June 24, 1930. J. W. A. ELLING 1,766,886

GAS TURBINE UNIT

Filed Dec. 2, 1924 2 Sheets-Sheet 1

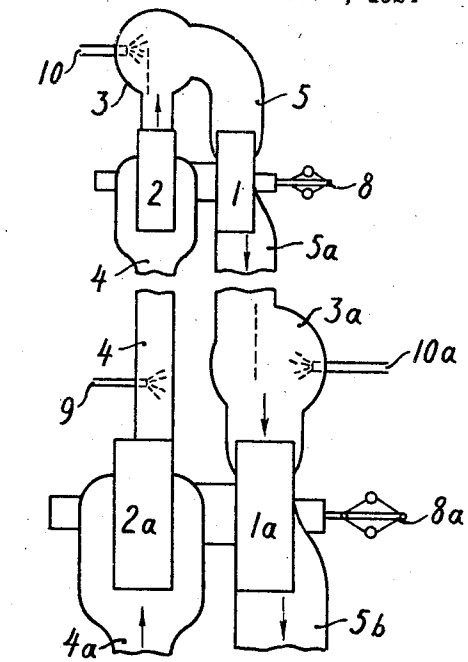


Fig. 1

Fig. 2

Fig. 3

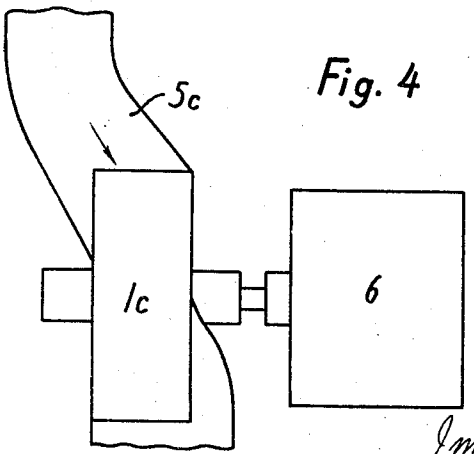


Fig. 4

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Fig. 5

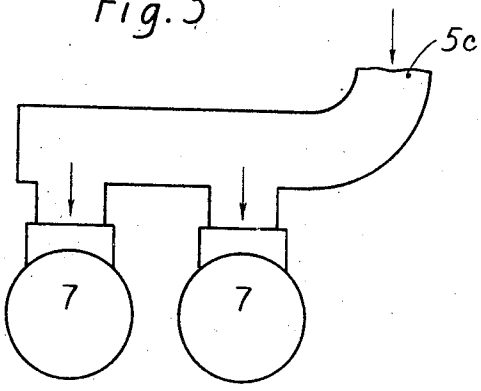
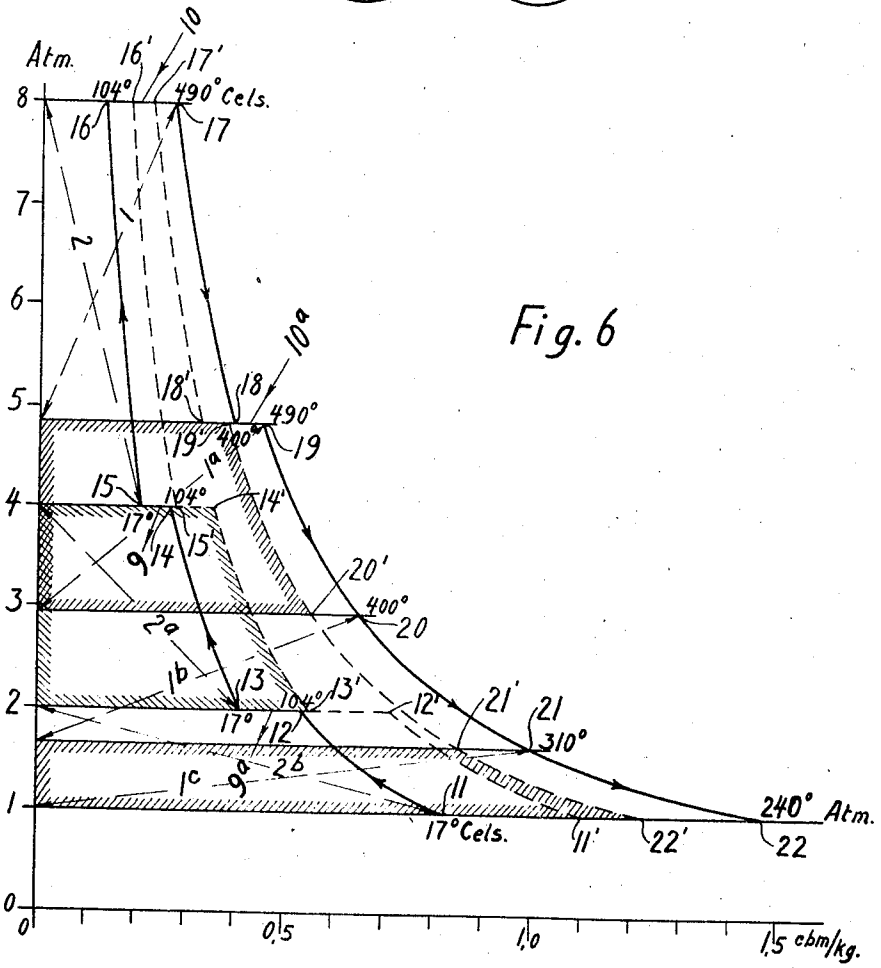


