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# THE ACOUSTIC PERFORMANCE OF EXHAUST SILENCER COMPONENTS AND THE INFLUENCE OF CAR SPEED ON SILENCER PERFORMANCE

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## ABSTRACT

In all the internal combustion engines whether fitted on trucks, tractors, buses, cars or motor-cycles etc. it is necessary to have exhaust gases let out to the open away from the passengers and driver with less sound. This paper introduces an experimental study has been carried out to investigate the acoustic performance of exhaust silencer components. In particular, the performance of the open exhaust pipe, the expansion chamber, and the resonator at different engine speeds and loads is outlined. The influence of car speed on the acoustic performance of exhaust silencer also has been investigated. Exhaust noise spectra were recorded and the overall noise level were measured.

## INTRODUCTION

Exhaust noise emitted by vehicle engine makes a very noisy and unpleasant environment, and it is one of the major contributors to vehicle noise(1,2). Owing to developments in engine power and performance, the exhaust noise is constantly increasing, and it is also changing continuously both in intensity and quality due to the operation of the engine over a wide speed and load range. Quite rightly considerable efforts are being made to reduce the level of exhaust noise to a more comfortable level, and engineers hope to get exhaust noise down to 65-68 dBA for trucks of the next decade. Fortunately by suitable exhaust system design this problem can be solved without much expense, or increase in exhaust back pressure which could affect engine performance, gaseous emissions and degrades fuel economy(3,4). And the modern exhaust systems attenuate sound to such an extent that other components of vehicle noise tend to predominate.

The exhaust gases after having passed out of exhaust valve find their way out to exhaust silencer via exhaust manifold and exhaust pipe. The silencer reduces the temperature of exhaust gases, damps down its sound, and controls the back pressure. From the acoustic point of view the silencer is a broad band filter with a maximum attenuat required in the range 100-500 Hz, the noisiest part of exhaust spectrum(5,6). The attenuation requirements vary

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from engine to engine, but may reach a 1000-fold decrease in the acoustic power. This attenuation is achieved by allowing the exhaust gases to expand in various chambers built in the silencer. Due to more space available for expanding, the exhaust gases loose the velocity and loose their temperature too (7). This work presents an experimental investigation has been carried out to study the acoustic performance of exhaust silencer components. In particular, the performance of open exhaust pipe, absorption expansion chamber, and absorption resonator at different engine speeds and load is outlined. Car speed influence on the acoustic performance of the exhaust system also has been investigated.

## EXPERIMENTAL WORK

The overall noise levels and the spectra of exhaust noise emitted from silencer components of a car has a four-stroke four-cylinder petrol engine with a capacity of 1500 cc have been measured and recorded. The measurements were carried out using 0.5 in. Bruel&Kjaer condenser microphone type 4166 where its signal was fed into a Bruel&Kjaer precision sound pressure level meter type 2209 with connected fast Fourier transform analyser type 2033 works in the real time and Bruel&Kjaer x-y recorder type 2308. A suitable test site has been organized and consists of a level hard material, flat surface, free from grass, loose soil, and ashes. It is also an open space free from large reflecting surfaces within 4.0 meter radius from microphone location. The exhaust outlet open pipe (tail) used in this work was straight and the height of its flow axis above the ground was 0.25 meter. The microphone of the sound level meter is located at a distance of 0.5 meter from the exhaust pipe outlet with its axis has an angle of 45 degree to the flow axis where microphone sensitivity is maximum (8) and at the same height as the axis of gases flow. A complete description for the instrumentation system, their function and operation can be found in (9).

Before testing, the sound level meter had been calibrated using a Bruel&Kjaer sound level meter calibrator type 4220 which is accurate to 0.5 dB, and a calibrated engine speed measuring device of photoelectrical pick-up along with engine tachometer was also used, it is accurate to 100 rpm at 4000 rpm. The sound level meter was set for slow dynamic response, figure (1) shows the instrumentation system used and microphone location. During the measurements, exhaust silencer components which are used in this study and are shown in figure (2), were suspended on resilient vibration absorbing mountings. The background noise level and exhaust silenced engine noise level, were low enough to have no effect on the measured results and no correction of the results due to these noise was necessary. The engine was kept at normal operation temperature, the engine speed was slowly increased from idle speed to the required speed, held constant at this speed for sufficient time to obtain a sound level meter reading. The location of the observer relative to the meter was according to instrument manufacturer's specification.

Exhaust noise measurements and recording were carried out with; the original round curved exhaust pipe of the silencer which has an approximate length of 2.5 meter, exhaust pipe has length of 4.5 meter to be equivelant to the total length of car silencer approximately, car silencer without resonator, and complete exhaust silencer.

To study the cooling effect of car speed on silencer acoustic performance, the silencer is provided with a calibrated thermocouple close to its end to determine the outlet exhaust gas temperature, and it is placed in water-cooling tunnel, figure (3). Then exhaust noise spectra as well as the overall noise levels are obtained without cooling-water first, and with water flow-rate always adjusted to give $30 \pm 2\,^{\circ}C$ reduction in exhaust gases outlet temperature. After ,the silencer is surrounded with air-cooling tunnel, figure 3, where the velocity of air is controlled through the inlet gate of the blower and its values are calculated from the readings of the manometers which are placed at different positions through the tunnel. Figure 4, shows the reduction in exhaust gases outlet temperature against air maximum velocity through the tunnel.

