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CHARACTERISTICS OF METAL-POLYMERIC BEARINGS OF BLADE DRAG HINGES, REALIZED ON COAXIAL HELICOPTERS

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Abstract - Metal-polymeric sliding bearings of coaxial helicopter blade drag-hinges are installed in a hinge which is under action of a shearing force and a bending moment in the flapping plane besides a centrifugal force and loads in the rotation plane. Angular displacements of a blade in the drag hinge occur at rotational frequency of the main rotor as well as at "ground resonance" frequency under conditions of full-scale "ground resonance" tests of the helicopter. To provide similar conditions of drag hinge work and to determine characteristics of the metal-polymeric bearing on a test rig in a laboratory is a complicated and difficult task. The present paper describes an algorithm which might be used to determine characteristics of the metal-polymeric bearing in coaxial helicopter "ground resonance" test conditions in proximity to the boundary area of allowable moment values of the bearings.

Metal-polymeric dry sliding bearings [1] with different moment values for each rotor are used in blade drag hinges of coaxial helicopters with hinged hubs of main rotors. Moment values of these bearings are usually measured during "ground resonance" tests of the helicopter.

"Ground resonance" safety of the coaxial helicopter is checked in the following full-scale test conditions: ground run, hover landing, ground taxiing, running takeoffs and landings. Ground runs are performed throughout the range of operating main rotor speeds and compressions of landing-gear shock-absorber rods from a parking position to a fully extended one, with "ground resonance" provocations. The provocations are accomplished by pilot's cyclic pitch-stick oscillatory motions resulting in vibrations of blades

with the "ground resonance" frequency of a stator (fuselage). It is known that at free vibrations of the "ground resonance" type, frequencies of the stator - P_S , blades in the rotation plane - P_{bL} and a rotational frequency of the main rotor - ω are connected by the relationship: $P_S = \omega - P_{bL}$. It should be noted also that circular and elliptic motions of the cyclic pitch stick are performed clockwise (the direction of upper main rotor rotation) and counter-clockwise (the direction of lower main rotor rotation) [2]. During ground runs with provocations, vibration amplitudes of the stator and blades in the rotation plane, at frequencies of P_S and P_{bL} respectively, reach their highest values in case of vibrations of the helicopter resting on landing gear tires only,

