The Patent Files: Turning Vanes

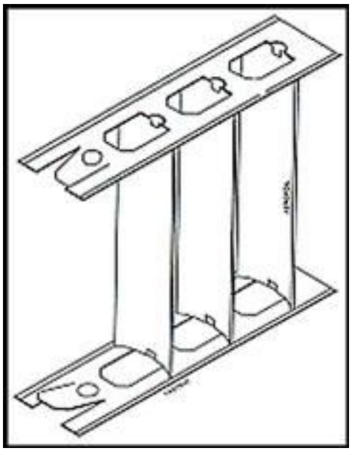
Improving head and intake manifold flows by using tiny vanes to help the gases turn the corners.

The US Patent and Trademark Office

United States Patent No. 5,662,079 was awarded on September 2, 1997. Filed by John Michael Snider (2116 Hobbs Rd., N-7, Nashville, TN 37215), the patent covers a novel way of improving gas flow through intake manifolds and heads.

Click here to jump to an explanation of fluid flow around corners.

Background



Some texts on fluid mechanics refer to a practice developed in the Heating Ventilating and Air-Conditioning industry. This industry has developed a method to lower the loss coefficient of ducts that have zero radius ("mitre-ed") ninety degree turns. Mitre-ed turns occur frequently in the ventilation systems of buildings - they occur wherever a duct turns from the ceiling to go down a wall, etc. This method has improved flow around the mitre-ed turn to the point that the loss coefficient approaches that of an ideal turn, eliminating the need to have an ideal turn with an inside radius that is twice the duct diameter. These mitre-ed ducts use vanes to guide the flow around the turn. "Turning vanes" are centred along a radius line that passes through the centre of the turn. (For a ninety degree turn this is at forty-five degrees).

Turning vanes divide the duct into multiple ducts that have ideal inside radius to diameter ratios, and they provide a surface that forces the molecules in the flow stream around the turn. This external momentum change from the array of vanes eliminates the large pressure and velocity gradients that a turn in a duct without turning vanes develops. Turns equipped with turning vanes almost fully use the duct cross-section and greatly reduce the pressure drop across the turn.

However, these vanes can also be a source of flow loss. The upstream edge of the turning vane will stop flow, creating a stagnant area. Downstream edges that end abruptly and do not allow the flow to recover will form a similar stagnant area. These stagnant areas result in momentum changes leading to pressure drop. However, with careful design, this "bluff body flow loss" can be minimised.

Engines

Inlet air, air fuel mixtures, and combustion products must negotiate many turns and flow around many obstructions while flowing through an engine. Typically, inlet air is ducted from the front of the car, where the air is cool and at high pressure, to an air cleaner. Using turning vanes allows the ducting to be made of smaller diameter components that are more compact. After passing through an air cleaner, the inlet air usually must turn ninety degrees and enter a carburettor or throttle body. Turning vanes will greatly reduce the flow loss from this turn and the entrance losses into the carburettor or throttle body.

Next, the flow from the carburettor or throttle body enters the intake manifold. Unless the manifold has individual runners (a carburettor or throttle body for each cylinder), the flow enters a plenum chamber, or in a dual plane manifold, two plenum chambers. Plenum chambers receive the flow stream from the carburettor or throttle body and distribute portions of the flow to ducts that carry the flow to each cylinder. These ducts are known as runners. Turning vanes can be used to help turn the flow into each runner and to distribute it equally between the runners. Runners also must turn the flow, sometimes in multiple planes, to get the flow to each cylinder's intake port. Vanes will reduce the loss that these turns add to the engine's total loss coefficient.

Flow streams in the intake port of the typical cylinder head are complex. Space considerations result in a rectangular intake port near the manifold. Some engine designs have a protrusion into the intake port to provide room for cylinder head bolts or the pushrods that operate the overhead valves. This protrusion adds additional flow loss. Flow must then pass from the rectangular intake port into a cavity of round cross-section just above the poppet valve, while simultaneously making nearly a ninety degree turn. This round cavity just upstream of the intake valve is known as the intake valve bowl, or simply bowl.