## RESULTS AND ANALYSIS

The spectra and the overall levels of exhaust noise emitted at different engine speeds without external load, and at different engine load at 2000 rpm engine speed are shown in figures 5 to 12. From these figures it can be seen that, the noise level at any frequency as well as the overall noise level are slightly increased if the speed of the engine is increased but below 2000 rpm and they are markedly increased when the speed is increased above 2000 rpm. These levels are remained almost constant with engine load increasing up to about sixty percent of engine full load, and they are only slightly increased when engine load is increased greater than this percentage. The overall noise level, $I_o$, can be expressed as a function of engine speed, N, rpm as follows:

| | | N, less than 2000 rpm | N, greater than 2000 rpm |
|---|---|---|---|
| with the original open exhaust pipe, $I_o$, | in dB ≃ | 11.5 log N + 69 | 33.5 log N - 3.5 |
| | in dBA ≃ | 14.5 log N + 47 | 50 log N - 70 |
| with the extended open exhaust pipe, $I_o$, | in dB ≃ | 10 log N + 72 | 37 log N - 17.5 |
| | in dBA ≃ | 13 log N + 50 | 54 log N - 85.5 |
| with the expansion chamber, $I_o$, | in dB ≃ | 98.5 | 26 log N + 13 |
| | in dBA ≃ | 13 log N + 36 | 49 log N - 83 |
| with complete silencer, $I_o$, | in dB ≃ | 95.5 | 19 log N + 33 |
| | in dBA | greatest influence at about 1500 and 3500 rpm | |

Therefore, the reduction in the overall noise level, $\Delta I_o$, as a function of engine speed, N, rpm is:

| | | N, less than 2000 rpm | N, greater than 2000 rpm |
|---|---|---|---|
| due to exhaust pipe length increase, | in dB ≃ | 1.5 log N - 3 | - 3.5 log N + 14 |
| | in dBA ≃ | 1.5 log N - 3 | - 4 log N + 15.5 |
| due to the expansion chamber, | in dB ≃ | 11.5 log N - 29.5 | 7.5 log N - 16.5 |
| | in dBA ≃ | 1.5 log N + 11 | log N + 13 |
| due to resonator, | in dB ≃ | 3 | 7 log N - 20 |
| | in dBA ≃ | from 2 to 5 | |
| due to cooling, | in dB ≃ | 1.5 | 1.5 |
| | in dBA ≃ | 1.5 | 1.5 |

As engine load increases greater than sixty percent of engine full load, the value of $\Delta I_o$, increases with the extended exhaust open pipe and the resonator, but it decreases with the expansion chamber. Also the effect of cooling on the level of exhaust noise is diminishing with engine load increasing.

## DISCUSSION

Exhaust noise is a mixture of multitonal noise generated by the valve events and resonances in the pipe superimposed on broad band noise generated by the gas flow. And there is no known accurate method of predicting exhaust noise intensity from a knowledge of engine operational and design data. As might be expected, exhaust noise is a function of valve timing, valve clearance, camshaft design, manifold geometry and many other parameters. Even if the combustion cycle is well defined non-linear sound propagation (high pressure levels) and complex duct geometry (moving piston, moving valves), make accurate calculation impossible in many cases. As a result, exhaust noise must be evaluated either directly for radiated noise measurements, or indirectly, from in-duct pressure or velocity measurements. Therefore, the radiated exhaust noise is measured and analysed using 5 Hz narrow band filtr which is necessary to evaluate the tonal content of the signal.

From exhaust noise spectra recorded with the open exhaust pipe, figures 5 & 7 it can be seen that, the spectrum has a high low frequency content and decreases in level steadily up to frequency of about 400 Hz. Although it would exhibit additional frequency peaks and valleys throughout the mid and high frequency ranges, the levels of these peaks are low. The lower frequency part of the spectrum appears to be due to a resonance effect between the varying capacity of the cylinder and exhaust system as the piston moves in the exhaust stroke, and the area through the exhaust valve as it opens and closes. The high frequency part of the spectrum is due primarily to the rlease of high pressure gas through the exhaust ports. Alteration of engine speed whilst affecting the level of the spectrum at any frequency do not materially influence the pitches of the two parts of the noise. The increase in exhaust pipe length has no effect on the general shape of the spectrum, it causes only a slight decrease in spectrum level as well as in the overall noise level. This reults from the increase in friction and heat loss from exhaust gases, and it increases with engine load increases greater than sixty percent of engine full load, but it diminishs with engine speed increases higher than 2000 rpm, figures 11 & 12.
After fixing the expansion chamber, where the exhaust gases are made to pass from exhaust pipe to a straight-through perforated tube in an outer casing filled with absorbent material, the peaks of high-frequency pressure waves pass out through the perforations into the absorbent material and thereby reduced in magnitude, but may return after some delay out of phase with other peaks. Therefore , these waves are smoothed down so as to give a more or less continuous pressure condition associated with low frequency noise at exit. Also due to more space available for expanding, the exhaust gases loose the velocity and loose their temperature too. Figures 6, 8 & 11 illustrate this influence where noise spectrum level and the overall noise level have been greatly reduced, the reduction in spectrum level was so great throughout mid and high frequency ranges. And the decreasing in the overall noise level was about 16 dBA although it is only 5 dB at 1000 rpm increases to 10 dB at 4000 rpm. With engine load increasing, the decreasing in the overall noise level in dB remained almost constant, figure 12, but its value in dBA is decreased as a result of the increase in the level of the spectrum throughout the mid and high frequency ranges.

The resonator used is quite similar to the expansion chamber, but small in size, it has a central perforated tube in an outer casing filled with absorbent material. It can be considered as an auxiliary expansion chamber to help the main chamber to further reduce the sound intensity and change its quality. By fixing the resonator, figures 6, 8, 11 & 12 show that, the overall level of noise as well as the sound pressure level throughout the low frequency range of the spectrum are considerably reduced at all engine speeds. At certain engine speeds (1500,3500 rpm) and due to resonator tuning to the engine, the sound pressure level throughout mid and high frequency ranges of the spectrum is also reduced, and hence the reduction in the overall noise level was great. When engine load has been increased greater than about sixty percent of engine full load, the influence of the resonator on the level of mid and high frequency noise is increased,and therefore, a further reduction in the overall noise level in dBA was obtained.

Figure 4 shows that, air cooling effect of exhaust gases has been increased by increasing the velocity of silencer surrounding air, the decreasing in the outlet temperature of exhaust gases was about 30 °C at air velocity of about 40 kilometer per hour, And after, this reduction in temperature becomes approximately linearly proportional to air velocity. Hence, the increase in car speed from about 40 to 100 kilometer per hour could cause reduction in the outlet temperature of the exhaust gases from about 30 °C to about 75 °C . But 30 °C reduction in the outlet temperature caused more than 1.5 dBA reduction in the overall noise level,figures 11 & 12, due to its influence on the flow noise of exhaust gases which is almost clear throughout mid and high frequency ranges of the spectrum,figures 9 & 10. Therefore, a reduction of about 3 dBA in the overall noise level of exhaust could be expected at car speed of about 100 kilometer. THis means that, the acoustic power of exhaust gases emitted from the silencer could be reduced to about fifty percent of its original value at high car speed.

