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SLEEVE VALVE ENGINES

By DONALD T. JOHNSTONE, '29



THE advent of the automobile into modern industry has given rise to extensive research and experimental work on valves and valve gear for the internal combustion engine, consequently, we may classify our present automobile engines by the type of valve and valve gear with which they are equipped. The two prevailing types are the poppet valve and sleeve valve with their respective gear. Of the many sleeve valve engines on which patents have been taken out, only two have come into extensive commercial use: the double sleeve valve, invented by Charles Y. Knight, an American automobile engineer; and the single sleeve engine, invented by P. Burt, a Scotch engineer.

Charles Y. Knight was the pioneer of sleeve valve engine design. In 1905 Knight began work along this line and built a car equipped with the first sleeve valve engine. His principal desire was to eliminate the noise which the poppet valve engine created, for at this early stage of motor car development many of the poppet valve engines were made with much of the valve train outside of the case so that the noise of metallic surfaces coming into contact with each other could not be muffled. At the time the Knight engine was invented, the best engines were very noisy even though operating speeds were low as compared with out present engine speeds.

The sleeve valve design was not considered practical by American manufacturers at this time; but after convincing tests Knight succeeded in selling his British rights to the Daimler Motor Company, of Coventry, England. The Daimler Company was the largest producer of expensive motor cars in England, consequently it occupied a very important place in the British motor car industry. Immediately following the adoption of the sleeve valve engine by Daimler, Knight placed his rights with one manufacturer in each of the principal countries of Europe. The Mercedes concern secured the German rights, the Minerva Company of Antwerp the Belgian rights, and Panhard-Levassor of Paris the French rights. These firms were recognized as the foremost in motor car manufacture in Europe, so his success with these firms created a great interest throughout the automobile industry of the world. The British Daimler concern adopted the new engine for their total production and in 1908 exhibited models equipped with this engine at the London show, but the other European manufacturers turned only a part of their production to the Knight engine.

After his striking success in Europe, Knight returned to this country, where he planned to place his patents with four manufacturers, instead of one as in each of the countries of Europe. The licenses were eventually placed with the F. B. Stearns Company, the Columbia Motor Car Company, the Stoddard-Dayton Company, and the Moline Automobile Company. These four licenses are now controlled by the Willys-Overland Company, the F. B. Stearns Company, the Sterling-

Knight Company, and the Yellow Sleeve Valve Works. Of these, the Willys-Overland Company is the largest producer.

The single sleeve valve engine invented by P. Burt and commonly known as the Burt-McCallum, or Argyll engine, is now used in Europe but promises to become an extensive American product due to the acquisition of the basic patents by the Continental Motors Corporation, of Detroit, Michigan.

As its name implies, the distinguishing feature of the Knight double sleeve engine is the valve construction. The valve functions are performed by two concentric ported sleeves which are placed between the cylinder wall and piston. These sleeves are given a reciprocating motion past ports in the cylinder walls to admit and release the gases. Each sleeve has an exhaust port on one side and an inlet port on the opposite side, the passage for either the inlet or exhaust being open when the three ports on a particular side are in registry. As the sleeves move upward they pass into an annular space between the cylinder wall and an especially constructed cylinder head so that during the compression and power strokes the gases do not come into contact with the cylinder wall, but are separated from it by two layers of cast iron and two films of lubricating oil. The inlet passage begins to open when the bottom edge of the port in the outer sleeve, moving downwardly, passes the top edge of the port in the inner sleeve, also moving downwardly but at a slower rate. The inlet passage closes when the bottom edge of the port in the inner sleeve, moving upwardly, passes the top edge of the port in the outer sleeve, also moving upwardly. This passing of the edges of the ports in the sleeves takes place while they are opposite the inlet port in the cylinder wall. The inlet ports of the two sleeves also come into registry 360 degrees of the crank motion later, when the piston has started on its power stroke, but these ports are then high up between the cylinder wall and cylinder head, and the port in the inner sleeve is sealed by a ring in the cylinder head. The strokes of both sleeves are alike, but the lengths of their connecting rods are different.

Sleeve valve engine ports can be made larger than is consistent in poppet valve engine design due to the fact that the sleeve valve engine produces less noise when operating. The fact that exceptionally large port area can be obtained with the sleeve valve never has been an important factor in the design of American racing car engines because these engines are not designed for quiet operation. The desired port area can be obtained with the poppet valve if the noise they make is no objection. To obtain maximum efficiency with the poppet valve, the lift should be one-fourth the clear diameter and rapid, but this construction is not adhered to except in racing engines where the height and lift are determined only by the physical properties of the metals. At

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moderate speeds the specific output of sleeve valve engines is apparently about 15 per cent greater than poppet valve engines.

