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B. V. Roman

HARDWARE-IN-THE-LOOP SIMULATION TABLE CHARACTERISTICS DETERMINATION

Aviation computer-integrated complexes department, National Aviation University, Kyiv, Ukraine
E-mail: bada02@mail.ru

Abstract—*This article is devoted to investigation of metrological characteristics of hardware-in-the-loop simulation tables. Methodology for accuracy parameters estimation is shown, and experiment planning procedure is defined.*

Index Terms—Hardware-in-the-loop simulation table; testing; verification; metrology; accuracy improvement.

I. INTRODUCTION

During the flight aircraft is exposed by a lot of different factors affecting on a flight in undesirable manner (angular position, velocity and acceleration of aircraft), that can lead to unintended change trajectory or fail of equipment or even aircraft. Due to mass parameters, these negative effects are even stronger for unmanned aerial vehicles (UAV). The main way to detect any change in angular position and angular velocity is to measure them during the flight and compare with given course. Gyroscopic measurement devices, such as various inertial navigation systems obtained wide usage in aviation.

Usage of navigation systems in aviation is connected with great demands and put forward to the navigation system, because wrong flight route can lead to some problems of legal, economic and technical nature. In case of UAV wrong sensors indications can lead to even more failures, due to automatic control and full dependence on data from sensors. Accordingly, there are certain high-level requirements for flight safety and compliance trajectory. Consequently, these requirements apply to navigation systems. For checking the equipment on compliance we should make some tests (verification), both during the any aircraft design and maintenance. The most important part of the organization is competent test development and approval of testing methods.

II. HARDWARE-IN-THE-LOOP SIMULATION TABLE

Most productive way to perform such tests (taking into a count economical and accuracy benefits) is seminatural modeling of flight with the help of hardware-in-the-loop (HIL) simulation tables.

Main mean for this ground testing are seminatural modeling test benches which allow to simulate flight. There are a lot of different seminatiral testing benches types, according to their functionality, quantity of degrees of freedom, load capacities, accuracy characteristics and others. Different simulation tables are presented in Fig. 1.

Fig. 1. Different HIL motion simulators

As it is seen from general structure of HIL test benches presented in Fig. 2, human-operator interacts with test bench through External data input and visualization system. Test program is transmitted to HIL system from here, and measured values of important equipment parameters together with movable platform data are also presented here. Then needed trajectory data is transmitted to data processing system, where needed control influences are determined. Motion control system is responsible for correct control signals transformations suitable to execution by motion producing elements. Power supply and transformation system mostly refers to supplying whole system with different needed voltages and currents. Motion producing elements usually have rigid connection with moveable platform and can be different motors, hydraulic or pneumatic devices. Equipment under test data acquisition system together with additional functions devices (such as for example, heat chambers or pressure chambers) and tested equipment are mounted on top of movable platform. Movable platform sensors and equipment under test data acquisition system send data back to data processing system where they are compared and saved.

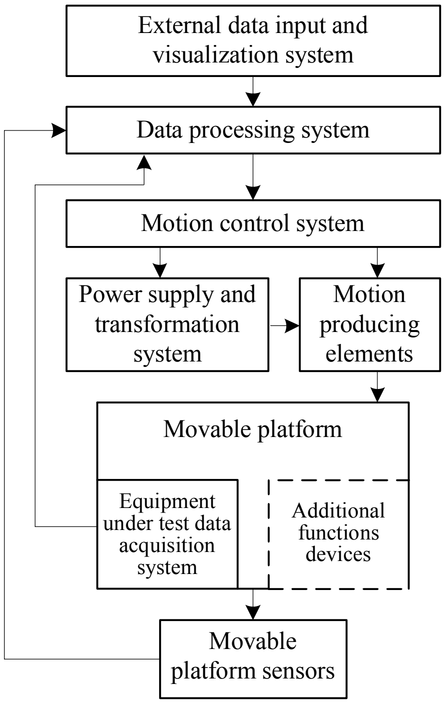

Fig. 2. General structure of HIL simulation table

Hardware-in-the-loop simulation table under investigation is triaxial test bench with high load capacities.

Triaxial test benches are applied when there is a requirement about simultaneous rotation of the load on the three axes. Data about motion simulation (angular positions, velocities, accelerations) is transferred from sensors from corresponding sensors into system, where it is processed and saved. Conclusion on navigation equipment performance and workability is be made on the basis of this data analysis.

III. PROBLEM STATEMENT

Strict requirements to parameters and characteristics of test benches are put forward during design stage. Consequently there is the problem of estimating the parameters of the test benches, in other words, of their certification.

Due to HIL simulation table is referred to laboratory testing system strict legislative requirements are applied to it. As the result of test bench use the following must be actions must be performed:

– identifying nonconformities (eg from complaints and internal audits);

– determining the causes of nonconformities;

– the elimination of nonconformities;

– evaluation of the needed actions to prevent their repetition;

– identification of the necessary actions and their timely implementation;

– documentation of the results of taken actions;

– analysis of the effectiveness of corrections.

