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NOISE AND VIBRATION CONTROL ON A NARROWBOAT

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1. INTRODUCTION

This paper describes a recent research project submitted in partial fulfillment of the requirements for the Diploma in Acoustics and Noise Control. The study involved a 54' long narrowboat which had recently been fitted out for the purpose of a holiday boat. The boat was powered by a 1.5 litre diesel BMC engine mounted at the rear of the long cabin. Subjective assessment was that existing noise and vibration levels were nowhere near comfortable. Noise levels in all three rooms forward of the engine room were at least 10 dB(A) above the average background levels without the engine on. Vibrations were evident and it was obvious that resonance significantly contributes to the noise level. Whole body vibration was experienced, and whilst health problems due to whole body vibration are remote, the helmsman with his/her hand constantly on the tiller could potentially encounter hand-arm vibration. The research documents the investigation and reduction of the initial noise and vibration levels.

Very few studies have been carried out to measure noise and vibration levels aboard narrowboats. More research has been carried out regarding transportation noise from inland waterways, for example the International Standard ISO 2922 – Acoustics - Measurement of noise emitted by vessels on inland water-ways and harbours, which uses pass-by tests. However, by reducing transportation noise as measured from the side of the canal, it is likely that internal noise will also be reduced, and vice versa. Health and safety requirements are becoming more and more stringent aboard inland waterway vessels, instigated by Europe. The European Recreational Craft Directive – 94/25/EC states that, "All inboard mounted engines shall be placed within an enclosure separated from living quarters and installed so as to minimise ... hazards from ... noise or vibrations in the living quarters." This Directive focuses on health and safety issues, with only a passing mention of the health effects of noise and vibration. Despite the Directive stating that they should be considered, and noise and vibration minimized, there are currently no standards or procedures for assessing these internal levels. Relevant standards that were used for comparison in this study were BS 6472:1992 – Evaluation of Human Exposure to Vibration in Buildings (1Hz to 80Hz), ISO 2631 Evaluation of human exposure to whole-body vibration, and BS 8233: 1987 Sound Insulation and Noise Reduction for Buildings.

1.1 NOISE REDUCTION MEASURES

The noise was controlled at source by reducing the mechanical noise of the engine through regular maintenance, partially (due to time restrictions) enclosing the engine using heavy, dense material. The reverberant field was controlled by the application of sound absorbing materials to room surfaces to decrease the reverberant field. In the boat, the ceiling and walls were of varnished wooden paneling, and so the floor was the only surface available on which carpet could be laid. On some narrowboats, carpet is laid along the lower half of the sides, which would further increase the level of absorption.

