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METHODS OF FLIGHT PARAMETERS INDICATIONS MATCHING IN HELMET-MOUNTED DISPLAY SYSTEMS

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Abstract

The article presents selected results of the analytical work carried out in the Air Force Institute of Technology regarding the possibility of computer matching systems, digital display and analogue devices, both in the static states and in dynamic states while manoeuvring the aircraft. On the example of parameter of vertical speeds provided a method of matching the indications for the helicopter Mi-17-1V with built helmet-mounted display system of flight data SWPL-1 Cyclops (developed by the Air Force Institute of Technology and cooperating with analogue avionics). Adjusting the display of vertical speed achieved by an inertial element of first row, implemented programmatically in the computer graphics KG-1.

On the other hand, method of adjusting of indications on the information presented in the helmet-mounted cueing system NSC-1 Orion (built in the Air Force Institute of Technology for helicopter W-3PL Capercaillie) and obtained from the integrated avionics system (with digital avionics), exemplified by magnetic heading (obtained from heading layout KCS-305) and geographic heading (obtained from inertial navigation system EGI-3000).

Adjusting of indications realized by introducing amendments to the indications of the multifunctional monitor MW-1, translucent display HUD and helmet-mounted display WDN-1 (in the form of elected declination, implemented programmatically on the computer mission KM-1) and the amendments to the magnetic deviation (introduced periodically to heading compensator layout KCS-305).

Keywords: *transport, aviation, aircraft helmet-mounted display systems, joint helmet-mounted cueing systems*

1. Introduction

Helmet-mounted display systems (HDMS) of the flight parameters currently constitute a standard component of the modern avionics equipment. These systems directly support a pilot both in controlling the military aircraft flight, and in using on-board weapons [1, 5, 7, 9-11].

Their task is also to improve the ergonomics of the pilot's workplace, by displaying piloting-navigational information directly in front of the pilot's eyes. At the same time, it results in the increase of the pilot's situational awareness and the possibility of using on-board systems [3, 5].

The HMDS western systems are mainly intended to cooperate with digital avionics, and designed as a dialogue element within the framework of integrated avionics systems. These systems can be also installed in helicopters with the analogue avionics (as their additional equipment), and then, they require the analysis in terms of the possibility of obtaining information on the flight parameters and technical condition of the aircraft on-board equipment [6]. Such a task was taken up by the Air Force Institute of Technology within the framework of providing additional equipment for the Mi-17 helicopter, at the stage of its modernisation to the Mi-17-1V version and preparation for taking part in exercises and missions [1, 2].

One of the problems solved by the Air Force Institute of Technology was to match indications of the selected flight parameters presented in the helmet-mounted imaging systems of piloting-navigational data [6]. It involved the need to ensure similar on-board indications of analogue devices and the helmet-mounted display of a new digital system, both under static (during the helicopter steady flight) and dynamic conditions (during the performance of manoeuvres).

The basic criterion adopted for implementation in the helmet-mounted data imaging system installed in the Mi-17-1V helicopters, was to ensure the reliability of information presented to the pilot. Although the reliability of information is a relatively new concept introduced, among others, in the maritime navigation area [4], then, in aerospace applications, it is treated in three ways: as "integrity", which characterises the system's ability to timely inform the user about its unfitness for using in the navigation process, as "monitoring before the occurrence of data faults" (data sensitive-fault) constituting a measure of information unfitness (measurement data errors) sent to the system user as a result of processing of individual sets of digital and analogue data in this system, and as "reliability", which is a measure of trust of the system user in correctness of information provided by the system [4].

In the helmet-mounted flight parameter display systems [1, 10], designed in the Air Force Institute of Technology, the reliability of presented piloting-navigational information was provided at three levels: verification of correctness of the system operation by carrying out tests of readiness, calibration of the system measurement channels and correction of their errors, as well as matching the indications between the existed analogue and newly installed digital measurement channels, which present the same piloting-navigational parameter.

