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(54) VACUUM PUMP IMPELLER

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(57) **ABSTRACT**

The invention relates to a vacuum pump impeller (**10**) which comprises a shaft (**14**) made of steel, and a one-piece rotor (**12**) supported by the shaft (**14**) and made of a material different from the steel of the shaft. The shaft (**14**) comprises an axial cavity (**22**), and the rotor (**12**) comprises an axial projection (**16**) seated in the cavity (**22**) in positive and/or non-positive engagement therewith.

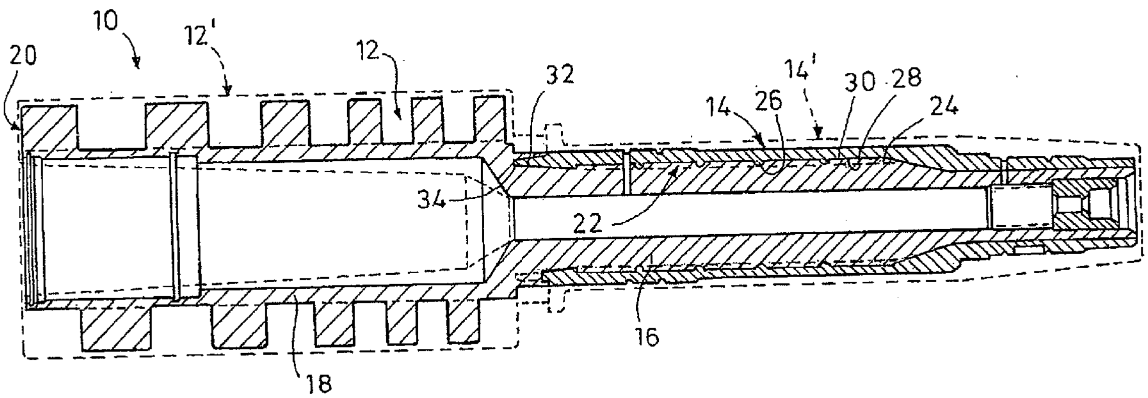


Fig.1

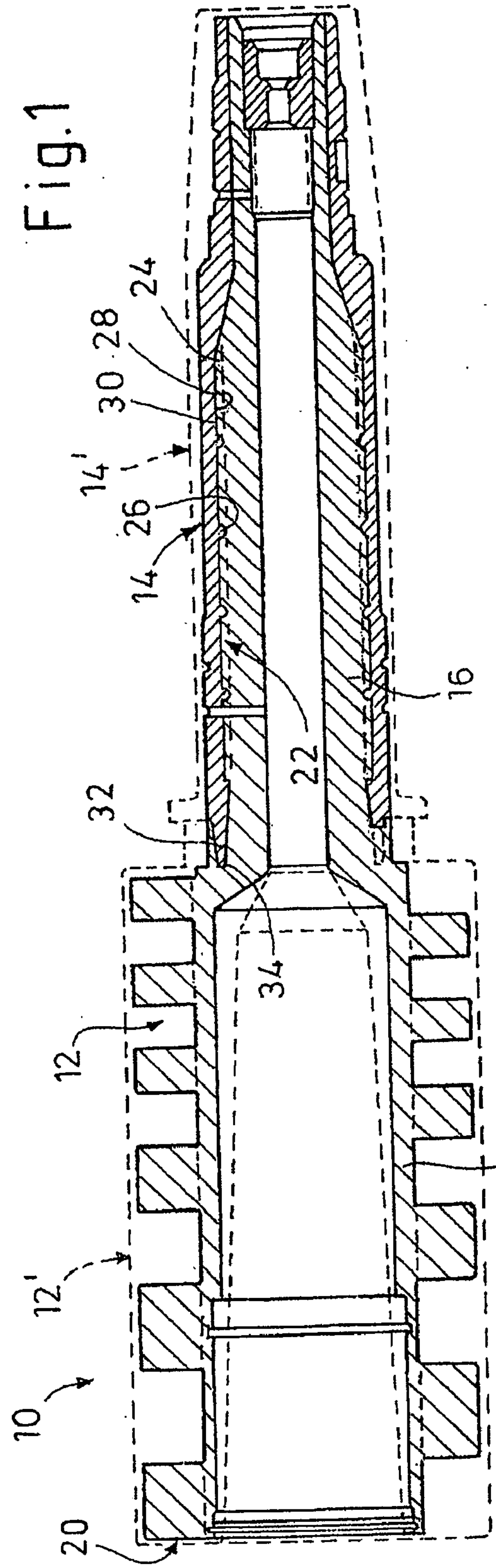


Fig.2

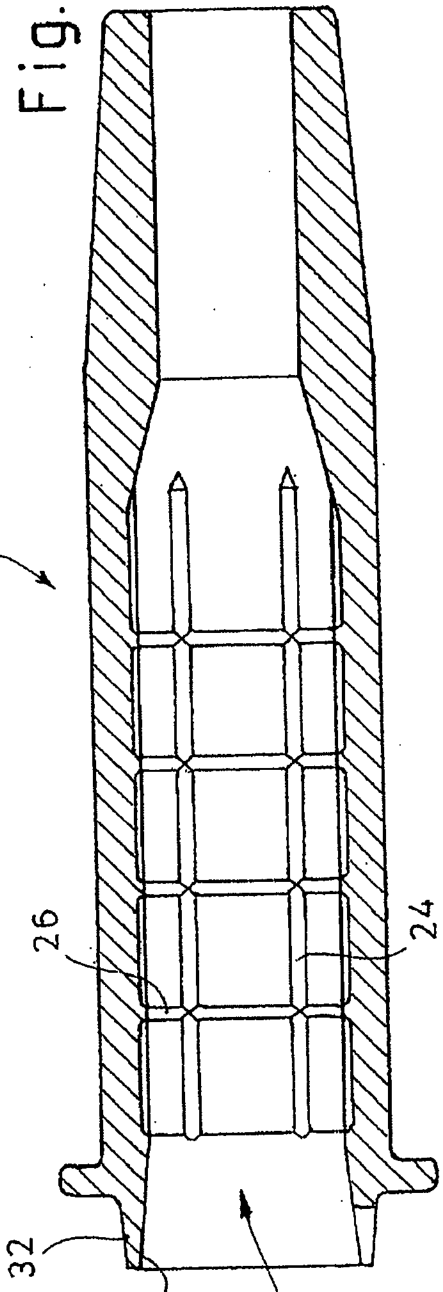


Fig.3

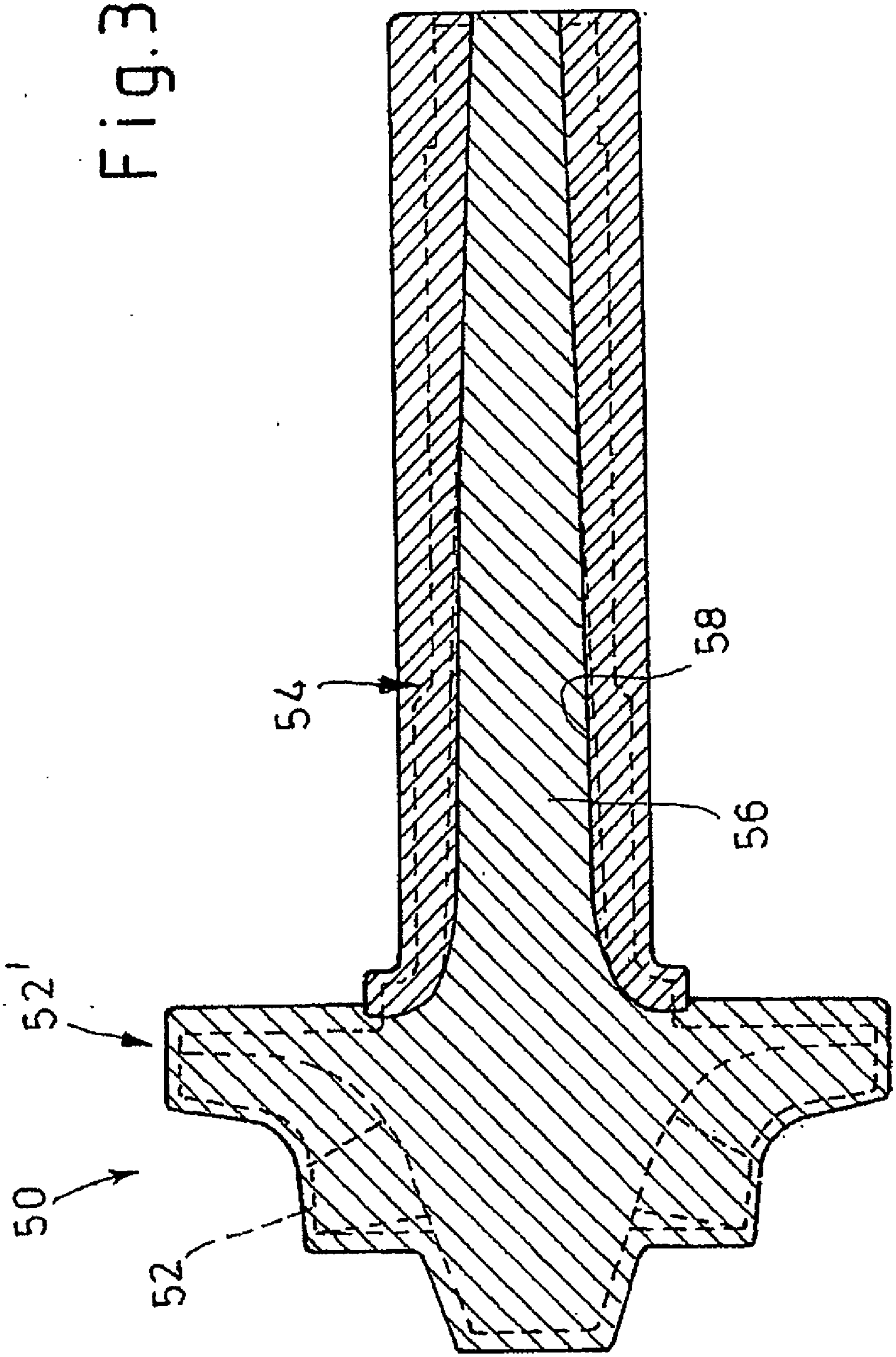
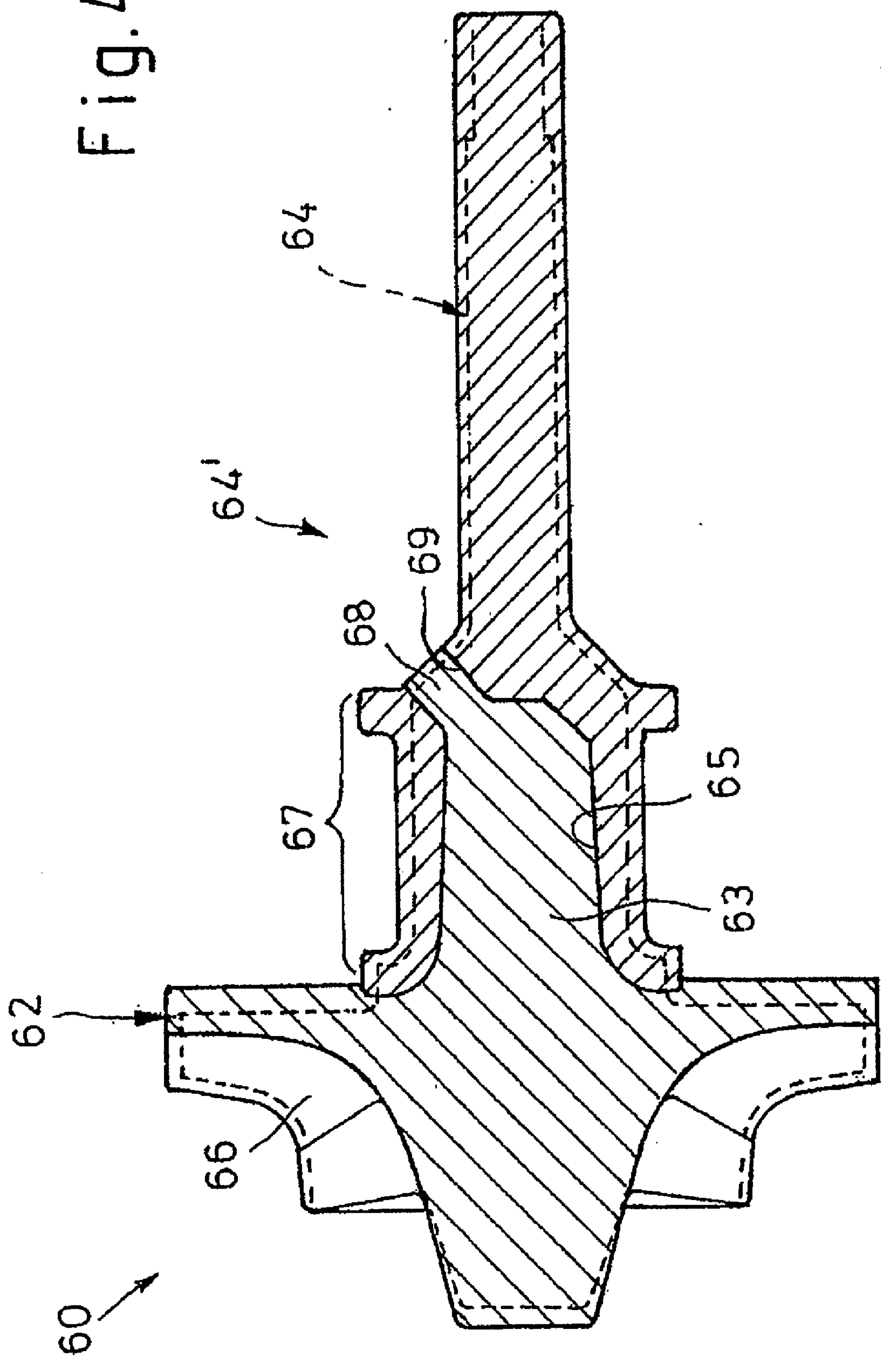


