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EXPERIMENTAL INVESTIGATION OF THE EFFECT OF INJECTION ADVANCE ANGLE IN DIESEL ENGINE ON ENGINE SOUND

By

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Abstract:

Injection advance angle has a great effect on diesel engine performance, exhaust and sound emissions. An experimental investigation was conducted to acquire enough data and apply acoustic emission analysis techniques in order to analyze engine sound with respect to injection advance angle changing. A single cylinder diesel engine was used and the test rig was equipped with all necessary instruments to measure and record all the needed parameters. Engine sound emission is recorded and analyzed to determine the fundamental frequencies especially those relevant to the combustion process. Measurements were conducted at wide range of variations of injection advance angles and at different engine speeds and loads set by changing the dynamometer readings and fuel pump rack position.

A special mechanism was designed, machined assembled to the injection pump drive coupling in order to enable the setting of different static fuel injection points. Optimum injection advance is 19 degree BTDC (the angle at which engine produces its maximum torque and operate smoothly and is achieved from BMEP calculations), measurements are done at it, before, and after it. A set of four microphone-audio amplifier arrays was used to measure the engine acoustic emission while a PC multichannel data acquisition system was used to collect and record the measured signals. Fast Fourier transform is applied on the combustion sound signals to get the amplitude-frequency relations at different operating conditions. The results show remarkable changes of these relations with the injection advance angle. Too early or very late injection advance angles result in irregular and rough engine operation.

Keywords: Injection advance angle, BMEB: brake mean effective pressure, BTDC: before top dead center

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Introduction

Acoustic measurement can be performed at a distance from the engine, avoiding safety risks and obviating the need for high-temperature vibration testing equipment with its associated mounting considerations. Yang et al [4], concluded that instantaneous angular speed is closely related to the gas pressure in the cylinder and the power and torque acting on the crankshaft. Thus, the diagnosis of the combustion-related faults, which affecting the gas pressure, by analyzing the instantaneous angular speed is desirable. Breda Kegl [9] discusses the influence of timing set up of the injection pump on performance characteristics of a diesel engine working with biodiesel.

The main object of this work is to determine the optimum injection timing with respect to engine harmful emissions while keeping the other characteristics at acceptable levels. Hao Zhi-yong et al [3] analyzed the major sources of engine front's exterior sound emissions using continuous wavelet transform analysis (CWT). They made characterization of engine sound sources depending on the time of occurrence of such sounds (events) in the engine cycle. After the measurements were conducted, the analysis task was to determine the sources of various components because of, an efficient sound control strategy for an engine, needs to identify the strongest sound sources first. The results show that the major sound energy frequency (fundamental frequency) is around 100 Hz and 200 Hz, respectively and signals response to engine combustion can be found from 200 to 600 Hz.

TEST STAND DISCRIPTION

The experimental work was conducted on a complete test stand for testing a naturally aspirated and direct injection diesel engine (Duetz F1L511). The test stand includes a single cylinder diesel engine and the needed instrumentations to measure and record the operating parameters. An acoustic measuring system was employed to record and analyze the engine sound and a data acquisition system was also furnished to enhance the speed and accuracy of collecting and recording data. Software was developed to manage the measuring process and perform the analysis.

