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NOISE CONTROL ON BACKHOE LOADERS BY COHERENCE AND INTENSITY TECHNIQUES

K. Alper Yalçınkaya[1], Mehmet Çalışkan[2]

[1]HİDROMEK LTD. ŞTİ. 1. Organize Sanayi Bölgesi Osmanlı Cad. No:1,
Sincan/ Ankara, TURKEY
[2]Department of Mechanical Engineering
Middle East Technical University
06531 Ankara, TURKEY
alper.yalcinkaya@hidromek.com.tr

Abstract

The aim of this study is to control the interior and exterior noise emitted by the backhoe loader. A noise source identification methodology is developed throughout this work. This methodology consists of sound power level determination tests, spectral analyses of acquired noise data, coherent output power tests, and sound intensity measurements. Finite element analyses on engine hood and cabin cavity are performed to identify dynamic characteristics of the plates and the operator cabin. Results of these analyses are compared with the experimental results to identify the noise sources. Upon identification of the significant noise sources, proper noise control treatments are performed. Consequently, a required reduction of 2 dBA with reference to European Noise Directive 2000/14/EC is achieved in airborne sound power level of the backhoe loader. Cabin interior noise level at operator's ear position also benefited from the improvements by the same amount i.e., 2 dBA.

1. INTRODUCTION

Backhoe loader is a popular earth-moving machine (figure 1), which is used commonly in construction and road building applications. The machine is self-propelled, highly mobile with mainframe to support and accommodate both rear-mounted backhoe and front-mounted loader [1].

Backhoe loader may emit high levels of noise, which is unacceptable from occupational and environmental standpoints. For this reason, legislations concerning noise emitted by earth-moving machinery are published to protect the health and well being of citizens as well as to protect the environment. Legislation concerning environmental noise of backhoe loaders is published by European Council, called European Council Directive 2000/14/EC [2]. The upper limits of sound power levels emitted by backhoe loaders are declared within this directive.

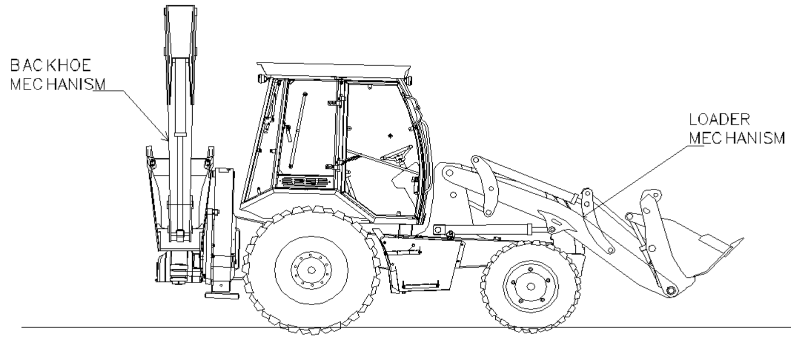

Figure 1 HMK 102 B Energy Series Backhoe Loader General View

Noise level at the operator's ear position is also another issue that backhoe loader manufacturers must consider due to noise legislation, called European Directive 2003/10/EC [3]. This directive is mainly about the minimum health and safety requirements regarding the exposure of workers to the risks arising from noise.

The objective of this study is to reduce noise emitted by backhoe loaders, manufactured by Hidromek Ltd. in order to keep within the limits stated in directives 2000/14/EC and 2003/10/EC.

2. METHODOLOGY

In this study, a noise source identification methodology based on spectral analysis techniques is developed. This methodology is composed of sound power level determination tests, exterior noise spectra analyses, correlation analyses, acoustic intensity measurements and numerical studies. First of all, exterior and interior sound levels emitted by the backhoe loader are measured. In accordance with the measured exterior sound power level and interior sound level, spectral analyses of the exterior and interior noise are performed. For the exterior noise sources, coherent output powers corresponding to hypothesized single input - single output (SISO) systems are estimated. Sound intensities over possible exterior vibroacoustic noise sources are also measured. Determination of vibration characteristics by numerical means for these possible exterior vibroaocustic sources and the cabin cavity are performed.

3.EXPERIMENTS AND RESULTS

Experiments were conducted on HMK 102B Energy Series Backhoe-Loader, manufactured by HİDROMEK. Tests are mainly classified into two groups; namely tests related with exterior noise and tests related with cabin interior noise.

Experiments related with exterior noise are grouped into four: 1) Airborne sound power level determination, 2) Spectral analysis of exterior noise, 3) Coherent output power tests, and 4) Sound intensity measurements.

Firstly sound power level of the machine is determined. Secondly, frequency spectrum of the exterior noise is obtained. This spectrum is evaluated with the expected noise source frequencies in terms of machine operational frequencies. Third step consists of another noise source identification method, coherent output power tests. Hypothetical SISO systems are constructed and analyzed to be able to determine the remaining unidentified sources. More detailed noise source identification analysis, which constitutes the fourth step, is performed by using sound intensity technique.

