Jan. 3, 1967 J. T. PARSONS 3,295,190

METHOD OF MACHINING METAL CASTINGS FOR SCREW PROPELLERS AND THE LIKE

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FIG. 1

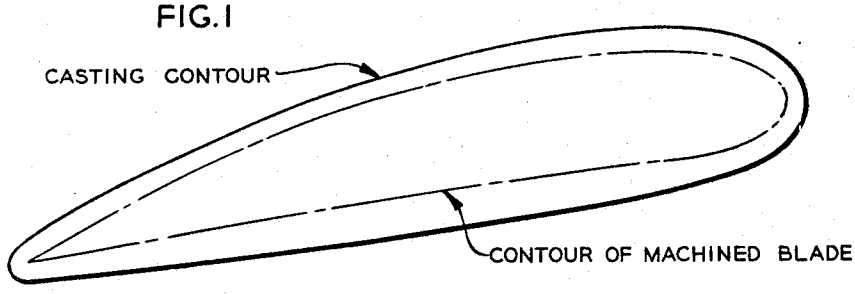
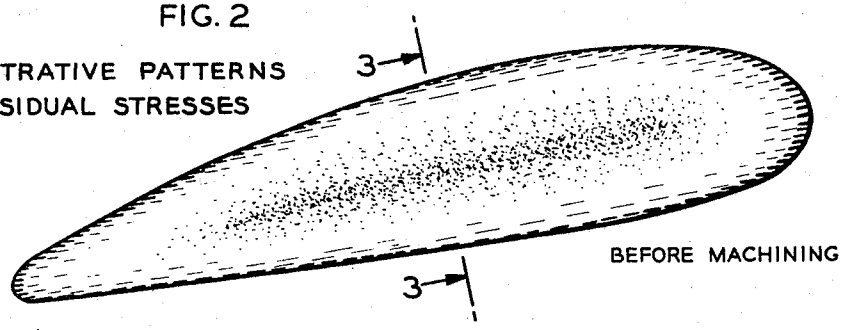


FIG. 2

ILLUSTRATIVE PATTERNS OF RESIDUAL STRESSES



COMPRESSION

TENSION

FIG. 4

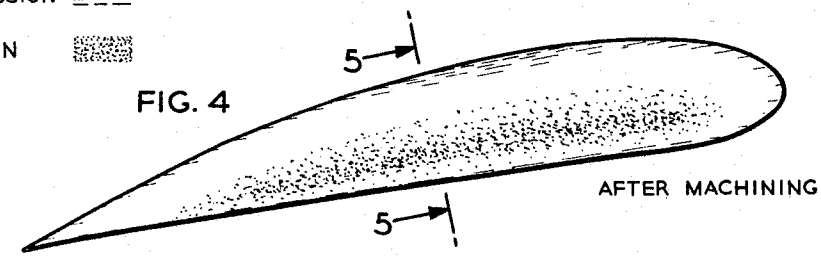


FIG. 3

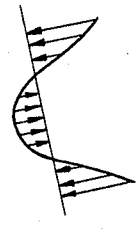
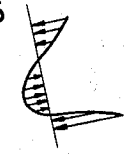


