

May 18, 1937.

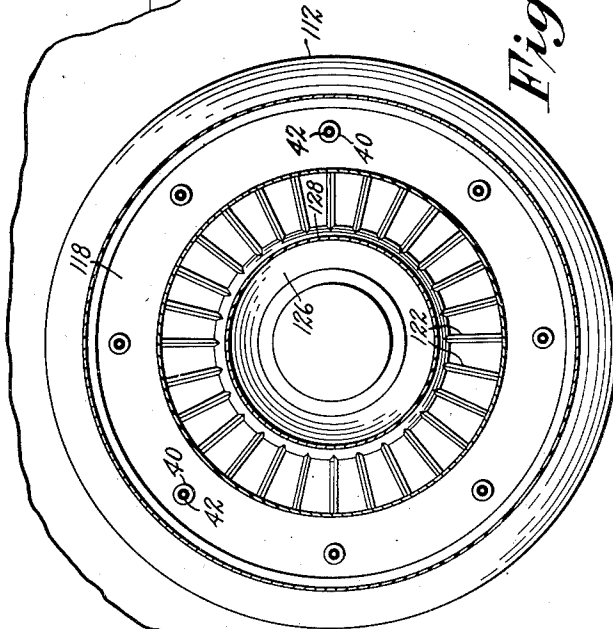
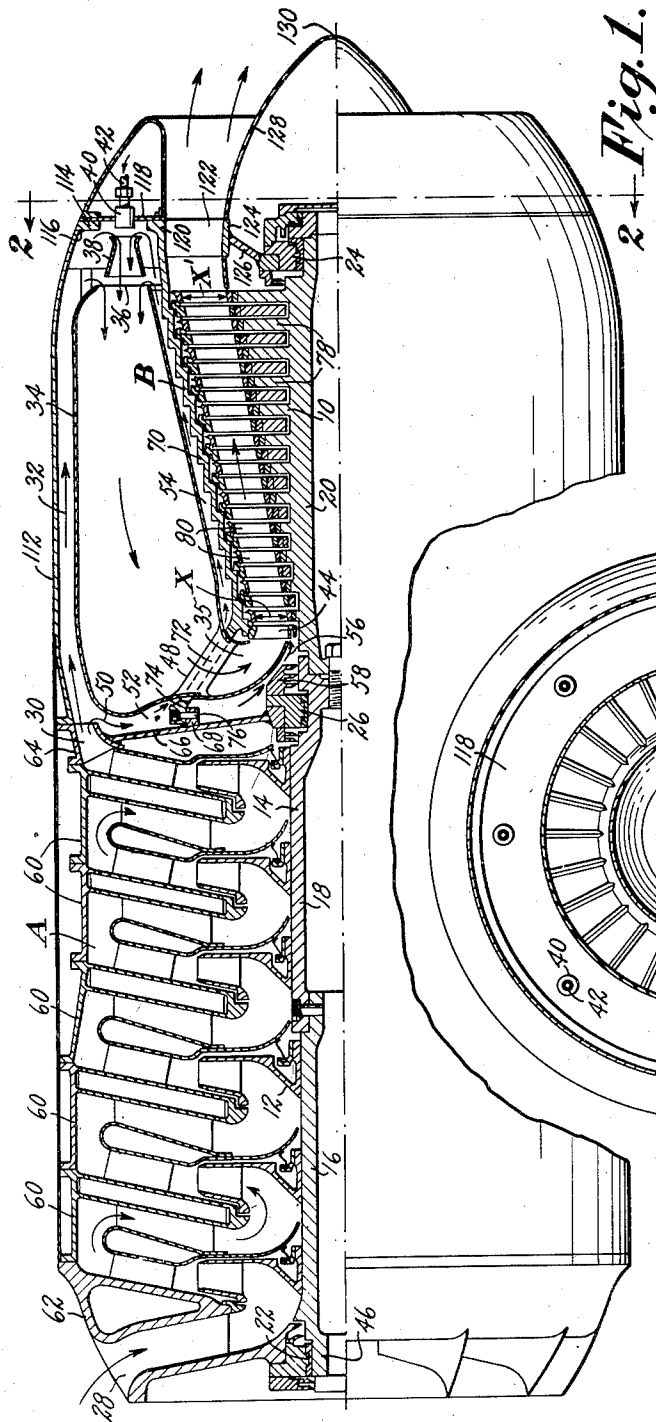
A. LYSHOLM

2,080,425

TURBINE

Filed Feb. 9, 1934

3 Sheets-Sheet 1



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Fig. 3

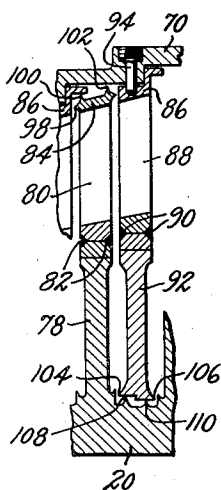


Fig. 7.

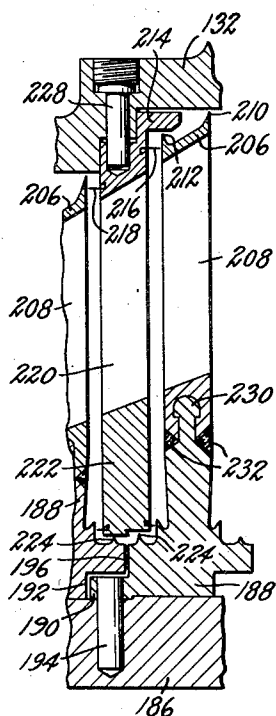
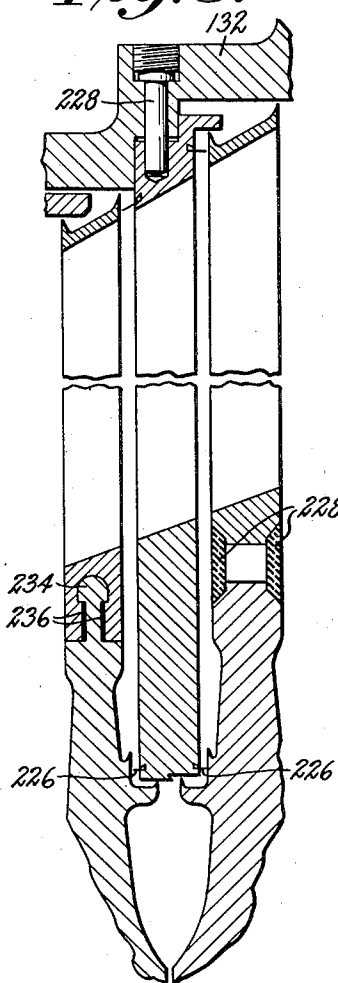


Fig. 8.



