TWENTY FIRST EUROPEAN ROTORCRAFT FORUM

Paper No VI.4

GROUND RESONANCE OF HELICOPTERS WITH FAILED LAG DAMPERS.

RESULTS OF ANALITICAL AND EXPERIMENTAL INVESTIGATIONS.

BY

Y.A.Myagkov, B. S. Godes

MIL MOSCOW HELICOPTER PLANT
MOSCOW, RUSSIA

August 30 - September 1, 1995
SAINT - PETERBURG, RUSSIA

Paper nr.: VI.4

Ground Resonance of Helicopters with Failed Lag Dampers. Results of Analytical and Experimental Investigations.

Yu.A. Myagkov; B.S. Godes

TWENTY FIRST EUROPEAN ROTORCRAFT FORUM
August 30 - September 1, 1995 Saint-Petersburg, Russia

GROUND RESONANCE OF HELICOPTERS WITH FAILED LAG DAMPERS. RESULTS OF ANALYTICAL AND EXPERIMENTAL INVESTIGATIONS.

Yu. A. Myagkov , B. S. Godes
Mil Moscow Helicopter Plant
Design Bureau

INTRODUCTION

Usually in helicopter ground resonance problem solution the main rotor with the identical characteristics of blades and lag hinge dampers is considered. In this case stability analysis of rotor system positioned on elastic support with two degrees of freedom , along OX and OZ axis's is reduced to solution of four second order linear differential equations with constant coefficients. This approach to the problem permits to get the results satisfactory for practical purposes. However such an approach doesn't give an answer the question about ground resonance of helicopter with different characteristics of individual blades and lag dampers of the main rotor. Such dissimilar conditions can take place, for example, when one of rotor hub dampers fails or in tests with simulation of damper failing in accordance with the FAR 29.663 requirements. These considerations make ground resonance analysis of the helicopter with different blade characteristics quite topical. The paper is devoted to the described problem solution.

PROBLEM FORMULATION

A multi-blade rotor with different blades and lag dampers characteristics is analysed in the paper. Such a rotor is not isotropic one, in a sense. Each blade has one degree of freedom - oscillations with respect to lag hinge. In this case the rotor support is considered as an elastic system with 2 degrees of freedom in two orthogonal planes.

Mass and stiffness characteristics of such rotor support are assumed to be equal in both directions. The system under consideration includes equations connecting displacements of elastic and damping elements of spring-hydraulic damper (SHD) with typical successive engagement of the spring and hydra-damper. The equations are given in rotating co-ordinate-system and have the following form :

$$\ddot{x} - 2\omega\dot{y} - \omega^2 x + 2\overline{n}_0(\dot{x} - \omega y) + x - \sum_{k-1}^{n}\left\{A\cos\frac{2\pi}{n}k + B\sin\frac{2\pi}{n}k\right\} = 0$$

$$\ddot{y} + 2\omega\dot{x} - \omega^2 y + 2\overline{n}_0(\dot{y} + \omega x) + y - \sum_{k-1}^{n}\left\{A\sin\frac{2\pi}{n}k - B\cos\frac{2\pi}{n}k\right\} = 0$$

$$\ddot{\xi}_k + 2\overline{n}_b\xi_{d_k} + v_{0_k}^2\omega^2\xi_k + \frac{S_{\text{вш}}}{I_{\text{вш}}}\left[\left(\ddot{y} + 2\omega\dot{x} - \omega^2 y\right)\cos\frac{2\pi}{n}k - \left(\ddot{x} - 2\omega\dot{y} - \omega^2 x\right)\sin\frac{2\pi}{n}k\right] = 0$$

$$2\overline{n}_{b_k}\dot{\xi}_{d_k} + \overline{p}_{0_k}^2\xi_{d_k} - \overline{p}_{0_k}^2\xi_k = 0$$

$$A = \frac{m_{b_k}}{M_\Sigma}\omega^2 l_{\text{вш}} + \frac{S_{\text{вш}_k}}{M_\Sigma}\left(\omega^2 + 2\omega\dot{\xi}_k\right)$$

$$B = \frac{S_{ВШ}}{M_{\Sigma}}\left(\ddot{\xi}_k - \omega^2 \xi_k\right)$$

where

x,y- displacements of rotor support system in two mutually orthogonal planes

$l_{ВШ}$ - lag damper offset

m_{b_k} - blade mass

M_{Σ} - mass of rotor with support

$S_{ВШ}, I_{ВШ}$ - blade first and second moments of inertia relative to lag hinge axis