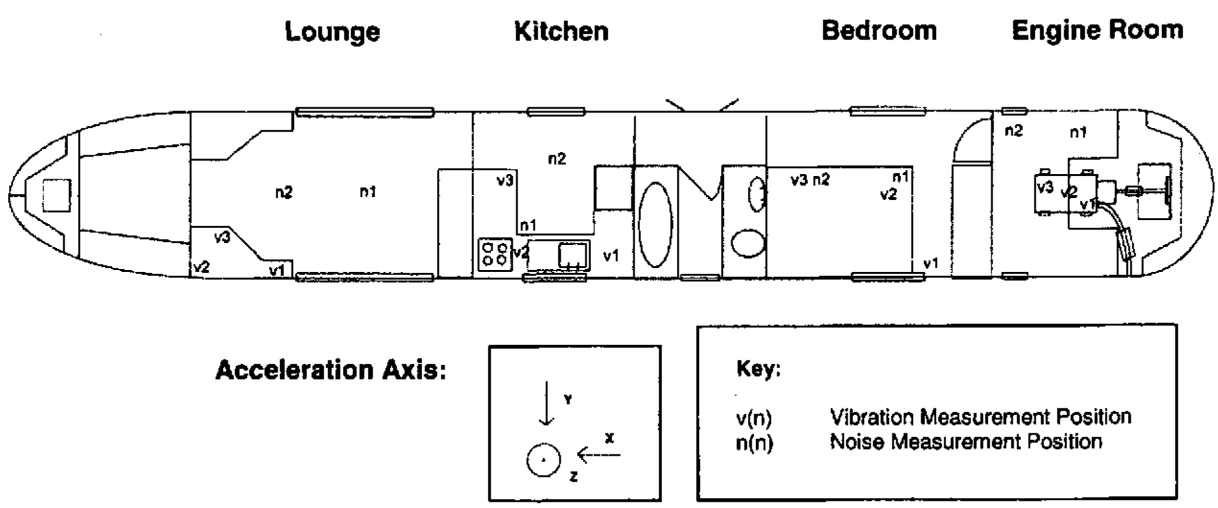
1.2 VIBRATION REDUCTION MEASURES

The engine on the boat produced vibrations which were transmitted to all structures in direct contact with the engine. Initially the engine was bolted straight onto the steel hull of the boat, and so vibrations were easily transmitted along the length of the boat. Vibrations occurred in all three dimensions, along the X, Y and Z axis. Because the engine on the boat had four in-line cylinders, the primary forcing movement was vertical ie. the Z axis. The propeller shaft at the rear of the engine was separately attached to the hull of the boat. This provided another path for vibrations to be transmitted from the engine to the boat structure.

The degree of isolation chosen as 80%, (or a transmissibility of 0.2). Assuming a damping coefficient of 0.5, the ratio of forcing frequency to natural frequency was found to give the required degree of isolation, which was 5, using a transmissibility-frequency graph. The required natural or resonance frequency of the system was calculated from the target frequency and frequency ratio. Ie. 26.6/5 = 5.32. This can be converted into static deflection by $f_0 = 15.8\sqrt{1}/X_{st}$, $5.32 = 15.8\sqrt{1}/X_{st}$, $X_{st} = 8.82$. The weight of the engine and attached gearbox was 400 Kg, and 4 isolators were to be used, 1 at each corner of the engine. Therefore the weight loading of the isolators was 100Kg each. Using the isolator load and the required static deflection, suitable isolators were chosen from manufacturer's product data.

An engine vibrating on soft engine mounts requires total freedom of movement from its driveshaft if noise and vibration are not to be transmitted to the hull. An 'Aquadrive' unit was fitted as a control measure. It consisted of two constant velocity joints, which isolated the movement of the engine from the prop shaft on the other side of the joints. To the rear of the C-V joints, a thrust bearing was attached to a cross brace in the hull of the boat so that the thrust from the propeller acted directly on the boat structure and not through the engine. The gearbox was connected to the rear of the engine only, ie. not rigidly mounted to the hull, and so with four anti-vibration mounts isolating the engine itself, and the driveshaft isolated from the hull, all direct vibration transmission paths were isolated.

Figure 1. NarrowBoat Plan To Show Measurement Positions



2. METHODOLOGY

2.1 Engine speeds

Three engine speeds were chosen representative of the way in which the boat will be used, although for practical reasons the boat was moored in position throughout, and not actually moving:-

1) Warm tickover, or idle. Out of gear. 800 rpm.
2) Normal cruising speed. In gear. 1100 rpm.
3) Full speed. In gear. 1700 rpm.

Measurements were made before and after the control measures were put in place so that direct comparison was possible.

2.2 Noise Measurement Procedure

Two microphone positions were chosen as centrally as possible in each of the four rooms: engine room; bedroom; kitchen; and lounge. Microphone heights were chosen to represent likely head heights. In the absence of standard test procedures for noise measurements on inland craft, it was considered that as long as consistency was applied with each measurement and location, comparability would be achieved. The number of measurement positions per room was restricted to two due to the limited space available. An L(L)eq period of 30 seconds was used.

2.3 Vibration Measurement Procedure

Three vibration measurement positions were chosen within each of the four rooms:-

1) Engine room – on the engine
2) Bedroom – floor
3) Kitchen – worksurface
4) Lounge – table

Measurements (Max L) in each of the axis X, Y and Z were repeated 3 times at each position, to achieve concurrent results. These results were then arithmetically averaged.