Often used method of certification is to compare the readings of the investigated device with the readings of a higher accuracy class instrument, exposed to the same influences as investigated device. However, such control devices are often expensive, especially when it comes to the most accurate devices and it is not convenient to use this control equipment at the stage of early testing. So, the problem of primary HIL simulation table behavior and metrological characteristics determination and analysis arises.

IV. EXPERIMENT PLANNING

The main goal of the experiment – is to determine the possibility of navigational equipment test bench usage for the certification of aircraft or UAV angular values gauges (position, speed, acceleration). The experiment consists of two main parts.

1. Estimation of the ability of test bench to reproduce (simulate) the specified movement of the aircraft during flight.

2. Estimation of the accuracy characteristics of navigational equipment test bench.

Following methodology can be used to estimate the ability to reproduce (simulate) the specified movement of the aircraft during the flight.

Experimental input data X_{inp} is pre-recorded data aircraft flight (matrix of dimension $n \times 3$, with a row for roll (r), pitch (p) and yaw (y), n is the number of measurements).

$$X_{\text{inp}} = \begin{bmatrix} r_1 & r_2 & \cdots & r_n \\ p_1 & p_2 & \cdots & p_n \\ y_1 & y_2 & \cdots & y_n \end{bmatrix}.$$

Output data X_{out} are values of angular positions taken from the platform sensors (the matrix of the same dimension and the organization as the input matrix X_{inp}).

$$X_{\text{out}} = \begin{bmatrix} r_{\text{o}1} & r_{\text{o}2} & \cdots & r_{\text{o}n} \\ p_{\text{o}1} & p_{\text{o}2} & \cdots & p_{\text{o}n} \\ y_{\text{o}1} & y_{\text{o}2} & \cdots & y_{\text{o}n} \end{bmatrix}.$$

Modern means of the angular displacement measurement, are closely associated with the use of microprocessor technologies (that means they are digital), which lead to their high data removal rate. On the other hand, the angular movement of the aircraft during flight is slowly changing process, particularly for civil aviation, allowing to slightly change the classical methods of data analysis.

The total positioning error (Δ_{pos}) consists of a plurality of error items, such as movable platform mechanical backlash, positioning errors of motors, etc., and is calculated as the difference between the input signals and the corresponding output data:

$$\Delta_{pos} = X - X_{out} = \begin{bmatrix} r_1 - r_{o1} & r_2 - r_{o2} & \cdots & r_n - r_{on} \\ p_1 - p_{o1} & p_2 - p_{o2} & \cdots & p_n - p_{on} \\ y_1 - y_{o1} & y_2 - y_{o2} & \cdots & y_n - y_{on} \end{bmatrix} = \begin{bmatrix} \Delta_{r1} & \Delta_{r2} & \cdots & \Delta_{rn} \\ \Delta_{p1} & \Delta_{p2} & \cdots & \Delta_{pn} \\ \Delta_{y1} & \Delta_{y2} & \cdots & \Delta_{yn} \end{bmatrix}.$$

V. EVALUATION OF THE ACCURACY CHARACTERISTICS OF NAVIGATIONAL EQUIPMENT TEST BENCH

In order to estimate accuracy characteristics of testing equipment generally accepted method is to compare the readings of the investigated equipment with the readings of the control device.

The total error of navigational equipment test bench can be determined as:

$$\Delta = \Delta_{pos} + \Delta_{meas};$$

where Δ_{pos} is movable platform positioning error; Δ_{meas} is movable platform measuring devices error.

Error of movable platform sensors may be caused by a number of factors that should be considered during the evaluation. Such factors may include:

– impact of a measuring object (mostly impact of high voltage transformation units on sensors);

– errors introduced by means of measurements (inaccuracy of axial sensor positioning(mounting), zero position error, sensor dead zones (for digital sensors are usually by their digital nature i.e. their discreteness), and others);

– the impact of the external environment (Electromagnetic fields action, action of external forces, partially action of inertia forces (for high load capacities)).

It is known from metrology that increase of the number of independent measurements of the same parameter the average value of the measurement approaches the true value. To determine the accuracy of movable platform positioning it is proposed to use several devices of the same accuracy class as the tested device. It will allow to determine the total absolute error (Δ) as:

$$\Delta = X_{cd} - X_{out} = \begin{bmatrix} r_{av1} - r_{o1} & r_{av2} - r_{o2} & \cdots & r_{avn} - r_{on} \\ p_{av1} - p_{o1} & p_{av2} - p_{o2} & \cdots & p_{avn} - p_{on} \\ y_{av1} - y_{o1} & y_{av2} - y_{o2} & \cdots & y_{avn} - y_{on} \end{bmatrix},$$

where X_{cd} are data (readings) of control devices;

$x_{av} = \frac{\sum_{0}^{m} x_{cd}}{m}$ is average reading from control devices in a given point; m is quantity of control devices.