ν_0 - non-dimensional frequency of blade oscillations in the plane of rotation (pendulum oscillation form)

$\overline{n}_b$ - relative coefficient of blade damping

$\overline{P}o$ -blade frequency of oscillations ,when $\omega = 0$

$\overline{n}_0$ - relative coefficient of support damping

ξ - angle of enplane blade rotation about lag hinge

ξ_d - component of enplane blade rotation angle created by deflection of hydraulic part of SHD

z - number of blades

k - current blade number

$$\varepsilon = \frac{z}{2}\frac{S_{ВШ}^2}{I_{ВШ}M_{\Sigma}}$$

Conclusion about the system stability is drowned basing on the analysis of the signes of characteristically polynom eigenvalues. The rotors with 4 (Mi-26, figures 1-5) and 5 blades (Mi-28, fig.7-8) have been analysed in this paper . The 8-bladed rotor of Mi-26 helicopter is considered as 4-bladed one with "equivalent" blades. Mass and stiffness characteristics of such a rotor are recalculated from the characteristics of the eight-bladed rotor so that the nondimentional frequency V_0 of blade oscillations in the plane of rotation and parameter ε remain the same. In this case the requirements will be fulfilled if C_{eqv} and K_{eqv} coefficients (stiffness and damping) and moments of inertia $S_{ВШ}, I_{ВШ}$ of equivalent blade of Mi-26 helicopter will be increased twofold.

RESULTS OF INVESTIGATIONS

One can see from the paper (figures 1-4) that 10-20 % difference in SHD characteristics has small effect on ground resonance boundaries. Figure 1 illustrates variations of the real and imaginary part of eigenvalues of the system of equations under consideration as a function of main rotor speed. In comparison with Fig.1 Figure 2 and 2a show eigenvalues of similar system of equations but stiffness coefficients of damper elastic element are reduced by 20%. This was done for one of dampers on Fig.2, and for two of dampers on Fig.2a. Figures 3 and 3a illustrate similar changes of damping part of dampers. Figure 4 presents eigenvalues of equations describing the system, in which one of damper has a reduced by 20% coefficients of elasticity and damping.

It is needed to be aware that when one is talking about one or two dampers of equivalent 4 - bladed rotor this is corresponding for two or four dampers of neighbour blades.

Figures 5 and 7 show correspondingly the results of equation solution for the system with one failed blade damper for the Mi-26 and Mi-28 helicopters. It is seen from analysis of the calculation results for the Mi-26 helicopter (represented on Fig.8) that though for the case of simulation of two dampers failing the instability boundary is practically unchanged, but increment of oscillation in the centre of the instability area is increased twofold (q = +0.06 instead of q=+0.03). Figure 6 shows values of real and imaginary parts of eigenvalues of characteristical equation for the Mi-28 helicopter which has equal characteristics of all dampers ,and Fig.7 shows the results for the system,where one of dampers has zero values of stiffness and damping coefficients. For these cases Fig.9 shows separated eigenvalues having positive real part.Comparison of these roots shows that at rotor speeds distant at 15-20 % from instability boundary oscillation decrements may have difference in several times. For comparison of analysis and test on these figures are plotted also the values of logarithmic decrement of blade lead-lag oscillations obtained from special ground resonance tests of the Mi-28 helicopter.

In these tests Mi-helicopter pilot excited blade oscillations about lag hinge by cyclic stick movement in lateral direction. The oscillation frequency had been set so that one of the combinatory frequencies corresponded to blade natural frequency in rotating system. Needed degree of coincidence had been reached by multiple training. After the excitation halting the oscillations faded away. The oscillation amplitude was used to define logarithmic decrement of blade oscillations. The tests have been performed at different rotor speeds in the range from its minimal to maximal permitted exploitation values. The test results are shown on Figures10,11 and 12. Simulation of one damper failing performed by pouring off working liquid from valves case in such manner that it's piston moved in cylinder practically without resistance. This was controlled by tests recording of moments on dampers . Figure 10 presents an example of the test recording, showing practically zero moment on simulated fail blade damper. Figure11 shows this recording after high frequencies filtration. Figure 12 has on horizontal axis values of rotor speed and on vertical axis values of blade oscillation logarithmic decrements. It is seen from the figure that oscillation decrements of blade with "failed" damper are less than decrements of blade with normal damper prepared in accordance with standard requirements. The difference between values of these blades decrements becomes small with the increasing of rotor speed and bottom boundary of instability region is reached approximately on the same rpm. both for the rotor corresponding standard and rotor with simulated failing of one damper.

