CHAPTER 7.

Turbocharger or Supercharger?

All devices that boost the intake charge pressure are called superchargers.
Superchargers that are driven by the residual heat from the exhaust gas are called turbochargers because the machine that drives the air compressor is a gas turbine.
Other externally mechanically driven compressors are usually called superchargers.

The turbocharger and supercharger both perform the function of ramming in the inlet charge rather than allowing it to be naturally induced.
They vary somewhat in their method of operation and both have inherent advantages and disadvantages.

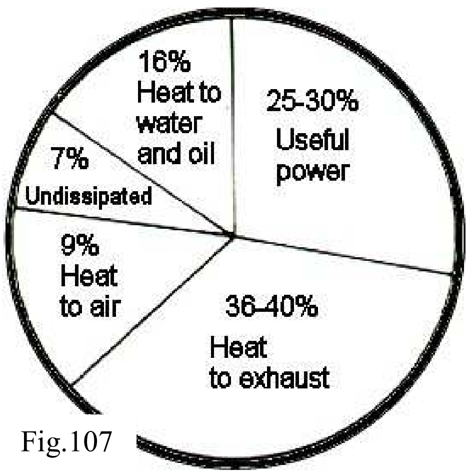
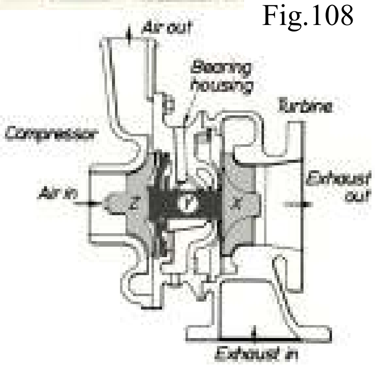


Fig.107

If we look at the power "pie" diagram in Fig. 107, it will be seen that, of every 100% of heat energy put in the form of fuel, only 10-30% actually gets converted into useable horsepower, whereas nearly 40% gets dumped as waste heat, down the exhaust pipe.

The turbocharger uses this energy to drive a turbine coupled to a centrifugal compressor.
This combination is successful because, in order to be compact and efficient, a centrifugal compressor needs to be turned at very high speed, typically around 100,000rpm, and a gas turbine also operates efficiently at those sort of speeds.

Fig.108



The compressor in turn, takes the inlet air, or in some cases the inlet mixture, if the carburettor is upstream, and rapidly accelerates it, causing adiabatic compression (compression at constant volume) in the inlet manifold.

As the inlet valve opens, this pressure drives inlet gas into the combustion chamber.

A typical turbocharger installation and section schematic are shown here. (Fig.108)

A schematic of the way in which it is utilised with the engine is shown in Fig.109.

The high operating speed obviously calls for a high degree of precision in manufacture and servicing and this means that turbochargers are relatively costly and short-lived in small petrol engines.

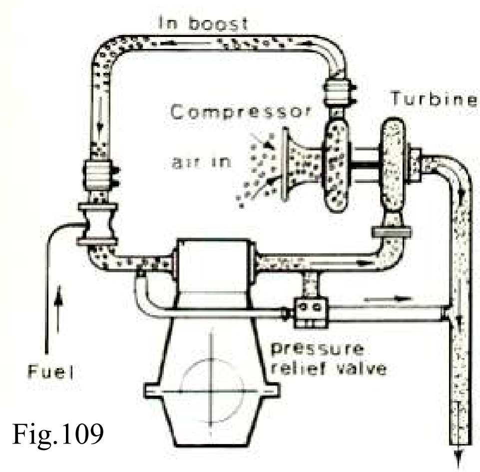


Fig.109

Exhaust Turbo Circuit

They are also deceptively difficult to fit as retro-fit power boosters, as properly engineered systems require complex lubrication and intercooling equipment.

Supercharging compressors which take the form of a "Roots" (Fig.110) or "Vane" pump (Fig.111), use a positive drive from the crankshaft. In fact, these are not true compressors but are positive displacement pumps, which pack in "slugs" of gas faster than the engine can digest them.

Both types carry the gas round between the rotor segments and the casing and force it out opposite the intake.

Roots
Lobe type blower.

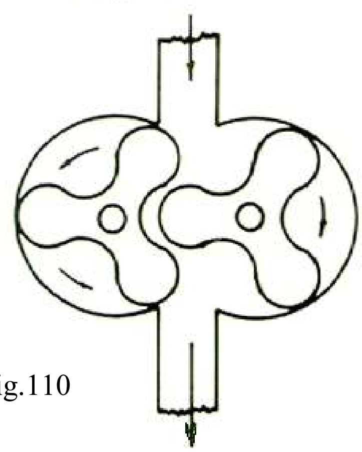


Fig.110

This type of supercharger demands a considerable amount of power to drive it. For example, the supercharger of a 1000 horsepower dragster will be consuming something in excess of 200bhp to drive it.

