Nov. 6, 1956 P. SCHWARZKOPF 2,769,611

GAS TURBINE ROTORS AND THEIR PRODUCTION

Filed Aug. 15, 1951 2 Sheets-Sheet 1

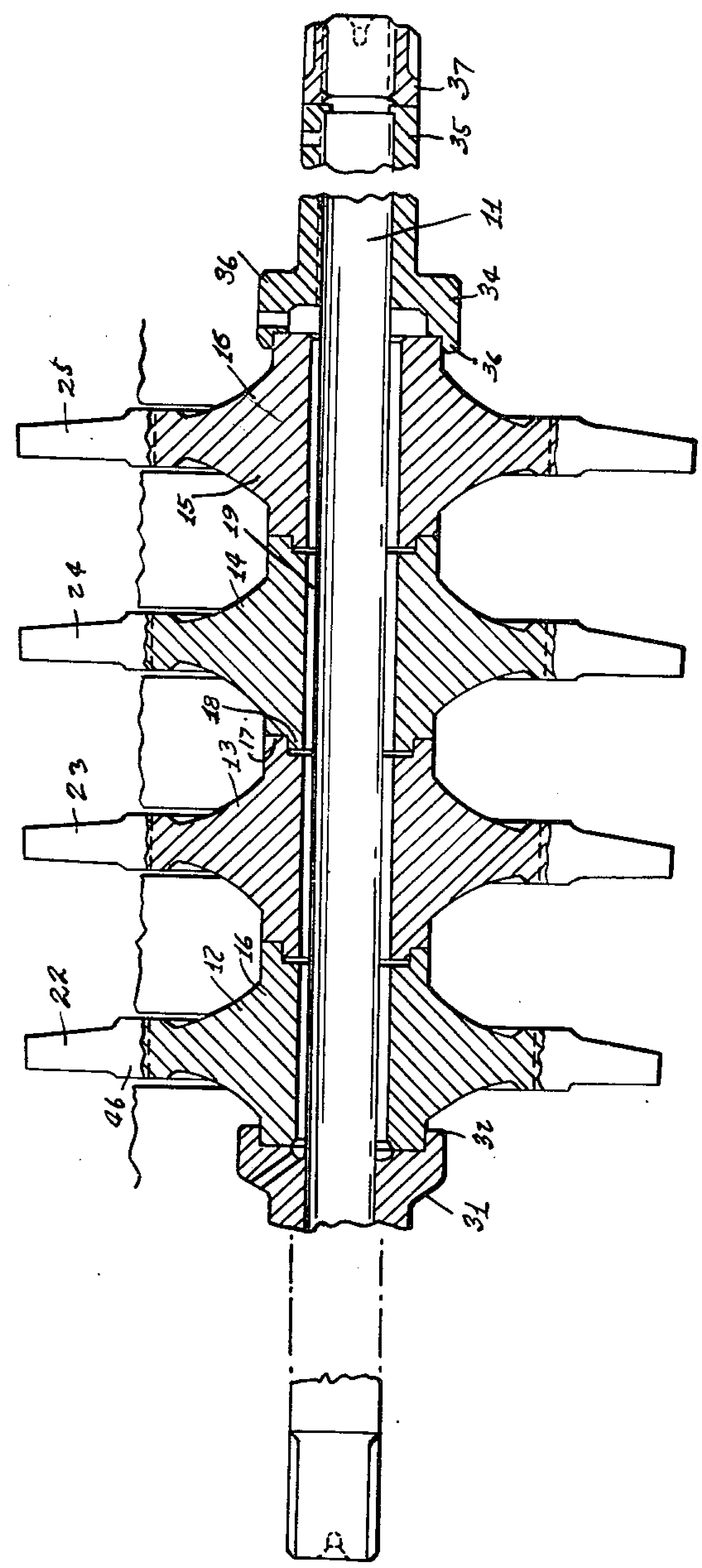

FIG. 1

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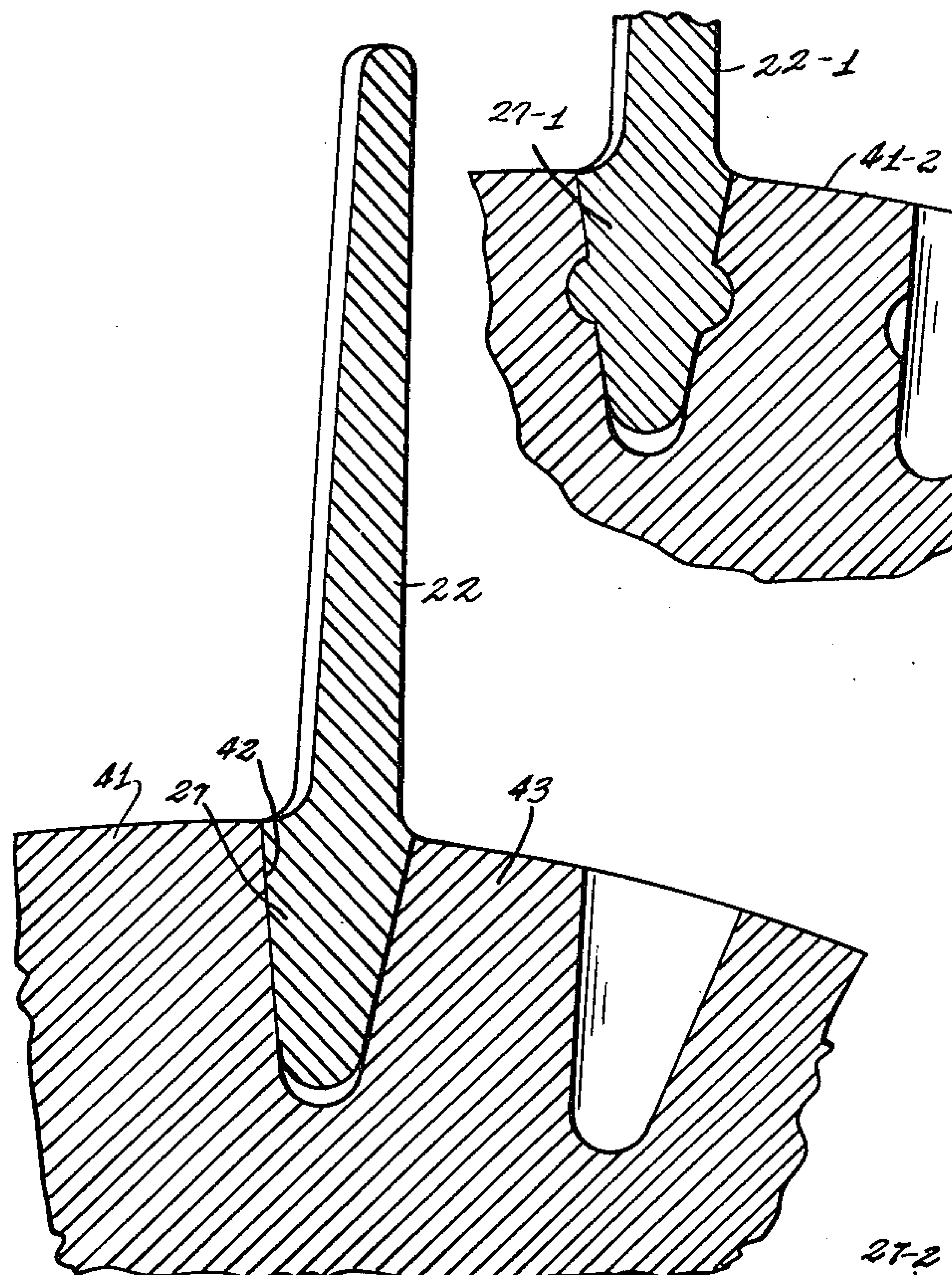