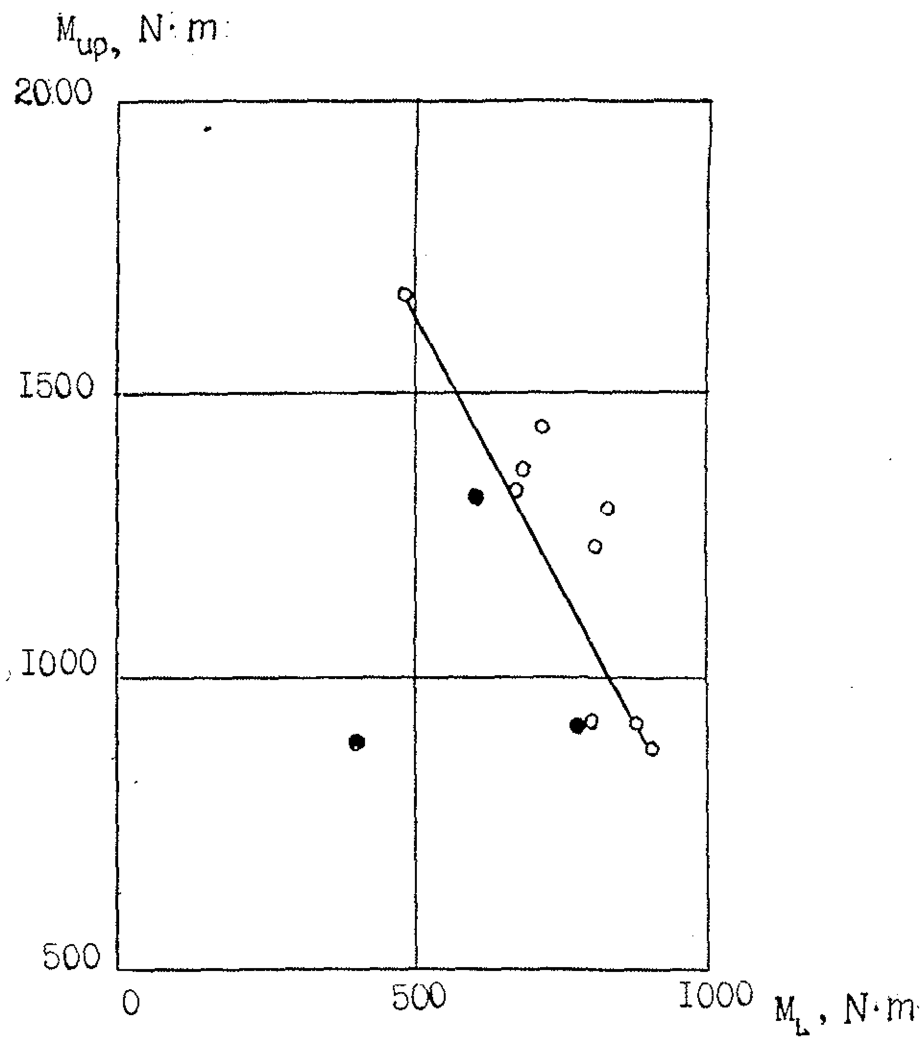

Fig. 1. Moments about drag hinges of the Ka-32 helicopter
• - "ground resonance", o - "out-of-ground resonance",
— an assumed boundary of the zone of allowable moments

when shock-absorber rods are fully extended and shock-absorbers of the landing gear do not work. The lowest "ground resonance" margins of all checked conditions take place during ground runs with provocations caused by control stick motions and at fully extended rods of landing gear shock-absorbers.

Moments of the upper and lower main rotors - M_{up} and M_L respectively, were measured during ground runs with "ground resonance" provocations carried out on the Ka-32 coaxial helicopter equipped with metal-polymeric bearings in blade drag hinges. Basic results of these special tests for a wide range of moments are presented in Fig. 1 in the form of the M_{up} and M_L values area, and an assumed relationship of $M_{up} = f(M_L)$ for a boundary area of allowable values is marked by a solid line. The helicopter is unstable in respect of "ground resonance" if its moments are less than the allowable ones.

Typical dependence of the M moment (subscripts "UP" and "L" are omitted here) on γ, obtained at "ground resonance" tests of the Ka-32 helicopter, is shown in Fig. 2. The metal-polymeric

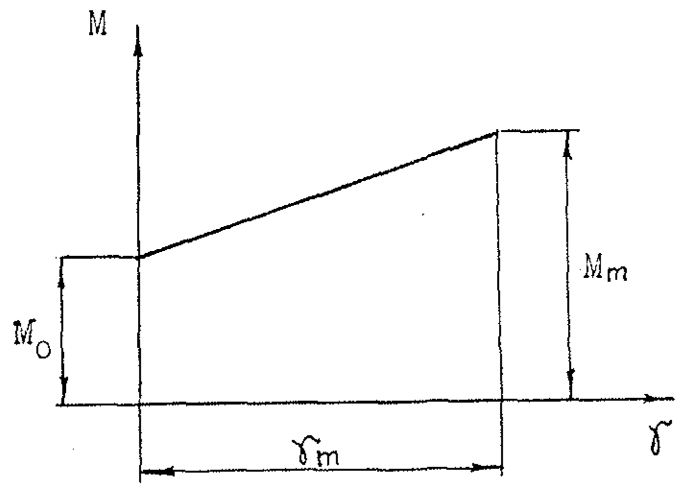

Fig. 2. Relationship between the metal-polymeric bearing moment and the angle of blade deflection in the drag hinge

bearing moment depends on the angle of blade deflection in the drag hinge. Beginning from M_o, it reaches the maximum value of M_m at the maximum angle of γ_m. Commonly it is attributed to dry and viscous friction of the metal-polymeric bearing. But it should be also attributed to elastic properties of the metal-polymeric bearing installed in the drag hinge. Proceeding from the aforesaid, stiffness of the metal polymeric bearing might be presented in the following form:

$$C = b\,(M_m - M_o)/\gamma_m, \qquad (1)$$

where b - a coefficient, the value of which should be less than 0.5.

