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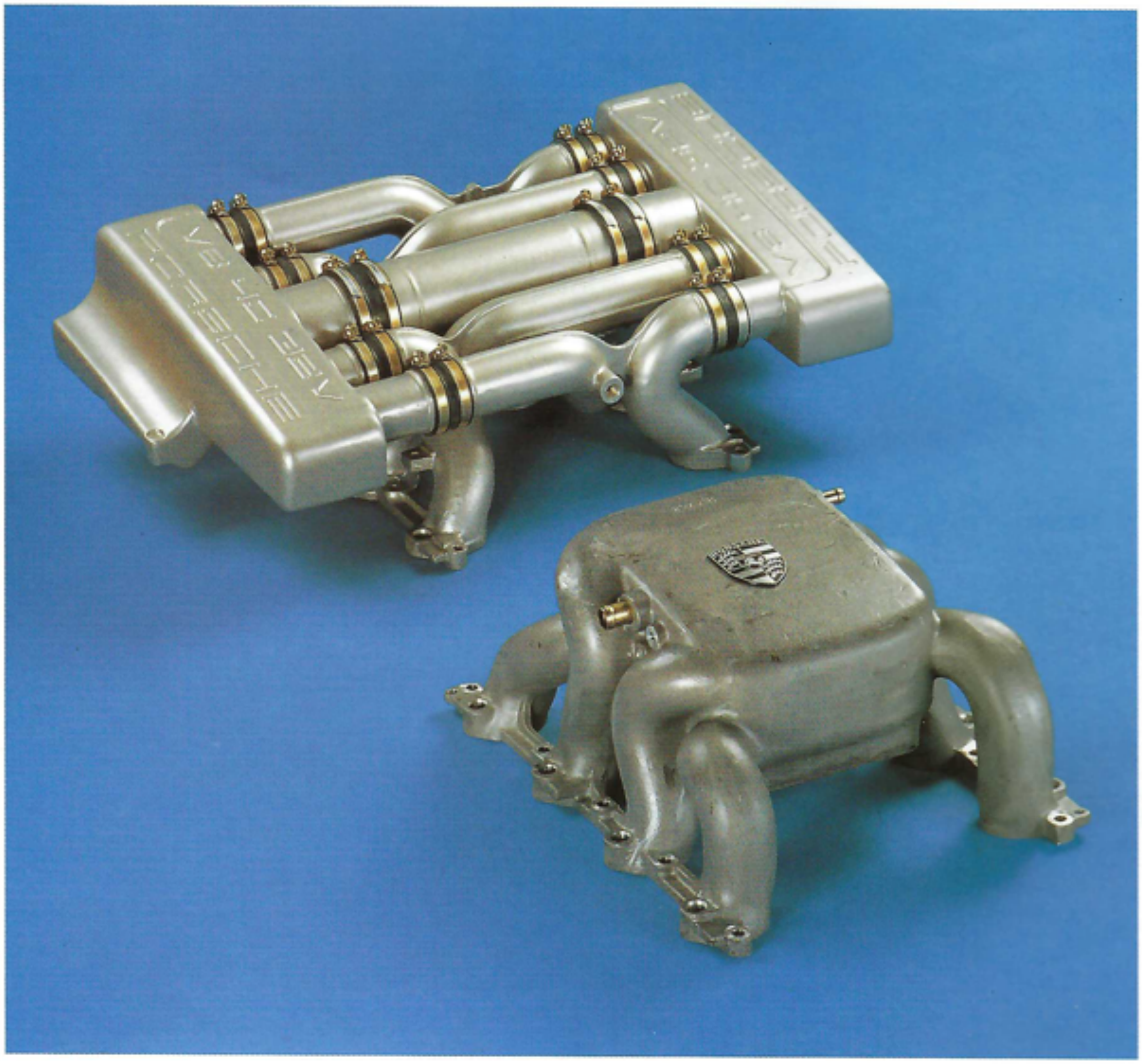
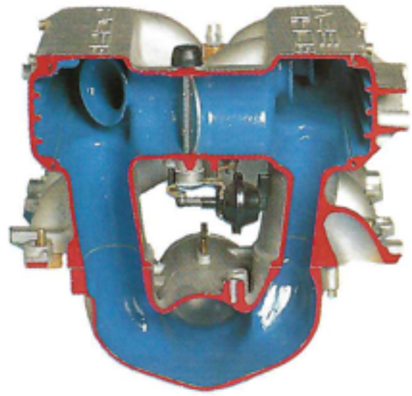
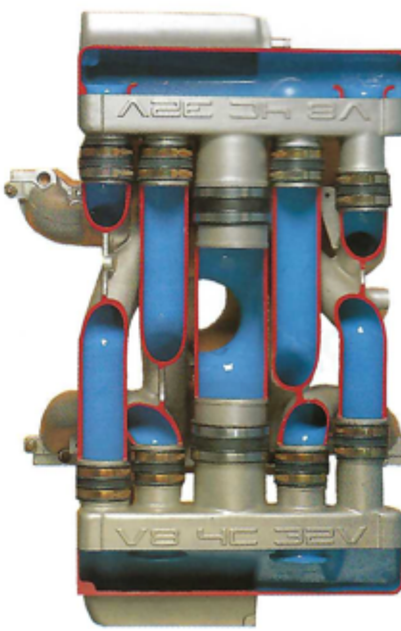