At first sight of these operating requirements, it would seem that the obvious choice must be the turbo, which apparently offers us something for nothing in terms of power boost.
However, it's not quite as simple as that!

Because the turbo compressor accelerates according to exhaust flow, the boost at low rpm is non-existent and a properly matched turbo will really only work efficiently between mid-range and maximum rpm.
At low speed, there can be a momentary but unpleasant lack of response as the rotors accelerate.
This phenomenon will always be there until the multi-stage turbocharger is evolved, or a method of "secondary combustion" in the exhaust manifold is used to keep the turbine spinning.

Vane type blower

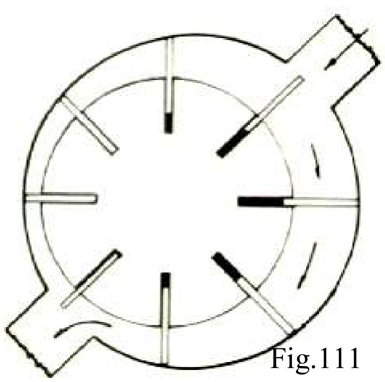


Fig.111

The turbocharger system of operation is fine for engines that spend most of their time in "steady state" operation like long distance trucks, "Indy" cars and power boats, but isn't really acceptable for dragsters that need to come off the line like a rocket.

Single seater circuit racers that constantly need to be changing gears for corners, inducing wildly varying loads, require highly sophisticated intercooling, lubrication and computer control systems.

Certainly, dragsters need the instant response that is available from the supercharger at the moment of dropping the clutch.

Fig.112 Drag bike turbo installation

A common misconception is to believe that “turbo lag” can be avoided, is to raise the engine revs high before the start, in order to get the turbo rotors spinning, but this is not so.
The turbo depends on waste heat energy from an engine on load, to work properly.
Therefore, if the car is not accelerating against a load, then little work is being done; consequently the waste energy to drive the turbo is not being created.

Fitting a Turbocharger/Supercharger.

If the decision to use a supercharger has been made and the appropriate equipment selected, the next step is to decide how to modify the engine to accept the change in power and still remain reliable.

Standard showroom cars supplied with turbochargers already fitted are largely catering to a fashion trend.
The engines are only boosted at very low pressures, about 0.25bar, and then only when the engine is at fairly high crank speeds, so the average “shopping” driver never actually uses the turbocharger and pays his money for the “Turbo” badge on the boot.

It ***is*** possible to just bolt a kit on a standard engine and get a good power boost, but it will only be a matter of time before some kind of mechanical disaster occurs.
Bitter experience has shown that there is only one way to do it, properly.
Strip the engine down and start from scratch. It will be cheaper in the long run....

First consideration is space.
Modern vehicles, whether cars or bikes, have already got quite a lot of hardware packed into the engine compartment.

Fig.113 Positive drive blower on drag bike

Positive drive blowers will need a tooth-belt drive of considerable width, inevitably driving from the crank nose to step the blower speed.

This alone can take up a lot of space that could mean moving a radiator or accepting a reduction in cornering clearance on a bike.

These constrictions make the turbo look more attractive, but remember that turbine rotation depends on a tightly sealed exhaust system between engine and turbine housing.
As the turbocharger will almost certainly call for a different exhaust manifold to facilitate reasonable packaging, then the manufacture of the manifold itself becomes quite a problem.
Ideally, it should be cast-iron, with heavy flat attachment faces that will guarantee a good seal.
O.K. for mass production, but not for one-offs, so it must be fabricated from heavy gauge steel tube and plate to be effective.
A 16-guage steel tube manifold, with buckled and leaking faces, will kill the whole job.

To retain highest efficiency, the turbocharger should be sited on the exhaust side of the engine, so on cross flow engines this means that the compressed inlet gas will have to be piped, either over the top of the rocker or cam box, or round the end of the engine, to reach the inlet ports.

If the carburettor is upstream of the blower, then modified throttle linkage and air cleaner must be considered.
If down-stream, then float chamber fuel and air pressure compensating devices must be fitted, together with all the attendant additional plumbing.

Both types of blower need additional external lubrication supply and return.

Lubrication is critical for the turbo.
With its high rotor speed, and a clear, efficient, drain back is essential to ensure that oil superheating does not take place in the bearing housing.