In order to illustrate the problems of ensuring the reliability of information presented to the pilot in the helmet-mounted imaging systems of piloting-navigational data, two parameters were chosen: vertical speed (for the SWPL-1 Cyklop system installed in the Mi-17-1V helicopter with analogue avionics) and magnetic heading (for the NSC-1 Orion system intended for installation in the multi-purpose helicopters, W-3WA and W-3PL Głuszec with a digital avionics system).

2. Methods of matching indications in the helmet-mounted systems with analogue avionics

The requirements in terms of the way of matching indications of the same flight parameters, presented on the aircraft board by various (independent) measurement systems, depend on determining by the ordering entity (director of equipment) or directly by the equipment user, which one is the basic (master) system, and which is a secondary system that requires correction of indications [1, 6, 8].

An example of the helicopter with analogue avionics is Mi-17, operated in the Polish Armed Forces since 1979. For the purposes of using it in foreign military operations, this helicopter was modernised and additionally equipped, among others, with the SWPL-1 Cyklop helmet-mounted flight parameter display system, and marked as the Mi-17-1V helicopter (Fig. 1).

Fig. 1. View of the Mi-17-1V helicopter with the SWPL-1 Cyklop digital system (left) and the current panel of analogue on-board instruments (right)

Among the on-board systems providing piloting-navigational information, there are, among others, the WD-10WK barometric altimeter, the US-450K speedometer, the WR-10MK variometer, the AGB-3K attitude indicator, the GMK-1AE heading system. The measurement signals are imaged on the indicators located on the left and right panels of on-board instruments.

2.1. Description of the SWPL-1 Cyklop system for the Mi-17 military helicopter with analogue avionics

The SWPL-1 Cyklop helmet-mounted flight parameter display system was developed as part of the Polish scientific and industrial consortium formed by: Air Force Institute of Technology (Warsaw) as a project leader, Przemysłowe Centrum Optyki/Industrial Optics Centre (Warsaw) and Wojskowe Zakłady Lotnicze WZL-1 S.A/Military Facility (Lodz).

The SWPL-1 system receives the piloting-navigational and diagnostic information from the helicopter on-board systems, processes them, and then, transmits to the helmet-mounted displays in the alphanumeric form and as graphic symbols. This system visualises the flight parameters necessary during the performance of the helicopter combat mission for the pilot, the crew commander or the pilot-operator. As the helmet-mounted system, it can be applied under both day and night conditions, using night vision goggles [1, 8].

During day flights, the SWPL-1 system cooperates with the DWN-1 helmet-mounted day display (Fig. 2), installed in the THL-5 aviation helmet, regardless of the lighting conditions. During night flights, the system uses the NWN-1 helmet-mounted night display, which cooperates with the PNL-3 night vision goggles. The imaging on the display is readable in the lighting conditions, under which it is possible to use the goggles [1].

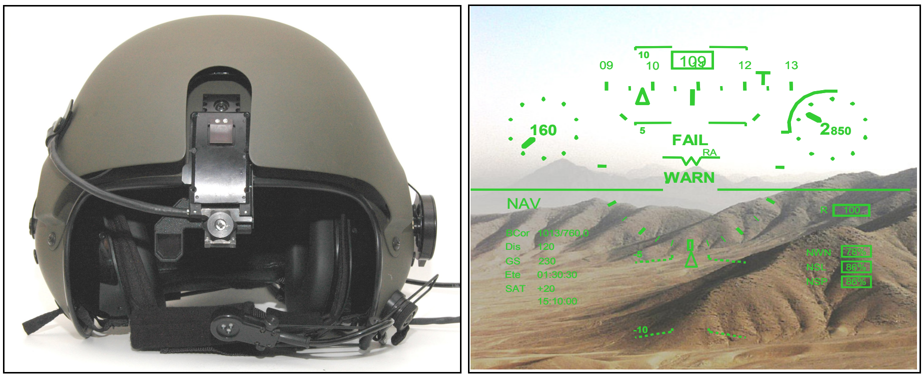

Fig. 2. View of the DWN-1 helmet-mounted display installed on the THL-5 pilot helmet (left) and imaging of piloting-navigational parameters in the navigation mode (right)

2.2. Matching of the ADU-3200 digital air data unit and the WR-10MK analogue variometer

One of the flight parameters, simultaneously imaged by the SWPL-1 Cyklop helmet-mounted digital system and the WR-10MK analogue membrane variometer, includes the vertical speed. In the SWPL-1 system, the vertical speed can be determined on the basis of the signals received from the ADU-3200 air data units (Fig. 3): directly or indirectly (by continuous calculation of its value in the KG-1 graphic computer based on information on the static pressure), with implementation of the adopted procedure of matching the indications [1].