FIG. 4

FIG. 2

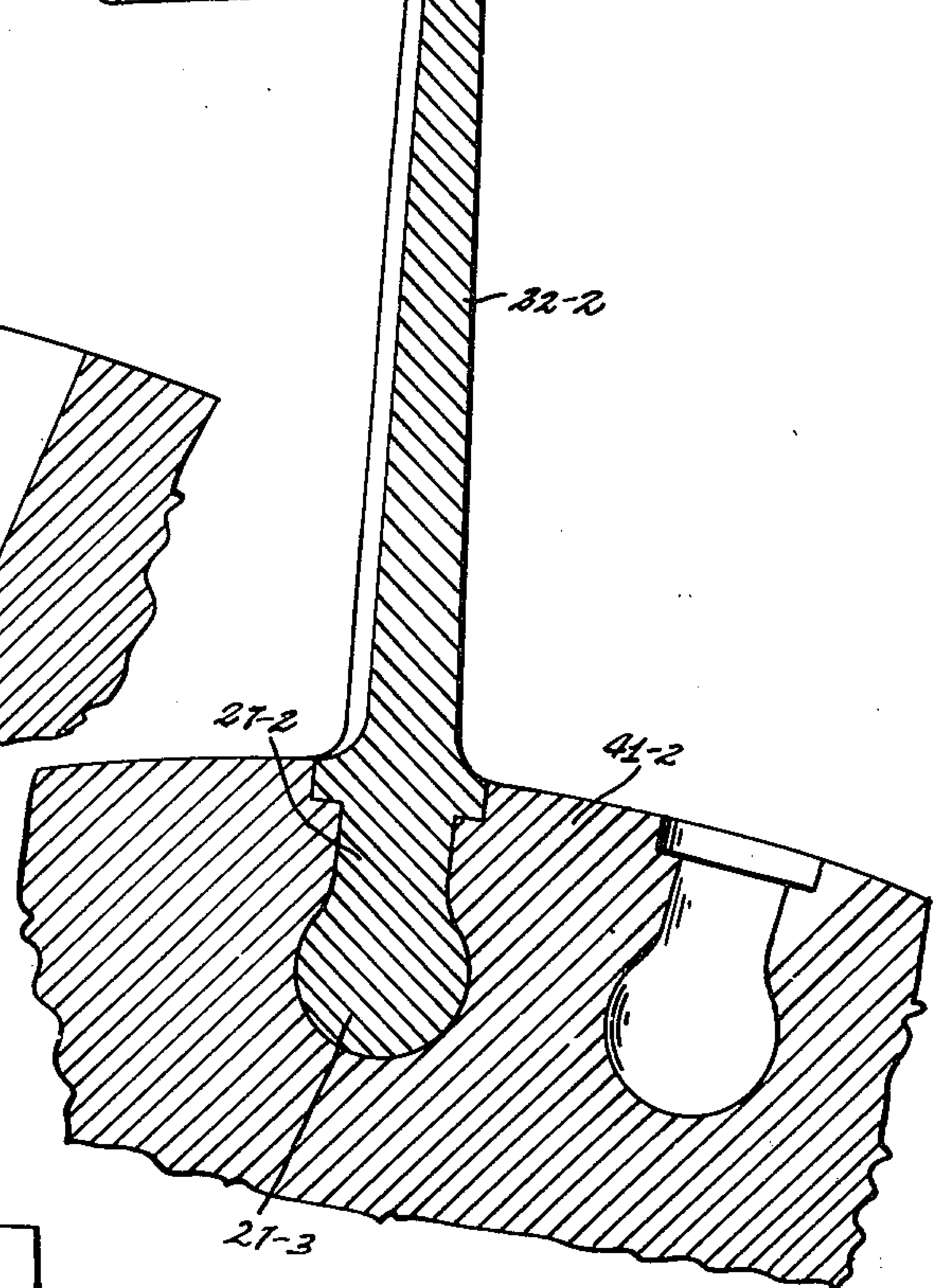

FIG. 5

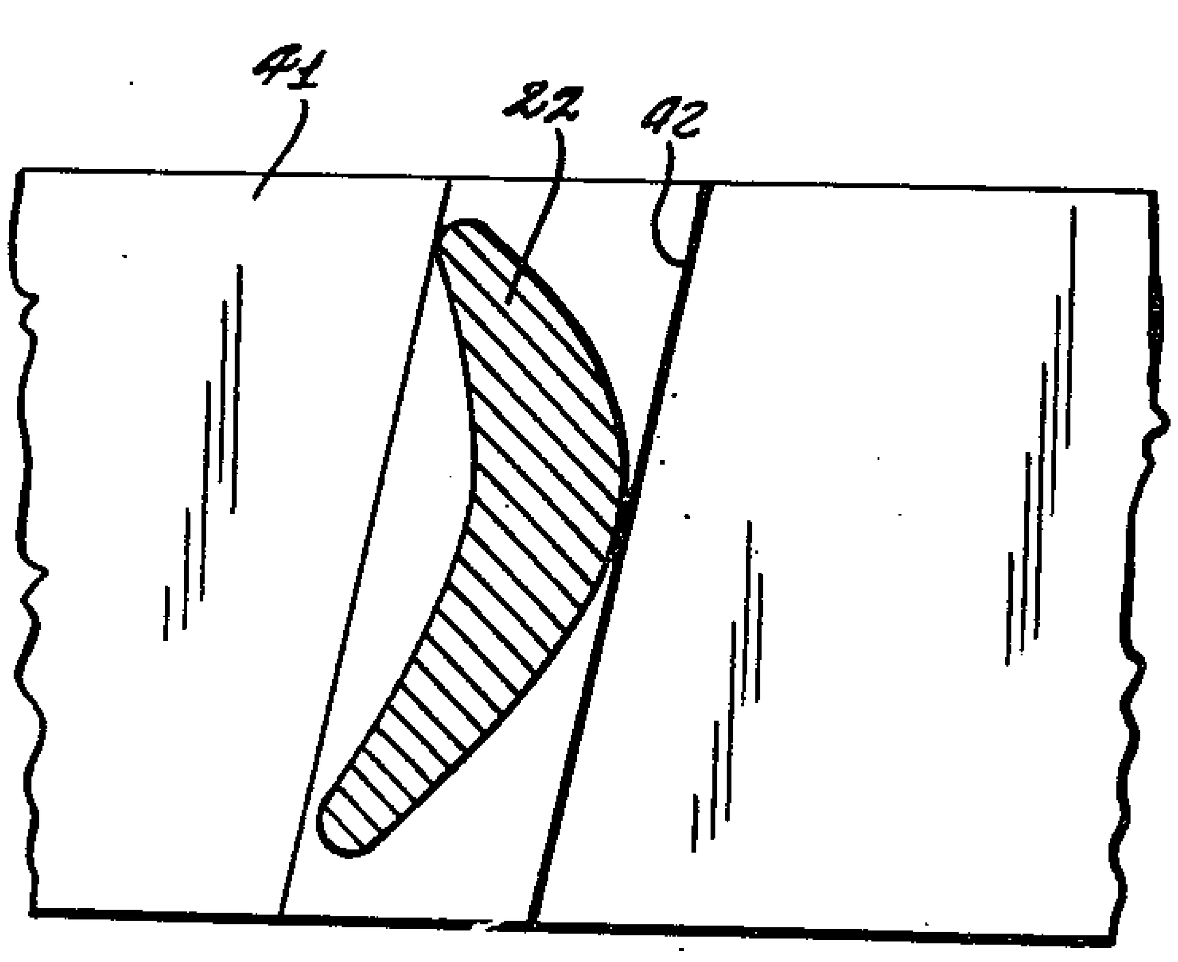

FIG. 3

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GAS TURBINE ROTORS AND THEIR PRODUCTION

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Application August 15, 1951, Serial No. 242,023

2 Claims. (Cl. 253—39)

This invention relates to gas turbines in which compressed air and admixed fuel are subjected to combustion, and the energy of the high-temperature, high-pressure combustion gases is utilized to develop rotary driving power by discharging them by way of one or more successive arrays of stationary fluid guiding vane nozzles into one or more successive arrays of fluid guiding bucket passages of a turbine rotor for imparting thereto the mechanical driving power. The efficiency of such turbines is limited by the maximum temperature at which the hot combustion gases can be discharged into initial gas turbine stages, this limitation being imposed by the hot-strength and corrosion resistance of the materials available for bucket passages of the turbine rotor which has to rotate at high speed at which the buckets are subjected to relatively high stresses.

The thermal efficiency at which each stage of the turbine operates, rises with the temperature of the combustion gases discharged through the initial bucket stages.

The material heretofore generally used for such gas turbine buckets consisted essentially of a cobalt base alloy containing about 60% cobalt, about 20% chromium, about 5% nickel, the balance consisting of additional alloy ingredients. However, the hot strength of such material, if it is to be used for a minimum useful life, does not exceed about 800° C., and for this reason all gas turbines have heretofore been operated only with combustion gases of a correspondingly limited temperature of about 800° only.

There have been available various cemented corrosion-resistant materials which exhibit relatively high strength in the temperature range from about 950° C., to about 1500° C., and which have substantially the same transverse rupture strength at such high temperatures as at normal temperatures. Among such known materials are cemented zirconium borides, such as described in the copending applications of F. W. Glaser, Serial No. 170,240, filed June 24, 1950; also cemented molybdenum disilicides, such as described in the copending applications, Serial No. 177,548, filed August 3, 1950, and cemented titanium carbides, such as described in application, No. 39,881, filed July 21, 1950, now abandoned.

However, in the past, it has been generally believed that it is impossible to use such cemented corrosion-resistant materials in applications such as of gas turbine rotor buckets which rotate at a high speed of about 20,000 R. P. M., or more, because when stressed such known cemented materials have too little elongation and area reduction.