Fig. 6



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UNITED STATES PATENT OFFICE

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GAS-TURBINE UNIT

Application filed December 2, 1924, Serial No. 753,530, and in Norway December 13, 1923.

The gas turbines of the impulse type hitherto known are based upon the same idea as gas motors with pistons, viz. compression, combustion and then an extensive expansion. This principle which is very well suitable in piston motors is, however, connected with great difficulties in turbines. If, namely, the efficiency shall be maintained at a reasonable value the great kinetic energy contained in the gases of combustion before their passing into the turbine wheel must be transformed into a velocity so high that only with difficulty can it be utilized within the wheel, because the latter should not be given a higher velocity than what the materials actually used can safely stand, and the outlet velocity will be very high. In addition thereto, there are inconveniences in connection with the high temperatures and the extra increase in temperature, to which the blades are subjected. Moreover, the high velocity of the runner requires gearing in order to enable the utilization of the useful work. The starting will be difficult, and a reversal will be practically impossible.

The present invention has for its object to avoid completely the drawbacks which in the said respects have been connected with the systems hitherto known and this is obtained by a division of the process into two or more stages and by such an arrangement that the work of compression for the last stage or stages is effected substantially by the preceding stage or stages. All stages are independent of one another in mechanical respect, particularly the last stage, wherein the useful work is taken out, is mechanically quite independent of the preceeding stages.

In order to enable the invention to be understood, the same will be described with reference to the accompanying drawings showing in Figures 1 to 4 diagrammatically a multi-stage system constructed in accordance with the invention. Figure 5 shows a modification and Fig. 6 is a Rankine-diagram for the system shown.

In the drawing, Figures 1, 2, 3, 4 represent the different stages, which hereinafter for sake of convenience will be termed shortly I, II, III, IV. 1, 1^a, 1^b designate gas turbines and 2, 2^a, 2^b, respectively, compressors connected therewith, and 1^c is a turbine of stage IV.

The air enters the compressor 2^b of stage III (Figure 3) and is compressed therein. Having passed out from 2^b the air is cooled at 9^a and passes through a conduit 4^a to a second compressor 2^a forming one element of stage II (Figure 2). In the second compressor the air is further compressed and is then cooled again at 9 and passed through conduit 4 to a third compressor 2 of stage 1 (Figure 1) in order to be finally compressed therein. In this highly compressed stage the gas passes into a combustion chamber 3 into which a suitable combustible is sprayed at 10. The products of combustion are now passed through the conduit 5 to the driving turbine 1 of stage I and from there through the conduit 5^a into a combustion chamber 3^a, into which a combustible is sprayed at 10^a, and they then pass through the turbine 1^a of stage II. From the latter the gases are passing further through the conduit 5^b to the turbine 1^b of stage III preferably without passing through any further combustion chamber. The gas expanded in the turbine of stage III may then be passed through conduits 5^c to a driving turbine 1^c, for instance for a dynamo 6, or to piston motors 7, 7 (Figure 5).

The compressors of each stage are coupled directly to turbines for the respective stages, and the velocity is controlled by a separate governor at each stage as indicated at 8, 8^a and 8^b.

Thus the compressor 2 is coupled mechanically to turbine 1 of stage I, compressor 2^a to turbine 1^a of stage II, and compressor 2^b to turbine 1^b of stage III, and all these three stages are independent of each other in mechanical respect.

By means of the diagram of Figure 6 the operation will be clearly understood. In this diagram the abscissas represent volume of air and gases, and the ordinates represent pressure in the ordinary manner. The horizontal bottom line represents the absolute zero-pressure and the next horizontal line above same represents the atmospheric pressure, where-

from it started. Numbers and letters correspond to those used in Figures 1 to 4. The three curves shown in full lines and located next to the ordinate axis represent useful work of compression, and the two curves shown in full lines and located most remote from the ordinate axis represent gross work of expansion.

