and rotation.

The SRM ignition occurs at the distance where the gunner is safe, when the rocket is about 3 m away from the launching tube muzzle. The THCW fuse is armed around the missile minimum range.

The designed sequence of events verification and control during the launching and the initial flight is made utilizing the registration and processing of the characteristic signals obtained through real experiments and field testings. From that point of view, the most important signals are: thermal battery voltage (U_{TB}), BRM igniter voltage (U_{SRM}), bipolar command signal ($K_{1n} + K_{2n}$), positive command signals (K_{1n} and K_{2n}), bipolar gyroscope signal $(V_n + D_{nn})$, signal of the vertical position (V_n) and position signal (D_{nn}).

These signals were registered by the DAS connected to the communication link CLU – missile (interface of microcable on the side of CLU) and to the TB exit ports, the BRM igniter and the measuring points inside the CLU.

References

[1] KOBILAREV,M., sa saradnicima. *Protivoklopni raketni sistem za male daljine BUMBAR*, Int. doc. VTI-03-01-0311, Beograd, 1994.

[2] KOBILAREV,M., BJELOGLIĆ,Z. Identifikacija parametara snažnog sistema za upravljanje vektorom potiska protivoklopne rakete. *Naučnotehnički pregled,* 1999, vol.49, no.4, pp.3-7.

[3] KOBILAREV,M. Dinamička analiza snažnog sistema za upravljanje vektorom potiska protivoklopne rakete. *Naučnotehnički pregled,* 2000, vol.50, no.6, pp.5-11.

[4] KOBILAREV,M., LAZIĆ,R., NIKITOVIĆ,B. Prikaz algoritma za određivanje položaja trasera i zaštitu lokatora od ometanja. *Naučnotehnički pregled,* 1995, vol.45, no.1-2, pp.50-56.

[5] KOBILAREV,M. Analiza signala vođenja i upravljanja pri letnim ispitivanjima protivoklopne rakete. *Naučnotehnički pregled,* 2001, vol.51, no.4, pp.5-8.

[6] KOBILAREV,M., LAZIĆ,R. Prilog upravljanju protivoklopnim raketama. *Naučnotehnički pregled,* 1998, vol.48, no.1, pp.17-23.

[7] KOBILAREV,M. Realizacija i ispitivanje generatora impulsne komande protivoklopne rakete. *Naučnotehnički pregled,* 2000, vol.50, no.4-5, pp.112-117.

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Analiza i izbor optimalne sekvence lansiranja protivoklopne vođene rakete

Prikazan je postupak analize i izbora optimalne sekvence događaja u toku lansiranja i prve faze leta protivoklopne vođene rakete koju strelac može da lansira sa ramena ili postolja. Ukazano je na uticaj savremenih taktičko-tehničkih zahteva na pomenutu sekvencu događaja. Izvršena je detaljna analiza događaja po vrsti i trajanju sa aspekta bezbednosti strelca, normalnog leta rakete i njenog dejstva na cilju. Za potrebe verifikacije projektovane sekvence događaja, izvršena je analiza signala snimljenih u toku ispitivanja u letu raketa u fazi lansiranja.

Ključne reči: **protivoklopna raketa, vođena raketa, lansiranje rakete, ispitivanja u letu, sistem za upravljanje vektorom potiska, analiza signala.**

Analyse et le choix de la séquence du lancement d'un missile antichar

Un procédé d'analyse et de choix d'une séquence optimale pendant le lancement et la première phase du vol d'un missile antichar portative est présenté. L'influence des conditions techniques et tactiques exigées sur la séquence des événements du lancement est soulignée. Les événements sont analysés en détail selon l'espèce et la durée par rapport de la sécurité du tireur, le vol normal de la missile et son effet sur la cible. Afin de vérifier les séquences conçues, les signaux régistres pendant les essais en vol du missile en phase du lancement.

Mots-clés: **missile antichar, missile guidé, lancement du missile, essais en vol, commande du vecteur de poussée, analyse des signaux.**