The present invention is based on the discovery that notwithstanding these limitations, the known corrosion-resistant cemented materials of the foregoing type may be used in applications such as gas turbine buckets provided that the gas turbine is designed with a rotor of small diameter only, such as only about 12 to 18 inches, and that the buckets as well as the massive bucket mounting

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body of the turbine rotor are both formed of cemented particle material, with the buckets joined to the massive rotor mounting body by a conjoined sintering operation or forming an integral part of a continuous sintered cemented material structure.

Among the objects of the invention is, accordingly, a gas turbine rotor having a buckets and bucket mounting body formed of corrosion-resistant cemented material which in operation does not subject the material of the buckets to strains at which their relatively low limits of elongation and area reduction are exceeded.

Among the broader objects of the invention is also a composite structure comprising at least two members of sintered refractory particle material which in operation is subjected to large operative stresses at junction surfaces at which said two members have been united to each other by sintering at an elevated temperature, one of said members having an embracing junction region embracing at least in part an embraced junction portion of the other of said members held within an opening or junction recess bounded by the embracing junction region, the embracing junction region of said one member having the property of tending to shrink more than the embraced junction portion of the other member when said two members are subjected jointly to the same sintering treatment at an elevated temperature so as to cause said embracing junction region to become shrunk over and establish clamping engagement and hold fixed said embraced junction portion of said other member within said junction recess.

The foregoing and other objects of the invention will be best understood from the following description of exemplifications thereof, reference being had to the accompanying drawing wherein:

Fig. 1 is a vertical sectional view of a portion of a gas turbine rotor exemplifying one form of the invention;

Fig. 2 is an enlarged transverse sectional view of a portion of the rotor showing the junction of the bucket and the mounting region of the turbine rotor;

Fig. 3 is the top view of the elements shown in Fig. 2;

Figs. 4 and 5 are views similar to Fig. 2 showing other modifications.

The principles of the invention which have wide application will be described in connection with a specific exemplification thereof shown in the form of the initial high temperature section of a turbine rotor for a small gas turbine with the outer diameter of the high temperature section about 12.5 inches and with the outer diameter of the rotor at the periphery of the buckets being about 10 inches.

