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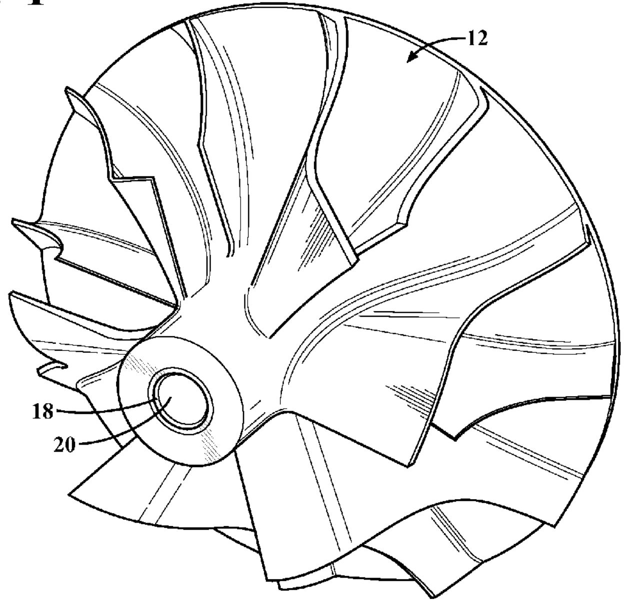
Declarations under Rule 4.17:

— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

[Continued on next page]

(54) Title: COMPRESSOR WHEEL COMPRISING A TITANIUM SLEEVE

FIG. 1



(57) Abstract: A compressor wheel (12) adapted for use with a turbocharger that has a sleeve (18) of high-strength material, such as titanium, in a bore (14) of the compressor wheel (12) that is made of a different material, such as aluminum, than the sleeve (18). The sleeve (18) can extend through the entire bore (14) of the compressor wheel (12) as a through sleeve (20) or can be an insert (30) in an end section of the bore (14) adjacent to a backwall (32) of the compressor wheel (12). The sleeve (18) preferably forms a conical interface (22) in the bore (14) of the compressor wheel (12). Friction welding or other bonding means capable of securing of the sleeve (18) in the compressor wheel (12) can be used to make a compressor wheel (12) with a sleeve (18) forming a bond or a joint between dissimilar materials.

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— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

— *of inventorship (Rule 4.17(iv))*

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COMPRESSOR WHEEL COMPRISING A TITANIUM SLEEVE

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims priority to and all the benefits of U.S. Provisional Application No. 61/991,789, filed on May 12, 2014, and entitled “Compressor Sleeve,” which is incorporated herein by reference.

BACKGROUND

Field of the Disclosure

This disclosure relates to a compressor sleeve used in conjunction with a bore of a compressor wheel. More particularly, this disclosure relates to a high-strength sleeve secured in a compressor wheel made of a different material and to methods of making such a compressor wheel with a sleeve.

Description of Related Art

Advantages of turbocharging include increased power output, lower fuel consumption and reduced pollutant emissions. The turbocharging of engines is no longer primarily seen from a high-power performance perspective, but is rather viewed as a means of reducing fuel consumption and environmental pollution on account of lower carbon dioxide (CO_2) emissions. Currently, a primary reason for turbocharging is using exhaust gas energy to reduce fuel consumption and emissions. In turbocharged engines, combustion air is pre-compressed before being supplied to the engine. The engine aspirates the same volume of air-fuel mixture as a naturally aspirated engine, but due to the higher pressure, thus higher density, more air and fuel mass is supplied into a combustion chamber in a controlled manner. Consequently, more fuel can be burned, so that the engine's power output increases relative to the speed and swept volume.

In exhaust gas turbocharging, some of the exhaust gas energy, which would normally be wasted, is used to drive a turbine. The turbine includes a turbine wheel that is mounted on a rotatable shaft and is rotatably driven by exhaust gas flow. The turbocharger returns some of this normally wasted exhaust gas energy back into the engine, contributing to the engine's efficiency and saving fuel. A compressor, which is driven by the turbine, draws in filtered ambient air, compresses it, and then supplies it to the engine. The compressor includes a compressor wheel that is mounted on the same rotatable shaft so that rotation of the turbine wheel causes rotation of the compressor wheel.

