CONTRIBUTIONS TO IMPELLERS PROTOTYPES EFFICIENT MACHINING

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Impellers prototypes machining subject is developed in this paper, with accent for turning. These are complex parts and, in this work, the necessity to design a special model for turning operation, starting from final part model, is demonstrated. A short presentation of main impeller surfaces was considered, in accordance with technological necessities. For efficient machining, originally model of part impeller must to be technologically re-engineered, with specific useful areas for turning, milling and measurement. The paper presents three technological solutions of these issues, and defines the estimation formulae for its parameters. Three steps turning process was proposed, by considering these technological improvements, highlighting the sensitive points for correct machining. Finally, a model for impellers fixture, when machining, is proposed. This is designed to be utilised in all processing: turning, milling, measurement, in a single clamping, and is conceived for multiple dimensions for presented rotor's geometry.

Keywords: impeller, turning model, prototype, technological design, single fixture.

Notations

A – Diameter position of indexing bore [mm];
d – Indexing element diameter [mm];
D – Impeller diameter [mm];
B – Technological strip width [mm];
h – Technological strip high [mm];
e – Distance between rear face and lower point of exhaust channel [mm];
Db – Starting blank diameter [mm];
W – Slot width [mm];
C – Technological shoulder diameter [mm];
E – Technological shoulder width [mm].

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1. Introduction

The impellers are, by nature of its construction, parts with high mechanical stresses during operation. This is due to the loads that occur by given rotational motion and fluids handling. In the case of certain centrifugal air compressors, rotors can reach speeds close to Mach 1 at the extremity. Air compressor impellers are made from selected materials, carefully checked, with technological path and traceability. Titanium alloys are utilised for aviation applications and high strength stainless steels for industrial cases. Some papers describe 3D numerical analysis to study impeller interaction in a turbomachine [1] or simulation method to study the kinetic centrifugal compressors surge [2]. Another zone of interest for researchers is noise produced by centrifugal compressors, in fact by their parts in movement, impellers [3].

For these reasons, impellers are parts that require special attention during design and execution. Relevant aspects of the process of obtaining the impellers were presented in various scientific papers. A research of appropriate of inserts' geometries when are turned profiled impellers' surfaces are made [4]. For rough turning, most effective choice is to use linear engagement, and inserts geometry type C, D and W, in this specific order, with suitable tool-holders. Contour turning method for roughing is efficient when using inserts with apex angle of 60 deg., or near. The process of milling the impellers in aeronautics was studied in the case of using taper ball end mill cutter [5]. Forces prediction model for this type of milling tools is presented in this paper with the purpose of adequate process parameters calculus. In the case of cylindrical ball end mill cutter, case of milling the impeller's blades, a series of papers studied the importance of the inclination angle of the cutter, when working, for processing efficiency [6, 7, 8]. The approach of clean-up of the interspace between blades, to enhance milling efficiency, gave rise to new methods of generating tool path [9]. Not least, milling impellers profiles are performed on five axes milling centres, equipped with rotary tables, and for finish machining all axes are in usage simultaneously [10].

Impellers turning are less studied than their milling operations. This happens due to the higher blades surfaces complexity than rotor profile. However, in case of rotor prototypes or in a small series, no special precautions are taken to achieve appropriate blanks. Because of this, utilised material is usually drop forged with significant material additions. This material is prepared to the desired state of heat treatment, with mechanical properties checked, and ultrasonic inspection conducted. A properly chosen processing sequence allows considerable savings of time, tools and money. This paper aims to propose an original approach for this case.

2. Impeller specific geometry

The geometrical configuration of the impellers may be slightly different depending on particular applications considered. A common geometrical configuration of such parts is shown in Fig 1. Under the aspect of technological process states, another configuration of the part is obtained at the end of turning. This form is presented in Fig. 2 and is different from final version in the blades zone. This particular geometry is obtained as an envelope by one blade rotation against the axis of rotation of the rotor. With this part geometry, the technological process of turning can be designed, and in the same time, milling blades process can be start. Turning model is made using the same software, in the same way that for 3D model of impeller. These two models are the result of CAD phase.

