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Development of a vibration absorbing handle for rock drills

by

Johannes Petrus De Wet Strydom

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Supervisor: Professor P. S. Heyns
Co-supervisor: Professor J. L. van Niekerk
Department: Mechanical and Aeronautical Engineering
Degree: M. Eng

Excessive vibration exerted on the human body can cause many harmful phenomena that can result in permanent bodily damage or permanent disability. Human vibration is classified into two main categories: Hand-arm vibration and whole-body vibration. Hand-arm vibration is vibration transmitted through a percussive tool handle via the hand-arm system to the rest of the body. The main diseases concerning hand-arm vibration are Vibration White Finger (VWF), neurological diseases in the hand and fingers and musculoskeletal diseases like carpal tunnel syndrome.

These diseases, especially VWF and musculoskeletal disorders, are mainly associated with lower frequencies. VWF in particular is more likely to occur when an operator is subjected to vibrations with high magnitudes in the 25-40 Hz region. The operating frequencies of most rock drills vary between 30 and 50 Hz. Although there are many other contributing factors like grip force, hand temperature and subject variability, prevalence of VWF among rock drill operators is relatively high in the world. The situation in South Africa is not yet very clear, and further research must be done to evaluate the current status of VWF in South Africa.

Vibration energy at higher frequencies can be attenuated with rubber grips or gloves, and these types of dampers are already available on the market. The problem concerning the operating frequency of the drill has not yet been successfully addressed, and thus remains a problem in the rock drill industry as it is at the moment.

The main objective of this thesis was the development and testing of a concept that can potentially be implemented on a rock drill to attenuate the operating frequency of a rock drill. The concept must be able to account for minor changes in operating frequency on a specific drill. In addition to that, the drill operating frequency varies from one drill to another. The thesis also aims to lay the mathematical foundation to design an attenuating handle for a specific drill with a specific operating frequency. All the objectives must be obtained without noticeable sacrifices in drill control or performance.

The thesis includes the concept generation, optimisation, design and manufacture of a rock drill vibration absorber. The absorber has been tested, and the results are presented.

Keywords: Vibration, absorber, rock drill, vibration white finger, hand-arm vibration, operating frequency

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Ontwikkeling van 'n vibrasie-absorberende handvatsel vir rotsbore

deur

Johannes Petrus De Wet Strydom

Leier: Professor P. S. Heyns
Mede-leier: Professor J. L. van Niekerk
Departement: Meganiese en Lugvaartkundige Ingenieurswese
Graad: M. Ing

Wanneer die liggaam aan oormatige vibrasie blootgestel word kan dit 'n aantal hand- of gewrigskwale, of permanente liggaamlike skade of gebrek tot gevolg hê. Vibrasie blootstelling aan die menslike liggaam word in twee katogorië verdeel naamlik hand-arm vibrasie en heelliggaamsvibrasie. Hand-arm vibrasie kom voor wanneer vibrasie deur 'n gereedskap stuk via die hand en arm na die res van die liggaam oorgedra word. Die hoof kwale wat deur hand-arm vibrasie veroorsaak word is Raynaud se fenomeen (Vibration white finger) en spier-en beenkwale soos karpale tonnel sindroom.

Hierdie kwale, en spesifiek Raynaud se fenomeen, word hoofsaaklik geassosieër met laer frekwensies. Raynaud se fenomeen is veral geneig om in die 25-40 Hz gebied voor te kom. Die oorgrote meerderheid van rotsbore se werksfrekwensie is tussen 30 en 50 Hz. Alhoewel Raynaud se fenomeen redelik algemeen onder rotsboor operateurs in die res van die wêreld voorkom, is die situasie in Suid-Afrika nog nie heeltemal duidelik nie.

Hoë frekwensie vibrasie-energie kan geattenueer word met rubbergrepe of handskoene, en hierdie tipe dempers is ook algemeen op die mark beskikbaar. Die probleem ten opsigte van die werksfrekwensie van die boor kon egter nog nie suksesvol aangespreek word nie.

