TURBINE NOZZLE-VANE CONSTRUCTION

Inventors: Richard L. Wachtell, Tuxedo Park; Edward C. Palmenberg, Nanuet, both of N.Y.

Assignee: Chromalloy American Corporation, Orangeburg, N.Y.

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ABSTRACT

The invention contemplates a multi-part construction for a turbine-nozzle assembly, to take the place of certain single-piece investment castings currently in use for such assemblies, intended primarily for gas-turbine application. The construction basically employs a blade element of desired airfoil-section development, and two base members, each locally recessed to define a locating socket or opening for the respective longitudinal ends of the blade. The recesses are carefully controlled in their location with respect to base-member geometry, to the end that the assembly may produce a given performance-class number for the resulting nozzle, once assembled and united into an integral whole, by welding, brazing, coating and the like finishing steps. The construction is described in the context of methods of achieving the same (a) as new construction and (b) as repair of worn conventional constructions, i.e., constructions which were originally fabricated as single-piece investment castings, but which have served their normal life span and are therefore consigned to disposal as scrap. The invention is also described in the context of application (a) to a single-piece gas-turbine nozzle assembly or stage, and (b) to a single-piece nozzle-component assembly.

7 Claims, 22 Drawing Figures
TURBINE NOZZLE-VANE CONSTRUCTION

This is a division of application Ser. No. 221,306, filed Jun. 27, 1972, now U.S. Pat. No. 3,802,046.

This invention relates to the construction and reconstruction of nozzle assemblies and nozzle-component assemblies for use in gas turbines.

Turbine-engine nozzle guide vanes or blades are subjected to rapid extremes of temperature and differential-pressure loading, in the context of high flow rates, and as a result the individual parts comprising a nozzle assembly become bent, eroded and otherwise distorted. Any local departure of nozzle-throat area from design conditions establishes an asymmetry of flow and pressure distribution at any given engine stage, accelerating the destructive process. Since the nozzle assemblies, or nozzle-component assemblies as the case may be, are conventionally investment castings of superalloy materials, their replacement is expensive and various repair techniques attempt to salvage as much as possible of the original casting. Hot-forming, inlaying of blade edges, and filling are among the several techniques in use, all basically operative on the entire original casting, i.e., on the blade with its integrally cast end-base members.

It is an object of the invention to provide a new construction for a nozzle assembly or nozzle-component assembly of the character indicated and lending itself to new-construction and to the repair or reconstruction of a worn assembly.

It is a specific object to achieve the above object in application to an assembly which is so far worn as to be deemed unacceptable for reconditioning by existing techniques and, therefore, consignable to the scrap heap.

It is a further specific object to achieve the foregoing objects with such a high degree of control of blade size, orientation and location that nozzle class can be specified and held within limits which are at least as close as those by which conventional original castings (or assemblies of original castings) are judged.

Another object is to provide a construction of the character indicated wherein investment-casting techniques and requirements are substantially simplified.

It is also an object to provide such a construction wherein a greater latitude is inherently available, as to choice and use of materials.

It is a general object to achieve the foregoing objects with constructions and methods which can be applied with relative simplicity using existing tools and technology, and at competitive and relatively low cost.

Other objects and various further features of novelty and invention will be pointed out or will occur to those skilled in the art from a reading of the following specification, in conjunction with the accompanying drawings.

FIG. 1 is a perspective view of a gas-turbine nozzle assembly, being specifically a nozzle guide-wide assembly for an auxiliary power unit, and exhibiting wear such as to render the same unfit for further use, but nevertheless repairable in accordance with the invention;

FIG. 2 is a side elevation of the assembly of FIG. 1, to illustrate a first repair step of the invention;

FIG. 3 is a view as in FIG. 2, to illustrate another step;

FIG. 4 is left-end view of the left base member of FIG. 3, to illustrate another step.

