

EXPANSION CHAMBERS

This entire process can work wonderfully well – and it also can fail miserably if the various elements of the expansion chamber are not properly dimensioned. All of the various waves and pressure sucking and surging about the exhaust port must operate in agreement with the engine's requirements. When they disagree, the result is worse than can be obtained at a much lower price paid in time and money with the stock muffler. As it happens, the motions of those waves are stubbornly tied to exhaust gas temperature, and supremely indifferent to what the engine would prefer in terms of their arrivals. The time intervals between the initial wave departure, and the return of its reflected components is a function of wave speed, and the system's lengths. Thus, as wave speed is subject only to the laws of physics and exists as something one must simply use without altering, the task of designing an expansion chamber for some particular application is to establish lengths, diameters and tapers that will use the pulsations within the exhaust system to the engine's benefit.

TUNED LENGTH

We may start by determining the proper length through the entire system back to the expansion chamber's closed end. That task requires that we know the speed at which sonic waves travel within the chamber, and therein lies a great difficulty. As noted previously, these waves' velocities are determined largely by the temperature of the gases through which they are propagated – and that factor, temperature, varies continuously in the course of a single operating cycle. Exhaust gases emerge from the cylinder at about 1200° F., and have very nearly (about 800° F.) the same temperature back in the outlet pipe. But expansion within the chamber itself cools them (prior to recompression and reheating back in the baffle cone) to perhaps 500° F., or less, in the midsection, and a wave does not move as rapidly through those cooler gases. It is possible to calculate fairly exactly the temperatures at all points throughout the system, but that is a very complex thermodynamic problem and certainly beyond the capabilities of the layman. Indeed, honesty compels me to admit that it is not a problem I would like to face without a computer and the assistance of someone experienced in that kind of work.

Happily, in this instance it is possible to arrive at a satisfactory solution to the problem by determining wave speed – by starting with the answer and working back. In short, you can measure a lot of existing expansion chambers known to be effective, and by comparing their lengths, exhaust port timings and the speeds at which the engines develop their power, eventually come up with a figure for wave speed representing a workable average for a whole range of high-output engines. My own research, conducted along the pragmatic

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lines just described, was begun in about 1960 and I arrived at a conclusion in 1964 that has required only slight modification over the succeeding eight years. That conclusion was, and is, that one may use a wave speed figure of 1700 ft/sec in combination with the anticipated engine speed at maximum power to arrive at a system length (measured between the exhaust port window and the point of mean reflection in the cone that constitutes the closed end of virtually all expansion chambers). That figure provides an excellent starting point for the system, as it represents a high average and any error will merely result in a lower-than-projected power peak. Actually, the addition of more examples to my charts in recent years make me inclined to think that something like 1670 ft/sec is more accurate, but I still use the 1700 ft/sec figure as a starting point, and subsequently shorten the system slightly, perhaps an inch, if tests indicate that the power peak obtained with the chamber is too low.

Using that high-average figure for wave speed (or indeed any figure your fancy dictates, if your findings contradict my own) you may establish the exhaust system's tuned length by means of the following formula:

$$L_t = \frac{E_o \times V_s}{N}$$

Where L_t is the tuned length, in inches
 E_o is the exhaust-open period, in degrees
 V_s is wave speed, in feet per second
 N is crankshaft speed, in revolutions per minute

For example, in an engine with an exhaust-open period of 180-degrees, and a power peak at 7000 rpm, and using the 1700 ft/sec figure for wave speed, then,

$$L_t = \frac{180 \times 1700}{7000}$$
$$L_t = 43.7\text{-inches}$$

That length is, I must again stress, measured from the exhaust port window back to a point slightly more than halfway down the baffle cone at the end of the system. The exact point, and how to find it, will be dealt with shortly, along with an explanation of why we use a cone to close the system instead of a flat plate – and how the taper of that cone influences an engine's power curve. First, we'll consider the size and taper of diffusers.

