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INVESTIGATION OF THE CHARACTERISTICS OF THE SENSOR UNIT OF THE PA-2 HORIZONTAL STABILISATION SYSTEM

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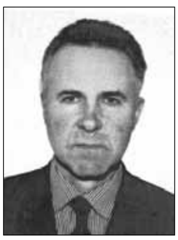

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Abstract. For tasks such as radiation and environmental monitoring using an unmanned air vehicle, it is necessary to maintain stable flight level. The authors used a PA-2 horizontal stabilization system, manufactured by Futaba Inc., to maintain the orientation of an unmanned aircraft during flight. This work represents the investigation of the characteristics of a PA-2 sensor unit in the laboratory. The authors obtained the optical and output characteristics of the sensor unit, operating angles, and dependence of output characteristics on UAV orientation.

Keywords: unmanned air vehicle, sensor unit, stabilisation system, operating angle, illumination.

1. Introduction

For some tasks conducted by an unmanned air vehicle (UAV), it is necessary to stabilise the level of flight for long time (Goraj *et al.* 2003; Chatys, Koruba 2005; Danek 2003). In this case, manual control of the UAV by radio channel is difficult (Kanashchenkov, Merkulov 2003). That is why autopilots are usually used for the solution of such tasks. But since the cost of such autopilots is high, it is preferable to use a horizontal stabilisation system, such as the PA-2 produced by Futaba Inc., to maintain level flight (PA-2… 2011). Therefore all that remains is to control the speed and direction of flight. To create an inexpensive UAV control system/autopilot, it is proposed to use the PA-2 as the horizontal optical sensor element (or some subsystem). The Futaba PA-2 cannot be used without knowing its exact characteristics. The manufacturer of the PA-2 does not provide consumers with a diagramme of direction or transfer coefficients or the sensitivity or accuracy of this device. The main goal of this paper is therefore to determine the input and output exploitation characteristics of this sensor element for further application of the PA-2 in existing and future UAV control systems at our university.

Methods of using the PA-2 are described in the user manual (PA-2… 2011). To create the stabilisation system, we also need the optical and output characteristics of this system.

The PA-2 consists of two units: a sensor unit and a logical unit (Fig. 1).

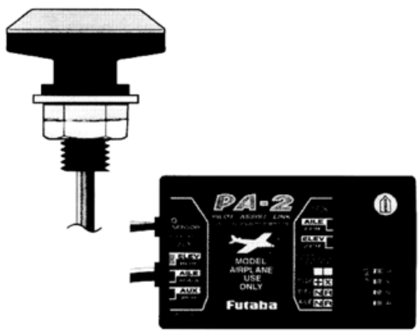

Fig. 1. PA-2 system:

1 – sensor unit with differential booster;
2 – logical unit.
- supply voltage: + (5 ± 0,5) V;
- input current: 5mA (4.8 V)

Photodetectors are situated on the sides of the sensor unit. The angle between different photodetectors is 90°. The sensor unit is mounted under fuselage in such a way that two photodetectors are directed forward and back, and two photodetectors are directed right and left. To stabilise the level of flight, this system uses the difference in illumination between the sky and the ground. During level flight, the output signal from the sensor unit is neutral and the PA-2 does not control the ailerons or elevator. If the UAV declines from level flight, the output signal of the two opposite photodetectors will be different. The sensor unit forms an error signal and the logical unit changes the position of control surfaces. The PA-2 automatically controls the elevator and ailerons. When the pilot manually controls it, the sensitivity of the PA-2 decreases proportionally to the decline of the control stick. The sensitivity of the PA-2 may be regulated from 0 to 100%.

The optical and output characteristics of the sensor unit are determined in this work.

2. Measuring illumination of ground and sky

A TEC0693 digital photometer was used to measure the illumination of the ground and sky (Liuksomer… 2011). This photometer is suitable for measuring the illumination created by sources of artificial and natural light and to measure the brightness of self-luminous objects (recommended by the Ukrainian State Standard).