FIG. 5 is a simplified diagram to illustrate movable support of the members of FIG. 3 in conjunction with an electrical-discharge machining tool;

FIG. 6 is an enlarged fragmentary plan view of an electrode holder used in the apparatus of FIG. 5 for performing the step of FIG. 4, said view being partly broken-away and in section to reveal internal construction;

FIG. 6A is a fragmentary perspective view of the holder of FIG. 6, with a mounted electrode element;

FIG. 6B is a perspective view of the electrode element of FIG. 6A;

FIG. 7 is a view as in FIG. 6, to illustrate a second electrode holder used to perform the step of FIG. 4;

FIG. 8 is an enlarged fragmentary perspective view of the blade-supporting face of the base member at the right side of FIG. 3, to illustrate the step of FIG. 4 as applied to said base member;

FIGS. 9 and 10 are, respectively, side-elevation and plan views of one kind of blade element to be assembled to the base members of FIGS. 4 and 8;

FIGS. 11 and 12 are views corresponding to FIGS. 9 and 10, respectively, to show a second kind of blade element to be assembled to the base members of FIGS. 4 and 8;

FIG. 13 is a fragmentary perspective view of the completed reconstruction of the assembly of FIG. 1;

FIGS. 14 and 15 are views corresponding to FIGS. 9 and 10, respectively, to show a modified blade element, with FIG. 15 being partly in section at the plane 15-15 of FIG. 14 and in the context of adjacent base-member structure;

FIG. 16 is a simplified view in perspective of a single-piece nozzle-component assembly, being a buttress-type guide-vane assembly for a jet-aircraft engine, and exhibiting wear such as to render the same unfit for further use, but nevertheless repairable in accordance with the invention;

FIG. 17 is a perspective view of the left buttress of FIG. 16, after performing several steps of the invention;

FIG. 18 is a perspective view of a new blade element, for assembly to the buttress of FIG. 17;

FIG. 19 is a simplified fragmentary perspective view of work-holder and tool-holder parts for performing one of the operations to make the buttress of FIG. 17; and

FIG. 20 is a perspective view of the completed reconstruction of the assembly of FIG. 16.

Briefly stated, in application to the repair of damaged gas-turbine nozzle structures, the invention contemplates removal of all original blade material and its replacement with new individually cast blades, relying upon precision machining of base-member material of the original structure in such manner as to orient the assembled parts and to permit the resulting nozzle-throat area to be controlled with a high degree of dimensional precision. The assembly is consolidated into an integral whole, by welding the new blades to the machined original base members, and by a high-temperature braze operation. Following this, the assembly is given a protective coating to minimize the effects of high-temperature oxidation.

The invention is first shown in application to the nozzle guide-vane assembly (FIG. 1) of a gas-turbine engine in aircraft as an auxiliary power unit, i.e., a prime mover for stand-by generation of electric power. The particular assembly shown in FIG. 1 is a single invest-
3,909,157

ment casting of left and right annular base or vane-supporting members or rings 10-11, integrally united to an angularly spaced plurality of vanes or blades 12 for accommodating radially inward and circumferentially swirling flow of hot gases within the engine. The particular assembly is a stator within which a suitably formed impeller (not shown) is supported for rotation and for discharge of the gas flow axially out the right end of the right-hand base member 11. The conventional means of attachment of the stator to other engine structure include external threads 13 at the reduced discharge end of member 11, spaced radial lugs or feet 14 at the periphery of member 10, and clamp slots 15 in a radial flange 16 of member 10.

The stator of FIG. 1 is shown with substantial damage at all or most of the radially inner or trailing edges of the vanes 12. The extent of the damage is typical of that which would normally call for scrapping the entire stator assembly, i.e., replacement with a new and relatively expensive single integral investment casting of the entire stator. However, the present invention permits reconstruction of the stator to at least the performance capabilities of the original, at but a fraction of the original cost.

Referring to FIGS. 2 and 3, the first step is to remove all blade material. This is suggested in FIG. 2 at 17, being an alignment for cutting (e.g., sawing) the vanes 12 at substantially mid-span. Once cut, vane fragments remain as cantilevered stubs, projecting axially from each of two, now separate, base members 10-11. Following a stress-relieving heat cycle, a machining operation (including surface grinding) is used to restore base member reference surfaces 18-19 (from which the original vanes 12 extended) to the desired degree of flatness. In this part of the process, it will be understood that, if necessary, any surface defects and deteriorated areas of the base members 10-11 are repaired by welding and remachining as required to achieve the design reference surfaces 18-19. Also in this part of the process, the turbine scroll section 20 is repaired and/or machined as may be necessary to achieve design contour.