The air may be introduced in 2^b with say 17° C. (at 11 in Figure 6) and is compressed to a temperature of say 104° C. (point 12). Thus the curve 11—12 represents the useful work of compression. The gross work of compression is represented by the curve 11′—12′, it being assumed that the work 11—12 be 75% of the work 11′—12′ corresponding to an efficiency of 75% in the compressor. The air from 2^b has a temperature of 104° C. and is cooled at 9^a to a temperature of say 17° C. (12—13, Figure 6). Then it passes into compressor 2^a and is further compressed corresponding to a rise in temperature from 17° to 104° C. The curves 13—14 and 13′—14′ represent the corresponding useful and gross work of compression respectively. Cooling is again effected at 9 down to 17° (14—15, Figure 6) and then a final compression is effected in compressor 2 from 17° to 104°. The curves 15—16 and 15′—16′ represent the corresponding useful and gross work of compression respectively.

At 10 the compressed air receives heat, whereby its temperature is raised to 490° (16—17, Figure 6) and is then expanded in turbine 1. The curve 17—18 represents the gross and curve 17′—18′ useful or net work of expansion, it being assumed that the work 17′—18′ is 85% of the work 17—18. At 10^a the partly expanded gases receive heat energy and are raised from 400° to 490°. A further expansion (from 490° to 400°) takes place in turbine 1^a, the gross and net works of expansion, being represented by curves 19—20 and 19′—20′ respectively. From turbine 1^a the gases pass directly to turbine 1^b in order to be further expanded (from 400° to 310° C.), the gross and net work of expansion being represented by the curves 20—21 and 20′—21′ respectively. The gases are now prepared for exerting useful work in the engine 1^c, having an increased pressure as compared with the initial pressure (1 atmosphere) before the compression and having also an increased volume corresponding to the temperature (310° C.) prevailing at the outlet from turbine 1^b. This prepared gaseous driving fluid can therefore be utilized in any suitable engine, either a fourth turbine 1^c for driving the dynamo 6 (Figure 4) or a plurality of piston motors 7, 7 (Figure 5).

As will be seen from the drawing the engine 1^c or 7, is not mechanically coupled to the aggregates of the stages I, II, III, but is mechanically quite independent thereof. Consequently the transferring engine thus can be retarded, accelerated, stopped and even reversed independently of the rotating masses of the first three stages and independently of the working conditions thereof. The manipulation of the engine therefore can be effected very easily and with a reasonable mass, because the rotating masses of the said three stages will in no way take part of such manipulation but can run with unaltered speed and in a constant direction of rotation. Obviously this result is of great practical importance. Moreover, as the driving fluid entering the engine through conduit 5^c has a comparatively low pressure but a large volume, it can be utilized in the turbine 1^c with a reasonable peripheric velocity and size of this turbine, consequently at a moderate number of revolutions, whereby in many cases gearing between the engine, such as 1^c or 7, and the driven machine such as 6, can be avoided.

I have pointed out above that engine 1^c or 7 is mechanically independent of stages I, II and III, but it is also very well possible to make the several stages I, II, III, independent of one another mutually. In fact, just this construction is shown in the drawing, wherein the shaft of machines 1, 2 of stage I, shaft of 1^a, 2^a of stage II and shaft of 1^b, 2^b of stage III are without any mechanical connection with one another. Each shaft therefore can be run with the most suitable number of revolutions.

From the diagram, Figure 6, will be seen that the net work of expansion of turbine 1 (curve 17′—18′) is equal to the gross work of compression of compressor 2 (curve 15′—16′) it being easy to arrange the conditions in this manner, whereby the energy taken by turbine 1 is just consumed by the compression energy absorbed in compressor 2 and by friction resistances, losses of heat, etc. Consequently no work will be delivered out from stage I, and only the energy contained in the outlet gases from turbine 1 will be transported on to the next stage II.

In this stage the conditions are just similar to those of stage I, because the net work of expansion of turbine 1^a (curve 19′—20′) is equal to the gross work of compression of compressor 2^a (curve 13′—14′). Finally, in stage III the net work of expansion of turbine 1^b (curve 20′—21′) is equal to the gross work of compression of compressor 2^b (curve 11′—12′).

After having left turbine 1^b the gases are exerting their useful work (curve 21—22) in the engine 1^c, 7 etc., which consequently is not hitherto loaded with any work of compression.