Lastly, the flow encounters the intake valve on its way into the cylinder. Intake valves create large flow losses; the flow stream runs into the head of the intake valve that is perpendicular to the flow. The flow then passes through a narrow annular passage between the valve head and valve seat. Flow stream energy is used to generate high velocities to compensate for the reduced flow area in the annular passage and to turn the side stream flow caused by the valve head. Combined, these effects cause high flow losses.

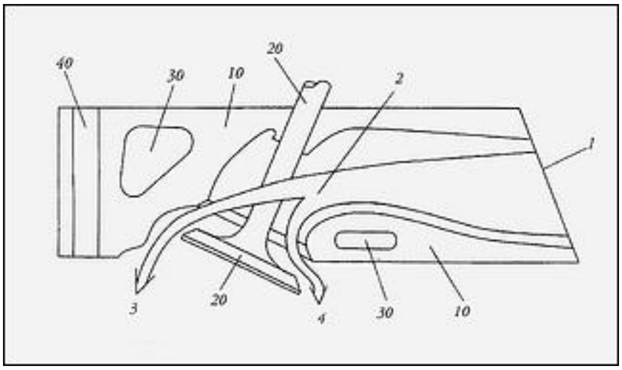
The turn into the intake valve bowl causes a flow pattern like a river bend, where most of the flow passes near the intake port roof just before the turn. Main flow then nears the inside edge of the port bowl at the apex of the turn. Momentum carries the main portion of the flow across the head and stem of the intake valve and out into the cylinder. Flow losses due to the turn, poor utilisation of the available intake valve flow area, bluff body flow loss from the valve stem, and the momentum imported to the flow by the valve head that is perpendicular to the main flow direction all combine to cause large flow losses.

Turning vanes will decrease these flow losses while retaining the current compact design. Suitable turning vanes will assure an even flow across the intake port and minimise flow losses as the inlet stream passes around obstructions and any turns encountered in the head before the bowl. "Transition turning vanes" located in the bowl serve two functions. The first function is to turn the flow from a direction parallel to the axis of the intake port to a direction parallel to the axis of the stem of the intake valve. Secondly, transition turning vanes distribute the flow evenly across the circular bowl as it leaves the rectangular intake port with minimal flow loss. Attaching a circular turning vane to the intake valve will reduce the flow loss caused by the valve on its upstream side.

Similarly, turning vanes improve flow on the exhaust side of the engine. On the exhaust stroke, cylinder movement and residual combustion pressure forces the exhaust gases around the exhaust valve. The valve opening makes flow losses known as entrance losses. Entrance losses are caused by fluid that enters the flow space from the side causing momentum that is not in line with the flow. This causes a vena-contracta - a flow area that is smaller than the valve opening area. Downstream of the vena-contracta, the flow must slow and distribute itself across the available flow area. In piping systems, re-establishing even flow takes a straight length of pipe ten diameters long.

Exhaust ports in an engine make a turn immediately after the valve and flow losses are near the maximum. A turning vane mounted to the stem of the exhaust valve will provide a momentum reaction surface that will spread the flow evenly around the available flow area of the exhaust valve opening. Exhaust valve turning vanes direct the flow stream into the exhaust port transition turning vanes evenly, using the entire area of the valve bowl. Also, an exhaust valve with a turning vane would help the flow stream recover pressure or reduce speed after passing by the seats of the exhaust valve. Turning vanes in the exhaust manifold(s) and in other exhaust system bends with low radius-to-diameter ratios would keep these components small without contributing to total pressure losses. Flow losses would be reduced to a minimum, while volumetric efficiency and specific output of the engine would be maximised.

