12 Ergonomic seat with viscoelastic foam reduces shock on underground mobile equipment

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Operators of underground mobile equipment, particularly shuttle cars, are often exposed to significant levels of whole-body vibration (WBV) and shock. The Human Factors group at the NIOSH–Pittsburgh Research Center has investigated the use of viscoelastic foam to reduce shock for the equipment operator and improve seats on mine shuttle cars. In-mine data were recorded on a JOY 21 SC shuttle car for the original seat and an ergonomic version with viscoelastic foam. A review of the data shows improved isolation across the driver/seat pad interface. For the full-load case, the ergonomic seat decreased transmissibility and isolated the shuttle car operator down to 15 Hz. Additional testing of the foam materials with the development and use of a lumped-parameter analytical model showed different composites of the foam materials can reduce the isolation frequency to below 5 Hz. This paper describes the underground mine trials and the testing done to evaluate properties of the viscoelastic foams. The paper also discusses the development of an analytical model using the data from underground trials and the foam testing.

Introduction

Studies sponsored by the U. S. Bureau of Mines (USBM) have reported that as many as one-third of the equipment operators in underground coal mines may be exposed to adverse levels of whole-body vibration (WBV) (Remington et al., 1984). Shuttle cars are identified as a primary source of this adverse exposure. The operator experiences WBV and shock when the shuttle car travels over rough mine floor marked by bumps, ruts, and potholes. In low-coal mines (< 1.25 m or 50 in), restricted space makes seat suspension systems difficult to use in isolating operators from WBV and shock. Miners log 25 million hours of work annually in these mines.

Interviews with underground mobile equipment operators revealed complaints mostly about shocks or jolts they received when operating shuttle cars. Hence, the feedback from equipment operators made the case for research to reduce shock. Specifically, this research focuses on a more ergonomically designed seat and on identifying how well various types and thicknesses of viscoelastic foams reduce the shock experienced by shuttle car operators.

Underground mine trials

Researchers at the Pittsburgh Research Center (PRC) modified the original seat in a JOY 21SC shuttle car used at an eastern Kentucky mine. The coal seam at this mine is 0.889 m (35 in) thick with an operating height of approximately 1.09 m (43 in). Owing to the low mining height, operators must adopt a reclining posture to operate the shuttle car. From observing and talking with the shuttle car operators, it became obvious that the original seat provided little adjustability or lower back support. Modifications to the original seat resulted in a more ergonomically designed version with an easily adjustable lumbar support, fore-aft seat pan movement, and viscoelastic foam padding. The padding included six layers, each .013 m (5 in) in thickness, of the following order from top to bottom: EXTRA-SOFT, PUDGEE, BLUE, YELLOW, SOFT, and GREEN. The BLUE, YELLOW, and GREEN layers are CONFOR medium-density, open-celled polyurethane foams from E-A-R Specialty Composites Corp., Newark, DE. The remaining materials are manufactured by Dynamic Systems, Inc., Leicester, NC. EXTRA-SOFT and SOFT are SUN-MATE polyurethane foams with organic composition of more than 50% plant derivatives. SUN-MATE PUDGEE is unique among the materials as a viscoelastic gel-foam with a soft dough-like consistency. Data were recorded for a typical shock with the shuttle car operating empty and with a full load. In terms of transmissibility across the driver/seat pad interface, the ergonomic design shows considerably improved isolation for the full load case. Below 15 Hz, transmission increases across the seat due to the improvement in isolation frequency. The design objective was to lower the isolation frequency and improve the damping characteristics of the seat so an increase in transmissi-bility is minimized.

Although the seating foam composite above provided substantially improved isolation for the shuttle car operator, PRC researchers were interested in further reducing the isolation frequency. Consequently, additional testing of the viscoelastic foams was arranged with a company specializing in noise and vibration engineering, Roush Anatrol.

Material property evaluation

Using the forced oscillation technique, investigators at Roush Anatrol evaluated the six foams above plus SUN-MATE MED-SOFT. This method was used to quantify the influence of static preload, dynamic strain amplitude, and temperature on the modulus of elasticity and damping properties of the foams. Test temperatures were selected from actual readings and knowledge of the mine environment. The chamber temperature was held constant at these temperatures for testing at pre-strain levels of 0%, 10%, and 45%.

Analytical model

The isolation system provided by the foam was analyzed dynamically using a lumped-parameter, analytical model. The dynamic interaction of the vehicle, isolation system, and driver was simulated with the model using a seven degree of freedom spring-mass-damper system. Six material layers with variable material thickness were included in the model.

The ergonomic seat was chosen as the baseline seat in the model because of its known material configuration and properties.

A shock input, taken from in-mine data recordings, was applied analytically to the system to determine the driver's response for each material configuration. Responses were generated at the driver/seat interface (seat accelerometer location) and at the driver's torso. The responses were then compared to the experimentally measured, modified seat response and to the analytically predicted driver response. An analytical transfer function between the input force and the torso was also generated to show the isolation frequency and the amplification at resonance. Accordingly, investigators optimized the seat material configuration using an iterative process.

Analytical model results

For isolating the shuttle car operator, EXTRA-SOFT, SOFT, and PUDGEE foams exhibited characteristics that make them the best of the materials evaluated. At 4.4° C (40° F) and 21.1° C (70° F), the SOFT and EXTRA-SOFT have lower modulus of elasticity values than the YELLOW with EXTRA-SOFT the lowest. The SOFT and EXTRA-SOFT are relatively stable with temperature and have similar damping properties. Across the temperature range tested, PUDGEE shows less than an order of magnitude change in modulus of elasticity. Across the frequency span and temperature range, the dampmg properties of PUDGEE are also fairly uniform. Moreover, PUDGEE has the lowest modulus of elasticity values of the seven foams tested. PUDGEE'S higher damping than the EXTRA-SOFT could, however, restrict its ability to expand from a compressed state during a jolt or shock.

The EXTRA-SOFT and PUDGEE composite was evaluated as Case #2. This provided the maximum depth of a low modulus foam as well as one that maintains its stiffness and damping properties over the expected operating temperature range. The isolation characteristics of the seat are improved to approximately 4 Hz. A small amplification in the 3 Hz region appears due to the lowering of the driver/seat resonance.

Five inches of EXTRA-SOFT constituted Case #6. For a low-coal application, this design represents nearly the maximum amount of seat padding that might be used. The design also employs the best single material m terms of low modulus of elasticity, low and consistent damping, and low temperature sensitivity. This foam configuration provides analytical isolation frequency of 5 Hz.

Conclusions

The shuttle car seat design that shows the best isolation properties corresponds to foam configurations of Case #2 or #6. Either of these selections maximizes the isolation performance of the seat in the limited space available. The analytical model provides a usable tool to design and optimize shock and vibration isolation systems for use on a variety of seating configurations in underground mines. It will greatly aid investigators at the NIOSH - PRC in providing mining companies and manufacturers with guidelines for the construction of ergonomically designed seats to reduce the shock exposure of underground mobile equipment operators.

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