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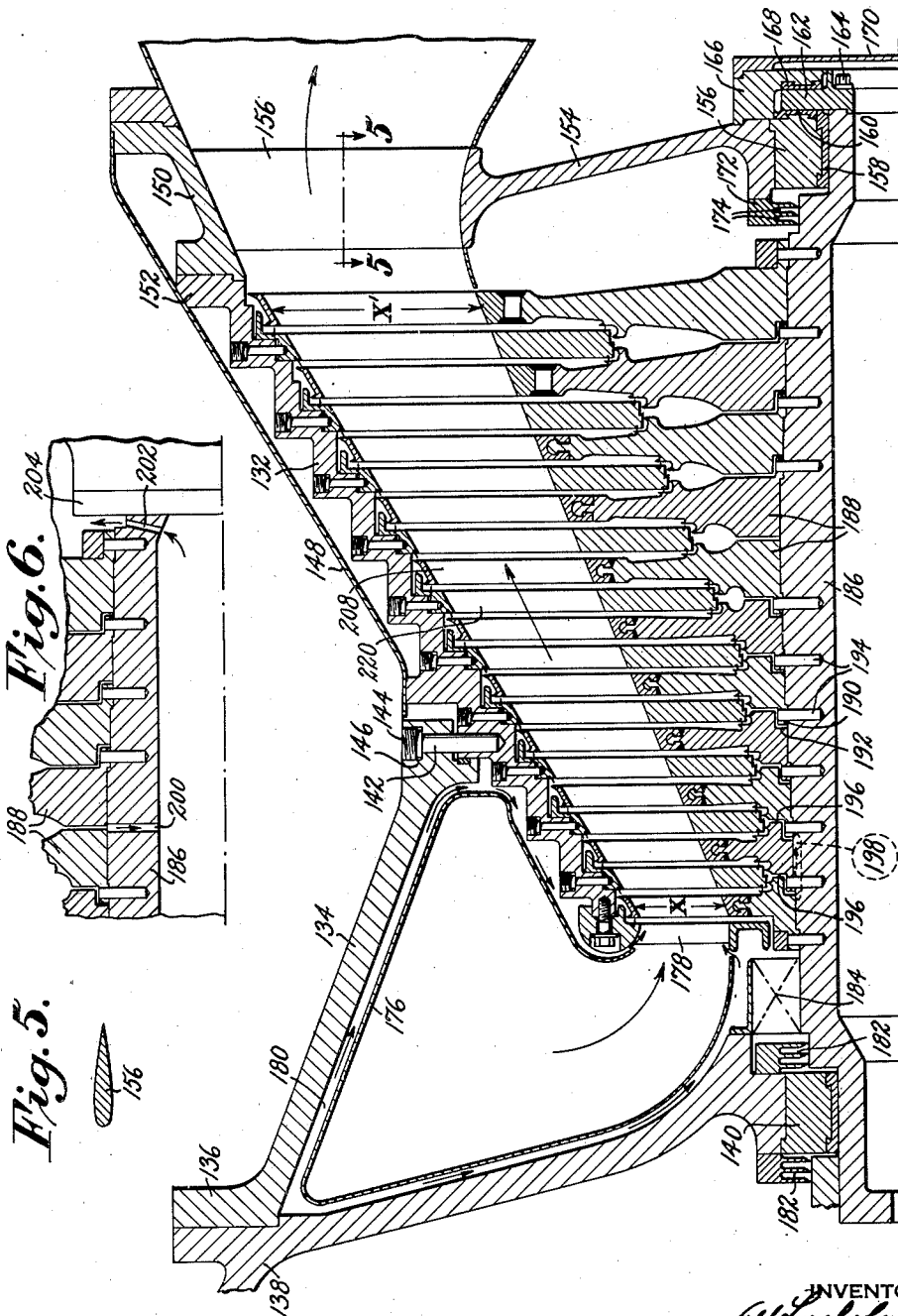
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3 Sheets-Sheet 3



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UNITED STATES PATENT OFFICE

2,080,425

TURBINE

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Application February 9, 1934, Serial No. 710,465
In Germany February 10, 1933

27 Claims. (Cl. 253—69)

Briefly stated, a general object of the invention is the provision of improved gas turbine structure whereby gaseous motive fluid having the above mentioned temperature and pressure characteristics may be utilized practically in an axial flow turbine of the multiple stage kind giving high thermodynamic efficiency. This general object is principally attained by the provision of a novel form of turbine structure embodying a multiplicity of stages of axial flow reaction blading in which the path of flow for motive fluid through the blade system is of progressively increasing mean diameter from an inlet end of relatively small diameter with full admission of motive fluid to the blade system and in which the lengths of the turbine blades are much greater with reference to the mean diameters of the respective blade rows, particularly at the inlet end of the blade system, than is the case with the practice of the prior art. In accordance with the invention, the lengths of the turbine blades at the inlet end of the turbine are at least ten per cent of the mean diameters of the respective blade rows and are preferably of the order of one-fifth of such diameters. The term "mean diameter" as herein employed designates the diameter of a blade row measured from center to center of diametrically opposed blades in the blade row.

The detailed nature of the above general object and of further and more detailed objects of the invention, together with the manner in which the several objects are attained, will appear more clearly in the ensuing description of the several forms of apparatus illustrated in the accompanying drawings, in which:

Fig. 1 is a longitudinal sectional view of a turbine compressor unit embodying the invention;

Fig. 2 is a section taken on the line 2—2 of Fig. 1;

Fig. 3 is a section on enlarged scale of part of the blade system shown in Fig. 1;

Fig. 4 is a longitudinal sectional view of another turbine embodying the invention;

Fig. 5 is a section taken on the line 5—5 of Fig. 4;

Fig. 6 is a fragmentary section showing a different form of turbine shaft heating arrangement; and

Figs. 7 and 8 are enlarged sectional views showing different turbine blade structures in accordance with the invention.

Turning now to Fig. 1, the turbine compressor unit illustrated comprises a compressor desig-

nated generally at A and an axial flow turbine designated generally at B. The turbine rotor, indicated generally at 10, and the compressor rotor, designated generally at 12, are mounted on a common shaft designated generally at 14. Shaft 14, in the illustrated embodiment, is built up of a plurality of hollow sections 16, 18 and 20, and is supported at its ends in the journal bearings 22 and 24. An intermediate shaft bearing 26 is also provided.