The MI-28 helicopter tests have confirmed the conclusions obtained through analytical methods that instability boundary is changed insignificantly when one damper is shut off (failed). This boundary change consists of 3-4 % for the examined model parameters when potential instability region are above operational range of rotor speeds. At the same time the blade oscillation decrements with normal and failed damper can differ in several times (see fig.9) in operational range of rotor speed (20-30 % below of instability boundary). Taking in account these results one can see that tests with simulation of damper failing, required by FAR 29.663, appears not to be validation criterion, because of needed margin of rotor r.p.m to instability boundary with account of all operational circumstances must be equal or more then 10-15 %. This circumstance is more essential for multibladed rotors, when the number of blades is 5 or more

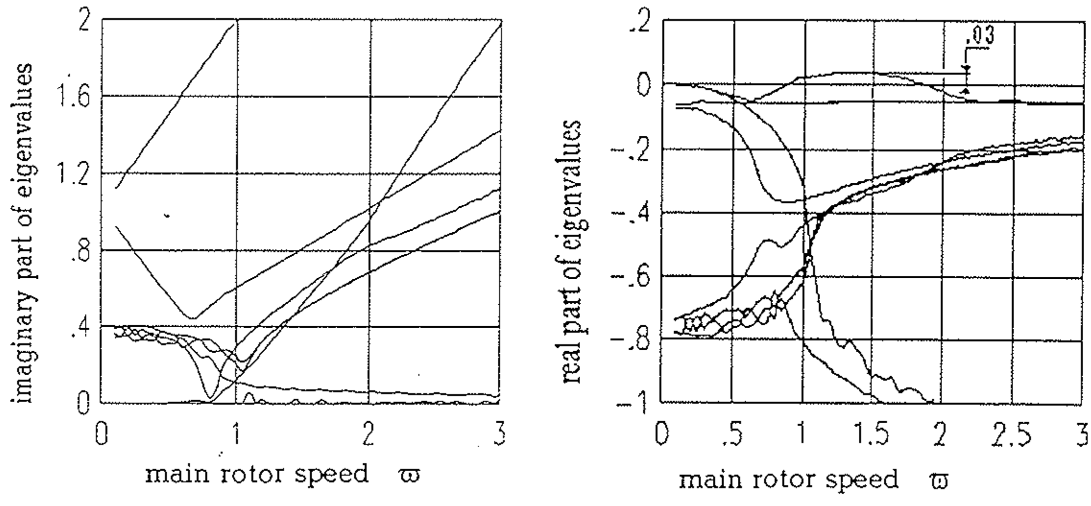


Fig.1 Eigenvalues of the system with equal characteristics of dempers.

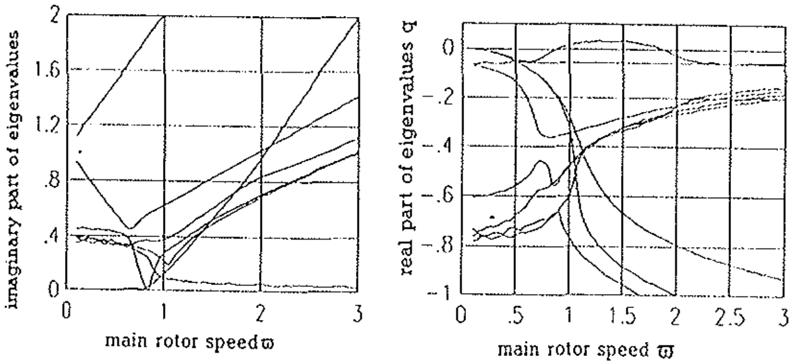


Fig.2 Eigenvalues of the system having reduced stiffeness of one of all dampers.

