Chapter 4
The Exhaust

IT IS TRUE to say that the largest contribution towards achieving the current high power levels from the two-stroke engine has come from increasing knowledge in the area of exhaust system design. Originally, the exhaust pipe was designed to get burnt gases out of the engine as quickly as possible. Then, as designers learned more about pressure waves, they attempted to make use of them to scavenge the cylinder of exhaust gases.

The basic theory of pressure waves is quite easy to understand, but the practical application of pressure wave phenomenon is very difficult to formulate. Fortunately, the experimental work done by two-stroke engineers during the past twenty years has made the task of building an effective exhaust well within the grasp of any two-stroke engine tuner. This is not to imply that the first exhaust you fabricate will be perfect. The Japanese manufacturers, and in particular Yamaha and Suzuki, know as much as anyone about exhaust tuning, but you will find they are constantly updating the expansion chambers on both their works and production racers, proving they are still looking for the best design.

Understanding exhaust design begins with an appreciation of the behaviour of sonic waves travelling through a pipe. These waves travel at a speed determined by the temperature and pressure of the outflowing exhaust gas. This speed always equals the speed of sound, which averages around 1675ft. per second in hot exhaust gas.

Sonic waves have the strange property of being reflected back along the pipe they are travelling through, regardless of whether the pipe has an open or closed end. Even more peculiar is another fundamental law of acoustics which causes a pressure wave to invert its sign on reaching the open end of a pipe. A positive pressure wave, on reaching the pipe's open end, goes back up the pipe as a negative wave, and vice versa. Reflection from a pipe's closed end does not change sign, a positive wave stays positive.

The earliest exhausts were a piece of straight pipe, but these were not able to take full advantage of pulse waves to 'suck' exhaust gases out of the cylinder. In this type of

system a positive pressure wave charged down the pipe immediately the exhaust port opened. On reaching the end of the pipe it was reflected as a negative wave, but with reduced intensity because much of its wave energy was lost to the surrounding atmosphere. However, some energy did remain and if, when the negative wave reached the exhaust port, the port was still open, it would assist in a small way in evacuating the cylinder. This being the case, the wave would turn round and travel back down the exhaust still negative, then, on reaching the open end of the pipe, be reflected up again as a positive pressure wave. If the exhaust was of the correct length, the positive wave should have arrived back at the exhaust port just before it closed, forcing any fuel/air mixture that had spilled into the exhaust back into the cylinder to be burned.

In theory it sounds good, but in practice the straight pipe exhaust never worked too well, primarily because so much kinetic energy was lost each time the sonic wave reached the open end of the exhaust pipe. A two-stroke engine requires strong pressure pulses to work efficiently, so engineers added a megaphone to the end of the straight pipe.

A megaphone, more correctly called a diffuser, is in effect a relatively efficient energy inverter. In a diffuser the walls diverge causing the sonic wave to react just as though it had reached the open end of the exhaust. However, the reflected wave retains most of its energy and can create a vacuum as low as 6 psi. Obviously a pulse wave of this magnitude can be very effective in drawing exhaust gas out of the cylinder, and in pulling the fresh charge from the crankcase up through the transfer ports.

The problem with this system is that much of the time the strong negative pulse wave will arrive at the wrong moment, and draw a considerable amount of fuel/air mixture into the exhaust. The exhaust port will close before the reflected positive wave arrives, to force the mixture back into the cylinder.

The next step was to add a reverse cone with a small outlet to the diffuser, and this proved to be the real break-through in two-stroke exhaust design. This type of exhaust is referred to as an expansion chamber. The addition of the reverse cone with a small bleed-off hole acts as a closed pipe, giving the exhaust a double pulse action. When the positive wave reaches the diffuser, part of the wave is inverted and reflected as a negative wave to evacuate the cylinder. However, part of this wave continues on to be reflected by the reverse cone. Because of the pressure buildup caused by the small bleed hole, the reverse cone acts like a closed pipe, reflecting the wave with the same positive sign. This strong positive pulse arrives just before the exhaust port closes, forcing any escaped mixture back into the cylinder, increasing power output and reducing fuel consumption.

On paper that theory, too, sounds very simple, but there is much more involved when we actually set about designing a system. Obviously the expansion chamber must be of the correct length to ensure the pulse waves are reflected to arrive at the exhaust port at the proper time.

The formula we use to determine the tuned length of the exhaust is:-

$$L = \frac{ED \times 42545}{rpm}$$

where L = tuned length in mm
ED = exhaust duration in degrees
rpm = engine speed exhaust is tuned to work best at

Assuming we had an engine with an exhaust duration of 196° and producing maximum power at 11,000rpm, the tuned length would be:

$$L = \frac{196 \times 42545}{11{,}000}$$

$$758\text{mm}$$

The length of 758mm is measured from the piston face to the assumed reflection point of the reverse cone. This point is half way along the cone but, because the top is cut from the cone, the point must be calculated mathematically. (FIGURE 4.1).

The first part of the expansion chamber, the header pipe, may be either a straight pipe with parallel walls, or a tapered pipe with diverging walls. A tapered header pipe is to be preferred, as it will improve the power and power range; however, it is much more difficult to fabricate than the straight pipe. For this reason, some designs utilise a parallel-wall header. Most go-kart headers, and also the Honda CR250R expansion chamber for example, have a non-diverging header pipe. (FIGURE 4.2).

The actual length required for the header pipe can only be determined accurately by testing. Over the years, I have devised and tried all kinds of formulae to calculate the length of the header, but I've never found one that works too well. It has been my experience that it is much quicker to make an educated guess and work from there.

In TABLE 4.1, I have set out what I consider to be a good starting point in working out the header pipe length. For example, if you are building a chamber for a road race 125 with an exhaust port inside diameter of 38mm and you intended to fabricate a multi-stage diffuser, then the header would be between 247mm and 285mm long. However, if you were to use a single stage diffuser, the header would be a little longer at 296 to 323mm. Usually, you will find the shorter length in both instances to be very close to what is required for best performance. Lengthening the header has the effect of increasing mid-range power at the expense of a drop in maximum hp.

It is important to note that the above rule for calculating the header length can work only if the exhaust port is of a standard diameter for that particular size of engine. If the engine has a port size outside that shown in TABLE 4.2, then it will be

TABLE 4.1 Calculating header pipe length

	Road race		**Motocross & Enduro**	
Cylinder size (cc)	*single stage*	*multi-stage*	*single stage*	*multi-stage*
50-80	8.5-9.5	8-9	10-11	8.5-9.5
100-125	7.8-8.5	6.5-7.5	7.8-8.5	6.5-7.5
175-250	7.3-8.3	6.5-7.5	9-10	8.2-9.2
350-500			8.5-9.5	7.5-8.5

Note: To calculate header pipe length multiply exhaust port diameter by the appropriate multiplying factor.
Single stage refers to a single stage diffuser.
Multi-stage refers to a multi-stage diffuser.