Die hoofdoelwit van hierdie vehandeling was om 'n konsep te ontwikkel en te vervaardig wat die werksfrekwensie van 'n rotsboor attenueer, en potensieel op 'n rotsboor implementeer kan word. Die attenueerder moet kan kompenseer vir klein variasie in die werksfrekwensie van 'n boor gedurende bedryf. Werksfrekwensies verskil egter ook van boor tot boor, en moet ook geakkomodeer kan word in die ontwerp. Die verhandeling mik ook om die basiese wiskundige grondslae wat nodig is vir die ontwerp van so 'n absorbeerder te lê.

Sleutelwoorde: Vibrasie, absorbeerder, rotsboor, Raynaud se fenomeen, hand-arm vibrasie, werksfrekwensie

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List of symbols

Symbol	*Meaning*	*SI Units*
A	Area	m^2
a	Port area	m^2
a_i	Acceleration measured at the i^{th} element	m/s^2
b	Base area	m^2
[C]	Damping	Ns/m
C_{eqx}	Equivalent damping coefficient	Ns/m
c_f	Damping due to flow losses	Ns/m
c_i	i^{th} integration constant	
c_i	Damping coefficient of the i^{th} damper	Ns/m
D	Material constant	
D_b	Diameter of base	m
D_h	Diameter of handle	m
D_p	Diameter of port	m
D_1	Housing diameter	m
E	Young's modulus	GPa
E_k	Kinetic energy	J
E_p	Potential energy	J
f_{ex}	Excitation frequency	Hz
F_L	Damping force due to flow losses	N
F_i	Force applied at the i^{th} element	N
f_I	Frequency of minimum T_r	Hz
f_{MT}	Frequency of maximum T_r	Hz
f_n	Natural frequency	Hz
g	Gravitation	m/s^2
h_{fMT}	Fluid flow losses	m
H_{ii}	Transfer function of MDOF system	
I	Moment of inertia	m^4
[K]	Stiffness	N/m
k_i	Stiffness coefficient of i^{th} spring	N/m
k_r	Polyurethane rubber stiffness	N/m
K_{SE}	Loss coefficient due to sudden expansion	
K_{SC}	Loss coefficient due to sudden contraction	
L	Length	m
ℓ	Length	m
[M]	Mass	kg
M_{eqx}	Equivalent mass	kg
m_a	Apparent mass	kg
m_1	Mass to be attenuated	kg
m_2	Absorbing mass	kg
n_p	Number of ports	
P	Phase angle	Degrees
P_L	Pressure loss	Pa
Q_1	Distributed load	N/m
R	Rayleigh's dissipation function	Nm/s
R_{ed}	Reynolds number	Dimensionless
r	Radial length	m

r_a	Radial length	m
r_b	Radial length	m
s	Laplace transformation	
T_r	Transmissibility	Dimensionless
T_{ii}	Transmissibility of MDOF system	
t	Thickness	m
t	Time	s
W	Transverse deflection	m
X_i	Amplitude of $x_i(t)$	m
x, y, z	Cartesian co-ordinates, displacements	m
x_1	Handle displacement	m
x_2	Absorbing mass displacement	m
x_3	Drill displacement	m
$\dot{x}_i$	i^{th} element velocity	m/s
$\ddot{x}_i$	i^{th} element acceleration	m/s^2
β	Structural damping coefficient	
γ	ω_{MT}/ω_I	Dimensionless
γ_t	Natural frequency ratio	Dimensionless
κ	Radius of gyration	m
μ	Mass ratio	Dimensionless
μ_f	Fluid viscosity	Ns/m^2
θ	Angular displacement	Radians
$\dot{\theta}$	Angular velocity	Rad/s
ρ	Density of fluid	kg/m^3
ν	Poisson's ratio	
ω	Frequency	Rad/s
ω_{ex}	Excitation frequency	Rad/s
ω_I	Frequency of minimum T_r	Rad/s
ω_i	i^{th} natural frequency	Rad/s
ω_{MT}	Frequency of maximum T_r	Rad/s
ω_n	Natural frequency	Rad/s
ζ	Damping ratio	Dimensionless
ζ_i	i^{th} damping ratio	Dimensionless

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