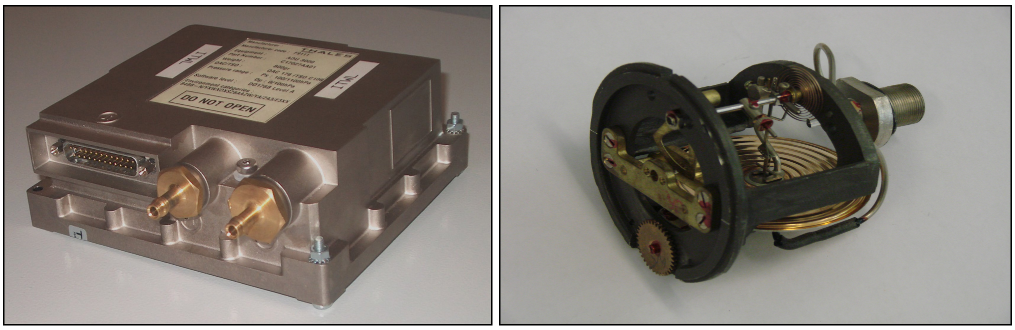

Fig. 3. View of the ADU-3200 digital air data unit (left) and the WR-10MK analogue membrane variometer (right)

The current value of the vertical speed displayed on the SWPL-1 system helmet-mounted indicator, is matched to the WR-10MK membrane variometer indicators as a basic instrument in the Mi-17 helicopter [1, 2, 6]. The dependency generally determining the principles of matching the vertical speed indications can be presented in the following form:

$$w^*_{Z\_SWPL}(t) = w_{Z\_ADU}(t) + \Delta w_{Z\_WR}(t), \qquad \Delta w_{Z\_WR}(t) = w_{Z\_WR}(t) - w_{Z\_ADU}(t), \tag{1}$$

where:

$w^*_{Z\_SWPL}(t)$ – indicated vertical speed on the SWPL-1 helmet-mounted display,
$w_{Z\_ADU}(t)$ – vertical speed determined by the ADU-3200 unit,
$\Delta w_{Z\_WR}(t)$ – the difference of indications between the WR-10MK and the ADU-3200 unit,
$w_{Z\_WR}(t)$ – vertical speed indicated by the WR-10MK variometer.

The difference of indications between the WR-10MK variometer and the ADU-3200 unit is dependent on dynamic parameters of the static pressure signal transmission line in the variometer and the aircraft flight altitude. In the SWPL-1 system, matching the indications between the WR-10MK variometer and the ADU-3200 unit was implemented with the use of the first row inertial element, implemented by software in the KG-1 graphic computer, according to the dependency:

$$W_{Z\_SWPL}(s) = G_{MATCH}(s)\cdot W_{Z\_ADU}(s), \qquad G_{MATCH}(s) = \frac{K_{MATCH}}{T_{MATCH}\cdot s + 1}\cdot W_{Z\_ADU}(s), \tag{2}$$

where:

$W_{Z\_SWPL}(s)$ – Laplace transform of vertical speed on the SWPL-1 helmet-mounted display,
$W_{Z\_ADU}(t)$ – Laplace transform of vertical speed determined by the ADU-3200 unit,
$G_{MATCH}(s)$ – transmittance of matching the indications of the ADU-3200 unit to the WR-10MK,
K_{MATCH} – strengthening the matching transmittance,
T_{MATCH} – time constant of the matching transmittance.

