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Boyle et al.

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[45] **Nov. 19, 1974**

[54] **PRECISION CASTING WITH VARIABLE ANGLED VANES**

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[52] **U.S. Cl.** **164/34**, 164/45, 164/137, 164/246, 164/249

[51] **Int. Cl.** **B22c 9/02**

[58] **Field of Search** 164/34, 249, 245, 235, 164/246, 238, 247, 35, 36, 248, 236, 45, 59, 333; 249/102, 155, 156, 159, 57, 59, 61, 62

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Assistant Examiner—V. K. Rising

[57] **ABSTRACT**

The manufacture of a nozzle having optimum flow characteristics by angular variation in the vanes in which such angular variation between vanes is a function of mating angular surfaces and may be achieved by ring segments having differently angled sockets for the vane patterns and/or by vanes having angular rotation relative to their locating studs adapted to be received within the sockets of the segment members.

3 Claims, 9 Drawing Figures

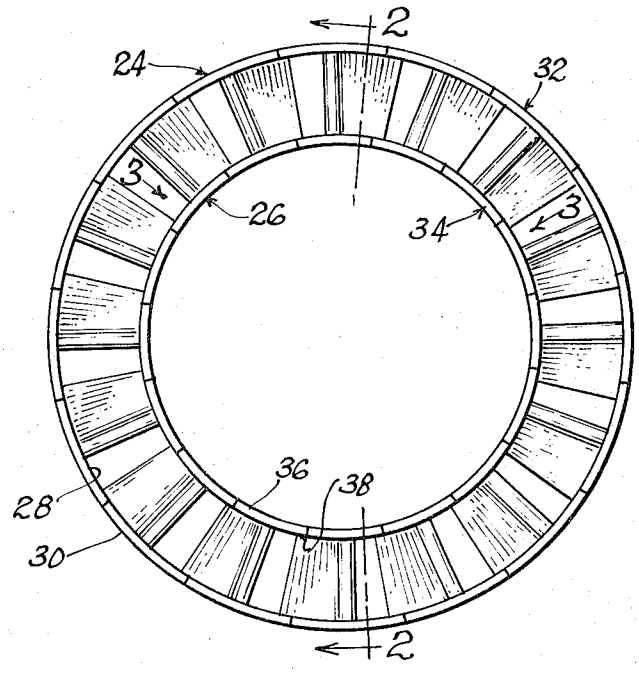


FIG. 1

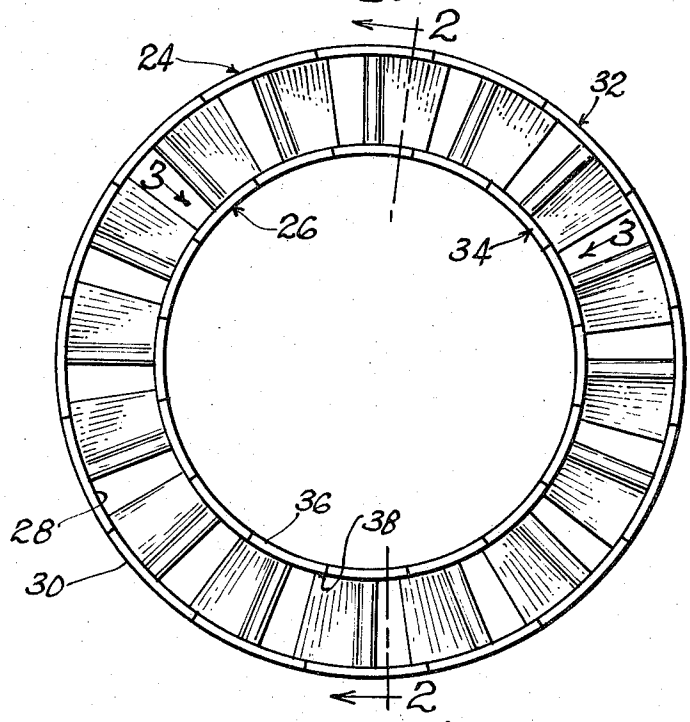


FIG. 2

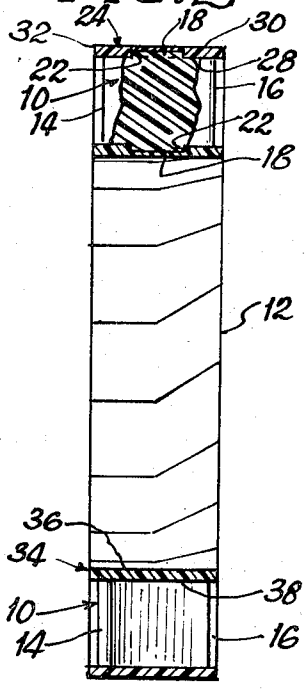


FIG. 3

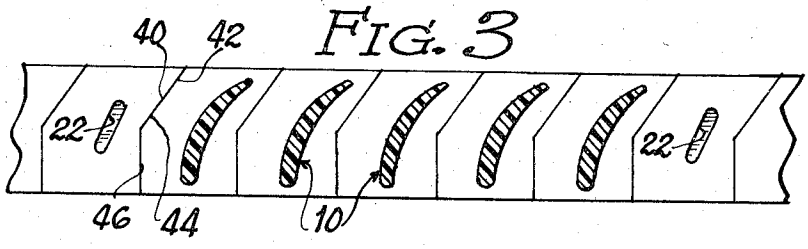


FIG. 4

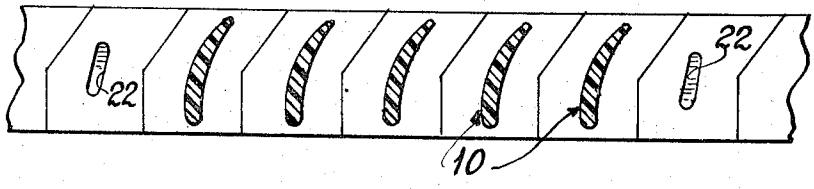


FIG. 5

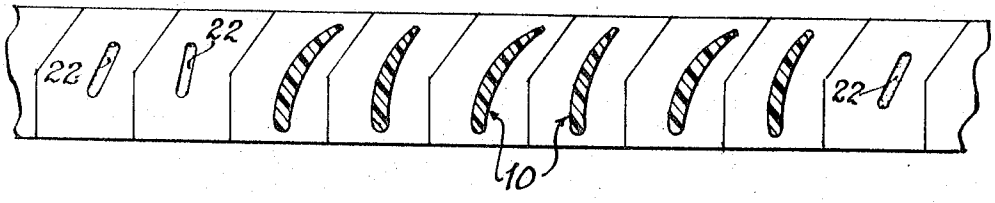


FIG. 6

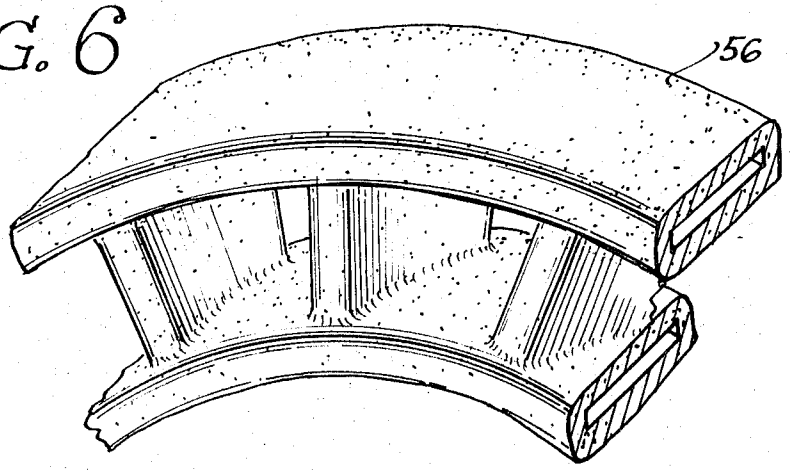


FIG. 7