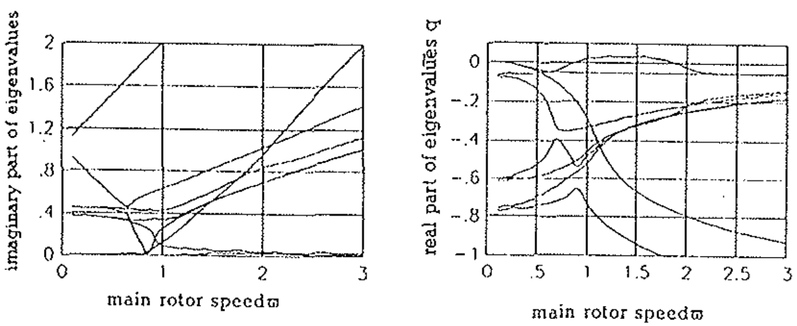


Fig.2a Eigenvalues of the system having reduced stiffeness of two of all dampers.

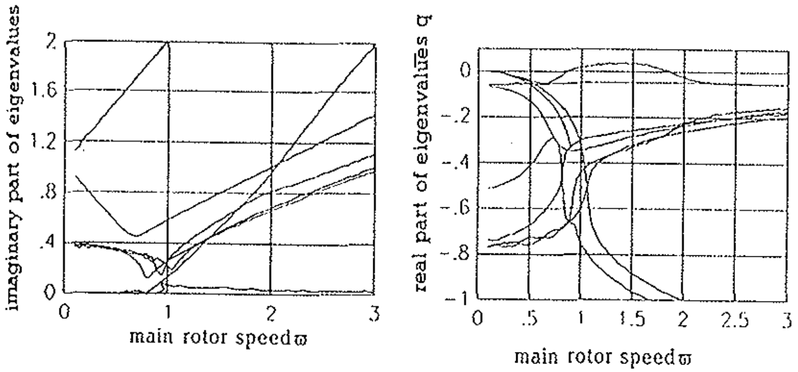


Fig.3 Eigenvalues of the system having reduced coef. of damping of one damper.

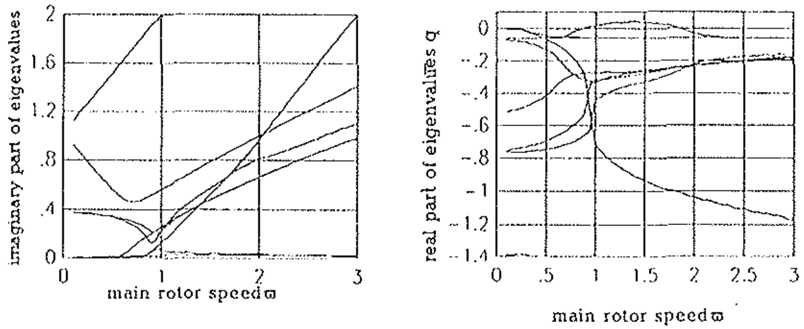


Fig.3a Eigenvalues of the system having reduced coef. of damping of two rotor dampers.

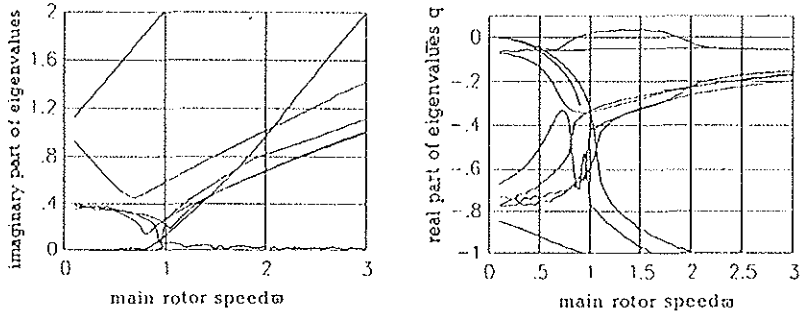


Fig.4 Eigenvalues of the system having reduced coef. of damping and stiffeness of one dampers.

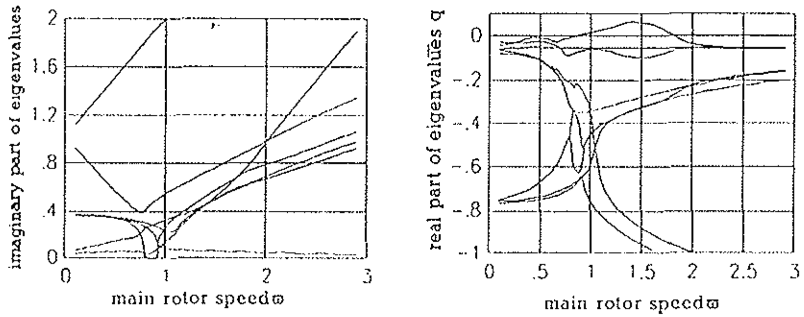


Fig.5 Eigenvalues of the system having one damper failed.