FIG. 5



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FIG. 6a

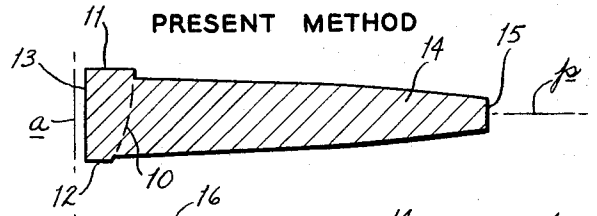


FIG. 6b

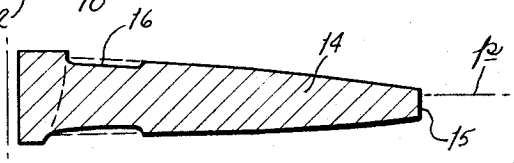


FIG. 6c

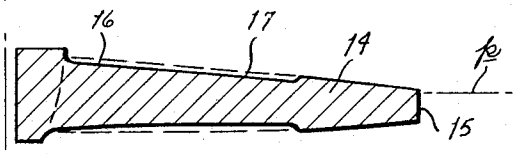


FIG. 6d

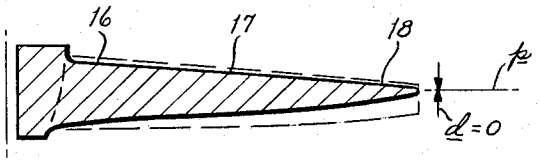


FIG. 7a

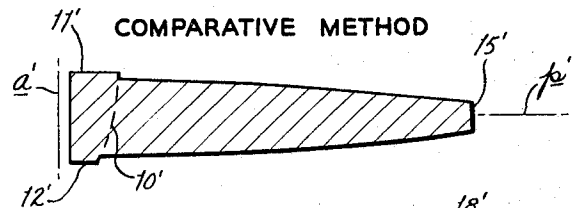


FIG. 7b

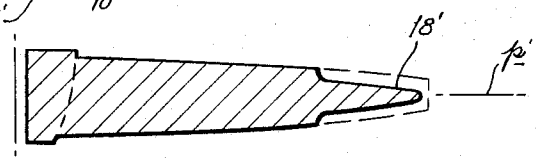


FIG. 7c

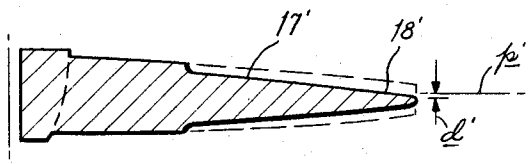
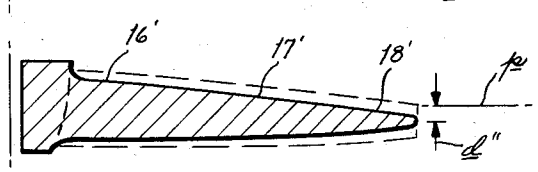


FIG. 7d



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METHOD OF MACHINING METAL CASTINGS FOR SCREW PROPELLERS AND THE LIKE

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4 Claims. (Cl. 29—156.8)

The present invention relates to the machining of metal castings for one-piece screw propellers and the like.

Such castings have thick hub portions and relatively thick blade root portions adjacent to the hub, from which the blades extend as cantilevers to substantially thinner sections at their tips. In the final machining, the root sections are to fillet into the hub, and the blade sections at progressively outboard stations are to be formed to precise propeller contour at each station measured outboard from the hub. It is desirable, for proper balance and performance, that each blade be precisely like the other blades in its contour, alignment and tip tracking.

In an effort to avoid rejection of propellers, it has been the practice to machine their casting blade portions starting at their tips, working inward, sometimes more or less tentatively, until the preliminary shaping of the several blades has progressed to the root. Modern methods of precisely controlled milling have not been adopted, partly because of the fear that residual casting stresses will cause the blades to deflect as the casting is reduced to the final blade sections.

The present invention is intended to overcome these prior difficulties, substituting a positive method of machine operations for the skill and judgment of individual machinists. Specific purposes include effecting alignment of the blades at each station, resulting in precise tracking of their tips. Recognizing that the casting residual stresses may cause excessive deflections, the purposes also include minimizing the rejection problem, for those castings inherently subject to extreme deflections.

The present invention may be simply summarized by the following somewhat generalized statement of procedure: The hub portion of the casting is first machined to establish its axis of rotation and a tip tracking plane. The casting is then supported by its hub portion along the axis so established, leaving the blade portions cantilevered therefrom and avoiding support of any portion of a blade, during its machining, which is outboard of its station being machined. Machining of blade portions commences, not at its tip end as has been customary, but at its root end adjacent to the hub portion. At each blade station, starting with the station adjacent to the hub, the machining cut is completed to substantially final contour out of that portion of the casting material which is then presented in desired alignment with the hub axis. In this way the cantilevered blade portion being machined adjusts its position to a new stress balance as the machining cut thereat is completed out of the material so held in the desired alignment. Such final machining cuts progress station-by-station from the root end of the blade to its tip, so that the blade tip is cut from that portion of the casting tip material which is finally presented in alignment with the tip tracking plane.

The method so generally summarized is presented in greater detail hereinafter, and the drawings illustrate in a schematic manner the problems which the present invention solves.

