Determination of the Dynamic Rigidity of Magnetic Controllable Hydromount Dependence on the Frequency of Vibration

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Abstract. Building damping characteristic of magnetocontrollable hydromounts and their correlational relationship with dynamic rigidity is considered in this article. Damping characteristics of hydromounts primarily comprise their amplitude-frequency characteristics (AFC). Building damping characteristics of magnetocontrollable hydromounts unaffected by magnetic field was performed basing on vibration tests data on vibrostand Star28, generating broadband random vibration (Random), in order to determine their resonance frequencies at 50 m/s\textsuperscript{2} input root-mean-square vibration acceleration (RMS).

1. Introduction
Development of breakthrough active vibration protection means of metal-cutting machines with precision, work process controlling equipment, is inextricably connected to their vibration testing on Random, maximum approximated to actual operating conditions of a given machine or a machine center unit [1,2,3].

The purpose of Random tests is their maximum approximation to the hydromounts actual operating conditions.

These tests allow to reduce hydromounts diagnostics time compared to other types of vibration testing. It occurs due to exaggeration of conditions bringing about resonance excitation, in test samples randomly changing in time input vibration signal spectrum [4,5]. Therefore, excitation of all resonances of hydromounts under test will allow to reveal their cross-effect, which is impossible at other testing types.

Research of magnetocontrollable hydromounts (further hydromounts) amplitude-frequency characteristics (AFC) was carried out in order to find their connection with their dynamic rigidity. On test vibrostand Star28, generating Random, HM-95 hydromounts were tested with hydraulic MRF MR Flujd MRF-132DG not affecting the magnetic field magnetorheological transformer (MRT).

Tuning hydromounts with MRT to the preset resonance frequencies it is necessary to know and calculate their vibration AFC without any active feedback action, i.e. in an open-cycle control system [6,7,8].
2. Mechanical System Dynamic Rigidity

In order to analyze hydromounts rigidity connection with their AFC it is necessary to obtain hydromounts dynamic rigidity dependence on their excitation frequency. Such dependence can be obtained by experimental AFC of HM-95 hydromounts at 50 m/s² input RMS and knowledge of dynamic rigidity minimal value on hydromounts resonance own-frequency. Dynamic rigidity minimal value on hydromounts resonance own-frequency is supposed to correspond to their static stiffness.

Herewith, to understand hydromounts dynamic characteristics it is necessary to define dynamic rigidity and compliance [9,10,11].

Mechanical system dynamic rigidity \( D(\eta) \) is a ratio of external harmonic force amplitude \( F(j\omega) \) to complex amplitude of oscillations \( x(j\omega) \).

For a system with one degree of freedom, dynamic rigidity is:

\[
D(\eta) = \frac{F(j\omega)}{x(j\omega)} = \frac{F_0}{\tilde{A} \eta}.
\]

The system dynamic compliance \( f(\eta) \) is a dynamic rigidity inverse value:

\[
f(\eta) = \frac{1}{D(\eta)} \tag{1}
\]

Around resonance, mechanical system dynamic compliance appears to be at the maximum. At loss coefficient values - \( \eta \), small compared to unity, function \( f(\eta) \) does not greatly differ from static compliance.

As soon as HM-95 hydromounts are designed for damping vibrations within the frequency band of up to 100 Hz, it would be sufficient to consider their AFC within the frequency band itself and basing on them to build hydromounts transient rigidity dependencies on their excitation frequency.

Fig. 1 shows HM-95 hydromounts AFC up to the frequency of 100 Hz at 50 m/s² input RMS. AFC were obtained basing on experimental data.

![Figure 1. AFC of a HM-95 4-hydromount system up to the frequency of 100 Hz at 108 kg loading slab mass and 50 m/s² input RMS.](image)

From these AFC it is evident that below the frequency of 20 Hz vibration processes are unstable and vibration damping does not take place. At the frequency increase effective damping by hydromounts takes place at the frequencies of 25 Hz, 52 Hz and 80 Hz – the input white noise is damped to 10 dB, 22 dB, 63 dB respectively.

AFC ordinates are determined by decimal logarithms difference for each output and input harmonics under study in decibels according to

\[
K(\text{dB}) = 20 \log \left( \frac{U_{\text{out}}}{U_{\text{in}}} \right) = 20 \log U_{\text{out}} - 20 \log U_{\text{in}} \tag{2}
\]
hence finding input and output harmonics by their decimal logarithms comes to solution of equation $a' = N$, i.e. logarithm $x = \log_a N$ of $N$ number at radix, $a$ can be determined as solution of equation $a' = N$ \cite{12,13,14}.