Resonance charging requires specific lengths and cross sections: intake unit of a 928 S4 alongside the old "intake spider" (left). Bottom, cutaway model of the new unit.



ENERGY FROM PULSES

Better cylinder filling via decisive pressure pulses in the intake system



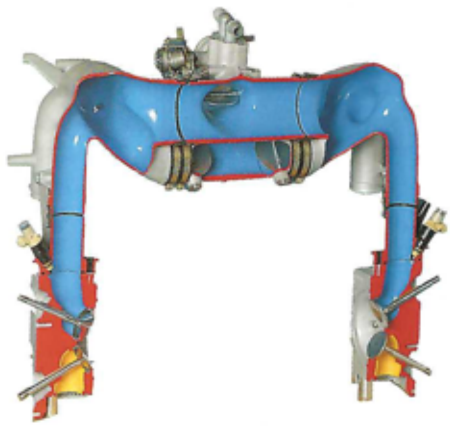
Erwin Rutschmann
Ludwig Theilemann

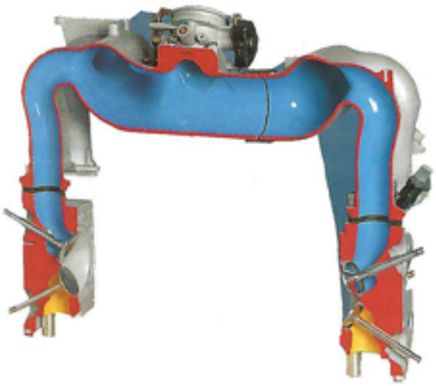
Offering Porsche customers maximum engine performance is a major development goal in engine tuning. Performance tuning of unblown engines means, basically, shaping and layout of the charge exchange system for maximum cylinder filling over the entire rev range. Here, dimensions of the charge exchange system depend on the varying demands put upon the performance and torque characteristics of an engine. For sporting agility you want torque to remain as high as possible until rated revs are reached, for low-rev highway use, extra-proportional torque figures. That would also be true for concentrated propeller drive performance for a safe airplane takeoff.