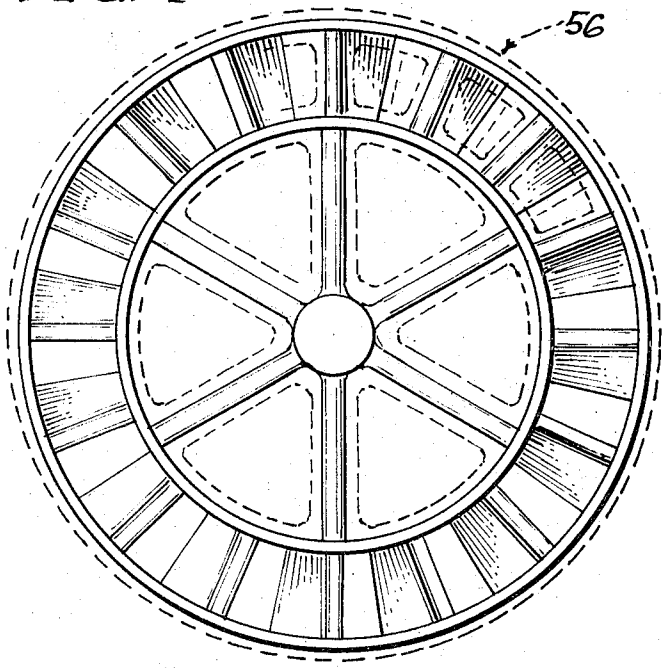


FIG. 8

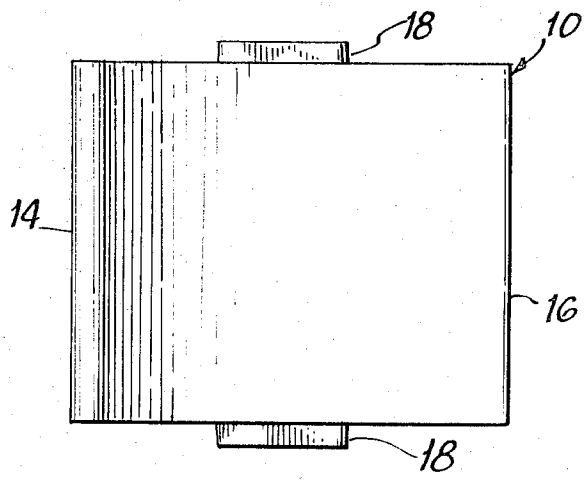
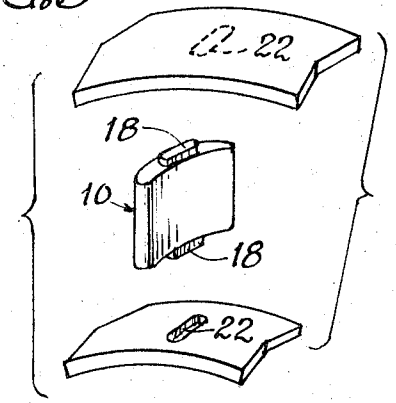


FIG. 9



PRECISION CASTING WITH VARIABLE ANGLED VANES

This invention relates to the utilization of the lost wax process in precision casting in the development of a turbine nozzle with mixing vanes selectively adjusted at angles to provide an optimum flow area and to the construction of disposable vane patterns into a composite mold to enable the casting of the turbine nozzle as an integral unit embodying the developed design features.

To the present, it has been necessary to re-tool for evaluation of each of various gas flows through the nozzle, as effected by angular arrangement of the nozzle vanes in the assembly. When consideration is given to the number of vanes making up the nozzle, evaluation for the various gas flows for the entire nozzle would be very expensive, especially in the design development stage. Such angular variations have been achieved usually by a machining operation performed on selected vanes, which usually are fabricated of hard to machine super-alloys.

It is an object of this invention to adapt the precision casting process to the production of integral turbine nozzles with angular arrangement of mixing vanes for optimum gas flow, and in which the development of the particular nozzle design by angular adjustment of the vanes can be conducted in a simple, efficient, and relatively inexpensive manner.

These and other objects and advantages of this invention will hereinafter appear and for purposes of illustration, but not of limitation, embodiments of the invention are shown in the accompanying drawings in which

FIG. **1** is an elevational view of a nozzle assembly formed of a plurality of heat disposable plastic and/or wax patterns assembled into a ring for use in casting an integral nozzle;

FIG. **2** is a sectional view taken along the line **2—2** of FIG. **1**;

FIG. **3** is a sectional view taken along the line **3—3** of FIG. **1**, illustrating the vane patterns in an angular position, referred to as a closed angle;

FIG. **4** is a sectional view similar to that of FIG. **3** in which the vane patterns are arranged at an angle, referred to as an open angle;

FIG. **5** is a sectional view similar to those of FIGS. **3** and **4**, in which some of the vane patterns are at an open angle while others are arranged at closed angles;

FIG. **6** is a perspective view of a segment of the ceramic shell mold formed about the assembled patterns to form the vaned nozzle;

FIG. **7** is an elevational view of the integral cast metal nozzle; and

FIG. **8** is a side elevational view of a normal design for a single nozzle vane pattern with the cross-sectional view being illustrated in FIGS. **3** to **5**.