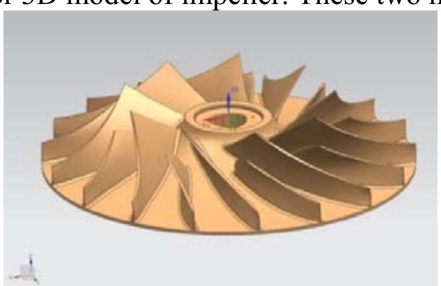


Fig. 1. Model of an impeller

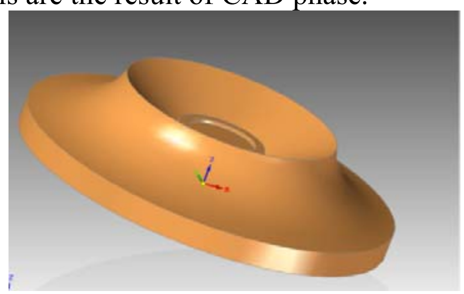
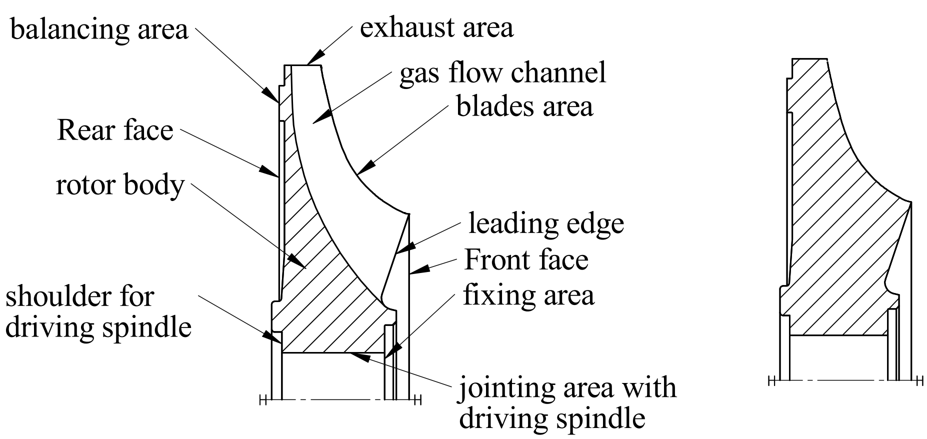


Fig. 2. Model for turning of same impeller



a. b.

Fig. 3. Impeller section: surfaces definition (a); after turning (b).

A short presentation, highlighting functional areas of the rotor is shown in Fig. 3.a. The working principle of a centrifugal rotor can be noticed. Working gas comes in suction into the central area along the leading edges, it is compressed by the blades and then, it is driven in the exit area. Impellers are parts working at high speeds, so they need a special area for balancing. This area is located on the rear side, on outer diameter. In the same side, it can be found the contact area with driving spindle shoulder, in that case, close to its rotation axis. In front side of the rotor, the blades area with gas flow channels and the fixing area for driving spindle are located. In Fig. 3.b, a section in the same rotor after final turning, without technological changes, is presented.

3. Technological model of impeller during manufacturing - proposals

The part achieved by turning must allow the following characteristics:

• steady fixing during processing;

• avoid deformations due to tightening in turning or milling process;

• accurate impeller orientation when machining and at measurement;

These reasons lead to rotor geometry reengineering after turning. For proper solve of these issues, two measures are proposed:

• use of additional, or existent, rotor material excess for steady fixing when machining;

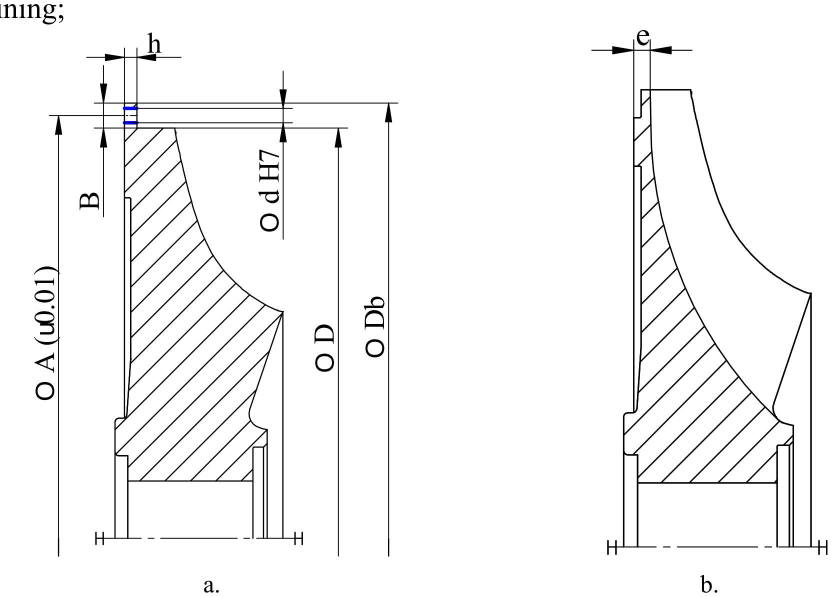


Fig. 4. Proposal for correct impeller indexing and fixing at machining and measurement: after turning with technological changes (a); at final (b).

• achievement of guidance elements, placed in this new designed rotor areas, for indexing at machining and measurement.

