

July 23, 1957

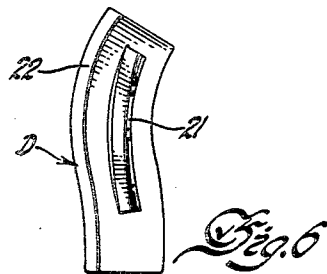
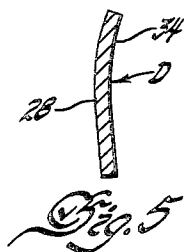
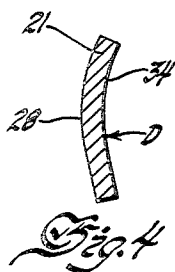
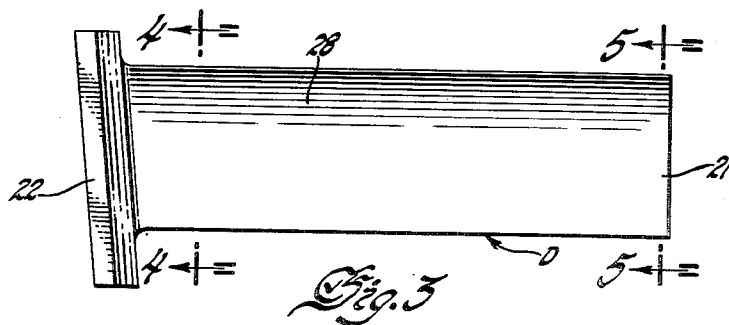
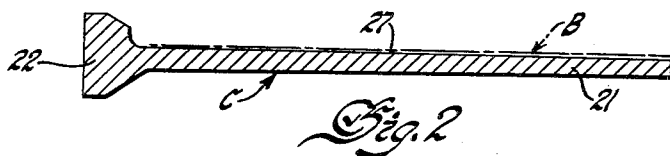
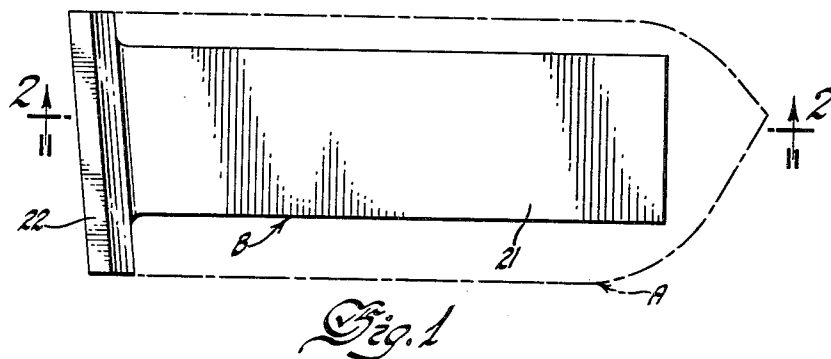
J. L. GOLDTHWAITE ET AL