Turbochargers typically include a turbine housing connected to the engine's exhaust manifold, a compressor housing connected to the engine's intake manifold, and a bearing housing coupling the turbine and compressor housings together. A turbine wheel in the turbine housing is rotatably driven by an inflow of exhaust gas supplied from the exhaust manifold. A rotatable shaft connects the turbine wheel to a compressor wheel in the compressor housing so that rotation of the turbine wheel causes rotation of the compressor wheel.

This disclosure focuses on a compressor wheel of a turbocharger. In many instances, the lifetime of a turbocharger corresponds to the lifetime of the compressor wheel. One damage consideration is based on material fatigue under cyclic loading at low frequency. This phenomenon is known as "low cycle fatigue" or LCF. We distinguish between time dependent loading and fatigue at high frequency (HCF) and low frequency (LCF).

Fatigue behavior can begin with an accumulation of deformations that lead to micro fatigue cracks. These micro cracks can lead to larger cracks, which if significant enough can lead to component failure, such as hub burst.

Compressor wheel duration regarding low cycle fatigue is mostly limited by backwall or bore stress. Centrifugal forces cause stress at the bore, and the plane of the backwall typically has the most mass concentration resulting in high stress. To reduce stress concerns, a compressor wheel might run at lower tip speeds or be made with high-strength materials with higher load capability, such as titanium.

Compressor wheels can be made entirely of titanium, but they are expensive. Titanium is an expensive material, and it is expensive to manufacture. Titanium has special properties as a cast materials, including being reactive to the environment when molten, requiring chemical milling to produce curved compressor blades. Use of high-strength materials for a compressor wheel has benefits and drawbacks.

In the aerospace industry, rotary friction welding is a known process used to bond dissimilar materials. Solid state joints of dissimilar materials can be obtained by rotary friction welding processes, which may combine the heat generated from friction between two surfaces and plastic deformation. The strength of the joints varies with the friction time and use of different pressure values. Heating for the union can be mechanically generated by friction and rotation between the parts to be welded, and bonding can be produced at temperatures lower than the melting points of the base materials. The increase of temperature in the bonding interface and the application of pressure at the joining interface originate the diffusion and bonding between the two dissimilar materials.

U.S. Patent 8,512,002 discloses a method of manufacturing an aerofoil structure capable of being diffusion bonded and superplastically formed to create a substantially hollow cavity within the aerofoil structure.

Earlier patents EP 1413767 A2 (compressor wheel assembly) and WO 2002001075 A1 (compressor wheel with prestressed hub and interference fit insert) are existing art. EP 1413767 discloses a cylindrical sleeve located concentrically around a shaft to thereby support the shaft co-axially within the bore. WO 2002001075 A1 discloses a compressor wheel having a prestressed hub with an interference fit insert.

The life expectancies for compressor wheels can vary based on low cycle fatigue by controlling and balancing backwall or bore stresses. Thus, it would be desirable to control backwall and bore stresses to maximize the duration of a compressor wheel with accommodating materials in a practical manufacturing process.

SUMMARY

This disclosure relates to a high-strength compressor sleeve secured in a bore of a compressor wheel made of a different material than the sleeve. Methods of making such a compressor wheel with a sleeve inserted and bonded in the bore are also disclosed.

Costly material upgrades to compressor wheels can be avoided by assembling a thin compressor sleeve, i.e. steel or titanium, into a compressor wheel bore. The partial or full length high-strength sleeve can be attached, secured or bonded to the compressor wheel by friction welding, ultrasonic welding, or other bonding means that are capable of bonding dissimilar materials.

The benefits of using such sleeve attachments include that the sleeve absorbs the peak bore stress. High-strength materials, such as titanium, of the sleeve can form the portion of the combined compressor wheel closest to the axis of rotation. The stress in the bore of a cast portion of the compressor wheel can be greatly reduced, estimated by up to half, allowing the cast portion of the compressor wheel to be formed of aluminium or similar materials.

The outer portion of the compressor wheel can be cast with the benefits of making the impeller portion with a larger bore to accommodate the sleeve. The separately formed compressor sleeve can be inserted into the bore and attached, secured or bonded. Also, the in-welded sleeve gives flexibility to reduce blade root fillet stress by allowing larger fillets.

