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ENGINE SUPERCHARGING BY ACTIVE ADJUSTMENT OF MANIFOLD RESONANCES

J.E. FFOWCS WILLIAMS and K. ROUSSOPOULOS

Cambridge University Engineering Department
University of Cambridge
Cambridge CB2 1PZ
ENGLAND

ABSTRACT

The improvement of internal combustion engine volumetric efficiency by inclusion of active elements in the inlet manifold is discussed. An experiment in which the resonant characteristics of the inlet tract are altered is described. The results indicate that such techniques can improve the volumetric efficiency of the engine in the experimental situation by up to 25%.

INTRODUCTION

It has long been known that the inducting efficiency of internal combustion engines is affected by the geometry of the inlet system, which influences the pressure at the inlet valve during the inlet event. Work by Ohata & Ishida (1982) confirms that it is the pressure at the inlet valve during a short period before valve closure which determines the volumetric efficiency of a given engine.

Of interest in this paper are dynamic pressure effects which in general vary with engine speed. These effects have been exploited in order to tune an engine to have torque peaks at particular speeds, although in general this is accompanied by reduced torque at other speeds; see Tabaczynski (1982). In some modern car engines dual intake tracts are fitted, with switching between them occurring at some engine speed, in order to be able to optimise the torque curve over a greater range of engine speeds; details can be found in Kato & Kobayashi (1987) or Isomura *et al.* (1987).

This paper demonstrates the potential for altering the inlet flow without altering the main inlet geometry, but rather by the inclusion of active or resonant elements in the inlet system.

ACTIVE PULSE CHARGING

It is interesting to consider the possibility of supercharging an engine by including active pressure generating elements in the inlet system and having such elements act so as to cause an increase in valve pressure during the critical period before valve closure. For example, it could be possible to place a loudspeaker in the inlet system and generate a pressure pulse timed to arrive at the manifold during this period. If this "brute force" approach to pulse supercharging is followed, the existing pressure waves in the inlet are largely irrelevant: one seeks to superimpose upon the existing pressure field one's own pressure waves to charge the engine. In order to illustrate the difficulty of this task, the required performance of such a pulse generating loudspeaker will be considered.

It is possible to consider the power required to charge the engine by a particular increase in volumetric efficiency, by considering the rate at which work must be done on the air in the cylinder. To a first approximation, for a 2 litre engine running at 6000 rpm, supercharging by 10% requires an average power of approximately 100 W. Note that such an engine could well produce 100 kW of shaft power. Therefore, even if perfect energy transfer is assumed actuators capable of producing 100 W of acoustic power at fundamental frequencies under 200 Hz are required. Such a specification is orders of magnitude more rigorous than can be achieved with electromagnetic loudspeakers.

That kind of active pulse supercharging is probably not practical due to the acoustic power that must be generated. Although the energy required could be generated over a number of cycles using resonances, power must still be supplied at the rate calculated to overcome the power absorption doing the actual charging. It should be noted that passive pulse generation techniques have been suggested by Ma (1989).

RESONANCE ADJUSTMENT

It is felt that the best hope for positive improvements in charging lie with conditioning the wave energy already in the inlet system as a result of the inherently unsteady nature of the intake process. The power loss generating this energy is manifested as a component of pumping losses in the intake stroke. To that end this paper investigates the use of passive elements, which do not add any energy to the system from external sources but are powered by the energy already in the pressure waves.

The method chosen of doing this is to place a pressure stabilising element at a point in the inlet manifold. The element is a resonator with a selected resonance frequency. The effect of the resonator will be to force a node of that pressure component. In this way the pressure field in the inlet will be changed significantly. In particular, if the controlled mode is adversely affecting performance, the induction efficiency should be increased.

In principle such pressure stabilisation elements could be realised experimentally in a number of manners. That chosen for the purposes of this research was to couple a tuned Helmholtz resonator to the inlet pipe at the desired point. In a practical implementation the use of elements whose action could be controlled electronically is envisaged.

The effect of this implementation was tested using a manifold dynamics simulation program developed by the Ford Motor Company and described by Chapman *et al.* (1983). This indicated that major benefits might accrue from relatively simple inlet modification. Although the simulation did not agree in detail with the later experiments, the beneficial performance was indeed achieved.