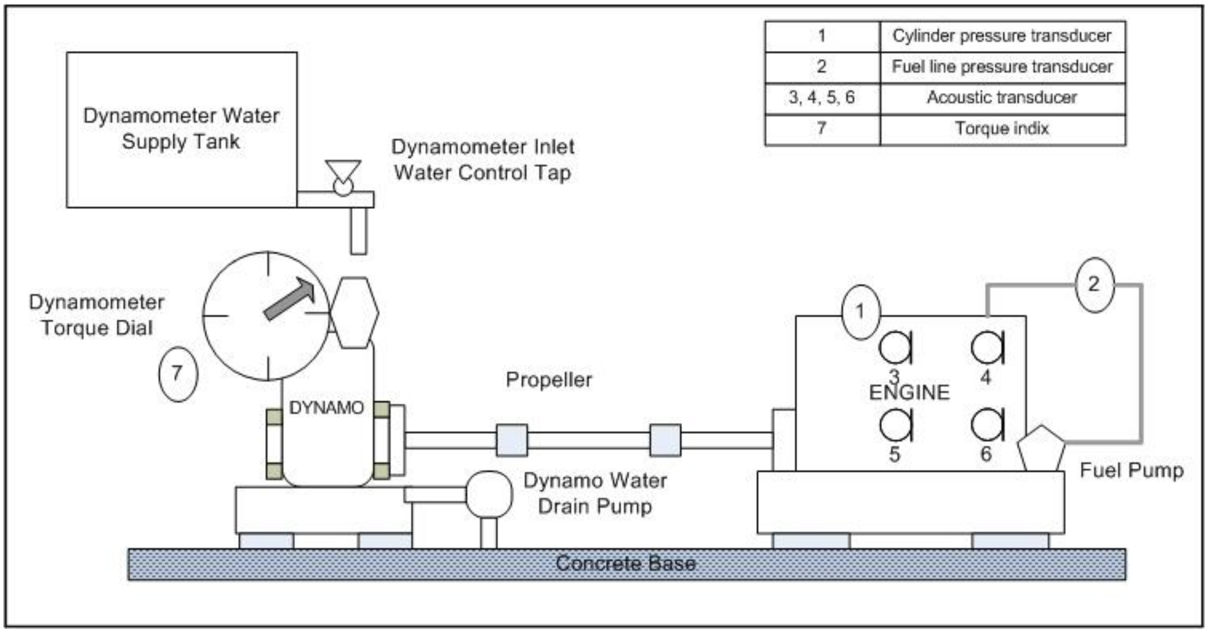


Fig.(1) Schematic drawing of the test rig

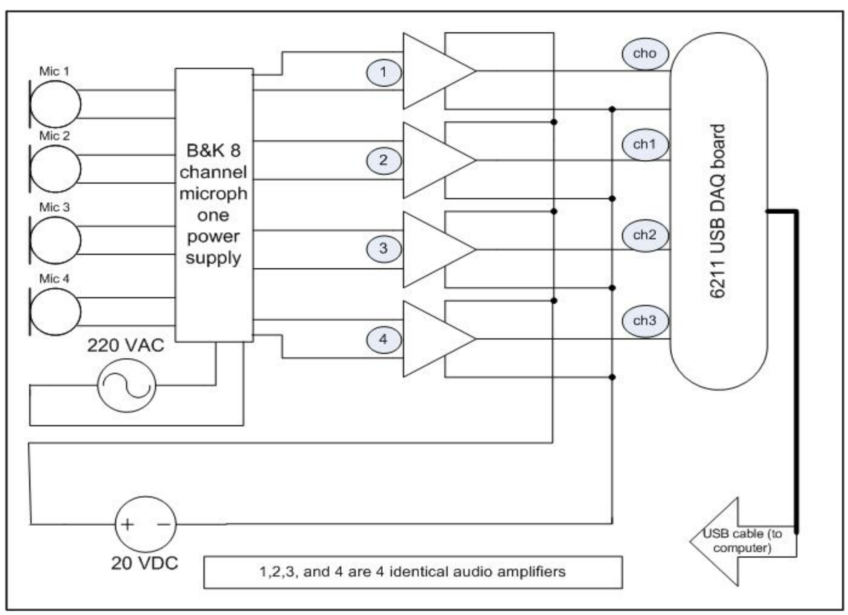


Fig. 2 Schematic diagram for the acoustic measurement system

INJECTION PUMP DRIVING MECHANISM

This mechanism consists of 2 helical gears the first one is the crank gear which has 33 teeth, the second is the pump gear with 66 teeth. To change the injection angle via changing the gear meshing with 1 tooth this will shift the injection angle by 1\66*360 = 5.45 crank degrees and this value is not suitable so, a modification in this mechanism was carried out by changing the coupling between the pump cam gear and the pump cam shaft.