Referring to Fig. 1, there is shown a shaft **11** having affixed thereto a plurality of generally circular disc-like bucket-mounting rotor members **12**, **13**, **14**, **15**, each carrying on its periphery an array of fluid-guiding turbine buckets **22**, **23**, **24**, **25**.

Each bucket **22** to **25** has an air-foil shape and is shown provided with a root **27** through which it is joined to the respective rotor mounting members **12** to **15**.

The annular arrays of the turbine buckets **22**, **23**, **24**, **25** shown, are designed for cooperation with sets of stationary diaphragm nozzle vanes, not shown, arranged in front of each array of buckets for guiding streams of high-temperature, high-pressure gases through the passages formed by adjacent buckets of each of the several rotor members **12**, to **15**, and thereby develop the desired driving forces which are imparted to the turbine rotor and utilized for driving a suitable load not shown. Thus, the rotor shaft **11** may be utilized to drive either the compressor of the turbine or both the compressor and an external load, not shown.

In the form shown, the hot combustion gases are discharged and flow from the combustion chambers, in the direction from left to right, as seen in Fig. 1, through the successive arrays of buckets **22, 23, 24, 25** of the several stages of the high temperature section of the gas turbine, the balance of the energy in the combustion gases, which are of a temperature not higher than about 800° C. being utilized in subsequent turbine stages which may be made in a conventional way and need not be described herein.

The rotor mounting members **12** to **15** and the buckets **22** to **25** of the high temperature turbine section **10** are formed of cemented refractory particle material of great corrosion-resistance and hot-strength, for instance, of the type described in the copending application of Frank W. Glaser, Serial No. 170,240 filed June 24, 1950.

Each rotor mounting member is provided with an inward hub section **16** of relatively great axial length. Successive hub sections **16** are provided with interfitting abutting shoulder portions **17, 18** whereby they are joined into a continuous sleeve-like hub body surrounding the shaft **11**, which may be held spaced therefrom by a space gap **19**. The so-formed conjoined rotor assembly **12** to **15** is held in its desired position on the shaft **11** by axial and radial clamping engagement with collar members **31, 34** forming part of or affixed to the shaft **11**.

In the form shown, shaft collar member **31** has a circular flange **32** and forms with its adjoining axial transverse seating surface a mounting seat engaging the end surfaces of the hub **16** of the adjacent rotor mounting member **12** thereby fixing the axial and radial position of the adjoining end of the combined rotor body structure **12, 13, 14, 15**. The generally similar other collar member **34** has a similar collar **36** engaging the end surfaces of hub **16** of the adjacent rotor member **15**, thus fixing in conjunction with collar **31** the axial and radial position of the rotor body **12** to **15**. The axial clamping position of the seating collar **34** is suitably fixed, as by a nut **37** engaging a threaded portion of the shaft so that by turning the nut the collar **34** may be forced against the hub **16** of the combined rotor assembly **12, 13, 14, 15** for holding it affixed in its properly centered coaxial position on the rotor shaft **11**.

Figs. 2 and 3 show one arrangement of the invention whereby separately produced buckets of cemented refractory are joined to the periphery of a rotor mounting member of generally similar material to form a turbine bucket rotor which will operate efficiently in the high temperature stage of a gas turbine with combustion gases of temperatures higher than 800° C. and up to 1200° C. to 1500° C., while revolving at a high speed such as 20,000 to 30,000, or even higher, R. P. M., without exceeding the elongation and area reduction limits of such material under the great operating stresses.

Since each turbine rotor member **12** to **15** is of substantially alike construction, only that of turbine rotor member **12** will be described.

The peripheral rotor body **41** of the circular rotor members **12** (and of the similar rotor members **13** to **15**) is formed with an array of axially extending generally similar junction grooves **42** bounded by adjacent junction projections **43** of the rotor body **41**. The roots **27** of the individual buckets **22** have junction surfaces shaped to fit, engage and be clamped within generally similar junction surfaces of the individual junction grooves **42** of the rotor body **41** and are joined thereto into an integral bucket rotor. The bucket **22** of Fig. 2 is shown provided with a root **27** having generally straight downwardly tapering junction surfaces shaped to engage and be held clamped within similar junction surfaces of the rotor body **41** junction grooves **42** of the rotor body **41**. Alternatively, as shown in Fig. 4, the downwardly tapering root **27–1** of another form of bucket **22–1** may be provided with an additional rounded protuberance interfitting and held clamped within with correspondingly shaped junction surfaces of the rotor junction grooves of the rotor body. Alternatively as shown in Fig. 5, the root **27–2** may be provided with an enlarged generally circular anchoring portion **27–3** shaped to interfit and be clamped within correspondingly shaped junction grooves of the rotor body **41**.