FIG. **9** is an exploded view indicating a relationship between the vanes, studs, and sockets.

Castings of complex shapes have been precision cast of metals and super-alloys by providing patterns of heat disposable material, such as of wax or plastics or combinations thereof, conforming to the shape and dimension of the part or parts to be molded. One and preferably a plurality of such patterns are assembled into a cluster having the necessary sprues and runners which are also formed of heat disposable material.

The cluster is then processed through a series of alternating dip coats and stucco coats of ceramic materials as described in U.S. Pat. No. 2,961,751, until a ceramic shell of sufficient thickness and strength, when cured, has been built up about the exposed surfaces of the cluster. After sufficient drying or setting of the applied dip and stucco coats, the assembly is exposed to high temperature sufficient to melt out as well as to burn out the heat disposable components, leaving a ceramic shell having mold cavities formerly occupied by the patterns and other heat disposable material and conforming to the shape and dimensions thereof.

The ceramic shell is then further heated to cure and/or preheated prior to metal pouring. The poured metal flows through the gates and runners to fill the mold cavities formerly occupied by the heat disposable patterns. After allowing the casting to cool for solidification of the metal, the ceramic shell is broken away to expose the metal casting which is separated into its elements and cleaned.

The described casting process embodies the principles of the "lost wax process," but with considerable improvement for precision casting of complicated shapes of super-alloys and other metals, such as titanium, which are difficult to machine or otherwise process.

Referring now to the drawings for a description of the invention, a nozzle vane **10** has the general shape of the body portion **12**, shown in FIG. **8** in side elevational view, with the front to back having the shape shown in cross-sectional view in FIGS. **3** to **5** in the form of an arcuate member in which the leading edge portion **14** is shown as extending in the downward direction in FIGS. **3** to **5** and which tapers gradually from the leading edge portion to a trailing edge portion **16** of lesser dimension.

The pattern for the vane is pressure molded to the desired shape and dimension of wax, thermoplastic or wax-plastic combinations, or of other heat disposable material with a locating stud **18**, preferably of trapezoidal shape, extending beyond the opposite ends thereof for interfitting into a similarly dimensioned socket **22** in outer and inner rim segments **24** and **26**, which are also molded of heat disposable material, as previously defined.

Each segment **24** of the outer rim is formed with concentric curvilinear inner and outer walls **28** and **30**, spaced one from the other by an amount corresponding to the radial thickness of the outer rim **32** of the nozzle, with each segment **24** forming an equal cord or segment of a circle with its center at the axis of the nozzle whereby the outer walls **30** of each segment will have a curvature having a radius corresponding to the distance between the outer wall to the axis while the inner wall will have a curvature having a radius corresponding to the distance between the inner wall and the axis. Similarly, each segment of the inner rim **34** is formed with concentric curvilinear inner and outer walls spaced radially by an amount corresponding to the radial thickness of the inner rim of the nozzle with each segment forming an inner cord of equal dimension of a circle about the same axis as the outer rim whereby the inner wall **36** of the inner segment will have a curvature having a radius corresponding to the distance to the center while the outer wall **38** will have a curvature

with a radius corresponding to the distance between the outer wall and the axis.

The segments of the inner and outer rims are each formed with leading and trailing walls **40** and **42** which are adapted to effect an interfitting relationship therebetween so that the segments of the outer rim can be interfitted to form a complete circular rim while the segments of the inner rim can be interfitted to form a complete circular member. This can be accomplished as shown in the drawing, by designing the leading walls **44** and **46** to extend angularly from an intermediate portion thereof with parallel trailing walls, or by a type of tongue and groove arrangement in the form of grooved or rectangular recessed portions on the leading edge and trailing edges.

Each segment is formed with a socket **22** extending radially outwardly from an intermediate portion of the inner wall and shaped and dimensioned to receive the locating stud **18** in fitting relationship therein to secure the vane pattern in position of use between the rim members. Usually the segments are fitted onto the opposite ends of the vane pattern to form a unit, a plurality of which may thereafter be interfitted to form the nozzle assembly, as a pattern of heat disposable material, as shown in FIG. **1**, with the vane pattern equally circumferentially spaced to extend radially between the inner and outer rim members.

In accordance with one embodiment for the practice of this invention, the vane patterns are all of the same construction to define a single pattern design while the segments are formed with sockets at varying angles, such as one set in which each socket is rotated about its center to a −10% or −10° angle with the normal for an open angle position while in another set the sockets are rotated about the center to a +10% or +10° angle to a closed angle.