As a result of the calculations made, expression for finding maximum dynamic rigidity $D_{\text{max}}(j\omega)$ of the hydromount is obtained through its minimal dynamic rigidity $D_{\text{min}}(j\omega)$:

$$D_{\text{max}}(j\omega) = D_{\text{min}}(j\omega) \cdot 10^{\frac{K_{\text{dB}}}{20}} \left[ \frac{\text{N}}{\text{m}} \right]$$

(3)

Substituting maximum and minimal dynamic rigidity for $i$- (current) dynamic rigidity $D_i(j\omega)$ and dynamic rigidity $D_0(j\omega_0)$ at the hydromount resonance, current values expression $D_i(j\omega)$ is obtained basing on which the hydromount dynamic rigidity dependence $D_i(j\omega)$ on the excitation frequency is built:

$$D_i(j\omega) = D_0(j\omega_0) \cdot 10^{\frac{K_{\text{dB}}}{20}} \left[ \frac{\text{N}}{\text{m}} \right]$$

(4)

where $D_0(j\omega_0)$ – minimal dynamic rigidity on the main resonance frequency for a 4-hyromount system under 108 kg total load mass.

Further on according to AFC of up to 100 Hz for an HM-95 4-hydromount system with 108 kg loading slab mass, dynamic rigidity dependence for the whole system is built.

At 50 m/s$^2$ input RMS and 108 kg loading slab mass, the force acting on the 4-hyromount system will be equal to:

$$F_{1.4} = m \cdot 5 \cdot g = 108 \text{ kg} \cdot 5 \cdot 9.81 \text{ m/s}^2 = 5297.4 \approx 5300 \text{ N.}$$

(5)

At 50 m/s$^2$ input RMS let us assume maximum displacements as equal to ±4 mm. Thereafter, minimal dynamic rigidity on the main resonance frequencies for a 4-hyromount system under 108 kg total load at 50 m/s$^2$ input RMS equals:

$$C_{0.1.4}(f_{0.1.4}) = F_{1.4}/4 \cdot 10^{-3} = 5300 \text{ N}/4 \cdot 10^{-3} \text{ m} = 1325 \cdot 10^3 \text{ N/m,}$$

(6)

where $C_{0.1.4}(f_{0.1.4})$ – minimal dynamic rigidity of the 4-hyromount system under 108 kg total load on the main resonance cyclic frequency.

Substituting minimal dynamic rigidity of 4 hydromounts under 108 kg total load (6) into expression (4) for this hydromount system at 50 m/s$^2$ input RMS with the help of Microsoft Office Excel Pack, dependence of their dynamic rigidity on excitation frequency is built.

Fig. 2 shows dynamic rigidity dependence $C(f)$ for an HM-95 4-hydromount system up to the frequency of 100 Hz at 50 m/s$^2$ input RMS.

**Figure 2.** AFC of a HM-95 4-hydromount system up to the frequency of 100 Hz at 108 kg loading slab mass and 50 m/s$^2$ input RMS.
Comparing dynamic rigidity dependence and AFC diagrams for an HM-95 4-hydromount system within the range of up to 100 Hz at 50 m/s² input RMS, shown in (Fig. 1) and (Fig. 2) we prove that within the range below 20 Hz there is no correlation between them as within this range the damping process is unstable. Within the frequency range from 20 to 30 Hz correlation between AFC and dynamic rigidity is about 80%. For the frequency range from 45 to 60 Hz and from 65 Hz up to 90 Hz correlation between AFC and dynamic rigidity is about 95%.

3. Conclusion
As a result of magnetocontrollable hydromounts tests on Random their dynamic rigidity has been determined on resonance frequencies. Dynamic rigidity dependence on damping has been found. Hydromounts AFC have been built basing on which it is possible to judge their efficiency. Further on, according to the calculated and built experimental dependence of magnetocontrollable hydromounts dynamic rigidity, calculation of poles and polynomial zeroes \( X(s) \) and \( Y(s) \), and transfer-functions \( T(s) \), along with pre-estimate of the included coefficients is carried out, allowing to build HM-95 magnetocontrollable hydromounts AFC considering the impact of the hydraulic MRF heating temperature and the external magnetic field action.

4. References
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Acknowledgments
The work has been carried out at the expense of Russian Science Foundation (project №15-19-10026).