Examples of Turning Vanes

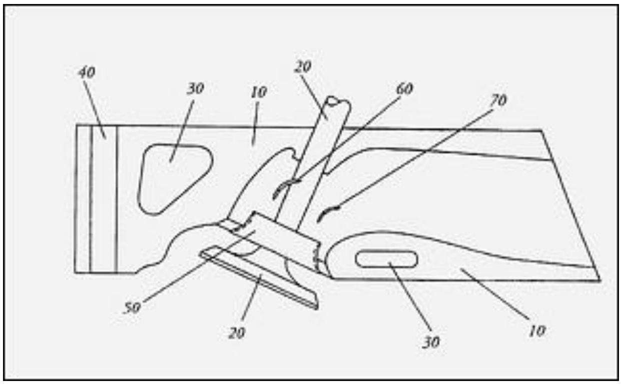


This is a cross-sectional view at the intake passage of a typical cylinder head. A valve (20), cooling passages (30), and a cylinder head bolt hole (40) are also depicted. On the right side is a flow stream that enters the intake passage at a point identified as 1. At 1, the flow stream in an engine should be fully developed - flow that uses almost all of the flow area and the velocity across the area is of the same speed. Manifold design influences how closely the actual flow stream is to being fully developed. Point 2 is where the flow stream splits, and the smaller portion is forced to turn to point 4. The tight turn causes high velocity/low pressure flow at point 2. Low pressure pulls the flow stream to the bottom or floor of the intake passage. The space below, where the valve stem passes out of the top of the cylinder head 10, is not used. Instead, stagnant flow is occasionally swept into the high velocity stream causing momentum loss, causing unrecoverable pressure losses (flow restriction).

The larger portion of the flow stream moves across the valve bowl passing around the valve stem at high velocity, reaching point 4. The valve stem causes bluff body flow losses. Additionally, the flow stream is not distributed evenly around the circumference of the valve, limiting flow potential. Large pressure drops generated by the above flow losses cause incomplete cylinder filling. Maximum flow of air and fuel is not achieved. Besides poor cylinder filling, changing the velocity and pressure of the intake charge will cause the atomised fuel (a petrol mist) to coalesce, forming droplets. These droplets are too large to stay in the flow stream and fall out, resulting in poor combustion and reduced engine performance.

This is the same cylinder head cross-sectional view as above, but it includes three turning vanes. Two upstream turning vanes (60 and 70) turn the flow into the third vane (50). Vane 50 is attached to valve 20, moving with it. Attaching this turn vane to the valve can be done as follows. Use several struts that run radially inward from vane 50 and attach the central ends of these struts directly to the valve by welding or to a bushing that is pressed onto the valve's stem. Alternatively, turn vane 50 can be welded to the head of the valve using suitable aerodynamic support legs.

The upstream ends of the two turning vanes (60 and 70) divide the flow area of the intake passage into thirds. The radius of these vanes and the positioning of the down-stream ends forces the flow stream to distribute evenly over the flow area in the valve bowl, and so into turning vane 50. Vanes 60 and 70 not only reduce the flow losses to near ideal, they also guide the flow stream from a rectangular duct to a circular duct. The force that these vanes apply to the flow stream changes the direction of the flow stream without large velocity gradients, pressure gradients and unnecessary momentum changes. In practice, the number and placement of these valve and cylinder head turning vane(s) may be found by experimentation or analysis to be different from that shown here.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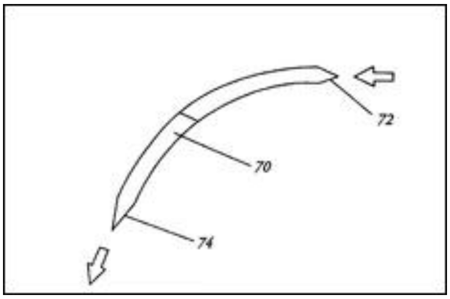
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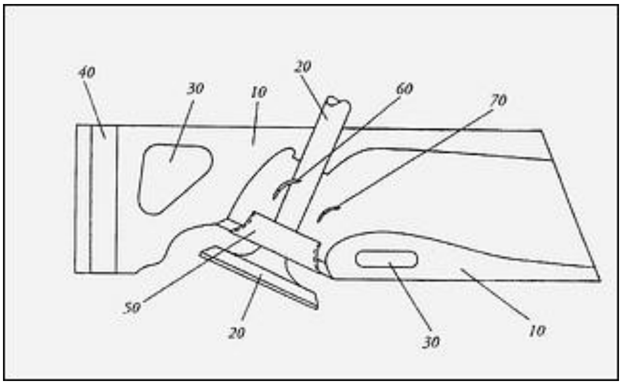
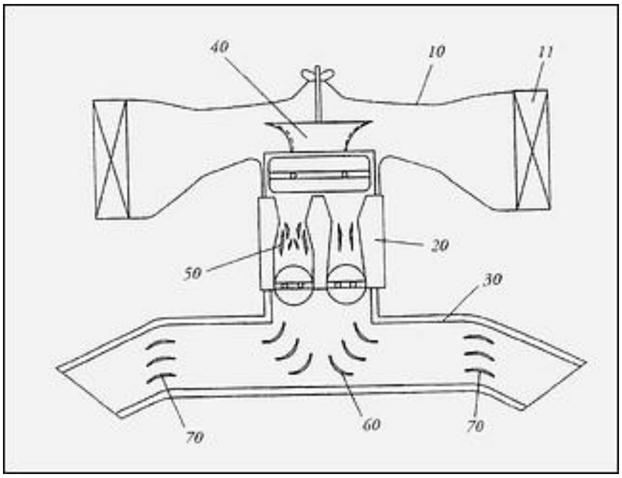
74