The oil supply should be tapped off the main gallery, then line filtered if possible, and restricted to a minimum hot flow of 2.0 litres/min. at about 30psi.
Drain-back should be as large as possible, at least 13mm dia., venting into the engine above normal oil level, and with a small baffle if possible.
!NO! The dipstick hole is not large enough!

Both types of system will also need to incorporate some sort of booster pressure control that will relieve either inlet pressure, exhaust pressure, or a combination of both.

For systems boosting over about 0.5bar, an inter-cooler will also be necessary to lower the pressurised inlet gas temperature and avoid detonation.
For the same reason, it may also be necessary to retard the ignition as boost pressure rises.

Engine Modifications for Turbocharging/Supercharging.

The first and most vital step, is to lower the compression ratio.
Any reasonable final power output must depend on a boost pressure of over 0.75bar.
A correctly matched blower, running at this figure, will give a pressure ratio in the order of 1.7:1.
This means, effectively, that if you start with a C.R. of 10:1, then you will be running on 17:1 on full boost… a bit much for the average 98 or even 100 octane fuel.
Indy engines run boost pressures up to 3 or 4bar on alcohol, but petrol engines are very limited by their fuel.

However, working on the basis of 1.7:1 and assuming that an effective ratio of 13 is acceptable, then the normal compression ratio should be lowered to:

$$\frac{13}{1.7} = 7.6:1$$

These figures are still assuming a boost of 0.75bar.
As boost increases the efficiency of the pumping ratio falls, so at about 2.0bar, which is approximately twice atmospheric pressure, the effective compression ratio is not twice the nominal, but about 1.8 x nominal.

This fortunate coincidence means that, for virtually all turbocharged or supercharged applications, the nominal or starting compression ratio should be around 7:1.

The actual process of lowering the ratio will cause more aggravation than any of the other modifications.
The correct way to do it is to fit low compression pistons, but unfortunately they are rarely available.
This forces us into devious alternative methods:

1. Select a suitable piston from another engine, having a lower compression height, i.e. distance from gudgeon pin to crown.

2. Open up the combustion chamber in the head to a sufficient volume.
This is O.K., but be careful not to overdo it by reducing the crown thickness so much that it collapses under combustion pressure.

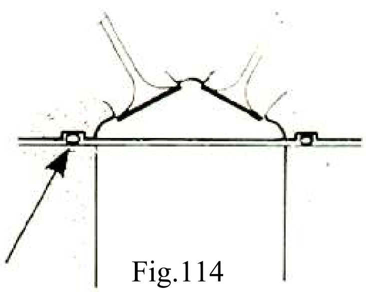


Fig.114

3. Use a compression reducing plate between head and block… not advisable except as a last resort, due to the fact that the plate, usually with a head gasket on either side, acts as a heat flow barrier and will often "cook-up" and cause detonation. If it has to be used, then the only acceptable way is sealed with "Wills" (gas filled expansion) rings, top and bottom. (Fig.114)

With the extended cylinder pressures, head gaskets themselves can be quite a problem and must be selected and fitted with great care.
Block and head surfaces must be absolutely flat and true, with not too fine a ground finish.
Make sure those surfaces immediately adjacent to head stud or boltholes are recessed to properly distribute pressure areas in head gasket.

Again, the ideal pressure seal is a "Wills" ring, recessed into the head.

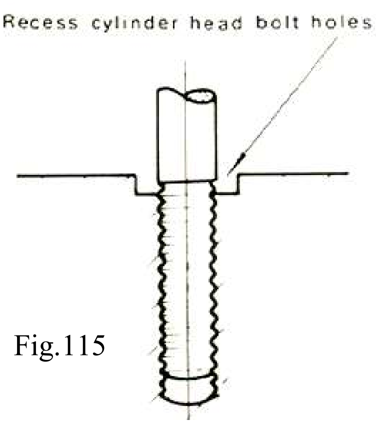


Fig.115

Camshafts for Turbocharged/Supercharged engines.

The way in which both systems produce the extra power is by extending the working pressure time on the piston. It would, therefore, seem logical to delay the exhaust opening time to take advantage of this.
This is, in fact, the case with the supercharged engine and there is not much point in opening the exhaust more than about 8degs B.B.D.C.

However, the need to keep the turbine spinning in the turbocharger is so important that it is worth losing a little of the driving pressure and letting it out as heat energy to do this job.

This means opening the exhaust up to 9degs B.B.D.C., and, in fact, puts up an argument for longer exhaust timings on mild street applications, to keep the turbo spinning at low engine speeds, in readiness for the traffic light Grand Prix.

Similarly, exhaust closing times want to be slightly later for the turbo than for the supercharger, but neither of them wants to be too late or else the pressurised incoming charge will escape from the open exhaust port.