The base-member reference surfaces 18-19 are now ready for machining to form airfoil-shaped sockets conforming to the vane-airfoil configuration. This step is preferably done by electrical discharge machining (EDM), i.e., spark-discharge removal of base-member metal, in a circulating dielectric medium. While this may be done as a succession of different socket-machining operations, it is preferred to generate all sockets in both reference surfaces 18-19 at one and the same time. More particularly, in a first step, all vane sockets 22 in base member 18 and all vane sockets 23 in base member 19 are machined to desired depth and, in a second step only certain sockets are further bored all the way through the respective base members, as suggested at 24-25 in the respective base members, for tensioned blade-element anchorage, as will be explained. In a typical configuration wherein the net blade span S, i.e., between reference surfaces 18-19, is about 2.2 cm, the machined depth of sockets 23 is about 0.62 cm, in base member material which is in the order of 0.4 cm thick.

FIG. 5 schematically shows support and manipulative means for performing the indicated EDM operation. Specifically, a tool holder or electrode 26 is positioned by fixed means 27 within the dielectric bath, and the reference surfaces 18-19 of base members 10-11 are held by suitable support means 28-29, in face-to-face relation with each other and with adjacent parts of electrode 26. The support means 28-29 are shown as slides longitudinally displaceable in opposite directions, upon rotation of a differential lead screw 30 having a first direction of threaded engagement with means 28 and an opposite direction of threaded engagement with means 29. Thus, rotation of lead screw 30 will simultaneously feed or retract both base members 10-11 with respect to electrode 26, depending upon the direction of rotation, as suggested by a double-headed curved arrow. Of course, it will be understood that the support and guide system for tool and work includes adequate provision for holding strict axial alignment and angular register of tool and work at all times.

FIGS. 6, 6A and 6B illustrate detail of the electrode structure for performing the first EDM step, namely, generating all vane-airfoil sockets 22-23. A relatively thick circular base plate 31 is characterized by plural spaced slot openings 32, larger than the vane-airfoil section but precisely positioned and formed in accordance with the design number and spacing of vanes 12. The inner and outer limits of openings 32 are formed as precisely indexed drilled holes 33-34, between which spaced substantially parallel inner and outer walls 35-36 complete the openings 32. Each inner wall 35 is a flat reference surface for positioning orientation of an inserted electrode element 37 (FIG. 6B), of vane-airfoil section; as shown, a locating flat 38 is milled or ground in the convex airfoil surface of electrode element 37 for positively referenced abutment with inner wall 35, said flat preferably straddling the region of closest proximity to the trailing (inner) edge of the next-adjacent vane. Wall 35 is offset in the amount d from the line between centers for each pair of bores 33-34, the offset d being selected to position the trailing (inner) edge of the electrode element 37 at substantially the point of intersection between said line and the inner side of the bore 33; this relationship is illustrated by phantom outline of an electrode-element airfoil section 37' at one of the openings 32 in FIG. 6 and will be seen to assure utmost radial-positioning accuracy in the insertion of each electrode element 37. Each element 37 is of the same axial extent, being selected to project by equal amounts D beyond both faces of the base plate or tool holder 31. To secure such position, clamp screws 39-39' engage tapped holes between the outer wall 36 of each opening 32 and the peripheral wall of the plate; and, as best seen in FIG. 6B, the airfoil surface of the electrode 37 is presented to receive the clamp forces of screws 39-39'. Preferably, the tapped holes for screws 39-39' are aligned to straddle the throat-defining region (closest proximity to trailing edge of adjacent airfoil), all as best seen in FIG. 6.

