UDC 621.396.67: 629.735.45(045)

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SIGNAL DISTORTION IN HELICOPTERS ANTENNA SYSTEM

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Abstract. *It is shown that the system "standard non-directional antenna – metal body helicopter" during rotation of main screw is parametric. In this case, the parameter antenna system is effective length. The result of periodic changing its values is distortions spectrum radio signals at the terminals of standard antenna. Was a developed method of spectral composition radio signals analysis after parametric changes: quantitative evaluation attenuation of spectral components useful signal, identifying values combination frequencies undesirable components-satellites. Spectral distortions of some types of modulated and manipulated radio signals at the output of parametrical antenna system are investigated.*

Keywords: directivity diagram; effective length of the antenna; helicopter screw; parametric signal transduction; spectrum, radio signal; video impulses.

Introduction

General properties of antennas devices are determined by their internal and external parameters electrodynamics characteristics and indicators and depend on the design features of the current-carrying surfaces individual elements and their mutual spatial orientation commensurability geometric dimensions relative to the wavelength λ . This explains, for example, indented directivity diagram (DD) systems such as "Standard non-directional antenna – metal body aircraft" [1–3]. If the same antenna installed on another type of airframe or helicopter body, then the form DD and extent its indented will be different.

During the rotation metallic or metalized main screw helicopter, which is part of fuselage, DD in either direction will be change periodically, i. e. helicopter antenna system becomes parametric properties. Therefore modulated useful radio signal that is emitted or received by helicopter parametric antenna system (PAS), inevitably suffers spectral transformations and energy losses. Unwanted frequency components that arise in the spectrum of useful signal is energy intensive. Therefore, the amplitude useful signal components at the output PAS in the mode rotation main screw is always smaller amplitude of the same signal components if the screw does not rotate (in ground tests). This statement is experimental confirmation of – the weakening useful signal at the output of PAS when flying helicopter can reach 12 dB [4], but any procedures theoretical analysis of this phenomenon in the available publications we have not found. Natural that effect of frequency and power distortions signals airborne radio communication systems, navigation and landing in a helicopter PAS negative impact on quality of operation of these systems and separate helicopter flight safety and flight few helicopters in the group. It is therefore necessary to make the primary theoretical research results of the interaction of different types of modulated radio signals with PAS helicopter and discover appropriate regularities.

Problem

In PAS "Standard non-directional antenna – metal body helicopter" detect generalized factor which varies in time according to the periodic law and identify the main features of distorted useful signal structure of any type.

Justification mathematical model of the effective length PAS

Parameters specific antenna device are interconnected either directly or through intermediate function. Therefore, changing one of them is displayed in the appropriate quantitative or qualitative changes indicators of all the others. In consequence, it can be argued that changing in time DD PAS is a consequence of some changing in the time internal antenna device parameter, whose value is depends on momentary spatial position of helicopter rotor blades. This parameter can be found, if you define the voltage $u(t)$ at the terminals of standard antenna, which is under influenced of electromagnetic field $E(t)$ that contains information about useful signal

$$u(t)=E(t)h_{eo}. \qquad (1)$$

In equation (1) h_{ec} – effective (active) length of the antenna device in the chosen constructions point. This parameter is only one in the ratio (1) directly related to PAS. Therefore, in accordance with antenna installed on the helicopter body, equation (1) is necessary to give in the form

$$u(t)=E(t)\,h_{\text{e}}(t)\,, \qquad (2)$$

where $h_{\text{e}}(t)$ – instantaneous value of the effective length of PAS. From ratio (2) immediately follows that in PAS the useful signal suffers multiplicative distortion that can not be eliminated in the future at all.

The mathematical model of the effective length PAS can be represented as

$$h_{\text{e}}(t)=h_{\text{e c}}-\Delta h_{\text{e}}(t)=h_{\text{e c}}\left[1-\frac{\Delta h_{\text{e}}(t)}{h_{\text{e c}}}\right]. \qquad (3)$$

In this model $\Delta h_{\text{e}}(t)$ – part which is periodical function of angular velocity rotation the main rotor helicopter. Maximum value ripple $\Delta h_{\text{e max}} < h_{\text{e c}}$ and in other similar conditions depends on the electrical characteristics of the material from which made the main rotor blades. If the material in its electrical characteristics is close to ideal dielectric then $\Delta h_{\text{e}}(t)$ is close to zero.