The compressor A draws in air through a plurality of inlet openings, one of which is shown at 28, and discharges the compressed air through the annular discharge passage 30. The compressed air flows in the direction of the arrow 32 past the outside of a combustion chamber 34 and enters the chamber from the rear through a plurality of inlet openings 36 distributed around the perimeter of the rear end of the chamber. Air also flows through a plurality of air inlet cones 38, each discharging through an opening 36, and in the current of air passing through each of these cones, which may be considered as primary air, fuel, for example, crude oil, is injected by means of nozzles 40. Ignition of the fuel is effected in known manner, and through suitable regulating apparatus, which also may be of known form and which need not be described herein, the quantity of fuel passed to the nozzles 40 through the fuel supply pipes 42, is suitably regulated so that the air is heated to the temperature desired for the motive fluid for the turbine. Motive fluid is discharged from the combustion chamber 34 through the annular discharge passage 44, which is advantageously provided with stationary guide vanes for guiding the motive fluid into the first row of moving turbine blades. The motive fluid, before it enters the turbine proper, is not passed through nozzles which serve to increase the velocity and reduce the temperature, and because of the resulting high temperature of the motive fluid entering the first row of moving turbine blades, this row and the adjacent rows at the inlet end of the turbine are subjected to very high temperatures, and accordingly the diameter of the first row of blades, and the adjacent rows, is kept as small as possible. In a turbine of the kind illustrated, this diameter may be, for example, 200 mm. The length x of the turbine blades, which, in the illustrated embodiment, in accordance with the present invention, is long in comparison with the mean diameter of the blade row, and, as

shown, is approximately 20 per cent of the mean diameter, or about 40 mm.

The turbine of the kind illustrated in Fig. 1 may be employed either to extract all the useful energy possible from the motive fluid and convert it into mechanical energy, in which case power over and above that required to operate the compressor will be obtained, which power may be conveniently taken off from a shaft attached to the forward end 46 of the shaft 14, or less than the total available energy of the motive fluid may be converted into mechanical energy in the turbine and the resulting exhaust gases of high velocity as discharged from the turbine may be employed to produce propulsion by reactive or rocket effect. In the embodiment illustrated, the latter form of turbine is shown, the blade length x' at the exhaust end of the turbine being little, if any, longer than the blade length x , at the inlet end of the turbine. As a consequence, the ratio of the blade lengths to the mean diameters of the rows of blades decreases from the inlet to the outlet end of the turbine rather than remaining substantially constant, as is the case where it is desired to convert the maximum available energy in the motive fluid to mechanical work. In the illustrated embodiment, the combustion chamber 34 is in the form of a hollow annular shell which surrounds the turbine casing. At the end of the combustion chamber adjacent to the compressor a number of angularly disposed conduits 48 are provided, which permit air flowing in the direction of the arrow 50 to the space 52 to pass to the space 54 between the turbine casing and the inner wall of the combustion chamber 34. A part of the air which flows to space 52 passes along the path indicated by the arrow 56 and enters the turbine blading in the form of a thin annular stream between the stream of hot gas from the main outlet 34 and the turbine shaft. This thin stream of relatively cool air serves to protect the intermediate shaft bearing 26 and packing 58 from heat radiated from the combustion chamber.

The compressor casing is preferably built up of a number of similar sections 60 suitably bolted or welded together, the forward end of the casing being provided by an end section 62 and the rearward end of the casing being provided by an end section 64. Section 62 provides the air inlet openings 28 and also serves to support the front end bearing 22. A conical plate 66 secured to section 64, preferably by welding, serves to support the intermediate shaft bearing 26. Plate 66 carries a circular flange 68 which serves to support the forward end of the turbine casing in a manner to be described. The turbine casing 70 terminates at its forward end in a conical portion seen at 72 terminating in an annular flange 74. Flange 74 is connected to the flange 68 by means of a plurality of radially extending pins or bolts 76 which permit relative movement between the two flanges in radial direction to compensate for expansion and contraction of the parts at different rates. The conical part 72 of the turbine casing is provided with a number of openings through which the main part of the combustion chamber 34 is connected with the outlet part 35 which forms in effect an admission chamber for the turbine. The spaces between these openings provide for the conduits 48 through which air flows to the spaces 54.

In accordance with one phase of the present invention the entire turbine casing is made up as a single piece, and, as will be observed from

Fig. 1, the diameter of the casing increases from the inlet end to the outlet end of the turbine, in order to accommodate the increased diameters of the rows of turbine blades, in a series of steps. The wall thickness is substantially uniform from end to end of the casing and, as will be noted from the figure, both the inner and outer surfaces of the casing are stepped in substantially the same manner. The wall of the casing is comparatively thin. This thin wall section is made possible because the casing is in one piece, and the thin casing of the form shown is of substantial advantage in the construction of a turbine designed to operate with motive fluid at the temperatures contemplated because of the fact that the casing is comparatively rapidly and uniformly heated by the motive fluid, so that expansion of the casing is not only comparatively uniform but it also is heated and expands more nearly together with the turbine shaft than would otherwise be the case.

The turbine rotor consists of the hollow shaft part 20 which in the present embodiment has integral therewith the discs 78 carrying the rows of moving turbine blades 80 (see also Fig. 3). The blades 80 may be secured to the discs 78 by one of a number of different forms of mechanical connection such, for example, as dove-tail and bolt connections, but such connections, regardless of their specific forms, are further secured by welding. In the arrangement shown in Fig. 3 the welds are indicated at 82. The welding of these parts is very important in the turbine construction, since the operating temperatures for which the turbine is designed are such as to produce "creep" of the metal, and welding of the parts is highly desirable to prevent loosening of the connections due to creep of the metal. At their outer ends the blades 80 are suitably connected to an annular ring 84.

The guide blade structure comprises a plurality of annular guide blade rings 86, which are Z shaped in cross section, to which the outer ends of the stationary guide blades 88 are secured. The inner ends of the guide blades are secured by connections including welds such as are shown at 90 to an inner guide blade disc 92. The welding of the joints in the guide blade structure is equally as important as in the moving blade structure in order to prevent loosening of the connections due to creep of the metal.