In the accompanying drawings:

FIG. 1 is a sketch illustrating the contour or outline of a typical casting at a blade station, with the blade contour as to be finally machined shown therein in phantom lines.

FIG. 2 illustrates a somewhat simplified possible pattern of residual stresses at a cross-section of a blade portion of the casting, prior to machining.

FIG. 3 is a stress diagram, illustrating the balance of the residual stresses shown in FIG. 2.

FIG. 4 is a cross-section corresponding to that of the machined blade section shown in phantom lines in FIG. 1, indicating stresses which may make up a new balance after machining.

FIG. 5 is a stress diagram illustrating the balance of stresses of the machined blade section shown in FIG. 4.

FIGS. 6*a* thru 6*d*, inclusive, are sectional views, taken with reference to a propeller axis, which illustrate progressive steps in the machining of blade castings according to the present method.

FIGS. 7*a* thru 7*d*, inclusive, are similar views which illustrate the likelihood of extreme tip deflection if comparative procedures were carried out under the prior art concept of commencing machining at the blade tip.

For purposes of this specification, the term "blade station" is used not merely as a measurement of the radial distance from the hub axis of a particular cross-section. Rather it is used in the sense of a blade portion of finite width, measured radially or along the thread of a blade, such as would be considered for the purpose of measuring and checking conformity with desired contour and alignment. Accordingly, a blade may be considered as consisting of the material which makes up the progressive stations which are to be checked for contour and alignment. These blade stations are, in the present method, to be successively machined to substantially final contour before proceeding to the next station. It is of course recognized that the blade contour and alignment will change gradually between adjacent stations to be checked.

In FIG. 1 there is shown the contour of the blade portion of a casting at a particular station, with the contour of the machined blade shown spacedly inward thereof; the space between representing the material of the casting which is to be machined off to establish final contour. In prior thinking, it has been believed possible to visualize the position of the finished blade within the rough casting prior to actual machining. As a practical matter I have found that this is true only of the root station. The reason will become apparent after consideration is given to the problem of deflection of the casting attendant to its machining.

FIG. 2 is illustrative of a simple pattern of the residual stresses which may exist at a cross-section of an elongated casting such as a bladed propeller casting. Residual stresses are likely to be so complex as to defy precise illustration. In the simplified illustration of FIG. 2, compressive stresses are shown in horizontal dashes while tension stresses are shown in dots. These elements of stress may occur on cooling of the casting, wherein the outer portions cool and set fore quickly than the inner portions. Thermal contraction attendant cooling may thus impose compressive stresses on the outer casting material; and its resistance to the contraction of the inner portion as it shrinks perpendicular to the plane of the cross-section may result in tension stresses in the inner material. The illustrated pattern of stresses is far from complete; shear and twist would greatly complicate the illustration.

FIG. 3 shows the balance of compressive and tension stresses in the pattern of FIG. 2. Consistent with principles of statics, the resultant of forces and moments at any section must be zero. In FIG. 3 the tension stresses are in balance with the compressive stresses; and their near-symmetrical alignment in the outer material of the casting creates a balance of moment.

FIG. 4 shows the section after excess casting material has been machined away. If previously stressed material has been machined away, an unbalance will follow; consider for example the result of cutting away the tensioned material from one side of the pattern of FIG. 3. The result is that the blade will deflect or "warp" until a new balance is set up between the stresses, as illustrated in FIG. 5. Therefore, to machine a casting containing residual stresses in its outer material involves disturbing the balance of residual stresses; the warping deflection which results modifies the pattern of stresses, and such warping establishes a new static balance of stresses.

It will be apparent that "warping" or bending at any inboard station will cause deflection of every station outboard thereof. However slight such warping may seem to be at inboard stations, the result may throw the blade tips seriously out of track.

FIGS. 6*a*–6*d* are a succession of views showing a propeller axis *a* established by machining the propeller casting generally designated **10**, on its forward hub face **11** and aft, parallel hub face **12**, and then boring perpendicular to these faces a central propeller shaft bore **13**. When the casting **10** is supported on its shaft bore **13**, a tip tracking plane *p* may be established for the blade parts **14** of the casting **10**. The plane *p* may be defined by its axial spacing from one of the hub faces **11**, **12**, or it may be located about midway along the depth of the casting material presented at the tip portions **15**.