Effective length of the PAS model (3) is valid in modes reception and radiation. The value $h_{\text{e c}}$ in the model is formally defined based on known ratios provided for example in [4]. However for antennas devices installed on aircraft effective length are determined based on experiments by the method given in [2]. This can be also calculating method grid simulation electrodynamics objects of complex configuration [1].

If the main rotor blades are metal, then character of changing in time DD PAS in either direction is identical to the changing character of pulsations $\Delta h_{\text{e}}(t)$. This fluctuations in the physical interpretation is periodical sequence of identical shape and duration τ, in the selected direction, unipolar impulses which border with one another, and their envelope is a smooth curve that has no jumps and discontinuities. Pulse duration τ is equal period of follow *T*. Such a periodic sequence of pulses can be decomposed in the classical Fourier series in order to detect levels of constant component and separate harmonic components in a mathematical model of the effective length PAS (3). The frequency of the first harmonic F_1 periodic sequence of pulses irrespective of their forms the envelope each of them determined by the ratio, Hz

$$F_1=\frac{1}{T}=\frac{nN}{60}\,, \qquad (4)$$

where *n* – number of revolutions of a shaft main rotor for one minute; *N* – number of propeller blades. If the screw is biaxial, the frequency is increased to four times.

On the basis above individual pulses in the periodic sequences in the general case in order to simplify analysis while preserving main regularities should be provide smoothed form. Simplest is cosine pulse shape. With such choice in the ratio (3) pulses $\Delta h_{\text{e}}(t)$ will be provided schedule periodic sequence of pulses cosine in Fourier series [5]

$$\begin{aligned}\Delta h_{\text{e}}(t)&=\Delta h_{\text{e}}\sum_{k=-\infty}^{\infty}\left|\cos\frac{\nu_1}{2}(t+kT)\right|=\\&=\frac{2}{\pi}\Delta h_{\text{e}}\left[1+\sum_{p=1}^{\infty}2\frac{(-1)^p}{1-(2p)^2}\cos p\nu_1 t\right].\end{aligned} \qquad (5)$$

in which Δh_{e} – amplitude value of fluctuations in the general case; $\nu_1=2\pi F_1$ – the first angular harmonic parametric frequency conversion; *p* – number of harmonic parametric frequency conversion signal, *l* = 1, 2, 3, ...

In the general case voltage at the terminals of the receiving antenna standard on the basis of the relations (2), (3) and (5) is given by the expression:

$$\begin{aligned}u(t)&=h_{\text{e o}}\left[1-\frac{\Delta h_{\text{e}}(t)}{h_{\text{e c}}}\right]E(t)=\\&=h_{\text{eo}}\left\{1-\frac{2}{\pi}\frac{\Delta h_{\text{e}}}{h_{\text{e o}}}\left[1+\sum_{p=1}^{\infty}2\frac{(-1)^p}{1-(2p)^2}\cos p\nu_1 t\right]\right\}E(t).\end{aligned} \qquad (6)$$

From the expression (6) implies that output level PAS is always less than input level (1) that is at $\Delta h_{\text{e}}=0$. In the worst case if, $\Delta h_{\text{e}}/h_{\text{e c}}\approx 1$ the amplitude of the carrier signal in PAS weakened 2.75 times that is nearly 9 dB. Also weakened all harmonic components input signal. Energy loss of signal $E(t)$ at a constant efficiency factor PAS is spent on creating new spectral components that appear in the output signal. In this case, general attenuation useful signal in the PAS helicopter can closer to 12 dB measured experimentally [4].

Relation (6) is the basis for the analysis of parametric distortion of radio signals of any type in PAS helicopter.

Of course *N* (240 ... 350) rev / min., *N* = (2 ... 8), $F_1\approx(8...50)$ Hz. If main rotor helicopter is biaxial, then frequency F_1 is increased up to four times, but would remain low. Thus equation (6) in its structure coincides with generally accepted form of amplitude-modulated (manipulated) narrowband signal $E(t)$.