One of the first stages leading to the development of the procedure of matching the indications was the identification of static and dynamic parameters of the selected analogue instruments installed in the Mi-17 helicopter (including the WR-10MK variometer). On its basis, numerical models of these instruments (nonlinear models and their linearised versions) were developed, and then, checks were carried out. The idea was to define linearisation errors of non-linear models of the analysed measurement lines and conclusions, if the assumed simplifications allow to correctly image the indications of analogue instruments by the data digital processing and imaging systems in the helmet-mounted system [1].

The verification of correctness of the applied procedure of matching the SWPL-1 system indications to the WR-10MK variometer indications was carried out for the air pressure gradual change (Fig. 4). These changes, as the input signals simultaneously entered to analogue on-board instruments and digital measurement lines of the SWPL-1 system, were produced with the use of the SGO-1 air pressure generator, constructed in the Air Force Institute of Technology [1].

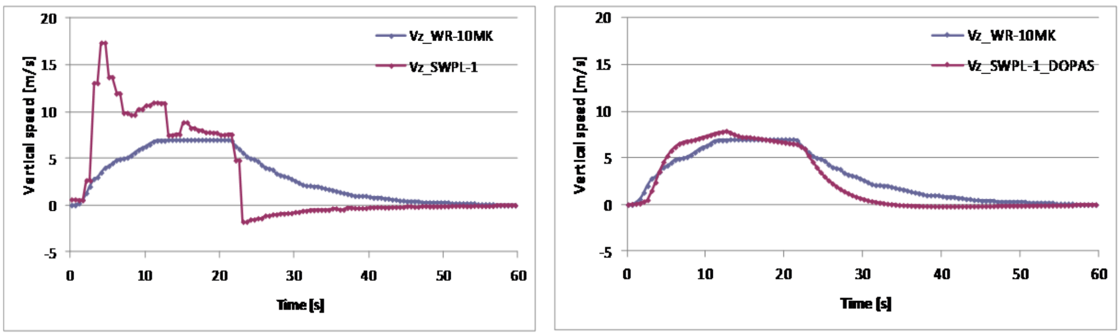

Fig. 4. Example vertical speed courses before (left) and after matching the indications (right)

The differences occurred in the obtained courses of indications (Fig. 4) between the SWPL-1 system (with the procedure of the vertical speed signal correction), and the WR-10MK membrane variometer allowed to determine optimal values of the matching coefficients of the selected test conditions (dependent, among others, on the assumed calibration height).

3. Methods of matching indications in the helmet-mounted systems with digital avionics

An example of the helicopter with digital avionics, which cooperates with the helmet-mounted flight parameter display system, is W-3PL Głuszec (Fig. 5). This helicopter has been operated in the Polish Armed Forces since 2010. On its board, an integrated avionics system, which was developed and constructed in the Air Force Institute of Technology, was installed. In order to transmit information, this system uses digital data buses, i.e. MIL-1553B and ARINC-429 [10].

Fig. 5. View of the W-3PL Głuszec helicopter with the integrated avionics system (left) and the panel of instruments with digital avionics elements (right)

Among the compound equipment of the W-3PL helicopter integrated avionics system, it is possible to distinguish, i.e.: digital measurement systems (EGI-3000 inertial navigation unit and ADU-3000 air data unit), digital information processing systems (the KM-1 mission computer and the KS-1 concentrator of signals), and digital imaging systems of piloting-navigational parameters (MW-1 multifunction monitors and the HUD transparent indicator).

The W-3PL Głuszec helicopter was created on the basis of the W-3WA helicopter mainly equipped with analogue avionics. The composition of the W-3WA helicopter on-board instruments providing piloting-navigational information includes, i.e.: the PW-12K barometric altimeter, the PS-08K speedometer, the WRm-15K variometer, AG-77-15, 510-27B, and 1200-1R attitude indicators, and the KNI-582 indicator of the KCS-305 heading system. These instruments are placed on the instrument panel in the W-3WA helicopter cabin (Fig. 6) and image the signals obtained from analogue and digital on-board systems [12].

