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N361 A Systematic Comparison of Different Seats on Shuttle Cars Used in Underground Coal Mines

N. Kumar Kittusamy

National Institute for Occupational Safety and Health

Spokane Research Laboratory

315 E. Montgomery Avenue, Spokane, WA. USA 99207

NKITTUSAMY@CDC.GOV

Alan G. Mayton, Christopher C. Jobes, and Dean H. Ambrose

National Institute for Occupational Safety and Health

Pittsburgh Research Laboratory

Pittsburgh, PA. USA

ABSTRACT

A field study was conducted to evaluate seat designs on shuttle cars. Eight operators participated in evaluating seat designs on the basis of perceived levels of vehicle jarring/jolting and discomfort. Researchers also measured the levels of vehicle jarring/jolting. Four basic seat designs were compared on low and mid-coal seam shuttle cars during production operations at two underground coal mines. Two seats were currently used on the shuttle cars and another two were NIOSH designs. Objective data were collected using accelerometers with pre-amplifiers and filters connected to a data recorder; whereas subjective data were gathered with a visual analog scale (VAS) and a questionnaire. Results from measured levels of jarring/jolting showed that the NIOSH Seat L2A smoothed out bumps better than any other seats. Using the VAS, mid-seam and low-seam shuttle car operators rated the levels of jarring/jolting and discomfort lower with the NIOSH seat than the other seats. Questionnaire responses indicated that operators rated NIOSH seat designs as more comfortable. This research will provide the industry with better seat designs for isolating jarring/jolting in vehicles. Furthermore, researchers plan to improve the NIOSH

seats using information gathered in this study.

INTRODUCTION

Modern transportation vehicles continually expose individuals to whole-body vibration (WBV) and mechanical shock. This includes airplanes, ships, trains, and a variety of industrial and agricultural equipment. Exposing individuals to WBV and mechanical shock can negatively impact their health, safety, comfort, and working efficiency [1, 2]. Until recently, insufficient attention was given to seat design. In designing a comfortable seat, it is important to understand the vibration environment to which individuals are exposed and how well they can tolerate this environment. Moreover, human sensitivity to low frequency WBV has pointed to ride quality as an important need in seat design [1].

An earlier study by Mayton et al [3] reported on a low-coal shuttle car seat design that underwent limited, yet successful underground mine production trials. The intent of the current seat design comparison study was to build on earlier work by performing a more systematic evaluation of the low-coal shuttle car seat design and a second mid-coal shuttle car seat design. The NIOSH seat designs include viscoelastic foam that has properties similar to those found in a mechanical spring/damper suspension system. The seats also include an adjustable lumbar support and a fore-aft seat adjustment. This contrasts with the some existing seats, which have little or no lumbar support and include inexpensive furniture foam padding.

METHOD

Eight shuttle car operators participated in the study, five operated the JOY 10SC and three operated the JOY 21SC. The operators were all males from 24 to 58 years of age and averaged about 39 years. They ranged in height from 175 to 185 cm (average of 180 cm) and in weight from 73 to 91 kg (average of 87 kg). The subjects' experience at operating a shuttle car varied from to ½ to 24 years and averaged about 9 years. Similarly, their underground mining experience varied from ½ to 37 years and averaged 14 years. Moreover, before participating, the shuttle car operators were briefed about the study and were asked to sign an informed consent and photo release forms.

Seat design trials were conducted on a JOY 21SC shuttle car operating at the Black King mine (≤ 122 cm, low-coal seam) and a JOY 10SC side-saddle-style shuttle car operating at the

Laurel Alma mine (122 cm to 244 cm, mid-coal seam). Different seat designs were compared on each shuttle car. The existing seats were designated Seats L1 and M1 for trials with low and mid-seam shuttle car models, respectively. The NIOSH seats were designated as follows according to the viscoelastic foam arrangement for the low-seam shuttle car: 1) Seat L2A – included padding with a combination of Pudgee (PU) and Sun-Mate Extra-Soft (XSS) and a total thickness of 7.6 cm; 2) Seat L2B – included a total thickness of 12.7 cm XSS foam padding; and 3) Seat L2C – included padding with a combination of PU and XSS and a total thickness of 12.7 cm. The NIOSH seats for the mid-seam shuttle car were designated according to viscoelastic foam arrangement as follows: 1) Seat M2A – included a total thickness of 12.7 cm XSS foam padding; and 2) Seat M2B – included padding with a combination of PU and XSS and a total thickness of 12.7 cm.