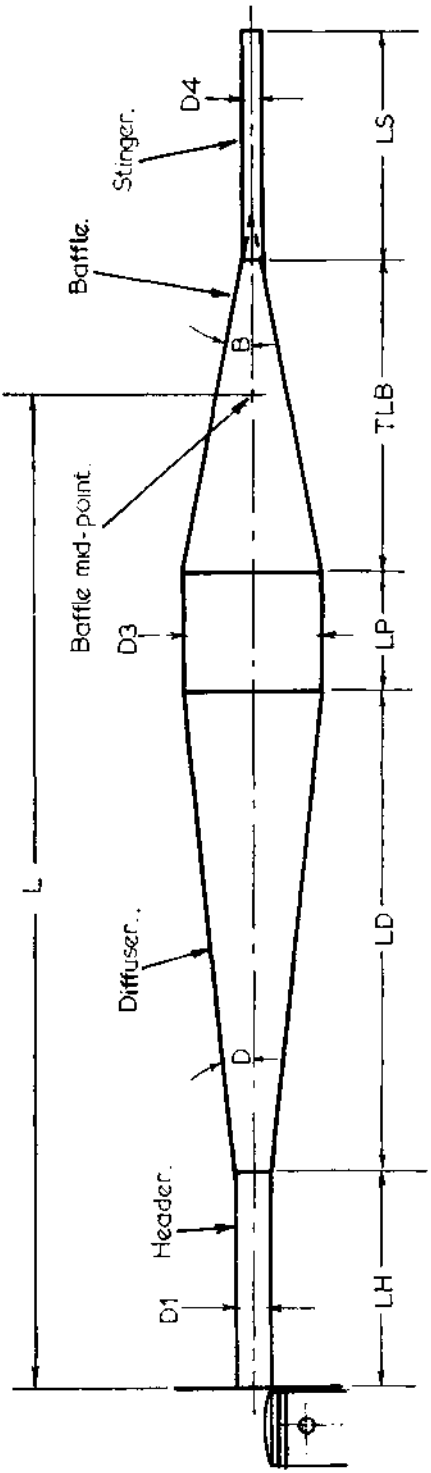
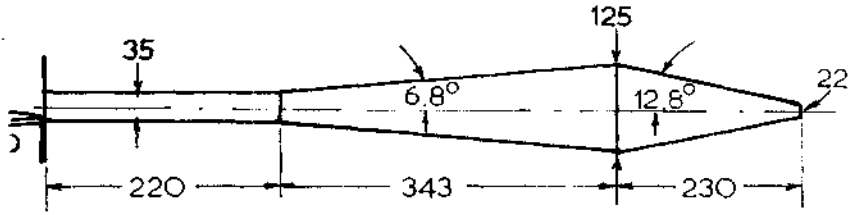


Fig. 4.1 Basic two stroke expansion chamber.

Hartman go-kart pipe.

All dimensions in mm.



Yamaha MX360 pipe.

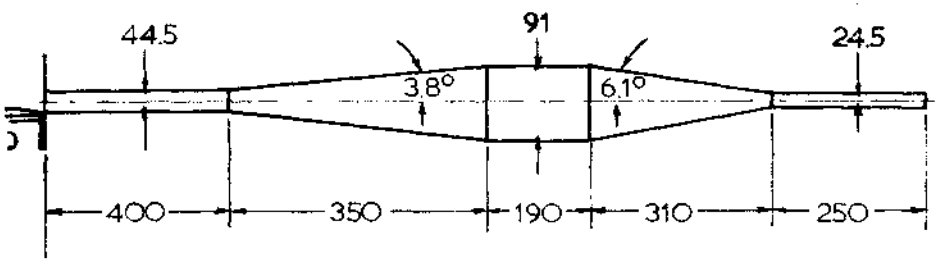


Fig. 4.2 Expansion chambers with parallel-wall header pipes.

necessary to work out the length based on a standard port diameter. Also, keep in mind that the calculated length of the header is the measurement from the piston to the end of the header pipe. Therefore, when you fabricate the pipe, remember to subtract the length of the exhaust port.

Over the past ten years the majority of manufactures have realised the benefits to be gained from a tapered-wall header and have gone over to this design. In the first instance it increases chamber volume, which effectively broadens the power range. Secondly, its diverging walls reduce flow resistance both in and out of the cylinder. The burnt gases flow out easily with a minimum of turbulence and any fuel mixture which has spilled into the exhaust is rammed back into the engine more efficiently. Thirdly, and this is the most important reason for the justification of tapered headers, the shallow taper allows the exhaust gas to expand and cool more gently. This results in less loss of kinetic pulse energy than if the gases were to expand rapidly and abruptly on passing from a straight header into the diffuser section of the expansion chamber. With

TABLE 4.2 Standard exhaust port diameter

Cylinder size (cc)	Port inside diameter (mm)
62-80	30-32
100	34-37
125	37-40
175	42-46
250	44-48
350-500	45-50

more pulse energy available, a stronger evacuation wave to scavenge the cylinder, and a stronger wave to ram spilled mixture back into the cylinder, is produced.

The taper of the header is normally between 1.15° and 1.5°. However, some manufacturers have used tapers as shallow as 0.8° and as steep as 2.3° in certain circumstances. If the diffuser taper is very shallow (i.e., 2.8° to 3.25°) then a 0.8° header taper is at times in order. Conversely, if the exhaust port and flange is very long (i.e., 75mm to 100mm) a steeper 1.7° to 2.3° header may be necessary. (FIGURE 4.3).

To work out the physical size of a diverging header pipe of a particular length and **taper,** we use this formula:-

$$D_2 = \left(\frac{LH \times 2}{\text{Cot } H}\right) + D_1$$

where D2 = header pipe major inside diameter

D_1 = header pipe minor inside diameter

LH = header pipe length minus the length of the exhaust port and flange

Cot H = cotangent of header pipe's angle of taper

We will assume our road racer has a cylinder volume of **125cc** and an exhaust port and flange 70mm long by 40mm id. The total length of the header will be (40 x 6.5) - 70 = 190mm. The taper of the pipe will be 1.5°, which has a cotangent of 38.19 (from TABLE 4.3)

$$\text{Therefore } D_2 = \left(\frac{190 \times 2}{38.19}\right) + 40$$

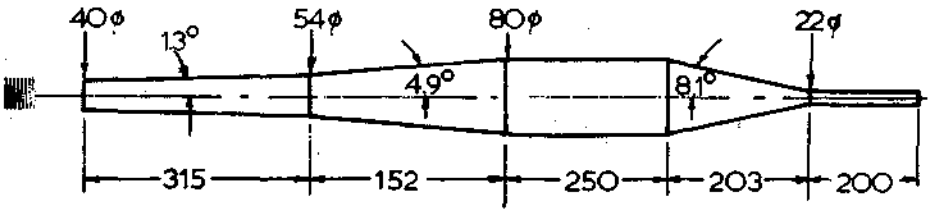
$$= 50\text{mm}$$

TABLE 4.3 Useful Cotangents

Angle	Cotangent	Angle	Cotangent	Angle	Cotangent
0.8	71.62	6	9.5144	11	5.1446
1	57.29	6.5	8.7769	11.5	4.9152
1.25	45.83	6.75	8.4526	12	4.7046
1.5	38.19	7	8.1443	12.5	4.5107
1.75	32.73	7.25	7.8712	13	4.3315
2	28.64	7.5	7.5958	13.5	4.1653
2.5	22.90	7.75	7.3498	14	4.0108
3	19.08	8	7.1154	15	3.7321
3.5	16.35	8.5	6.6912	16	3.4874
4	14.30	9	6.3138	17	3.2709
4.5	12.71	9.5	5.9758	18	3.0777
5	11.43	10	5.6713	19	2.9042
5.5	10.39	10.5	5.3955	20	2.7475

Yamaha TZ750C pipe.

All dimensions in mm.



Morbidelli 125 production racer pipe.

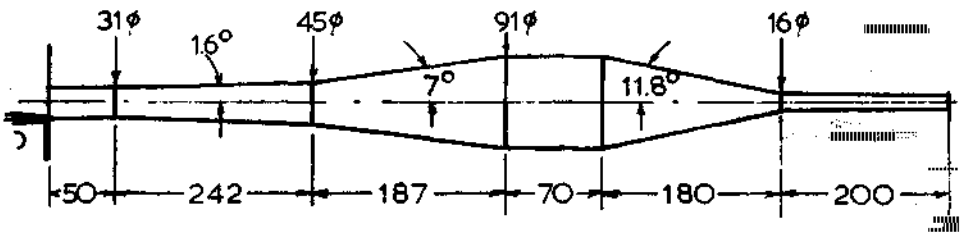


Fig. 4.3 Expansion chambers with tapered header.

The next stage of the expansion chamber, the diffuser, is, as we mentioned **earlier,** a wave inverter. The duration and intensity of the inverted return wave is determined by the diffuser taper. A shallow taper returns a wave of long duration and low intensity. This has the effect of cutting maximum power but, beneficially, it boosts mid-range power by allowing the expansion chamber to stay **'in tune'** with the engine over a larger **rpm** band. (FIGURE 4.4).

Conversely, a steeply-tapered diffuser reflects a pulse of high intensity and short duration. Maximum power will be increased but at the expense of narrowing the power band. In applications such as road racing this may be acceptable if the machine has a close ratio 6-speed gearbox and the rider has the necessary riding skill to ride a bike with a narrow power range and a sudden rush of **power.**

In TABLE 4.4, you can see the sort of angles that I recommend for **diffusers.** Some people build expansion chambers with larger diffuser tapers, but I tend to value good mid-range power and a **wide,** easily managed power band much more than all-out power.