The sleeves are operated by their connection to an eccentric shaft which is driven from the crankshaft at half engine speed. The stroke in the older type engines at least, was from 1 to 1¼ inches. The reciprocating motion of the valve mechanism creates a problem of balance in this engine and the speed of the original Knight engine had to be kept comparatively low because of the inertia of the sleeves, but refinements in the sleeve construction have cut down weight so that now the sleeve valve engine can be operated at speeds equal to the average poppet valve engine. Tests have shown that the power required to operate the valve gear does not lower the mechanical efficiency of the engine to any appreciable extent, although greater starting torque is required due to congealed oil on the surface of the sleeves. The distinguishing point about the valve gear is that the valves are positively operated and valve timing is therefore absolutely independent of the speed.

The construction of the combustion chamber and cylinder in the Knight engine allows a greater percentage of heat energy, released by combustion, to be transformed into useful work than the construction of the conventional poppet valve type allows. The proportion of heat which passes into the cooling jacket varies with the ratio between the cooling area and the volume of the combustion chamber. It is important to have the cooling area as small as possible during the early part of the power stroke as the gases are then at the highest temperature and they lose energy to the cooling jacket most rapidly. From this point of view, the most favorable form of combustion chamber is a sphere and this form is more closely approached in the Knight engine than any other. Measurements, made by Professor Riedler of the Charlottenburg Technical College on three different models of sleeve valve engines, showed the difference in heat loss to the water jacket to be from 4.9 per cent to 11.2 per cent less in sleeve valve engines than in poppet valve engines.

Conservation of heat in the working fluid during the power stroke is due not only to the relatively small extent of combustion chamber wall surface but also to the nature of this wall surface. At the beginning of the power stroke less than half of the combustion chamber wall surface is directly exposed to the water jacket, this being the under side of the cylinder head. The rest of the combustion chamber is separated from the cooling jacket by three layers of metal and two oil films. The two sleeves and two oil films undoubtedly furnish better insulation from the water jacket, even though the exact amount is unknown.

The slower rate of heat flow to the cooling jacket might be expected to cause trouble from overheating. In the conventional engine there are three points that usually reach temperatures above the average of the combustion chamber wall, the exhaust valve head, spark plug, and piston head. In the Knight engine there is no ex-

haust valve head; the spark plug is so surrounded with water that it is sufficiently cooled; and the piston head has never given any undue trouble. Compression ratios are as high in the present sleeve engine as in any poppet valve engine, so it seems that this saving of heat tends to greater mechanical efficiency.

Formerly, lubrication of the sleeves was the greatest problem in the sleeve valve engine design because, with the original splash lubricating system, the oil would not travel upward along the surface of the sleeves. At the present time, some makers have installed pressure lubricating systems which have overcome the original troubles, and others that depend on the splash system, have provided holes and grooves for oil reception and distribution. Refinements of the past few years have practically eliminated the objections to the sleeve valve engine due to lubrication difficulties.

The latest models of the Daimler motor cars are equipped with steel valve sleeves, and due to this fact an increase of power has been secured which places this particular sleeve valve engine on a level basis at least as high as the best of poppet valve engines intended for normal use. The Daimler Motor Company manufactures four different engines ranging from 114 cubic inches piston displacement developing 55 brake horsepower, to 350 cubic inches displacement developing 120 brake horsepower. The power increase in each case is at the top of the speed range and results partly from the higher speeds made possible by the use of steel valve sleeves. The steel sleeves, which are about half as thick as the usual cast iron sleeves, have white metal contact surfaces applied by centrifugal process. The other factors tending toward the power increase are, the larger and rectangular valve ports permitted by the use of steel sleeves, the increase of compression ratio, and the use of pressure lubrication. Formerly, a smoky exhaust was noticeable, but Daimler has overcome this difficulty by the use of baffle plates below the sleeves.

Panhard-Levassor of Paris has developed the original Knight engine to a high degree of operating efficiency until it now embodies many features for which the French firm holds patents. They have recently placed a 450 horsepower aviation engine on the market that successfully passed the 240-hour French government test. This engine was the first Knight type aviation engine to be successful in public competition. It was a 12-cylinder, V-type at 60 degrees and because of the absence of overhead valve gear the height was only 35.4 inches. This compares with heights of 47 to 49 inches for poppet valve engines, with overhead camshaft, of equal power.

The use of steel sleeves, in place of cast iron, has been general in Panhard-Levassor automobile and aviation engines for the past four years. The steel sleeves give the advantage of less weight, reduced vibration, and economy in oil consumption by reason of the smaller clearances which they render possible. The present steel sleeve is only 1.5 millimeters thick while the usual cast iron sleeve was 4 millimeters thick. The port area also can be increased almost indefinitely without having to increase the depth of the com-

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pression rings in the cylinder head. Apart from the use of sleeve valves, the outstanding feature of Panhard-Levassor engines is the white metaling of the inner surface of the outer sleeve and the walls of the steel cylinder.

Belgium recently adopted a Knight sleeve valve engine built by the Minerva Company for use in government aviation service. Belgium's choice of this type of engine shows that the double sleeve valve engine is making an important bid for service in aeroplanes in Europe.