The main characteristics of the TEC0693 are presented in Table 1.

Table 1. Characteristics of TEC 0693 photometer

Illumination measuring range, lux	10^{-1} – 10^{5}
Spectrum range of sensitivity, mkm	0.38 – 0.78
Limits of main permissible relative error, %	±5
Time of continuous running, hours	6
Nominal power consumption, Watts	0.1

During investigations in May and June, average values were obtained in Table 2.

The ground is nearly 45° under the line of the horizon. The sky is nearly 45° above the line of the horizon. So, difference in illumination is nearly 2000 lux.

Table 2. Illumination of sky and ground

Time	8.00		16.00	
Weather condition	Sunny day Cloudless		Sunny day Partly cloudy	
Illumination, lux × 10^3				
	City	Unpaved airfield	City	Unpaved airfield
Ground surface	6.6	6.0	3.7	2.9
Horizon	7.6	7.4	4.7	4.0
Sky area	8.7	8.5	5.7	5.5
Directed to sun	62	60	53	54

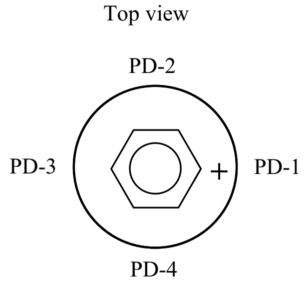

Fig. 4. Disposition of PD-1, PD-2, PD-3, PD-4

3. Description of experimental assembly

An incandescent lamp is used as a source of light during the test. It is calibrated by the scheme in Fig. 1. The evenness of the stream of light in cross section is provided by cone 2. This cone is composed of diffusing material (Fig. 2).

Changing the illumination was achieved by changing the voltage of the incandescent lamp by rheostat. The dependence of the illumination created by incandescent lamp on bulb voltage is shown in Fig. 3.

The photodetectors (PD) of the sensor unit are placed on the aircraft in accordance with Fig. 4. The sensor unit is powered from the logical unit by supply voltage +3.0 V. When aircraft is level the output signal from PD-1 and PD-3 (bank) is +1.5 V. PD-2 and PD-4 (pitch) have the same output signal. In right bank $V_{out} > +1.5$ V, and in left bank $V_{out} < +1.5$ V. PD-1 and PD-3 have the same characteristics during pitch.

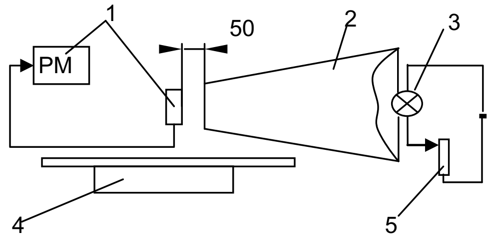

Fig. 2. Experimental assembly to calibrate incandescent lamp: 1 – digital photometer TEC0693; 2 – cone; 3 – incandescent lamp; 4 – rotary table; 5 – rheostat

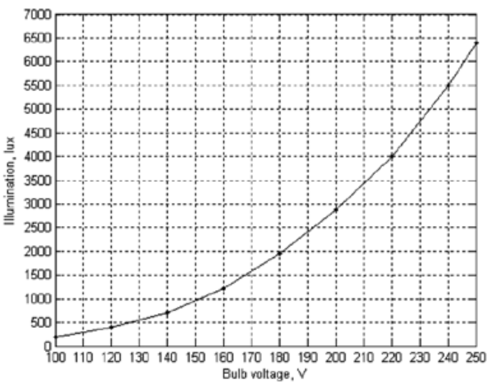

Fig. 3. Illumination created by incandescent lamp

The optical characteristics of the photodetectors were determined in accordance with Fig. 4. The experimental assembly consists of an incandescent lamp (3) and rotary Table (4) with the PA-2 sensor unit (1) fixed on it. A cone (2) is placed 50 mm from the photosensitive surface of the sensor unit. The power supply of the sensor unit is not shown in the Fig. 5.