Fig. 4



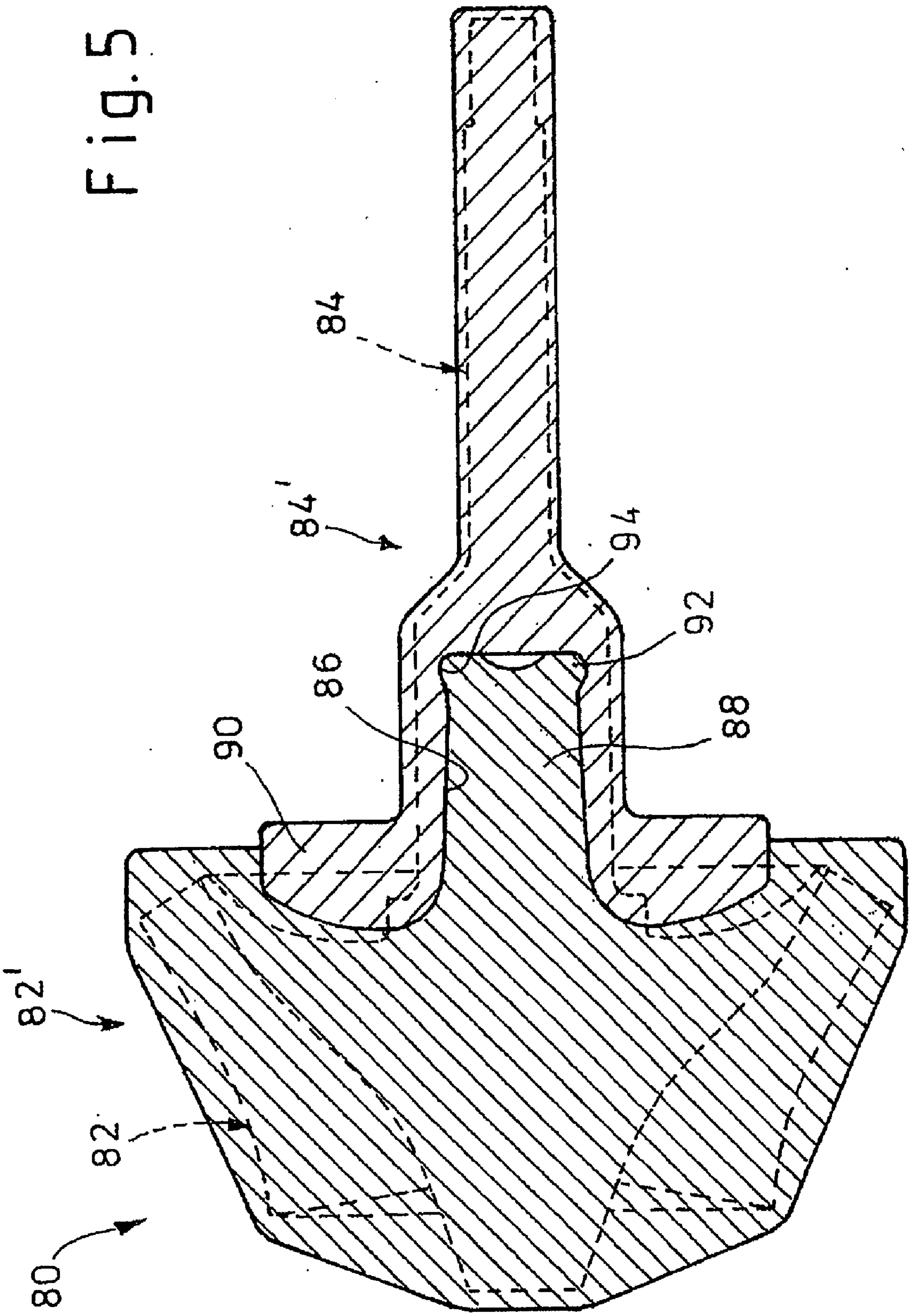


Fig.5

VACUUM PUMP IMPELLER

[0001] The invention relates to a vacuum pump impeller comprising a steel shaft and a one-piece rotor held by the shaft and made from a material different from the shaft steel, and to a method for producing a vacuum pump impeller.

[0002] Vacuum pump impellers are known in various variants, e.g. as screw impellers, turbo impellers, rolling-piston impellers, side-channel impellers, inter alia. Vacuum pump impellers can be configured for cantilevered arrangement, i.e. the impeller is supported only on one axial end so that the rotor is arranged in overhung position. Impellers are partially operated at high rotational speeds so that high radial forces can occur. For these reasons, when designing the impellers, efforts are made to keep the weight particularly of the rotor as small as possible and to provide the shaft with the highest possible strength and rigidity. In practice, this is realized by attaching the rotor on the outer side of the steel shaft, and by forming the rotor of a material having a particularly light weight, e.g. aluminium. Since, due to high temperature and high centrifugal forces, the rotor may in operation may expand more than the shaft, a permanent and free-from-play fixing of the rotor to the shaft can be effected only with difficulty and in a complicated manner, e.g. by welding, soldering, bonding, axially biased toothed engagement on the end sides, tie rods etc.

[0003] In view of the above, it is an object of the invention to provide a vacuum pump impeller and a method for producing the same which allow for a simple and permanent fixation of the rotor the shaft.

[0004] According to the invention, the above object is achieved by the features of claim **1** and **9**, respectively.