Blade root stresses are the highest stress location on some compressor wheel designs. Minimizing these stresses typically require large backwall deck thickness on the compressor wheel. Increasing backwall deck thickness, however, increases the already high bore stress. With the cast wheel/sleeve combination, the backwall thickness can be increased, and the increased stresses can be transferred to the high-strength sleeve.

The increased mass of high-strength materials of the sleeve will not significantly increase inertia because the mass is close to the axis of rotation. The sleeve of high-strength materials, which are also typically more expensive, can be less with a smaller amount of such materials and that such high-strength material is often harder and more expensive to fabricate than other materials, such as cast aluminium. The friction welding or ultrasonic welding of the sleeve into the compressor wheel bore may be less costly than making the entire compressor wheel of the costly, high-strength material.

As an example, an aluminum cast compressor wheel, per centrifugal analysis results, can have a bore stress/yield strength of 85%; whereas, a compressor wheel with a through sleeve joined in a compressor wheel can have a bore stress/yield strength of 53%. Similarly, a partial sleeve portion inserted and joined in a portion of bore of a compressor wheel can have a bore stress/yield strength of 49%. The high-strength sleeve should be permanently attached into the bore of a cast aluminum compressor wheel.

A bore that is more capable of handling higher stress may increase the life of a compressor wheel.

BRIEF DESCRIPTION OF THE DRAWINGS

Advantages of the present disclosure will be readily appreciated as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings wherein:

Figure 1 is a perspective view of a through sleeve joined in a compressor wheel adapted for use with a turbocharger;

Figure 2 is a cross-sectional side view of a through sleeve joined in a compressor wheel;

Figure 3 is a partial cut-away perspective view of a conical through sleeve joined in a compressor wheel;

Figure 4 is a cross-sectional side view of a through sleeve with a conical interface bonded in a compressor wheel;

Figure 5 is a rear end view of a compressor wheel including a partial sleeve portion joined in a bore of the compressor wheel; and

Figure 6 is a cross-sectional side view of a compressor wheel including a partial sleeve portion joined in a bore of the compressor wheel.

DETAILED DESCRIPTION OF THE EMBODIMENTS

Turbochargers are generally known and include a turbine and a compressor, wherein a compressor wheel 12 is rotatably driven via a rotatable shaft by a turbine wheel.

The compressor wheel 12 is mounted on one end of the shaft and is housed within the compressor housing. As is known in the art, the turbine wheel is rotatably driven by an inflow of exhaust gas supplied from an exhaust manifold, which rotates the shaft, thereby causing the compressor wheel 12 to rotate. As the compressor wheel 12 rotates, air is drawn in and is compressed to be delivered at an elevated pressure to an intake manifold of an engine. In other words, the compressor wheel 12 is rotatably driven by the turbine wheel.

Figures 1 and 2 show a compressor wheel 12 having a bore 14 in a molded impeller portion 16 with a compressor sleeve 18 joined in the bore 14. In this example, the sleeve 18 extends along the entire length of the bore 14 of the compressor wheel 12 as a through sleeve 20. The compressor wheel 12 has a sleeve 18 of high-strength material in the bore 14 of the compressor wheel 12 that is made of a different material. The high-strength material of the sleeve 18 can be is titanium, approximately 1.5 mm thick, and the compressor wheel 12 can be aluminum molded or machine formed with a bore 14 that corresponds to and complements the sleeve 18 to be inserted and bonded.

Figures 3 and 4 show the sleeve 18 as a through sleeve 20 that is conical joined in a compressor wheel 12. The compressor wheel 12 has the sleeve 18 forming a conical interface

22 in the bore 14 of the compressor wheel 12. The conical interface 22 that bonds the sleeve 18 in a compressor wheel 12 allows for better bonding.

Figures 5 and 6 show the sleeve 18 as a partial sleeve portion 30 joined in a bore 14 in an end portion of a compressor wheel 12. The sleeve 18 as a sleeve portion 30 is an insert in a section of the bore 14 adjacent to a backwall 32 of the compressor wheel 12. The compressor wheel 12 has the sleeve 18 bonded in a section of the bore 14 adjacent to a backwall 32 to avoid the sleeve 18 extending the entire bore 14.

