A SHORT HISTORY OF THE GAS TURBINE

by

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During the last ten years, in the specialized application of power units for jet-propelled aircraft, the gas turbine has undergone intensive development and has been brought to the quantity production stage. This short sketch attempts to show, in correct perspective, the development of the gas turbine up to the time when it was applied successfully to aircraft, since a knowledge of the obstacles encountered in the past contributes to an appreciation of the factors involved in a successful gas turbine design.

Most of the basic patents had been granted a century ago and the gas turbine has been a workable proposition, but not an economic one, almost as long as the steam turbine. The two major factors which prevented a much earlier realization of the practical gas turbine were the lack of efficient rotary compressors and of materials suitable for conditions of high stress and temperature. The aerodynamic knowledge necessary to design efficient rotary compressors was not available until recent years, and this led to metallurgical research directed towards high-temperature materials.

Early Ideas

The gas turbine has probably received more attention from inventors than any other kind of machine, and patents in this field running into thousands have been granted. The first patent covering the gas turbine was British Patent No. 1833 of 1791 granted to John Barber, which included all the elements of the modern gas turbine. Gas distilled from coal or oil was pumped into a combustion chamber where it was mixed with compressed air and ignited, the resultant gases being expanded in a jet against a turbine wheel. To prevent overheating the turbine parts provision was made for cooling the gases by water injection ; the compression of the air and gas was to be by reciprocating pumps. The fanciful drawing of the patent specification makes it fairly certain that this machine was never built but the completeness of the basic gas turbine requirements in this patent of 150 years ago is truly remarkable. A later patent of less merit was that granted to John Dumbell in 1808. The turbine consisted of a rotor with 11 rows of moving blades ; there were no stator blades and the products of combustion of coal, mixed with steam, traversed the rotor. The idea of compressing the air before combustion was not included in this patent.

Breeson of Paris in 1837 designed a plant in which a fan delivered compressed air to a combustion chamber where it was mixed with gaseous fuel and burnt. The products of combustion, cooled by excess air, were directed against a turbine wheel. Many patents were granted about this time for turbines driven by mixtures of products of combustion and steam ; typical of these was the patent of 1850 granted to W. F. Fernihough. In a refractory-lined chamber, fuel was burnt on a grate with air delivered from below. Water was sprayed on to the fire-grate from above, and the mixture of steam and gases was delivered through a nozzle on to turbine vanes.

Hot-Air Engines

At this time a number of hot-air engines were made, and though they were reciprocating machines and not gas turbines, they deserve mention by virtue of the

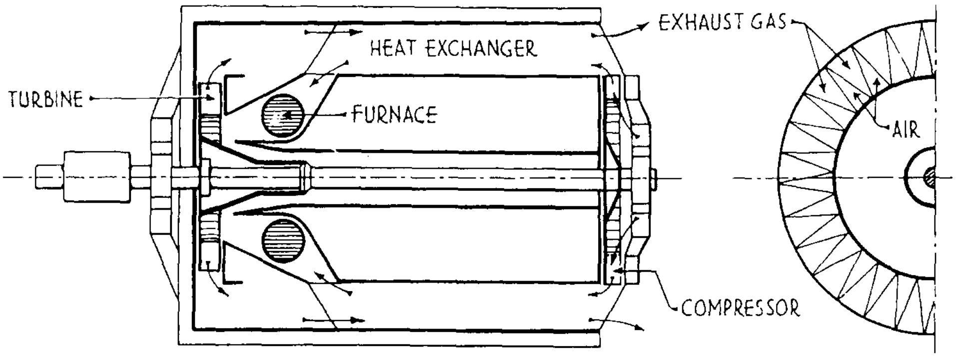

FIG. 1.—MENNONS PATENT (1861)

heat cycles on which they worked, which were very similar to the modern gas turbine cycles.

The Cayley engine of 1807 and the Ericsson engine of 1850 worked on a constant-pressure open cycle, the working fluid being rejected to the atmosphere after doing work. The Stirling and Rider engines of 1827 worked on the constant volume closed cycle, the working fluid being used repeatedly. These engines suffered from exactly the same disadvantage as the gas turbine in its earlier stages in that a very large proportion of the output was used to drive the reciprocating compressors, leaving only a small margin for useful work. These engines served to draw attention to the various forms of heat engine cycles and probably stimulated interest in the gas turbine.