[0005] In the vacuum pump impeller of the invention, the shaft is provided with a cavity on one axial end thereof, and the rotor is provided with a corresponding axial projection seated in positive and/or non-positive engagement in the axial cavity of the shaft. Thus, the rotor is not fixed to the outer side of the shaft but is fixed substantially on the inner side of a sleeve-like portion of the hollow steel shaft. Under the effect of the centrifugal forces and the introduction of heat into the rotor as occurring during operation, the rotor projection seated in the shaft can expand more than the hollow shaft. In operation and particularly in case of high rotational speeds, the connection between the rotor and the shaft will thus become stronger. This effect obviates the need for complex connection arrangements involving the use of tie rods etc., as well as the need for holes in the shaft and the rotor so that, by the resultant homogenization of the force flows, breakage of the shaft or the rotor is avoided. Further still, by the omission of complex fastening arrangements, the weight of the impeller is kept low, so that—particularly in case of high rotational speeds at which e.g. turbo impellers are operated—the bearing support can be simplified. Thus, with the inventive impeller, higher rotational speeds and/or a lower weight and a reduced constructional size can be realized.

[0006] Preferably, the rotor projection and the shaft each comprise, within the cavity, suitably shaped portions for effecting a positive engagement with each other in the axial direction and/or the circumferential direction. The provision of a positive connection results in a safe and easily established connection between rotor and shaft.