Thus by the selection of pairs of segments with open or closed angles, it becomes possible with only two segment designs to achieve wide variation in the angles of each of the vanes of the nozzle between open and closed positions to enable production of nozzle castings of various designs of angular arrangement of vanes throughout the entire nozzle. This enables development of nozzles of various angle designs for testing to achieve an optimum gas flow for the particular nozzle application.

Once the nozzle has been selected for the desired gas flow-through properties, the designed nozzle with the determined variation in the angles of the various vanes can be duplicated by duplication of the segment arrangement of the designed unit to provide nozzles having variable angled vanes in predetermined arrangement.

It will be apparent that instead of providing segments which differ only between two angles in socket arrangements, additional sockets can be provided with angular arrangements in between open and closed angles to provide still greater flexibility in design and finally in production.

By way of an alternative embodiment of this invention, instead of providing vane patterns of identical construction and segments having differently angled sockets, it will be apparent that the elements can be reversed with the sockets in the segments all being formed with a single angle to enable free interchange between segments but in which variation in angular arrangement is introduced into the body portion of the vanes relative to their locating studs which are adapted to be received in fitting relation in the sockets. In this instance, the angular relation of the vanes relative to their locating studs can vary from normal between closed and open angles and, as previously pointed out, at various angles therebetween. Under these conditions, the segments are all of the same design and flexibility in angular design of the vanes for variation in gas flow-through characteristics is achieved only by variation in vanes molded at the different angles.

The segments are joined together in the ring assembly in the usual manner, such as by the application of adhesive or hot wax at the adjacent surfaces to interbond one segment to the other in the pattern assembly.

From this point on, the conventional processes and materials employed in shell molding manufacture and metal casting are followed.

Briefly described, the runners **50** and gates of heat disposable material are joined to connect the segments of the outer and inner rim portions of the nozzle pattern with a central pouring cup **54.**

The assembly is then wet first with a conventional dip coat composition, as described in U.S. Pat. No. 2,961,751, as by immersion in a bath of the dip coat composition or by rotation of the ring assembly while partially immersed in the fluid dip coat composition, as described in the copending application Ser. No. 855,941, filed Sept. 8, 1969 now U.S. Pat. No. 3,668,177. After the excess dip coat composition has been drained from the surfaces of the assembled mold patterns, and while the surfaces of the assembly are still wet, the stucco coat is applied as by sprinkling the ceramic stucco materials onto the wet surfaces of the assembly, as described in the aforementioned patent, whereby an amount of stucco is retained by the dip coat to form a first layer on the pattern surface.

The steps of wetting with the dip coat composition and stuccoing are repeated, with intermediate drying, until a shell **56** of the desired thickness and strength has been built up about the pattern assembly, or cluster as it is referred to in the trade.

After the shell of ceramic material has been built up about the pattern assembly, the heat disposable material is removed by exposure of the assembly to elevated temperatures sufficient to melt and/or burn out the wax and plastic materials. For this purpose, it is sufficient to heat the assembly to an elevated temperature, usually about 1,800° F, but can be higher, for from 3 to 30 minutes, depending somewhat upon the mass of material requiring removal and the thickness of the ceramic shell mold. At such temperatures, the small amount of organic material which does not flow from the inverted assembly upon heating will be burned out to leave a shell mold having mold cavities corresponding to the patterns and connecting channels through which the molten metal may flow from the pouring cup to the shell molds.

After removal of the pattern, gates and runners of heat disposable material, the resulting shell mold can be fired to cure the ceramic material. Such firing to cure can be achieved as a part of the heating step for pattern removal or it can be carried out as a separate pre-heating step prior to metal pouring. In any event, it is desirable to heat the shell mold to an elevated temperature which approximates the temperature of the molten metal to be poured, such as to a temperature

within the range of 1,600° F in the casting of superalloys or other high melting point alloy having a nickel or cobalt base. This temperature may be higher depending upon the part to be cast and the alloy. After the mold is pre-heated to the desired pouring temperature, the molten metal is poured into the mold through the pouring cup to fill the mold cavities and the mold with the motlen metal cast therein is set aside to cool for gradual solidification of the molten metal.

When sufficiently cooled, the ceramic shell is broken away to release the cast nozzle, illustrated by FIG. 7, with the vanes integrally joined to the inner and outer rims as an integral assembly in which the angular rotation of the vanes corresponds to the angular rotation of the patterns originally assembled between the rims of heat disposable material in making up the pattern assembly.