3. DISCUSSION OF RESULTS

3.1 Vibration Results

On the engine itself, the results before the control measures were put in place show the X and Y axes as having comparatively low vibration. The Z axis had by far the largest vibrations, as expected, since the engine had in line cylinders which meant that the primary forcing movement was vertical. With the control measures in place, there were increases in vibration which would not be expected if the accelerometer had been positioned on the isolated structure of the boat. But because the accelerometer was placed on the engine itself, increased vibrations were evident due to the soft engine mounts which allowed the engine to vibrate more freely without being damped by the rest of the boat. At speeds 1 and 2 in the Y axis, there was increased vibration corresponding to the motion of the alternator belt and the rotation of the driveshaft. Rotational forces in the Y direction were freer and therefore increased after the isolation. The X axis in general shows some reduction in vibration, although there is little movement in this direction within the engine.

Figure 2. Comparative Vibration Measurements

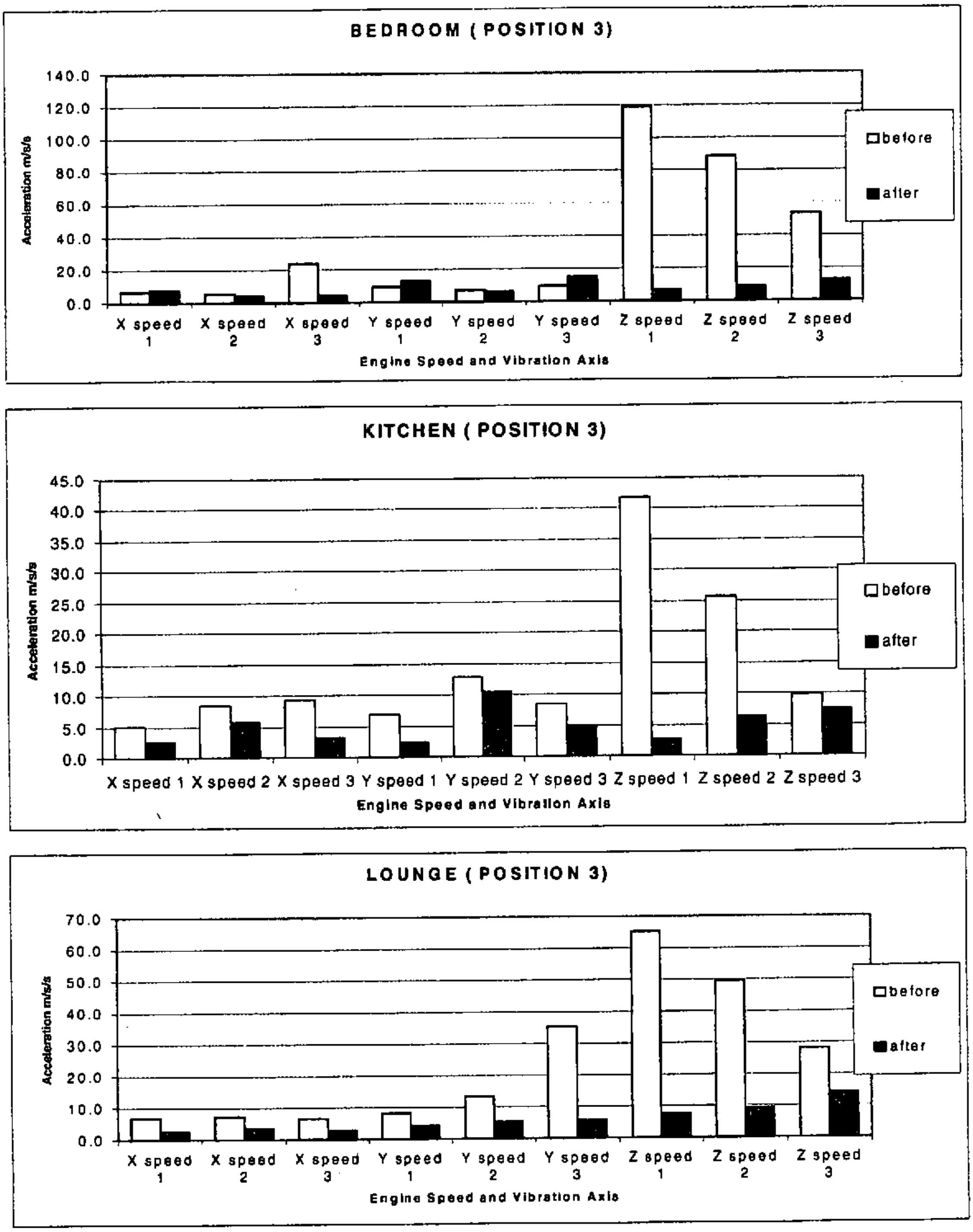


Figure 2 shows the vibrations as measured in the three rooms forward of the engine. The levels decrease as the rooms become further away from the engine. However, in the furthest room which is the lounge, vibration levels increased because panels were beginning to resonate. The levels for the Z axis are higher than for the X and Y axes. It would therefore seem that the vibrations noted subjectively are likely to be the vertical vibrations which concurs with ISO 2631 Evaluation of human exposure to whole-body vibration. There were considerable reductions of up to 94% measured in this axis. Within these rooms, there is a reduction in the level of vibration as the speed increases, due to the fact that isolation efficiency increases with frequency.

3.2 Noise Results

Figure 3 shows the L_{Aeq} levels before and after the control measures, which corroborate subjective assessment that the noise had significantly reduced despite strong tonal components remaining. The values for positions 1 and 2 in each room were arithmetically averaged to obtain single figures for each room. The sound pressure levels in the engine room were the loudest, which was as expected. The levels increased as the engine speed increased. Maximum reductions were achieved at speed 1 ie. idle. The engine frequency peak approximated to the calculated frequency (40Hz cf. 37Hz as calculated at speed 2), and harmonics were evident. Typical reductions at 1000 Hz are 8 dB at speed 1, 5 dB at speed 2 and 