When all four stages I, II, III, IV are considered as a complete unit, it will thus be seen that the output of the different stages before the last one may be so selected that

the output of the latter will be just equal to the total useful work of the complete gas turbine unit, and further the work of compression effected in the different stages may be selected just in conformity with the useful work of the turbine appertaining to the stage in question. From the different stages before the last one no mechanical work is taken out, and the turbines operating in each of these stages may therefore run with just the number of revolutions most convenient to the stage in question. Under these circumstances it is preferred to increase the wheel diameter through the stages according as the gas volume is increased and to reduce correspondingly the number of revolutions of the turbines of the successive stages. The different stages therefore should be provided with separate governors independently of each other.

The different stage sections need not be connected to one another in any other manner than through air pipes which connect the compressors in succeeding stages together and through gas pipes which connect the outlet from the turbine of one stage with the combustion chamber for the turbine of the next stage.

If the useful work of the gas turbine aggregate is to be transmitted through a turbine which may for instance be coupled directly to the driven machine element, this turbine proper may possess one or more stages like ordinary steam turbines. The total fall in pressure between inlet and outlet, however, will be comparatively small and the theoretical efficiency consequently correspondingly higher.

As will be understood, it is possible in this manner to obtain a gas turbine unit of a very practical construction without using, as hitherto ordinary, high ratios of gearing, because the several stages I, II, III, IV are mechanically independent of each other, and consequently the number of revolutions in any of these stages may be chosen independently of that of the other stages.

The starting of the different stages takes place easily one after the other.

Obviously, the invention is not limited to any specific number of stages.

Having thus described my invention what I claim is:

1. A gas turbine unit, comprising a series of mechanically independent means for compressing the gas in stages, means for adding energy of heat to the gas after compression, a series of means for expanding the compressed gas in stages down to an appropriate degree, each compressing means being mechanically coupled to one of the expanding means, an engine mechanically independent of said means for compressing and expanding the gas, and means for conducting the gas after final expansion as a driving fluid to the said independent engine.

2. A gas turbine unit comprising means for gradually compressing the gas in separate stages connected in series but mechanically independent of one another, means for adding energy of heat to the gas at suitable places after compression, means for expanding the gas gradually to an appropriate degree in separate stages connected in series but mechanically independent of one another, means for mechanically coupling together the first compressing means in the series of compression stages with the last expanding means in the stages of expansion, means for mechanically coupling together the second compressing means with the last but one expanding means, and so on, a driving engine mechanically independent of said compressing and expanding means, and means for conducting the so expanded gas as a driving fluid to the said engine.

3. A gas turbine unit, comprising compressors for gradually compressing the gas through a series of stages, said compressors being mechanically independent of one another, means for adding energy of heat to the gas after compression, turbines for expanding the so compressed gas through a series of stages down to an appropriate degree, said turbines being mechanically independent of one another, means for coupling mechanically together the first compressor in the series of compression stages with the last turbine in the series of expansion stages, means for coupling mechanically together the second compressor with the last but one turbine, and so on, a driving engine mechanically independent of said compressors and turbines, and means for conducting the so expanded gas as a driving fluid to said engine.

4. A gas turbine unit, comprising a series of mechanically independent turbo compressors for compressing air in stages, means for adding energy of heat to the air by combustion after the last compression, a series of turbines for expanding the compressed air and gases of combustion in stages down to an appropriate degree, each turbine being mechanically coupled to one of the compressors, an engine mechanically independent of said compressors and turbines, and means for conducting the gases after expansion in said stages as a driving fluid to the said independent engine.

5. A gas turbine unit, comprising a series of mechanically independent means for compressing air in stages, means for cooling the gas between said stages, means for adding energy of heat to the air by combustion after the last compression, a series of means for expanding the compressed air and gases of combustion in stages down to an appropriate degree, each compressing means being me-

chanically coupled to one of the expanding means, an engine mechanically independent of said compressing and expanding means, and means for conducting the gases after expansion in said stages as a driving fluid to the said independent engine.

6. A gas turbine unit, comprising a series of mechanically independent means for compressing air in stages, means for cooling the air between said stages, a series of means for expanding the compressed air in stages down to an appropriate degree, each compressing means being mechanically coupled to one of the expanding means, means for adding energy of heat to the air by combustion between two of the expanding stages, an engine mechanically independent of said compressing and expanding means, and means for conducting the gases after expansion in said stages as a driving fluid to the said independent engine.

In testimony whereof I have signed my name to this specification.

JENS WILLIAM AEGIDIUS ELLING.