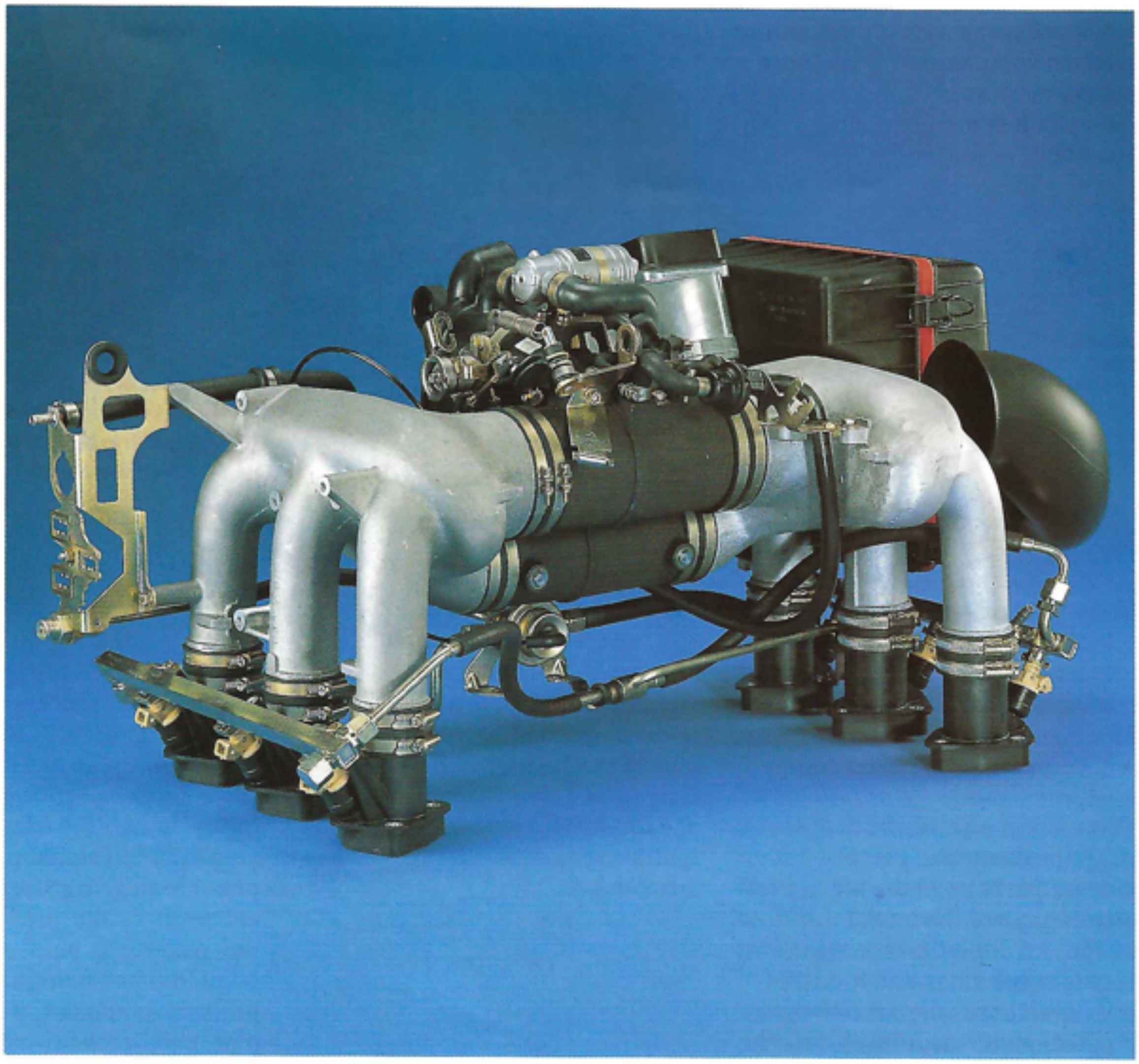
The most important charge exchange component is the intake manifold. Its principles and dimensions have decisive influence on engine characteristics. To a layman, the intake manifold is an uninteresting and scarcely-noticed component but for the technician and insider it is instrumental in shaping performance and torque characteristics. As part of the intake system a manifold has the task of directing air/fuel mixture to the individual cylinders for combustion.

Optimally utilized intake paths for six-cylinder boxer engine of the 911 Carrera: new (top) and old.

Right: complete new intake spider for the 3.6 liter Carrera.







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The level of performance yield is largely determined by the amount of air which an engine ingests. But there is very little time for taking in air. The fact that for today's usual production engines running at 6000 RPM, around 6 milliseconds are available to fill the cylinder, indicates the importance of flow patterns in the tubes and chambers of the intake manifold. Optimum filling is only possible within that brief span of time when utilizing gas dynamics procedures. Oscillating piston movements deliver energy to the intake air which can be used to bolster the intake process, in the form of pressure pulses.