Fig. 6. View of the W-3WA Sokół helicopter with analogue on-board systems (left) and the panel of instruments with analogue avionics elements (right)

In order to improve the flight safety and the W-3PL Głuszec helicopter combat capabilities, the NSC-1 Orion helmet-mounted targeting system, which is intended for imaging flight parameters and targeting, was designed in the Air Force Institute of Technology [10]. This system successfully passed construction tests and is prepared to be introduced to the helicopter board.

3.1. Description of the NSC-1 Orion system for the W-3PL military helicopter with digital avionics

The NSC-1 Orion helmet-mounted flight parameter display system was developed in 2009-2012 by the scientific and industrial consortium formed by: Air Force Institute of Technology (Warsaw) as the project leader, Wytwórnia Sprzętu Komunikacyjnego "PZL-Świdnik" S.A. (Świdnik), Zakłady Mechaniczne/Mechanical Works "Tarnów" S.A. (Tarnów), FAS Mariusz Ficoń (Bielsko-Biała) and Przemysłowe Centrum Optyki/Industrial Optics Centre (Warsaw). Its implementation was held within the framework of the Ministry of Science and Higher Education and National Centre for Research and Development research projects [10].

The NSC-1 helmet-mounted targeting system (Fig. 7) is primarily intended for the W-3PL Głuszec helicopter, but it can be installed in each combat helicopter with the integrated avionics system on the MIL-1553B digital bus [10]. The system allows controlling the angular movable position with the WKM-B 12.7 mm rifle and other elements of the on-board weapon system, i.e. Toplite observation and targeting movable head with IR sensors installed on the intercept heads of targeted missiles. The NSC-1 system cooperates with the KM-1 mission computer, which manages the functioning of the entire integrated avionics system of the W-3PL helicopter. In order to operate, it requires the helmet-mounted system for determining the angular helmet position and the helmet-mounted system of imaging the piloting-navigational parameters and targeting symbols (including the so-called reticle allowing creating a line of sight for the pilot's eye).

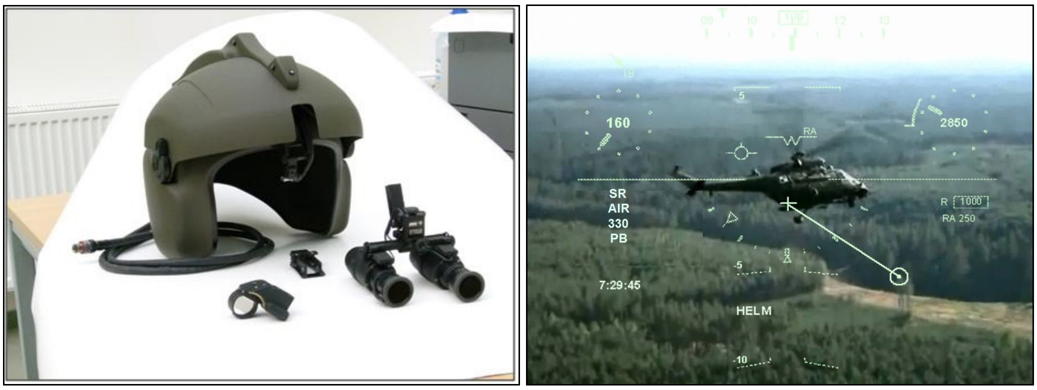

Fig. 7. View of the WDN-1 helmet-mounted display installed on the THL-6NSC/P pilot's helmet (left) and imaging the piloting-navigational and targeting parameters (right)

In the W-3PL Głuszec helicopter helmet-mounted weapon control system, the NSC-1 targeting system performs measurement functions of the azimuth angles and the pilot's helmet elevation in relation to the helicopter cabin and sending them in the digital form to the application generating the targeting data in the KM-1 mission computer. Thanks to this fact, the helmet-mounted visualisation of targeting symbols on the transparent display (including currently used weapons and its ballistic data) and the helmet-mounted targeting of the selected movable weapon system in the helicopter to the chosen air or ground target are possible [10].