This diagram shows vane 70 in greater detail. The leading edge (72) has been angled 22 degrees relative to the direction of the flow stream. Trailing edge flow losses have been minimised by angling the trailing edge to 15 degrees relative to the flow direction. These angles of 22 and 15 degrees, are approximate - slight variations (eg plus or minus two degrees) will not increase flow loss appreciably. Fluid dynamic experiments conducted by the inventor and others have shown that drag, or pressure drop, is minimised when leading and trailing edges are so angled. If the leading edge or the trailing edge angle is less, friction losses are larger. When leading edge or trailing edge angles become larger, pressure losses from stagnation occur and drag (or pressure drop) goes up dramatically.



The valve-mounted turning vane (50) divides into two parts the flow area in the annulus between the valve stem and valve seat of the cylinder head. Vane 50 also forces the flow to turn from a path parallel to the valve stem to one that parallels the valve seats, avoiding unrecoverable pressure losses. Poppet valve pressure loss is similar to orifice plate pressure loss in a piping system. Vena-contracta form downstream of the orifice or valve seats causing reduced effective flow area and higher velocity gradients. Side flow into the stream provides the momentum to form the vena-contracta. Vane 50 will reduce this effect and assure even distribution of flow around the valve.



Cylinder head inlet passage losses are the highest losses on the intake side of the engine due to the combination of the intake valve and eighty degree (approximately) short inside radius turn. Other losses on the intake side of engines are caused by flow stream turns in the intake manifold, carburettor, and air cleaner. Turning vanes can almost reduce these losses to those that occur in a turn of ideal radius. This diagram depicts these flow stream bends and turning vanes that recover much of the flow. An air cleaner (10) with its air filter (11) are shown on top of a carburettor (15) with its choke and throttle plates. The carburettor is on an intake manifold (30) that distributes air and fuel from the carburettor to the multiple cylinders in a "V" engine.

Turning flow losses occur inside the air cleaner where the flow must turn ninety degrees into the air horn of the carburettor; in the plenum where the flow stream to each cylinder must turn ninety degrees into manifold runners; and at bends in each runner. Turning vane 40 *(looking like a bellmouth - Editor)* provides a surface that forces the air around the turn into the carburettor with minimal pressure and flow loss. A secondary benefit derived from vane 40 is that the flow will be approaching the venturi of the carburettor straight on, eliminating any turning losses that were occurring inside the carburettor. While one vane is depicted, it may be found by experiment or calculation that more vanes placed differently will further improve the flow.

Once in the carburettor, air passing through the venturi is forced to flow in a smaller diameter where it gains velocity, causing the pressure to drop. This low pressure zone is used to pull in fuel. As the air and fuel leave the vena-contracta, the flow must slow and distribute across the increasing area of the lower part of the venturi. The angle of the recovery portion of the venturi cannot exceed nine degrees or separation, eddying, and flow losses will occur. Conical turning vanes 50 (they are shown in cross-section) may be used to increase this angle and make carburettors more compact. As shown in the figure, the lower portion of the venturi is approximately half as long as the conventional venturi shown on the right.