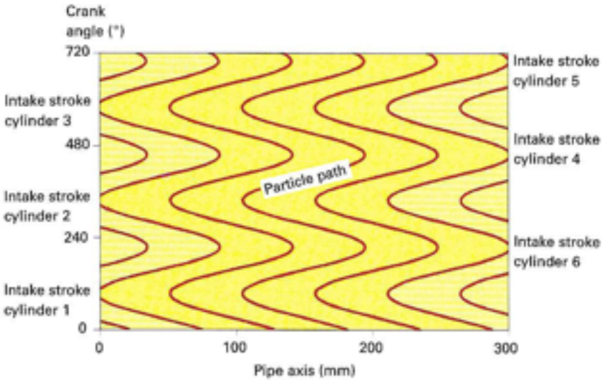
For example, a race engine with open intake pipes will achieve an excess pressure of around 1 bar at the valves at the end of each intake cycle, although you have only atmospheric pressure at the other end of the intake pipe. Additional air is pressed into the cylinder in this manner, when the piston has passed bottom dead center and is already compressing gas mixture in the cylinder.

This use of pressure pulses in the intake manifold is called pulse charging. It is used today in all engines with fuel injection, although in lesser measure than with race engines.
A further method for utilizing additional energy in intake air consists of connecting the cylinders to a pulse system consisting of two chambers. If these chambers are connected by a pipe, an energy-rich pulse can be built up between them and used for self-charging of the engine. This is most effective when the intake frequency can be brought into resonance with the intake air's inherent frequency.

Therefore, this form of self-charging is called resonance charging.
Such a system was used for the first time on the 3.2 liter Carrera engine, as of 1983. Advantages were so convincing that this principle was also taken over for the four-valve 928 engine. In order to use resonance charging over a wider revolution range, these intake manifolds were further developed as two-stage, selective units for today's six- and eight-cylinder engines.

Function

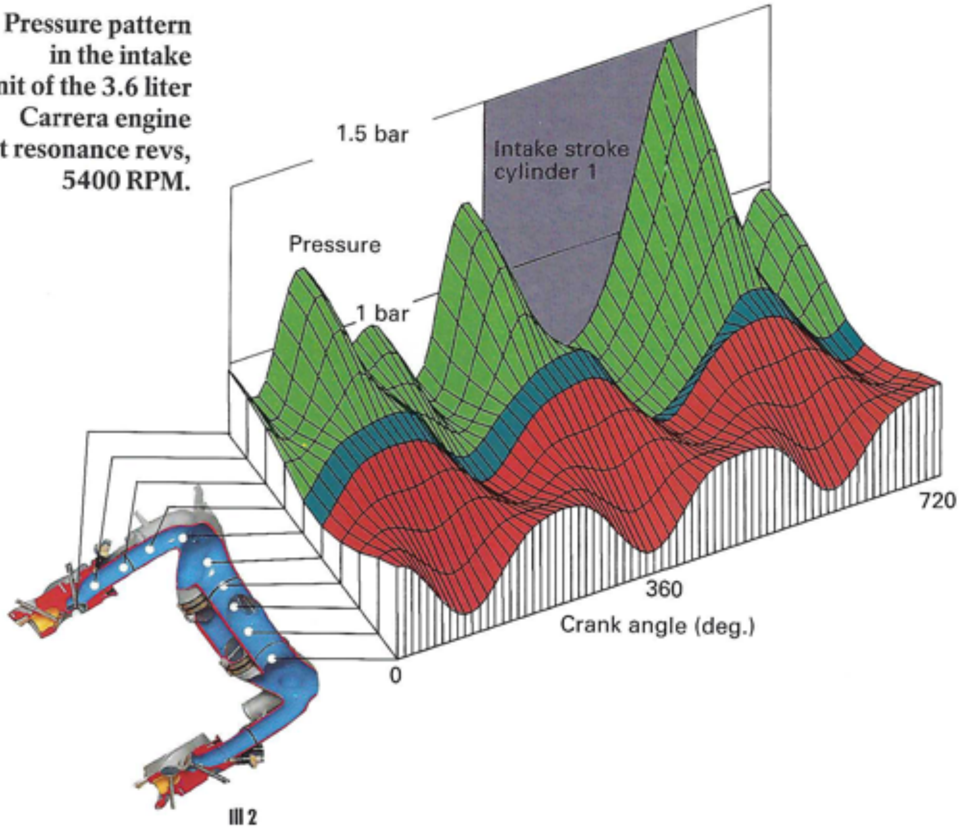
In an intake manifold of two chambers, connected with one another via one or more resonance pipes, balance takes place between the chambers during the intake stroke. Combustion air flows through the resonance pipes to the chamber a cylinder is drawing upon. If individual cylinders are connected to the chambers so that intake will occur from one chamber and then the other, in rotation, combustion air will be constantly moved back and forth.