In accordance with the invention, the roots of gas turbine buckets each made of cemented refractory particle material, are united into strong corrosion-resistant structures with their rotor mounting member of generally similar cemented material, by subjecting the combined rotor member with the roots of the individual buckets, held in the interfitting junction grooves of the rotor member, to a sintering treatment at elevated temperature at which the combined bucket rotor member undergoes a limited differential shrinkage which causes the junction regions of the rotor mounting member to shrink over and thereby establish a clamping engagement with the bucket root while a sintering junction is formed between the junction surfaces of the bucket roots and the junction grooves of the rotor member.

The differential shrinkage between the junction regions of the bucket roots and the rotor mounting member may be achieved in a number of different ways.

First, the rotor mounting member, such as the rotor member **12**, is provided with a relatively larger radially extending body than the bucket roots **27** so that when heated at a sintering temperature the larger volume of the mounting body which causes its outer peripheral rotor body **41** to shrink by a larger amount than the relatively short root portion **27** of the bucket **22**. As a result, the junction region of the mounting body **41** which shrinks at a greater rate than the bucket root **27**, will shrink over and clampingly engage the root **27** and thereby establish by itself a very strong connection of the root to the mounting body **41** without subjecting their junction regions to excessive strains.

Second, the cemented material of the bucket **22**, or its root **27**, may be so chosen and formed so as to cause the peripheral region of the mounting body to shrink at a greater rate than the bucket root. For instance, when using the same cemented material, the bucket or its root may be given lesser porosity, either in the initial powder compacting operation or in the initial sintering operation or both, than the bucket mounting body. Alternatively, the cemented material of the buckets may be of a different character than that of its mounting body and have a lower rate of shrinkage, at least at the bucket root than the material of the junction region of the mounting rotor body.

In each case, as the rotor member with the roots of its array of buckets **22** is subjected to a sintering operation at an elevated temperature which causes a certain degree of shrinkage of the rotor body **41** and the buckets held in its junction grooves, the greater shrinkage of the junction region of the rotor mounting body **41** will cause it to shrink over and clampingly engage the bucket root which shrinks to a less extent and thereby establish a very strong connection between the bucket root and the rotor body **41** while the sintering operation independently provides an additional, firm junction connection between the bucket roots and the junction groove regions of the rotor mounting member.

In order to enable those skilled in the art to more readily practice the invention, and without thereby in any way limiting its scope, there will now be given specific examples whereby very effective and strong junctions are formed established between turbine bucket roots of cemented refractory particle material and junction grooves of a turbine rotor mounting body of generally similar cemented material.

There is prepared a powder particle body containing about 90 parts of zirconium boride ZrB_2 and about 10 parts boron. (Throughout the specification and claims, all proportions are given in weight.) Such powder mixture body may be prepared, for instance, in the manner disclosed in the co-pending application of F. W. Glaser, Ser. No. 170,240, filed June 24, 1950. The powder mixture may also contain a lubricant, for instance, about 1% of camphor.

This powder body is used for forming compacts in the form of turbine buckets and in the form of turbine rotor bodies, such as the buckets **22**, **23**, **24**, **25** and their associated rotor mounting members **12**, **13**, **14**, **15**. The green powder compacts are designed so as to take into account the shrinkage to which the buckets and rotor members so compacted will undergo in the subsequent sintering and shaping operations to which they are subjected as hereinafter described.

Out of this powder body are formed—by cold pressing in properly shaped steel dies, with a pressure of about 7 t. s. i.—green bucket compacts and green rotor member compacts of a shape corresponding to the shape of the buckets **22** to **25** and rotor members **12** to **15**, shown in Figs. 1 to 3. In designing the dies for such green powder compacts, allowance is made for the further shaping and for the shrinkage to which the compacts are subjected in the further treatments described below by which they are formed into the combined bucket rotor body of the desired shape and physical characteristics.

The cold pressed compacts so formed, which have a density of about 3.0 are then presintered at a temperature in the range of 1350° C. to 1800° C. for 15 minutes.

The similarly cold pressed rotor member compacts of substantially the same density are similarly presintered at the same temperature as the bucket compacts, but for a somewhat shorter time of about 12 to 13 minutes, so that when subjected together with the cold pressed buckets to same subsequent heat treatment, the rotor member will positively undergo a greater shrinkage than the roots of the individual buckets.

The so presintered bucket compacts and rotor member compacts, with their differential shrinkage characteristics, are then subjected to further shaping operations for giving the buckets and the rotor members a shape which, after the subsequent heat treatments, will result in a bucket rotor of the desired shape and dimensional characteristics.

After the shaping operations, the roots of its set of presintered buckets are assembled and affixed into interfitting engagement within the junction grooves of each presintered rotor member. The so assembled presintered combined bucket and rotor member is then subjected to a further final sintering operation at about 2200° to 2500° C. for about ½ to 1 hour. In this final sintering treatment both the rotor member and the buckets affixed thereto acquire the desired ultimate physical characteristics. In this final sintering treatment the somewhat greater shrinkage of the junction regions of the rotor member cause them to shrink over and clampingly engage the roots of the individual buckets which undergo less shrinkage and while the abutting surfaces of the root and of the junction groove surfaces of the rotor member become sintered to each other and additionally establish a strong sintered junction therebetween.