EXPERIMENTAL DETAILS

A Ricardo E6 500 cc single cylinder research engine, capable of being motored at speeds of up to 3000 rpm, was used in these experiments. The inlet configuration is illustrated in Figure 1. It consisted of a single pipe of total length 1.8 m and internal diameter 42 mm. At 0.7 m from the inlet valve a small volume of 600 cm^3 was included. Into this was attached a Helmholtz resonator via a valve, which allowed the resonator to be coupled or decoupled from the volume. The resonator comprised a volume of capacity 7910 cm^3, and a duct of internal diameter 51 mm. The length of the duct was varied to tune the resonator.

The inlet pipe drew air from a 200 litre settling reservoir, not shown in the figure, into which air was admitted through a non-return valve, a Lucas hot wire automotive airflow meter and an air cleaner.

The cylinder pressure was measured with a Kistler piezo-electric pressure transducer, and the peak pressure in the cylinder during compression was used as a measure of the mass of the cylinder charge (note that the engine was motored with wide open throttle throughout the experiments). This was the best indicator of induction efficiency. The airflow into the system was measured with the airflow meter, but this was not ideal, the pulsations making the measurement of mean airflow uncertain. The pressure in the inlet manifold was monitored with Druck semiconductor strain gauge pressure transducers. Pressure measurement points in the inlet manifold were at the valve, in the junction volume and in the Helmholtz resonator volume. Experimental data was stored and processed digitally.

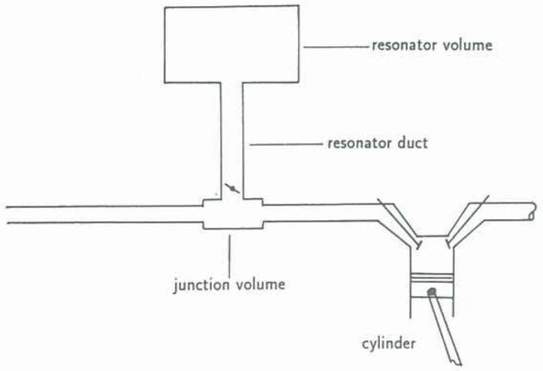


Figure 1: Experimental configuration

EXPERIMENTAL RESULTS

In Figure 2 the large points show the 'charging' of the cylinder as a function of engine speed over the operating range of engine speeds, with the resonator uncoupled. The light points show the charging of the cylinder with the resonator coupled and tuned to approximately 20 Hz, its duct length being 2.1 m. In this and the following similar plot, the y-axis is peak pressure in the cylinder, in bar gauge. The uncoupled case was taken as the control case, against which attempts to increase the volumetric efficiency would be judged. It is seen that a chief characteristic of the uncoupled case is a significant dip in the region of 2400 rpm. The resonator was tuned to 20 Hz as this is the fundamental frequency of inlet events at this engine speed. It can be seen that when the resonator is coupled the volumetric efficiency is significantly increased in the region of 2400 rpm, with a peak improvement of approximately 25%.

There was evidence from sonogram analysis (see below) to suggest that the second harmonic of engine speed is of great significance in the charging process. To investigate this, the resonator duct was shortened to approximately 0.45 m, to give a resonance frequency of approximately 40 Hz. Figure 3 shows the cylinder charge over the