It will be seen that the described electrode base 31 and element 37 structure enables tool-room precision and techniques to be applied to the assembly of a particular electrode structure. Electrode-element material, which may for example be cast copper or graphite, machined tungsten-copper alloy or extruded copper, is conveniently formed as elongate bars, which need only be cut to length as needed for particular electrode elements 37. Then, depending upon the class number (throat area) desired for a particular vane assembly, the flat 38 is generated for all electrode elements 37 of the tool assembly, at a precise angle α to the flat sur-
face or other reference axis of the airfoil section. For example, in the context of vane dimensions generally indicated above, and for a 23-vane stator of about 30-cm overall diameter, a useful succession of nozzle-throat areas is achievable with the same vane-airfoil section and same electrode-element stock, by machining the flat 38 at constant depth (at the throat-line region of the convex surface of the airfoil section) and at a selected angle \( \alpha \) in the range 0°4' to 3°12', corresponding respectively to a total nozzle-throat area range of 40 to 50-cm².

Thus far, the detailed description has been concerned only with the first EDM step, namely, precision-forming of the airfoil sockets 22–23. The second EDM step involves boring the openings 24–25, to permit tensed anchorage of the assembly.

FIG. 7 illustrates another tool-holder or electrode base 41, of thickness and circular extent corresponding to the base 31, and usable at 26 (FIG. 5) in the work and tool-supporting and feeding mechanism. As shown, at spacings no more than every fourth vane position, the bottom of the vane socket is EDM-bored with a rectangular section, as determined by the end formation 42 of a rodlike electrode element 43. Each of the elements 43 is positioned in drilled bores 44 in plate 41, being securely held in position by clamp screws 45–45', the orientation of each projection 42 being preferably such that its elongation axis is parallel to the elongation axis of the socket bottom (22, 23). The EDM process proceeds as with the tool of FIGS. 6 and 6A, upon feeding rotation of lead screw 30 to full traverse of the base-member thickness, as will be understood.

FIGS. 9 and 10 and FIGS. 11 and 12 respectively illustrate the two types of blade element used to complete assembly. The blade element 50 of FIGS. 9 and 10 is used at those socket locations 22–23 which are not provided with the through bores 24–25. Blade element 50 may be an individual investment casting of suitable alloy, or it may be cut to length \( S_1 \) from an elongate bar of extruded or otherwise formed alloy of vane-airfoil section. The length \( S_1 \) exceeds the ultimate vane span \( S \), to the extent of the combined depths of socket recesses 22–23. Preferably, the span-end edges are chamfered, as indicated at 51, to permit secure bottom-referenced seating in sockets 22–23. The blade element 52 of FIGS. 11 and 12 may be similar in all respects to that of FIGS. 9 and 10, except for integral tang projections 53 beyond span \( S_1 \), of sectional proportions to fit the bores 24–25 and of projecting length \( \Delta S_1 \) to pass fully through bores 24–25. As a step preliminary to assembly to the EDM-processed base members 10–11, blades 50–52 are preferably given an electroplated coating of suitable "wetting" metal to an extent \( \Delta S_2 \), as indicated by light-phantom margin limits 55, at spacing \( S_2 \), in FIGS. 10 and 12. The spacing \( S_2 \) is preferably less than the ultimate vane span \( S \) so that fluxing treatment extends beyond base members 10–11, for filler-holding purposes, as will become clear.

To complete the structure, all tang ends 53 are welded directly to members 10–11 at axially outer ends of the bores 24–25, thus providing tensed-tang retention of blade elements 52 in seated relation with associated socket bottoms (22–23); such retention also compressionally retains the remaining blade elements 50 in abutment with their socket bottoms (22–23). Additionally, a predetermined amount of brazing filler material (compatible with the material of the flux plating, to margins 55) is placed at each of the vane interfaces with members 10–11 to permit fillet formation and complete filling of the vane-ring joint. Brazing of the clamped assembly may be performed in a vacuum furnace after an appropriate heating and stabilization cycle at intermediate temperatures. After stabilizing for the proper brazing operation, the furnace is allowed to cool while maintaining the desired vacuum level and until a temperature of approximately 1500°F is reached. Argon may then be admitted as a backfill gas to increase the rate of cooling to room temperature.