## CONCLUSIONS

1 - Exhaust pipe length does not affect noise spectrum shape, and its effect on the overall noise level is little and diminish with engine speed increase.
2 - The absorbing expansion chamber has the greatest influence on noise spectrum shape as well as on the overall noise level, it greatly reduces sound intensity and also changes its quality.
3 - The resonator could be considered as an auxiliary expansion chamber to obtain further reduction in sound intensity and changes its quality. Also it can be tuned to the engine for maximum reduction at certain engine speeds.
4 - Sound damping down properties of silencer increases with car speed increase which causes an increase in silencer surrounding air velocity and hence its cooling effect. The reduction in the acoustic power of exhaust gases emitted from the silencer could be reached to about fifty percent of its original value at high car speed.

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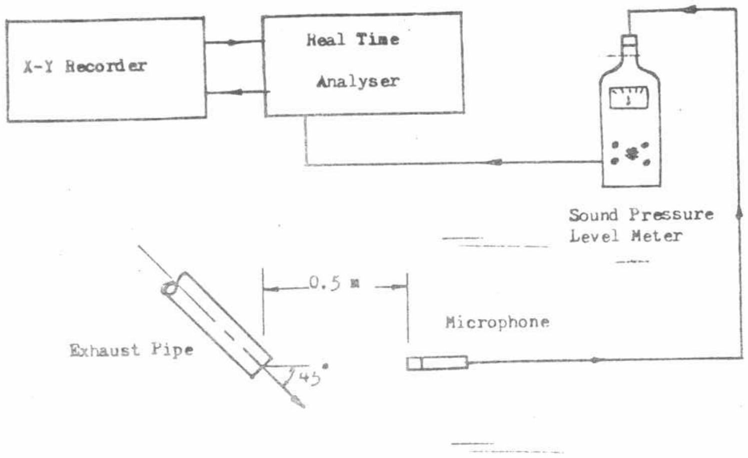



Figure ( 1 ) Layout of measurement and recording instrumentation.

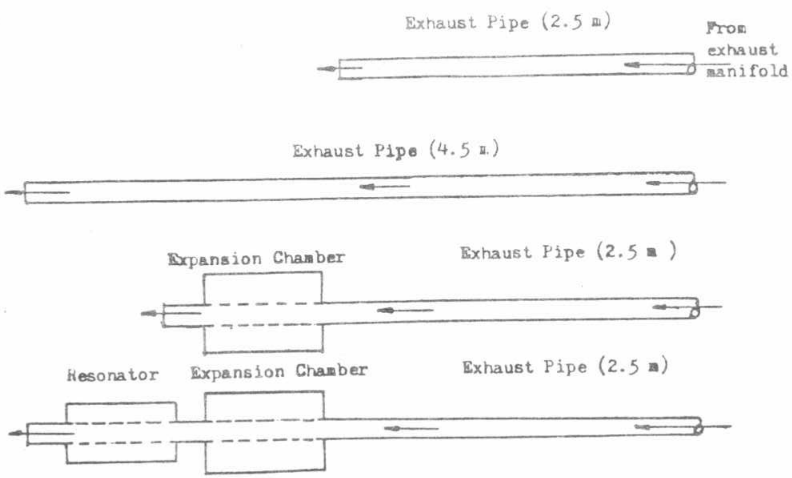



Figure ( 2 ) Exhaust system components under test.

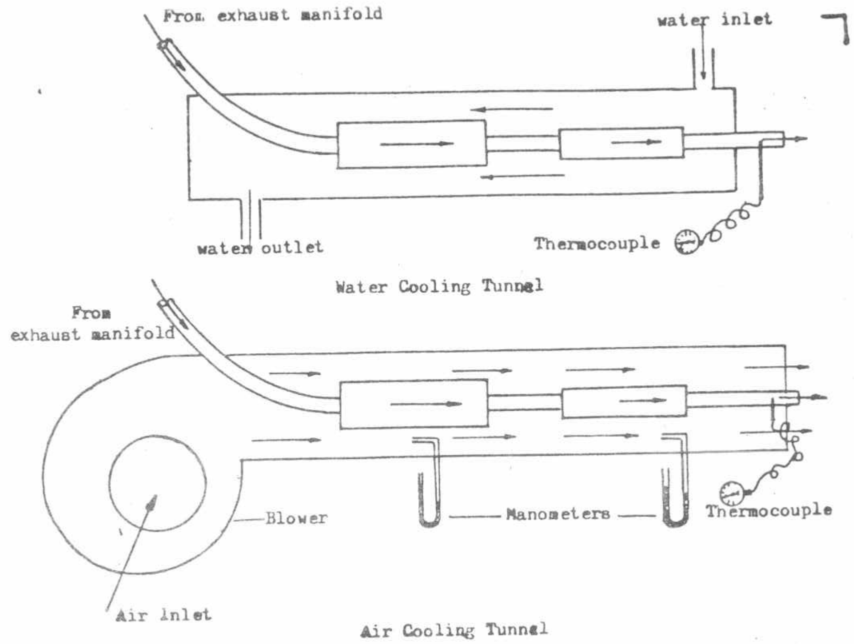



Figure ( 3 ) Cooling Tunnels

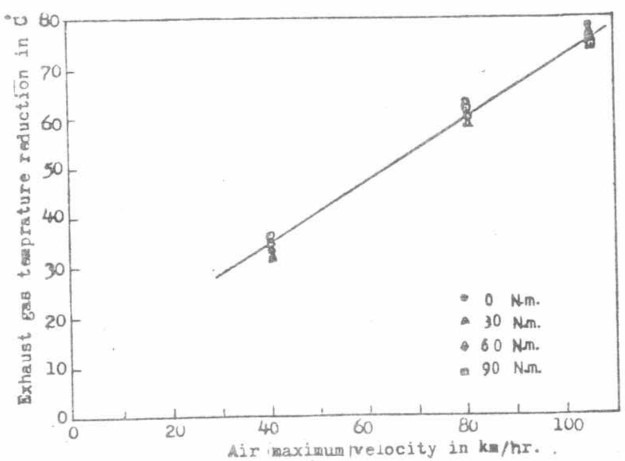



Figure ( 4 ) Air cooling effect at 2000 & 3000 rpm. and at different engine load.