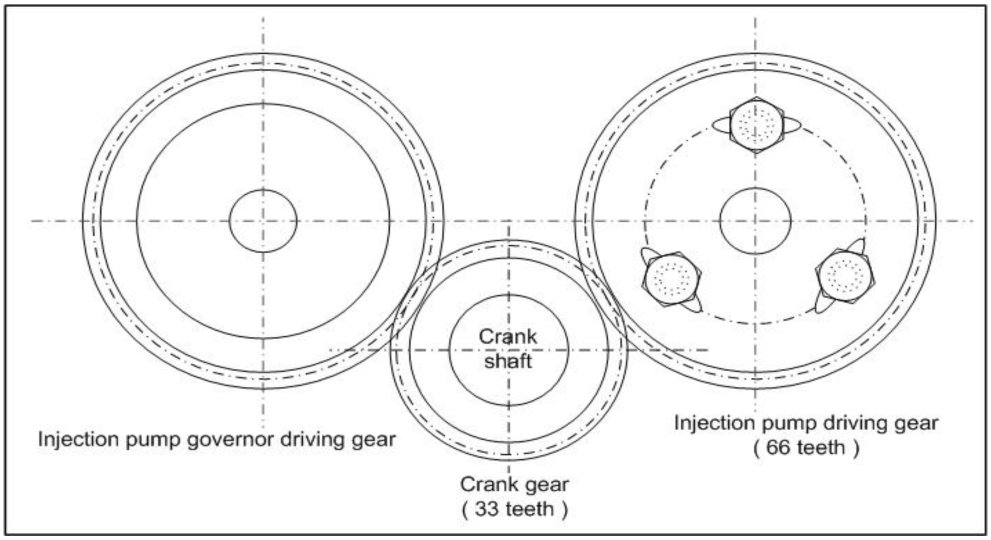


Fig.(3) Injection pump driving mechanism

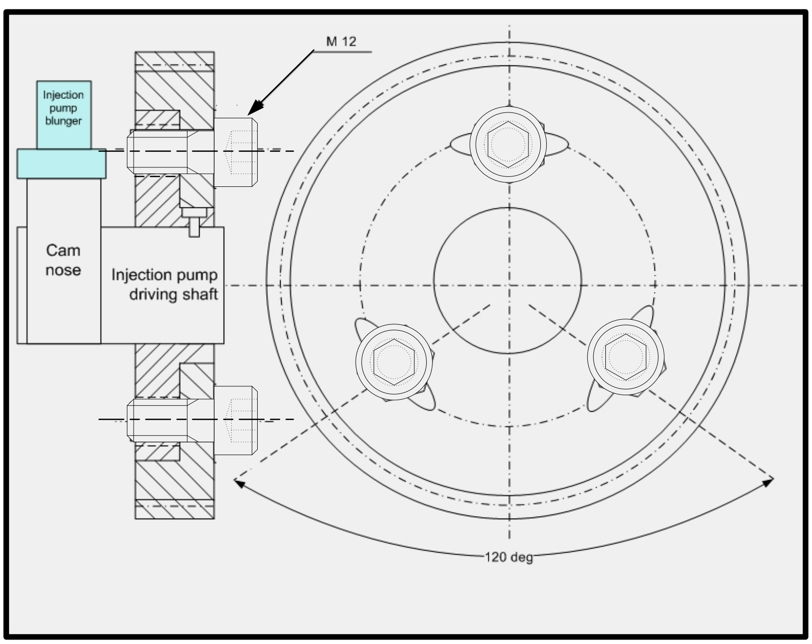


Fig.(4) Injection pump driving gear

STEPS OF TESTING

1. Starting the engine and adjusting the engine injection pump rack at its full position, after defining the TDC position.
2. When the engine is steadily running, dynamometer load is applied gradually by controlling the water throttle until the engine speed reaches 500 rpm and become steady.
3. Starting the measuring instruments (4 audio channels, combustion and injection pressures) from the testing software. The program will record the engine sound

pressures, combustion and injection pressures data relative to the crank shaft angle.