The length of the diffuser is determined by the diameter to which it expands, which should normally be **2.5** times the exhaust port diameter. If you have room on the bike, and you wish to experiment, you may be able to spread the power range by making the diffuser taper to 2.7 - 2.9 times the port diameter. This move will at times suppress maximum power, but the improvement lower down the scale usually compensates. On many bikes, it is difficult to find room for a large diameter exhaust, so you may have to be satisfied with a less than perfect chamber. Most bikes have trouble catering for an exhaust in excess of **110mm** diameter, so this could restrict the diffuser outlet to something closer to 2.2 times the port diameter in bikes over 175cc.

Going back to our previous example, we calculate the diffuser size based on a 7° taper (i.e., 14° divergence) and 2.5 times the port diameter (i.e., 40mm x 2.5 = 100mm).

The formula is:-

$$L_D = \left(\frac{D_3 - D_2}{2}\right) \times \text{Cot } D$$

where L_D = diffuser length

D_3 = diffuser major inside diameter

D_2 = header pipe major inside diameter

Cot D = cotangent of the diffuser's angle of taper

$$\text{Therefore } L_D = \left(\frac{100 - 50}{2}\right) \times 8.1443$$

$$= 204\text{mm}$$

Today, instead of relying on a single taper diffuser, we are using multi-stage diffusers. Generally, a two or three section diffuser is utilised, although some tuners

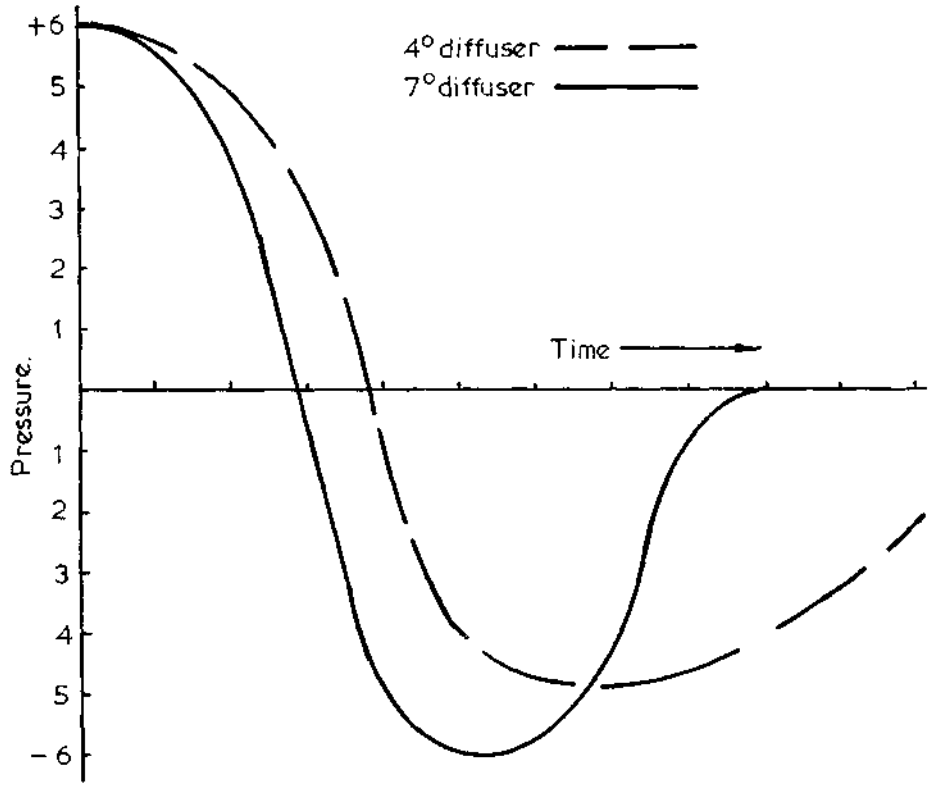


Fig. 4.4 Effect of diffuser taper on intensity & duration of return wave.

TABLE 4.4 Diffuser tapers

Cylinder size (cc)	**Diffuser angle** (degrees)				
	Road race			**Motocross & Enduro**	
	single stage	*two stage*	*three stage*	*single stage*	*two stage*
50-80	6.5 to 7	4.5 & 7	4 & 6 & 8	3 to 3.5	3 & 5
100-125	6.5 to 7.5	4.5 & 7.5	4.5 & 7 & 9	4 to 4.8	3.3 & 6
175	6.5 to 7.5	4.5 & 7	4.5 & 7 & 10	3.5 to 4,5	3.5 & 6
250	7 to 7.5	4.5 & 7	4.5 & 7 & 10	4 to 4.5	4 & 7
350-500				4 to 5	3.5 & 6

and manufacturers are turning to the use of four stage diffusers. For motocross and enduro bikes, I usually work with a two-stage diffuser as relatively shallow tapers are involved. Road race engines and 125 motocross engines with near road race porting require a three stage diffuser, due to the need for steeper angles of taper to pick up peak power.

A multi-section diffuser allows the exhaust gas to expand and cool more gradually, which means there is less loss of kinetic pulse energy than if the gases were allowed to expand more rapidly in a single taper diffuser. With extra pulse energy available, the expansion chamber can do a better job of scavenging exhaust gases out of the cylinder and drawing up the fresh fuel/air charge through the transfer ports.

In TABLE 4.4 you will note the diffuser angles which I have found to work well when multi-stage diffusers are utilised. For example, a twin cylinder road race 250 would use a diffuser with the first section tapering at 4.5°, the second section at 7° and the third section at 9°. Just how long each section should be is a secret most two-stroke tuners keep to themselves. However, I will tell you this: motocross and enduro bikes using a two-stage diffuser will usually require the first section to be 200 to 240mm long; road race bikes with a two-stage diffuser will usually require the first stage to be 140 to 160mm long and, with a three-stage diffuser, the first stage will be 110mm to 140mm long. If, after building an expansion chamber with a diffuser like this, you find that the engine is too peaky, then increase the length of the first stage of the diffuser. This will broaden the power band. Conversely, if the engine lacks peak power, decrease the length of the first diffuser section and lengthen the second stage. In FIGURE 4.5 you will note the diffuser designs which a variety of manufacturers are using.

The parallel belly section of the expansion chamber naturally has the same diameter as the diffuser outlet, but we cannot calculate its length until we have arrived at a suitable size for the rear baffle cone. After that, the mid-section fills the gap to give the chamber its correct tuned length.

As noted earlier, the baffle cone (or reverse cone) reflects a wave of like sign to stuff the fuel/air charge back into the cylinder. A flat plate could do the same job but the wave duration would be so short that this would only occur over a very narrow rpm range. A cone, on the other hand, extends the duration of the pressure pulse, although reducing its intensity. This serves to broaden the engine's useful power band.

Again, the actual taper of the baffle cone affects the pulse time/intensity factor just as in the case of the diffuser. A short, sharp baffle will increase maximum power, but the motor will lose out in the mid-range; also it will tend to cut dead at just a couple of hundred revs past maximum power rpm. A shallow taper baffle reduces top end