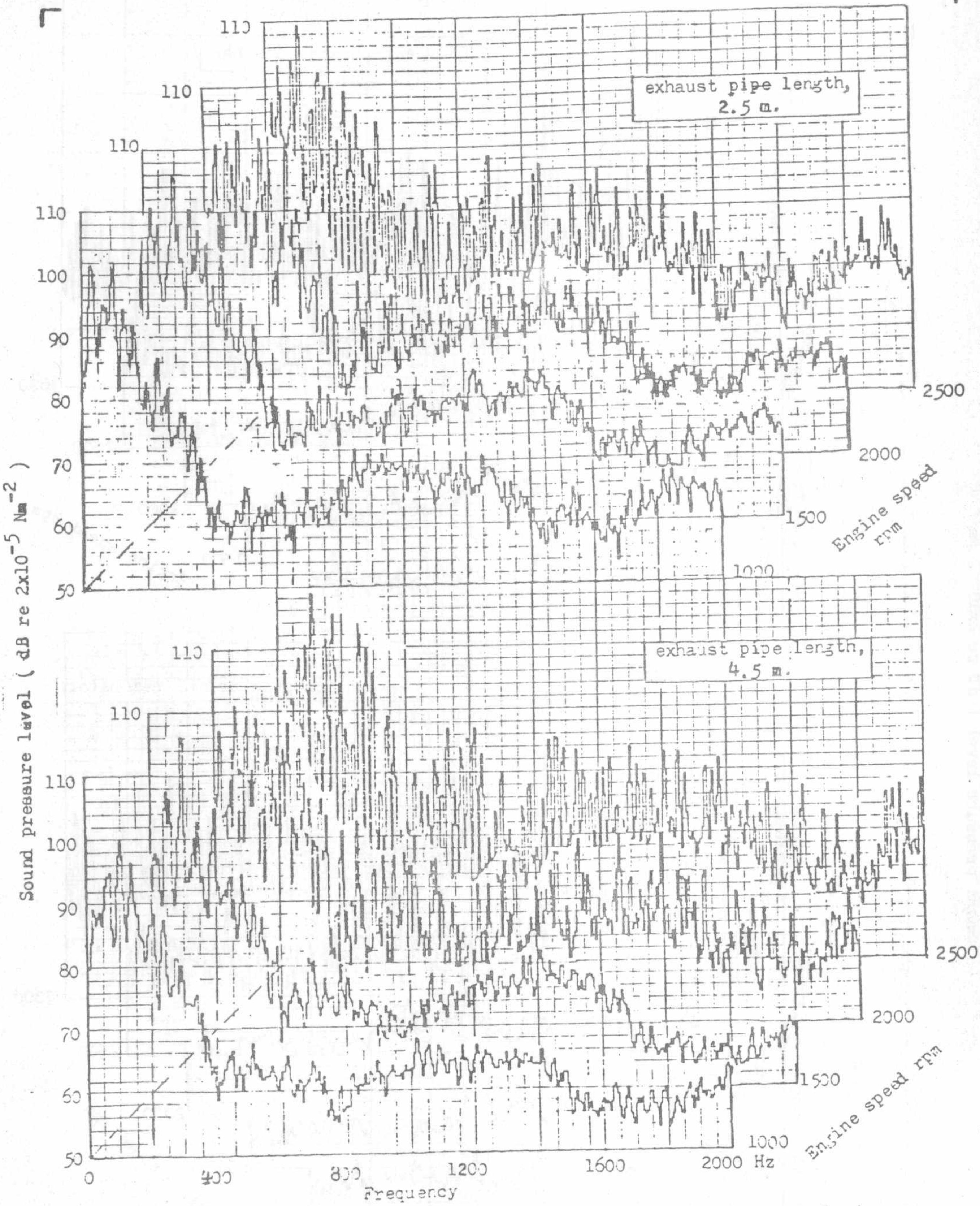



Figure 5 Exhaust noise spectra as a function of engine speed at no load conditions with an open exhaust pipe.