The first real advance in ideas since the time of Barber's patent was in 1853 when M. Tournaire delivered a very remarkable paper to the Académie des Sciences describing a scheme for a gas turbine advanced by M. Burdin. This paper shows a full appreciation of the basic principles of multi-stage gas turbines and axial compressors. In contrast to Tournaire's proposal for multi-stage axial turbines and compressors, a patent of 1861 by M. A. F. Mennons incorporated a single stage centrifugal compressor and an outward radial flow turbine. The furnace was intended to burn solid fuel and a contra-flow heat exchanger was specified between the compressor and turbine. However, as with all the previous projects the practical difficulties proved too formidable and no experimental work seems to have been undertaken.

The Advent of the Workable Gas Turbine

The Prussian patent of 1872 granted to Dr. Stolze of Charlottenburg followed closely the ideas of Tournaire but the fact that this machine was actually built and incorporated the basic elements of a modern gas turbine marks a great advance. This machine worked on the continuous combustion, Joule, or constant pressure, cycle and incorporated a multi-stage reaction turbine, axial flow compressor, probably the first of its kind, and a tubular heat exchanger. The trials were not run until 1900 and were not successful ; it would appear that the machine was barely self-running so that its overall efficiency must have been nil. The efficiency of the axial compressor, due to the rudimentary blade sections, was so low that all the turbine output was used to drive it.

As a comparison, it is to be noted that in 1883 the Swedish engineer De Laval built the first practical steam turbine. Parsons, in his celebrated patent No. 6735 of 1884 solved the steam turbine problem from a fundamentally different point of view. This patent also foresaw the development of the axial compressor to be used for compressing air which was to be passed through a combustion chamber and then through a reaction turbine. Apart from this state-

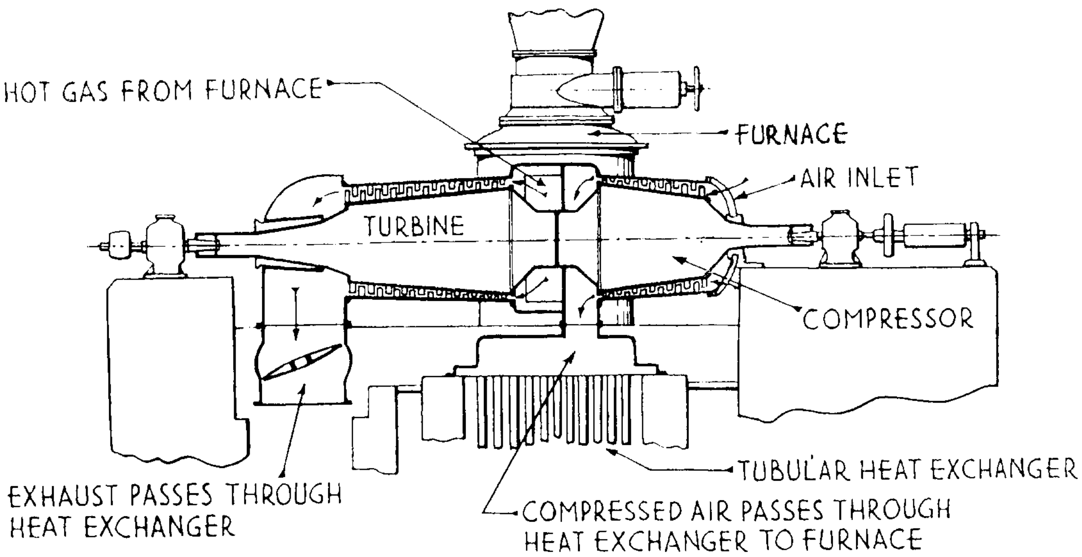

FIG. 2.—STOLZE'S TURBINE (1872-1904)

ment of possibilities Parsons seems to have done little towards the construction of a gas turbine in his earlier days. This was probably due to the difficulty which he encountered in developing the axial flow compressor ; by 1907 the greatest efficiency attained was 60%—a value too low to be of practical use in a gas turbine. Early difficulties associated with axial compressors, which were regarded as reversed reaction turbines, were mainly due to the different nature of the flow in them compared with turbines. In a turbine the flow usually accelerates and this can be done efficiently over a wide range whereas in a compressor the flow diffuses and to do this efficiently is a much more difficult design problem.

