

THEORY AND METHODS OF SIGNAL PROCESSING

UDC 621.396.67: 629.735.45 (045)

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ATTENUATION AVERAGE SIGNAL POWER HELICOPTER ANTENNA SYSTEM

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Abstract—The relations allow quantify degree of redistribution average signal power between its spectral components and satellites that arise at the combination frequencies during rotation the main rotor of the helicopter. Recommendations for permissible levels of signal attenuation in the parametric system “standard antenna – the fuselage of the helicopter” are provide.

Index Terms—Helicopter; helicopter screw; screw blades; directional diagram; mathematical modeling diagram; diagram pulsation.

I. INTRODUCTION

Metal body of the helicopter and installed on it omni-directional antenna form a single system, radiating and receiving radio frequency energy. Rotation conductive main rotor blades (metallic, carboxylic), length of which is comparable with the overall dimensions of the fuselage, makes this system parametric properties. Internal factor parametric antenna system (PAS), which periodically changes in time with the frequency ν , can only be it effective (acting) length – only one technical parameters of the antenna, belongs, for example, in the formula of a perfect radio transmission, and in the formula that determines the difference potentials at the output terminals of the antenna in the radio mode. In [1] substantiated possibility the mathematical model instantaneous values of the effective length pulsating PAS:

$$h_e(t) = h_{e0} - \Delta h_e(t) = h_{e0} \left[1 - \frac{\Delta h_e(t)}{h_{e0}} \right]. \quad (1)$$

In relation (1): Δh_{e0} is the effective length PAS in the absence of pulsations $\Delta h_e(t)$. Instantaneous values pulsation $\Delta h_e(t)$ are determined based on the Fourier expansion periodic sequence of unipolar, adjacent to each other cosine video pulses [2]:

$$\begin{aligned} h_e(t) &= \Delta h_e \left| \cos \frac{\nu}{2} (t + kT_N) \right| \\ &= \frac{2}{\pi} \Delta h_e \left[1 + \sum_{p=1}^{\infty} 2 \frac{(-1)^p}{1 - (2p)^2} \cos p\nu t \right]. \end{aligned}$$

In ratio (2): Δh_e is the pulsation amplitude ($\Delta h_{e \max} < h_{e0}$) in the direction of the vertical θ and horizontal φ spatial angles; $p\nu$ is the circular

harmonics frequency pulsations $\nu = \pi nN/30$, dependent on n is the number of revolutions the shaft main rotor of the helicopter for one minute (from 240 to 350) and from; N is the number of rotor blades (2 to 8); $T_N = 2\pi/\nu = 60/nN$ is the recovery period geometric configuration of PAS in the direction angles θ and φ .

Based on the model (1) and (2) can make a preliminary conclusion that in PAS spectrum of the useful signal is distorted. In the vicinity of the carrier frequency useful signal ω_0 and near its lateral components at frequencies $\omega_0 \mp n\Omega$ arise satellites for combinational sum-difference frequencies types $\omega_0 \mp p\nu$ and $\omega_0 \mp n\Omega \mp p\nu$ respectively. In these relations $n\Omega$ are harmonic frequency modulation useful signal. Satellites accompany every spectral component useful signal, which becomes for them energy donor. At the indicated values of n and N are possible values of the cyclic frequency pulsations $F_N = 1/T_N$ are in the range eight to forty-seven hertz. Combination frequency satellites, embedded in the signal, very small different from the frequency corresponding donors. In the spectrum of the distorted signal satellites are fundamentally irremovable components that do not contain useful information. Therefore their can be attributed to totality multiplicative noise, distributed over the spectrum of the signal. The level of this kind of noise can be reduced by technical solutions that allow reduce the amplitude of pulsations Δh_e the effective length PAS. One such decisions can be attributed choice of a point placing standard antennas on the fuselage of the helicopter. This procedure can be performed using known methods of mathematical modeling of electromagnetic fields generated by objects with complex configurations [1].

The average power useful signal at the output of PAS other things being equal reduced irreversibly

regardless of the type its modulation or manipulation. Therefore, under certain conditions, the weakening of average signal power caused by the occurrence satellites can exceed conditionally permissible value. In the radio link between the two helicopters signal coming at the input receiver airborne is subjected to a double parametrical transformation at comparable frequencies ν and γ . When this frequency signal distortion in the communication channel and attenuation of each of its spectral component are increases.