3.2. Matching of EGI-3000 digital inertial navigation system and KCS-305 heading system

In order to illustrate the way of matching indications in the helicopter avionics system, in which a digitally integrated avionics system is a master system, a navigation parameter in the form of the magnetic heading was selected. On the W-3PL Głuszec helicopter board, the magnetic heading is imaged on the MW-1 multifunction monitors (Fig. 8) and the HUD transparent indicator. After introduction of the NSC-1 Orion system on the W-3PL helicopter board, this parameter can be also imaged on the WDN-1 helmet-mounted indicator [10].

Fig. 8. View of imaging the piloting-navigational parameters on the MW-1 multifunction monitor screen (left) and the EGI-3000 inertial navigation unit providing these parameters (right)

In the digital system, the magnetic heading can be determined in the KM-1 mission computer based on the true heading defined in the EGI-3000 unit and current magnetic declination (or directly from the unit on the basis of the map introduced to the WGS-84 system). With the use of the MIL-1553B digital data bus, this parameter is sent to the information receiver as an adjusted value, which takes into account the magnetic declination correction [10].

The current magnetic heading value imaged on the WDN-1 helmet-mounted indicator of the NSC-1 Orion system, and also on the integrated avionics system indicators (MW-1 multifunction monitors and the HUD transparent indicator), can be described in the following form:

$$\psi_{M\_KM}(t)=\psi_{G\_EGI}(t)+\delta_{M\_EGI}(t), \qquad \delta_{M\_EGI}(t)=\delta_{M\_EGI}(\lambda,\varphi), \tag{3}$$

where:

$\psi_{M\_KM}(t)$ – magnetic heading presented on the MW-1 and HUD indicators and the WDN-1 display,

$\psi_{G\_EGI}(t)$ – true heading determined by the EGI-3000 unit,

$\delta_{M\_EGI}(t)$ – magnetic declination dependent on the aircraft geographic location

λ,φ – length and width of the aircraft current geographic location.

However, in the W-3WA helicopter, the magnetic heading (gyromagnetic) is determined by using the KCS-305 heading system with the KMT-112A magnetic sensor, and its imaging is implemented on the KNI-582 integrated radio magnetic indicator (Fig. 9). The element, which is used to specify the heading in the heading indicator gyroscopic system, process signals from the KMT-112 inductive sensor, and transmit the heading, signals to the heading indicator is the KSG-105 directional gyroscope. In turn, the KA-51B correction device allows selecting the heading system-operating mode (magnetic correction or gyroscopic heading), setting the assumed heading on the heading indicators in the heading indicator gyroscopic system, and compensating the system errors. In case of the helicopter rapid manoeuvres or long-term turns, the KNI-582 indicator may display the signals warning of the lack of reliability of indications. After achieving the stable flight, their automatic correction at the speed of 14°/s occurs, and the heading indications are tuned to the magnetic heading. The KCS-305 system calibration in terms of magnetic deviation includes only elimination of the KMT-112 sensor installation error and the semi-circular error using the KA-51B compensator (the lack of the quadrantal error compensation). The maximum indication error of the KCS-305 system in the magnetic correction system should not exceed ±2° [12].

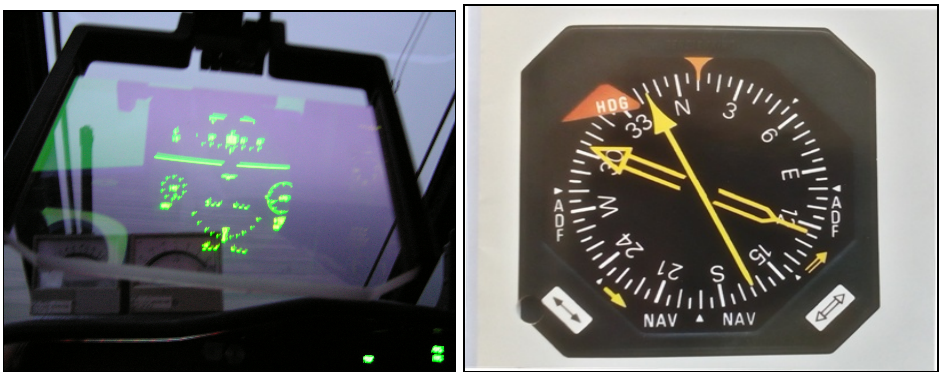

Fig. 9. View of imaging flight parameters on the HUD transparent indicator (left) and imaging the heading on the KNI-582 radio magnetic indicator (right)