[0007] According to a preferred embodiment, the rotor is a cast piece whose projection is integrally cast in the shaft cavity. Prior to casting the rotor, the shaft is inserted, by its portion including the cavity, into a casting box, and then the liquid rotor material is injected into the rotor casting box, with the liquid rotor material flowing into the shaft cavity. In this manner, the shaped portions in the cavity of the shaft are transferred to the rotor projection already when casting the rotor. No further production step for fixing the rotor to the shaft will be required. Thereby, in turn, the weight is reduced and causes of possible imbalances are avoided.

[0008] Preferably, the above shaped portions are configured as grooves and bars. The grooves and bars can be arranged in axial and circumferential directions; however, they can be arranged also in other directions. The exact shape and orientation of the bars and grooves will depend, inter alia, on the thermal expansion behavior of the materials used for the rotor and the shaft, the rotational speeds and centrifugal forces occurring during operation, and other limiting conditions.

[0009] According to a preferred embodiment, it is provided that the wall thickness of the shaft on the rotor-side end of the shaft decreases toward the opening of the cavity, i.e. the wall thickness of the shaft casing continuously decreases towards the opening so that the stiffness of the shaft end becomes weaker towards the opening of the cavity and the axial cavity opening is relatively elastic in radial directions. Thereby, relatively large and/or sudden changes of the moments of inertia of the shaft are avoided, which otherwise would cause high bending and/or torsional stresses and thus—particularly in case of massive variations in stress—could result in premature fatigue with generation of fissures. The danger of breakage of the rotor projection in this region is considerably reduced, so that a correspondingly small dimensioning and thus a reduction of weight of the rotor projection can be realized. The region of decreasing wall thickness as compared to the overall length of the shaft can be less than 1/10 but should at least 3 mm long.

[0010] In principle, the vacuum pump impeller can comprise two shafts, each of them arranged at a respective axial end of the rotor. Preferably, however, only one shaft is provided, holding an axial end of the rotor. In this manner, there is obtained a vacuum pump impeller adapted for cantilevered support; in such a vacuum pump impeller, the reduction in weight which can be realized by the inventive construction is of particular advantage.

[0011] Preferably, the rotor material is a light metal or a plastic material. If the rotor is to be produced as a cast piece, the rotor material must have a melting temperature which allows for the rotor material to be poured into the shaft cavity without causing damage to the steel shaft. Apart of light metal, also plastic or fiber-reinforced plastic can be used for the rotor.

[0012] According to a method for producing a vacuum pump impeller comprising a rotor with an axial projection and further comprising a steel shaft having a corresponding cavity formed therein, the following method steps are provided:

[0013] inserting the shaft having the axial cavity into a rotor mold,

[0014] filling in the liquid rotor molding material into the rotor mold and into the shaft cavity, and

[0015] removing the vacuum pump impeller from the mold after the impeller has been cooled.

[0016] Using the above described manufacturing method, upon provision of suitably shaped portions in the shaft cavity, a positive connection can be established between the shaft and the rotor. In this manner, no further components will be needed for effecting a positive connection between the rotor and the shaft. The method is relatively simple and thus inexpensive.

[0017] According to an alternative method for producing a vacuum pump impeller, the shaft comprising an axial cavity is laid into a rotor drop-forge die; the red-hot rotor forging material is forged into the drop-forge die for the rotor and into the shaft cavity; and finally the vacuum pump impeller is removed from the drop-forge die.

[0018] When applying this method, advantages similar to those mentioned in connection with the molding method are obtained.

[0019] Several embodiments of the invention will be explained in greater detail hereunder with reference to the drawings.

[0020] In the drawings, the following is shown:

[0021] FIG. **1** is a longitudinal sectional view of a first embodiment of a vacuum pump impeller comprising a rotor which has been cast into the shaft and then machined,

[0022] FIG. **2** is a longitudinal sectional view of the shaft of the vacuum pump impeller,

[0023] FIG. **3** is a longitudinal sectional view of second embodiment of a vacuum pump impeller,

[0024] FIG. **4** is a longitudinal sectional view of third embodiment of a vacuum pump impeller,

[0025] FIG. **5** is a longitudinal sectional view of fourth embodiment of a vacuum pump impeller.

[0026] Illustrated in FIG. **1** is a vacuum pump impeller **10** to be used as one of the two impellers of a screw vacuum pump. Impeller **10** substantially consists of two parts, notably a one-piece rotor **12** made of aluminum and a one-pieced steel shaft **14** formed as a hollow shaft throughout its length. The interrupted line in FIG. **1** schematically indicates the contour of shaft **14'** and of rotor **12'** presented by these components immediately after casting and prior to machining.