Theoretical analysis of the distortion narrowband radio signals in PAS helicopter

Consider some specific examples.

1. *The input signal is multi-frequency amplitude modulation of the carrier.* Mathematical form of writing such signal is known [6]:

$$E(t)=E_0\left[1+\sum_{i=1}^{\infty}M_i\cos(\Omega_i t+\Phi_i)\right]\cos(\omega_0 t+\psi_0)=$$

$$=E_0\left\{\cos(\omega_0 t+\psi_0)+\sum_{i=1}^{\infty}\frac{M_i}{2}\cos[(\omega_0-\Omega_i)t+\psi_0-\Phi_i]+\sum_{i=1}^{\infty}\frac{M_i}{2}\cos[(\omega_0+\Omega_i)t+\psi_0+\Phi_i]\right\}, \qquad (7)$$

where ω_0 and ψ_0 – circular frequency of the carrier and its initial phase; M_i – partial coefficients modulation depth; Ω_i – circular frequency of the *i*-th component modulating signal; Φ_i – corresponding initial phase.

Instantaneous values of voltage (6) PAS output terminals determined by the ratio:

$$u(t)=E_0 l_{e0}\left\{\left[1+\sum_{i=1}^{\infty}M_i\cos(\Omega_i t+\Phi_i)\right]\cos(\omega_0 t+\Psi_0)-\right.$$

$$-\frac{2}{\pi}\frac{\Delta l_e}{l_{e0}}\left[1+2\sum_{p=1}^{\infty}\frac{(-1)^p}{1-(2p)^2}\cos p\nu_1 t\right]\cos(\omega_0 t+\Psi_0)-$$

$$-\frac{1}{\pi}\frac{\Delta l_e}{l_{e0}}\left[1+2\sum_{p=1}^{\infty}\frac{(-1)^p}{1-(2p)^2}\cos p\nu_1 t\right]\sum_{i=1}^{\infty}M_i\cos\left[(\omega_0-\Omega_i)t+\Psi_0-\Phi_i\right]-$$

$$\left.-\frac{1}{\pi}\frac{\Delta l_e}{l_{e0}}\left[1+2\sum_{p=1}^{\infty}\frac{(-1)^p}{1-(2p)^2}\cos p\nu_1 t\right]\sum_{i=1}^{\infty}M_i\cos\left[(\omega_0+\Omega_i)t+\Psi_0+\Phi_i\right]\right\}. \qquad (8)$$

The first component of (8) characterizes the main AM – signal and subtrahend is the product of its parametric transformations and does not contain useful information. The combination of these subtrahend, after multiplication corresponding harmonic functions that come to them, determines the spectral composition fluctuations (6).

From expression (8) make following conclusions:

– spectral composition of the output signal board antenna helicopter differs from the spectral composition of the incoming influence;

– every high-frequency component of the input signal becomes partial carrier that on the output PAS accompanied by the emergence corresponding lateral components satellites on frequencies specified in lines 3 and 4, the first column of the table below;

– the voltage signal at the carrier frequency ω_o in PAS decreases in proportion to the value $\left(1-\frac{2}{\pi}\frac{\Delta h_e}{h_{ec}}\right)$ and when $\Delta h_e \approx h_{ec}$ weakened in 2,75 times, another words almost on 9 dB; level other components useful signal (7) weakened in PAS proportion to the value of the ratio $\Delta h_e / h_{ec}$.

– general weakening useful signal components in the PAS may exceed 9 dB;

– in PAS signal energy is redistributed between the constituent distorted spectrums – the satellite components exist at the expense of the energy selected from signal.

When Δh_e = 0 equation (8) determines the instantaneous values and the law of modulation voltage at the terminals standard antennas.