Objective data were collected using accelerometers with pre-amplifiers and filters connected to a data recorder; whereas subjective data was gathered with a visual analog scale (VAS) and a questionnaire. Objective data were collected using a SONY data recorder, PCB accelerometers, signal conditioning amplifiers and in-line, low-pass filters. Triaxial accelerometers were placed on the floor of the operator's compartment near the base of the seat (frame measurement) and on the seat at the subject/seat interface (seat measurement). Because of muddy conditions the frame accelerometers were mounted to the frame of the shuttle car above the control panel. Researchers analyzed this data to determine the acceleration and impact energy entering the seat from the through the floor and vehicle frame. During the field trials, road-way conditions were noted. Road-way conditions were noted as smooth, pothole-riddled, debris strewn, rutted, dry, wet, and water-filled.

The subjective data were gathered using a visual analog scale (VAS) form to obtain the operators' immediate impressions of shock, vibration and discomfort levels for the vehicle ride on each of the seats and viscoelastic foam configurations. The VAS consisted of a line approximately 10 cm line anchored by two extremes of jarring/jolting level and level of discomfort. The two extremes were "zero or none" and "maximum". Operators were asked to make a vertical mark on the line which represents their level of perceived discomfort or jarring/jolting level. The rating scale was scored by measuring the distance (from left to right) from the beginning of the line to the operator's mark and dividing this value by the total length of the line. The shuttle car operator marked this scale after traveling with and without a full load of coal on the first, third and sixth round trip of the trials for each seat. A round trip consisted of traveling to the coal face with no load and returning to the load discharge location with a full load of coal. After each segment of the trip, participants were asked to rate the vehicle ride in terms of the level of jarring and jolting experienced through the selected seat. A decimal value was calculated for each rating and varied from 0 to 1. Each operator, unless otherwise shown, rated levels of jarring and jolting and discomfort three times. These values were summed and averaged to obtain an average operator rating for the individual seats. In turn, the average operator ratings were summed and averaged to obtain a total average operator rating.

Also, a brief questionnaire was used to obtain subjective data through interviews with shuttle car operators. Researchers administered a 10 minute questionnaire, at the conclusion of each trial for each seat. The questions contain items on shuttle car operator's judgment of body's exposure to comfort and vibration or shock, operator's opinions about seat padding and lumbar support, operator's likes, dislikes, and suggestive improvements concerning each seat were noted and finally a summary was developed comparing the seats.

RESULTS

Whole-Body Vibration

The Joy 10SC, mid-seam shuttle car, was evaluated at the Laurel Alma mine. Five operators were tested on three seats (original (M1) and two NIOSH seats denoted as M2A and M2B) and the data sets were separated into full load and no load conditions. No information was collected for operator numbers 3 and 5 on Seat M2A due to scheduling problems. Thus, from a possible 30 data sets, researchers obtained and analyzed a total of 26 data sets. The data were initially examined according to RMS acceleration, peak acceleration, and crest factor. Ratios of input (frame) to output (seat) were used to normalize the data for different travel paths and operators. Averages were derived for each operator and load condition and overall. An auto-power spectrum was plotted in each case for both the frame and seat data and was used to create a transmissibility curve. The data were further reduced by overall averaging of the operators for the no- load and full-load conditions. In comparing Seat M1 (original seat) with the two NIOSH seats the following results were observed for no-load condition: 1) Seat M2A showed a decrease in peak amplitude by 16% and crest factor by 23%, but an increase in RMS of 13%; 2) Similarly, Seat M2B showed a decrease in peak amplitude by 4% and crest factor by 10%, but an increase in RMS of 12%. Similarly, comparing Seat M1 (original seat) with the two NIOSH seats the following results were observed for full-load condition:1) Seat M2A showed increases in peak amplitude, RMS, and crest factor by 30%, 20%, and 9%, respectively; 2) Similarly, Seat M2B showed increases in peak amplitude, RMS, and crest factor by 52%, 27%, and 20%.