Rings 86 are attached to the turbine casing 70 by means of a plurality of radially extending bolts or pins 94. The outer rings 84 of the moving blade rows are provided with a plurality of packing edges. In the embodiment illustrated, the ring 84 is provided with axially extending edges 96 and 98 adapted to cooperate with radial faces of the rings 86 at each side of the moving blade row, and radially extending edges 100 and 102, the former cooperating with a cylindrical surface of an adjacent stationary ring 86 and the latter cooperating with an inner cylindrical surface of the casing 70. The stationary guide discs 92 are packed with respect to the rotor in substantially the same way. The inner part of each disc is provided with axially extending packing edges 104 and 106 adapted to cooperate with suitable radially extending surfaces on the rotor, and the rotor is provided with two radially extending packing edges 108 and 110, preferably of different diameter, cooperating with suitable cylindrical surfaces on the disc 92.

Referring again to Fig. 1, an outer shell 112 is secured to the compressor casing part 64, and to

the rearward end of this shell is secured a flange 114 which may be advantageously welded as at 116. An annular plate 118 is secured to the flange 114 in any suitable manner, and the exhaust end 120 of the turbine casing 70 is secured to this plate. Extending radially inwardly from the part 120 of the turbine casing is a plurality of ribs 122 which are preferably stream-lined in cross section and the inner ends of these ribs are joined by a ring part 124. A conical plate 126 is secured to ring 124 and serves to carry the turbine shaft bearing 24. The bearing 24 and the turbine parts associated therewith are protected against hot exhaust gases by means of a shield 128 of generally conical form, which extends from the outlet of the turbine blade system to a rounded point indicated at 130 at the rearward end of the apparatus. The shape of the shield 128 is of importance in securing flow of exhaust gas from the turbine with minimum outlet loss, and this shape of the shield is particularly important in cases where the reactive effect of the exhaust gases is to be utilized for rocket propulsion.

In accordance with the invention the plate 118 is made relatively thin and flexible in order to compensate for relative axial expansion between the turbine casing 70 and the outer shell 112. The arrangement whereby the rear shaft bearing 24 is carried by the exhaust end of the casing and the arrangement of the bearing within the annular exhaust passage insures minimum relative axial movement between the bearing and the shaft under the influence of expansion and contraction, and the nature of the bearing permits the shaft to expand freely when heated.

Turning now more particularly to Figs. 4 to 8, a somewhat different construction is illustrated. In this embodiment the turbine is designed to convert as much as possible of the energy of the motive fluid into mechanical work, and accordingly the relation between the length of the blades in a given blade row and the mean diameter of the given blade row is substantially the same from the inlet to the outlet end of the turbine. As will be evident from Fig. 4 the absolute length x' of the blades in the last row is substantially greater than the absolute length x of the blades in the first row.

The turbine casing 132 is, like the casing illustrated in Fig. 1, made in one piece and in a series of steps corresponding to the number of turbine stages. Adjacent to the inlet end of the turbine the casing 132 is connected to a conical flange 134 having a radially extending flange 136 adapted to be secured to a casing part 138 for an associated machine, which latter part may advantageously provide a support for a center shaft bearing 140. The parts 132 and 134 are connected by means of a plurality of radially extending bolts or pins 142, and these pins are preferably held against radial displacement by means of plugs 144 threaded into countersunk recesses 146 in the part 134. The turbine casing 132 is preferably surrounded by a shell 148 of appropriate form. A ring flanged at 150 is secured to the flange 152 at the exhaust end of the turbine casing, and this ring is connected to a conical end wall 154 by means of a plurality of radially extending webs 156, preferably of stream-line section as shown in Fig. 5. Webs 122, shown in Fig. 1, are advantageously of the same cross sectional contour as the webs 156. The end wall 154 carries the shaft bearing for supporting the exhaust end of the turbine shaft, and in the illustrated embodiment this bearing comprises a bearing block 156 suit-

ably lined with anti-friction bearing metal 158 which engages a suitable journal on the turbine shaft. A radially extending anti-friction bearing is also provided at 160 against which bears the end plate 162. Plate 162 is secured to the end of the turbine shaft by means of suitable bolts 164. A stationary end disc 166, provided with bearing metal at 168, is suitably secured to the end wall 154. The end plate 162 which rotates between the radially extending bearings at 160 and 168 serves to hold the turbine shaft against axial displacement. A cover plate 170 is advantageously secured to the outer face of the disc 166. Suitable shaft packing is provided at 172 to prevent leakage of oil from the bearing 158 to the interior of the turbine. In the form illustrated, the packing is of the labyrinth type and air for sealing purposes may be supplied to the spaces 174 in known manner. In the space between the conical part 134 and part 138 there is located an admission chamber 176 for motive fluid having an annular outlet 178 for the passage of motive fluid to the turbine. This admission chamber 176 is spaced from the walls of the adjacent parts in much the same manner as is the part 35 described in connection with Fig. 1, and air or other relatively cool fluid is admitted to the space 180 so as to flow in the direction indicated by the arrows in a manner protecting the adjacent turbine parts from heat radiated from the chamber 176. Motive fluid is admitted to chamber 176 through suitable inlet openings, none of which appears in the section shown in Fig. 4. This protection is particularly desirable for the packing 182 providing against oil leakage from bearing 140 and the packing for preventing leakage of motive fluid indicated at 184. The latter packing is preferably of labyrinth form.

The present embodiment differs from that previously described in that the discs for carrying the rows of moving blades of the turbine are separate from the turbine shaft. In the present case the turbine shaft 186 is hollow as in the previously described forms, and its outer surface is provided with a series of steps so that the shaft is of increasing diameter from the ends toward the central part of the shaft. The several turbine discs 188 are provided with shouldered inner bores of diameters such that they will abut against the proper shoulders of the stepped turbine shaft, and the discs are provided at their opposite sides with circular flanges 190 and recesses 192, as may be seen more clearly in Fig. 7. The discs are secured to the shaft by a plurality of radially extending pins 194 which pass through suitable holes in the flanges 190, and, as will be evident from the figures, the discs, when in assembled position, are fitted so that the flange 190 on one disc fits within the recess 192 on an adjacent disc, so that the pins 194 are held against radial displacement. With this arrangement, the turbine rotor can be assembled by slipping the turbine discs on to the shaft from the ends thereof, commencing with the discs having the largest shaft holes, and the discs can be progressively pinned to the shaft as they are assembled. A certain amount of axial clearance indicated at 196 is left between adjacent turbine discs. This clearance serves to compensate for expansion and may be made larger than is required for expansion in order to permit hot motive fluid to reach the shaft 186. Heating of the shaft to a temperature substantially the same as that of the discs is desirable in order to minimize differences in the rates of expansion

and the amount of expansion. In order to facilitate heating of the shaft, adjacent clearance spaces 196 may be connected by axially extending slots 198 in the outer surface of the shaft. It will be evident that motive fluid will flow from the clearance space between two stages of higher pressure to the clearance space between two stages of lower pressure, and in flowing along the shaft will serve to rapidly and effectively heat the shaft.