The first notable test on a sleeve valve engine was made in 1909 before the Royal Automobile Club of Great Britain on a 4-cylinder Daimler engine of $3\frac{3}{4}$ -inch bore and 5-inch stroke. This engine was first placed on a bench and run continuously for 5 days 12 hours and 58 minutes at 1,000 feet per minute piston speed where it developed 38.83 average horsepower with a fuel consumption of 0.668 lb. per horsepower hour. After this test it was placed in a 3,300-lb. car, driven 2,143 miles at an average speed of 41.88 miles per hour, then again placed on a bench for 5 hours' time where it developed 38.96 average horsepower on 0.667 lb. per horsepower fuel consumption. Inspection showed no appreciable wear on fitted surfaces and that the cylinders and pistons were notably free from carbon.

The first run of any importance in America was made in 1913 in New York City by a Moline-Knight 4-cylinder engine of 4-inch bore and 6-inch stroke. At the end of a continuous run of 337 hours under full load, the engine was examined for wear and carbon and found to be in perfect condition.

Parallel to the adoption of the Daimler-Knight by the London General Omnibus Company, which as early as 1914 had 2,600 buses in daily use in London, was the adoption of the Moline-Knight by the Fifth Avenue Coach Company, of New York City, and the Chicago Motor Coach Company, of Chicago. More recently, the Knight, after a long period and carefully observed test in 125 taxicabs, has been adopted as standard by the Yellow Cab Company, of Chicago. The cabs of this company averaged about 45,000 miles each last year.

Since its invention, the sleeve valve engine has proven very satisfactory under endurance, power, and economy tests, but it has only been within the last three years that the speed of the sleeve valve engine has rivaled that of the poppet valve engine. Comparatively recent speed tests have proven that the Knight will equal the poppet valve in this field. A 4-cylinder Panhard-Levassor engine of $3\frac{3}{4}$ -inch bore and $5\frac{1}{2}$ -inch stroke, on Montehiry track, has established the following records: 50 kilometers at 114.1 miles per hour; 50 miles at 115.06 miles per hour; 100 kilometers at 115.19 miles per hour; and a distance of 115.4 miles in one hour. This engine was capable of turning up to 5,000 revolutions per minute. A Voisin-Knight set a world's record for six hours of just over 600 miles, and in November, 1925, this French car averaged 107 miles per hour for 500 miles.

The Burt-McCallum, or Argyll, sleeve valve engine is distinguished by having a single sleeve to perform the valve functions instead of two sleeves as used by the Knight engine.

The sleeve has a number of specially shaped parts at the top and a single universal driving connection at the bottom. Two exhaust and two inlet ports appear in each cylinder while each sleeve has but three ports, the middle port of the sleeve serving alternately as inlet and exhaust openings. On the intake stroke the middle port in the sleeve uncovers one of the inlet ports in the cylinder and vice versa on the exhaust stroke. The exceptionally big valve ports permit complete filling and scavenging of the cylinder without any of the lubrication difficulties attending other types.

The sleeve is actuated by a short shaft consisting of a disc with an eccentric pin on the end engaging in a universal joint at the bottom of the sleeve. This disc is driven by means of a skew gear from the valve shaft, the equivalent of a cam shaft on the poppet valve engine. The disc, rotated by the valve shaft and eccentric pin thereon, imparts to the sleeve a combined vertical and horizontal travel, as the universal joint allows the sleeve freedom to partially rotate on its axis. The resultant path of the sleeve is elliptical. Each cross shaft is run at half engine speed, therefore the ports in the cylinders are uncovered by corresponding ports in the sleeve once in a complete revolution of the valve shaft, or two revolutions of the crank shaft. The action of the sleeve valve is positive at all engine speeds and improves with use.

The popularity of the sleeve valve engine is rising. This fact is especially noticeable in the European automobile and aeroplane industries, but at this time some of the largest manufacturers of poppet valve engines in America are experimenting with various types of sleeve valve engines. This fact promises a more general adoption of the sleeve valve principle in our American cars of the future.

At the present time sleeve valve equipped cars cost more money than corresponding poppet valve equipped cars; they are slightly harder to start in cold weather due to the large sleeve surfaces being covered with congealed oil; and the engines may be badly damaged if operation is attempted without sufficient quantity, or the right kind, of oil. These disadvantages are apparent, but they are gradually being overcome and there is no doubt that they will be practically eliminated in the near future. The advantages of the sleeve valve engine, however, are such that its growing popularity is well deserved and we may expect to gain by using the sleeve valve engine: greater fuel economy, because it is practical to use higher compression, less heat is lost to water, and there is less valve leakage; increased power, because of improved sealing with carbon; quiet operation, because of continuous, regular valve action with no metallic surfaces making contact; greater mileage without mechanical attention, because of no valves to grind or adjust; less trouble from carbon, as pistons and cylinder heads keep notably free and seldom need cleaning; and less dilution of crank case oil, because of higher operating temperatures.