4. FFT is applied on the engine combustion sound signals (after splitting them) using the software for average 20 engine cycles to define the combustion sound fundamental frequencies.
5. The combustion sound frequency is defined as the one gives max sound pressure on the location of the combustion chamber.
6. Defining the injection start angle from the injection pressure curve (the end of the static pressure) fig.(4).
7. Taking the average combustion sound frequency from the 4 FFT curves (for every microphone). Then computing the engine BMEP and power from the measured data.
8. Recording the measured and computing data (injection start angle, average combustion and injection pressures, combustion sound frequency and amplitude, max combustion pressure position, engine torque, power, and BMEP) in excel files.
9. Changing the engine load until reaches 600 rpm and repeating steps from 4 to 9.
10. Repeating the same procedures (4 to 9) for engine speeds (700, 800, 900, 1000, 1100, 1200, 1300, 1400, and 1500 rpm).
11. Changing the engine injection start angle again for another 8 angles and repeating the test.

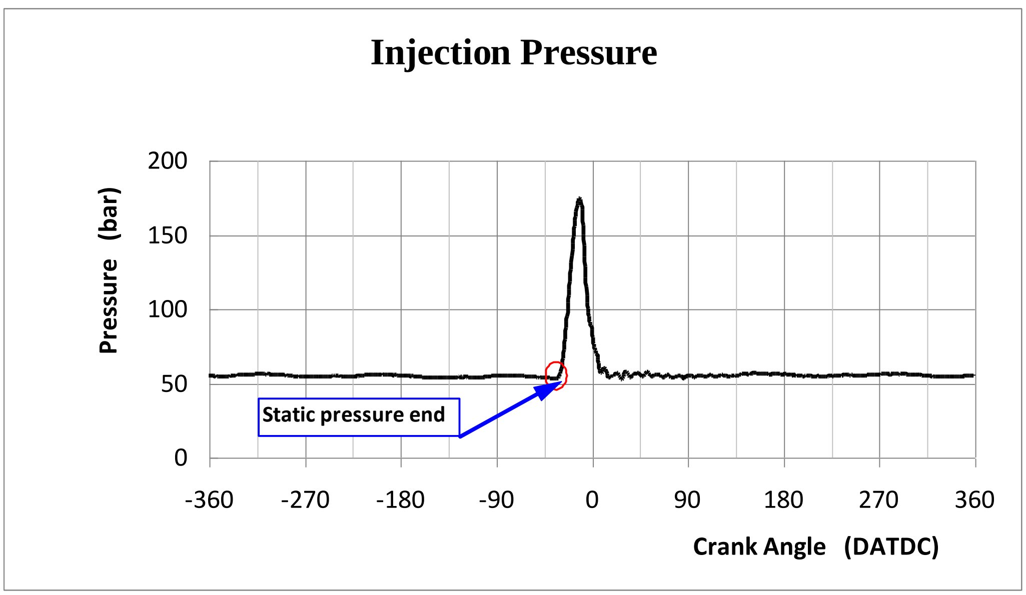


Fig.(5) Injection Start Angle

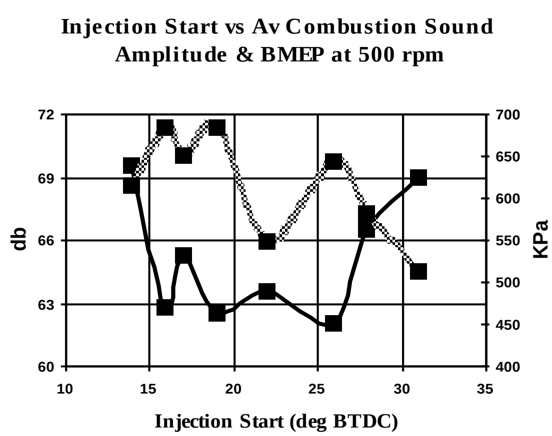
RESULTS AND DISCUSSION

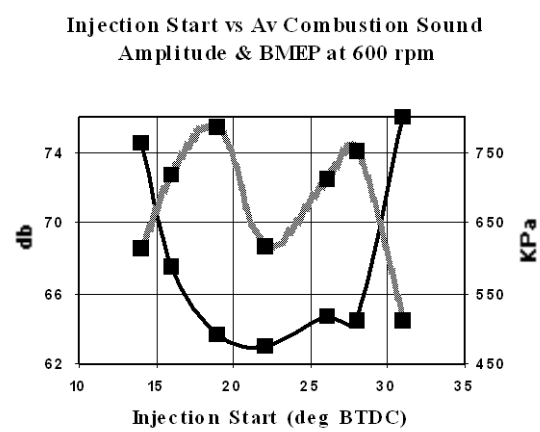
1. Effect of injection advance angle on BMEP and combustion sound amplitude:

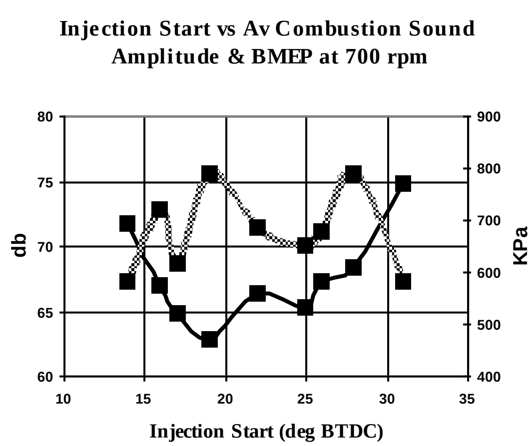
The variations of the BMEP and the combustion sound amplitude at the fundamental frequency with the injection advance angle at different engine speeds are shown in fig. (6). Setting the injection point at crank angle less than 16 DBTDC results in irregular engine running and loss of power. This can be deduced from the plots where the drop in BMEP accompanied by a sharp increase in sound amplitude become apparent. This trend is confirmed at nearly all engine speeds and is attributed to short ignition delay periods that results in slow diffusion burning during the expansion stroke.

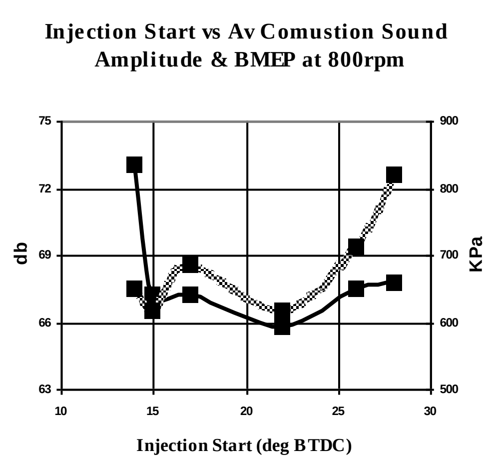
The engine torque (BMEP) rapidly drops in all cases when the injection timing is advanced more the 27 DBTDC. This is attributed to physical and chemical delay periods being long enough so that the premixed combustion dominates the fuel burning period. The early start of combustion with limited diffusion burning results in diesel nock and rough operation, with higher sound amplitude. Further advanced in injection timing may result in extreme irregularities in engine operation as most of the fuel is burnt before the engine reaches the TDC. This effect, as the figure shows, is reflected in lower BMEP accompanied by higher sound amplitudes.

The BMEP is at its highest level with the injection advance angle set to nearly 19 DBTDC. The figures show that the sound amplitude at this point is almost minimum at all operating conditions. The following figures showing the effect of changing advance angle on BMEP and combustion sound amplitudes at fundamental frequency.