2,799,918

COMPRESSOR BLADE MANUFACTURE

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2 Sheets-Sheet 1



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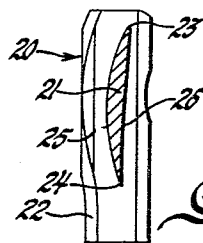
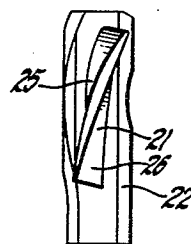
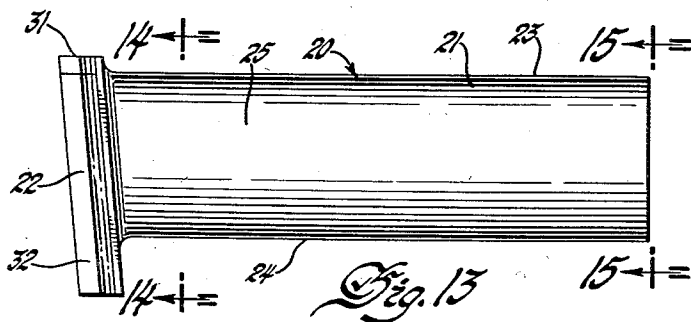
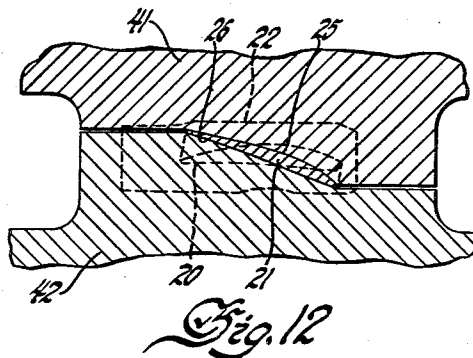
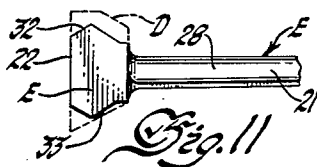
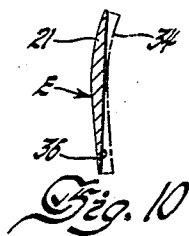
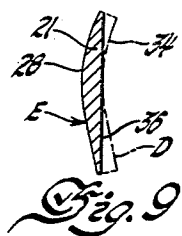
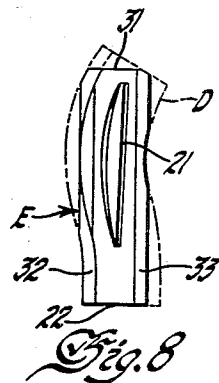
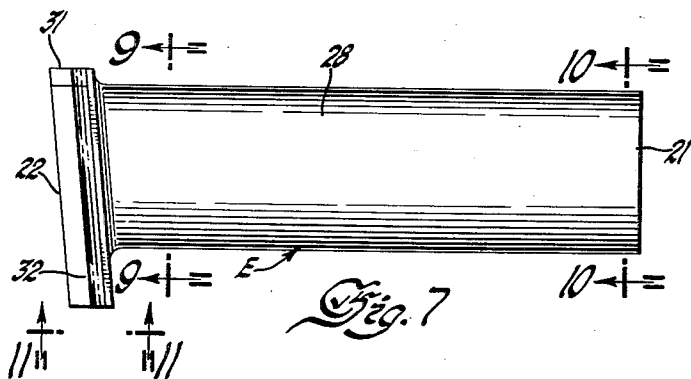
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2 Sheets-Sheet 2



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1

2,799,918

COMPRESSOR BLADE MANUFACTURE

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6 Claims. (Cl. 29—156.8)

This invention is directed to a process for forming metal parts having curved surfaces. It is particularly intended and specially suitable for the manufacture of blades for axial-flow compressors, but, as will be apparent, may be employed beneficially in the manufacture of other pieces of complex form.

Since the preferred application of the invention is to be manufacture of compressor blades, the invention will be described in terms of its utilization for this purpose, which will serve to illustrate the principles of the invention. The manner of employment of the principles of the invention in other connections will be clear to those skilled in the art.

Axial-flow compressor blades ordinarily are of airfoil form in cross section, with one convex face and one concave face. The blades ordinarily are twisted. It will be seen, therefore, that the surfaces are complex; therefore, the formation of such blades has always presented a difficult problem. Rotor blades, as distinguished from typical stator blades, present additional difficulties in that the blade must be provided with a foot or root of considerably heavier section than the blade for attachment to the compressor rotor, and the blade usually tapers in thickness from the root to the tip. The process of the invention is particularly directed to the manufacture of footed blades, but could readily be utilized for the manufacture of footless blades, which present fewer difficulties. In some cases, of course, a compressor stator blade is provided with a root for mounting in the casing of the compressor, and thus presents a manufacturing problem similar to that of rotor blades.

The difficulty of forming a blade with an integral foot has inspired many proposals to form the blade and foot separately, and unite them as by brazing or welding. While some of these schemes are workable, they present numerous disadvantages, which are obviated by the invention.

Many processes have been proposed for the manufacture of compressor blades with integral bases, some of which have been adopted commercially. Among these is precision forging, which is usually not sufficiently accurate to meet high standards of compressor performance. Another process involves rough forging of the blade with subsequent overall machining of the blade surface. Good results are obtained by this method, but since it involves machining of the complex surfaces of the blade, complicated machinery is required and the blades are quite expensive. A third process, which is used commercially at present, is a hot rolling process in which the blank is rolled in a press, the rolling being accomplished in several stages. This process, although more economical than finish machining of the blades, is nevertheless expensive.

The process of the invention is particularly adapted to produce blades of high strength and great accuracy at very low unit cost. The process is particularly suited to the production of blades in large quantity with a minimum requirement of skilled labor. Moreover, the process is

2

such that it may be performed with the aid of relatively simple and conventional tools and apparatus.