Friction welding or other bonding means are capable of securing dissimilar materials of the sleeve 18 and the remainder of the compressor wheel 12 as the impeller portion 16. The sleeve 18 of a high-strength material can be joined into the bore 14 where two pieces are joined despite being dissimilar materials.

Rotary friction welding can be used to make a compressor wheel 12 with a sleeve 18 to form a bond or a joint between the sleeve 18 and remainder of the impeller portion 16 that are made of dissimilar materials, such as a titanium sleeve 18 being joined with an aluminum compressor wheel 12. Bonding the sleeve 18 into a compressor wheel 12 via friction welding allows flexibility to use standard sleeves for different frame sizes.

The method of making a compressor wheel 12 using rotary friction welding to bond dissimilar materials may include forming the compressor wheel 12, preferably molded and machined with the bore 14 that is conical. A sleeve 18, which is preferably a complementary conical shape, can be inserted into a bore 14 of the compressor wheel 12, and the sleeve 18 is rotated in the bore 14. Pressure is applied with the sleeve 18 into the bore 14, and heat is generated from friction to form a bond or a joint between the sleeve 18 and the compressor wheel 12. The time and pressure are controlled to form an appropriate bond between the sleeve 18 and the compressor wheel 12, which are made of dissimilar materials, in a practical application of this method.

Another method of making a compressor wheel 12 with a sleeve 18 may include making a casting around the sleeve 18, such as a titanium sleeve that extends the entire bore 14 of the compressor wheel 12. Making the casting around the sleeve 18 may be cost-effective and lessen balancing issues for the combined compressor wheel 12 with a sleeve 18 as a through sleeve 20 extending through the entire bore 14 of the compressor wheel 12.

Although the disclosure focuses on a compressor wheel for use in an exhaust gas turbocharger, it is contemplated that the compressor wheel disclosed herein has other applications, including, but not limited to, use in an electric turbocharger consisting of an high speed turbine-generator and an high speed electric air compressor (sometimes referred to as an “e-turbo”), and a flow compressor driven by an electric motor placed as a component before or after the turbocharger (sometimes referred to as an “e-booster).

The invention has been described in an illustrative manner, and it is to be understood that the terminology used is intended to be in the nature of words of description rather than limitation. Many modifications and variations of the present invention are possible in light of the above teachings. It is, therefore, to be understood that within the scope of the appended claims, the invention may be practiced other than as specifically described.

CLAIMS

What is claimed is:

1. A compressor wheel (12) adapted for use in a compressor, the compressor wheel (12) having a sleeve (18) formed of high-strength material disposed in a bore (14) of the compressor wheel (12), the compressor wheel (12 being made of a different material than the sleeve (18).

2. The compressor wheel (12) of claim 1 wherein the sleeve (18) is bonded within the bore (14).

3. The compressor wheel (12) of claim 1 wherein the high-strength material of the sleeve (18) is titanium, and the compressor wheel (12) is aluminum.

4. The compressor wheel (12) of claim 3 wherein the sleeve (18) is approximately 1.5 mm thick.

5. The compressor wheel (12) of claim 1 wherein the sleeve (18) extends through the entire bore (14) of the compressor wheel (12) as a through sleeve (20).

6. The compressor wheel (12) of claim 1 wherein the sleeve (18) forms a conical interface (22) in the bore (14) of the compressor wheel (12).

7. The compressor wheel (12) of claim 1 wherein the sleeve (18) is an insert (30) in an end section of the bore (14) adjacent to a backwall (32) of the compressor wheel (12).

8. A method of making a compressor wheel (12) using rotary friction welding to bond dissimilar materials comprising the steps of:

inserting a sleeve (18) into a bore (14) of the compressor wheel (12);

rotating the sleeve (18) in the bore (14); and

applying pressure with the sleeve (18) into the bore (14) and generating heat from friction to form a bond between the sleeve (18) and the compressor wheel (12),

wherein the sleeve (18) and the compressor wheel (12) are made of dissimilar materials.