2. *The input signal is a single frequency with angular modulation carrier.* The overall shape of this recording signal at the point of placing antenna has the form [6]

$$E(t)=E_0\left\{J_0(m)\cos(\omega_0 t+\psi_0)+(-1)^n\sum_{n=1}^{\infty}J_n(m)\cos\left[(\omega_0-n\Omega)t+\psi_0-\Phi_n\right]+\right.$$

$$\left.+\sum_{n=1}^{\infty}J_n(m)\cos\left[(\omega_0+n\Omega)t+\psi_0+\Phi_n\right]\right\}. \qquad (9)$$

In the ratio (9)

$$J_n(m)=\sum_{k=0}^{\infty}\frac{(-1)^k(0,5m)^{2k+n}}{k!(k+n)!}, \qquad (10)$$

is the Bessel function of n-th order from argument m; k – sequence number terms in the series, which this function is provided. According to expression (9) in the ratio (10) value n coincides with the numbers harmonic frequency Ω modulating signal, and the value m is the index of possible types angular modulation – phase or frequency. The spectral composition voltage at the terminals of antenna can be identified on the basis ratio (6) with (9)

$$u(t)=E_0\,h_{ec}\left\{1-\frac{2}{\pi}\frac{\Delta h_e}{h_{ec}}\left[1+\sum_{p=1}^{\infty}2\frac{(-1)^p}{1-(2p)^2}\cos p\nu_1 t\right]\right\}\{J_0(m)\cos(\omega_0 t+\Psi_0)+$$
$$+(-1)^n\sum_{n=1}^{\infty}J_n(m)\cos\left[(\omega_0-n\Omega)+\Psi_0-\Phi_n\right]+\sum_{n=1}^{\infty}J_n(m)\cos\left[(\omega_0+n\Omega)t+\Psi_0+\Phi_n\right]\}. \qquad (11)$$

In the spectrum of the signal (11) are present parasitic components-satellites on combinational frequencies, whose values depend from the speed of shaft rotation the main rotor helicopter.

From equation (11) it follows that all spectral components of the useful signal (9) attenuated at PAS equally in the previous case.

Frequency components of the output signal (11) PAS is provided in the second column of the table.

3. The input signal is a single-frequency with amplitude manipulation meander. Instantaneous signal value at the point of acceptance provided by the expression

$$E(t)=\frac{1}{2}E_0\left(1+\frac{4}{\pi}\sum_{n=1}^{\infty}\frac{\sin n\frac{\pi}{2}}{n}\cos\Omega t\right)\times$$
$$\times\cos(\omega_0 t+\Psi_0)\,, \qquad (12)$$

in which $\Omega=\frac{2\pi}{T_m}$, and T_m – period following rectangular pulses.

Instantaneous values distorted signal (6) at the terminals of the antenna determined with regard relation (12)

$$u(t)=0,5E_0h_{ec}\left\langle\left\{1+\frac{4}{\pi}\sum_{n=1}^{\infty}\frac{\sin n\frac{\pi}{2}}{n}\cos n\,\Omega t-\frac{2}{\pi}\frac{\Delta h_e}{h_{ec}}\left[1+2\sum_{p=1}^{\infty}\frac{(-1)^p}{1-(2p)^2}\cos p\nu_1 t\right]\right\}\cos(\omega_0 t+\Psi_0)-\right.$$
$$-\frac{4}{\pi^2}\frac{\Delta h_e}{h_{e0}}\left[1+2\sum_{p=1}^{\infty}\frac{(-1)^p}{1-(2p)^2}\cos p\nu_1 t\right]\times$$
$$\left.\times\sum_{n=1}^{\infty}\frac{(-1)^p}{1-(2p)^2}\left\{\cos\left[(\omega_0-n\Omega)t+\Psi_0\right]+\cos\left[(\omega_0+n\Omega)t+\Psi_0\right]\right\}\right\rangle. \qquad (13)$$

From ratio (13) follows that all spectral components of the useful signal (12) weakened in PAS as in previous cases.

Frequency components of the output signal PAS is shown in the third column of the table.

