HAND-HELD IMPACT MACHINES WITH NONLINEARLY-TUNED VIBRATION ABSORBER

***Hans Lindell, Viktor Berbyuk, Snævar Leó Grétarsson, Mattias Josefsson**

***Swerea IVF, Box 104, 431 22, Mölndal, Sweden**
Chalmers University of Technology, 412 96, Göteborg, Sweden
E-mails: hans.lindell@swerea.se, viktor.berbyuk@chalmers.se, snaevar9@gmail.com, mattias.josefsson@live.com

Introduction

Vibration exposure from hand-held impact machines (HHIM) such as rock drills, rammers and breakers with a reciprocating action is a major cause for injuries to the workers in the industry. In order to improve the work environment in the stone industry, a project was started with the objectives to redesign the tools to achieve low vibration as well as improved ergonomics, dust removal and reduced noise while maintaining productivity[1]. Redesign of current hand-held pneumatic impact machines can reduce the vibration level and thereby reduce injuries to workers. Hand-arm vibration injury, often called Hand Arm Vibration Syndrome (HAVS) is one of the most common reasons for work related injuries among this group of workers in the industry.

Although pneumatic impact machines have been used since the early 20th century little has been changed in their fundamental design to date. Despite their being robust and efficient, vibration, noise, dust and poor ergonomics cause a large number of injuries to the operators. Previous work has been done to reduce vibrations from these machines of which some have been patented[2,3]. One approach is to use traditional linear tuned vibration absorbers (TVA) invented in 1909 by Frahm and described by Den Hartog[4]. Although this technology is to a large extent limited in practical use on this application due to it is only effective in a narrow frequency range. At higher frequencies the TVA will instead increase the vibration and at lower frequencies will the effect rapidly decrease.

However, by introducing nonlinear spring characteristic of the absorber mass the effective frequency range can be greatly increased and thereby can the technology be effectively implemented to this kind of machines[5]. As a result a new generation of impact machines is developed by approaching the redesign from a user perspective, and starting adhering to strict conditions of low vibration, noise and dust as well as sound ergonomics. The objective of this study has therefore been to develop a user friendly low vibration impact machine using nonlinear tuned vibration absorber together with integrated vibration isolation. A HHIM with a nonlinear tuned vibration absorber combined with vibration isolation has shown to significantly reduce the vibration on the operator from 20 m/s^2_{haw} to a level close to 2.5 m/s^2_{haw}.

Methods

The machine consists of a piston moving inside a cylinder hitting the working tool driven by compressed air. The cylinder is in turn attached to a housing via vibration isolators. The operator handles are attached to the top of the housing. An engineering model (E-model) of the HHIM in question is shown in Figure 1. The Nonlinear Tuned Vibration Absorber (NTVA) comprises a mass which is moving along the machine restricted by a nonlinear stiffness. The nonlinearity is in the simplest execution realized by introducing a gap between two springs and prestress in the springs. From the E-model a mathematical model (M-model) is developed by setting up the equations of motion which in turn is transformed to a computational model (C-model) realized in MATLAB code.

The vibration reduction of the HHIM was accomplished by using two combined approaches: 1) a NTVA was designed that creates a counter force to the reaction forces on the cylinder of the piston and is effective in a broad frequency range, and 2) vibration isolation between the impact mechanisms and the housing that the handles are attached to. The isolation is applied in the axial, radial and rotational direction in order to further reduce the vibrations that still remain from the piston and those from the chisel hitting the stone. Care has been taken not to compromise the ability to accurately control the machine.