The indicated welding and brazing operations produce weldments 56 (FIG. 13) and fillets 57, it being understood that the brazing material has achieved a void-free fill of the chamfered and other vane-socket interface regions. The completed assembly of FIG. 13 is then inspected for braze imperfections, and dimensional checks are made for throat-area control. Once past such checking, the assembly is given an overall protective coating to reduce the effect of oxidation and erosion at field conditions. It will be understood that weld techniques, brazing material, fluxing material, and the overall protective coating are selected for operating effectiveness in the context of the particular material employed. For example, suitable brazing, fluxing, wetting, and coating techniques are described in detail, for the case of inserts of well-known cobalt-base and nickel-base superalloys, to existing investment castings, in copending application, Ser. No. 17,752, filed Mar. 9, 1970.

FIGS. 14 and 15 illustrate application of the invention to an upgrading of a given nozzle-vane stator assembly, in the sense that an air-cooling feature is incorporated in the vanes or blade elements 60, supported by socket fit to opposed supporting or base members 10–11'. The blade elements 60 are formed with a manifold passage 61 extending the full span \( S \), and within the leading-edge or maximum-thickness region of the blade section. Spaced elongated bleed passages 62 communicate with manifold 61 and discharge virtually tangential to the adjacent flow streamlines in the nozzle-throat region of the convex surface of the airfoil. Air-supply passages, as at 63 in base member 10' may be EDM-bored, using suitable electrode elements at 26 (FIG. 5) projecting in the direction of the upstream base member 10'. For those vane locations served by tangles, as at 53–54, it will be understood that tang location and tang-bore location (24–25) are selected to avoid interference with air supply to and manifolding within the blade elements 56.

FIGS. 16 to 20 serve to illustrate application of the invention to reconstruction of a nozzle-component assembly, which is shown in FIG. 16 as a severely worn single-piece investment casting, comprising a hollow vane 65 integrally united with buttresses 66–67 at the respective ends of the vane span. Damage to the vane 65 is evident at surface spalling 68 and at regions 69–69' of severe loss of trailing edge material, to the extent that vane 65 can no longer function (with its next adjacent similar vane, in a gas-turbine stage) with anything like acceptable nozzle performance.

According to the method of the invention, the material of vane 65 is first removed, as by saw cuts close to but spaced from the respective buttresses 66–67. After a stress-relieving heat cycle, the vane-support surfaces 70 of buttresses are machined to the design reference contour and location, whereupon vane sockets 71 are
generated in such surfaces by techniques analogous to those described for the auxiliary power unit of FIGS. 1 to 13. For efficient production, it is preferred to EDM-machined plural sockets 71 at the same time. Thus, in FIG. 19, we show an electrode base or tool holder 72 as an elongate thick plate, with plural spaced openings 73 for receiving and mounting electrode elements 74 having projecting span ends characterized by the particular airfoil section and relative angle of incidence required at juncture with the vane-supporting surface 71 of each of the respective buttresses 66–67. As with the earlier-described electrode assembly, the electrode element openings 73 are characterized with precisely oriented flat reference surfaces, as at wall 75, to receive and locate a precisely formed flat 76 in the mid-span region of each electrode element; and clamp-screw means, suggested at 77, secures the mounting of each electrode element 74, when its trailing edge is abutted to the far end of opening 73. A suitable jig 78 appropriately retains and positions plural machined buttresses 66 with their vane-supporting surfaces facing the correctly profiled airfoil ends of electrode elements 74; in a suitable, span-end suitable jig 79 is suggested by phantom outline to position plural machined buttresses 67 in spaced relation with the other correctly profiled airfoil ends of electrode elements 74.

After EDM-machining to desired depth, which, in the case of the hollow vane 66 shown, may be all the way through both buttresses, a newly cast blade element 66 (FIG. 18) is assembled to the machined buttresses in the manner already described. Thus, after plating a wettable metal on the span ends of vane 65, the parts 65–66–67 are clamped in a suitable jig, with span ends of vane 65 substantially flushed with outer walls of buttresses 66–67. At the outer adjacent flush interface edges, a weldment 80 is laid, and the filling and brazing step eliminates voids and establishes smooth fillets 81. The remaining steps, including coating, are then performed.