Let's consider motion of a blade in a drag hinge at ground run of the helicopter. Shock-absorber rods of the landing gear are fully extended, wheels of the landing gear are braked, and vibrations occur at the helicopter resting on front and main tires without their taking off from the ground. The cyclic pitch stick is displaced forward (or backward) and fixed by a pilot in its static position. A value of static displacement of the cyclic pitch stick is selected such as to exclude motion of the helicopter forward (or backward) along the pad. At such conditions the blade drag hinge

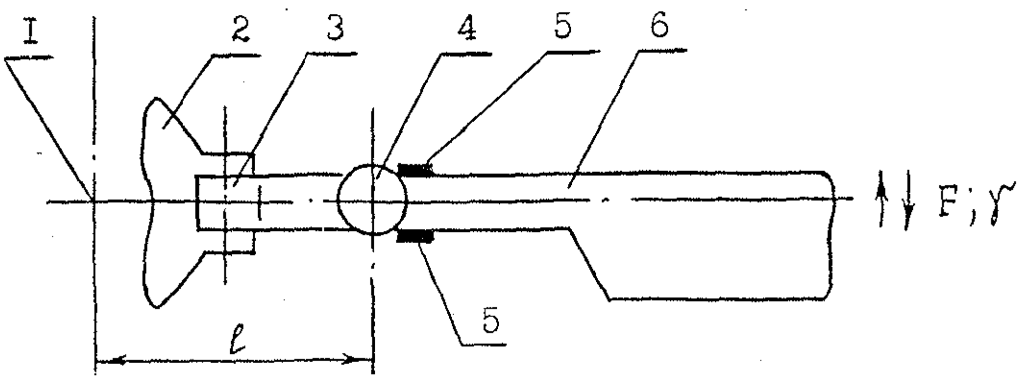

Fig. 3. Diagram of a helicopter main rotor section
1 - a rotation axis of the rotor,
2 - a case of the rotor hub,
3 - a flapping hinge,
4 - a drag hinge,
5 - a strain-gauge resistor,
6 - a rotor blade

(see Fig. 3) is under action of a variable moment with rotational frequency of the rotor - ω :

$$F = F_o \cos\omega t. \qquad (2)$$

This moment is brought about by Coriolis forces that result from static deviation of the rotor thrust vector in the longitudinal direction, and by wind effect during tests. The tests should be carried out under no-wind conditions or at a constant or small value of wind speed, i.e. at the absence of wind gusts. Under such conditions, at ground run of the coaxial helicopter, motion of the blade in the drag hinge results from elastic deformation of the metal-polymeric bearing. Slippage of the metal polymeric bearing is absent. Let's assume that the differential equation of blade motion about the drag hinge is of the following form:

$$J\ddot{\gamma} + (C_0 + \omega^2 \ell S)\gamma = F, \quad (3)$$

where: J - a blade inertia moment about the drag hinge,

S - a static moment of the blade about the drag hinge,

ℓ - a distance from the rotation axis of the rotor to the drag hinge axis,

C_0 - a stiffness of the metal-polymeric bearing of the drag hinge at its elastic deformations without slippage.