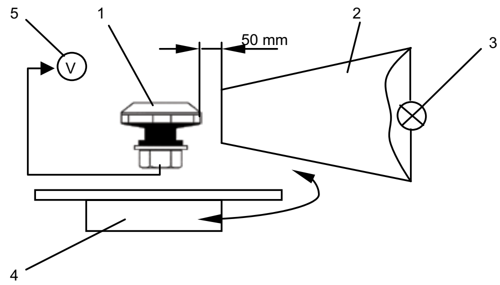

Fig. 5. Structure of experimental assembly: 1 – PA-2 sensor unit; 2 – cone; 3 – incandescent lamp; 4 – rotary table; 5–digital voltmeter

4. Optical characteristics of the sensor unit

During the test, the photodetectors were in turn pointed in the direction of the cone (2). The rotary Table 4 rotated on a horizontal plane until the maximum signal (output voltage) was obtained from the photodetector. It was recorded by the digital voltmeter (5). The other photodetectors were covered with opaque paper. The results obtained for PD1 and PD2 are shown in Fig. 6.

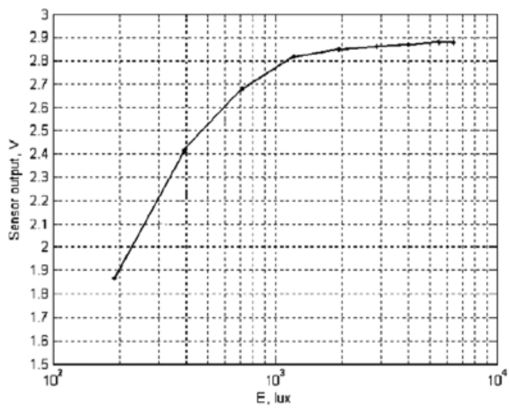

Fig. 6. Typical sensitiveness of the photodetector against illumination

There are inverse relations for PD-3 and PD-4. The difference in indication of various PDs was less than 7%. When illumination was higher than 1000 lux, the PD's characteristics were in the saturation range. Directional diagrams of PDs with illumination 400 and 2880 lux were studied. The rotary table rotated in the horizontal plane and vertical plane. The error in positioning was ±0.3 degrees. Horizontal directional diagrams are shown in Figs 7 and 8. Vertical directional diagrams are shown in Figs 9 and 10.