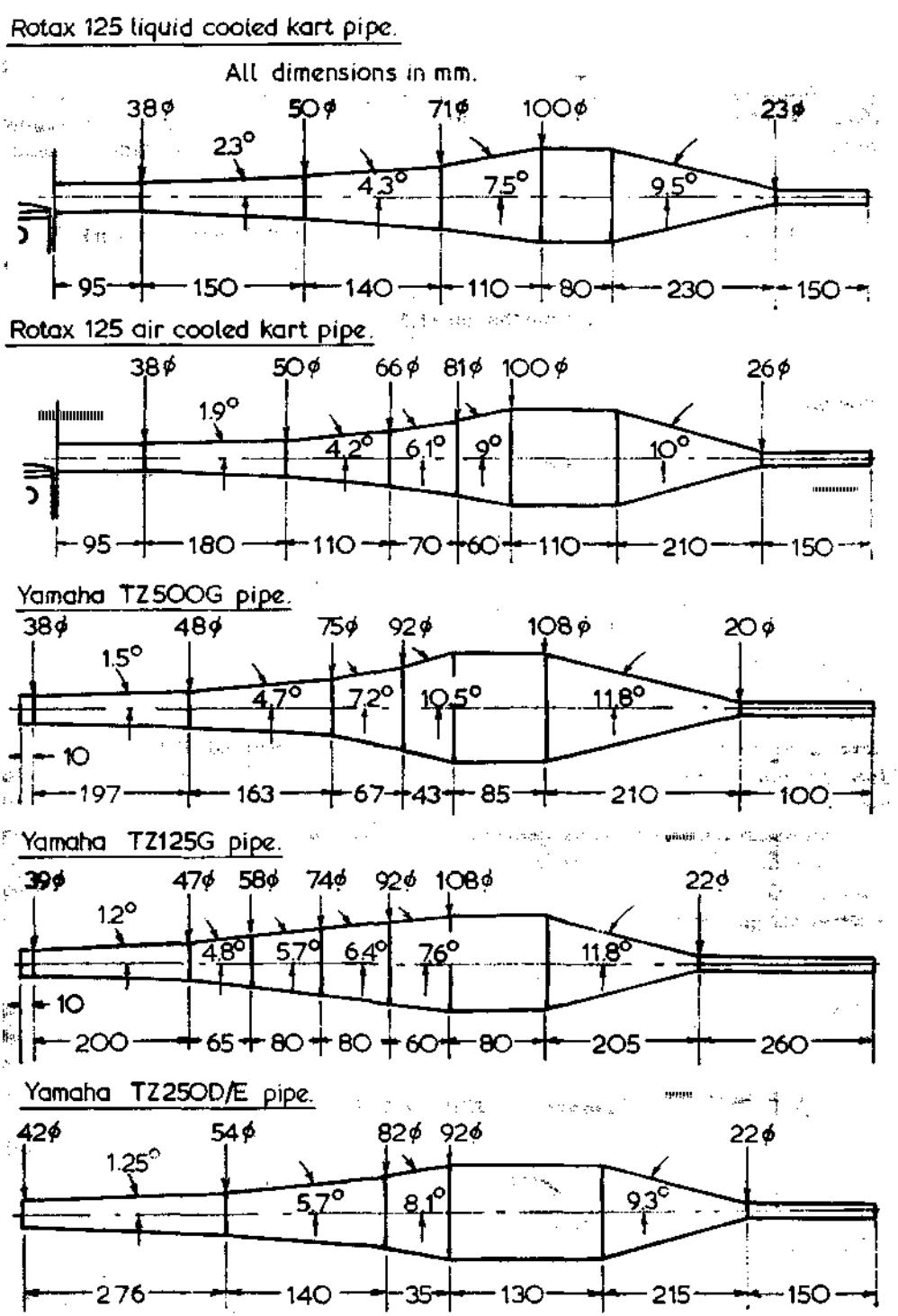


Fig. 4.5 Expansion chambers with multi-stage diffusers.

power, but the engine will develop more power lower down the rpm range and it will -ev on well past the maximum power engine speed. This broadens the engine's effective power range and means that the bike's speed down the main straight will be less affected by changing wind conditions during a race. If a head wind blows, the engine will have enough power below maximum to fight against it and, if a tail wind comes in, :he shallow baffle will enable the engine to over-rev and pick up some more speed. ;FIGURE 4.6).

TABLE 4.5 indicates the baffle cone tapers with which I prefer to work. These ingles have proved to give a good power range without suppressing maximum hp excessively.

In our example, we will assume that an 11.5° baffle taper is used. The formula is:-

$$OL_B = \frac{D_3}{2} \times \text{Cot } B$$

where OL_B = overall length of baffle cone

D_3 = baffle major inside diameter

Cot B = cotangent of the baffle's angle of taper

$$\text{Therefore } OL_B = \frac{100}{2} \times 4.9152$$

$$= 246\text{mm}$$

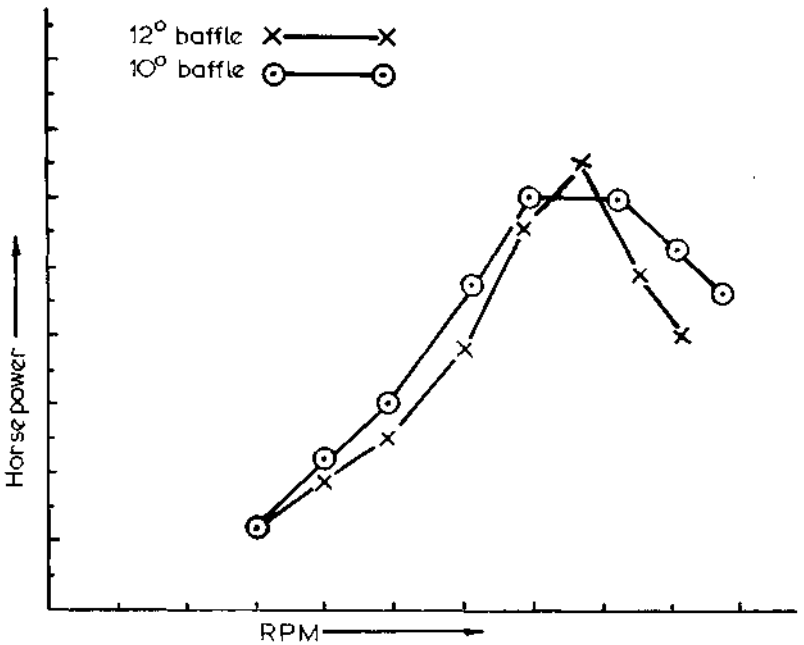


Fig. 4.6 Effect of baffle angle on horsepower output.

You will note that this calculation gives us the overall length of the cone, without allowing for a part of the top to be cut off where the stinger will be attached to bleed pressure from the chamber. By halving this figure, 246mm, we can determine the mean reflection point of the baffle and then go back and calculate how long the belly section has to be to give us the tuned length of 758mm which we originally worked out.

$$L_P = L - \left(L_H + L_D + \frac{OL_B}{2}\right)$$

where L_P = length of parallel section

L = tuned length of chamber

L_H = length of header pipe including the port

L_D = length of diffuser

OL_B = overall length of baffle

$$\text{Therefore } L_P = 758 - \left(260 + 204 + \frac{246}{2}\right)$$

$$= 758 - 587$$
$$= 171\text{mm}$$

In an effort to broaden the power band on motocross bikes and small displacement road race bikes, tuners and manufacturers have been experimenting with two-stage baffles over the past few years (FIGURE 4.7). Unfortunately the results have not been as promising as expected. However, small gains have been made by some tuners working with 62cc and 125cc size cylinders. If you wish to do some experimentation along these lines, start out using a baffle which has the first stage tapering at 4.5° to 5.5° over a length of 70 to 90mm, and the second stage tapering at 12° to 14°.

The last section of the expansion chamber, called the **'stinger',** is in reality a bleed pipe. Its function is to restrict gas flow out of the exhaust and create back pressure by slowly bleeding off exhaust gas. This serves to assist the positive pulse wave in pushing any spilled fuel/air charge back into the motor.

TABLE 4.5 Baffle tapers

	Baffle angle	
Cylinder size (cc)	*Road race*	*Motocross & **Enduro***
50-80	10.5-12	8.5-9.5
100	10.5-12	9-10
125	9.5-12	8.5-10
175	10-12	8-10
250	10-12	7.5-10
350-500		9-11

Suzuki RM125B/C pipe.

All dimensions in mm.

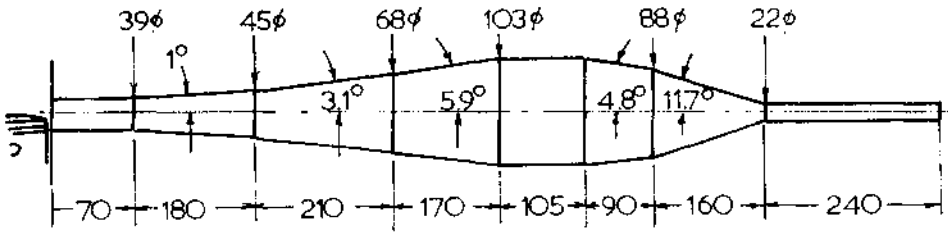


Fig. 4.7 Expansion chamber with multi-stage baffle.