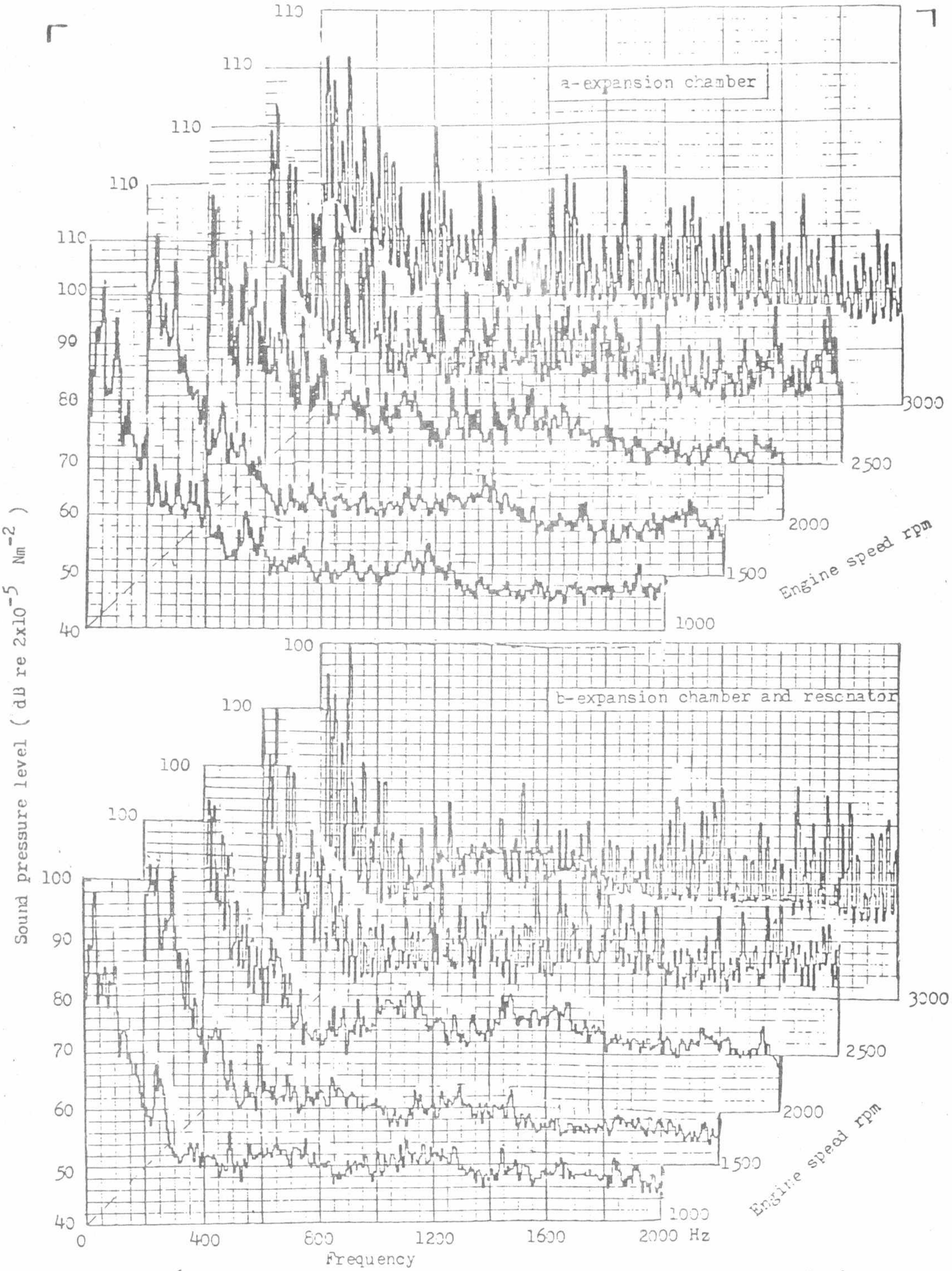



Figure 6 Exhaust noise spectra as a function of engine speed at no load conditions with; a-an expansion chamber
b-an expansion chamber and resonator

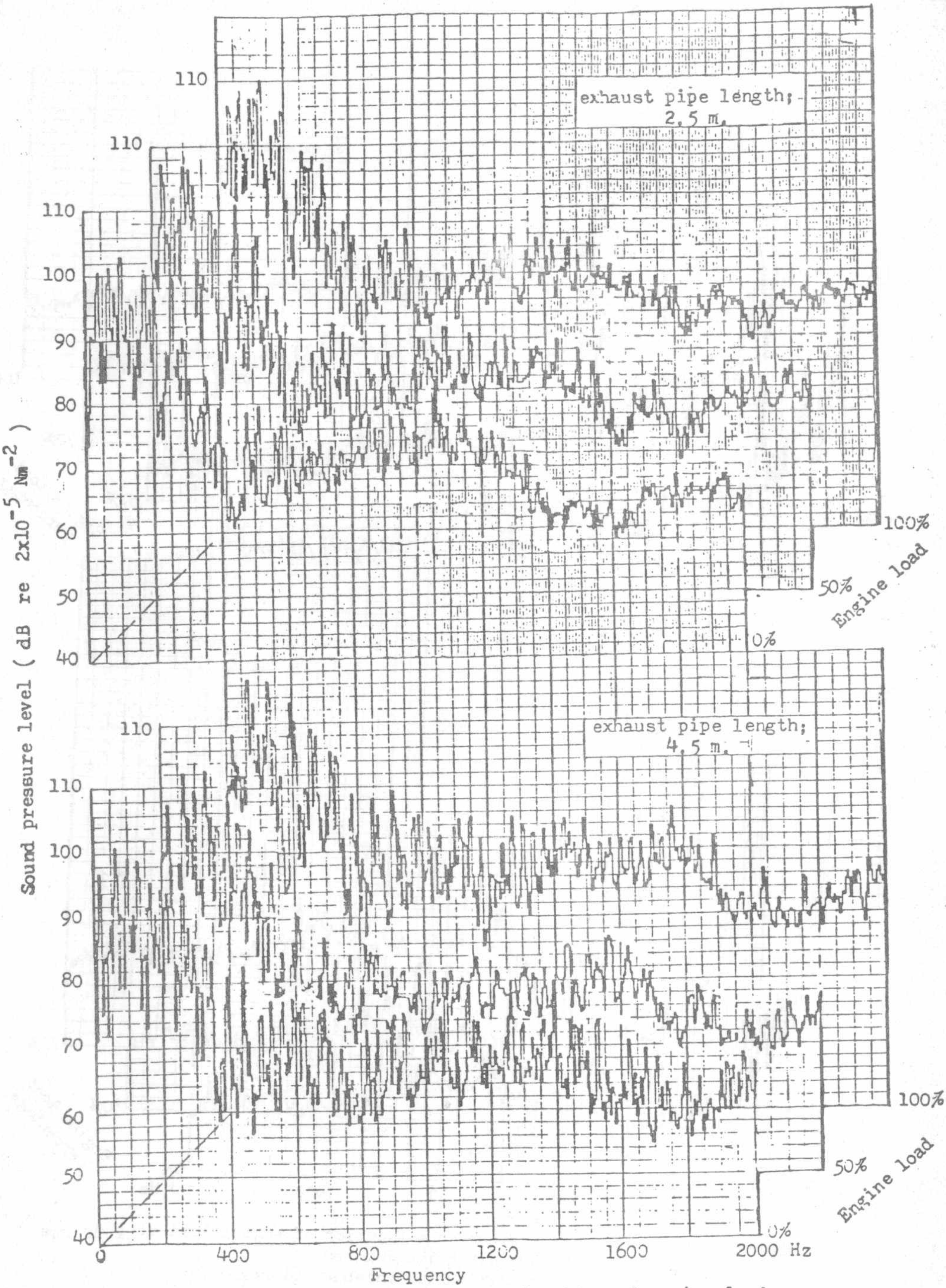



Figure 7 Exhaust noise spectra as a function of engine load at 2000 rpm with an open exhaust pipe.