DIFFUSER PROPORTIONS

Arriving at the proper size for a diffuser is, thanks to the work of several

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researchers, almost entirely a cut-and-dried proposition. Diffusers should have an 8-degree included taper for maximum energy recovery, and an outlet area 6.25-times that of their inlet. Thus, a diffuser to be attached to an inlet having a 1.5-inch diameter should have an outlet of 3.75-inch diameter. Outlet diameters for diffusers of all inlet diameters may be determined in the following manner:

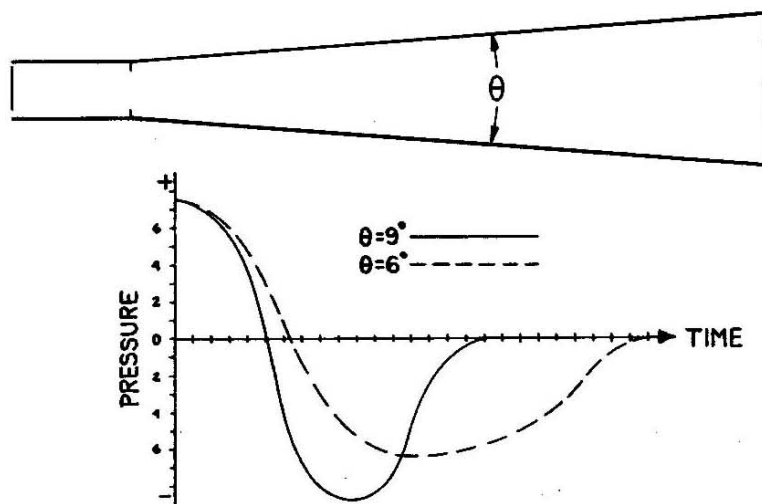
$$D_2 = \sqrt{D_1^2 \times 6.25}$$

Where D_2 is the diffuser outlet diameter

D_1 is the diffuser inlet diameter

6.25 is the outlet/inlet ratio constant

Although these diffuser diameters, tied to the 6.25 constant, remain the same, diffuser length may be varied, as there are reasons for using diffuser tapers other than 8-degrees. That taper does the best overall job of energy recovery, but it is possible to get a stronger inverted wave with diffuser tapers greater than 8-degrees, at the expense of wave duration. Conversely, one also may extend the wave duration by accepting some diminishing of its amplitude with shallower tapers. A long wave duration spreads an engine's power band; a short-duration wave with high amplitude is best for maximum power at peak revs. Diffusers having tapers of more than 10-degrees return a wave of



Wider angles of divergence in diffusers return stronger reflections of shorter duration and both narrow and intensify power output.

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such brief duration as to be almost useless even for a road racing engine coupled to the rear wheel via a multi-speed, ultra-close ratio transmission, and also are rather inefficient in terms of energy recovery. For that reason, I do not recommend that you use a diffuser taper greater than 9-degrees even when planning an expansion chamber for a road racing machine, as you may otherwise find it impossible to keep the engine operating within its power band. At the opposite extreme, do not try to use anything below a 5-degree taper diffuser in an expansion chamber for an off-road motorcycle. You will find that even a 5-degree taper results in a diffuser that is almost impossible to accommodate within the system's tuned length, and that it returns an inverted wave to the exhaust port too feeble in amplitude to be very effective in scavenging a two-stroke engine. As a rule of thumb, I would suggest employing diffusers having tapers of 8- to 9-degrees for road racing, small displacement motocross bikes (up to 250cc) should have tapers of 7- to 8-degrees, and for big motocross bikes, tapers of 6- to 7-degrees. These last usually have more horsepower than they can comfortably apply to the ground anyway, and one does not therefore give away anything by extending their power range at the expense of peak horsepower.

All of the tapers given are for single-taper diffusers. In the future we shall be seeing more of multi-taper diffusers, which I first saw on the Yamaha GP racing machines and which have since begun to appear on most of Japan's expansion chamber-equipped production motorcycles. These multi-taper diffusers would seem to be intended to accommodate themselves to the fact that a wave, passing down a diffuser — or any containing vessel with diverging walls — tend to separate from those walls at the diffuser entry unless the taper is slight, but is willing to accept substantially greater angles of divergence once it has moved into the diffuser far enough to have expanded and slowed. From this behavior, if I understand it correctly, one must conclude that the best diffuser would be one diverging along exponential lines — like a trumpet. Of course, such a shape would be excruciatingly difficult to fabricate, and I think it is for that reason Yamaha and Suzuki chose to employ instead diffusers with two or three tapers. My own investigation into this matter is still in its very early stages, and I cannot offer any opinion (much less facts) except to note that Yamaha has been working with diffusers tapered 7-degrees for 70-percent of their length, and the remaining 30-percent tapered 12-degrees. Both Yamaha and Suzuki have recently begun to connect these two-stage diffusers to the exhaust port with a lead-in pipe that is also tapered 2- to 3-degrees. This slight taper probably is provided to minimize flow resistance and thereby enhance the lead-in pipe's ability to inertia-evacuate the cylinder, rather than to function as part of the diffuser.

Incidentally, the use of two-stage diffusers also facilitates coping with the often-conflicting requirements of expansion chamber volume and lead-in pipe