Let's assume also that angular displacements of the blade are of the following form:

$$\gamma = \gamma_0 \cos \omega t. \quad (4)$$

At static positions of the helicopter flight controls, an amplitude of the blade drag-hinge moment M_ω, acting at rotational frequency of the rotor, is determined by means of strain-gauge resistors (see Fig. 3). The moment about the drag hinge might be expressed in the form of the following relationship:

$$M_\omega = C_0 \gamma_0 . \quad (5)$$

It should be noted that, having determined a frequency of free vibrations of the non-rotating blade about the drag hinge - λ at elastic deformations of the metal-polymeric bearing without slippage, we obtain a value of its stiffness:

$$C_0 = \lambda^2 J. \quad (6)$$

Having substituted expressions (2), (4), (5), (6) into the equation (3) and having solved it relative to F_0, we'll obtain:

$$F_0 = M_\omega \left[1 - \frac{(J - \ell S)\omega^2}{\lambda^2 J} \right]. \quad (7)$$

For the case when, during ground runs, a pilot provokes "ground resonance" by oscillatory motions of the cyclic pitch stick relative to its static position, let's assume that a value of F_0 remains changeless in accordance with the expression (7). Vibrations of the blade relative to the drag hinge will occur then both at rotational frequency of the rotor and at "ground resonance" frequency with slippage of the drag hinge. At such character of blade motion, stiffness of the metal-polymeric bearing - C might be determined from an amplitude value of the drag-hinge moment M_ρ acting with rotational frequency of the rotor at "ground resonance" provocations performed by means of oscillatory motions of the cyclic pitch stick relative to its static position. A value of amplitude of blade deflection in the drag hinge γ_1 corresponding to an amplitude of the M_ρ moment is connected by the following relationship:

$$M_\rho = C\,\gamma_1 . \qquad (8)$$

The equation of equilibrium of drag-hinge moments, acting at rotational frequency of the rotor, is of the following form:

$$-(J - lS)\omega^2\gamma_1 + C\,\gamma_1 = F_0 \qquad (9)$$

Having substituted (7) and (8) into (9), we'll obtain an expression to calculate the stiffness C:

$$C = \lambda^2 J \frac{M_P}{M_\omega} \frac{1}{1 - [1 - \frac{M_P}{M_\omega}][\frac{\lambda}{\omega}]^2 \frac{1}{1 + \nu^2}} , \qquad (10)$$

where $\nu^2 = \frac{lS}{J}$.

The value of coefficient $b = 0.3$ in the expression (1) corresponds to the obtained values of stiffness C.

Having known a value of C and using dependence of the moment in the drag hinge on γ (see Fig. 2), we calculate a linear coefficient of equivalent damping of the metal-polymeric bearing - K from its dissipative work [3]. The linear coefficients of stiffness and damping of the metal-polymeric bearing, obtained in that way, are used to calculate a boundary of the "ground resonance" zone. For determination of boundaries of the coaxial helicopter instability zones, an analytical model is used, which takes into account linear oscillations in the rotation plane of upper and lower rotor blades, displacements of the stator along longitudinal, vertical, lateral axes and turns about them, bending of main rotor shafts in the longitudinal and lateral planes. The helicopter landing gear is diagrammed as springs and dampers having linear characteristics. During calculation, experimental values of landing gear stiffness and damping are used [4]. As a result, it has

