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EXPERIMENTAL STUDIES ON SOME VIBRATION ISOLATORS DEVELOPED FOR POWERED KNAPSACK SPRAYER

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ABSTRACT

The paper presents the experimental studies on the effectiveness of some vibration isolators developed for reducing transmission of vibration from the powered knapsack sprayer to the back and shoulders of the operator. A test rig was used to conduct detailed experimental studies on the powered knapsack sprayer mounted on it and fitted with different vibration isolators. Strucutral features of vibration isolators have been presented and their effectiveness of isolating transmission of vibration, from the engine-blower of the sprayer to its main frame and the operator, has been presented and discussed. Vibration measurements and analyses made by using B & K equipment have proved that the vibration isolators are quite effective in reducing the vibration transmission. The operators felt much less discomfort when they used the sprayer fitted with the isolators developed for the purpose, as compared to the existing arrangement.

INTRODUCTION

A powered knapsack sprayer is extensively used for spraying and dusting of chemicals, especially on small farms and orchards. The powered knapsack sprayer constitutes a compact unit of small high-speed two-stroke single-cylinder petrol engine coupled to a blower to atomise the liquid chemical (Fig.1). The engine is mounted on the frame in such a way that the piston executes its to and fro motion above the crank shaft and in the vertical direction. The axis of rotation of the crank-shaft is horizontal and along the longitudinal direction. One end of the crank-shaft carries a starting pulley while on the other end the impeller of the blower is attached. The blower casing, which houses the impeller, supprts the engine on one side while its other side is attached to the sprayer-frame through two rubber blocks. The sprayer is carried by the operator on his shoulders with the help of leather strap attached to the frame. Back cushion provided on the frame avoids the direct contact of the sprayer frame with the operator's back. Some preliminary studies on the dynamic performance of powered knapsack sprayer were conducted earlier, "Bansal (1988)". These studies were based on the field tests with the sprayer mounted on the back of the operator. Fully balacing of the engine was the only vibration control measure adopted which reduced the vibrations in the vertical direction that are most harmful, "Gupta 1979)".

Subsequently some vibration isolators were developed "Sahota (1989)" for attenuating the transmission of vibration from the sprayer-engine to the back and shoulders of the operator. These are the steel-strip spring isolators replacing the rubber block isolators through which the engine-blower assembly of the sprayer is attached to its main frame, a foam back pad of appropriate dimenstions and the spring shoulder-pad isolators. A brief description of the isolators together with the results of their effectiveness are presented in the sbsequent sections.

EXPERIMENTAL SET-UP

A test rig was required for mounting the sprayer so that the dynamic behaviour of the equipment could be studied over an extended period. This also provided idential conditions for conducting experimental studies on different isolators; besides avoiding fatique to the operator. It comprises of a rectangular frame of MS angle-iron welded to form a regid structure, Fig.2. The rig was installed on to a thick masonary wall which was found to be convenient and served as an ideal foundation for it. Provision was made to mount the sprayer on the test rig either with the help of Split Clamps or the Mechanical Shoulders with back plate, as shown in the Figure.

Split Clamps

The split Clamp mounting of the sprayer on the test rig was by means of four Split Clamps, with the help of which the sprayer was held firmly on the Rig by clamping its frame at four points. This arrangement proved to be quite useful in studying the vibration transmitted throug the existing rubber blocks or the suggested isolators which coupled the engine-blower assembly to the frame of the sprayer. Tapped holes were provided on all the four Split Clamps for measuring vibration levels by mounting the accelerometer in all the three directions - verticle (v), transverse (t) and longitudinal (1).