4 dB at speed 3 as measured in the engine room. In general, there were noise reductions at all frequencies. However, in all rooms the lower frequencies ie. below 250 Hz were erratic. After 250 Hz the levels became more stable. This may be because there were so many different parts of the boat vibrating and resonating at their own natural frequencies that there was an even distribution of the higher frequencies. Level difference increased at the higher frequencies, which was expected as high frequencies are easier to attenuate than low frequencies. The level difference achieved was maximum in the engine room which would also be as expected, closest to the source.

Level difference shows that at frequencies between 40 Hz and 63 Hz there was a large increase in sound pressure level after the control measures were implemented. This was not expected. It would indicate that something has changed in between the two sets of measurements being made. The enclosure could provide an explanation. Instead of insulating the sound from the engine, it is possible that it was itself vibrating and increasing the sound pressure level at those frequencies. These vibrations could have been transferred to all other rooms as the enclosure was fixed to the flooring. At speed 1, frequencies below 31.5 Hz and at 80 Hz show noise reductions of 20 dB. This is extremely good, however this level difference is not consistent. Only from 1600 Hz onwards does the level difference become consistent at a reduction of 10 dB. At speed 2, the level differences were much more consistent, being around 5 dB lower following the control measures. Reduction of the 20 Hz octave band centre were the greatest, and this reduction occurred in each room.

The dB(A) levels in the bedroom, kitchen and lounge reduced after control. However, at idle in the bedroom and lounge, levels were still higher than the levels recommended in BS 8233: 1987, eg. 69.7dB(A) in the bedroom cf. 30 to 40dB(A). When the doors are completed between the rooms a further reduction of about 10 dB may be achieved, depending on the completeness of the doors. Further noise reduction at source may then be necessary to reduce levels to the recommended maximum. The main engine frequency peak did not reduce, even though the rooms were further from the source. Level difference shows better reductions were achieved in rooms other than the engine room at the lower frequencies ie. below 630 Hz at speed 1, 80 Hz at speed 2, and below 315 Hz at speed 3. Level differences are comparable and steady at the higher frequencies. The lounge, furthest from the engine showed the most uneven distribution of sound and the presence of room modes.