It will be seen that the described invention achieves all stated objects and that, although described particularly in connection with repair of worn nozzle assemblies and nozzle-component assemblies, it is also applicable to new construction of such assemblies. Vanes may be restored to a condition which in some respects exceeds the capability of original investment castings, in that new vane-element parts may be the result of optimizing material selection, for resistance to high-temperature abrasion, and for optimum diffusion coating, in the context of less severe casting or other fabrication limitations. The indicated EDM techniques bring tool-room accuracy to the layout and assembly of the repaired structures, with resultant close control of nozzle-throat area, for a specified vane class. Assemblies built according to the invention are inherently braced to restrain and contain damage flowing from burst-wheel conditions, due to the socketed fit of the parts. The technique of welding and brazing assures utmost rigidity and integrity of the completed article, under the most extreme temperature cycles encountered in use. Finally, the technique of tool-hold systems, and electrode-element retention provides relatively simple and precise controlled selection of class number, for the ultimately assembled article, without requiring any change in the vane element inserted into the vane-supporting members of the assembly.

While the invention has been described in detail for the preferred forms shown, it will be understood that modifications may be made without departing from the invention.

What is claimed is:

1. As an article of manufacture, a nozzle-vane assembly comprising a longitudinally extending blade element of desired airfoil section, spaced first and second unitary base members having opposed adjacent smooth inner faces and having outer faces spaced from said inner faces, each of said inner faces having a straight-walled recess of constant section corresponding to that of one end of said blade, the spacing between said inner faces being a given blade span, the airfoil of said blade element extending longitudinally for a span which exceeds said given blade span by an amount at least no greater than the combined depths of said recesses, the profile and profile orientation of each recess and of the blade section fitted thereto being so precise as to establish by such fit alone the correct blade-base member orientation for the design class number of the nozzle-vane assembly, said blade element and base members being welded at and for retention of their interf, and means including a fused filler flux-drawn into the regions of interf and further uniting the ends of the airfoil section of said blade element to adjacent overlapped regions of said unitary base members.

2. The article of claim 1, in which said fused filler includes an integral fillet at intersection of said blade element with each inner face.

3. The article of claim 1, in which each base member is a vane buttress.

4. The article of claim 2, in which said base members are axially spaced rings, and in which the recess in each inner face is one of a plurality of uniformly angularly spaced recesses, said blade element being one of a corresponding plurality.

5. The article of claim 4, in which a second plurality of recesses in said inner faces is interlaced between those of said first plurality, the recesses of said second plurality being of said airfoil section and of depth less than ring thickness, and a second plurality of blades of said section received in the recesses of said second plurality.

6. As an article of manufacture, a nozzle-vane assembly comprising a longitudinally extending blade element of desired airfoil section, the profile of said section having axial ends each of which terminates in a transverse plane of relief from such profile, thereby defining an end-abutment seat adjacent such profile at each axial end, spaced first and second unitary base members having opposed adjacent inner faces and having outer faces spaced from said inner faces, each of said inner faces having a flat-bottomed straight-walled recess of constant section corresponding to that of one end of said blade and of depth less than the inner-to-out face thickness of the particular base member, each base member having at its recess a longitudinally extending through-aperture of less than said airfoil section area, the spacing between said inner faces being a given blade span, the airfoil section of said blade element extending longitudinally for a span which exceeds said given blade span by an amount at least no greater than the combined depth of said recesses, the profile and profile orientation of each recess and of the blade section fitted thereto being so precise as to establish by such fit alone the correct blade-base member orienta-
tion for the design class number of the nozzle-vane assembly, said end-abutment seats engaging the flat-bottom regions of the recesses to which they are fitted, fastening means including members passing through said respective apertures and rigidly welded to said base members at the respective outer faces thereof to retain the interfit of all blade elements at their recesses, and fused filler material flux-drawn into the regions in interfit and further uniting said blade elements to said base members.

7. The article of claim 6, in which said fastening members are end tangs projecting integrally beyond the respective ends of the airfoil section length of said blade element, each of said apertures communicating with the bottom of one of said recesses in aligned registry with one of said tangs when an end of the airfoil section of the blade is received in its recess.