TABLE 4.6 indicates the stinger dimensions which I have found to be most successful. You may find that a minor reduction in pipe diameter will raise the power output, but do be careful. A stinger pipe smaller in diameter or longer than specified could easily result in engine overheating and seizure. Therefore, I would suggest you make only small changes and then thoroughly test the pipe before going any smaller. Engine overheating, in its early stages, is indicated by the presence of oil burnt dark brown under the piston crown. On the next stage the burnt oil turns black, until finally 'death ash' appears. After this, the piston can be holed at any time.

TABLE 4.6 Stinger dimensions

Cylinder size (cc)	Stinger length (mm)	Inside dia. (mm)
50-80	205-230	17-19
100	230-250	19-21
125	265-290	22-24
175	270-295	25-27
250	280-305	26-28
350-500	285-310	27-29

Note: When using this table, first select an intermediate size in both length and diameter and work from there. Do not start with the smallest diameter and greatest length.
Most road race expansion chambers will require a stinger not more than 200mm long and of the smallest diameter indicated for each engine size.

All dimensions in mm.

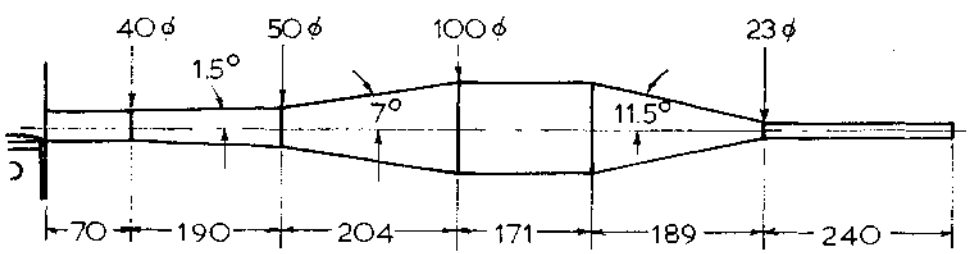


Fig. 4.8 125 road race expansion chamber.

In the example we have been using right the way through, we would select a stinger 23mm in diameter (id) and about 240mm long. The entire expansion chamber would look like that shown in FIGURE 4.8.

The addition of the stinger shortens the baffle cone; its final length can be calculated using the same formula as for the diffuser cone:

$$\text{Thus } TL_B = \left(\frac{D_3 - D_4}{2}\right) \times \text{Cot B}$$

where TL_B = true length of baffle cone

D_3 = diffuser major inside diameter

D_4 = stinger inside diameter

Cot B = cotangent of the baffle's angle of taper

$$\text{Therefore } TL_B = \left(\frac{100 - 23}{2}\right) \times 4.9152$$

$$= 189\text{mm}$$

To draw out the shape of either the diffuser or baffle cone on a piece of sheet metal is quite difficult. The cone's dimensions, when rolled out flat, can be worked out geometrically, or the sizes can be calculated mathematically. I prefer the latter method.

Assuming we were going to fabricate the baffle cone for this expansion chamber, we would calculate its size, before being rolled into a cone, in this way.

Looking at FIGURE 4.9, you will note we only know the inside diameter of the baffle's inlet and outlet, and its length through the centre. The next dimension we must calculate is the length of the cone when measured along the tapered wall, dimension AC. We use the formula:-

$$AC^2 = AB^2 + BC^2$$

where AB = 246mm

BC = 50mm (i.e., half the inside dia)

$$AC^2 = 246^2 + 50^2$$

$$AC = \sqrt{246^2 + 50^2}$$

$$= \sqrt{60516 + 2500}$$

$$= \sqrt{63016}$$

$$= 251\text{mm}$$

Now calculate the length of AC_1 using the same formula:-

$$AC_1^2 = AB_1^2 + B_1C_1^2$$

where AB_1 = 57mm (i.e., 246 − 189 = 57)

B_1C_1 = 11.5mm (i.e., half the inside dia)

$$\therefore AC_1^2 = 57^2 + 11.5^2$$

$$\therefore AC_1 = \sqrt{57^2 + 11.5^2}$$

$$= \sqrt{3249 + 132.25}$$

$$= \sqrt{3381.25}$$

$$= 58\text{mm}$$

The next calculations we make are to work out the circumference of the baffle cone's inlet using the formula:-

$C = \pi d$
where $\pi = 3.1416$
d = diameter of baffle inlet or diffuser outlet
$C = \pi \times 100$
$= 314\text{mm}$

The final calculation is worked on the formula:-

$$\theta = \frac{\text{Arc}}{r}$$

where r = the dimension AC
Arc = C the circumference of the baffle inlet or diffuser outlet

r = 251mm
Arc = 314mm

$$\theta = \frac{\text{Arc}}{r}$$

$$= \frac{314}{251}$$

$$= 1.2510 \text{ radians}$$

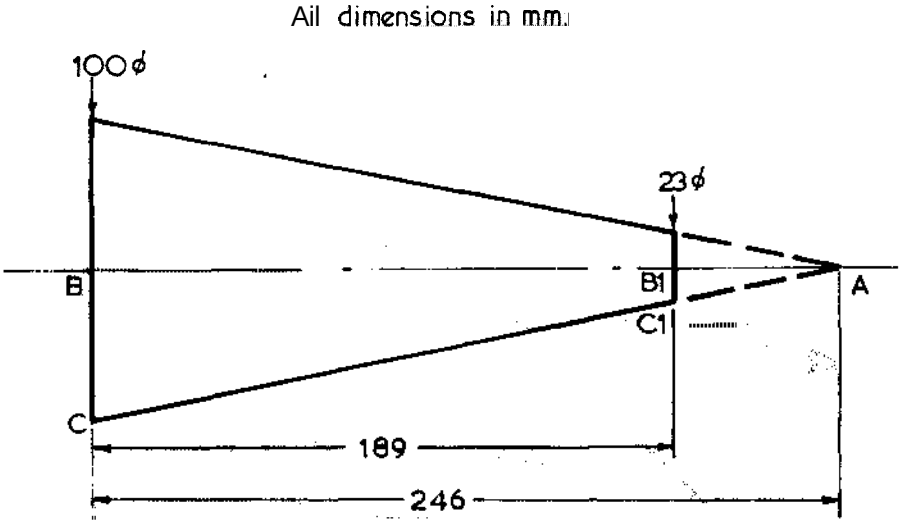


Fig. 4.9 Baffle dimensions.

The result, 1.2510, is in units called **'radians'. To be** of any value to us we must convert it to an angle by multiplying by 57.3° (note 1.0 radians equals 57.3°). This gives the answer $\theta = 71.7°$.

The final check which we should make involves quite a simple calculation. We multiply the baffle cone (or diffuser) taper by $\pi \times 2$. In this example the baffle taper is **11.5°** so the answer is **72.2°.** If all of our calculations have been correct, this figure should be very similar to the angle 0, which we calculated to be **71.7°.**

Now that all these calculations have been made, we have the dimensions and angles necessary to drawn the cone onto the piece of sheet metal from which the cone is to be cut. Actually, I recommend that you first make a template on a piece of stiff cardboard, and then transfer the shape to the sheet metal, as it is much easier to draw accurately on cardboard than on steel.

On your piece of cardboard, mark a cross **(+)** near one corner. Then adjust a pair of compasses to draw an arc, the radius of which will be equal to dimension AC, in this case 251mm. Using the cross as the centre, scribe the arc. Next adjust the pair of compasses to 58mm (dimension AC_1) and draw another **arc,** using the same centre **(+)** as previously. Then draw a straight line through the centre *(+)* approximately parallel with the edge of the cardboard. Position a protractor on the centre **(+)** and mark off the angle 9, calculated to be 72°. Draw a line from the centre through this point and you have the outline of the template. This is shown hatched in FIGURE **4.10.**

Once you have a template you can go ahead and cut out the metal required for the baffle cone. (Note a similar series of calculations are required to get the diffuser cone, or tapered header pipe shape, drawn onto a **template.).** If you have not had any experience with sheet metal, then I would suggest that you take your templates to a sheet metal fabrication shop and get them to cut and roll the cones. When the cones are formed, you can weld all the pieces together, and you have your super home-made expansion chamber.