9. The method of making the compressor wheel (12) of claim 7 further comprising an initial step of:

forming the compressor wheel (12) with the bore (14) having a conical shape;

wherein the sleeve (18) has a shape that is complementary to the conical shape of the bore (14) to bond with the bore (14).

FIG. 1

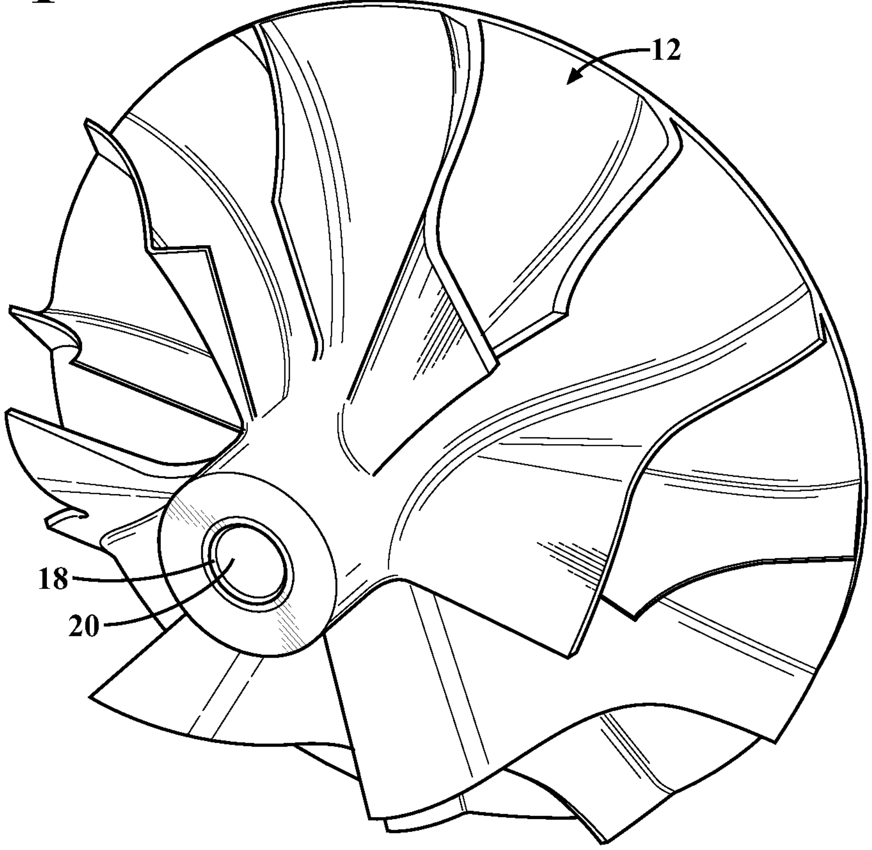


FIG. 2

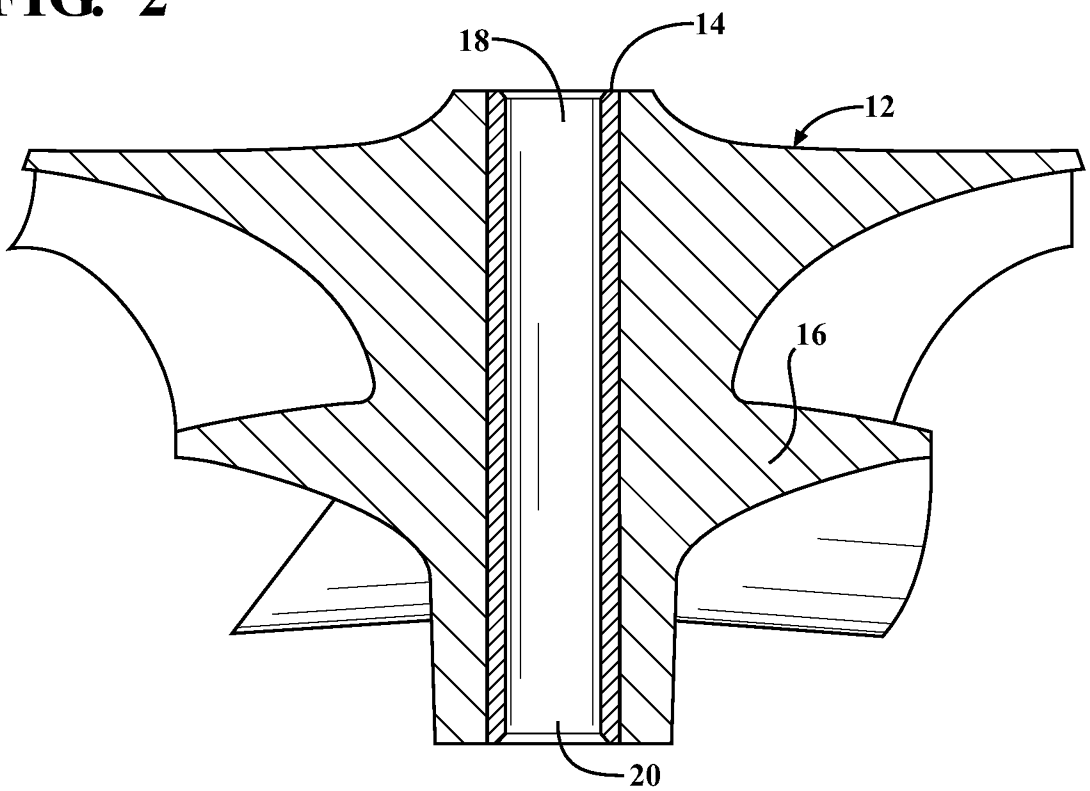


FIG. 3

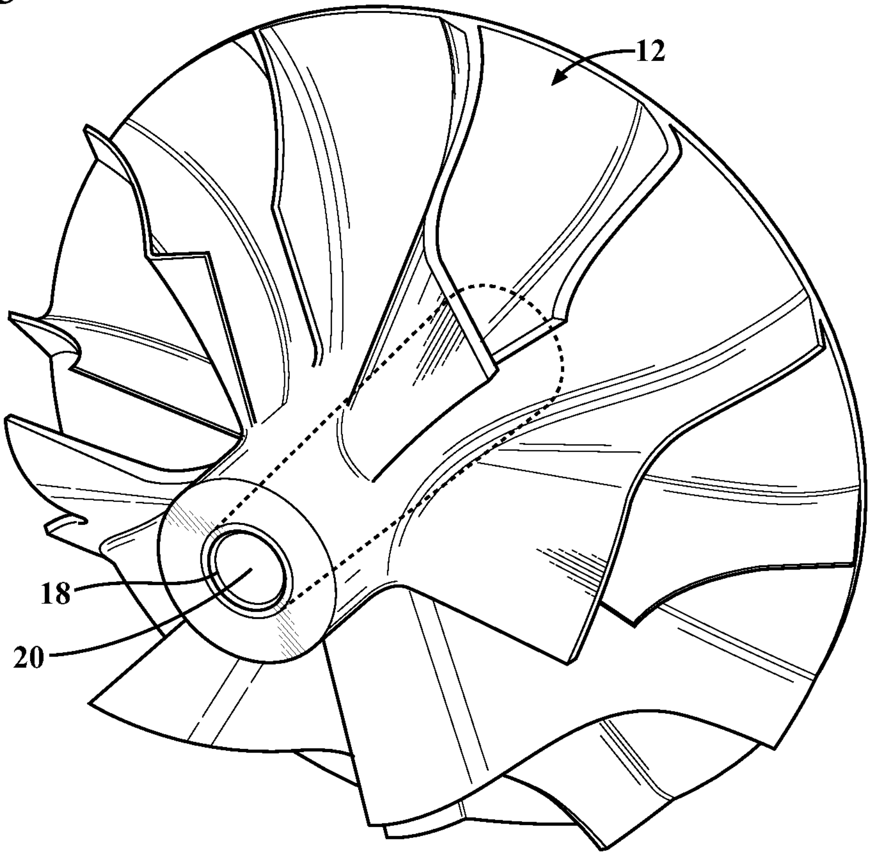


FIG. 4

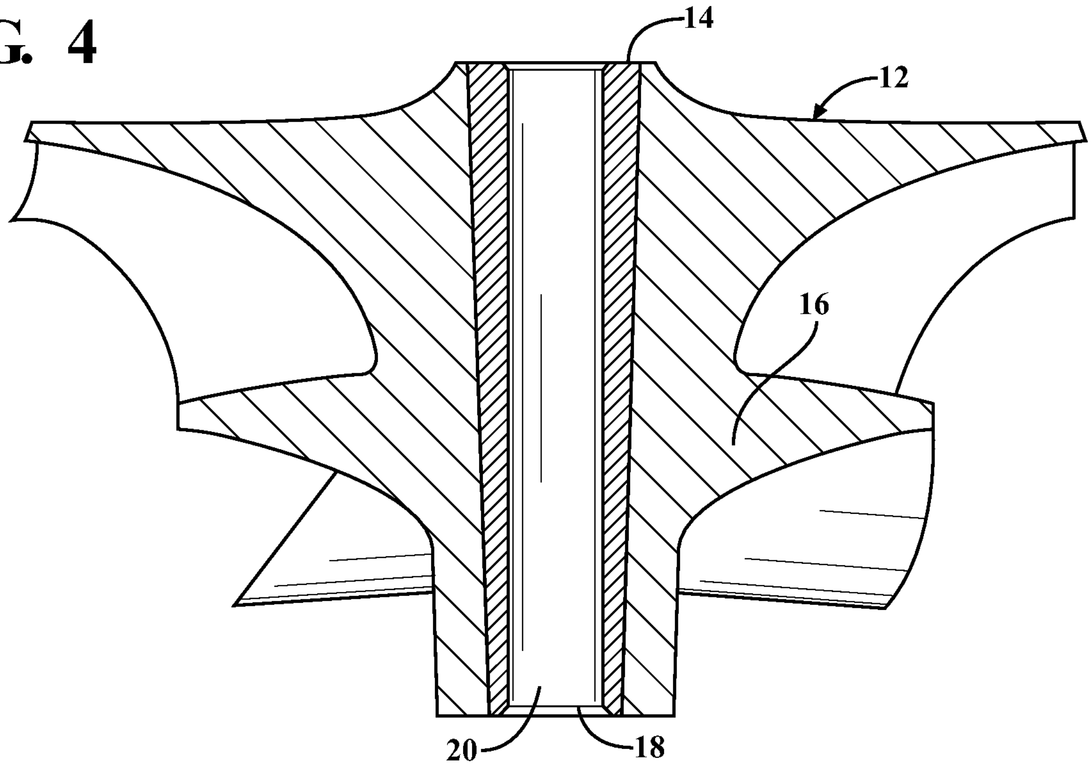


FIG. 5

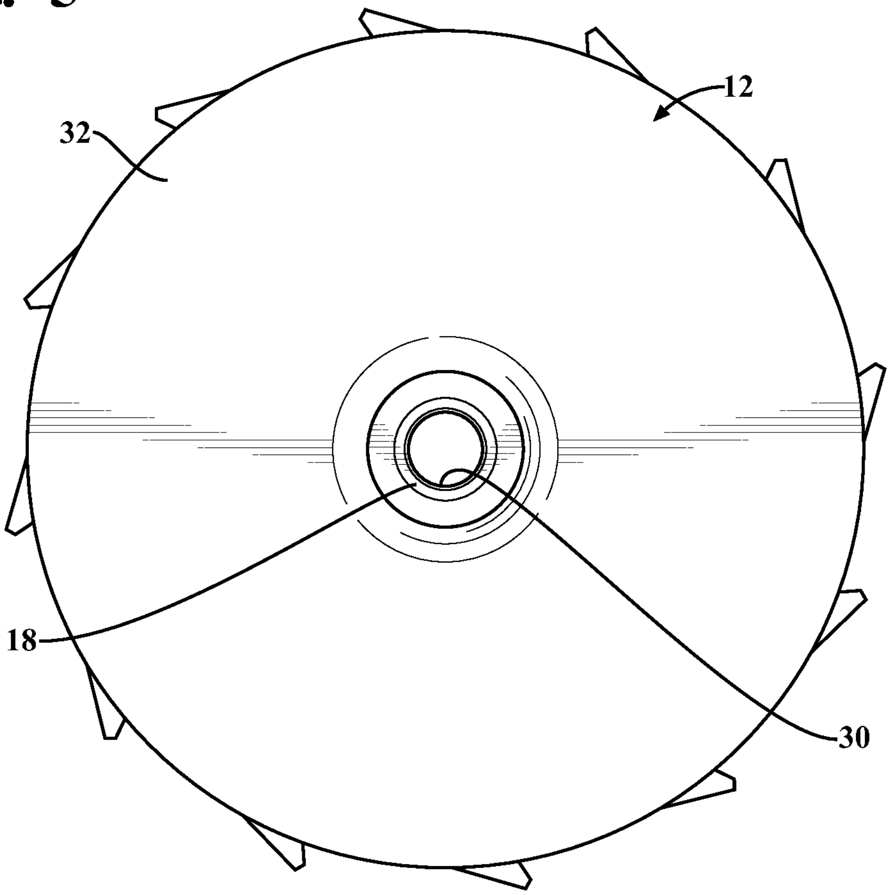