Referring now to FIG. 6*b*, in the present process the station of the blade adjacent to the root (hereinafter referred to as the root station **16**) is then machined to substantially final contour. The result of removal of outer material is much as was illustrated in discussing FIGS. 2, 3, 4 and 5. During its removal, the blade casting portion at the root station **16** gradually adjusts its position to a new balance of stresses. The machining of the material at the root station **16** therefore completes this station in the desired alignment relative to the hub. However, the casting tip portion may have been thereby caused to deflect greatly, with regard to the tip tracking plane *p*.

After machining the root station **16** for one of the casting blades **14**, the other blades may be similarly machined at their corresponding root stations; in the alternative a single blade may be machined to final contour from root to tip. Machining each station in turn may cause some warping, but relatively less tip deflection follows from warping at such progressively outboard stations.

In FIG. 6*c* such outboard stations are generally designated **17**. These are successively machined to final contour. As each is machined the gradual warping to a new progressively achieved balance of stresses gradually fixes the final warped position of the station so being machined. The machining cut at each outboard station **17** operates to machine that portion of the casting material which is then presented in desired alignment with the hub axis *a*. A new stress balance is achieved at each station while the machining at that station progresses, and the machining cut thereat is completed in the desired alignment relative to the hub. Thus while the casting as a whole may have deflected somewhat as a result of machining the root station **16**, as shown in FIG. 6*b*, and may have deflected further as a result of machining the intermediate stations **17**, each machine cut positions the finally formed blade station in the desired alignment with the hub axis. Furthermore each finally formed blade station positions the blade casting portion **14** immediately outboard for machining it in desired alignment. Therefore the machined blade is left in the desired propeller contour and alignment at each such station.

The machining to contour is completed as shown in FIG. 6*d*, by cutting the blade tip **18** from that part of the blade tip portion **15** which is then presented in alignment with the tip tracking plane *p*. This may be material which is adjacent to the extreme upper side of the casting tip portion **15**, as shown in FIG. 6*d* which reflects the excess of casting deflection on warping.

It has been mentioned that, in the prior art, machining work has normally commenced at the blade tip station **18** and progressed inward toward the root station **16**. Because of the likelihood of severe warping, there has been a preference for machining gradually to contour, at least for larger castings involving severe residual stresses. If a blade were initially machined to final contour, carrying out the prior art thinking, the result would be the "comparative method" presented in FIGS. 7*a* through 7*d*.

FIG. 7*a* shows the establishment of an axis *a'* by the machining of the casting **10'** along the hub forward face **11'** and rear hub face **12'**; and the establishment of the tracking plane *p'* at substantially the mid-thickness of a casting blade tip portion **15'**. If the machining then commenced at the casting tip portion **15'** and a blade tip **18'** is then first machined in alignment with the tracking plane *p'*, the results which follow may be as shown in FIGS. 7*c* and 7*d*. The machining of the intermediate stations **17'** involves the removal of outer residually stressed material and the achieving at each of a new stress balance, causing the deflection *d'* shown in FIG. 7*c*. Bending attending the machining cut to the blade root station **16'**, as shown in FIG. 7*d*, is likely to cause further deflection, for warping of inboard stations greatly magnifies the total deflection *d''* at the blade tip. Hence, not until the root station **16'** is machined will the full extent of tip deflection manifest itself.

Persons familiar with the art will realize the importance in performance of precise alignment and tracking. If the problems of machining be approached tentatively, as with reliance on the skill of the machinist to transform a casting possessing such residual stresses into an aligned blade group, modern precision-controlled machining cannot be used. The substitution of the present process makes possible precise milling to contour, in accordance with predetermined patterned information. The blades which result from the present process are therefore of substantial uniformity; the propellers as a whole are therefore well balanced and efficient.

It is understood that after the machining to final contour there may be a succession of finishing operations such as grinding and polishing, which do not upset the stress balance of the individual blades.

The stations whose warping has the greatest effect on tip deflection are the stations nearest the blade root; accordingly, if a substantial amount of machine work is done first at the root and thence outward, a certain amount of leeway may be permitted in practice in determining the sequence of other final operations.