The emergence the radio channel parametric effects considered type may be accompanied by decrease radio coverage, an increase of bit errors during data transmission, general deterioration of performance characteristics the communications, navigation and surveillance when exerting control air traffic. In [3] contain general information about the adverse effects of the type considered parametric effects on the quality radio channel. However, any method of quantitative estimates parametric effects arising in system "standard antenna-body helicopter" as we know absent in the literature. Therefore becomes necessary to development of appropriate methods and recommendations.

II. FORMULATION OF THE PROBLEM

To establish the dependence average power losses of the useful signal from the relative amplitude pulsations effective length PAS helicopter $\Delta h_e/h_{e0}$, substantiate the level of acceptable average power attenuation signal in the radio channel.

1. The relative loss of average power signal

The voltage $u(r, \theta, \varphi, t)$ at the output of PAS which is in receiving mode, taking into account ideal formula radio transmission represented in the form:

$$u(r, \theta, \varphi, t) = \frac{30k}{r} I_A l_e(t) F_l(\theta_l, \varphi_l) \times h_e(t) F_h(\theta_h, \varphi_h) \cos \omega_0 t. \quad (3)$$

In the ratio (3): I_A is the current amplitude in the antenna onboard radio transmitter of one of the helicopters; $l_e(t)$ is the instantaneous value of the effective length PAS helicopter transmitting information; $h_e(t)$ is the instantaneous value of the effective length PAS helicopter receiving information; $F_l(\theta_l, \varphi_l)$ is the normalized directional diagram of the transmitting PAS; $F_h(\theta_h, \varphi_h)$ is the

normalized directional diagram receiving PAS; k is the propagation constant (wave number); r is the distance direct visibility between antennas helicopters.

In the formula (3) we denote:

$$A(r, \theta, \varphi) = \frac{30k}{r} I_A F_l(\theta_l, \varphi_l) F_h(\theta_h, \varphi_h),$$

and write it in the next form:

$$u(r, \theta, \varphi, t) = A(r, \theta, \varphi) l_e(t) h_e(t) \cos \omega_0 t. \quad (4)$$

In this case turn out highlighted individual characteristics of parametric systems "standard antenna – body helicopter" and the carrier frequency ω_0 in the channel radio communication between helicopters. Instantaneous values of the effective length PAS, each of the two helicopters are determined from a mathematical model (1) with including ripple (2) at frequencies ν and γ , dependent on design features of the main rotor.

The average power of the signal (4) at the output of PAS generally defined on the basis of the known relationship:

$$P_{av} = \lim_{T \rightarrow \infty} \frac{1}{T} \int_0^T u^2(r, \theta, \varphi, t) dt. \quad (5)$$

When determining the average power (5) taking into account multiplication of two similar structurally the Fourier series expansion (2) there are some technical difficulties arising from a large volume of computation. Therefore we simplify the relation (2), confining it first harmonics ($p = 1$) corresponding to decompositions. In this case mathematical model effective length (1) PAS individual helicopters are simplified and take next form:

$$h_e(t) = h_{e0} - \Delta h_e(t) = h_{e0} \left[1 - \frac{2}{\pi} \frac{\Delta h_e}{h_{e0}} \left(1 + \frac{2}{3} \cos \nu t \right) \right], \quad (6)$$

$$l_e(t) = l_{e0} - \Delta l_e(t) = l_{e0} \left[1 - \frac{2}{\pi} \frac{\Delta l_e}{l_{e0}} \left(1 + \frac{2}{3} \cos \gamma t \right) \right]. \quad (7)$$

In this case, the average power of the signal (5) at the output of PAS, in view the ratio (4), (6) and (7) can be represented by the formula:

$$P_{av} = \frac{\sum A_m^2(r, \theta, \varphi)}{2} l_{e0}^2 h_{e0}^2 \left\{ 1 - 0.496 \left[\left(\frac{\Delta l_e}{l_{e0}} \right)^2 + \left(\frac{\Delta h_e}{h_{e0}} \right)^2 - 0.246 \frac{\Delta l_e}{l_{e0}} \frac{\Delta h_e}{h_{e0}} \right] \right\}. \quad (8)$$