In Fig. 6 another means of heating the shaft is illustrated, in accordance with which the shaft is drilled at 200 to provide a series of openings communicating with the clearance space between two adjacent discs, the adjacent discs preferably being on the portion of the shaft of largest diameter. Gases admitted through the openings 200 to the interior of the shaft serve to heat it and circulation of gas inside the shaft is provided by means of outlet openings 202 adjacent to the shaft packing 204, which is, in this form of construction, preferably different in form from the type of packing shown at 172 in Fig. 4. Heating of the shaft from the inside is particularly effective in reducing the relative expansion as between the shaft and the turbine casing. It will be apparent that both the arrangement comprising the annular slots 198 and the arrangement shown in Fig. 6 for admitting gas to the inside of the turbine shaft may be employed in the same turbine.

Referring now more particularly to Figs. 7 and 8, in which the details of blade construction are more clearly shown, the outer or shroud rings 206 to which the moving blades 208 are secured, are provided with two radially extending packing edges 210 and 212, the former bearing against the inner surface of casing 132, and the latter bearing against the outer ring 214 of an adjacent row of stationary guide blades. The rings 214 are each provided with axially extending circular packing strips 216 and 218 to engage the sides of adjacent rings 206. The stationary outer guide rings 214 are Z shaped in cross section, as in the embodiment illustrated in Fig. 1, and carry the rows of stationary guide blades 220, which at their inner ends are secured to the inner guide discs 222. In the present embodiment the packing between the guide discs 222 and the turbine rotor comprises radially extending packing edges 224 on the turbine discs, which edges are preferably of different diameters, and two axially extending packing strips 226 adapted to engage a suitable radially extending surface on an adjacent turbine disc. In this form of construction, as well as in the form shown in Figs. 1 to 3, the outer stationary guide rings 214 may be made in one piece because of the manner in which the turbine discs are assembled on the shaft by slipping them on from the ends of the shaft. Radially extending pins 228, similar to the pins 94 shown in Fig. 3, are employed to position rings 214 in the casing 132, and these pins, as well as pins 94, are advantageously of the same construction as pins 142 used to unite the casing parts shown in Fig. 4. As previously mentioned, numerous different types of mechanical connections may be employed for securing the moving and stationary blades to their respective rings.

In Fig. 7 a dove-tail connection is shown at 230 with welds indicated at 232. In Fig. 8, a similar connection 234 is shown, which is welded by means of electric butt welds at 236. Still an-

other form of welded connection is indicated at 238 in Fig. 8.

Referring again to Figs. 1 and 4, it will be observed that the mean diameter of each blade row increases progressively from the inlet to the outlet end of the turbine to provide a path of flow for motive fluid which is in the form of a conical annulus. As hereinafter pointed out, the generally conical annular form of path for expansion of motive fluid has certain very definite advantages for the kind of turbine under consideration. It will be understood that in the specific construction of the turbine, in order to provide a generally conical form for the expansion path of the motive fluid, it is preferable to construct each successive blade row or stage with larger mean diameter than the preceding row or stage, but this specific construction is not essential to the securing of the benefits of the invention. It is evident that the same general character of path of flow may be obtained by employing a series of small groups of rows, with the rows within each group having the same diameter, the several groups having diameters of increasing value from inlet to outlet. Such constructions are intended to be included within the terms of the appended claims wherein it is stated that the mean diameter of each of the successive stages is of generally increasing value from inlet to outlet. As previously noted, the invention relates to turbines having high thermo-dynamic efficiency which is obtained by multiple stage expansion of the motive fluid. This type of expansion results in a more or less uniform extraction of heat from the motive fluid in passing through the turbine, and consequently the heat drop through the turbine from the inlet end to the outlet end is gradual and relatively uniform. The conical path of flow for motive fluid provides a component of flow in radial direction of relatively large value which is particularly advantageous in the multiple stage reaction expansion of a high temperature motive fluid, since the extreme temperature stresses in the inlet portion of the blade system, due to the relatively high temperature of the motive fluid in this portion, are compensated for by the relatively small diameters of the blade rows in the inlet portions of the turbine. The blade rows adjacent the outlet end of the turbine, while of relatively large diameter, are subjected to lower temperature stresses due to the reduced temperature of the motive fluid when it reaches these rows. Consequently, the combined temperature and mechanical stresses on the parts of the blade system may be made relatively uniform by utilizing what may be termed an exaggerated conical form of blade system.

As previously noted, the inlet end of the blade system is kept to as small a diameter as is practically possible, and preferably this diameter, having regard to the speed of rotation of the turbine, is such that the peripheral speed of the blades at the inlet end of the turbine is of the order of 100 meters per second. The very small inlet diameter coupled with the relatively long blades comprises a distinct departure from the usual turbine practice, and in the case of a gas turbine for use with high temperature motive fluid produces materially improved results. One of the reasons for such improvement is the fact that, due to the high temperature of the motive fluid, substantial clearances must be used to allow for the relatively great expansion, and with the long blades operating on a small diameter, the

area of the clearance spaces relative to the area of the path of flow for motive fluid is very small even with the relatively great absolute clearance which must be provided. Consequently, the amount of leakage, which directly affects turbine efficiency, is very small as compared with the amount of leakage which would result if it were attempted to utilize relatively short blades in blade rows of relatively large diameter at the inlet end of the turbine. Furthermore, the use of relatively long turbine blades in accordance with the present invention permits sufficient clearance to be employed without involving undue leakage to allow for the "creep" in the metal which will occur when motive fluid of as high temperature as that contemplated in the present case is expanded in the manner necessary to secure high thermo-dynamic efficiency.

The use of small diameter blade rows at the inlet end of the turbine appears to be directly at variance with the teachings of the prior art which lead to the utilization of blade rows of maximum practical diameter throughout the length of the turbine in order to secure a high value for the sum of the squares of the blade speeds. The latter factor is one of the factors determinative of the Parsons figure of the turbine, and should be high to insure a turbine having high thermo-dynamic efficiency. Due, however, to the fact that the gaseous motive fluid has a relatively low specific heat value, it is possible to employ the construction according to the present invention and to secure the many advantages of such construction without having to resort to an undue number of stages of blading in the blade system in order to obtain a Parsons figure for the turbine having a value high enough to insure high thermo-dynamic efficiency.