In the unitary bucket rotor member so formed, the buckets are permanently affixed to and form integral parts of the rotor member. Such gas-turbine rotor buckets exhibit great corrosion-resistance, and will operate with high effectiveness for long periods of useful life in combustion gases at temperatures above 900° C., such as 1200° C. to 1300° C., and up to 1500° C. while revolving at speeds up to about 20,000 to 30,000 R. P. M.

Instead of obtaining the differential shrinkage by subjecting the rotor member to a somewhat shorter presintering treatment than the buckets, the rotor member may be cold pressed into a green compact with a lower pressure than the buckets—such as 6 t. s. i. instead of 7 t. s. i.—thereby giving the rotor member lower density than the buckets.

Alternatively the green rotor member compact may be so pressed with a powder mixture containing a greater addition of organic lubricant, such as 1½% camphor instead of 1%, likewise resulting in a presintered rotor member of less density than the buckets.

The subsequent presintering treatment of the same temperature and duration will yield presintered buckets of greater density than the presintered rotor member, with the result that in the final sintering treatment the rotor member of lower density will undergo greater shrinkage than the higher-density buckets and cause the junction region of the rotor member to shrink over and clampingly engage the bucket roots held in the rotor junction grooves as explained above while at the same time the roots are joined to the junction groove regions of the rotor member by sintering junctions.

In a similar manner, other cemented refractory particle materials may be used for forming turbine buckets and rotor members which are then joined into a combined bucket rotor member by utilizing differential shrinkage of the junction portions of the rotor member relatively to the junction portions of the individual buckets for causing the roots of the buckets to become firmly affixed and united to the rotor member so as to form therewith a unitary integral bucket turbine rotor member in which the buckets are retained and firmly anchored in their operative positions throughout a long operative life.

Although the present invention was conceived in connection with the production of turbine bucket rotors out of refractory cemented material, the principles of the invention are broadly applicable to composite bodies of cemented refractory materials which inherently have lower elongation and area reduction limits than most solid metal bodies, and which have to be joined into a unitary structure capable of withstanding high operative stresses.

Another phase of the invention involves a gas turbine rotor having a relatively massive circular rotor mounting member with an annular array of turbine buckets integrally formed out of cemented refractory particle material by a sequence of common compacting shaping and sintering operations.

According to this phase of the invention, a turbine rotor member together with its peripheral array of buckets is formed by first cold pressing or compacting in a suitable die a body of refractory powder particle material into a green compact of a shape generally corresponding to the rotor with its array of peripheral buckets. The green compact must be made oversize to allow for further shaping of the rotor body and of its buckets and for the shrinkage to which they are subjected in the further sintering or heat treatments.

By way of example, a gas turbine rotor such as rotor member **12** with its annular array of buckets **22** are produced as follows:

There is first prepared a refractory particle powder body containing about 90 parts of zirconium boride and about 10 parts of boron together with about 1% of a lubricant such as camphor. Out of this powder body is then formed, by cold pressing in a properly shaped steel die with a pressure of about 7 t. s. i., a suitably oversized green compact having the shape of the rotor member **12** with an annular row of turbine buckets **22** or alternatively with the bucket region of the rotor member having the form of a continuous rib-like circular extension of the rotor body of a cross section corresponding to the cross section of the buckets **22** as seen in Fig. 1. The oversized green powder compact so formed is then presintered at a temperature in the range of about 1350° C. to 1800° C. for about 15 minutes to give it strength required for the further shaping treatments. The presintered rotor and bucket blank so formed may be readily shaped by any conventional shaping tools to give the rotor blank its desired shape and also to form out of its outer rib-like region the row of properly shaped buckets, such as shown in Figs. 2 and 3. In this shaping operation, allowance should be made for the further shrinkage to which the so shaped presintered rotor-bucket blank is subjected in the further sintering treatment. After so shaping the presintered rotor blank into a rotor member having along its periphery the row of properly shaped buckets, the shaped rotor bucket structure is subjected to the final sintering operation at about 2200° C. to 2500° C. for about ½ to 1 hour by which it is given the desired ultimate physical characteristics. After this final sintering treatment, it is merely necessary to subject the bucket rotor to the final finishing and polishing operation whereupon it is ready for mounting in the turbine rotor.

As an example, in producing a turbine bucket rotor body with separately produced buckets, the following procedure of the invention may be followed:

Out of the powder body, of a particle size (minus) —325 mesh containing about 60% titanium carbide, 32% nickel and 8% chromium, there are formed, by cold pressing in suitable oversized dies with a pressure of about 2 to 20 t. s. i., green compacts of a shape corresponding to the bucket **22** and green compacts of a shape corresponding to the rotor member **12**.