Sound intensity emitted from the engine hood vibrating plates and the hydraulic pump is then measured. Noise treatments are performed to the identified noise sources. Finally, exterior sound power level measurement on the retrofitted/modified machine is performed.

Tests related with cabin interior noise are classified into two groups; namely sound level determination in the cabin at operator's ear location and spectral analysis of cabin interior noise.

Interior sound level measurement and spectrum analysis are performed as a starting point of a quieter cabin design. Air inside the cabin is modeled by acoustic and vibration analysis software, MSC. Actran. This model is used to determine the natural frequencies and the mode shapes of the cabin cavity. Calculated natural frequencies are compared with the results of spectrum analysis.

3.1 Experiments Related with Exterior Noise

3.1.1 Airborne Sound Power Level Determination

European Directive 2000/14/EC [2] states that A-weighted airborne sound power level of the backhoe loader is to be determined according to dynamic test method, which is described in ISO 6395 [5]. However, static test method, described in ISO 6393[4], is performed to determine exterior sound power level of the backhoe loader and to check the results of noise control applications as the reference, because static test is more practical to conduct and provides better controlled experimentation environment. Upon assessment of the quietest machine configuration in static tests, a final test is conducted according to dynamic test conditions, ISO 6395 [5].

Exterior noise level of the backhoe loader is determined according to procedures described in international standards ISO 6393 [4] and ISO 6395 [5]. The calculated sound power level of 104 dBA is evidently higher than the newly specified limit of 102 dBA. Therefore, noise control actions need to be determined in a systematic fashion.

3.1.2 Spectral Analysis of Exterior Noise

Spectral analysis of exterior noise emitted by backhoe loader, which is the second step in the developed methodology, is performed to identify the noise sources.

Exterior noise is measured at four sides of the machine, front, rear, left and right. Right and left measurement points have a distance of 5 m to the machine center, while front and rear ones are located 8 m from the center.

Frequency spectra of sound pressure at four sides of the machine are recorded between 0 and 2.8 kHz, in 1/24 octave bands. The microphone is placed on a microphone stand at 1.2 m height off the asphalt surface. Engine revolution speed data is also recorded.

Frequencies correspond to distinct peaks above 60 dBA are compared with known noise source frequencies. This comparison displays dominance of the cooling fan. The rotational frequency of the cooling fan is also evident.

The frequency corresponding to the engine rotational speed of 33 Hz and its harmonics are also observed in the exterior noise spectra. The second harmonic appearing at 65.9 Hz-67.8 Hz is clearly visible owing to its higher energy content.

Spectral analysis of exterior noise emitted by backhoe loader is performed three more times on different dates. Acquired spectra are compared with each other to determine differences in the measurements and to relate the noise sources with engine rotational speed. This ratio is used to compare the four spectra obtained in these tests and to classify the sources in three groups as:

1. Sources related with engine rotational speed
2. Sources not related with engine rotational speed
   a. Aerodynamic
   b. Hydrodynamic
   c. Vibroacoustic
3. Miscellaneous/Unknown Sources

After this classification, the contribution of these sources into overall noise power is calculated to determine the importance of each source. A noise source is thought to be associated with each frequency. If one calculates the ratio of the source contribution into the overall energy or power amplitude, then the importance of this particular source is obtained as well. This calculation is performed by using A-weighted pressure levels at each frequency. $p_A^2{}_{rms}$ ratios (rms squares of A-weighted pressure) are calculated for each frequency. The most significant noise source is identified as cooling fan.

3.1.3 Coherent Output Power Tests

Third step of the noise source identification methodology in this study involves coherent output power tests. In this step, undetermined noise sources are to be identified by coherent output power tests.

Microphone is placed at the left, right and rear sides; the accelerometer is located on the suspected noise sources one by one. Accelerometer and microphone configuration represents a single input single output system, in which input is the acceleration and output is the sound pressure. Power spectra of acceleration and sound pressure, and coherence function between acceleration and sound pressure are recorded. Coherence output power functions of these systems are estimated using coherence and power spectrum function estimates.