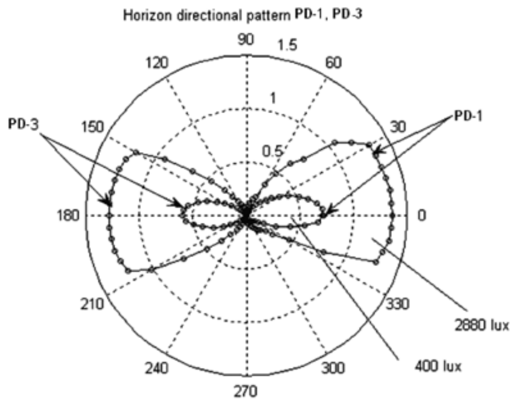

Fig. 7. Horizontal directional diagrams of PD-1, PD-3

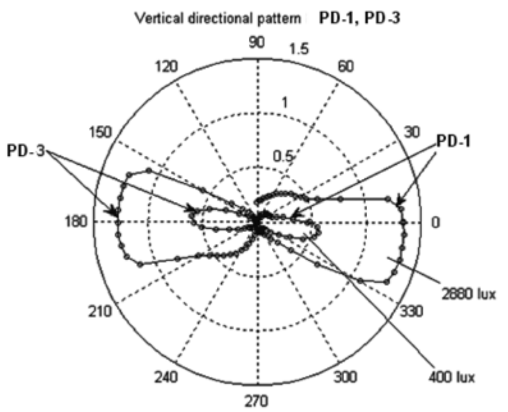

Fig. 8. Vertical directional diagrams of PD-1, PD-3

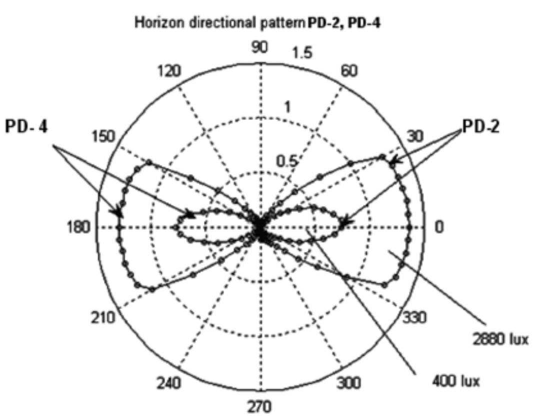

Fig. 9. Horizontal directional diagrams of PD-2, PD-4

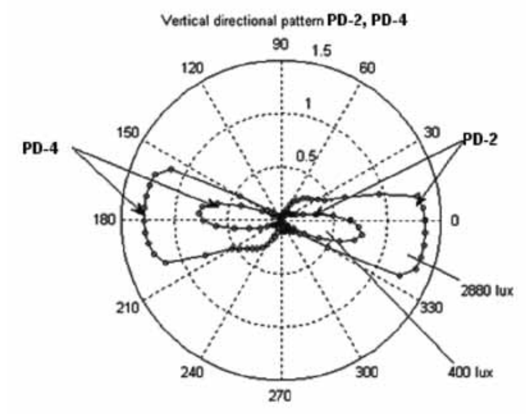

Fig. 10. Vertical directional diagrams of PD-2, PD-4

The operating angle in the horizontal plane is nearly 60 degrees for each photodetector. Operating angle in the horizontal plane is nearly 45 degrees for each photodetector.

The dissymmetry in the directional diagrams of opposite PDs was induced by errors in positioning.

5. Output characteristics of sensor unit

To determine the sensitiveness of the photodetectors in differential regime, the sensor unit was placed in the cone. The results obtained are shown in Figs 11 and 12.

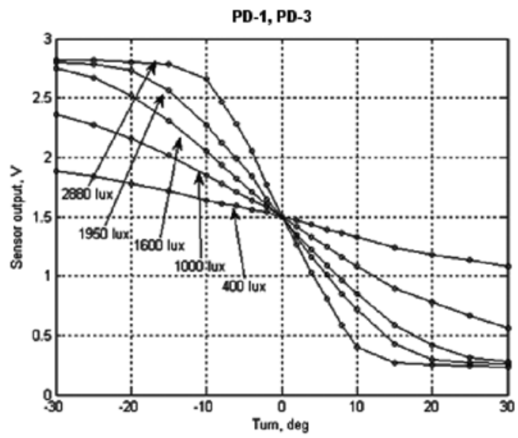

Fig. 11. Output characteristics of sensor unit (bank)

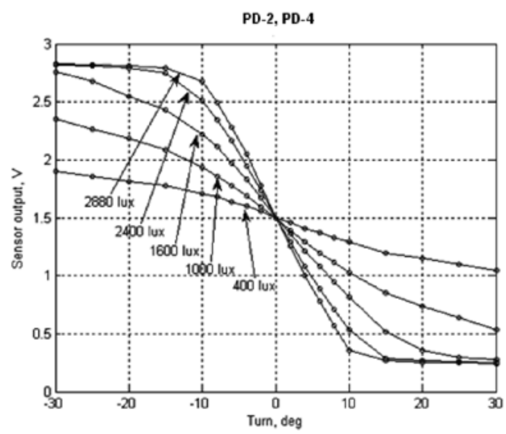

Fig. 12. Output characteristics of sensor unit (pitch)

For different values of illumination, the linear dependence is in the range ±10 degrees, with error not more than 5%. This value of error is enough to provide the required horizontal stabilization of the UAV.

Another result of the experiments is the determination of the characteristics of the PA-2, because these characteristics are absent from the manual and manufacturer's website (PA-2… 2011).