The American engineer C. G. Curtis was granted a patent, apparently the first in the United States, covering the gas turbine, in 1895, but no development work was done. A patent was granted in the United States in 1895 to L. Pontois for an explosion combustion chamber for a gas turbine but practical tests gave unfavourable results. A gas turbine was constructed at Cornell University in 1902 incorporating a De Laval turbine. Compressed air was supplied by a steam-driven compressor but the power required to drive the compressor was greater than that delivered by the turbine.

In 1901 Lemale obtained a patent in France for a gas turbine and in 1903 Lemale and Armengaud constructed a small continuous combustion turbine which ran successfully at the plant of the Société Anonyme des Turbomoteurs in Paris. This machine was made from a converted De Laval turbine of 25 h.p. which was supplied with compressed air from the Paris compressed air mains. The turbine operated at constant combustion pressure, the fuel being petroleum which, atomized by a nozzle, was ignited by a glowing platinum wire. The promising results obtained from this turbine led to the construction of a larger machine intended to give 400 h.p. This consisted of a Curtis wheel 37·4 inches diameter with 33 nozzles which drove a centrifugal compressor designed by Rateau ; the wheel was water-cooled by means of passages drilled radially in the hub and continued into the blades themselves. The gases after ignition were cooled by the injection of water in a cooling pipe to bring the temperature in the Curtis wheel down to about 850°F. Results from this machine were disappointing, the turbine was hardly able to do its own work of compression and the thermal efficiency was barely 3%. This work was really the first significant attempt at building a practical gas turbine on a large scale. However, small gasoline turbines were introduced by the Société as torpedo engines.

The comparative failure of these machines to give a useful output may be appreciated when it is pointed out that with a turbine efficiency of 78%, a compressor efficiency of 68%, and a pressure ratio of 4 to 1, which are values unlikely to have been attained at that time, and with gas admission temperature of 1,000°F. ; the efficiency of the gas turbine cycle is zero. It is the advances in aerodynamic knowledge made during the last twenty years which have made possible the improvement in compressor and turbine efficiency from say 60% up to the present 86% or more. The lack of this knowledge prevented the further development of the constant pressure gas turbine until about 1935.

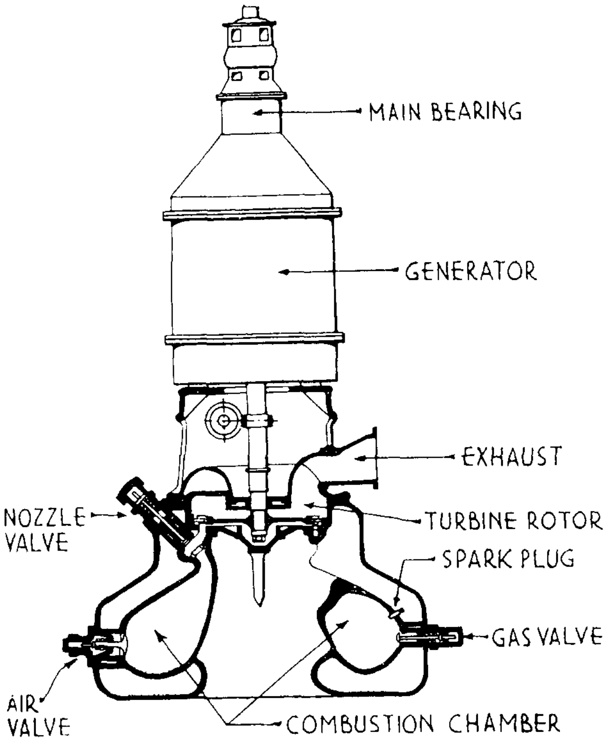

FIG. 2.—HOLZWARTH'S SECOND TURBINE

The Explosion Turbine

To overcome the failure of these constant pressure continuous combustion turbines to give a reasonable efficiency, Dr. Holzwarth in Germany proposed in 1905 a cycle in which the combustion of the fuel took place intermittently at constant volume as in a petrol engine, the combustion gases being led in pulses through the turbine. The first of his turbines operated on the Lenoir explosion cycle without precompression and were known as " explosion " turbines.

Karavodine of Paris in 1907 built a small explosion turbine developing about 2 h.p. which ran successfully and consistently for some time. The turbine wheel was of the De Laval type 5·9 inches diameter running at 10,000 r.p.m. There were four combustion chambers each with a separate nozzle and 38 explosions occurred per second. The specific consumption was 4·9 lb of gasoline/h.p./hr., the overall thermal efficiency was far too low to compare with contemporary reciprocating internal combustion engines.