In brief outline, the preferred embodiment of the process of the invention involves the steps of preparing a blank with a heavy section at one end to form the foot of the blade, machining the blank to form an accurate flat surface on one face of the blade, die-forming the blank to render the machined surface convex, machining the opposite or concave surface flat, and die-forming the blank to provide the required camber and twist of the blade.

Among the advantages of the invention is the fact that hot working of the metal is not required, and is preferably dispensed with entirely, except that it may be employed in the production of the original blank. Another is the fact that the curved surfaces of the blade are formed by the two simple operations of machining flat surfaces and die-forming the blade to transform these flat surfaces into complex curved surfaces. No excessive metal movement, with resulting weakness of the finished part, is involved. No contour grinding or analogous operation is involved in the process. The blade and foot are integral, eliminating the production difficulties and operational risks of blades welded or otherwise assembled from several parts. The advantages of the process will be apparent to those skilled in the art from the appended detailed description of the application of the preferred embodiment of the process.

The principal object of the invention is to manufacture compressor blades, or other objects having curved surfaces, of high quality in large quantities at low unit cost. Other objects will be apparent to those skilled in the art from the succeeding description.

Referring to the drawings, Figure 1 is a side or face view of a compressor rotor blade blank which has been trimmed, with the outline of the blank before trimming indicated by broken lines; Figure 2 is a longitudinal section of the blank illustrating the step of machining one face of the blank; Figures 3 to 6 are views illustrating the blank after the first forming operation, Figures 4 and 5 being sectional views taken on the planes indicated in Figure 3; Figures 7 to 11 are views illustrating the machining of the concave face of the blank and the preliminary machining of the foot, Figures 9 and 10 being sectional views taken on the planes indicated in Figure 7; Figure 12 is a sectional view illustrating the second die-forming operation; and Figures 13 to 15 are views of the product after the second die-forming operation, Figures 14 and 15 being views taken on the planes indicated in Figure 13.

Although the general form of compressor blades of the type referred to is well known, it may be advisable by way of introduction to refer first to Figures 13 to 15 which illustrate a compressor rotor element or blade of which the blade portion has been finished by the process of the invention. The compressor element 20 comprises a blade portion 21 and a root or foot portion 22. The foot is adapted for mounting in dovetail grooves or the like in a compressor rotor, and the blade projects from the rotor to impel air. The blade portion 21 is of airfoil form in cross section with a leading edge 23, a trailing edge 24, a convex surface 25 and a concave surface 26. The amount of camber of the blade, or, in other words, the curvature of the central line of the airfoil section from the leading edge 23 to the trailing edge 24, may vary according to the design of the blade. The particular blade illustrated is but slightly concave, but in some cases the concavity of face 26 is considerable. As will be noted from Figure 15, the blade is twisted from the root toward the tip, as is almost invariably the case. The foot, as illustrated in Figures 13 to 15, is not finished, and further machining would be required to prepare this

part for mounting in the compressor rotor. Since these additional machining operations may be performed by conventional methods to secure any desired form of foot, and are required regardless of the method of forming the blade portion, these operations are not illustrated and will not be described.

It is believed that the form of the finished blade is sufficiently indicated by Figures 13 to 15 and the preceding description to indicate the nature of the problem solved by the invention.

Referring now to Figure 1, the blank B illustrated in solid lines comprises a blade part 21, which is simply a flat metal strip of rectangular cross section, and a root part 22 extending across one end of the blade and of considerably heavier section than the blade. The root is also of greater length in this case than the width of the blade blank 21.

The blank B may be formed in any of several ways. As illustrated, it is formed by blanking or trimming from a rolled blank A indicated by the broken lines, the blanking operation removing the excess metal at the edges of the blade portion. The original blank A may be formed by hot rolling from a strip or block of metal, such as steel or stainless steel, by the use of gapped rolls or any other desired manner to reduce the thickness of the blade portion and leave the heavy root. Alternatively, the blank A could be sawed transversely from a rolled or extruded strip with a thick edge corresponding to the base portion 22; however, it is preferred to form the blank A by rolling in a direction longitudinally of the finished blade so that the grain structure of the metal is parallel to the axis of the blade for greater strength. The blank A could also be produced by forging or by upsetting a strip to form the foot portion. Since the original blank A may be formed in a number of ways well understood by those skilled in the metal-working arts, it is unnecessary to incorporate herein a detailed description of the production of the blank A.