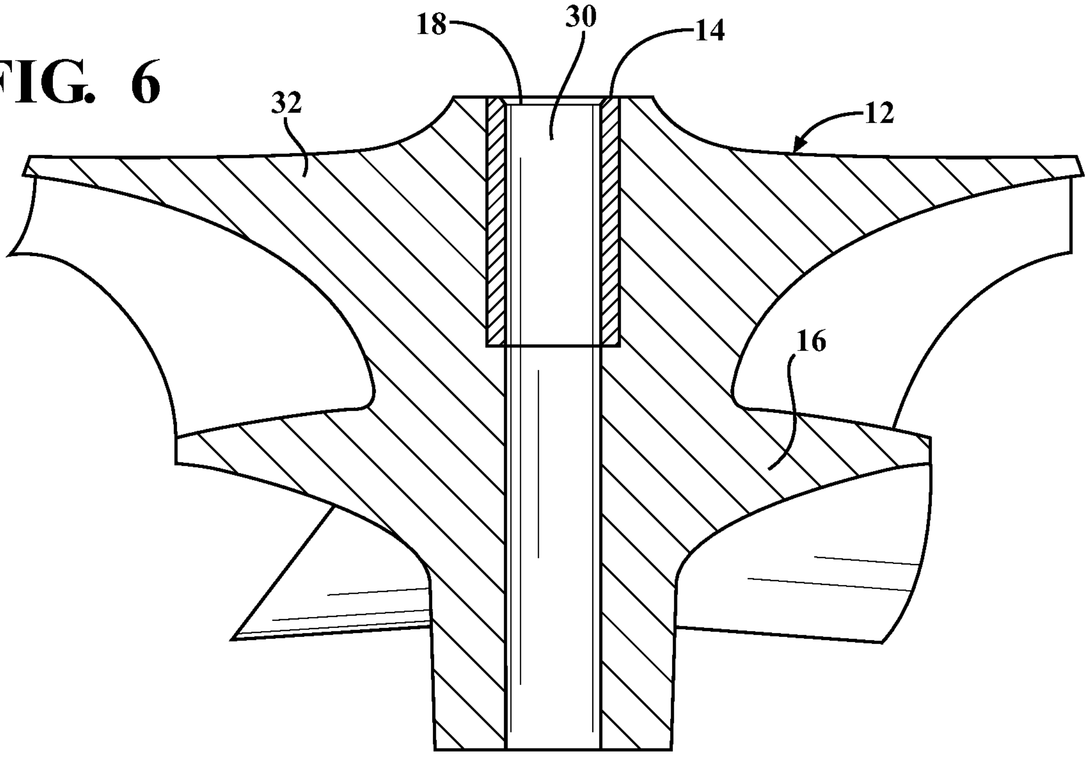


FIG. 6



INTERNATIONAL SEARCH REPORT

International application No
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A. CLASSIFICATION OF SUBJECT MATTER
INV. F01D5/04 F04D29/28
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F01D F04D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
14 July 2015	21/07/2015

Name and mailing address of the ISA/	Authorized officer
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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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