Actually, it is a little more difficult than that. Exhausts for go-karts, and single

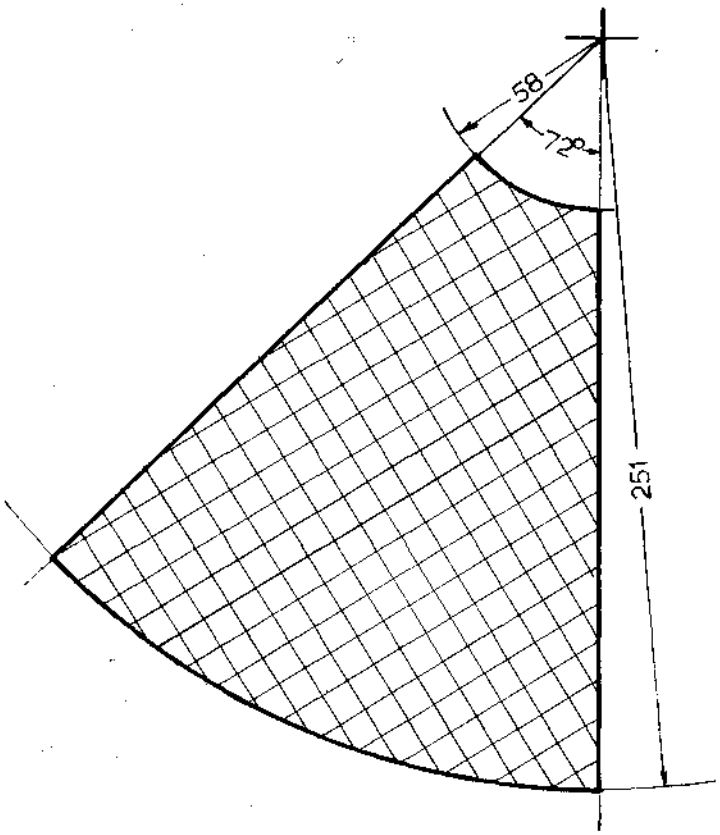


Fig. 4.10 Baffle template.

and twin cylinder road and road race bikes, are fairly straight forward, with the exception of the header pipe. Building a system for a motocross or enduro bike must be one of the worst forms of torture yet devised by man.

The main point to keep in mind, when you set about making the pipe fit, is to keep the header pipe entry into the diffuser cone smooth (FIGURE 4.11) and avoid the temptation to flatten the chamber anywhere. If the header entry is not smooth, gas flow out of the cylinder will suffer because any abrupt change in direction here, where gas velocity is very high, creates turbulence. Flattening the chamber doesn't upset gas flow, although the sonic pulse wave's effectiveness is reduced as any change in cross-sectional shape lowers the pulse's wave energy. Remember that an expansion chamber's basic function is to maintain and preserve the wave energy at a high level, so you will not want to do anything to cause a loss of this energy which is used to evacuate and recharge the cylinder.

While changes in cross-sectional shape affect pulse wave energy, abrupt bends or turns anywhere in the system do not. Sonic waves are willing to follow even the most tortuous curves without any reduction in pulse energy. Therefore, you can cut and resection the cones and parallel belly section to make the chamber fit your bike. The pulse waves will not know whether the system is straight, or bent all over the place.

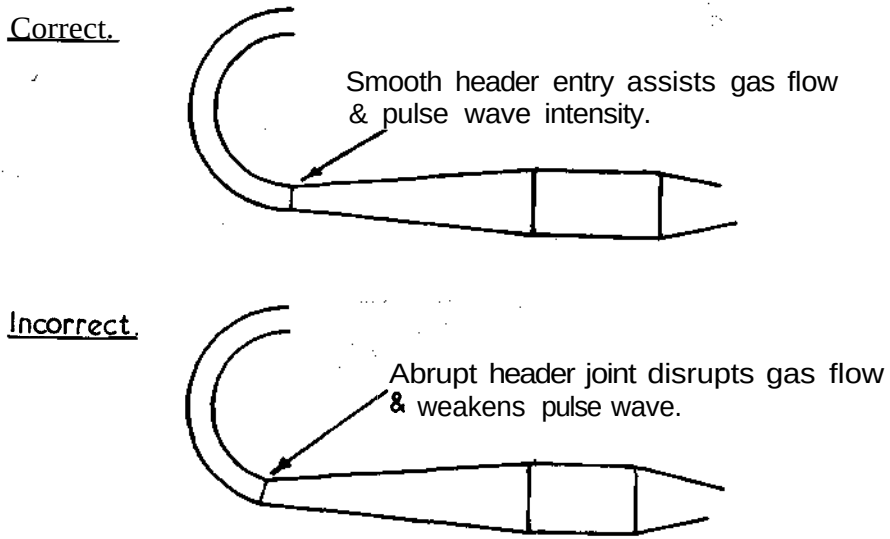


Fig. 4.11 Header joints must always be smooth.

There are two ways to cut and resection an expansion chamber to form a bend: the easy way and the right way. (FIGURE 4.12). When you cut a cone and reweld it the easy way, you will lose out in two ways. First, the length of the cone is reduced, altering the tuned length of the exhaust, and secondly wave energy will be lost as the exhaust gases will no longer be expanding at a progressive 7° (or whatever the cone taper is) along the inner wall of the cone.

The correct method to form a bend is to make the first cut right through the cone and then take the second cut only as far as the cone's centre. When the cone is resectioned, the piece which is cut out is welded into the outside of the bend. This technique keeps the length of the cone, through the centre, the same as it was when straight. There is still some change in the taper of the walls and in the cross-sectional dimensions, however, which will have a small effect on the pulse wave.

The next thing you must think seriously about is an effective muffler. I'm not too happy having to fit mufflers to a road racer, but this is what nearly all sanctioning bodies require. A muffler just adds more weight and knocks the edge off maximum power, also this requirement is just another example of discrimination against motorcycles. Racing cars are not required to be fitted with mufflers and yet bikes, running on the same road circuits and speedways, must be silenced.

On the other hand, I feel every effort should be made to silence motorcycles to a whisper when they are being used on public roads, on private and government land, deserts and reserves etc. The noise of two wheelers in these areas is upsetting a lot of people and driving wildlife back into more remote areas. This is bad for you and all other off-road riders, because every day a few more gates, which were previously always open to motorcyclists, will be closed and locked. If you want your freedom to ride in the places where you are currently permitted to ride, then you are going to have to make sure that the people who live around those areas are free of the noise of your motorcycle.

There are several choices open as to the type of silencer which can be fitted. A few

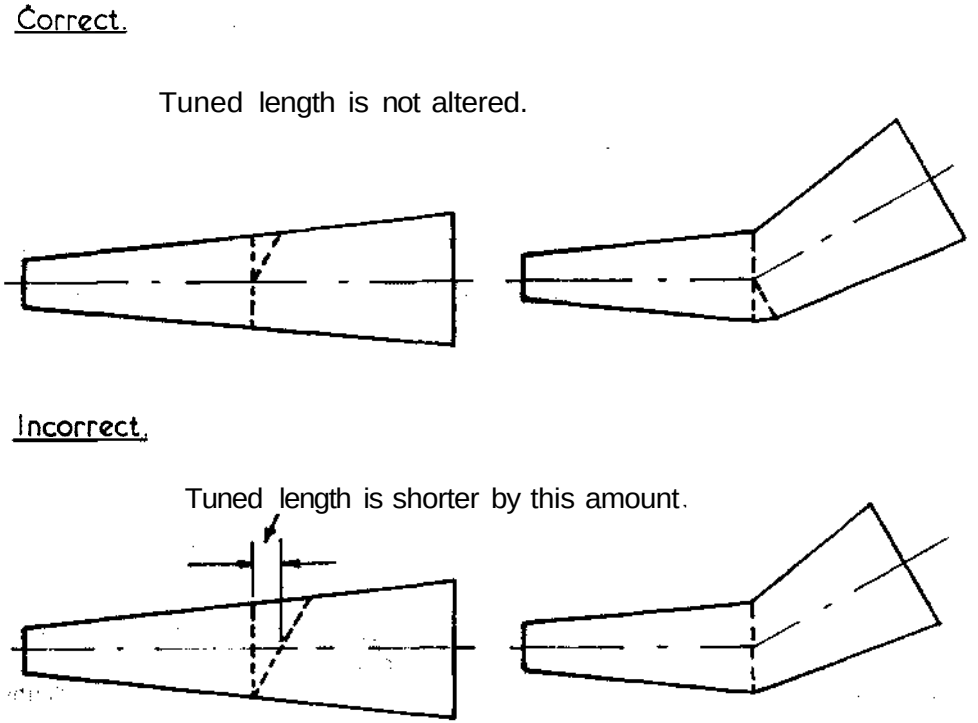


Fig. 4.12 Expansion chambers must be correctly cut & resectioned.

of the aftermarket mufflers are quite good, and relatively trouble-free, providing they are properly mounted to the bike. The Super Trapp is a particularly effective muffler, but I would suggest that you modify it in the same way Can-Am does on their motocross and enduro bikes. Instead of solidly bolting the front and rear sections together, Can-Am use four springs stretched over the silencing discs to hold the muffler together. This allows the silencing discs to work a little more effectively and slows down carbon build-up between the plates. Normally the Super Trapp is supplied with eight discs fitted, plus four spares which may be added if you want a little more power at the expense of more noise.