The JOY 21SC, low-seam shuttle car, was evaluated at the Black King mine. Three operators were tested on four seats (the existing, L1, and the three NIOSH seats denoted as seat L2A, L2B, and L2C) and the data sets were separated into full load and no load conditions. No information could be salvaged from operator 1 on seat L2C due to excessive battery bounce in the data recorder caused by a very rough ride. Thus, from a possible 24 data sets, researchers obtained and analyzed a total of 22 data sets. The data were first examined by RMS acceleration, peak acceleration, and crest factor. Ratios of input (frame) to output (seat) were used to normalize the data for different travel paths and operators. Similarly, an auto-power spectrum was plotted using the frame and seat signals. In turn, these curves were used to create transmissibility curves. The data were further reduced by averaging over all the operators for the no-load and full-load conditions. In comparing Seat L1 (original seat) with the three NIOSH seats the following results were observed for no-load condition: 1) Seat L2A showed decreases in peak amplitude, RMS, and crest factor by 23%, 10%, and 14%, respectively; 2) Seat L2B showed decreases in peak amplitude, RMS, and crest factor by 14%, 7%, and 8%, respectively; and 3) Seat L2C showed decreases in both peak amplitude and RMS by 8% and no change in crest factor. Similarly, comparing Seat L1 (original seat) with the three NIOSH seats the following results were observed for full-load condition: 1) Seat L2A showed decreases in both peak amplitude and crest factor by 3% and no change in RMS; 2) Seat L2B showed increases in peak amplitude, RMS, and crest factor by 18%, 16%, 2%, respectively; 3) Seat L2C showed increases in peak amplitude and RMS by 8% and 10%, but a decrease in crest factor of only 1%.

Subjective Ratings

Total average ratings were calculated for the shuttle car operators of the JOY 10SC mid-seam and JOY 21SC low-seam shuttle cars, respectively. Ratings from VAS responses indicated that the NIOSH-designed seats were better than the existing seats used in the shuttle cars. In the JOY 10SC, mid-seam shuttle car, for both no-load and full-load conditions, the operators rated levels of jarring/jolting and discomfort as <u>lower</u> with the NIOSH seat using two different 12.7 cm viscoelastic foam pad arrangements. Also, the viscoelastic foam arrangement, 12.7 cm of XSS foam padding, was the most preferred by operators of the mid-seam shuttle car. Moreover, a strong positive correlation for jarring/jolting and discomfort was determined for the different seats tested on the mid-seam, JOY 10SC shuttle car.

In the JOY 21SC, low-seam shuttle car, for no-load and full-load conditions, the operators rated jarring/jolting as lower with the NIOSH seat using three different viscoelastic foam pad arrangements. The viscoelastic foam arrangements, in order of operator preference, were 12.7 cm thick XSS foam, 7.6 cm PU/XSS, and 12.7 cm thick PU/XSS padding. Also, under no-load and full-load conditions for the low-seam shuttle car, operators rated discomfort levels as higher with the NIOSH seat using three different viscoelastic foam pad arrangements. The reason for this is that researchers had to use existing bolt holes to install the NIOSH seat. This caused the seat to be closer to the control panel and made the shuttle car operators to feel awkward and cramped. Furthermore, a weak to strong positive correlation (for jar/jolt and discomfort) was realized for the different seats tested on the low-seam, JOY 21SC shuttle car.

Questionnaire

The questionnaire evaluated the operators judgments on several characteristics of the existing seat (M1) and two other seats (M2A and M2B) on a JOY 10SC, mid-seam shuttle car. Seat M1 ranked the lowest in comfort, vibration reduction, seat padding and lumbar support. Suggestive improvements to Seat M1 include adding armrests and remove and replace the seat with a new original seat. Seat M2A was ranked most favorable. Operators liked the seats ability to absorb vibration and jar, provides good support to the back, and the seat felt comfortable. The Seat M2A was apparently too low for good visibility and seat placement caused the controls to be too close. Adding armrests and improving the seat location were the major suggestions to improve Seat M2A. Seat M2B was ranked second highest for seat padding and lumbar support. Operators like the seat comfort and firmness and dislike the way it absorbs shock and the back support was too stiff. Operators offered several suggestions to improve Seat M2B such as making the seat softer, adding armrests and improving lumbar support. In summary, Seat M2A is the favorite and rated highest for comfort, vibration reduction, favorable seat padding and lumbar support. Seat padding rated well for both Seat M2A and Seat M2B. Seat M1 is the least favorite in all ratings. Adding armrests was the improvement most often suggested for any of the seats.