Hypothesized SISO systems are listed as:

1- Accelerometer is on hydraulic tank microphone is at left side
2- Accelerometer is on chassis left side microphone is at left side
3- Accelerometer is on engine hood left plate microphone is at left side
4- Accelerometer is on engine hood top plate microphone is at left side
5- Accelerometer is on fuel tank microphone is at right side
6- Accelerometer is on hydraulic pump microphone is at left side
7- Accelerometer is on hydraulic pump microphone is at rear side
8- Accelerometer is on chassis right side microphone is at right side
9- Accelerometer is on engine hood right plate microphone is at right side
10- Accelerometer is on hydraulic valve casing microphone is at rear side

Evaluation of the results of these measurements reveal that coherent output power value at 600 (608, 592) Hz is greater in the configurations numbered 6, 7 and 9 than others and the second harmonic of this source is seen at 1200 Hz at these configurations. Noise source at 600 Hz (its second harmonic is at 1200 Hz) is thought that it could be hydraulic pump due to the highest coherent output power value in 7th configuration. Also noise source at 600 Hz is observed in 2nd, 3rd, and 8th configurations. Consequently, effect of this source is transferred to other parts of the machine like chassis and engine hood. In other words, the vibrational power flows from the source through the assembly of components stated in these three configurations.

Cooling fan blade passage frequency is observed in the 9th configuration.

Another outcome of coherent output power test is the noise source/sources at 1140 Hz and 1150 Hz. These frequencies are observed in the 1st, 2nd, and 4th configurations. The source/sources associated with these frequencies could be speculated as engine originated and effects of these sources are transmitted to the machine chassis through the engine mountings.

3.1.4 Sound Intensity Measurements

Sound intensity measurements are performed to identify vibroacoustic characteristics of engine hood plates and to determine the hydraulic pump working frequency on which information is not available.

Sound intensity measurements are carried on a 2-channel Dynamic Signal Analyzer with the following parameters: Sample record length 125ms, Number of averages: 128, Sampling frequency: 8200 Hz, Window type: Flat Top

Sound intensity measurement over engine hood right plate is shown in figure 2.

Figure 2 Engine Hood Right Plate Intensity Measurement

One can easily states by evaluation of the intensity measurement results that at 296 Hz, at 592 Hz (second harmonic of 296 Hz), at 1008 Hz and at 1144 Hz all engine hood plates (right, top, and left plates) emit high levels of sound energy.

It is also possible to constitute a relationship between results of sound intensity measurements and results of coherent output power tests by examining the frequencies of 592 Hz, 1200 Hz, and 1008 Hz. These frequencies are also observed in spectral analyses of exterior noise emitted by the machine.

3.2 Experiments Related with Interior Noise

3.2.1 Sound Level Determination In Cabin

A-weighted sound level at the operator’s ear position is measured to determine the extent of occupational noise exposure by the operator. Measurements are repeated for static and dynamic test methods. The noise level determination in the backhoe loader’s cabin is performed according to the static and dynamic test conditions described in international standards ISO 6394 [6], and ISO 6396 [7], respectively.

Cabin inside noise level measurements before and after noise control studies are given as, 77.6 dBA and 75.3 dBA, respectively. These values are obtained using experimental techniques described in the standard ISO 6394. These sound levels indicate that a 2.3 dBA noise reduction is achieved inside the cabin.

After noise control, noise level at operator's ear position is measured as 74 dBA according to dynamic test conditions, ISO 6396.

3.2.2 Spectral Analysis of Cabin Interior Noise

Cabin interior noise spectra are measured while the machine is stationary and engine is run at 2000 rpm. Cabin heating and ventilating fan is working at its maximum frequency while these measurements are performed as specified in the standard.

Obtained spectrum implies that cabin heating and ventilating fan is run at 1154.8 Hz. There is 7.1 dBA sound level differences at 1154.8 Hz between cabin fan on and cabin fan off situations.

4. CONCLUSIONS

Comparative evaluation of the results of spectral analyses of exterior noise emitted by the machine with possible noise source frequencies reveals the noise source frequencies, as cooling fan blade passage frequency, hydraulic pump operational frequency, and engine firing frequency in descending order of importance.

Hypothesized single input-single output systems display that hydraulic pump operational frequency might have attained a different value than calculated operational frequency. Estimates for coherent output power and coherence functions indicate that hydraulic valve does not contribute significant amount to the sound level measured at the rear side. Directivity effects can easily be observed from the results of coherent output power tests. In other words, coherent output power values and coherence functions do not provide meaningful results while there is no direct path between input and output, because reflections in due course do occur.

Noise control treatments comprising of replacement of the cooling fan with a quieter one, substitution of the isolation material on the inner side of engine hood with more effective one, covering the openings between the engine hood and the machine chassis to minimize acoustical leaks, are performed. Sound intensity measurements help to clarify the operational frequency of the hydraulic pump. Sound intensity measurements are also used to check the effectiveness of noise control attempts. After replacement of the cooling fan, replacing isolation material inside the engine hood and filling the gaps between the engine hood and the chassis, sound intensity values are reduced by considerable amount, varying from 2 dB to 6 dB with frequency.

A 2 dBA noise reduction is achieved in the airborne sound power level of the machine after noise control studies. Noise treatments also result in a 2 dBA reduction in the noise level at the operator's ear position.

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