If the blank A is prepared by rolling a slug in a set of gapped rolls, this operation would ordinarily be performed as a hot rolling operation. The remainder of the process involves no heating except for such annealing and heat treating operations as may be desirable to secure the desired working characteristics and final condition of the metal.

A suitable form of the foot portion 22 of the blade before machining is indicated in Figure 2. Figure 2 also illustrates the first machining operation by which the rolled or forged and trimmed blank B, the faces of which are parallel, is converted to a partially machined blank C. In this operation, one face 27 of the blade 21 is machined to form a plane surface in any suitable way, a milling operation being preferred. It will be noted that the face 27 is so machined that the blade tapers slightly toward the tip, which is desirable since the section of the finished blade is thinner at the tip. It will be apparent, of course, that the blank A could be formed with a taper, but since it is desirable in any event to machine the surface 27, it is unnecessary to provide taper in the original blank A.

The next operation produces from the milled blank C the blank D illustrated in Figures 3 to 6. The blank is struck in a die to bend the blank and thus provide a convex surface 28 on the face 27 previously machined. It will be noted that the curvature of the surface varies from one end of the blade to the other and that the foot of the blade is curved in accordance with the curvature of the base portion of the blade to avoid undesirable distortion and stresses at the junction of the blade with the foot. The surface 28 is of such form that it departs from an assumed reference surface (specifically, a plane) at all points by an amount equal to the desired final thickness of the blade 21. Preferably, the blank C is annealed before the forming operation, which forming may be accomplished in known manner by pressing the blank C between suitably formed dies in a hydraulic press.

Subsequent to the first forming operation, the formed blank D undergoes a series of machining operations to produce the blank E illustrated in Figures 7 to 11. First, the front end of the foot is cut off, as indicated at 31, preferably by milling, then the sides of the foot are rough machined, as indicated at 32 and 33 in Figures 8 and 11, preferably by broaching. While this rough machining of the foot could be accomplished at a later stage in the process, it is desirable to do it at this time to provide location points for a further machining operation on the blade surface and the second forming operation.

The next step in the formation of the blade, which is referred to as the second machining operation on the blade, is machining the concave surface 34 of the blank D indicated in Figures 4, 9, and 10. This operation reduces the concave surface to a flat surface 36 coinciding with the abovementioned reference surface. Since the surface 36 is flat, it may be easily formed by machining, preferably by milling.

The forms imparted to the surfaces 28 and 36 and the distances between these surfaces are such that the blade section remaining after the milling operation which forms the blank E corresponds in thickness at all points to the desired thickness of the finished blade. As a result, the blade may be finished by a simple die-forming operation which bends the blank to provide twist and full camber without necessarily requiring coining of the metal or any significant flow.

The final forming operation is effected by a die set illustrated rather schematically in Figure 12, comprising an upper die 41 and a lower die 42. Since the operation involves merely the bending of the blank to provide the concave surface and twisting of the blank, the forming step is quite simple and will be readily understood by those skilled in the art without detailed description; therefore, for conciseness, detailed drawings and descriptions of dies, which may be designed according to conventional practice and in conformity to the shape of the particular surfaces desired, are omitted. As illustrated in Figure 12, the blank is pressed between the two dies 41 and 42, the surfaces of which are so formed as to deform the blade to the desired final shape illustrated in Figures 13 to 15. The blade root may serve to locate the blank in the die.

In a blade as illustrated, this forming operation may not affect the blade root. In a blade with severe camber, such as a turbine bucket, it would be necessary to deform the base in this operation to prevent shearing at the junction of the blade and the base.

The blank may be annealed before this second forming operation and should be heat treated to secure the desired qualities after the forming.

The foot of the blade may be finish machined in any suitable manner according to previously known practices in the art and the blades then finished by tumbling, polishing, and inspection.

It will be apparent to those skilled in the art from the foregoing description that the various operations may be readily performed utilizing standard machine tools and industrial operations and that they are adapted to produce blades of high accuracy, uniformity, and strength at low unit cost. No coining or extensive distortion of the metal is required, and no machining of curved surfaces. The advantages of the process of the invention for production of compressor blades, or other articles presenting similar problems, will be apparent.