The value $\sum A_m^2(r, \theta, \varphi)$ in the ratio (8) determined by the sum squares amplitudes spectral components of signal formed at the output of PAS.

$$P_{av} = \frac{\sum A_m^2(r, \theta, \varphi)}{2} l_{e0}^2 h_{e0}^2 \left\{ 1 - 0.5 \left[\left(\frac{\Delta l_e}{l_{e0}} \right)^2 + \left(\frac{\Delta h_e}{h_{e0}} \right)^2 - 0.25 \frac{\Delta l_e}{l_{e0}} \frac{\Delta h_e}{h_{e0}} \right] \right\}. \quad (9)$$

From comparison relations (8) and (9) follows, that differences between the respective numerical coefficients constitute only 0.4%. Therefore, if necessary, as the mathematical models of effective length PAS appropriate to use simplified ratio (6) and (7). In the ratio (9) a group of multipliers, facing the curly braces defines average power of the signal at antenna output without parametric distortions that caused rotation of the main rotor helicopters:

$$P_{\sum av} = \frac{\sum A_m^2(r, \theta, \varphi)}{2} l_{e0}^2 h_{e0}^2. \quad (10)$$

Subtrahend contained in square brackets ratio (9), defines the average power consumed signal (10) for the maintenance arising satellites:

$$P_{av} = \frac{\sum A_m^2(r, \theta, \varphi)}{4} l_{e0}^2 h_{e0}^2 \left[\left(\frac{\Delta l_e}{l_{e0}} \right)^2 + \left(\frac{\Delta h_e}{h_{e0}} \right)^2 - 0.25 \frac{\Delta l_e}{l_{e0}} \frac{\Delta h_e}{h_{e0}} \right]. \quad (11)$$

In the ratio (11) the relative amplitude pulsations $\frac{\Delta l_e}{l_{e0}}$ and $\frac{\Delta h_e}{h_{e0}}$ effective lengths corresponding PAS depend on geometrical features fuselages helicopters and direction communication line, which is determined by specific values of spatial angles θ and φ .

Using ratio (9) and (10), evaluated quantitatively relative losses q signal power in the communication channel between two helicopters, due to parametric effects in antenna devices:

$$q = \frac{\Delta P_{av}}{P_{\sum av}} = 0.5 \left[\left(\frac{\Delta l_e}{l_{e0}} \right)^2 + \left(\frac{\Delta h_e}{h_{e0}} \right)^2 - 0.25 \frac{\Delta l_e}{l_{e0}} \frac{\Delta h_e}{h_{e0}} \right]. \quad (12)$$

Depending on the possible values of $0 \leq \frac{\Delta l_e}{l_{e0}} \leq 1$

and $0 \leq \frac{\Delta h_e}{h_{e0}} \leq 1$ relative power consumption useful signal (10) for the maintenance satellites (12), which arise in the communication channel between two helicopters is within the limits $0 \leq q \leq 0.875$ (87,5 %).

When determining P_{av} to take into account the contribution of all harmonics that are present in the ratio (2), we obtain the exact ratio:

If communication channel is formed between the helicopter and the object of another type (aircraft control tower), then ratio (12) is simplified and written on the structure:

$$q = \frac{\Delta P_{av}}{P_{\sum av}} = 0.5 \left(\frac{\Delta h_e}{h_{e0}} \right)^2. \quad (13)$$

In this case relative power consumed for formation satellites (13), which arise in the communication channel is within the limits $0 \leq q \leq 0,5$ (50 %).

2. Allowable attenuation of signal power in the PAS. Relative pulsations effective lengths $\frac{\Delta l_e}{l_{e0}}$ and

$\frac{\Delta h_e}{h_{e0}}$ PAS helicopters manifested in the pulsations electric field intensity antenna, which works in transmission mode, and in the voltage ripple (3) that is formed at the terminals of antenna, which is in the receive mode. Therefore pulsations effective lengths PAS is cause pulsations their directional diagram (DD).