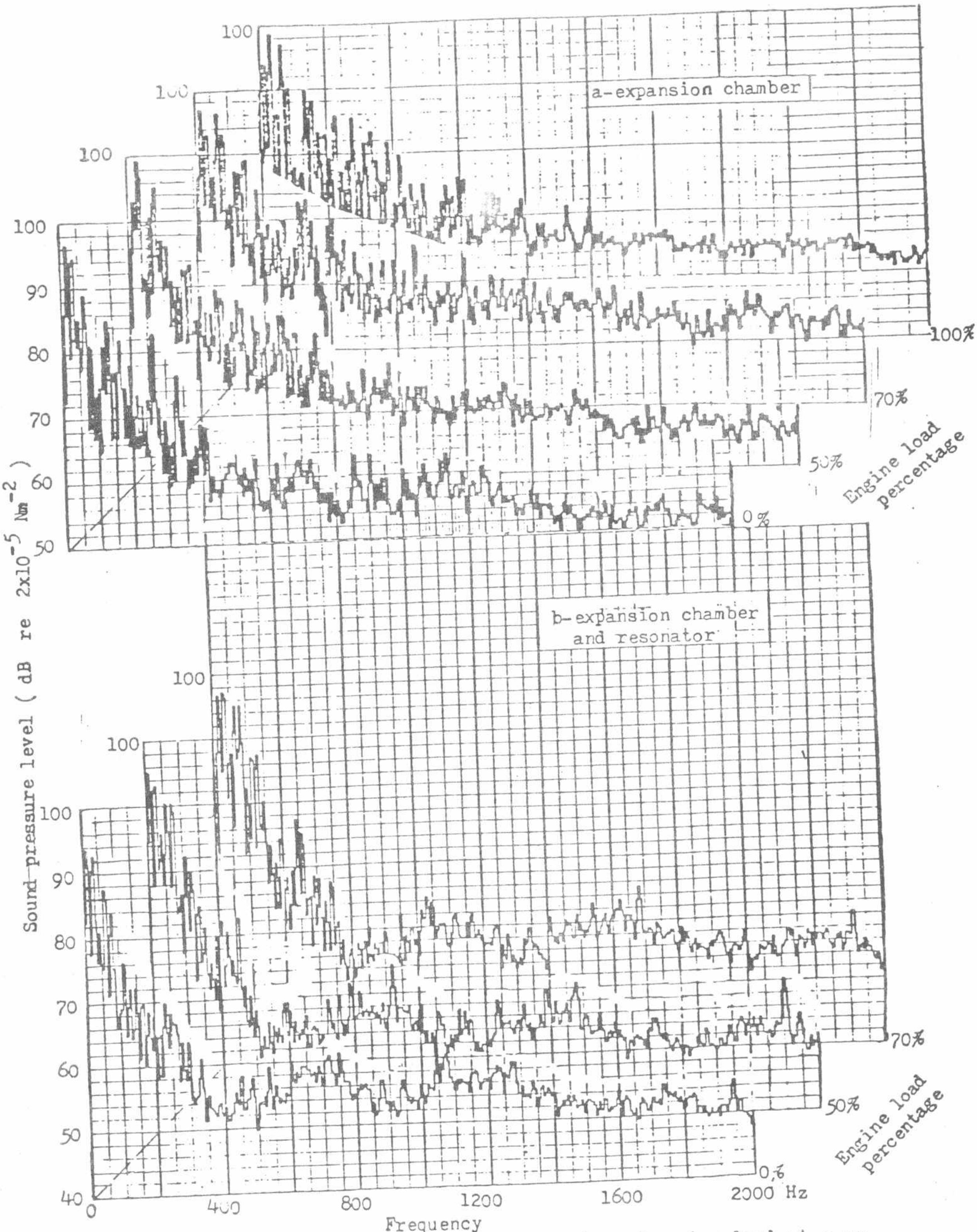



Figure 8 Exhaust noise spectra as a function of engine load at 2000 rpm with; a - an expansion chamber b - an expansion chamber and resonator