If you wish, you can make your own detachable muffler. It should be of similar dimensions to the one shown in FIGURE 4.13. To reduce weight and increase the silencing efficiency, consider fabricating a muffler from aluminium instead of steel tube. Steel tends to resonate more readily than aluminium and this reduces the effectiveness of a steel silencer. Riders operating very close to housing estates should seriously endeavour to reduce noise to the minimum by making their muffler double walled. Sliding another piece of tube over the muffler reduces resonance from the inner wall, hence less noise is emitted from the body of the muffler.

Mufflers for road race bikes and karts are best fabricated as part of the expansion chamber. (FIGURE 4.14). As the allowable noise level is reasonably high, usually around 96 dbA, this type of silencer does not have to be so elaborate. Preferably, the main body of the silencer should be 16 gauge aluminium.

 Whatever type of silencer you choose to use, make sure that it can be easily

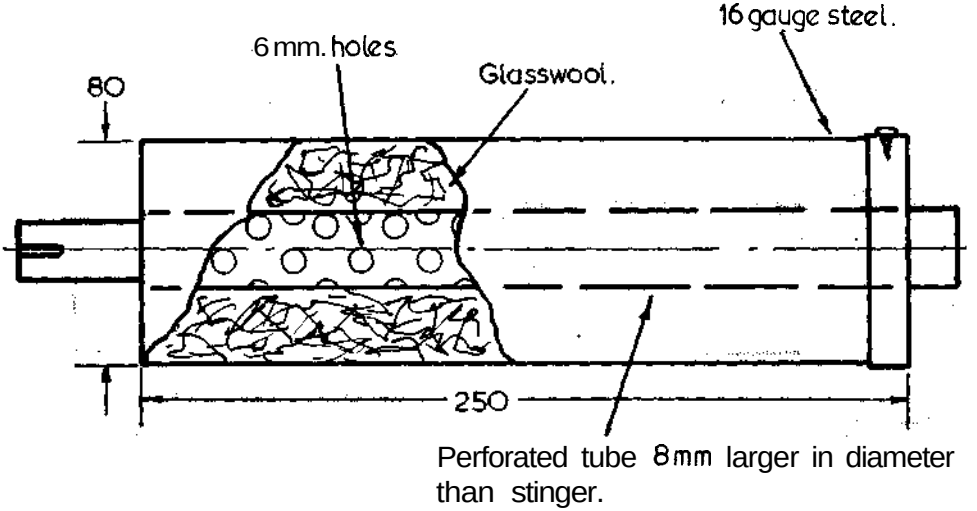


Fig. 4.13 Detachable muffler.

dismantled. Then, when the fiberglass sound-absorbing material is choked with oil and carbon, it can be easily replaced with new fiberglass to restore the muffler to its original silencing capacity.

It is not of much use if your exhaust has a good quiet muffler, but the expansion chamber is cracked and almost falling off because of incorrect mounting. FIGURE 4.15 shows the mounting arrangements that it is advisable to use. You will note in both instances, where the exhaust is attached to the machine by welded brackets, the large area over which the load is supported. This reduces the possibility of the chamber or the bracket cracking. If the mount does start to crack, a length of 6mm rod can be welded into the corners where the mount angles away abruptly from the chamber.

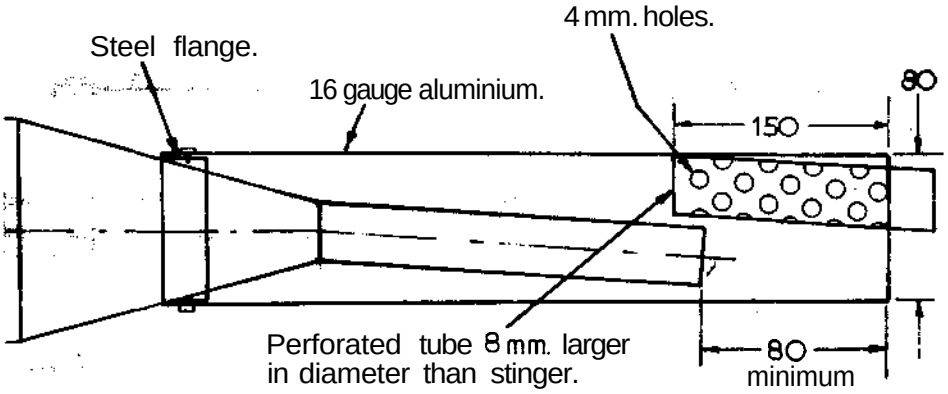
The third method of mounting is the system used by most go-karters. A saddle is fabricated out of fairly heavy steel, usually 4mm thick by 13mm wide, to support the chamber, which is held in place by two springs.

The exhaust flange and joint is also a mount of a kind, as well as being a gas and water-tight connection. Usually, the header pipe is secured to the exhaust flange by either a system of springs or a large flange nut. Whatever method is used, make sure the header pipe will not slip out of the flange in the middle of a race. This means if a flange nut is the method of attachment, it must be tight and properly prevented from loosening by the attachment of two springs from the header pipe to the nut as is done on the older Bultacos.

Most two-strokes use a flexible slip joint connection with the header pipe held into the exhaust flange by two or three springs. The thing to watch here is that the header and flange should overlap by at least 25mm. This reduces exhaust leakage and makes it much harder for the header pipe to jump out of the flange.

FIGURE 4.16 illustrates the two most common types of flexible slip joints. The simpler joint is used by the majority of motorcycle manufacturers for economic reasons. As you can see, if the exhaust port is made the correct diameter, the header pipe is too large, or if the manufacturer makes the header pipe the correct size, the exhaust port ends up too small. The joint I prefer is more complicated and can make

Low restriction muffler.



Low noise muffler.

The basic construction is similar to the low restriction muffler except the perforated tube is packed with glasswool.

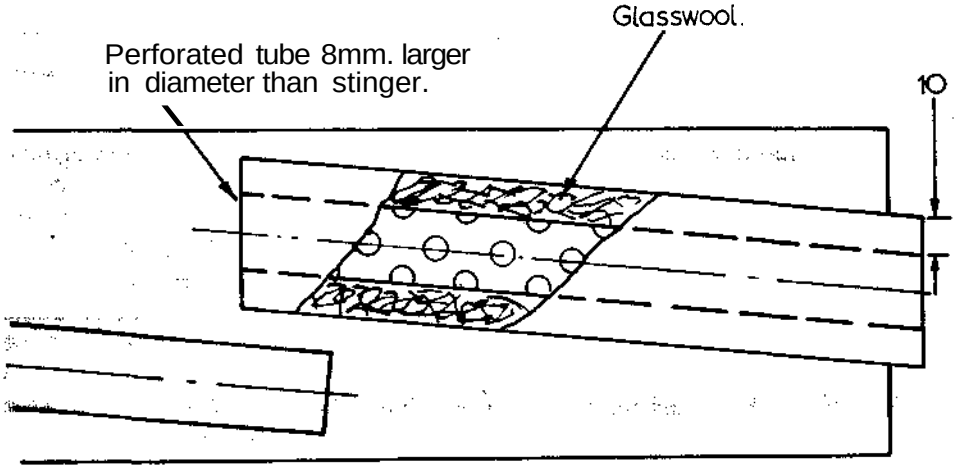


Fig. 4.14 Road race mufflers.

the expansion chamber difficult to get on and off the bike, but it does keep the port and header pipe sizes matched and it reduces leakage at the joint to a minimum.