A summary of these arguments is this :
If you refer to the camshaft section page 41 you will see that average exhaust timings, whether for road or race, when worked out with method 3 of timing checks on page 37, gives exhaust valve lift positions from 10degs to 11degs B.T.D.C.
Supercharger full lift position will lie between 11degs-110 B.T.D.C., and will effectively widen the angle between inlet and exhaust lobe centrelines.

Inlet valve timing is influenced in a slightly different way.
Because the inlet charge is under pressure, the flow efficiency of the inlet valve is almost doubled and, consequently, it does not need to be open so long before T.D.C., to get good flow started.
On the other hand, it is not necessary to close the inlet quite so early, because the pressure-assisted inlet flow will overcome the effect of the rising piston more readily than naturally aspirated inlet "ram".
This will result in later than normal inlet full lift positions, which will again result in wider P.D. angles (the angle between inlet and exhaust lobe centrelines).

Although camshaft suppliers should know of these phenomena, and supply cams accordingly for turbocharged of supercharged applications, they are often not readily understood and this information will help the individual tuner to make his own choice.

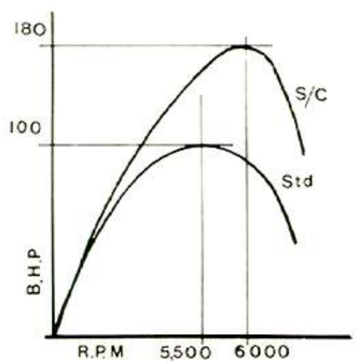
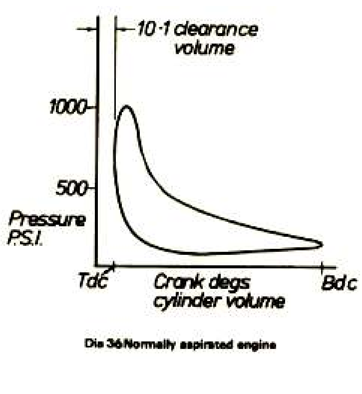


Fig.116

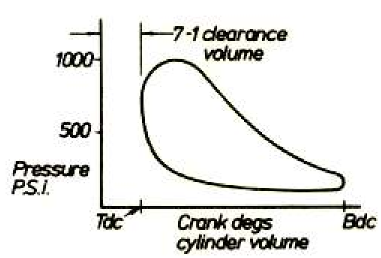
The advantage of choosing the supercharger system is that it does away with many of the detailed and expensive modifications that are necessary to get a similar performance increase from a naturally aspirated engine (with the exception of ultimate race units).
Typically, power boost comes at rpm that are not much higher than standard (Fig.116), which means that there are no great increases in inertia loads and that special valve springs are often not required.

Valves can remain at standard size (although it is often beneficial to increase the exhaust size) and seats can be wider.



Dia 36 Normally aspirated engine

Fig.117

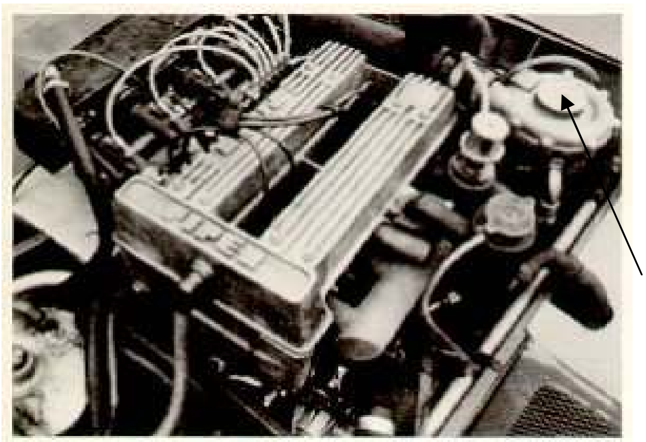


Dia37 Supercharged engine

Pressure energy increases are in time rather than in absolute maximums and standard crank, bearings and rods, providing they are in first class condition, can usually cope. (Fig.117)

Wide power spread characteristics often mean that close ratio gearboxes are unnecessary and the engine will pull high final drive ratios, to give economic road use.

The turbocharger is particularly rewarding, in that it adds the bonus of helping to clean up the exhaust and must surely be worth consideration, as a multi-stage unit, fully integrated with the engine design, for future generation of high performance production cars and motorcycles.



Waiting for the unwary.

The neatly packaged and nicely engineered turbocharger installation in this twin cam race car contains a recipe for disaster.

Turbochargers have special bearings to withstand high speeds and radial loads. This turbocharger is mounted with its axis in a vertical plane.
Not only will the bearing housing fail to drain it’s oil properly but the extra loads on the bearings and seals will cause early failure.