Mechanical Shoulder and Back Plate

Another arrangement that is available for mounting the sprayer on the Rig is by means of the Mechanical Shoulders and the back plate, shown in Fig.2. The sprayer is mounted on the Rig in a way similar to that of the actual operator, with the strips and the back cushion resting on the mechanical shoulders and against back plate, respectively. Provision exists for measuring the vibration transmitted to the shoulders and the back plate. The Mechanical Shoulders and the Back Plate, which is adjustable in the horizontal direction, are both detachable. These are attached to the main body of the rig only when the vibration transmitted to the shoulders and the back plate are required to be measured. The Mechanical Shoulders together with the adjustable back plate simulate to a great extent, the field conditions of mounting the sprayer on the back & shoulders of the operator. At the same time it helped in measuring the vibration levels in a large number of experiments.

A special MS bracket was fabricated for mountings the accelerometer for observing the vibration levels at the source (engine). The bracket was highly stiffened such that its natural frequencies as compared to the excitation frequency were much higher. The bracket could thus be assumed to be an integral part of the crank case of the engine.

VIBRATION ISOLATORS AND ABSORBER

Vibration isolation involves interposing a resilient element between the vibration source (Engine-blower) and the receiver (operator), whereas vibration absorption involves attachment of an energy absorber springs-mass auxiliary system at the location where vibration reduction is required. A tuned vibration absorber was designed and attached at the bottom of the engine with the help of the bracket, which was actually ment for mounting the accelerometer for vibration measurement at the source. Because its effectiveness is limited to a narrow fequency range and did not suit to the variation in speed of the sprayer engine, it was discarded and is thus not presented here. For vibration control in the present context, vibration isolators consist of resilient springs introduced at positions between the vibration source and the receiver. One such isolator is by introducing resilient springs in place of rubber blocks which attach the engine-blower unit to the sprayer frame. Another one is the provision of shoulder pads consisting of resilient compression/extension springs, which isolate the transmission of vibration to the shoulders of the operator. Still another is the replacement of the existing back cushion with a special local back cushion of appropriate thickness, which reduces the transmission of vibration to the back of the operator. These are briefly described below:

Steel-Strip Springs as Isolators

The two rubber blocks, through which the blower-engine assembly is attached to the main frame of the sprayer, were replaced by a set of 4 steel-strip springs. Details of one such spring are shown in Fig.3. Base brackets and clamps used to hold the strips in position are slightly curved off to avoid stress concentration. The orientation of the strips is such that they are very rigid in the transverse direction and very flexible in the vertical direction, the direction in which vibration isolation is most desirable. Two steel-strips measuring 40 x 15 mm were used in each spring. Steel-strips of three different thicknesses (0.32, 0.5 and 0.62 mm) were used to study the effectiveness and performance of the springs as vibration isolators. The stiffnesses of the strips are very low in the vertical direction and the natural frequencies of the system with the springs having 0.32, 0.5 and 0.62 mm thick strips were found to be 3.9, 7.6 and 10.5 Hz, respectively. These are far below the excitation frequency corresponding to 3900 rpm of the blower. Steel-strips of thickness more than 0.62 mm, being less resilient were not included in the study. Further reduction of the stiffness of 0.32 mm strips attained by decreasing their central width to 11.5 and 7.5 mm, no doubt, made the springs more flexible but that resulted in too much static deflection. These strips have thus not been included in the study.

Shoulder Isolators

The sprayer is carried by the operator by means of two leather straps provided with the equipment. Vertical vibrations reaching the sprayer frame from the engine are transmitted to the operator through the load carrying straps. As a substitute to the existing foam shoulder pads, which do not provide sufficient isolation, extension/compression spring shoulder isolators were designed and developed. The extension-spring shoulder isolators essentially consist of resilient extension-spring provided in the straps which can slide freely over curved brackets that rest on the shoulders. Likewise, the Compression-spring shoulder isolators consist of resilient compression springs through which the vertical load from the straps is transmitted to the shoulder through a curved bracket. The natural frequencies of the system with compression springs and the extension springs used were found to be 4.1 and 3.8 Hz, respectively, which are significantly below the excitation frequency corresponding to the engine RPM.