Ill 1

Air movements in cut-in resonance pipe of the 3.6 liter Carrera engine at 6400 RPM. Ignition sequence 1-6-2-4-3-5.

Pressure pattern in the intake unit of the 3.6 liter Carrera engine at resonance revs, 5400 RPM.



Ill 2

This motion is shown in Ill 1. It displays the computed paths of individual air particles in the second resonance pipe of the intake manifold of the 3.6 liter Carrera engine at engine revolutions of 6400 RPM.

It is notable that the overwhelming proportion of air remains in the second resonance pipe and is not ingested by the engine. In the first resonance pipe, where combustion air is flowing in, its pulses overlay the basic flow of combustion air.

Excitation of air pulses via oscillating movement of the piston can be compared to shoving on a swing. Several people shove the swing from both sides, alternating in a regular rhythm, analogous to the intake pattern of individual cylinders. Just as the swing must be pushed at the right moment and at proper intervals, namely in time with the swing's own frequency, so is the best effect achieved in an intake manifold when combustion air is ingested in time with its own pulse frequency. The engine then operates at resonance revs.

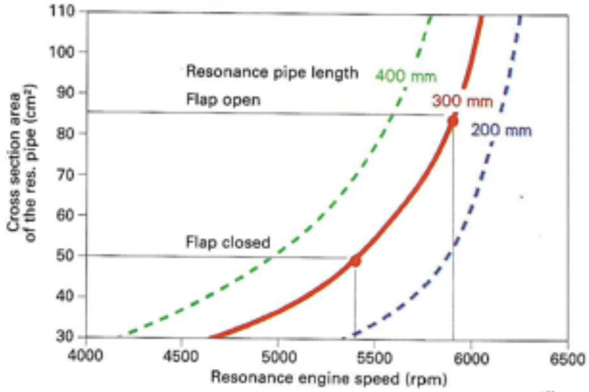
Air pulsing in resonance produces pressure changes in the chamber on the order of 0.2 bar. Such pumping up of a chamber occurs around 150 times per second in the Carrera engine. Pressure pulsing functions so that a pressure maximum will pass through the intake distributor which has just been exhausted, shortly before the end of the intake stroke. Excess pressure above atmospheric pressure produces recharging of the cylinder. Energy from the pistons, stored in pulses of intake air, is thus used again to fill the cylinders.

The pressure process at resonance revolutions (5400 RPM) in one portion of the intake system is presented in perspective for one working cycle of a 3.6 liter Carrera engine in Ill 2. The red portion of this pressure ridge represents the inherent form of the pressure pulse in the resonance pipe. At the same point in time (crankshaft angle) the pressure minimum will reach one pipe end, pressure maximum the opposite pipe end. The blue stripe shows the pressure pattern in intake distributor 1-2-3, the green area the pressure pattern in the intake tube. Highest pressure occurs at the valve, shortly before that valve closes completely. To achieve an optimum recharging effect pressure in the intake distributor 1-2-3 (blue stripe) must pass its maximum pressure level through a few degrees of crankshaft movement before this point in time. If engine revs vary from resonance revs, timing of the pressure pulse in the intake distributor will no longer be optimum.

If revs are too low, the pressure maximum in the intake distributor will be passed through too early. If they are too high, it will be reached too late. An increase of cylinder filling via resonance charging is thus only achieved within a revolution band in the area of resonance revs.