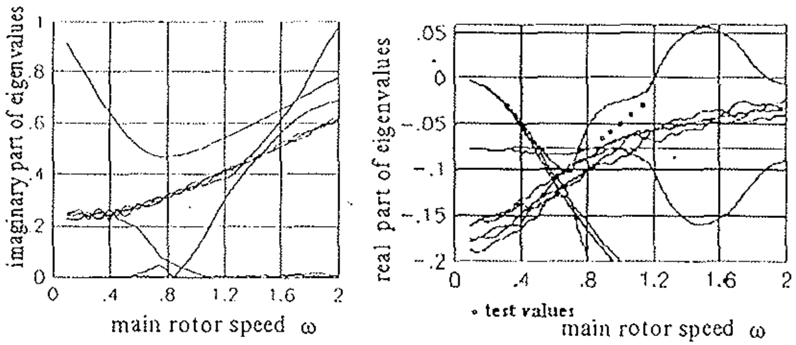


Fig.6 Eigenvalues of the system with equal characteristics of dampers for MI-28

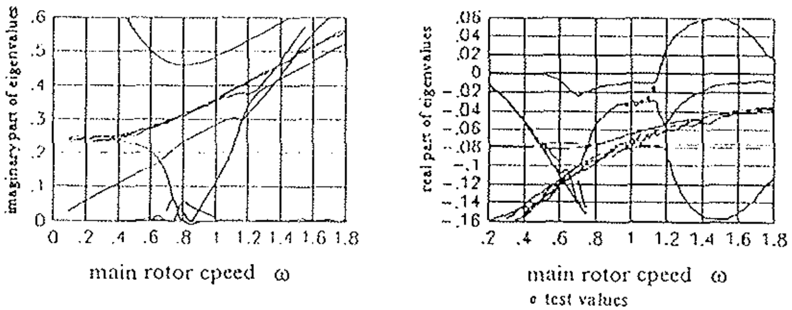


Fig.7 Eigenvalues of the system having one damper failed.

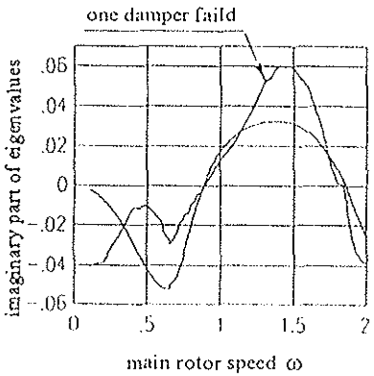


Fig.8 Comparison of unstaible roots of system with normal dampers and system with one failed damper for Mi-26 helicopter

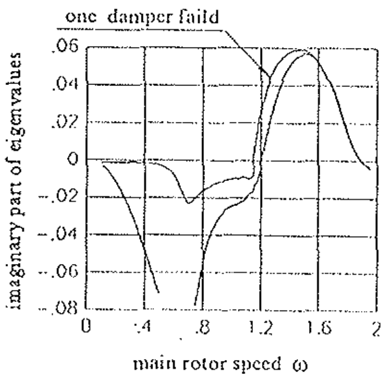


Fig.9 Comparison of unstaible roots of system with normal dampers and system with one failed damper for Mi-28 helicopter