In case of introduction of the NSC-1 Orion helmet-mounted system and the integrated avionics system to the W3-WA helicopter board with the remaining KCS-305 heading system, there is a problem of matching the indications between the newly implemented digital system and the already installed analogue one. Matching the indications in the scope of the MW-1 multifunction monitor and the HUD transparent display (Fig. 9) would be implemented as in the W-3PLGłuszec version that is in the KM-1 mission computer by introduction of the corrections to the true heading received from the EGI-3000 inertial navigation unit.

In order to match the KCS-305 heading system indications to the integrated system indications (as the master system), the description in the following form was adopted:

$$\psi^*_{M\_KCS}(t) = \psi_{M\_KCS}(t) - \Delta\psi_{M\_KCS}(t), \qquad \Delta\psi_{M\_KCS}(t) = \psi_{M\_KCS}(t) - \psi_{M\_KM}(t), \quad (4)$$

where:

$\psi^*_{M\_KCS}(t)$ – magnetic heading showed on the KNI-582 indicator after matching KCS-305,
$\psi_{M\_KCS}(t)$ – magnetic heading showed on the KNI-582 indicator before matching KCS-305,
$\Delta\psi_{M\_KCS}(t)$ – the difference between the KCS-305 system and the integrated system;
$\psi_{M\_KM}(t)$ – magnetic heading determined by the KM-1 computer based on the EGI-3000 unit.

On the W-3WA helicopter board, after its retrofitting with the digital avionic system, the NSC-1 Orion helmet-mounted system, as an isolated system, would use piloting-navigational information and targeting data from the integrated avionics system. The KCS-305 heading system indication matching to the indications determined on the basis of signals from the EGI-3000 inertial navigation unit under static conditions (in the steady flight) would allow for the (performed by the pilot) additional control of reliability of information presented in the avionics system.

On the basis of the magnetic heading indications (the parameter calculated in the KM-1 mission computer and the heading showed by the KNI-582 indicator of the KCS-305 heading system), the pilot could regularly check the proper operation of on-board systems specifying this flight parameter. If the difference of indications is greater than the assumed value in the steady flight (e.g. permissible error in the ±2 magnetic correction system°), the pilot should assess the magnetic heading indications as unreliable and perform verification checks [10], and in case of confirmation of the magnetic heading indication errors, he should use another source of navigation information (e.g. true heading from the GPS receiver).

4. Summary

Helmet-mounted systems of displaying the piloting-navigational and targeting parameters decisively influence the increase of the pilot's awareness, which is one of the fundamental factors that have a direct impact on flight safety and performance of a combat task. Therefore, the task of the designers of avionics systems is to make them provide the pilot with reliable information both in the piloting-navigational situation, the aircraft technical condition, and in the tactical situation of its environment. While introducing the helmet-mounted flight parameter imaging system with the digital avionics system to the board of the helicopter equipped with analogue piloting instruments and navigation systems, a problem of matching the indications between the newly implemented digital system and the already installed analogue one occurs.

In the solutions applied in the Air Force Institute of Technology, the principle of matching the secondary system indications to these of the master system was adopted. According to it, for the SWPL-1 Cyklop system installed in the Mi-17-1V helicopters, the helmet-mounted system indications are matched to the indications of on-board analogue instruments (e.g. in terms of vertical speed indicated by the WR-10MK membrane variometer). However, for the NSC-1 Orion system (proposed for W-3PL and W-3WA helicopters after modernisation), the requirement for matching the indications between digital and analogue systems, related to all flight conditions, was not adopted.

The indication matching procedure, presented for the W-3WA helicopter with the integrated avionics system, is aimed at providing their compatibility only in selected flight conditions (in the steady flight), and thereby obtaining the tools to verify the reliability of information acquired from these systems (e.g. in the scope of the EGI-3000 inertial navigation unit assessment).

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