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Development of a tunable vibration isolator utilising a smart actuator

by

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Summary

Vibrating machinery like rock drills and compactors are becoming more prominent in modern industry. The vibrations of these machines can damage surrounding structures and foundations and be harmful to their operators. Hand arm vibration syndrome is one example of serious injuries suffered by operators of these machines.

Due to the fact that these machines need to vibrate, vibration absorbers that minimise the vibrations of the machines cannot be used. In such cases vibration isolators are necessary to isolate the vibration between the vibrating machine and other bodies like the handle or foundations. A tuned vibration isolator is a type of isolator that is able to isolate a certain frequency very effectively. These isolators can retain low mass and high stiffness compared to traditional isolators and can obtain complete isolation at the isolation frequency if no damping is present. The liquid inertia vibration eliminator (LIVE) is such a tuned vibration isolator that makes use of hydraulic amplification, which result in a very compact design.

A LIVE isolator was designed incorporating the variable stiffness spring and a variable damping mechanism. Equations for the damped natural and isolation frequency of the LIVE isolator were also derived. The reason for changing the stiffness was to be able to adjust the isolation frequency of the isolator to coincide with the excitation frequency that resulted in a more effective isolator. The variable stiffness spring consisted of two leaf springs mounted on top of each other and separated at the centre to stiffen the whole spring assembly. The leaf springs were separated by a wax actuator that was controlled with a closed loop displacement control system to form a smart actuator. A stiffness change of 2.7 times the original stiffness was obtained by separating the springs.

The variable damping mechanism was to be able to control the amount of amplification of noise at the natural frequency. An experimental isolator was built and tested and resulted in a tunable vibration isolator. The isolation frequency of the isolator could be shifted from 22.8 Hz to 36.2 Hz and a transmissibility of 10% was achieved over that whole range. The variable damping mechanism increased the viscous damping ratio from 0.001 to 0.033.

A control system was designed and implemented that tuned the isolator automatically to the excitation conditions. It incorporated an optimisation algorithm to determine the optimum settings and then kept the isolator at that setting until the excitation conditions change. The whole process was then repeated.

A tunable vibration isolator was therefore successfully developed that can be used to isolate tonal vibrations very effectively. The isolation frequency and damping of the isolator can be changed while in operation and a transmissibility of 10% can be achieved at the isolation frequency.

Keywords: Vibration isolator, LIVE, tuned, variable stiffness spring, wax actuator, smart actuator, transmissibility, isolation frequency, variable damping, control.

Ontwikkeling van 'n verstelbare vibrasie isoleerder deur 'n slim aktueerder te gebruik

deur

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Opsomming

Vibrerende masjiene soos rotsbore en kompakteerders is besig om al hoe meer prominent in die moderne industrie te word. Die masjiene se vibrasies kan ernstige skade veroorsaak aan omliggende strukture, fondasies en operateurs. Hand-arm vibrasie sindroom is 'n voorbeeld van hoe ernstig die beserings aan operateurs is.

Omdat hierdie masjiene moet vibreer, kan vibrasie absorbeerders wat die masjien se vibrasies minimeer nie gebruik word nie. Vibrasie isoleerders wat die vibrasies van die masjien isoleer van omringende liggame soos die handvatsel of fondasie is nodig. Gestemde vibrasie isoleerders is 'n tipe vibrasie isoleerder wat vibrasie baie effektief by 'n spesifieke frekwensie isoleer. Hierdie isoleerders behaal goeie isolasie met hoë styfheid en lae massa in vergelyking met normale isoleerders en kan 100% isolasie behaal indien geen demping teenwoordig is nie. Die LIVE (liquid inertia vibration eliminator) is so 'n isoleerder wat van hidrouliese versterking gebruik maak wat die isoleerder baie kompak maak.