It will further be observed from the figures that the form of construction in accordance with the present invention permits a relatively great amount of expansion, which is necessary in the turbine, and the creep of the metal to take place without causing destructive stresses to be set up in the turbine structure. The turbine shaft, which is subjected at the inlet end of the turbine to the relatively close proximity of high temperature gases is quickly and readily heated more or less uniformly with the blade system, and the form and construction of the turbine casing permits this part to be also readily and quickly heated without setting up dangerous stresses therein. Furthermore, the manner in which the stationary guide blades are assembled in the casing permits freedom of radial expansion in a manner relieving the structure from serious stresses. Free relative axial expansion between the shaft and the turbine casing is provided for, due to the form and arrangement of the shaft bearings, and it will be noted that the shaft is anchored axially with respect to the casing at a place adjacent to the exhaust or outlet end of the turbine. This is important, since the radial clearance spaces at the outlet end of the turbine must be greater than the corresponding clearance spaces at the inlet end of the turbine where the blade rows are of relatively small diameter. Consequently, it is highly desirable to maintain the axial packing for the blade rows at the outlet end of the turbine as tight as possible, and this desired result is materially aided by anchoring the turbine shaft axially with respect to the casing close to the outlet end of the turbine blading. At the inlet end of the turbine, where the maximum relative movement axially

between the shaft and the casing takes place, the radial packings involve very considerably smaller clearance spaces, and consequently are more effective than the radial packings with large clearances at the outlet end of the turbine.

As previously noted, the blade systems in Figs. 1 and 4 differ in that in the system shown in Fig. 4 the lengths of the blades relative to the mean diameters of the blade rows decrease from the inlet end of the turbine toward the outlet end of the turbine, whereas in the structure shown in Fig. 1, the relative lengths remain substantially constant. The amount of the decrease in the relative lengths of the blades will, of course, vary depending upon how much residual energy it is desired to have in the exhaust gases in the form of outlet velocity, but by way of example, it may be stated that in a turbine of the character shown in Fig. 1, having blades at the inlet end the length of which is 20% of the mean diameter of the blade row at the inlet end, the length of the blades at the outlet end of the turbine may advantageously be in the neighborhood of 15% to 16% of the mean diameter of the outlet blade row.

From the foregoing description it will be evident that many changes and modifications may be made without departing from the spirit of the invention, and further, that certain features of the invention may be employed to the exclusion of others. It is accordingly to be understood that the invention embraces all forms of apparatus that may fall within the terms of the appended claims when construed as broadly as is consistent with the state of the prior art.

What I claim is:

1. A gas turbine for extracting energy from gaseous motive fluid at an admission temperature of at least 800° C. absolute comprising a rotor, a circumferentially integral casing of generally conical form increasing in diameter from the inlet to the outlet end of the turbine in a series of cylindrical steps, there being one step for each stage of the turbine, said rotor comprising a plurality of rows of moving turbine blades, and a plurality of rows of stationary guide blades between said rows of moving blades, said rows of stationary guide blades comprising stepped outer blade rings having outer surfaces cooperating with the stepped surfaces of the casing, said blade rings being insertable and removable axially of and independently expansible in radial direction with respect to said casing and radially extending pins for securing the said rings in said casing.

2. A gas turbine for extracting energy from gaseous motive fluid at an admission temperature of at least 800° C. absolute comprising a rotor and a casing, said rotor comprising a shaft and a plurality of turbine discs carried by the shaft, said turbine discs having flanged and recessed portions at their inner circumferences, radially extending pins passing through said flanged portions for securing the discs to the shaft, the discs radially expansible with respect to said shaft and said pins being positioned with the flange of one disc located in the recess of an adjacent disc whereby to prevent radial displacement of said pins, and a plurality of rows of stationary guide blades carried by said turbine casing and extending radially inwardly between adjacent turbine discs.

3. In an axial flow gas turbine of the character described, a rotor comprising a shaft, an integral casing around the rotor, said casing being open at the exhaust end of the turbine, an end member for the outlet end of the turbine comprising

a ring part secured to the casing, a plurality of ribs extending radially inwardly from said ring part and an inner part connected to the inner ends of said ribs, said inner part supporting a bearing for said shaft and said ribs being adjacent to the last row of turbine blades, whereby to provide a direct exhaust in axial direction from said last row of blades through the spaces between the ribs, and a tapered hollow shield extending axially of the turbine from the inner ends of said ribs for guiding flow of said direct axial exhaust, whereby to reduce the outlet loss of the turbine.

4. In an axial flow gas turbine of the character described, a circumferentially integral conical casing having an inner surface in the form of a plurality of steps, turbine blading comprising a plurality of guide blade rings the outer surfaces of which are stepped or shouldered to fit the steps in the casing surface and mounted for free radial expansion with respect to the casing, a plurality of rows of moving blades having outer shroud rings, and axial packing between said outer shroud rings and the adjacent guide blade rings.

5. In an axial flow gas turbine of the character described, a circumferentially integral conical casing having an inner surface in the form of a plurality of steps, turbine blading comprising a plurality of guide blade rings the outer surfaces of which are stepped or shouldered to fit the steps in the casing surface and mounted for free radial expansion with respect to the casing, a plurality of rows of moving blades having outer shroud rings, axial packing between said outer shroud rings and the adjacent guide blade rings, and radial packing between said outer shroud rings and both the casing and an adjacent guide blade ring.

6. In an axial flow gas turbine of the character described, a rotor having a shaft, casing structure including a conical portion around the rotor and an end member at the outlet end of the turbine comprising a plurality of ribs extending radially inwardly from said conical portion and an inner part connected to the inner ends of said ribs, a bearing carried by said inner part for supporting one end of said shaft and for holding said one end of the shaft in fixed axial relation with respect to said end member, a separate supporting member attached to said casing structure adjacent to the inlet end of the turbine, said supporting member being fixed axially and movable radially with respect to the casing structure, and a bearing carried by said supporting member for supporting said shaft at the inlet end of the turbine, said shaft being movable axially with respect to said last mentioned bearing.

7. In an axial flow gas turbine of the character described, a rotor having a shaft, a circumferentially integral casing surrounding said rotor, a plurality of rows of moving blades each having an annular inner blade ring, each of said inner blade rings being axially spaced from adjacent rings to provide for individual axial expansion of the rings on the shaft and each of said rings being secured to the shaft by radially extending pins whereby to permit radial expansion of the rings with respect to the shaft, a plurality of rows of fixed guide blades located between said rows of moving blades and each having an outer blade ring, and a plurality of radially extending pins for independent mounting of each of said outer blade rings in said casing, there being clearance between said outer blade rings and said

casing to permit radial expansion of the rings with respect to the casing.