4. The output signal is frequency-manipulated under the law meander, dual-frequency. Instantaneous values of voltage (6) on output terminal parametric AS in this case determined by the ratio

$$E(t)=\frac{1}{2}E_o\left\langle\cos\left(\omega_1 t+K_1\frac{\pi}{2}\right)+\cos\left(\omega_2 t-K_2\frac{\pi}{2}\right)+\right.$$
$$+\sum_{n=1}^{\infty}\frac{2}{n\pi}\sin n\frac{\pi}{2}\left\{\cos\left[(\omega_1-n\Omega)t+\left(K_1+n\frac{\pi}{2}\right)\right]+\cos\left[(\omega_1+n\Omega)t+\left(K_1+n\frac{\pi}{2}\right)\right]+\right.$$
$$\left.\left.+\cos\left[(\omega_2-n\Omega)t-\left(K_2+n\frac{\pi}{2}\right)\right]+\cos\left[(\omega_2+n\Omega)t-\left(K_2+n\frac{\pi}{2}\right)\right]\right\}\right\rangle, \qquad (14)$$

In ratio (14) frequency ω_1 and ω_2 correspond to the carrier logical units "+1" and "-1" is the frequency manipulation Ω determined by meander period T_m, $K_{1(2)}$ is the coefficient of proportionality between the values of carrier frequencies and frequency of manipulations (usually it is an integer)

$$K_{1(2)} = \frac{\omega_{1(2)}}{\Omega}.$$

In PAS spectrum of the signal (14) is distorted and acquires next mathematical interpretation

$$u(t) = \frac{1}{2} E_o h_{ec} \left[1 - \frac{2}{\pi} \frac{\Delta h_e}{h_{ec}} - \frac{4}{\pi} \frac{\Delta h_e}{h_{ec}} \sum_{p=1}^{\infty} \frac{(-1)^p}{1-(2p)^2} \cos p \nu_1 t \right] \left\langle \cos\left(\omega_1 t + K_1 \frac{\pi}{2}\right) + \cos\left(\omega_2 t - K_2 \frac{\pi}{2}\right) + \right.$$

$$+ \sum_{n=1}^{\infty} \frac{2}{n\pi} \sin n\frac{\pi}{2} \left\{ \cos\left[(\omega_1 - n\Omega)t + \left(K_1 + n\frac{\pi}{2}\right)\right] + \cos\left[(\omega_1 + n\Omega)t + \left(K_1 + n\frac{\pi}{2}\right)\right] + \right.$$

$$\left.\left. + \cos\left[(\omega_2 - n\Omega)t - \left(K_2 + n\frac{\pi}{2}\right)\right] + \cos\left[(\omega_2 + n\Omega)t - \left(K_2 + n\frac{\pi}{2}\right)\right] \right\} \right\rangle. \quad (15)$$

From ratio (15) implies that on the output PAS spectrum signal differs from the spectrum of its input (see column 4 in the table). Level of the useful signal (14) weakened the already known way.

5. The input signal is phase-manipulated under the law meander. In this case, the instantaneous values of voltage (6) on the output terminals of the PAS determined by the ratio

$$E(t) = \frac{4}{\pi} E_o \sum_{n=1}^{\infty} \frac{1}{n} \sin^2 \frac{n\pi}{4} \sin n\Omega t \cos \omega_o t = \frac{2}{\pi} E_o \sum_{n=1}^{\infty} \frac{1}{n} \sin^2 \frac{n\pi}{4} \left[\sin(\omega_o + n\Omega)t - \sin(\omega_o - n\Omega)t \right]. \quad (16)$$

After transformation in PAS useful signal can be given as:

$$u(t) = \frac{2}{\pi} E_o h_{eo} \left[1 - \frac{2}{\pi} \frac{\Delta h_e}{h_{ec}} - \frac{4}{\pi} \frac{\Delta h_e}{h_{ec}} \sum_{p=1}^{\infty} \frac{(-1)^p}{1-(2p)^2} \cos p \nu_1 t \right] \sum_{n=1}^{\infty} \frac{1}{n} \sin^2 \frac{n\pi}{4} \left[\sin(\omega_o + n\Omega)t - \sin(\omega_o - n\Omega)t \right]. \quad (17)$$

Signal (17) characterized by both effects, which are characterized by signals that are analyzed. The spectral composition of the signal (17) is given in the fifth column of the table.