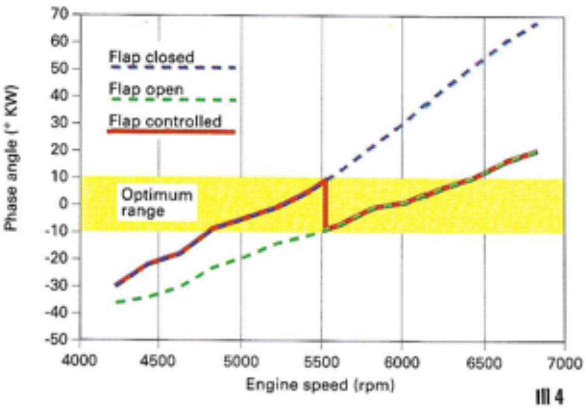
Altering resonance revs is only possible if you change the inherent frequency of gas pulses between intake distributors. Length and cross section area of the resonance pipes are decisive. As pipe length increases, inherent frequency drops, as it does with decreasing cross-sectional area. Intake pipe dimensions also influence the inherent frequency. In addition, it is dependent on the volume of the two intake distributors.

The geometric interrelationship of resonance pipes was applied constructively in laying out the intake system of the 3.6 liter Carrera engine and that of the 928 S4, to alter resonance revs. Cutting in a second resonance pipe increases resonance revs. Both resonance pipes are 300 mm long for the Carrera engine. Therefore cutting in the second resonance pipe acts like an alteration



Ill 3

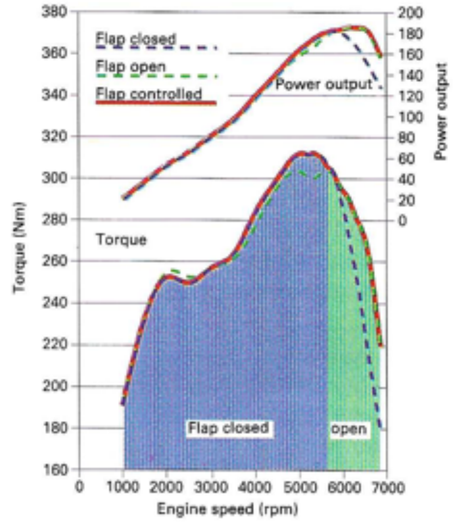
Dependence of resonance revs for 3.6 liter Carrera engine on resonance pipe cross section.



Ill 4

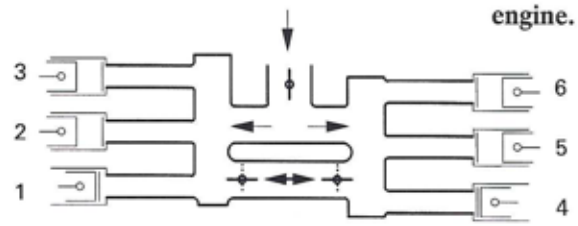
By switching flaps in the second resonance pipe, the phase condition of pressure pulses remains optimum over a wide rev band.

Performance and torque curves for the 3.6 liter Carrera engine.



Ill 6

Schematic presentation of the two-stage resonance unit of a 3.6 liter Carrera engine.



Ill 5

in the cross section. A cross section shift from 50 to 84 cm² lifts resonance revs from 5400 to 5900 RPM (Ill 3). Cut-in occurs at 5500 RPM and causes a shift in pressure pulses in the resonance pipe, earlier by 10 degrees of crankshaft angle (Ill 4). This allows the use of resonance charging effect to improve cylinder filling over a wide revolution band from 4800 to 6400 RPM.

For the 928 S4 engine, cutting in a short resonance pipe shortens the effective resonance pipe length and increases resonance pipe cross section area, shifting resonance revolutions over a relatively wide rev range.

System layout for six-cylinder boxer engine

Within the framework of studies of the principles of charge exchange during development of the 911 Carrera, 3.2 liter engine during the early 80s, the exceptionally favorable preconditions in a six-cylinder boxer engine for applying a resonance boost system were recognized.