8. An axial flow turbine of the character described, including a rotor having moving blading and a bearing at the inlet end of the turbine, supporting structure including a part carrying said bearing, a circumferentially integral conical casing part around said moving blading and carrying stationary blading cooperating with said moving blading to form a blade system, and means for connecting said casing part to said supporting structure so as to permit free radial expansion of said casing part with respect to said supporting structure at the place of attachment thereto and to said rotor adjacent to the inlet end of the turbine.

9. An axial flow turbine of the character described, including a rotor having moving blading and a bearing at the inlet end of the turbine, supporting structure including a part carrying said bearing, a circumferentially integral conical casing part around said moving blading and carrying stationary blading cooperating with said moving blading to form a blade system, and a plurality of radially extending pins connecting said casing part to said supporting structure so as to permit free radial expansion of said casing part with respect to said supporting structure at the place of attachment thereto and to said rotor adjacent to the inlet end of the turbine.

10. An axial flow turbine of the character described, including a rotor having a plurality of rows of moving blades thereon and a bearing at the inlet end of the turbine, supporting structure for supporting said bearing, a circumferentially integral conical casing around said rows of moving blades and carrying rows of stationary blades cooperating with said rows of moving blades to form a blade system, means for connecting said casing to said supporting structure for free radial expansion thereof with respect to said structure at the place of attachment thereto, and a plurality of rows of stationary guide blades carried by said casing and freely expansible with respect thereto in radial direction.

11. An axial flow turbine of the character described, including a rotor having a plurality of rows of blades, supporting structure for supporting said rotor at the inlet end of the turbine, a conical casing around said blade rows, means for connecting said casing to said supporting structure for free radial expansion of the casing with respect to said structure at the inlet end of the turbine, a plurality of rings of stationary guide blades carried by said casing and freely expansible with respect thereto in radial direction, and an admission chamber for motive fluid housed within said supporting structure, said admission chamber being spaced from said supporting structure and being freely expansible with respect thereto.

12. An axial flow turbine of the character described, including a rotor having a plurality of rows of blades, supporting structure for supporting said rotor at the inlet end of the turbine, a conical casing around said blade rows, means for connecting said casing to said supporting structure for free radial expansion of the casing with respect to said structure at the inlet end of the turbine, a plurality of rings of stationary guide blades carried by said casing and freely expansible with respect thereto in radial direction, an admission chamber for motive fluid housed within said supporting structure, said admission

chamber being spaced from said supporting structure and being freely expansible with respect thereto and said chamber having an outlet for full admission of motive fluid to the first row of moving blades, and a ring of fixed guide vanes for guiding the motive fluid delivered from said chamber.

13. In an axial flow turbine, a rotor including a plurality of rows of moving blades having shroud rings of progressively increasing diameter from the inlet to the outlet end of the turbine, a stepped casing member, a plurality of rows of stationary guide blades carried by said casing member and freely expansible with respect thereto in radial direction, each row of guide blades including a stepped outer ring part having a portion located radially outwardly of and axially overlapping an adjacent shroud ring.

14. In an axial flow turbine, a rotor including a plurality of rows of moving blades having shroud rings, a casing around said rotor, a plurality of rows of stationary guide blades alternating with the rows of moving blades, and radially extending pins for supporting said rows of guide blades in freely expansible relation in radial direction with respect to said casing, the rows of guide blades including parts extending radially outwardly of and overlapping adjacent shroud rings.

15. A high temperature gas turbine for extracting energy from gaseous motive fluid comprising products of combustion at an admission temperature of at least 800° C. absolute, including a multiple stage axial flow blade system, the mean diameter of each of the successive stages being of generally increasing value from the inlet stage to the outlet stage of said system, the ratio of the length of the blades in the inlet row of moving blades to the mean diameter of said inlet row being at least as great as the ratio of the length of the blades in the outlet row of moving blades to the mean diameter of said outlet row, and means providing for full admission of motive fluid to the inlet stage of said blade system.

16. A high temperature gas turbine for extracting energy from gaseous motive fluid comprising products of combustion at an admission temperature of at least 800° C. absolute, including a multiple stage axial flow blade system, the mean diameter of each of the successive stages being of generally increasing value from the inlet stage to the outlet stage of said system, the ratios of the lengths of the blades to the mean diameters of their respective rows being substantially constant from the inlet end to the outlet end of said blade system, and means providing for full admission of motive fluid to said blade system.

17. A high temperature gas turbine for extracting energy from gaseous motive fluid comprising products of combustion at an admission temperature of at least 800° C. absolute, including a multiple stage axial flow blade system, the mean diameter of each of the successive stages being of generally increasing value from the inlet stage to the outlet stage of said system, the ratios of the lengths of the blades to the mean diameters of their respective rows progressively decreasing from the inlet stage to the outlet stage of said blade system, and means providing for full admission of motive fluid to the inlet stage of said blade system.

18. A high temperature gas turbine for extracting energy from gaseous motive fluid comprising products of combustion at an admission temperature of at least 800° C. absolute includ-

ing a multiple stage axial flow blade system, the mean diameter of each of the successive stages being of generally increasing value from the inlet stage to the outlet stage of said system, the inlet stage of said system including a row of moving blades having a length within a range the lower limit of which is at least one-tenth and the upper limit of which is of the order of one-fifth of the mean diameter of said row and the ratio of the length of the blades of said row to the mean diameter of said row being at least as great as the ratio of the length of the moving blades in the outlet stage of said system to the mean diameter of the moving blade row of said outlet stage, and means providing for full admission of motive fluid to the inlet stage of said blade system.

19. A high temperature gas turbine for extracting energy from gaseous motive fluid comprising products of combustion at an admission temperature of at least 800° C. absolute, including a multiple stage axial flow blade system, the mean diameter of each of the successive stages being of generally increasing value from the inlet stage to the outlet stage of said system, the inlet stage of said system comprising a row of moving blades having a length within a range the lower limit of which is at least one-tenth and the upper limit of which is of the order of one-fifth of the mean diameter of said row, the ratios of the lengths of the blades in moving rows of the remaining stages of said system to the mean diameters of their respective blade rows being substantially the same as the ratio of the length of the blades in the first mentioned row to the mean diameter thereof, and means providing for full admission of motive fluid to the inlet stage of said blade system.