In designing the dies, allowance is made for the shaping to which the buckets are subjected and also for the shrinkage to which the buckets and the rotor member are subjected in the sintering and other heat treatments by which they are formed into the desired rotor bucket structure.

The bucket compacts and the rotor compacts are then presintered for about 15 minutes at 1100° C. to 2500° C. into blanks of substantial strength which may be readily machined in a conventional way to the desired shape. However, the buckets are presintered for a somewhat longer period than the rotor body which is presintered, for instance, only for 12 to 13 minutes instead of 15 minutes to give it greater porosity or smaller density.

The so differentially presintered bucket compacts and rotor member compacts are then subjected to further shaping operations in which the buckets and also the rotor member are given shapes such that after their assembly into a rotor bucket structure, a subsequent final sintering operation will cause the junction regions of the rotor member to shrink more than the bucket roots with the result that the junction regions of the rotor body will shrink over and clampingly engage and embrace the roots of the individual buckets.

After the shaping operation just described, the roots of the array of so-shaped presintered buckets are assembled and affixed into inter-fitting engagement with the junction grooves of the presintered rotor member. The so-assembled presintered combined bucket and rotor member is then subjected to a final sintering operation at about 1500° C. to 2500° C. for 5 hours or up to 50 hours. In this final sintering treatment, both the rotor member and the buckets affixed thereto acquire the desired ultimate physical characteristics and the roots of the buckets are joined to the adjacent junction regions of the rotor by sintering junctions. Since the presintered rotor body was of greater porosity, its junction region will shrink more than the bucket roots embraced thereby thus causing the junction regions of the rotor member to shrink over and clampingly engage the roots of the individual buckets and thus form positive strong connections between the buckets and the rotor member.

When producing a turbine bucket rotor with the buckets extending integrally from the rotor member, the following procedure may be followed:

Out of a refractory particle powder body as disclosed in the previous example, there is formed, by a similar cold pressing process, a suitable oversized green compact having the shape of the rotor member **12** with an annular row of oversized buckets **22** or with a continuous bucket region having the form of a continuous circular extension of the rotor member **22** having a cross-section generally corresponding to an oversized cross-section of the buckets **22**. The so-formed oversized green powder compact, combining the rotor member with its bucket region, is then presintered for about 15 minutes at 1100° C. to 2500° C. into a blank of substantial strength which may be readily machined in a conventional way to the desired final shape. The so presintered rotor bucket blank is thereafter shaped by conventional shaping tools to give the rotor blank its final shape and to form out of its outer rib-like extension the row of properly shaped desired buckets as shown in Figs. 2 and 3. The shaped presintered blank is then subjected to the final sintering treatment of 5 to 50 by which the bucket rotor body of the desired dimensions is given the ultimate physical characteristics. After this final sintering treatment, it is merely necessary to subject the rotor bucket body to the final finishing and polishing operation whereupon it is ready for mounting in the turbine rotor.

The features and principles underlying the invention described above in connection with specific exemplifications, will suggest to those skilled in the art many other modifications thereof.

I claim:

1. In an elastic fluid turbine for operation with hot combustion gases, a rotatable turbine rotor comprising a generally circular mounting member of sintered refractory particle material arranged to transmit rotary driving torque along its axis, and an array of fluid guiding members of sintered refractory particle material projecting generally radially from the periphery of said mounting member for guiding and being driven by hot gases streaming between adjacent guiding members; said mounting member having a peripheral mounting region provided with an array of junction grooves separating integral junction projections of said mounting member; each of said guiding members having a junction root fitting into one of said junction grooves; said mounting member being produced out of sintered hard powder particles to provide its said mounting region with a certain porosity and each guiding member having been produced out of sintered powder particles to provide a root with a smaller porosity than said certain porosity; said mounting member having been subjected in assembled condition to a sintering treatment wherein said mounting region has undergone a higher rate of shrinkage than said roots, and thereby causing the junction projections of said mounting region to be forced by said higher rate of shrinkage of said mounting member into clamping engagement with the roots of the guide members held between them.

2. In an elastic fluid turbine for operation with hot combustion gases, a rotatable turbine rotor comprising a generally circular mounting member of sintered refractory particle material arranged to transmit rotary driving torque along its axis, and an array of fluid guiding members of sintered refractory particle material projecting generally radially from the periphery of said mounting member for guiding and being driven by hot gases streaming between adjacent guiding members; said mounting member having a peripheral mounting region provided with an array of junction grooves separating integral junction projections of said mounting member; each of said guiding members having a junction root of shorter radial length than said mounting member and fitting into one of said junction grooves; said mounting member being produced out of sintered hard powder particles to provide its said mounting region with a certain porosity and each guiding member having been produced out of sintered powder particles to provide a root with a smaller porosity than said certain porosity; said mounting member having been subjected in assembled condition to a sintering treatment wherein said mounting region has undergone a higher rate of shrinkage than said roots, and thereby causing the junction projections of said mounting region to be forced by said higher rate of shrinkage of said mounting

member into clamping engagement with the roots of the guide members held between them.

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