Air and fuel from the carburettor enter the manifold, where in many engine designs, the flow must make a mitre-ed ninety degree turn. Tuning vane 60 is one of the six vanes shown which turn the flow leaving the plenum and passing into two intake manifold runners leading to two cylinders in a multicylinder engine. This known as a single plane manifold. Other manifold types will flow more fuel and air at comparable pressures if they, too, have similar turning vanes - particularly "H" pattern dual plane manifolds, which are found on most production V8s.

In the intake runner, the flow stream must pass several bends in different planes on the way to the cylinder head. Turning vanes 70 guide the intake runner flow around such a bend. Some intake manifolds have bends that turn the flow in two planes simultaneously. Turning vanes for each plane of such a turn are needed to achieve near ideal flow. Again, different numbers and arrangement of the turning vanes than shown here may yield lower pressure losses.

The development work has just scratched the surface of the potential. Exhaust gas flows occur at much higher pressures and velocities; creating vary large resistance to flow. High pressures at the end of the exhaust stroke leave more residual exhaust mass in the cylinder. Intake valve opening occurs during this point in the engine operating cycle. Exhaust and Intake flows interact with flow reversions and mixing. This contaminated charge does not burn well causing pollution and poor performance. Reducing exhaust flow losses should have a large impact on engine performance.

Getting Around the Corner

Flow in a curved duct is subjected to centrifugal force. For a given velocity, the fluid molecule is subjected to the least force by staying to the outside of the duct. However, this does not occur. A second force is also at work. The curvilinear velocity component that develops while the flow is turning, causes a second force. A pressure drop, due to this turn-induced velocity, is the source of this second force. Bernoulli's equation (a special form of the energy equation) relates kinetic energy to potential energy. In a fluid system this potential energy is pressure and kinetic energy depends on the square of the velocity. Therefore, the local pressure drops with the square of the velocity increase. Low pressure, from the turning velocity component, pulls the flow to the inside wall of the duct. Turning accelerations are highest at the beginning and end of the turn. While turning velocity peaks at the middle of the turn. When conditions are right, a balance occurs between these two forces.

Usually, centripetal and hydrodynamic forces combine to cause a flow regime described as follows. At the beginning of the curve there is a pressure increase that accelerates the flow to the outside of the turn. Reduction in flow area occurs and creates a high speed jet. Particles on the outside of the turn must go further because the radius is larger and the path they cover on the outside is longer. Together, this means the outer flow must go faster, but with this speed, comes a pressure drop that pulls the flow to the inside of the turn. As a result, the flow ends up on the inside of the duct at mid-turn. The high velocity flow then rushes across the duct to the outside wall where the flow slows, recovering pressure and redistributing across the duct area. Three volumes of stagnant flow develop. First, is the upstream stagnant zone on the inside of the turn. Second, is the mid-turn one on the outside of the duct. The last one develops on the inside of the exit of the turn.

This flow pattern is readily seen in a river. Just before a bend in the river the flow is on the bank opposite the turn. Half way through the bend, the flow is against the bank on the inside of the bend. The main part of the flow then moves back to the outside bank downstream of the bend. *(Maybe - but why then is it the outer bank that erodes, with deposition occurring on the inner bank? - Editor)*

This description of a typical flow regime is one that is not ideal. Curvature of the duct is too tight and centripetal accelerations and velocity accelerations are out of balance. High flow losses occur due to energy used to speed up and slow portions of the total flow. In addition, some slow-moving flow in the three stagnant areas is continually swept into the main flow stream, causing momentum losses.

Further complicating any analysis of corner losses is friction. Flow near the walls of the duct is stopped due to surface roughness and molecule interaction. A boundary layer develops as molecules rub past the stopped ones on the wall and continue. The boundary layer stops at the point away from the wall that the velocity is the same as the flow in the centre of the duct. Velocity, fluid viscosity, duct roughness, and duct shape effect this boundary layer thickness and determine its impedance to flow.

A round duct will develop secondary flow circulations. These flows result from the differences in the radius of curvature around the circular cross-section of the duct. Similar secondary flows also may develop in rectangular and other none circular duct cross-section shapes due to corner interaction. Secondary flows are yet another source of flow impedance.

When the curvature of the duct is ideal - the curvature with the least resistance to flow - the centrifugal forces balance the pressure gradient developed in the flow and flow separation from the walls of the duct does not occur.