The first explosion turbine designed by Holzwarth was one of 50 h.p. constructed by Messrs. Korting of Hanover in 1908, the results of tests were sufficiently promising to warrant the construction of a larger machine. To Holzwarth belongs the credit for building, in this machine, the first economically practical gas turbine, he was, however, guilty of stating that the gas turbine was a purely German invention. In 1910 Holzwarth's second turbine, designed to develop 1,000 h.p. and working with precompression, was built at Mannheim by Messrs. Brown Boveri & Co., and merits description.

Holzwarth's second turbine

This machine, like the first, was a vertical turbine. The base was formed by a ring of separate combustion chambers co-axial with the turbine shaft :

above the combustion chambers was a two-row horizontal turbine wheel. Above the wheel chamber was mounted the direct driven generator, the turbine and armature shaft being hung from a main bearing at the top of the generator. Each combustion chamber was provided with a nozzle valve, a gas valve, and an air valve. Compression of the air and combustible gas was effected by rotary compressors driven by separate electric motors. After combustion of the mixture the nozzle valve was opened allowing the products to issue through the nozzle on to the wheel, the flow ceasing when the pressures in the combustion chamber and the wheel chamber were equalized. The air valve was then opened and a blast of air scavenged the chamber. The nozzle and air valves were then closed, trapping a charge of air in the chamber, and the gas valve opened, causing a charge of combustible gas to enter, the gas valve was then closed and the charge electrically ignited. The high frequency of explosions and the number of chambers ensured no perceptible fluctuation in speed of rotation. Difficulties were met in the combustion of anthracite gas due to the fouling of the compressor with tar ; with coke oven gas, its poverty in hydrogen made ignition difficult. In fact, this turbine did not realize the promise shown by the smaller 50 h.p. machine, it only gave an output of 200 h.p. with a thermal efficiency of 5%. Holzwarth continued to work on the development of the explosion turbine in co-operation with the firm of Messrs. Thyssen of Mulheim from 1914 to 1927.

Continental Developments

It will be seen that the lead in gas turbine development was taken by Continental organizations, particularly German and Swiss, during the period under review. Many patents were taken out between 1910 and 1920 but little practical work was done ; among these may be mentioned the German patent of Bischof in 1913 for an explosion turbine which embodied a single-stage wheel surrounded by a revolving valve mechanism which connected the compression, explosion, and nozzle chambers in correct sequence. Bischof also patented a constant pressure turbine in 1914. A turbine was built by Baetz in Germany in 1918 which effected continuous self-compression by means of channels in the turbine wheel. The action was similar to that of a reciprocating internal-combustion engine, both the casing and rotor contained passages controlling the timing of compression, explosion, and exhaust. Two power impulses occurred during each revolution. The machine was said to have attained a thermal efficiency of 22% but its complexity prevented further development.

An interesting phase in the development of the gas turbine was provided by the many attempts to compress the gas by means of moving columns of water. The action of the Humphrey pump showed that a gas mixture could be ignited efficiently above a free water surface and in 1912, for example, a Brown Boveri patent provided for the compression of the air by a column of water alternately accelerated at its opposite ends by combustion chambers. It was hoped by this means to achieve a greater efficiency of compression than could be obtained from conventional compressors at that time.

Holzwarth's sustained influence

It would seem that, in Germany at least, the enormous amount of work devoted to the Holzwarth turbine led to the neglect of the possibilities of the constant pressure type. A third Holzwarth turbine was built in 1920 for the German State Railways followed by a 5,000 kW machine for Muldenstein power station in 1925. The overall efficiency, that is, the ratio of the actual work done to the heat added, attained by Holzwarth at this date was about 13%. In 1928, Messrs. Brown Boveri again took up the Holzwarth turbine and a number of units for blast furnaces and chemical factories were built having outputs of up to 10,000 kW. In some of these plants, to obtain extra thermal efficiency, the exhaust gases were used in a steam boiler, the steam being used to drive the separate gas and air compressors. The work done by Brown Boveri in connection with this turbine resulted in the development of the Velox boiler, in which the boiler is fired under pressure from a compressor driven by a gas turbine actuated by the exhaust gases from the boiler. In turn, the experience gained with the Velox boiler led back to the constant pressure turbine. The sustained efforts of Holzwarth for over 40 years contributed very greatly to the development of the gas turbine, yet despite the technical excellence of these designs their complexity is such that unless some revolutionary improvements can be effected they must give way to the theoretically less advantageous but simpler constant pressure cycle.