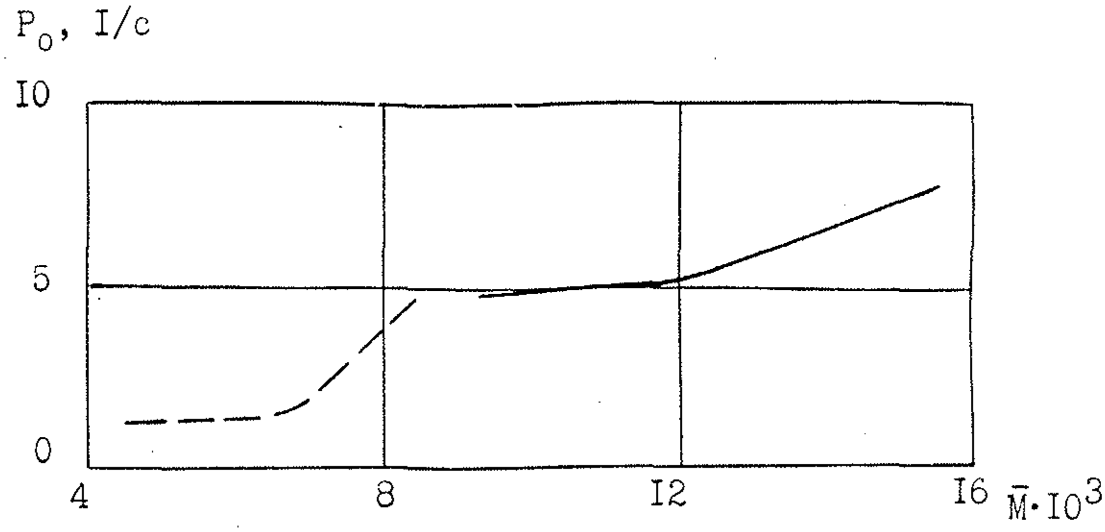

Fig. 4. Relationship between the P_0 parameter of metal-polymeric bearings and the value of drag-hinge moment
——— upper rotor, — — — lower rotor

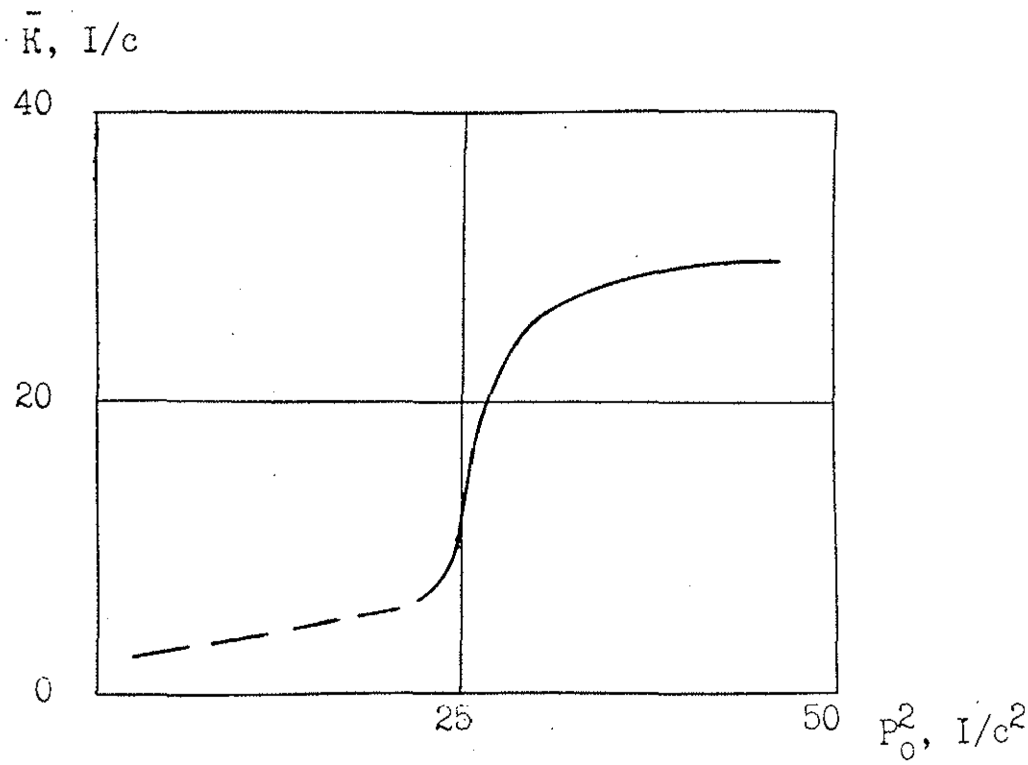

Fig. 5. Relationship between the damping coefficient of the metal-polymeric bearing and P_0^2
——— upper rotor, — — — lower rotor

been obtained that differences between analytical and experimental values of rotational frequencies of rotors on the boundary of the "ground resonance" zone do not exceed 5%. This fact gives reasons to believe that the developed algorithm allows to determine characteristics of blade drag-hinge metal-polymeric bearings, realized on the coaxial helicopter.