Similarly, the questionnaire evaluated the operators judgments on several characteristics of the existing seat (L1) and three other seats (L2A, L2B and L2C) on a JOY 21SC, low-seam shuttle car. Seat L1 ranks the lowest in seat comfort and vibration reduction. Consequently operators liked how the seat reduced jars and jolts; one operator thought it was fairly comfortable. Operator's disliked its durability and the lumbar was too thick. Suggestions to improve the seats were to make the back support better, improve adjustments for better visibility, and improve padding. Seat L1 did not have a seat-pan tilt or fore-aft adjustment. Seat L2A and Seat L2C rank well in comfort and vibration reduction. Operators liked how Seat L2A took the strain off the lower back when the shuttle car traveled across large holes. Also, operator's liked the thick cushion on Seat L2A and how the seat adjusts to the body. Operators liked Seat L2B for how comfortable it felt, how it reduced shocks, and for its thick cushion. Both seats were too close to the controls and did not fit the confined shuttle car area. Regarding Seat L2B, operators rode the shuttle car slower to avoid being bounced into the canopy. Suggestive improvements for Seat L2A and Seat L2B were to make the lumbar seat wider. An operator suggested improving the operator's control panel envelope to accommodate better seats. For Seat L2C, the operators liked the padding, how well it reduced shock, how well the lumbar support took the strain off the back, and how comfortable the seat was. Operators did not like the lumbar width. Also, the seat was too big for the shuttle car's confined area. Operators' suggest several improvements to Seat L2C: such as make lumbar support and seat wider and add a scaled down seat so to fit better behind the controls. In summary, seat comparisons ratings favor Seat L2B. Seat L1 is the least favorite in all ratings. Seat L2B was rated the highest in comfort, vibration reduction, favorable seat padding, lumbar support and seat-pan tilt. Reclining back is better on Seat L2B and favored on Seat L1. Making the seat a better fit for the operator compartment is a suggested improvement. This could improve clearance between operator and controls and allow for better operator adjustability and visibility.

SUMMARY

The quantitative levels of vehicle jarring/jolting showed the NIOSH Seat M2A (12.7 cm XSS foam pad), smoothed out bumps better than the Seat M2B on the mid-seam shuttle car. However, when considering peak acceleration, RMS acceleration, and crest factor both NIOSH seats (Seats M2A and M2B) showed little, if any, improvement for jarring/jolting. In contrast for the low-seam shuttle car, the NIOSH seat with the 7.6 cm viscoelastic foam pad (Seat L2A) provided significantly better results for vehicle jarring/jolting, in terms of peak acceleration, RMS acceleration, and crest factor.

Average ratings from VAS responses indicated that the NIOSH-designed seats were superior to the existing seats used in the shuttle cars. For both no-load and full-load conditions, average ratings of mid-coal seam shuttle cars operators showed levels of jarring/jolting and discomfort as <u>lower</u> with the NIOSH seat using two different 12.7 cm viscoelastic foam pad arrangements. The viscoelastic foam arrangement, 12.7 cm of XSS foam padding (Seat M2A), was most preferred by operators of the mid-coal seam shuttle car. Similarly, for shuttle car no-load and full-load conditions, average ratings of low-coal seam shuttle car operators showed jarring/jolting as lower with the NIOSH seat using three different viscoelastic foam pad arrangements. The viscoelastic foam arrangements, in order of operator preference, were 12.7 cm thick XSS (Seat L2B), 7.6 cm PU/XSS (Seat L2A), and 12.7 cm thick PU/XSS foam padding (Seat L2C). Nevertheless, concerning levels of discomfort, the average operator rating favored the existing seat slightly better than the NIOSH seat with the three different viscoelastic foam pad arrangements seat, under full-load and no-load conditions. The reason is that researchers had to install the NIOSH seat using existing bolt holes. This caused the seat to be closer to the control panel and made the shuttle car operators to feel awkward and cramped. Also, the Seats L2B and L2C (the 12.7 cm thick foam pads) caused the operators to be closer to the canopy.

Questionnaire responses indicated that operators for both shuttle car rated NIOSH seat designs as more comfortable overall. Vehicle operators most frequently suggested the addition of armrests as a way they would improve the seats on the mid-seam shuttle car. Making the seat a better fit for the operator compartment is a suggested improvement for the low-seam shuttle car. This would improve clearance between the operator and the controls and thus, allow for better seat adjustability and operator visibility.

Finally, these results can supply the mining industry with more evidence that NIOSH seat design, especially Seat L2A, can be better than existing designs for isolating operators from vehicle jarring/jolting. Furthermore, researchers at NIOSH-PRL have the opportunity to refine and improve the NIOSH seat designs from the added input of shuttle car operators.

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