Figure 3 – Comparison of total L_{Aeq}'s (averaged over room position).

	Speed 1	Speed 2	Speed 3
Engine Room			
SPL Before dB(A)	85.0	87.8	94.1
SPL After dB(A)	77.2	81.1	87.6
SPL Difference dB(A)	7.8	6.7	6.5
Bedroom			
SPL Before dB(A)	76.2	79.0	86.0
SPL After dB(A)	69.7	73.9	79.7
SPL Difference dB(A)	6.5	5.1	6.3
Kitchen			
SPL Before dB(A)	68.8	68.4	78.4
SPL After dB(A)	61.3	65.1	73.0
SPL Difference dB(A)	7.5	3.3	5.4
Lounge			
SPL Before dB(A)	61.8	63.8	70.0
SPL After dB(A)	54.8	59.5	64.8
SPL Difference dB(A)	7.0	4.3	5.2

3.2 Recommendations for further noise and vibration controls

Complete the engine enclosure so that there are no air gaps, to insulate the engine. This enclosure should also be lined with absorbent material which is formed so as to absorb the frequencies which the engine produces throughout its rev range. This will reduce the direct component of the engine noise.

Isolate the engine room from the rest of the boat. Currently floorboards pass underneath the bulkhead into the bedroom. These could be cut and an isolating material placed between the engine room flooring and the bedroom flooring. Similarly, the tongue and groove paneling along the sides of the hull continue through from the engine room into the bedroom and the rest of the boat. This will provide a flanking transmission path. These could be isolated between the engine room and the rest of the boat.

Isolate the flooring from the steel hull cross members with an isolating material and isolation fixings throughout the boat.

Fit doors in between each of the rooms within the boat. The doors should be well fitting to preserve their completeness.

Further silence the exhaust, and ensure that this is isolated from the structure of the boat.

3. CONCLUSIONS

The 1.5 litre diesel engine with 4 in-line cylinders produced vibrations very predominantly in the Z axis ie. vertically.

The fitting of the Aquadrive unit
Vibrations decrease with distance from the engine source.

The exact position of the accelerometer makes a great difference to the results obtained, for example, the presence of structural cross members underneath the accelerometer on the floor boarding.

L_{Aeq} at speed 3 was greater than at speed 2, which was greater than at speed 1.

The overall L_{Aeq} decreased for each position after the control measures were in place. The reductions ranged from 2.6 dB(A) to 7.9 dB(A).

The frequency at which the engine operated was easily distinguishable at each speed by frequency analysis. The measured frequency peaks for the engine at each speed corresponded to the calculated engine frequency.

Sound pressure levels at frequencies above 250 Hz were more consistent than at the lower frequencies where they varied. This was true of every room.

Between 40 and 63 Hz there was an increase in sound pressure level after the control measures were installed. This may be because the incomplete enclosure around the engine was resonating, even though it was not in direct contact with the engine.

The main transmission path on the boat is regenerated noise via flanking transmission through the structure, and not direct airborne transmission.

Low frequencies from the engine are exciting resonance in panels throughout the boat.

4. RECOMMENDATIONS FOR FURTHER STUDY

The measurement of the frequency of the intake and exhaust would provide data to compare to the frequency peaks obtained in this study.

Measurements with the engine enclosure completed, so that the engine is completely insulated, and with absorbent material on the inside of the enclosure would reveal if this would provide further reductions in noise throughout the boat.

Further measurements when internal doors are fitted inside the boat, and all are closed.

A standard should be drawn up to assess noise vibration in 'living quarters' as specified by the European Recreational Craft Directive.

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