Radio signals frequency components at the output of the PAS

No	Modulation type (manipulation) signal at the input parametric AS				
	Multi-frequency amplitude modulation	Single-frequency with angular modulation	Amplitude manipulation of meander	Frequency-manipulated meander, dual-frequency	Phase-manipulated meander
1	ω_o	ω_o	ω_o	$\omega_{1(2)}$	–
2	$\omega_o \mp \Omega_i$	$\omega_o \mp n\Omega$	$\omega_o \mp n\Omega$	$\omega_{1(2)} \mp n\Omega$	$\omega_o \mp n\Omega$
3	$\omega_o \mp pv_1$	$\omega_o \mp pv_1$	$\omega_o \mp pv_1$	$\omega_{1(2)} \mp pv_1$	–
4	$\omega_o \mp \Omega_i \mp pv_1$	$\omega_o \mp \Omega \mp pv_1$	$\omega_o \mp \Omega \mp pv_1$	$\omega_{1(2)} \mp n\Omega \mp pv_1$	$\omega_o \mp n\Omega \mp pv_1$

In the following table combination frequencies that are contained in rows 3 and 4, the corresponding columns, related to satellites, which appear in the output signal distorted PAS as parasitic lateral components around carrier at frequencies specified in lines 1 and 2.

Conclusions

1. Antenna system "Basic antenna – body helicopter" is parametric. Parameter of the system, which changes periodically in time, is an effective length. The root cause that determines periodic change the values of the effective length of PAS is rotating metal main rotor helicopter with a constant speed.

2. The result PAS is distortion frequency spectrum of the original narrowband signal. Distortions manifested in the occurrence of undesirable components-satellite in the combination frequencies, whose values depend on the frequency spectral components useful signal and the speed of rotation of the shaft main rotor helicopter.

3. All components of input useful signal of any type in PAS suffer attenuation.

4. Energy loss component useful signal PAS equal energy, which is concentrated in the satellite components that appear as unwanted side around each high-frequency components of input signal undistorted.

5. Theoretical studies are carried out in the work confirm and explain the known experimental data about attenuation useful signal PAS to 12 dB. The resulting ratio indicates that almost 9 dB can weakened carrier signal and almost 3 dB may weakened its other high frequency components at a constant value of coefficients efficiency PAS.

6. Unwanted parametric effects, which detected, characteristic of any radio signals necessary for normal functioning of the standard and special equipment onboard helicopter.

7. When radio communication between two helicopters same type signal attenuation in the channel radio communication between them, that due parametric effects to their antennas, doubled.

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Received 14 October 2013.

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В. О. Іванов, О. С. Задорожний. Спотворення сигналів в антенних пристроях вертольотів

Показано, що система «Штатна ненаправлена антена – металевий корпус вертольота» при обертаннях несучого гвинта стає параметричною. При цьому параметричним чинником виявляється ефективна висота антени. Наслідком періодичних змін її значень є спотворення спектру радіосигналів на клемах штатної антени. Розроблено методику аналізу спектрального складу радіосигналів після їх параметричних спотворень: кількісна оцінка послаблень спектральних складових корисного сигналу, виявлення значень комбінаційних частот небажаних складових – сателітів. Розглянуто спектральні спотворення деяких типів модульованих і маніпульованих радіосигналів на виході параметричної антенної системи.

Ключові слова: відео імпульси; гвинт вертольота; діаграма спрямованості; ефективна довжина антени; параметричний сигнал; спектр радіосигналу.

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В. А. Иванов, А. С. Задорожный. Искажения сигналов в антенных устройствах вертолетов

Показано, что система «Штатная ненаправленная антенна – металлический корпус вертолета» при вращениях несущего винта становится параметрической. При этом параметрическим фактором оказывается эффективная высота антенны. Следствием периодических изменений ее значений являются искажения спектра радиосигналов на клеммах штатной антенны. Разработана методика анализа спектрального состава радиосигналов после их параметрических искажений: количественная оценка ослаблений спектральных составляющих полезного сигнала, выявления значений комбинационных частот нежелательных составляющих-сателлитов. Рассмотрены спектральные искажения некоторых типов модулированных и манипулированных радиосигналов на выходе параметрической антенной системы.

Ключевые слова: видео импульсы; винт вертолета; диаграмма направленности; эффективная длина антенны; параметрический сигнал спектр радиосигнала.

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