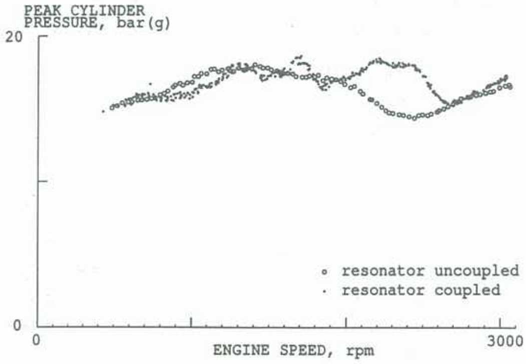


Figure 2: Engine charging with 20 Hz resonator

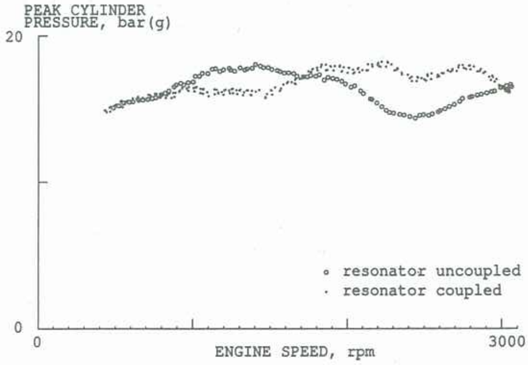
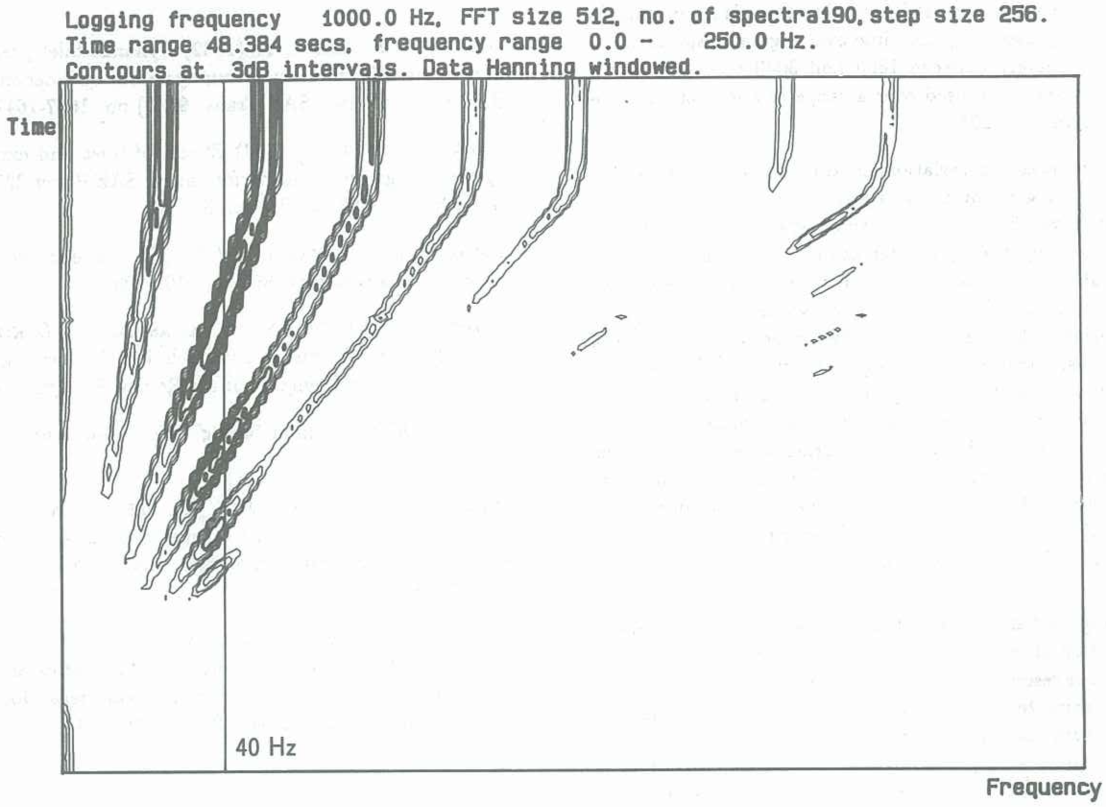