Improved Foam Back Pad

Vibration level in the longtudinal direction are transmitted to the operator's back through the foam back pad provided on the sprayer frame. The existing back pad, consisting of a 340 x 230 x 20 mm foam packed inside a rexion cover, was not found to provide sufficient isolation in the longitudinal direction. It was observed that more vibrations were transmitted at the lower side. An improved back cushion pad measuring 80 x 250 mm was designed to be positioned at the low back. The optimum thickness of the pad was determined experimentally.

EXPERIMENTAL PROCEDURE

First of all the sprayer as such was mounted on the test rig with the help of split clamps run at a constant speed of 3900 rpm with the pesticide tank empty, half full and full. Vibration levels at various stations were recorded. Effect of replacing the rubber block by the steel-strip springs was observed in terms of reduction in vibration transmitted to various points on the main frame while it was held in the split clamps of the test rig. Effectiveness of shoulder isolators and that of the back foam pad were also likewise studied. For this, the use of the mechanical shoulders and the back plate of the rig was made. The effect of back foam pad of varying thickness was observed by measuring the vibration levels on the back plate. The best combinations of the above changes were compared with the existing ones under the field conditions, where only a limited number of tests were possible. Two speeds of 3900 and 5000 rpm were tried on the subjects and the vibration response for each noted. Vibration measurement and analyses conducted by using the B & K equipment are presented and discussed below.

RESULTS AND DISCUSSION

Results of the experimental studies conducted to evaluate the performance and effectiveness of the vibration isolators presented in Tables 1 and 2 and Fig.5 are discussed in this section.

Foam Back Cushion Pad

To evaluate the effectiveness of the back cushion pad and to compare it with that of the existing back pad, the sprayer was mounted on mechanical shoulder of the rig without any other change. Vibration levels were measured at the back plate of the rig while the sprayer was operated at 3900 rpm. Higher vibrations were observed to be transmitted to the lower edge of the back plate as recorded at station BP_1 (Fig.2). Effect of the increase of thickness of the back cushion pad on the vibration transmission were observed and recorded. The first peak values (corresponding to 63 Hz) and the overall value of the vibration in m/s^2 are presented in Table-1 for different foam thicknesses which varied in intervals of 20 mm of the localised cushion back pad measuring 80 x 250 mm. It may be concluded that the peak values (and also the overall lin values at 63 Hz decrease with increase in foam pad thickness, approaching an asymptotic value of 1.5 m/s^2 (and 4.9 m/s^2) for a thickness of 140 mm of the pad. Further increase in thickness of the foam pad was found to be of little use. However, a pad of less thickness was selected such that its insertion at the back did not disturb the alignment of the sprayer equipment when mounted on the mechanical shoulder and the backplate of the test rig. For this reason a foam pad thickness of 100 mm was selcted. It may be observed that the vibration reduction is not mainly due to increase in the foam thickness but also due to decreased area of contact in comparison with the original back pad. This new pad was subsequently adopted for the field evaluation on the subject.

Performance of Steel-Strip Springs

For this study the sprayer frame was attached to the rig with the help of four split clamps (Fig.2). The effect of reducing the vertical vibration transmitted to the sprayer frame was investigated by replacing the rubber blocks by one of the sets of four springs using strips of thickness 0.32, 0.50 & 0.62 mm.

Vibration levels were recorded at the split clamps in all the three direction. Those measured at the top left clamp (Ist peak values, m/sec^2) in the vertical $T_1(v)$, transverse, $T_1(t)$ and longitudinal $T_1(l)$directions are presented in Table 2, for the springs with different strips. The corresponding values when the existing rubber blocks were used are also given in the table. The change (%)in vibration transmission, reduction (-) and increase (+) are also given in the table for the sake of comparison of the effectiveness of the steel-strip springs with that of the rubber blocks. Maximum reductions of vibrations (-71.47% and -28.88%) are provided by the most flexible springs with 0.32 mm steel-strips in the vertical and longitudinal directions. The springs being very stiff in the transverse direction, as compared to the rubber blocks, the vibration transmission in the transverse direction is more in case of all the steel-strip springs. The transmission further increases with the increase in thickness, and hence stiffness of the steel-strips of the springs. This is exactly what was expected. These vibrations being in the transverse direction are least harmful and hence insignificant.