The large distance between opposite cylinder banks and the intake strokes at regular time intervals between one bank and the other have decisive importance for the layout of an intake unit consisting of two opposing chambers, the so-called resonance chambers, each with three attached intake pipes and a connecting pipe between the chambers, the so-called resonance pipe. The flat design of the boxer engine is a further advantage. This permits arrangement of the entire system transversely above the engine without complicated and extensive pipe patterns or chamber design, so that the chambers can be connected with one another by a straight resonance pipe. The typical I-shape of the pipe/chamber layout which results, as well as central flow into the resonance pipe, are characteristic of Porsche resonance charging (Ill 5).

Intake pipes could also be virtually straight. Straight pipes are advantageous for minimal throttling of the air flow, minimal restraint of air pulses between resonance chambers and for equal distribution of cylinder filling.

The main intake pipe between air filter and intake system is attached to the approximate middle of the resonance pipe. If the system is in a resonance condition, the pressure pulse node will lie at the junction of the main pipe and resonance pipe. This prevents strong pressure pulses in the main pipe from having a reverse or upstream effect. Neither flap position of the air meter nor intake noise are negatively influenced with this.

In order to maintain the effect of resonance charging over the widest possible revolution range, today's 3.6 liter Carrera engine has a second resonance pipe installed parallel to the first. At its end there is one each blocking flap to close the pipe and to disconnect pipe volume. A vacuum box, controlled by revs, operates these flaps. They remain closed until shift revs of 5500 RPM are reached, and are then fully open, above that point. Although the engine uses only two-valve technology, the cylinders are fully filled with a fresh charge at the rated power point. Along with high maximum torque of 310 Nm at 4800 RPM, the engine achieves peak power of 184 kW (250 HP) at 6100 RPM (Ill 6).

System layout for the eight-cylinder engine

Eight-cylinder engines are generally fitted with single-chamber intake systems. The chief components of such a layout will be a central chamber, also called intake distributor or collector, and eight intake pipes connecting the chamber with intake passages.

Single-chamber systems are preferred for simple installation in the vee space between the cylinder heads, since they take up little space.

Single-chamber systems are primarily advantageous for V8 engines when high peak outputs are required. With the effects of pulse pipe charging which can be utilized through good design and tuning possibilities, respectable air flow rates can be achieved in the middle and upper rev ranges.

However, for evaluating elasticity in the important revolution range between 2000 and 3500 RPM a moment weakness cannot be overlooked. The minimal torque increase when moving through this rev range can be traced to intake pipes which are too short. Optimum pipe lengths cannot be fitted in for performance reasons, not to mention a pure torque layout, for space reasons.

Considering engines for the 928 range, and especially vehicles for the US market with automatic transmissions, using longer ratios and higher vehicle weight for comfort reasons, there was every reason to consider ways in which filling could be improved in this range.

Gas dynamics procedures for the Carrera engine were carried over to the eight-cylinder engine in a theoretical preliminary study. Calculations indicated that resonance pulses occur when realistic geometric tolerances are considered. That was the starting signal for development of a single-stage resonance system especially tuned to the lower rev range. Structure tests of an identical system in principle, with characteristic I shape, quickly led to the realization that a vee engine doesn't offer the ideal intake-side conditions of a boxer engine. Space between cylinder banks in particular and uneven ignition timing are not favorable for assembly of a unit with good flow.

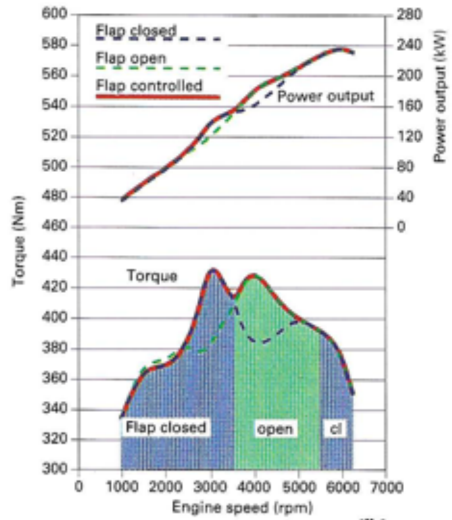
Initial attempts to fit this unit into the vee failed in the face of necessary dimensions and the desire to have straight resonance pipes. Compact design made it possible to mount the unit transversely above the engine. Resonance chambers above the cylinder heads are connected by a long, straight pipe. The main intake air pipe rises out of the vee to meet the middle of the resonance pipe.