[0027] Rotor **12** comprises two parts in its longitudinal direction, notably a projection **16** and an active part **18** which on its radially outer side has a helical structure **20**.

[0028] Shaft **14** is throughout its length provided with a slightly conical and/or cylindrical cavity **22** having the projection **16** of rotor **12** cast thereinto with positive engagement between the cavity and the projection. Internally of shaft cavity **22**, there are arranged longitudinal bars **24** and transverse bars **26** constituting said shaped portions, engaging corresponding longitudinal grooves **28** and transverse grooves **30** of projection **16**.

[0029] On the rotor-side end **32** of shaft **14**, the wall thickness of the hollow shaft continuously decreases towards the opening **34** of the cavity so that also the stiffness of shaft **14** in this region decreases towards the rotor-side shaft end **32**. The shaft end **32** can be axially toothed, as illustrated, so as to be able to transmit large torques from shaft **14** to rotor **12** in case that the positive connections via the transverse bars and grooves **24**,**26**,**28**,**30** are not sufficient for this purpose. The shaft end **32** both on its outer side and on its inner side is inclined by about 5° relative to the axial line. In combination with the transverse bars and grooves **24**,**26**,**28**,**30** of shaft **14** and rotor **12**—which bars and grooves have inclined flanks when viewed in cross section—this arrangement will compensate for thermal expansion effects caused by the differing thermal expansion effects of the two different materials of which the rotor **12** and the shaft **14** are made. In this manner, the connection will always reliably free of play.

[0030] For manufacture of the vacuum pump impeller **10**, a blank of shaft **14'** as illustrated in FIG. **4** is first laid into a molding box; the molding box is closed and aluminum as a rotor material is filled into the molding box while still in a liquid state. In the process, the liquid aluminum will also flow into the shaft cavity **22** and thus assume an outer shape which is complementary to the shaft-side bars **24**,**26**. After cooling, rotor **12'** and shaft **14'** are removed from the molding box and supplied to a machining process which will give the rotor and the shaft their final shape on their outer and inner sides, as illustrated in FIG. **1**.

[0031] In this manufacturing method, all shaped elements which are provided to take up forces and torques can be generated by casting technology. The use of a cast shaft will advantageously obviate the need for additional machining. Further, the casting method makes it possible to already shape all elements with cast radii which thus—because of reduced notch effect—are useful to obtain a good connection between the aluminum rotor **12** and the steel shaft **14**. During the casting of rotor **12**, the hollow shaft **14** can serve as a cooling iron by which a well-aimed cooling process of the rotor and thus increased non-porosity and better cohesion in the rotor material can be obtained.

[0032] By way of alternative to the above described casting method, the impeller can also be produced by a forging method carried out in analogous manner.

[0033] Illustrated in FIG. **3** is a second embodiment of a vacuum pump impeller **50** comprising a radial compressor rotor **52**, shown by interrupted lines, and a hollow shaft **54**. The conical rotor projection **56** is cast into the conical shaft cavity **58**. The positive connection between rotor **52** and shaft **54** is effected by bars and grooves in the longitudinal and circumferential directions. The rotor blank **52'** machined into the rotor **52** is represented by continuous lines.

[0034] In FIG. **4**, there is again illustrated a radial compressor rotor **60** whose rotor **62**, by means of high-precision casting and, inter alia, by wax melting, already after the casting presents blades **66** of which only the outer contour has to be machined. Shaft **67** includes a hollow portion **67** which does not extend throughout the length of the shaft but covers only about a third of the shaft length. In the region of hollow portion **67**, a conical or cylindrical axial cavity **65** is provided, with a conical or cylindrical axial projection **63** of rotor **62** seated therein. The positive engagement between rotor **62** and shaft **64** is obtained by at least one eccentric rotor pin **68** seated in a corresponding number of eccentric recesses **69** of shaft **64**. To avoid imbalances caused by the different materials of the rotor and the shaft, the pins have to be arranged in a manner effecting the best possible mass equilibrium, e.g. by means of two pins arranged at a relative displacement by 180° or three pins arranged at a relative displacement by 120°. In FIG. **4**, only one pin is shown for ease of illustration. The shaft blank **64'** and the rotor blank are shown by continuous lines, and the rotor **62** completed by machining as well as the machined shaft **64** are shown by interrupted lines.