Results of the tests in their generalized form are presented in Fig. 4 and 5 where the following parameters are used:

$$\bar{M} = \frac{M_m}{\omega^2 S \ell}, \quad P_o^2 = \frac{C}{J}, \quad \bar{K} = \frac{K}{J}. \tag{11}$$

Inasmuch as oscillations of blades about the drag hinge at rotational frequency of the rotor and "ground resonance" frequency are caused by the Coriolis forces acting with the corresponding frequencies, then, amplitudes of displacements depend on the following parameter:

$$a = \frac{G}{2\,k\,\omega^2 S}, \tag{12}$$

where: G - a weight of the helicopter,

S_o - a static moment of the blade about the rotation axis of the rotor,

k - a number of rotor blades.

Characteristics of metal-polymeric bearings of drag hinges of the Ka-32 coaxial helicopter (Fig. 4 and 5) have been obtained at the value of parameter a = 0.0663. This fact should be accounted while using the obtained generalized relationships in calculations. Usually the $\bar{M}$ value is set; P_o and then a value of C are determined from the relationship presented in Fig. 4. If the helicopter under consideration has the parameter $a_i > 0.0663$, then the following value is calculated:

$$C_i = \frac{0.0663}{a_i} C. \tag{13}$$

For the C_i value, the P_{oi}^2 is determined; from the relationship presented in Fig. 5, $\bar{K}_i$ is found, and then K_i is determined. The developed algorithm was applied to determine drag-hinge moment values of the Ka-32 helicopter at the increase of its weight approximately by 10%. As a result, it was recommended to increase

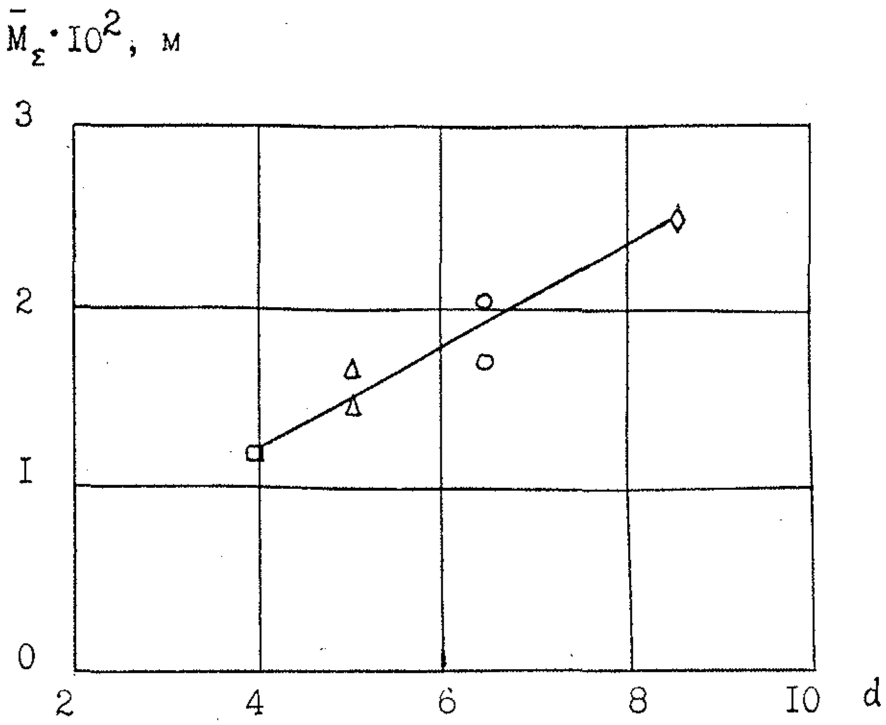

Fig. 6. Relationship between allowable moments of drag hinges and the inertia-mass parameter of the helicopter