It proved difficult to mate the intake pipe to the chamber. Due to uneven ignition timing, cylinders in each cylinder bank ingest air at 90, 180 and 270 degrees of crankshaft angle. Therefore the intake pipes for a cylinder bank couldn't be connected directly to the chamber on the same side. Equal, alternating intake from the chambers, required to excite the gases in the unit, is only possible when the inner intake pipes on each side cross to the chamber on the opposite side while the outer intake pipes feed into the chamber on the same side.

Due to intake pipe correlation, four short and four long intake pipes must be accommodated, meaning that the shorter intake pipes must necessarily be more bent.

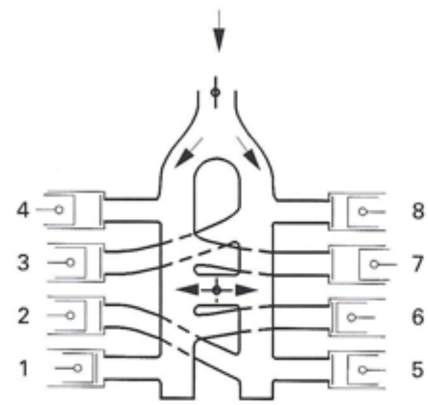
This single-stage resonance system, used on the 928 S, gave the engine pulling power attributes in the rev range mentioned. However, the narrow-band resonance effect was not satisfactory. Not until further development to a two-stage system during performance tuning for the 928 S4 engine, did results prove satisfactory over almost the entire rev range.

Basically, this was only possible through reshaping of the first resonance pipe. By using a U-shape form for the previously-straight pipe, the chambers could be moved from outside, above the cylinder head covers, to inside, between the cylinder heads. This made a connection between the two chambers, now lying close together, possible via an additional pipe.



Ill 8

Performance and torque curves for the 5.0 liter 928 S4 engine.



Ill 9

Schematic presentation of the two-stage resonance unit for a 5.0 liter 928 S4 engine.

Thus the system amounts to two resonance units, one with a long resonance pipe which carries fresh air to the main pipe connection, again in the middle, and one with short resonance pipe with a closing flap at its center point. Viewed separately, the two systems produce different resonance revolutions, due to different resonance geometries. With flap closed, the unit is in resonance through the longer pipe at 3000 RPM. With flap open, the phase position of the pulses is corrected and the unit is in resonance via the now-dominant shorter pipe, at 4000 RPM.

By opening the flap effective resonance cross section and, at the same time, resonance pipe length, are changed. A full-load curve (Ill 8) shows how effective this new system is. In the initial stage, meaning with flap closed, maximum torque of 430 Nm is achieved at the unusually low revs of 3000 RPM. If the second stage was not cut in, as revolutions increase, one would have to accept clear torque losses in the middle rev range, as before.

By cutting in the second resonance pipe at 3500 RPM, torque remains at the high level of the first stage, even with further rev increases, with the exception of a minor dip in the area of the cut-in point. Despite strong torque characteristics, maximum output of 235 kW (320 HP) could be achieved.

Conclusion

Increasingly higher peak outputs with simultaneously strong torque patterns in the lower and middle revolution ranges, place high demands on charge cycle. In the modern, high-performance, unblown engine cylinder filling and thus engine performance can only be influenced via gas dynamics means.

A dual-chamber resonance system was developed for the first time at Porsche, used with success on the six- and eight-cylinder engines. The resonance principle is suited to the six-cylinder boxer engine for high peak outputs and to the eight-cylinder engine to build up a distinct torque pattern.

Multi-stage systems must be the goal, to utilize resonance effect over the widest possible rev range. Resonance pipe lengths and cross section changes have proved useful means up to now, achievable technically with acceptable outlays.

For four-cylinder engines with rev ranges common today, promising resonance charging should not be expected due to the large time span between intake strokes. Assuming realistic intake unit dimensions, resonance pulses would only develop at around 7000 to 9000 RPM.