[**0035**] FIG. **5** shows a vacuum pump impeller **80** which comprises a diagonal compressor rotor **82** and a shaft **84** provided with an axial cavity **86** extending along only about a third of the axial length of shaft **84**. The shaft cavity **86** has a corresponding projection **88** of rotor **82** seated therein. The unworked rotor **82'** and the unworked shaft **84'** are shown by continuous lines, and the machined rotor **82** as well as the machined shaft **84** are shown by interrupted lines.

[**0036**] When subjected to high mechanical and/or thermal stresses, cast rotors may reach the limits of their stability so that other methods and materials have to be contemplated. The rotor **82** of impeller **80** according to FIG. **5** is a forged part which consists e.g. of aluminum and has to be hot-forged in a drop forge wherein the shaft **84** with its cavity **86** has been laid. The stability of the rotor is improved not only by the forging behavior but also by a radially toothed shaft collar **90** which is effective to reduce tensions caused by centrifugal forces and can be used to compensate for imbalances by removal of material and/or placement of compensation weights such as e.g. balancing screws. Additionally, for enhancing the positive connection, a collar **92** can be formed which together with a corresponding counterpart groove **94** will provide for axial guidance.

[**0037**] The corrosion resistance of the aluminum rotor can basically be improved by eloxadizing or hard-anodizing.

1. A vacuum pump impeller comprising:

a shaft made of steel, and a one-piece rotor supported by the shaft and made of a material different from the steel of the shaft, shaft defining an axial cavity and the rotor including an axial projection seated in the cavity in positive and/or non-positive engagement therewith.

2. The vacuum pump impeller according to claim 1, wherein the rotor projection and the shaft comprise, within the cavity respectively shaped portions, the shaped portions effecting a positive engagement with each other in the axial direction and the circumferential direction.

3. The vacuum pump impeller according to claim, wherein the rotor is a cast part having its projection cast into the shaft cavity.

4. The vacuum pump impeller according to claim 2, wherein said shaped portions are formed as grooves and bars.

5. The vacuum pump impeller according to claim 1, wherein on a rotor-side end, the wall thickness of the shaft continuously decreases towards an opening of the cavity.

6. The vacuum pump impeller according to claim 1, wherein the rotor is supported by a single shaft.

7. The vacuum pump impeller according to claim 1, wherein the rotor is formed of a light metal or a plastic material.

8. The vacuum pump impeller according to claim 7, wherein the rotor material is aluminum.

9. A method for producing a vacuum pump impeller according to claim 1 by casting, comprising the method steps of:

inserting a shaft having an axial shaft cavity into a rotor mold,

filling in the liquid rotor molding material into the rotor mold and into the shaft cavity, and

removing the vacuum pump impeller from the mold after the rotor has set.

10. A method for producing a vacuum pump impeller according to claim 1 by forging, comprising the method steps of:

inserting a shaft having an axial shaft cavity into a drop-forge die for the rotor,

forging red-hot rotor forging material into the rotor drop-forge die and into the shaft cavity, and

removing the vacuum pump impeller from the drop-forge die.

11. A vacuum pump impeller comprising:

a shaft defining an axial cavity in at least one end thereof;

a rotor constructed of a material which expands radially outward relative to the steel shaft when drawing a vacuum, the rotor including an axial projection which extends into the shaft axial cavity such that when drawing the vacuum, the rotor axial projection expands into a tighter relationship with shift to avoid slippage.

12. The vacuum pump impeller according to claim 11, wherein a thickness of a shaft wall surrounding the axial cavity thins toward the one end that receives the rotor axial projection such that a stiffness of the shaft decreases toward the rotor to reduce fatigue and a risk of the rotor breaking from the shaft.

13. The vacuum pump impeller according to claim 11, further including:

mating ridges and grooves defined in an interior of a peripheral wall of the shaft surrounding the axial shaft cavity and the rotor axial projection.

14. The vacuum pump impeller according to claim 11, wherein the rotor axial projection is one of cast or forged into the shaft axial cavity.

15. The vacuum pump impeller according to claim 11, wherein the shaft is constructed of steel and the rotor is constructed of aluminum.

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