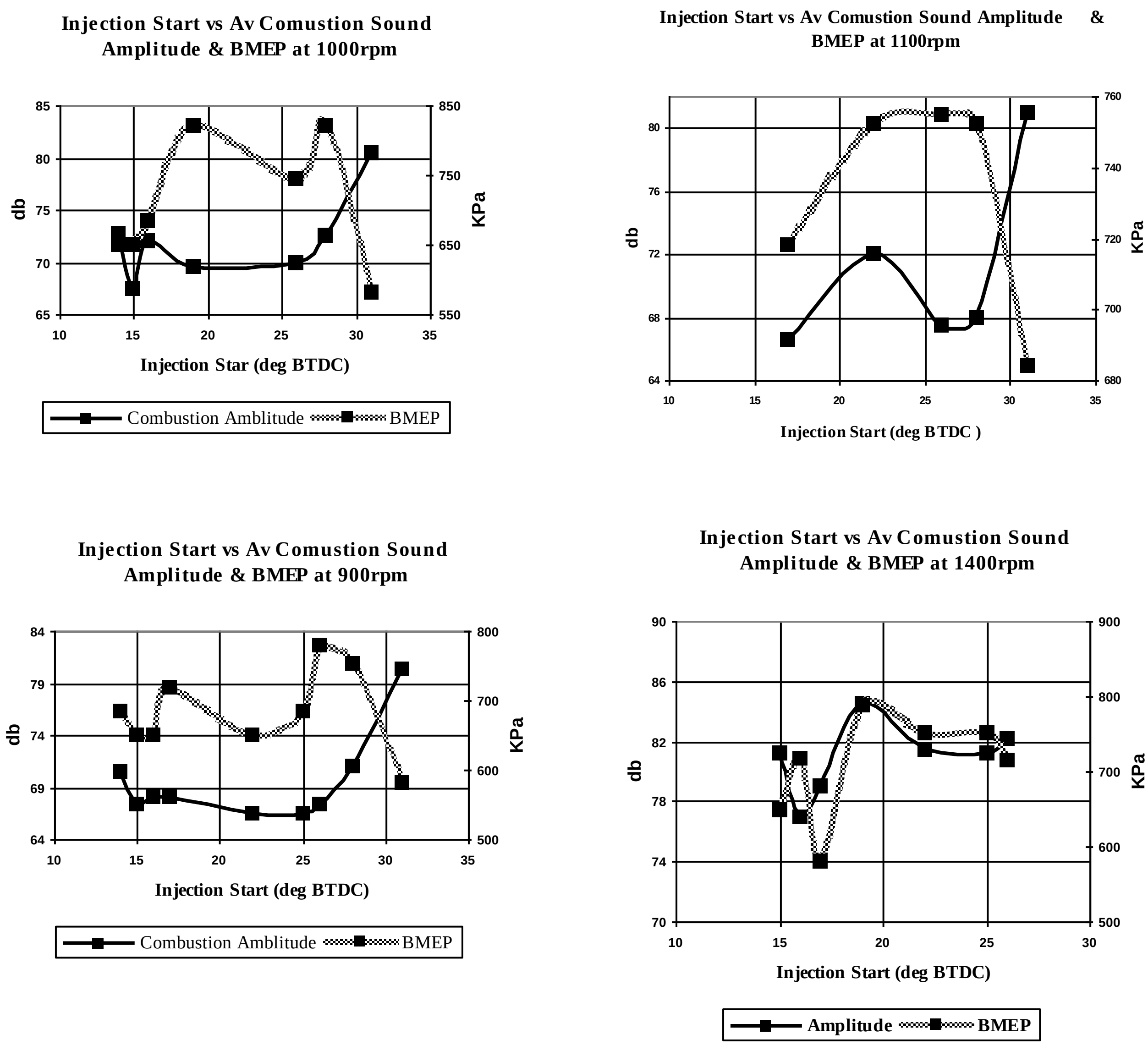


Fig.(6) Changing of combustion sound amplitude and BMEP with injection advance angle

CONCLUSION

Setting the injection point at crank angles less than 16 DBTDC results in irregular engine running, loss of power and sharp increase in sound amplitudes. This was obtained at all operating conditions and is attributed to short ignition delay periods that result in slow diffusion burning during the expansion stroke.

The engine torque (BMEP) rapidly drops at all operating conditions when the injection timing is advanced more than 27 DBTDC. This is due to physical and chemical delay periods being long enough so that the premixed combustion dominates the fuel burning period. The early start of combustion with limited diffusion burning results in diesel nock and rough operation, with seemingly higher BMEP. Further advancing in the injection timing may result in extreme irregularities in engine operation as most of the fuel is burnt before the engine reaches the TDC. This effect is accompanied by higher sound amplitudes. The injection advance angle, in the feasible range of 17 to 26 DBTDC, has the following effects:

1. Sound amplitudes at the fundamental frequencies are higher with retarded injection (less than 17 DBTDC). The lowest amplitudes are noticed when BMEP is at its maximum. Increasing engine speed seems to reflect on increasing the sound amplitude especially.
2. Sound amplitude, in the feasible range of advance angle, only changes within several dB. This makes it difficult for the human ear to notice the difference especially under the noisy conditions of engine running. Therefore, using the microphone sets and the procedure presented in this work provides a potentially accurate method with high resolution.

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