Severe stresses "locked into" castings on their cooling inherently will result in a certain percentage of rejects; and it is important to minimize the work done on any casting prior to rejection. From FIG. 6*b*, when the stations close to the blade root are first machined, the amount of tip portion deflection which then ensues may conceivably be so great as to require rejection. In contrast, if the comparative method be utilized, operations may proceed starting at the blade tip and through the intermediate blade stations **17'** for a substantial distance before it is noticed that the tip deflection *d* of the first formed tip has become so great as to require discarding the casting.

Further, the present method permits rejections to be minimized by providing casting tip portions whose excess material is somewhat greater than would be provided if the machining operations were thought of as a mere "finishing" of a casting. Excess thickness is preferably provided which increases progressively from the blade root station **16** to the blade tip station **18**. As shown in FIG. 6*d*, such excess thickness outboard of the blade root station **16** allows adequate material to take account of tip deflections attendant to anticipated warping on machining. Such increase in excess material outboard of the blade

root allows for unusual deflections, and still provides sufficient material for making the machining cuts in final desired alignment. Thus the relatively thick casting tip portion **15** permits making the machining cut illustrated in FIG. 6*b* principally out of the upper part of the material of the casting tip portion **15**. Providing such thickened tip portions therefore still further lessen the likelihood of rejects for warpage during machining.

Obviously many modifications and variations of the present invention are visible in the light of the above teachings. It is therefore to be understood, that within the scope of the appended claims, the invention may be practiced otherwise than as specifically described.

I claim:

1. The method of machining metal castings for screw propellers and the like, and simultaneously adjusting the positions of the machining cut for the unbalance of residual stresses accompanying such machining, characterized in the steps of

machining the hub portion of the casting to establish its axis of rotation and a tip tracking plane,

supporting the casting by its hub portion along said axis and while avoiding support of any blade portions outboard of the station being machined,

commencing machining of a relatively small blade portion near the root end adjacent to the hub portion of said blade, and

completing the machining cut so initiated to obtain substantially the final contour for each blade portion from that portion of the casting which is then presented in desired alignment with the hub axis, progressing to the next relatively small blade portion outboard of the first such portion, and repeating the process until the desired contour is achieved over the whole length of the blade,

whereby the blade tip is cut from that portion of the casting tip material which is finally presented in alignment with the tip tracking plane.

2. In machining metal castings for metal screw propellers and the like,

the method of minimizing work on those castings whose residual stresses are such as to be likely to result in rejects for excessive deflection, comprising

the method of machining as set forth in claim **1**,

together with the step of discontinuing such machining and rejecting the casting whenever deflection of a casting tip accumulates to the extent that less material is presented adjacent to the tip station than is required to obtain the desired contour of the blade when in alignment with the tip tracking plane.

3. The method of manufacturing metal screw propellers and the like, comprising

providing a metal casting including blade portions whose thickness at each station is in excess of that of the final intended blade,

the casting so provided being characterized in that such excess thickness increases progressively from the blade root station to the tip station,

followed by the method of machining as set forth in claim **2**,

whereby the excess in thickness outboard of the blade root station allows adequate material for the machining cut at each blade station despite accumulated deflection.

4. The method of machining metal castings for screw propellers and the like and simultaneously adjusting the position of successive machining cuts for the unbalance of residual stresses in the casting, comprising

machining the hub of the casting to establish its axis of rotation, a tip tracking plane, and the desired alignment at all stations along the length of the blade,

then, while supporting the casting by the hub and leaving the blade portions otherwise unsupported, machining the root station of a blade to substantially final contour, thereby removing material which has been residually stressed during the cooling of the casting, during the removal of which, said station gradually adjusts its position to a new balance of stresses,

and then, avoiding support of any blade portions outboard of the station being machined, machining each of the stations to substantially the final contour progressing from root to tip by positioning the machining cut at each such station so as to machine only that portion of the cast material which is then presented in the desired alignment with the tip tracking plane, whereby each station gradually adjusts its position to a new stress balance and such machining thereat is completed in desired alignment relative to the tracking plane, and

completing said machining to contour by cutting the blade tip from the final portion of the cast material which is presented in alignment with the tip tracking plane.

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