The explosion type is not dead, however ; it is still receiving attention in various forms. The form in which a reciprocating piston engine takes the place of a combustion chamber was first proposed by Buchi in 1915 and has received considerable attention. Piston generators have taken the form of the orthodox type and of the free piston type ; Sulzer Bros., Pescara, and Lutz have worked in this direction. In this field, small gas turbines have been used extensively for many years for driving superchargers on aircraft engines and in the marine application for supercharging Diesel engines. In 1918 in the United States, Dr. S. A. Moss, in conjunction with Rateau, constructed a turbo-supercharger driven by the products of combustion from the engine exhaust. This type requires a gas turbine to operate at high temperatures and stresses for short periods and the solution of its many problems has been of value in the development of the gas turbine as a prime mover. The Götaverken system proposed in Sweden in 1927 was a marine application in which Diesel engines drove reciprocating compressors and the exhaust gases were combined with the compressed air to drive the main turbines.

The Constant Pressure Turbine

After the work of Armengaud and Lemale the next attempt at a constant pressure gas turbine was probably that of the Bofors Company in Sweden.

This firm built a unit in 1934 with an 11-stage axial compressor driven by a Ljungström double-flow radial turbine, with which an overall efficiency of 15% was attained.

After many years of investigation Messrs. Brown Boveri decided that the best prospects of practical success were offered by the mechanically simpler constant pressure gas turbine. The demand for hot compressed air in connection with the Houdry cracking process created an opportunity for a gas turbine, where the waste gases resulting from the process could be used in the turbine. Accordingly, the first large constant pressure machine was built by Messrs. Brown Boveri and installed at Marcus Hook in America in 1936 for that purpose, the total output of this machine was equivalent to 5,300 kW. Ten further units were built by the same firm for similar duty in various parts of the world

Between 1936 and 1938, G. Jendrassik of Budapest built a small 100 h.p. unit which approached very closely the present day conception of the gas turbine.

This machine had a 10-stage axial compressor driven by a 7-stage axial turbine and incorporated a welded plate type contra-flow heat exchanger ; an overall efficiency of 21% was reached.

In 1939 a gas turbine power station was built by Brown Boveri for the city of

Neuchâtel, giving an output of 15,000 kW at the turbine and 4,000 kW at the generator with a thermal efficiency of 18%. This unit probably represented the peak of gas turbine development up to the outbreak of war.

It will be seen that little work was done in this country on the gas turbine problem before about 1930. It is said that Sir Charles Parsons often referred to the possibilities of the gas turbine but it was not until 1929 that he began seriously to examine the factors necessary to produce a successful unit ; his interest in the problem continued until his death in 1931. In 1938 work was begun by C. A. Parsons & Company in collaboration with the Parsons Marine Steam Turbine Company on a gas turbine unit of 500 h.p. but this was delayed by the war and was not completed until 1945.

To consider the application of gas turbines to aircraft, the first practical proposal to use a gas turbine as an aircraft power plant appears to have been made, in this country, at the Royal Aircraft Establishment in 1929 but little was done until 1936 when work was commenced on developing axial compressors of high efficiency. Air Commodore (then Flight Lt.) Whittle took out his first patent in 1930 and an order for the manufacture of an engine was placed with the British Thomson-Houston Company in 1936. Tests of this engine were started in April 1937 and the first flights were made with the developed engine in May 1941. Meanwhile, in 1937, the Royal Aircraft Establishment was authorized to start work on the problem of the gas turbine proper, and this was done in conjunction with the Metropolitan-Vickers Electrical Co. A unit consisting of an axial-flow compressor driven by a turbine designed to be self-running but delivering no useful power was tested in 1940. The first aircraft gas turbine engine designed by the Establishment which was actually made ran for the first time in December 1941 and flew in November 1943.

It will be seen that a century and a half of endeavour preceded the practical realization of the gas turbine. From the beginning of the present century many workable gas turbines have been made and this fact should not be forgotten when considering the meteoric development of the aircraft gas turbine under the impetus of war.

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