○ - Ka-32, △ - Ka-25K, ◊ - Ka-126, □ - Ka-26

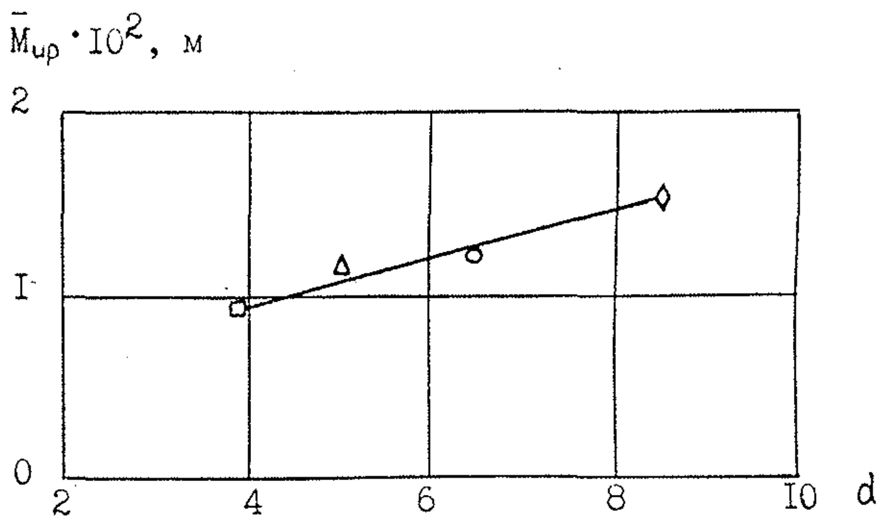

Fig. 7. Relationship between allowable moments of the upper rotor drag-hinge and the inertia-mass parameter of the helicopter

○ - Ka-32, △ - Ka-25K, ◊ - Ka-126, □ - Ka-26 metal-polymeric bearing moments of the upper main rotor drag-hinge by 250 N m. The performed full-scale "ground resonance" tests confirmed necessity of such increase of damping moments about the drag hinges.

In the process of designing, as a first approximation, one might assume values of allowable moments about the rotor blade drag hinges, relationships between which and the inertia-mass parameter are presented in Fig. 6 and 7 [2, 4]. Here, the following relationships are used:

$$\bar{M}_{\Sigma} = \frac{M_{up} + M_{L}}{G}, \quad \bar{M}_{up} = \frac{M_{up}}{G}, \quad d = \frac{Q h^2}{J_x}, \tag{14}$$

where: Q - a mass of the helicopter,

J_x - an inertia moment of the helicopter about the longitudinal axis,

h - a distance from the center-of-mass of the helicopter to the center of the upper main rotor hub.

It should be noted, that, for the Ka-25K and Ka-32 helicopters, average values of $\bar{M}_{up}$ are plotted in Fig. 7.

While plotting, besides allowable moment values of the Ka-32 helicopter that were determined during the "ground resonance" tests, the allowable moment values of the Ka-25K, Ka-26, Ka-126 helicopters are used. The Ka-25K helicopter has drag-hinge metal-polymeric bearings and friction disk-dampers installed on its upper main rotor; the Ka-26 has hydraulic dampers installed on its upper rotor; the Ka-126 - metal-polymeric dampers on its upper rotor. It should be noted that values of ν for these helicopters contain: 0.34 - Ka-32 and 0.3 - Ka-25K, Ka-26 and Ka-126. From relationships between allowable moments and the inertia-mass parameter d, it has been also obtained, that in order to provide "ground resonance" safety of the Ka-32 helicopter with the weight increased by 10%, it is necessary to increase moments about drag hinges of the upper main rotor blades approximately by 250 N m.

As a result of the performed investigations, generalized characteristics of the metal-polymeric bearings of blade drag hinges have been obtained, which might be used for estimation of safety of designed and modified helicopters from free vibrations of the "ground resonance" type.

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