To further evaluate the effectiveness of the steel-strip springs in the vertical direction, the sprayer was mounted on the mechanical-shoulders and the backplate of the rig with the help of leather straps, and operated at 3900 rpm as in the rest of the study. The vibrations (Ist peak, m/s^2) measured at the left shoulder of the rig (R_1) are presented in the last row of Table 2 together with the corresponding value when the existing rubber blocks were used. The reduction in vibration at R_1 for the three springs with strip thickness of 0.32, 0.50 and 0.62 are 88.29, 85.27 and 81.31% respectively. Variation of vibration level with frequency recorded at R_1 for 0.32 steel-strip springs is preseted in Fig.4 together with the response for rubber blocks with and without spring shoulder pads. The response corresponding to the second peak (which corresponds to 1/3 octave band centre frequency of 125 Hz, the first harmonic of the fundamental frequency) has been reduced to -66%, which is less as compared to that at the Ist peak. The steel strip springs are thus quite effective in isolating the vibrations. To keep a balance between the static deflection and vibration isolation the 0.50 mm steel-strip springs may be said to be the most suitable.

Shoulder Isolators

The effect of introducing spring isolators at the shoulder regions of the leather straps was also studied. Vibration levels were recorded at the left mechanical shoulder of the rig. R_1. Variation of vibration levels with frequency both for the compression and extension spring shoulder isolators are presented on Fig.4 and compared with that of the response of the system using existing foam shoulder pads. Vibration reductions of 41 & 64% provided by the compression and extension spring isolators, respectively, corresponding to the first peak. At the second peak the reduction of vibration is about 30% in both the cases. The overall performance of the extension-spring shoulder isolator is thus better than that of the other one.

Limited field studies were also conducted by operating the sprayer by actually mounting it on the back and shoulders of the operator. The operator felt a great relief when the isolators were introduced as compared to when they were not.

CONCLUSIONS

Various types of vibrations isolators, namely, steel-strip springs, improved foam back pad and spring shoulder-pad isolators, designed and developed for vibration control have been found to be quite effective in isolating vibrations and hence reducing the discomfort and fatigue to the operator. An improved foam back pad measuring 80 x 250 mm and of 100 mm thickness proved to be very effective in isolating longitudinal vibrations transmitted to the back of the operator. The steel-strip springs with a 0.5 thick strips provide 68% reduction of vibration in the vertical direction-the direction in which vibrations are most harmful. The spring shoulder isolators have been found to reduce vibration levels by 41 to 64%. The operators felt less discomfort while operating the sprayer fitted with the above said vibration isolator.

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Table 1. Effect of Foam thickness on vibration transmitted to the back plate.

Foam Thickness (mm)	0	20	40	60	80	100	120	140
Ist Peak m/s^2	11.7	3.9	3.6	2.9	2.5	1.9	1.8	1.5
Overall Lin, m/s^2	41.0	26.0	17.5	12.4	9.8	7.8	5.5	4.9

Table 2. Comparison of the effectiveness of different steel-strip isolators with the existing rubber-block isolators (-, reduction; +, increase in vibration)

Isolator / Obs. Station	Rubber Blocks Ist Peak	0.32 mm Strip Ist Peak m/s^2	0.32 mm Strip % Change	0.5 mm Strips Ist Peak m/s^2	0.5 mm Strips % Change	0.62 mm Strips Ist Peak m/s^2	0.62 mm Strips % Change
$T_1(v)$	3.4	0.97	-71.47	1.09	-67.9	1.2	-64.7
$T_1(t)$	0.815	1.02	+25.15	1.20	+47.23	1.28	+58.28
$T_1(1)$	0.18	0.128	-28.88	0.137	-23.88	0.170	-5.55
R_1	1.29	0.151	-88.29	0.19	-85.27	0.241	-81.31