It also will be apparent that the sequence of operations by which the blade portion is formed may be employed in cases where the blade which is to be formed does not have a foot; however, a primary advantage of the invention is that it makes possible the accurate and economical production of blades notwithstanding complications introduced by the presence of the foot.

The application of the principles of the invention to the manufacture of such structures as turbine nozzles, vanes, and buckets, vanes of hydraulic torque converters,

5

and, in general, to fluid-deflecting elements of fluid dynamic machinery, will be obvious. Other complex shapes may be formed by the process of the invention. The finally resulting surfaces may both be concave or both convex.

It is preferable, for ease of machining, that the faces be machined plane, and a great variety of finished forms can be made without machining surfaces of other than plane form. The process makes it possible to form two complex surfaces by simple machining and die-striking procedure. In some cases, the machined surfaces might beneficially vary from a plane. Cylinders, cones, and surfaces of revolution in general (including planes) may be generated by machining without great difficulty.

One or both die-striking operations may provide a surface crowned in two dimensions where advantageous.

The detailed description herein of the preferred embodiment of the invention is not to be considered as limiting the scope thereof, as many modifications may be made within the scope of the invention by the application of skill in the arts to which it relates.

We claim:

1. A process for the manufacture of compressor elements and the like from a rough blank having a blade part and a foot part substantially thicker than the adjacent portion of the blade part at one end of the blade part comprising machining one face of the blade part to form a plane surface, forming the blade and foot parts of the blank concurrently to form the said machined face of the blank to a convex surface departing from a plane reference surface in accordance with the desired thickness of the finished blade, machining the concave face of the blank to the said plane surface while the blank is so bent, and further forming the blank to provide the desired camber and twist of the blade.

2. A process for the manufacture of compressor elements and the like from a rough blank having a blade part and a foot part substantially thicker than the adjacent portion of the blade part at one end of the blade part comprising machining one face of the blade part to form a plane surface, forming the blank to form the said machined face of the blank to a convex surface departing from a plane reference surface in accordance with the desired thickness of the finished blade, machining the foot part of the blank, machining the concave face of the blank to the said plane surface while the blank is so bent, and further forming the blade portion of the blank to provide the desired camber and twist of the blade.

3. A process for the manufacture of compressor elements and the like from a rough blank having a blade part and a foot part thicker than the blade part at one end thereof comprising machining one face of the blade part to form a plane surface, cold-forming the blank to form the said machined face of the blank to a cambered surface departing from a plane reference surface in accordance with the desired thickness of the finished blade, machining the other face of the blank to the said plane surface while

6

the blank is so bent, and further cold-forming the blank to provide the desired camber and twist of the blade.

4. A process for the manufacture of compressor elements and the like from a rough blank having a blade part and a foot part substantially thicker than the adjacent portion of the blade part at one end of the blade part comprising trimming the blade part, machining one face of the blade part to form a plane surface and provide a taper in thickness from the foot, cold-forming the blade and foot parts of the blank to form the machined face of the blank to a cambered surface departing from a plane reference surface in accordance with the desired thickness of the finished blade, machining the other face of the blank to the said plane surface while the blank is so bent, and further cold-forming the blank to provide the desired camber and twist of the blade.

5. A process for forming a finished metal body of generally airfoil shape such as a compressor element having non-parallel curved faces from a rough metal blank comprising machining one face of the blank, which corresponds to one face of the finished body, to a flat surface, bending the blank so as to impart a camber thereto such that the distance of the said machined face from a predetermined reference surface varies so as to correspond to the desired distribution of the thickness of the finished body over the area of the machined face, machining the other face of the blank, which corresponds to the other face of the finished body, to the said predetermined reference surface while the blank is so bent, and further bending the blank so as to alter the camber thereof and conform both faces to the desired airfoil contour of the finished body.

6. A process for forming a finished metal body of generally airfoil shape such as a compressor element having curved faces from a rough metal blank comprising machining one face of the blank, which corresponds to one face of the finished body, to a flat surface, bending the blank so as to impart a camber thereto such that the distance of the said machined face from a plane reference surface corresponds to the desired distribution of the thickness of the finished body over the area of the machined face, machining the other face of the blank, which corresponds to the other face of the finished body, to the said plane reference surface while the blank is so bent, and further bending the blank so as to alter the camber thereof and conform both faces to the desired airfoil contour of the finished body.

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