The output characteristics are the dependence of changes in the control signal on the ailerons and elevator UAV from changes in the output voltage of the PA-2 block of sensors. For better understanding, let us use the scheme in Fig. 13.

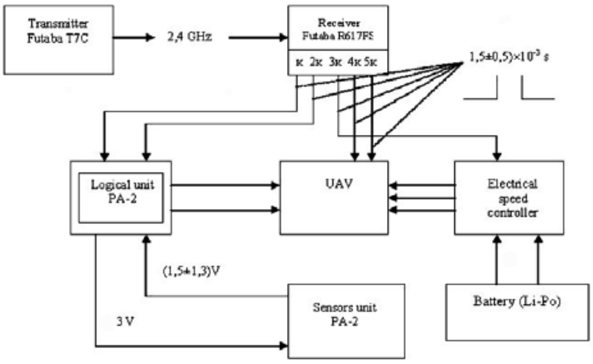

Fig. 13. Control system of UAV

A Futaba T7C 7-channel transmitter unit was used. Its working frequency is 2.4 GHz. The signal from the transmitter unit arrives at the receiver that is on the UAV. The receiver processes this signal and forms impulses in the levels of logical '1' at each of seven channels at its exit control. For all UAVs that are controlled by radio channel, the length of these impulses is approximately 0.5×10^{-3} s at repetition frequency 50 Hz. With a change in the position of the actuating positions on the transmitter, the length of signals is changed in the range of $\pm0.5\times10^{-3}$ s.

The regime of pulse-width modulation is carried out this way. The average duration value on each channel can be changed with the initial settings in the transmitter (regime of trimming) as well as maximum deviation from the average (amount of controls).

Usually, ailerons are connected to the first channel of the receiver and the dividing rudder to the second. In our case (Fig. 13), these channels are connected with the booster control (servo unit) of the UAV through the PA-2 logical unit. The block of sensors is attached to the fuselage of the UAV approximately in the centre of gravity.

The scheme in the Fig. 13 was shown without the plane. Two servos were plugged in to the logical output of the PA-2. The length of the impulses that reach these servos was measured by a F5041 frequency meter. The frequency meter was turned in the measurement of the duration mode with a change time of 1 s. In this case, the error of measurement is 1×10^{-6} s.

The mode of trimming on the transmitter unit is in the zero position and amount of controls are set 100% in both directions. The PA-2 block of sensors was not illuminated at first and then was set according to the scheme in Fig. 5.

The measured durations of the control impulses are shown in the Table 3.

Table 3. Control impulses

	Position of the control actuator on the transmitter	$\tau_{imp} \times 10^{-6}$ s
Ailerons	0	1510
	left	1110
	right	1910
Elevator	0	1594
	down	1101
	up	2028

It is necessary to mention that values τ_{imp} with the repeated measurements during repeated experiments were reproduced with the error .$\pm1\times10^{-6}$ s (frequency meter error). The experiments thus revealed the dynamic range of transfer coefficients and its errors.

Analysing the results of the laboratory experiment, we find that adjusted coefficient of amplification of illumination for this case should be not more then 80% of the possible maximum value.

6. Conclusions

The results obtained show that the operating angle of the sensor unit is nearly 60 degrees in the horizontal plane and 45 degrees in the vertical plane. Whether the output characteristics of the sensor unit are linear depends on the angle of bank and pitch in the range of ±10 deg for different values of illumination. If the bank or pitch angle is higher than 15 degrees, the output signal is constant.

According to the results of the flying tests of the UAV with onboard PA-2 the following was established. The recommended value of the transfer coefficients for roll and pitch at speeds around 100 km/h lead to auto-oscillations of the UAV. Such oscillation mode could lead to accidents and loss of the UAV. As a result, we found that a sufficiently safe and effective horizontal stabilisation mode for an unmanned airplane is achieved if transfer coefficients are 60% from those mentioned in (PA-2… 2011).

These results and data could be used to design a more complicated UAV control system that uses the PA-2 optical sensor like a horizontal stabilisation subsystem.

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