20. A high temperature gas turbine for extracting energy from gaseous motive fluid comprising products of combustion at an admission temperature of at least 800° C. absolute, including a multiple stage axial flow blade system, the mean diameter of each of the successive stages being of generally increasing value from the inlet stage to the outlet stage of said system, the inlet stage of said system including a row of moving blades having a length within a range the lower limit of which is at least one-tenth and the upper limit of which is of the order of one-fifth of the mean diameter of said blade row, the ratios of the lengths of the blades of the moving rows of the remaining stages of the system to the mean diameters of their respective rows progressively decreasing from the maximum value established in said inlet stage of the system to a minimum value in the outlet stage of said system, and means providing for full admission of motive fluid to the inlet stage of said blade system.

21. A high temperature gas turbine for extracting energy from gaseous motive fluid comprising products of combustion at an admission temperature of at least 800° C. absolute, including a multiple stage axial flow blade system, the mean diameter of each of the successive stages being of generally increasing value from the inlet stage to the outlet stage of said system, the inlet stage of said system comprising a row of moving blades having a length within a range the lower limit of which is at least one-tenth and the upper limit of which is of the order of one-fifth of the mean diameter of said blade row, the ratios of the lengths of the blades of the remaining rows of the system to the mean diameters of their respective rows progressively decreasing from the maximum value established in said inlet stage of the system to a minimum value in the outlet

stage of said system, said minimum value being of the order of three-quarters of said maximum value, and means providing for full admission of motive fluid to the inlet stage of said blade system.

22. A high temperature gas turbine for extracting energy from gaseous motive fluid comprising products of combustion at an admission temperature of at least 800° C. absolute, including a multiple stage axial flow blade system, the mean diameter of each of the successive stages being of generally increasing value from the inlet stage to the outlet stage of said system, the diameter of the inlet stage being so small that at the normal speed of operation of the turbine the speed of the moving blades of said inlet stage is of the order of 100 meters per second, the length of the moving blades of said inlet stage being within a range the lower limit of which is at least one-tenth and the upper limit of which is of the order of one-fifth of the mean diameter of the row of which they form a part and the ratios of the length of the blades of said row to the mean diameter of said row being at least as great as the ratio of the length of the moving blades in the outlet stage of said system to the mean diameter of the moving blade row of said outlet stage, and means providing for full admission of motive fluid to the inlet stage of said blade system.

23. In an axial flow gas turbine of the character described, a rotor having a shaft, a circumferentially integral casing around the rotor, said rotor and said casing carrying blades cooperating to form a blade system providing a path of flow in which the ratios of the lengths of the blades to the mean diameters of the blade rows of which they form a part are of decreasing value from the inlet toward the outlet of the system, whereby to provide an expansion path for the gases resulting in high residual exhaust velocity thereof, an end member for the outlet end of the turbine comprising a ring part secured to the casing, a plurality of ribs extending radially inwardly from said ring part and an inner part connected to the inner ends of said ribs, said inner part supporting a bearing for said shaft, and said ribs being adjacent to the last row of turbine blades whereby they provide a direct exhaust in axial direction from said last row of blades through the spaces between said ribs.

24. In an axial flow gas turbine of the character described, a rotor having a shaft, a circumferentially integral casing around the rotor, said rotor and said casing carrying blades cooperating to form a blade system providing a path of flow in which the ratios of the lengths of the blades to the mean diameters of the blade rows of which they form a part are of decreasing value from the inlet toward the outlet of the system, whereby to provide an expansion path for the gases resulting

in high residual exhaust velocity thereof, an end member for the outlet end of the turbine secured to said casing and including an inner part supporting a bearing for said shaft and a plurality of radially extending ribs adjacent to the last row of turbine blades, said ribs providing axially extending guide surfaces for guiding the exhaust gases in direct axial flow from the turbine.

25. A high temperature gas turbine for extracting energy from gaseous motive fluid comprising products of combustion at an admission temperature of at least 800° C. absolute, including a multiple stage axial flow blade system, the mean diameter of each of the successive stages being of generally increasing value from the inlet stage to the outlet stage of said system and said system having blades the lengths of which are of generally increasing value from the inlet stage to the outlet stage of said system, the ratio of the length of the blades in the inlet row of moving blades to the mean diameter of said inlet row being at least as great as the ratio of the length of the blades in the outlet row of moving blades to the mean diameter of said outlet row, and means providing for full admission of motive fluid to the inlet stage of said blade system.

26. A high temperature gas turbine for extracting energy from gaseous motive fluid comprising products of combustion at an admission temperature of at least 800° C. absolute, including a multiple stage axial flow blade system, the mean diameter of each of the successive stages being of generally increasing value from the inlet stage to the outlet stage of said system, and said system having blades the lengths of which are of generally increasing value from the inlet stage to the outlet stage, the ratios of the length of the blades to the diameters of their respective rows being substantially constant from the inlet end to the outlet end of said blade system, and means providing for full admission of motive fluid to said blade system.

27. A high temperature gas turbine for extracting energy from gaseous motive fluid comprising products of combustion at an admission temperature of at least 800° C. absolute, including a multiple stage axial flow blade system, the mean diameter of each of the successive stages being of generally increasing value from the inlet stage to the outlet stage of said system, and said system having blades the lengths of which are of generally increasing value from the inlet stage to the outlet stage, the ratios of the lengths of the blades to the mean diameters of their respective rows progressively decreasing from the inlet stage to the outlet stage of said blade system, and means providing for full admission of motive fluid to the inlet stage of said blade system.

ALF LYSHOLM.

CERTIFICATE OF CORRECTION.

Patent No. 2,080,425.

May 18, 1937.

ALF LYSHOLM.

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction as follows: Page 1, first column, line 1, before the words "Briefly stated" insert the following paragraphs:

The present invention relates to turbines, and has particular reference to turbines intended to be operated with a motive fluid of high temperature. Still more particularly, the invention relates to gas turbines adapted to be employed in gas turbine systems of the continuous combustion type and adapted to utilize motive fluid having a relatively low admission pressure, for example, from four to ten atmospheres, and having an admission temperature of at least 800°C absolute.

In some of its aspects the invention relates particularly to gas turbines of the axial flow type adapted to be embodied in a unit in a gas turbine system, in which the turbine is directly associated with a device to be driven thereby, such for example as a compressor providing a compressed gaseous medium to be utilized as a constituent of the motive fluid for the turbine. Further aspects of the invention relate to turbines of the above character which are adapted to provide propelling effect due to the reactive or rocket effect of exhaust gases discharged from the turbine at high velocity.;

and that the said Letters Patent should be read with this correction therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 27th day of July, A. D. 1937.

Henry Van Arsdale
Acting Commissioner of Patents.

(Seal)