Om die isoleerder so effektief as moontlik te maak, moet dit moontlik wees om die isolasiefrekwensie van die isoleerder te kan rondskuif om saam met die opwekkingsfrekwensie te val. Dit is moontlik gemaak deur 'n veranderbare styfheid veer te ontwikkel wat uit twee bladvere bestaan wat bo-op mekaar pas en dan in die middel uitmekaar gedruk word om die globale styfheid van die veersamestelling te verander. Die vere is deur middel van 'n was aktueerder uitmekaar gedruk wat deur 'n geslote lus verplasings beheerstelsel beheer is om 'n slim aktueerder te vorm. 'n Styfheidsverandering van 2.7 keer is behaal deur die vere uitmekaar te druk.

'n LIVE isoleerder is ontwerp wat die veranderbare styfheid veer inkorporeer asook 'n veranderbare demping meganisme. Die veranderbare demping is om die amplitude van versterking van geraas by die natuurlike frekwensie van die isoleerder te kan beheer. 'n Eksperimentele isoleerder is gebou en getoets. Die isolasiefrekwensie van die isoleerder kan van 22.8 Hz tot 36.2 Hz geskuif word en 'n transmissibiliteit van 10% is behaal oor die hele span. Die viskeuse dempingsverhouding kan verander word van 0.001 tot 0.033.

'n Beheerstelsel is ook ontwerp en geïmplementeer wat die isoleerder outomaties verstel om optimal vir die opwekkingstoestande to werk. Die beheerstelsel inkorporeer 'n optimeringsalgoritme wat die optimale verstellings bepaal en dan die isoleerder by daardie waardes hou tot die opwekkingstoestande verander. Die hele siklus word dan van voor af herhaal.

'n Suksesvolle verstelbare vibrasie isoleerder is dus ontwikkel wat gebruik kan word om vibrasies effektief te isoleer. Die isolasiefrekwensie en demping van die isoleerder kan verstel word en 'n transmissibiliteit van 10% kan by die isolasiefrekwensie behaal word.

Sleutelwoorde: Vibrasie isoleerder, LIVE, gestemde isoleerder, veranderbare styfheid veer, was aktueerder, slim aktueerder, transmissibiliteit, isolasiefrekwensie, veranderbare demping, beheer.

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Nomenclature

Symbol	Meaning	SI Units
A	Amplitude	m
A_a	Tuning port area	m^2
A_b	Reservoir area	m^2
c	Viscous damping coefficient	N.s/m
c_c	Critical damping coefficient	N.s/m
d_a	Tuning port diameter	m
d_b	Reservoir diameter	m
E	Modulus of elasticity	Pa
F	Force amplitude	N
F_0	Force transmitted to ground	N
F_i	Applied force	N
F_t	Transmitted force	N
F_p	Force due to pressure difference	N
f	Frequency	Hz
$f(t)$	Force as a function of time	N
$f_i(t)$	Applied force as a function of time	N
G_a	Ratio of undamped natural frequency to isolation frequency	
$G(s)$	Transfer function of system	
h	Hysteresis damping constant	N/m
I	Moment of inertia	
I	Current	A
k	Stiffness	N/m
l	Tuning port length	m
m	Mass	kg
m_b	Absorber mass	kg
P	Pressure	Pa
P	Power	W
r,R	Arm length	m
t	Time	s

T_r	Complex transmissibility	
V	Potential difference	V
X,x	Displacement	m
$x(t)$	Displacement	m
$\dot{x}(t)$	Velocity	m/s
$\ddot{x}(t)$	Acceleration	m/s^2
$Y(s)$	Response of system in Laplace domain	m
$Y(t)$	Response of system in time domain	m
δ_{st}	Static deflection	m
ϕ	Phase angle	rad
η	Loss factor	
τ	Time constant	s
ω	Circular frequency	rad/s
ω_a	Undamped isolation frequency	rad/s
ω_n	Undamped natural frequency	rad/s
ω_{ad}	Damped isolation frequency	rad/s
ω_{nd}	Damped natural frequency	rad/s
ζ	Damping ratio	

Abbreviations

DAVI	Dynamic anti-resonant vibration isolator
FEM	Finite element method
FFT	Fast Fourier transform
IFFT	Inverse fast Fourier transform
IRIS	Improved rotor isolation system
ISO	International standards organisation
LIVE	Liquid inertia vibration eliminator
LVDT	Linearly variable differential transformer
SMA	Shape memory alloy
RMS	Root mean square