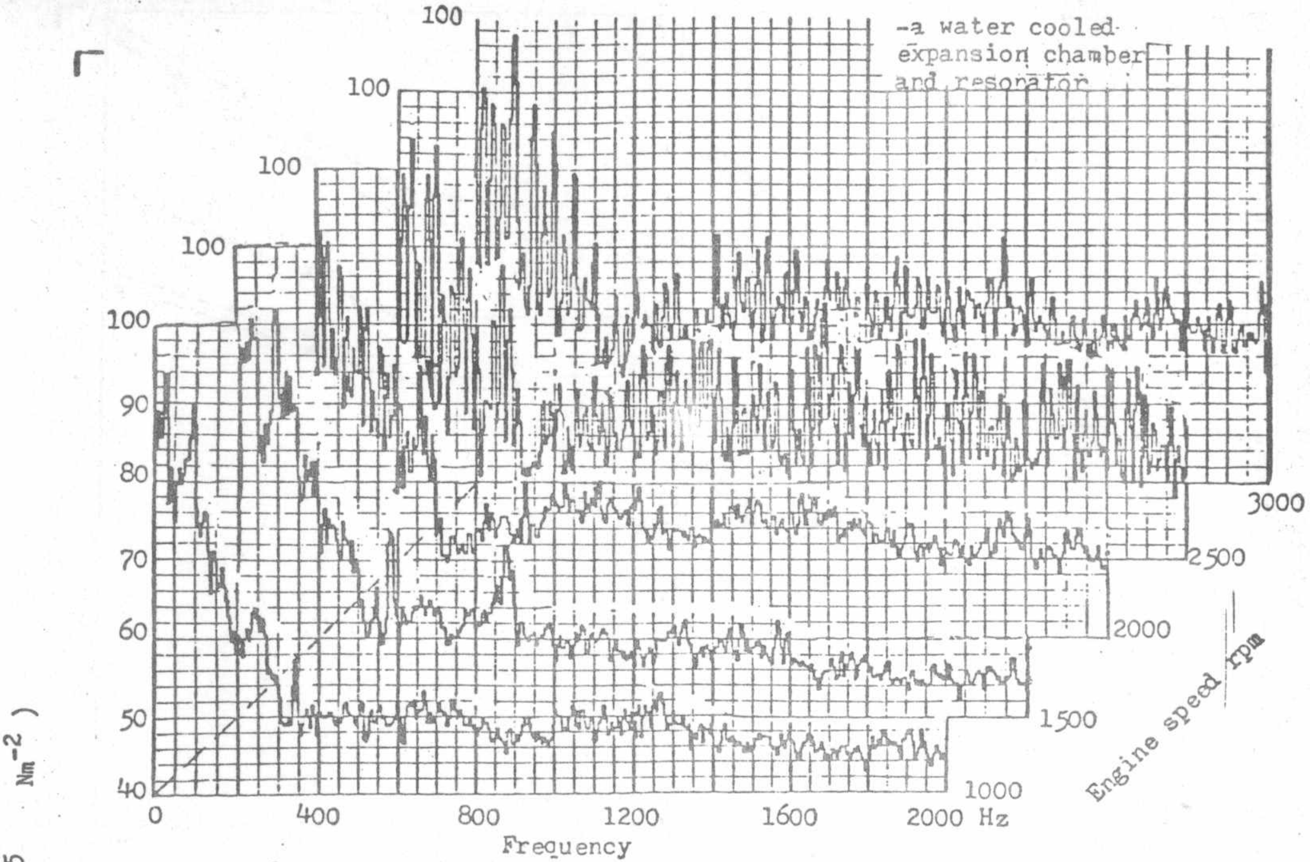



Figure 9 Exhaust noise spectra as a function of engine speed at no load conditions with;
- a water-cooled expansion chamber and resonator

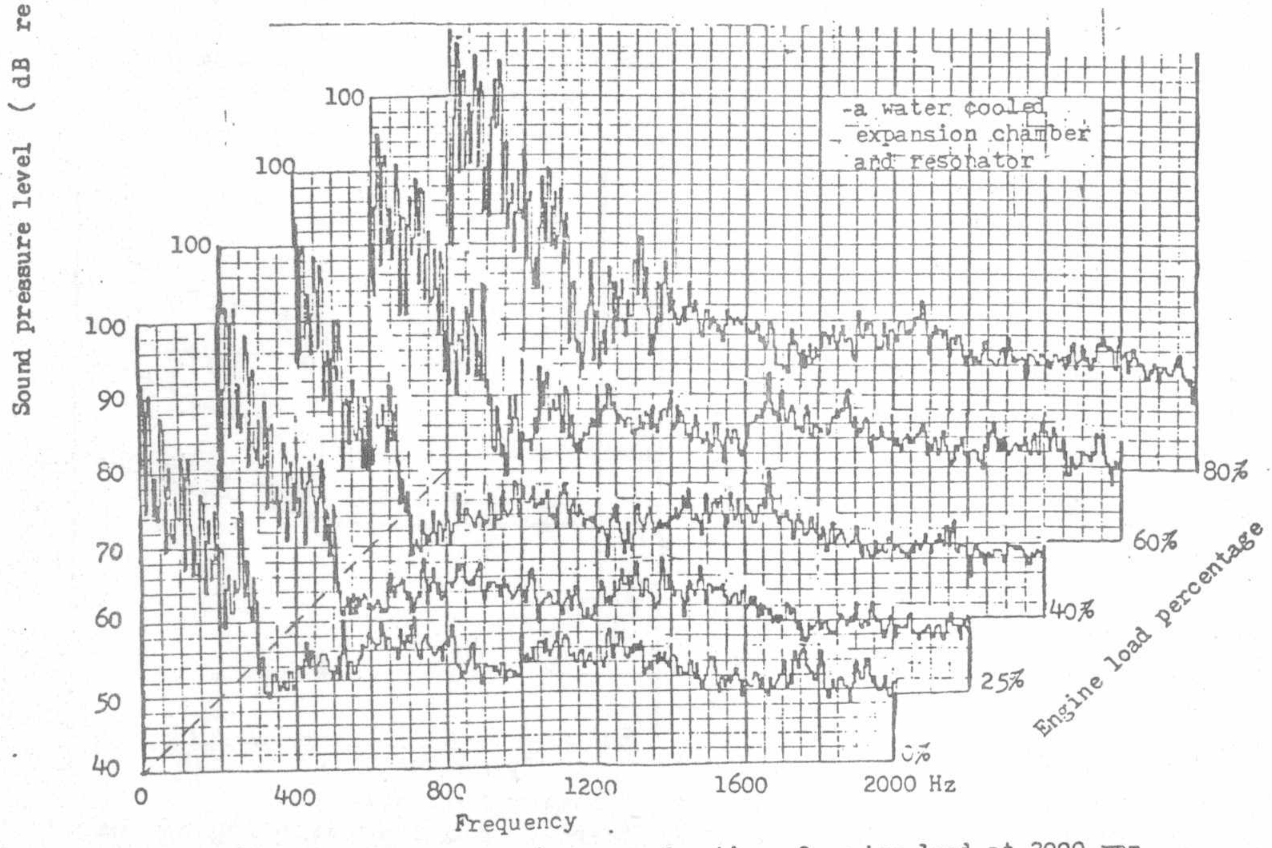



Figure 10 Exhaust noise spectra as a function of engine load at 2000 rpm with;
- a water-cooled expansion chamber and resonator

