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Damped vibrations of hydraulic cylinder with a spring-damper system in supports

Wojciech Sochacki*, Marta Bold

Institute of Mechanics and Fundamentals of Machinery Design, University of Technology, Czestochowa, Poland

Abstract

The description of the damped vibrations of hydraulic cylinder has been presented in this paper. The dissipation of vibration energy was caused by different kinds of damping on vibrations of hydraulic cylinder. Damping in adopted model is a result, of taken into account internal damping of viscoelastic material of beams that modelled the system, external viscous damping and constructional damping of supports. In this paper, the problem of transverse and longitudinal damped vibration of hydraulic cylinder was formulated and solved. The influence on the damped vibration frequency and the degree of vibration amplitude decay of damping coefficient and spring rigidity coefficient were presented.

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Keywords: damped vibration; hydraulic cylinder; transverse vibration; longitudinal vibration; spring-damper system;

1. Introduction

Papers [1-5] presents the different kind of solution the boundary problem of free and forced vibration with taking into consideration the influence of damping on vibration of systems. The effect of structural damping of fixations, on free vibration of the linear Bernoulli-Euler beam was presented in the study [1]. The dissipation of energy vibration was modelled by the rotational viscous damper. Comparisons of influence of damping from rotational viscous damper and from translational viscous damper on vibration of simply supported beam and cable were presented in work [2]. In [3] shown the effect of the damping caused by resistance forces, on the border between examined beam and fluid around the system (external damping), and by dissipation of energy vibration, modeled by translational viscous damper at free end of the beam. Equally interesting studies concerning the effect of external

* Corresponding author. Tel.: +48 34-32-50-683.
E-mail address: sochacki@imipkm.pcz.pl

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damping on vibration of beams with stepped cross-section was presented in paper [4]. The influence of small internal and external damping on stability of non-conservative beam systems is described in paper [5]. A lot of the published studies focused on the dynamics of hydraulic cylinder, with particular emphasis the interactions between the cylinder tube and piston rod and the dynamic stability of the cylinder. The interactions between the cylinder tube and piston rod as an object of research studies has been extensively investigated in the number of papers. The work [6] present an analysis of the effect of initial inaccuracy of connection between the piston and cylinder tube on critical loading force in the cylinder. Many authors also analysed the effect of sealing or the medium on the cylinder's dynamics and dynamic stability of cylinder. Calculations of free vibration frequencies were extended with the investigations of the dynamic stability of the cylinder by means of determination of geometrical parameters and load at the time of losing the stability were presented in study [7]. The problem of the stability and free vibrations of a slender system in the form of a hydraulic cylinder subjected to Euler's load was carried out in paper [8].

The aim of this paper is to analyse the simultaneous effect of the constructional damping, external damping and the internal damping on the transverse and longitudinal vibrations of hydraulic cylinder. Constructional damping occurs as a result of movement resistance in the piston and the cylinder supports and it was modelled by the system of rotational viscous damper and rotational spring with linear characteristic. The rotational spring-damper system proposed in this work represent dynamic properties of hydraulic cylinder fixation points. This system reflects the physical phenomena taking place in real working machine. The boundary problem connected to the free vibrations of the considered non-conservative (due to damping) system was formulated on the basis of Hamilton's principle. The results of numerical research taking into consideration influence of changes in geometry of the system and the variable values of all damping coefficients and spring rigidity coefficient were presented. The results obtained in the study were presented in 2D figures and spatial presentations.

Nomenclature

T	kinetic energy
V	potential energy
δW_N	virtual work of non-conservative forces originating from damping
$W_{mn}(x_{mn}, t)$	transverse displacement of beams that model cylinder and piston rod
$U_{mn}(x_{mn}, t)$	longitudinal displacement of beams that model cylinder and piston rod
E_{mn}	Young's modulus for individual beams
E^*_{mn}	material viscosity coefficient (internal damping)
J_{mn}	moment of inertia in beam cross-sections
A_{mn}	cross-sectional areas of the beams
ρ_{mn}	beam material density
c_e	external viscous damping coefficient ($c_e = 0$ for $m = 2$ and $n = 1$)
c_R	constructional viscous damping coefficient
μ	dimensionless constructional damping coefficient
η	dimensionless internal damping coefficient
ν	dimensionless external damping coefficient
l_{mn}	length of the beams
L_C	total length of the hydraulic cylinder ($L_C = l_{11} + l_{12} + l_{22}$)
P	cylinder loading force ($P = 0$ at the length l_{12})
P_C	critical load of the cylinder
ω^*	the complex eigenvalue of the system ($\omega^* = Re(\omega^*) + Im(\omega^*)i$)
k_R	stiffness coefficient of rotational spring
k	dimensionless stiffness coefficient of rotational spring
k_S	stiffness coefficient of translational spring
x_{mn}	spatial coordinates
t	time
$i = \sqrt{-1}$	
$m,n = 1,2$	