Directional diagram antennas installed on aircraft are irregularity. The degree of irregularity is evaluated coefficient unevenness DD in the horizontal plane. This coefficient is calculated as the ratio of the maximum value DD in the plane of the azimuth angle φ_j to the minimum value which is observed at an angle φ_i [4]:

$$k = \frac{F_{j\max}(\varphi_j)}{F_{i\min}(\varphi_i)}. \quad (14)$$

For non-directional on-board antennas used in wireless communication systems and automatic dependent surveillance (ADS) in the VHF and UHF, valid values are $k_{per} = 4$ (12 dB) [4]. Comparing the ratio (9) and (10) we may determine the coefficient of the parametric attenuation desired signal power in radio communication channel, in a logarithmic scale (dB):

$$d_0 = 10 \lg \frac{P_{\sum av}}{P_{av}} = -10 \lg(1 - q). \quad (15)$$

If information is exchanged between the two helicopters, the allowable relative power loss to products of parametric conversion in the radio channel on the basis of (12) will be $q_{per} = 0,055$ or 5,5 %, which corresponds to the permissible attenuation of the spectral components of the desired signal (15) on the $d_{0per} = 2.5$ dB (in 1,8 times). The maximum possible value losses $q_{max} = 0.875$ correspond to attenuation on the $d_{0max} = 0.9$ dB (8 times).

If the information exchange was fostered between a helicopter and an object of a different type then allowable relative power loss for the products of the parametric transformations arising in the radio channel are determined on the basis ratio (13) and constitute $q_{per} = 0,031$ or 3.1 %. This quantity corresponds to the value allowable attenuation of the spectral components useful signal on $d_{0per} = 1.25$ dB (1.3 times). The maximum possible losses $q_{max} = 0.5$ corresponds to attenuation of the spectral components useful signal on $d_{0max} = 3$ dB (2 times). From these examples follows that allowable levels attenuation of the spectral components useful signal in the channels of communication for above situations differ by 1.25 dB (1.3 times) and inadmissible attenuation differ by 6 dB (4 times).

CONCLUSIONS

1. With increase amplitude pulsation effective length PAS average power signal consumed for the maintenance of the satellite increases, which entails a corresponding weakening of the average power of each spectral component of useful signal supplied to the receiver input.

2. Satellites arising at the output of PAS, located very close to the corresponding spectral components

donor, and are technically their lateral components at the combination frequencies. They can not be filtered in any circumstances.

3. Radical method of reducing attenuation average power signal to the PAS helicopter is placing standard antenna at such a point its fuselage with respect to which depth of the dips of the antenna DD is minimum. In this case pulsation amplitude effective length PAS are minimum.

4. In the radio channel, which is formed between the helicopter and an object of a different type, the maximum attenuation of the signal power caused by to parametric effect its antenna can reach 3 dB when allowable 1.25 dB.

5. In the radio channel, formed between the two helicopters, the maximum attenuation of the signal power caused by parametric effects in their antennas can reach 9 dB, when allowable 2.5 dB.

6. All of the foregoing ratios are the original and can be used in practice for quantitative estimates average power loss in PAS helicopters.

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Received 10 March 2015

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В. О. Іванов, О. С. Задорожний. Послаблення середньої потужності сигналу антенною системою гелікоптера

Отримані співвідношення, що дозволяють кількісно оцінити ступінь перерозподілення середньої потужності сигналу між його спектральними складовими та сателітами, які виникають на комбінаційних частотах при обертанні несучого гвинта гелікоптера. Наведені рекомендації для вибору рівнів допустимого послаблення сигналу в параметричній системі «штатна антена – фюзеляж вертольота».

Ключові слова: гелікоптер; гвинт гелікоптера; гвинтові лопаті; діаграма спрямованості; математичне моделювання; схема пульсації.

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В. А. Иванов, А. С. Задорожний. Ослабление средней мощности сигнала антенной системой вертолета

Получены соотношения, позволяющие оценить количественно степень перераспределения средней мощности сигнала между его спектральными составляющими и спутниками, которые возникают на комбинационных частотах при вращении несущего винта вертолета. Приведены рекомендации по выбору уровней допустимого ослабления сигнала в параметрической системе «штатная антенна – фюзеляж вертолета».

Ключевые слова: вертолет; винт вертолета; винтовые лопасти; диаграмма направленности; математическое моделирование; схема пульсации.

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