VI. PROCEDURE FOR INVESTIGATING THE CHARACTERISTICS OF TEST BENCH

The next step is to establish testing procedure for evaluation of metrological characteristics of HIL test bench.

– Setting the test bench movable platform into the zero position.

– Determination of the static component of the navigational equipment test bench absolute error by comparing the output signal of the test bench with zero input signal.

– Estimation of the ability to reproduce (simulate) the specified movement of the aircraft during the flight by performing a set of movements by the movable platform without load.

– Determining the amount reference instruments.

– Installation of control equipment on the movable platform.

– Simulation of aircraft movements using data from a real flight with parallel control equipment and the movable platforms output data recording.

– Analysis of the data and determination of the accuracy characteristics navigational equipment test bench.

As a result this procedure will provide information about the accuracy of the test bench, and on the basis of this data information about accuracy class and other metrological characteristics of test bench. In the case of poor accuracy characteristics it is necessary to make a decision about modernization (revision) test bench as a whole or its individual parts.

Also, it is necessary to note that the accuracy class of HIL test bench must be higher than accuracy class of the tested equipment.

The main ways to improve the accuracy of testing equipment.

1. Replacement of less accurate sensors by more accurate – is effective when the instrumental components of error are dominant. But also, it should be noted that in case of replacement of sensors, increases the total economic value of test bench, accordingly, the procedure should be used only as a last resort.

2. Creating the conditions for the application of measuring instruments – useful if additional external errors of measuring devices dominate. For the most part it is used when excessive external influences (such as electromagnetic noise of the environment) and is often aimed at suppressing (reducing effect) these factors. The main advantage of this method is helps to improve the overall system stability, and reliability of testing.

3. Execution of multiple measurements in case of random error appearance. This method mostly improves the overall testing methodology, but greatly increases the time of testing, which in turn negatively affects the cost of testing, although a sufficient

amount of measurement allows to reduce the influence of random errors greatly.

4. Implementation of control methods operating condition of measuring devices during their operation – facilitates the detection, elimination or reduction of metrological failures of measuring instruments. This method increases the overall fault tolerance of testing equipment by introducing different protection stages into system. Reduces further service costs.

5. Information redundancy. Getting data about the same parameter from different sources minimizes the effect of random errors in the system, and increases the fault tolerance and reliability of the system, however, leads to a drastic increase in the cost of testing equipment.

VII. CONCLUSIONS

Primary analysis of the behavior of navigational equipment test bench, as well as its characteristics can be performed without the use of external control instruments. This allows to obtain the diagnostic card of equipment with its characteristics, to verify the accuracy and the condition of critical parts of the test bench, and make the necessary adjustments at the initial stage of testing.

The use of additional external control equipment allows to define accuracy class of HIL test bench, and will give more precise information on the metrological characteristics of the investigated test bench.

Generalized methods of navigational equipment test bench accuracy improvement are considered. Their strengths and weaknesses are identified.

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Roman Bohdan. Assistant.
Aviation Computer-Integrated Complexes Department, National Aviation University, Kyiv, Ukraine.
Education: National Aviation University, Kyiv, Ukraine (2012).
Research area: control systems, HIL simulation, FPGA.
Publications: 7.
E-mail: bada02@mail.ru

Б. В. Роман. Визначення характеристик випробувального стенду навігаційного обладнання

Визначенно метрологічні характеристики випробувальних стендів навігаційного обладнання. Запропоновано методику оцінювання точносних характеристик, і визначено порядок планування експерименту.

Ключові слова: випробування, підвищення точності; випробувальний стенд навігаційного обладнання.

Роман Богдан Валерійович. Асистент.
Кафедра авіаційних комп’ютерно-інтегрованих комплексів, Національний авіаційний університет, Київ, Україна.
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Напрям наукової діяльності: системи керування, напівнатурне моделювання, ПЛІС.
Кількість публікацій: 7.
E-mail: bada02@mail.ru

Б. В. Роман. Определение характеристик испытательного стенда навигационного оборудования

Определены метрологические характеристики испытательных стендов навигационного оборудования. Предложена методика оценки точностных характеристик и определен порядок планирования эксперимента.

Ключевые слова: Испытания, повышение точности; испытательный стенд навигационного оборудования.

Роман Богдан Валериевич. Ассистент.
Кафедра авиационных компьютерно-интегрированных комплексов, Национальный авиационный университет, Киев, Украина.
Образование: Национальный авиационный университет, Киев, Украина (2012).
Направление научной деятельности: системы управления, полунатурное моделирование, ПЛИС.
Количество публикаций: 7.
E-mail: bada02@mail.ru