Figure 3: Engine charging with 40 Hz resonator



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Logging frequency   1000.0 Hz. FFT size 512. no. of spectra190.step size 256.
Time range 48.384 secs. frequency range  0.0 -     250.0 Hz.
Contours at  3dB intervals. Data Hanning windowed.
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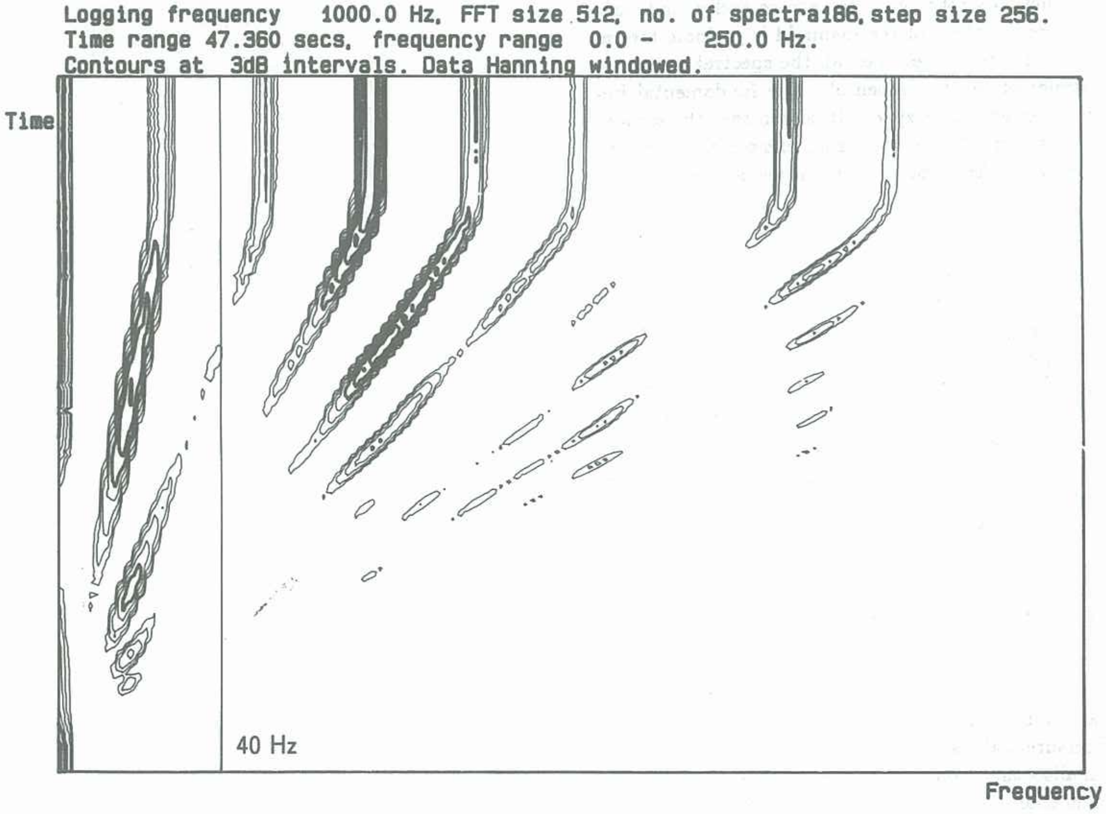
Figure 4: Junction pressure sonogram without resonator



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Logging frequency   1000.0 Hz. FFT size 512. no. of spectra186.step size 256.
Time range 47.360 secs. frequency range  0.0 -    250.0 Hz.
Contours at  3dB intervals. Data Hanning windowed.
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Figure 5: Junction pressure sonogram with 40 Hz resonator

speed range with the resonator coupled, and the control case for comparison. It is seen that there is again a significant improvement, this time over a greater speed range, approximately between 1800 and 3000 rpm. The peak improvement, realised over a range of about 600 rpm, is approximately 20%.

The pressure variations in the manifold were investigated using sonogram analysis to confirm that the resonator was having the expected effect. Sonograms are prepared by taking Fourier power spectrums of sequential short portions of the time series data. These spectrums are in effect stacked up in sequence so as to form a surface. In this manner a two-dimensional picture of power-spectral amplitude against time and frequency is built up, which can be plotted as a 3-dimensional surface picture or, as in this paper, as a contour map. If a slice is made through a sonogram at a constant time then its cross-section will be the Fourier spectrum of the time-series data in the region of that time. Hodges *et al.* (1985) includes a more detailed description of the preparation and use of sonograms.

Figure 4 shows a sonogram prepared from the pressure variation in the junction volume as the engine speed varies with the resonator decoupled. Over the time period of this sonogram, 48 s, the engine was accelerated from rest to 3000 rpm and then left at that speed. The contours are logarithmic at 3 dB intervals, and frequency content is on the x-axis and time the y-axis. The floor of the plot is 24 dB below the highest peak. At the top of the plot the region of constant speed is evident, and at the base of the plot the engine was stationary. The fundamental frequency of excitation is at half engine speed since there is one induction stroke every two engine cycles, and since the pressure variation in the manifold is periodic the response is a Fourier series: i.e., all the spectral content is at multiples of the fundamental. The fundamental frequency varies as engine speed. It is seen that the second, third, forth and fifth harmonics all exhibit peaks due to resonance at 40 Hz (marked with a vertical line on the plot).

Figure 5 shows a sonogram prepared from the pressure at the junction volume with the resonator coupled and tuned to 40 Hz. The engine speed varies over the sonogram period as in Figure 4. In comparison with Figure 4 it is seen that the resonance at 40 Hz is no longer seen: all the harmonics are instead greatly reduced when their frequency would be 40 Hz (again marked with a vertical line). This demonstrates clearly that the effect of the resonator is to stabilise the pressure in the junction at the tuned frequency, as was the intention.

CONCLUSIONS

It is concluded that adjustment of manifold resonances in internal combustion engines is both possible and beneficial. Pressure-stabilising elements positioned in the manifold can allow the resonances of the manifold to be altered. This alteration can have the effect of inhibiting manifold pressure modes which adversely affect engine charging, and thus of improving the engine volumetric efficiency.

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