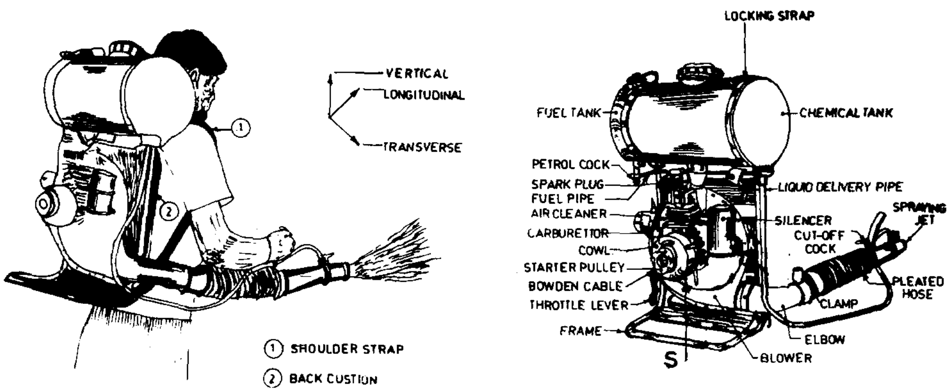

Fig. 1 Powered knapsack sprayer mounted on the back and shoulders of an operator and the directions of vibration measurement (a) and details of various parts of the sprayer and the station of vibration measurement at the source.

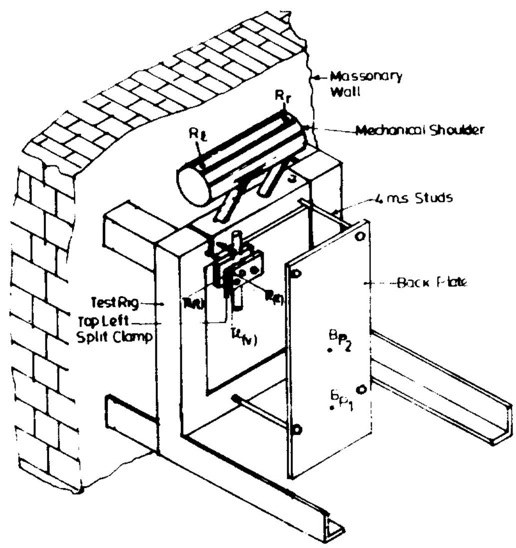

Fig.2 A rig for conducting vibration studies on the powered knapsack sprayer.

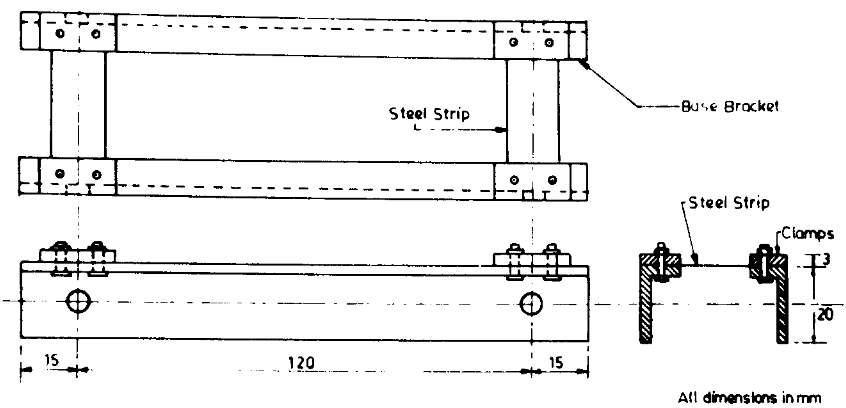

Fig.3 Details of the steel-strip spring.

Fig.4 Variation of vibration (m/sec^2) with frequency at mechanical shoulder of the Rig, R_1.————; rubber block isolators with existing strap pads; ●————● , steel-strip spring isolators with existing strap pads; – – – – – –; compression-spring shoulder isolators and existing rubber block isolators; ••••••••, shoulder isolators and existing rubber block isolators.