It will be apparent that integral nozzles with various angular rotations of the vanes can be produced in accordance with the practice of this invention merely by making use of pre-selected vane patterns and/or ring segments which vary either in the angular relation of the vanes relative to their supports or in the angular relation of the sockets in which the locating studs for the vanes are received and that such angular rotation of the vanes can be varied selectively throughout the entire ring in a simple and efficient manner, with a minimum number of segments and vane patterns.

It will be further understood that while the invention has been described with reference to the manufacture of vaned nozzles with variations in angular rotation of the vanes for development of optimum flow patterns, the concepts of the invention will have equal application to the development and construction of turbine wheel assemblies embodying buckets or blades, wherein variation in angular rotation is desirable for the development of optimum performance characteristics and in other wheeled or circular rim structures in which vanes, buckets or blades are mounted in a preferred integral assembly.

While the invention has been described with reference to the preparation of shell molds for casting nozzles, turbine wheels and the like metal castings wherein the shell mold is formed of ceramic material obtained from the dip coat composition and stucco, the invention is not limited with respect to the compositions of the dip coat or stucco but may include shell molds formed to include carbon or graphite and the like materials such as employed in the manufacture of shell molds for the casting of titanium and other active metals, and as described in U.S. Pat. No. 3,296,666; No. 3,266,106; No. 3,257,692; No. 3,256,574; No. 3,248,763; No. 3,241,200, and others.

It will be understood that changes may be made in the details of formulation, construction and operation, without departing from the spirit of the invention, especially as defined in the following claims.

We claim:

1. In the method of producing ring structures formed of a ring member with a plurality of vanes of the same design extending radially in circumferentially spaced apart relation from the ring member, with some of the vanes extending at an angle of rotation with reference to their radial axes normal to the ring axis which differs from others of the vanes, in which an integral pattern of the ring member and radially extending vanes is formed of heat disposable material for use in producing an integral casting by precision casting technique, the steps of providing separate heat disposable patterns of the vanes with locating projections extending from the ends thereof, providing separate ring forming segments of heat disposable material having sockets shaped to correspond with the locating projections on the ends of the vanes for receiving the locating projections therein in fitting relation for assembly of the vane patterns with the segments and in which the segments are formed with end walls shaped to interfit one with another for assembly into a composite ring structure, in which in order to assemble the patterns with vanes extending at an angle of rotation with reference to their radial axes which differ from others of the vanes in the assembled ring structure, each of the vanes are the same and each of the segments are the same except for the sockets which form one segment to another different in their angle of rotation with reference to the radial axis, assembling said vanes with the segments having the sockets differing in angles of rotation corresponding to the desired differences in angle of rotation of the assembled vanes in the ring structure, and joining the ring segments with the assembled vanes into the ring structure.

2. In the method of producing ring structures formed of a ring member with a plurality of vanes of the same design extending radially in circumferentially spaced apart relation from the ring member, with some of the vanes extending at an angle of rotation with reference to their radial axes normal to the ring axis which differs from others of the vanes, in which an integral pattern of the ring member and radially extending vanes is formed of heat disposable material for use in producing an integral casting by precision casting technique, the steps of providing separate heat disposable patterns of the vanes with locating projections extending from the ends thereof, providing separate ring forming segments of heat disposable material having sockets shaped to correspond with the locating projections on the ends of the vanes for receiving the locating projections therein in fitting relation for assembly of the vane patterns with the segments, and in which the segments are formed with end walls shaped to interfit one with another for assembly into a composite ring structure, in which in order to assemble the pattern with the vanes extending at angles of rotation with reference to their radial axes which differ from others of the vanes in the assembled ring structure, each of the segments are the same with sockets having the same angle of rotation and each of the vanes are the same except for the projections which form one vane to another different in their angle of rotation with respect to the radial axes, assembling the segments with the vanes having the projections with differences in angles of rotation corresponding to the desired differences in angle of rotation of the assembled vanes in the ring structure, and joining the ring segments with the assembled vanes into the ring structure.

3. The method as claimed in claim **1** which includes the step of forming a mold shell about the pattern assembly, removing the heat disposable material to leave a shell mold having an integral mold cavity of a ring structure with radially extending vanes which differ in angular rotation, and casting molten metal into the shell mold to fill the mold cavity and then removing the metal casting from the mold.

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