Results and Discussions

The C-model of the machine in question was verified both in a test rig and on a HHIM prototype and shows sufficient correlation. The C-model has been used to simulate the machine vibration dynamics for different operational scenarios. Sensitivity analysis of the vibration dynamics has been done with respect to system structural parameters. It was found that vibration dynamics is strongly sensitive to variation of the values of gap, stiffness and spring's prestress of the NTVA, and is subject to optimization. The optimization problem has been stated and solved numerically. Figure 2 shows the vibration reduction effect for different scenarios. Line A is the vibration from a traditional machine with *m, M and* M_H fixed. Line B is from a machine with vibration isolation between *M* and M_H. Line C is a traditional TVA and finally Line D is the vibration from an optimized NTVA. Due to variations in machine load, spread in production etc which leads to variations in operating frequency is the expected operating range between 23 and 33 Hz.

What can be found is that the average vibration reduction from the original machine in the operating range is estimated to be 95% for the NTVA plus vibration isolation (Line D), 50% for only vibration isolation (Line B). Finally the linear TVA plus vibration isolation is about 60% which is just slightly more than with only the vibration isolation but with very high frequency dependence.

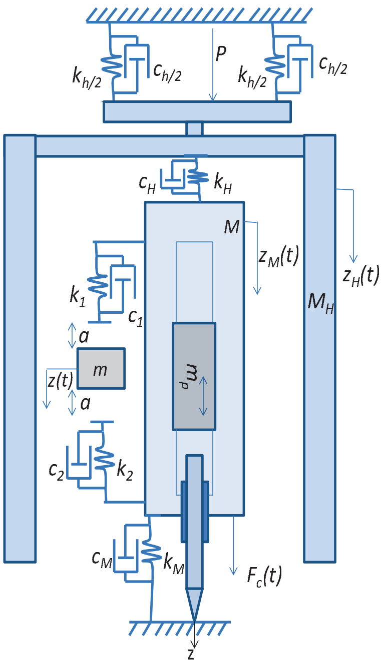

Figure 2 E-model of HHIM with NTVA

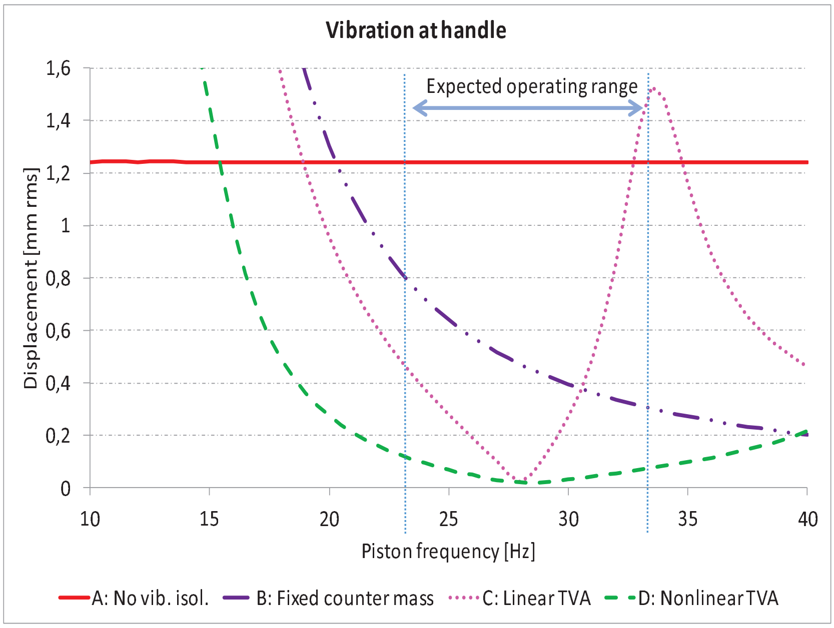

Figure 2 Vibration at machine handle from C-model

The project has built several prototype machines which have been field tested with good results and a small scale production is planned. In addition to the low vibration also other improvements have been measured and observed: feed force from the operator is more than halved, weight of the machine is halved, sound power is reduced by >10 dBA, increased efficiency, longer tool life, improved dust extraction and finally greatly improved ergonomics with adjustable handle length. The conclusion is that the concept with NTVA and potentially with a vibration isolation can greatly reduce vibration exposure from machines with reciprocating vibrations in a very cost efficient manner.

References

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