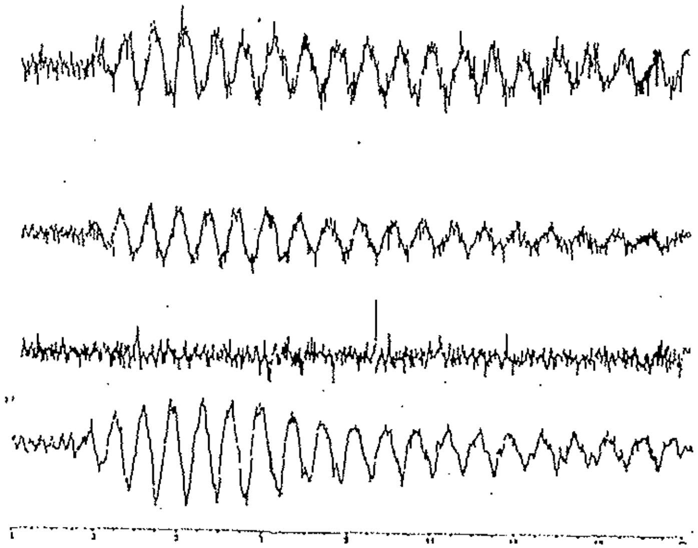


Fig.10 Exampl of non filtered record of the flight regime

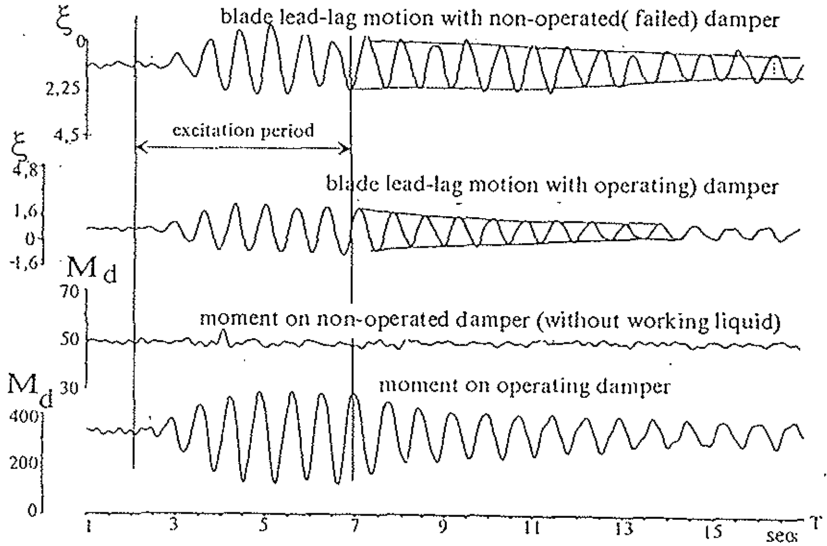
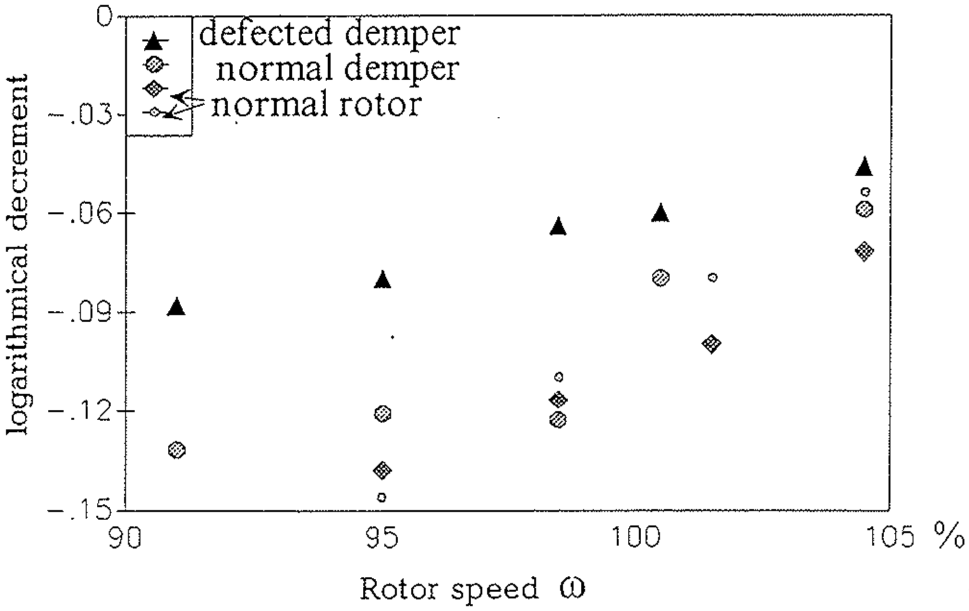


Fig 11 Filtered recording of the flight regime



defected demper
normal demper
normal rotor
logarithmical decrement
0
-.03
-.06
-.09
-.12
-.15
90
95
100
105 %
Rotor speed ω

Fig.12