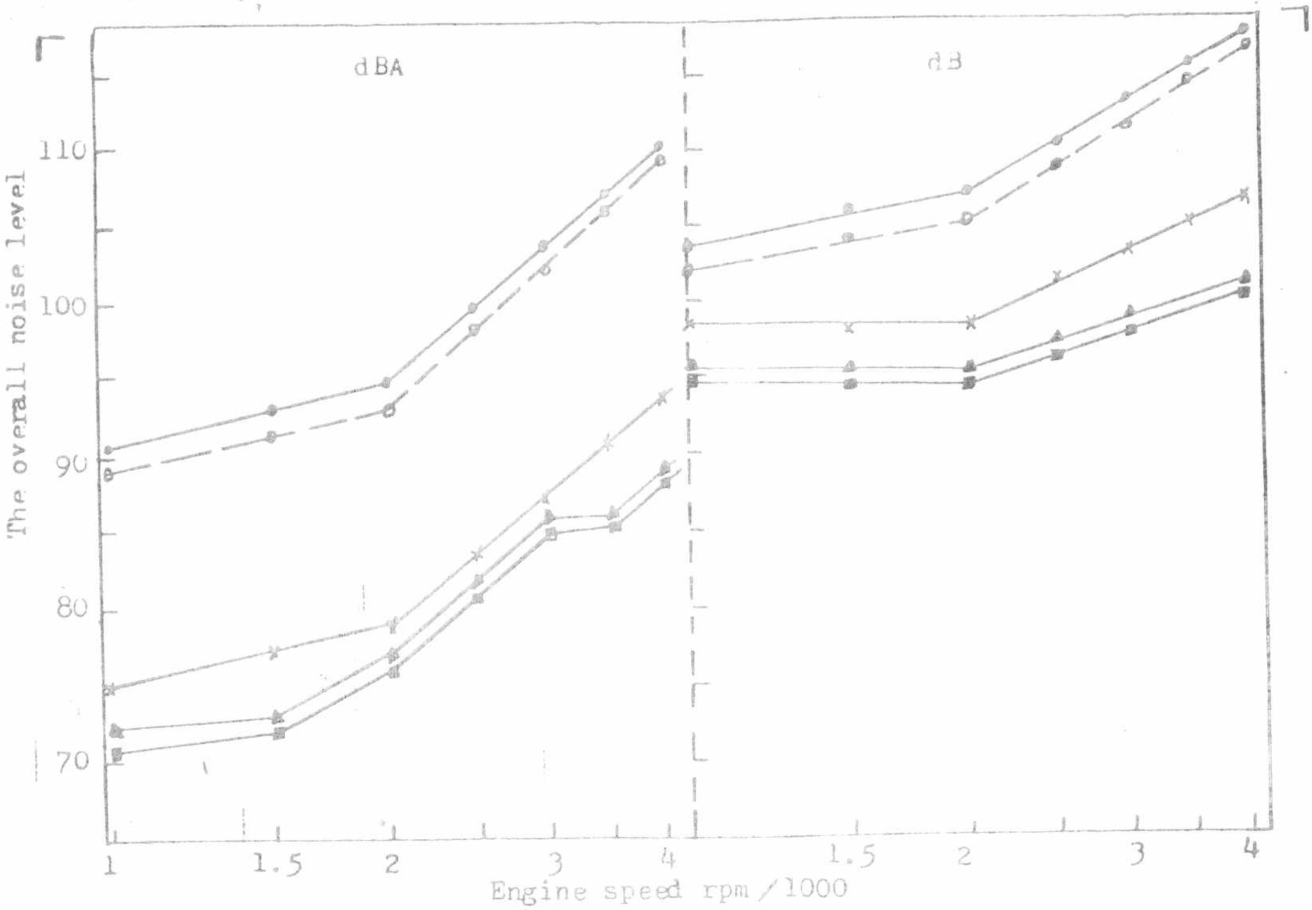
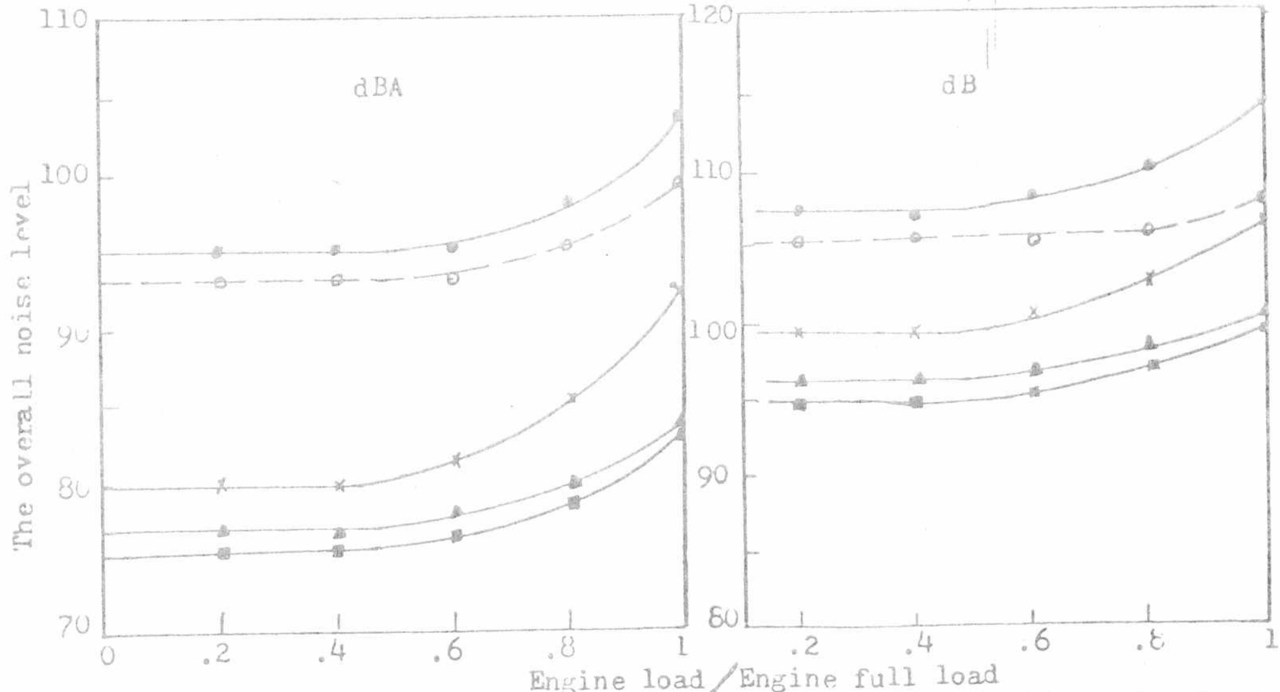



Figure ( 11 ) Variation of overall noise level in dBA & dB with engine speed. —●—●— open pipe(2.5 m), —o—o— open pipe(4.5 m), —x—x— silencer without resonator, —▲—▲— complete silencer, —■—■— water-cooled silencer.




Figure(12) Variation of overall noise level in dBA & dB with engine load. —●—●— open pipe(2.5 m), —o—o— open pipe(4.5 m), —x—x— silencer without resonator, —▲—▲— complete silencer, —■—■— water-cooled silencer.