Many people don't worry too much about exhaust flange leakage, yet every effort should be made to prevent this, as any leakage reduces the pressure in the chamber, upsetting sonic wave speed and changing the tuned length of the system. If the leak is serious enough, the chamber will cease to evacuate the cylinder properly. Instead, the suction pulse wave draws air into the chamber through the leaky joint. Then the pressure wave will push this air up the exhaust port, and into the cylinder. The fuel/air ratio is upset, power is lost and, in severe cases, piston burning and seizure is the end product.

If you are an off-road rider, you don't want an exhaust flange leak for another reason. A leak that gas can find its way through will also often allow water through

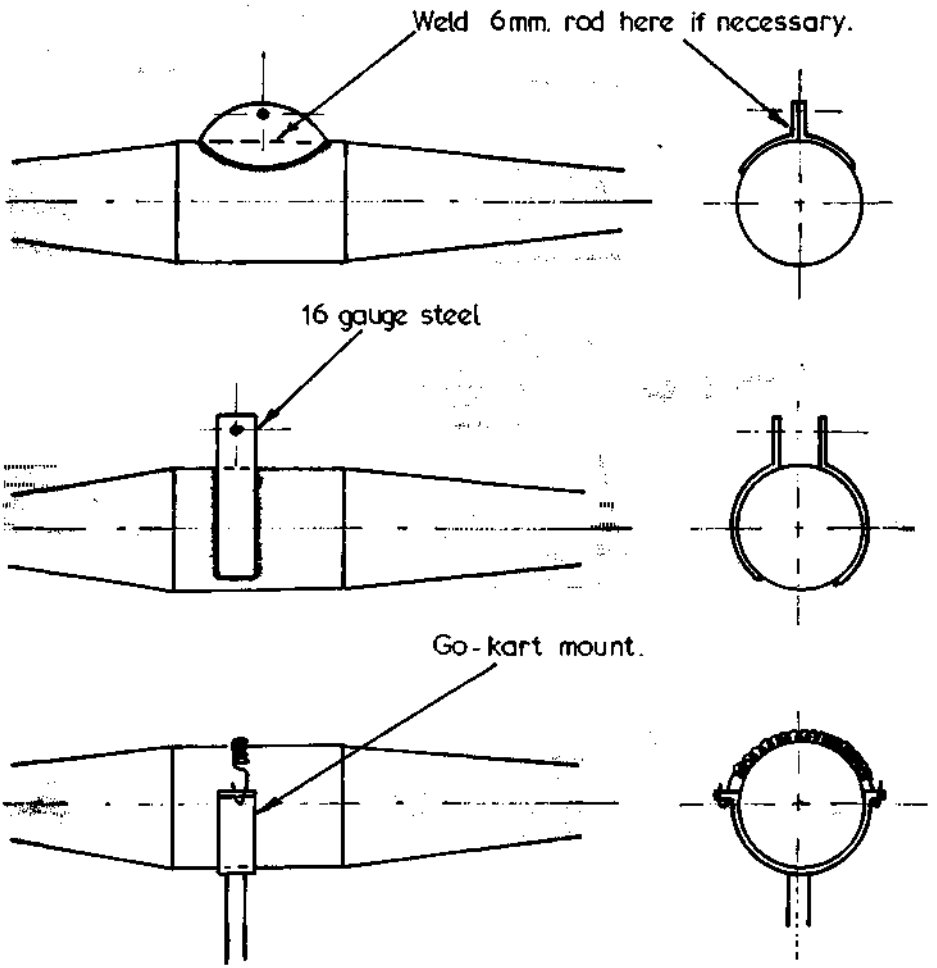


Fig. 4.15 Suitable expansion chamber mounts.

too. Every off **roader,** sooner or later, stalls or bogs in a creek, and when this occurs you don't want water to seep into the motor to worsen the situation in which you find yourself.

All exhaust flanges leak to some degree, but slip joint flanges appear to be the worst, until carbon begins to build up and seal the joint. Unfortunately, racing engines have the barrels and chambers removed too frequently for the carbon to seal properly, so it is necessary to use some sort of exhaust putty to stop leakage. I use Silastic RTV silicone to seal all exhaust **joints.**

Two-stroke exhausts are not a **fit-and-forget** proposition, as they require fairly frequent maintenance to clean out carbon build-up. Depending on the shape of the system, a layer of carbon **1-2mm** thick may form in the header pipe after just a few race meetings and the diffuser and baffle cones usually get a good coat of oily goo at the same time. The carbon and gum deposits upset gas flow by constricting the internal dimensions of the header pipe and by creating turbulence in the system. These effects adversely alter **performance,** therefore the system must be regularly cleaned out.

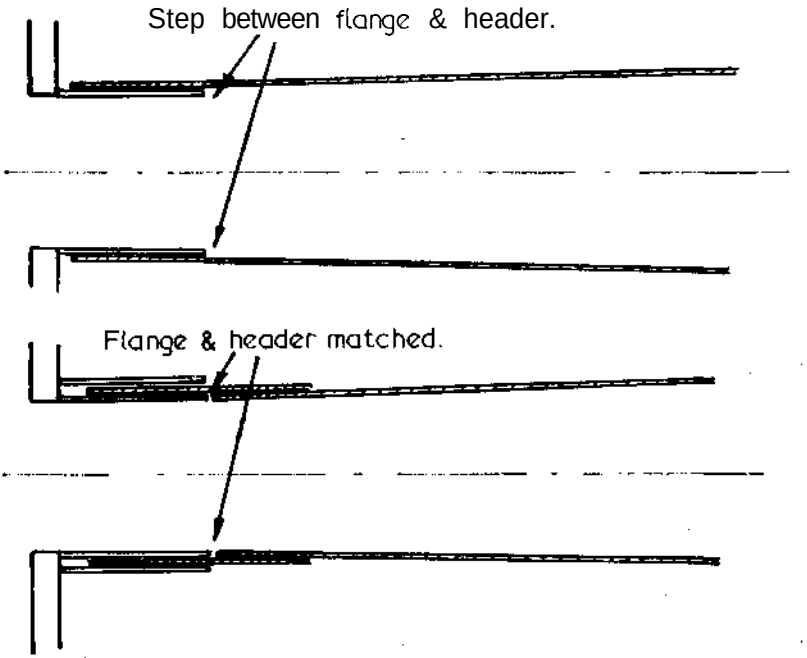


Fig. 4.16 Slip-joint header connections.

Some people use a hot caustic soda solution to scour the chamber internally, but I feel the most effective method is to burn the system clean with either an oxy-acetylene or propane gas torch. This may be done by heating the outside of the system to a red heat and occasionally directing the flame down the header pipe to ignite any oil gum present. If the chamber is made of 16 or 18 gauge steel, it is an idea to tap the chamber quite vigorously with a piece of broom handle as this will help free the carbon clinging to the walls. Wait until the chamber cools a little before you do any banging, otherwise the walls could easily be deformed.

Chambers made of 20 or 22 gauge material are much more difficult to clean, as the heating will often cause the chamber walls to deform slightly, and banging with a stick while the chamber is still hot, to loosen baked on carbon, is definitely out. About all you can do is not use an intense flame, but wait until the chamber is quite cool before attempting to free the burned carbon ash. You can tap the chamber lightly with a rod or you can throw a few rough stones or a short length of chain inside and give it a good shake.

There is something you should remember, and that is to give your exhaust a burn-out in a well ventilated area, and preferably outside your shed. The oil in the chamber gives off foul fumes, which will soon have your eyes watering and your throat hurting, so be warned.

The other part of exhaust maintenance involves a careful inspection for any sign of cracks. These usually appear in the mounting bracket proper, or around where the brackets are welded to the main body of the chamber. Chambers constructed of very light gauge material will often crack along seams in the parallel belly section, as this section tends to pulse in harmony with the system's sonic waves.