A first approach is presented in Fig. 4. This proposal should provide additional material strip at rotor largest diameter. This supplementary material will accompany rotor while machining, being removed at the end. On this strip can be machined a cylindrical hole, accurately executed and at precisely known distance from rotor axe (Fig. 4.a). These values, the bore position and diameter, will be used for 3D measurement of blades' profiles and for orientation of the material in fixture, when milling. Rotor rear is design without outside strip from the extremity, for increased stiffness during milling. The following equations should be considered:

$$A = D + d + 2 \tag{1}$$

$$B = d + 2 \tag{2}$$

$$e \geq h \tag{3}$$

$$Db = D + 2B \tag{4}$$

Formula 1 allows machining indexing element on the technological strip created. Normally, a 1 mm gap can be used between rotor wall and the bore extremity. Formula 2 define way to select width strip. The third formula is needed to avoid a situation that occurs in milling blades. At this operation, cutter performs blade surface including aria delimited by diameter D. If this relation does not comply, milling in the area will be done with uncontrolled additions. Formula 4 allows calculating minimum blank size diameter. For all proposed parameters, in Table 1 a number of recommendations are presented. These recommendations are made for efficient use of starting material. Usually, impellers diameters for centrifugal air compressor or for small turbo engines are below 400 mm.

Table 1

Recommendations for parameters B and d

D [mm]	B [mm]	d [mm]
< 250	6	4
250 ÷ 400	7 - 8	5 - 6

In Fig. 5 is presented another approach. Because in rotor rear side, usually, a certain quantity of material has to be removed, this area can be temporary place for an indexing element, like a cylindrical hole or a slot. The same as for the first approach, parameter A, which determine indexing element place, have to be exactly executed. Indexing element diameter and slot width used for indexing will be executed in the 7^{th} grade of accuracy. In that situation, thickness of the rotor extremity is increasing, allowing radial and central clamping at milling, in the same time. Advantage of this approach is highlighted in case of batch production, when important material quantities can be saved. In this approach, at measuring, first operation is fixture orientation relative to measuring machine, and then part in fixture.

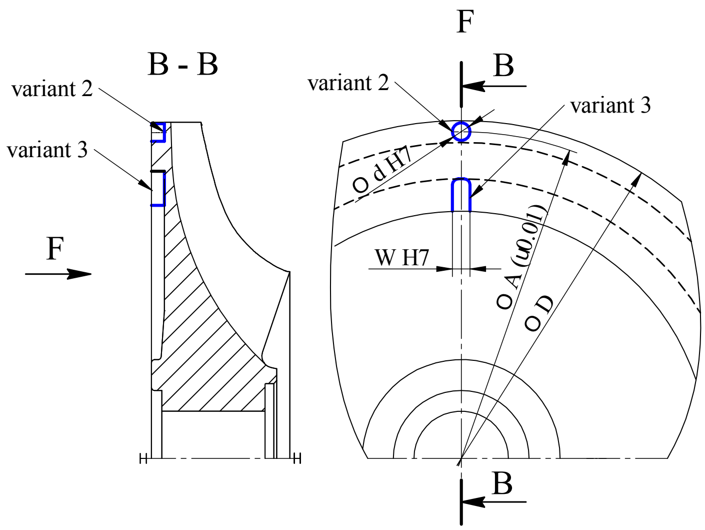


Fig. 5. Rear side used for indexing: bore based (variant 2); slot based (variant 3).

As a result of these technological changes, the geometry of the part after turning will be different. This new form will go through the rest of machining operations and measuring. Final machining will be removal of these additions, with final achievement of the outer diameter and rear surface. This operation is realised using a fixture, designed to use impeller central bore for orientation, or even driving spindle, in some cases.

4. Impeller turning process

Rotor turning operation, in prototype phase, can consume significant resources if it is not properly approached. Machines and tools available are utilised, and starting blanks are often generously sized. Obviously, main aim is to achieve the impeller as quickly as possible, with minimal cost, in required technical conditions. Some aspects can be considered:

• only one equipment for all operations or phases of operation should be used;

• minimum number of fixtures and clamps should be used;

• minimum number of toolholders and types of inserts should be used.

Impeller turning operation consists of two phases: roughing and finishing, like usually. In the following is presented a proposal of technological process in three steps, using a single appropriate CNC lathe. In these three steps a very important role is played by fixtures. In most of the cases, because they work at high speed, impellers have thin extremity. Approaches from chapter 3, are taken into account in this designed process. This technological chain can be studied in

Fig. 6. The machined surfaces are designed in blue and final contour is represented with black hidden line, before machining. First phase is rough turning at blades area (Fig. 6.a). During this operation, largest quantity of material from blank is removed. In that case, lathe chuck is recommended for fixture. Clamping is done from external diameter and must be suitable for an intense chip removing. Machining will be done until one mm stock material on profiled surfaces and rotor outer diameter is obtained. An important detail must be provided, at this phase, by process designer. For second turning phase part clamping, a technological shoulder must be provided. This shoulder is defined by parameters C and E (Fig. 6.a), and is performed on the leading edge area.

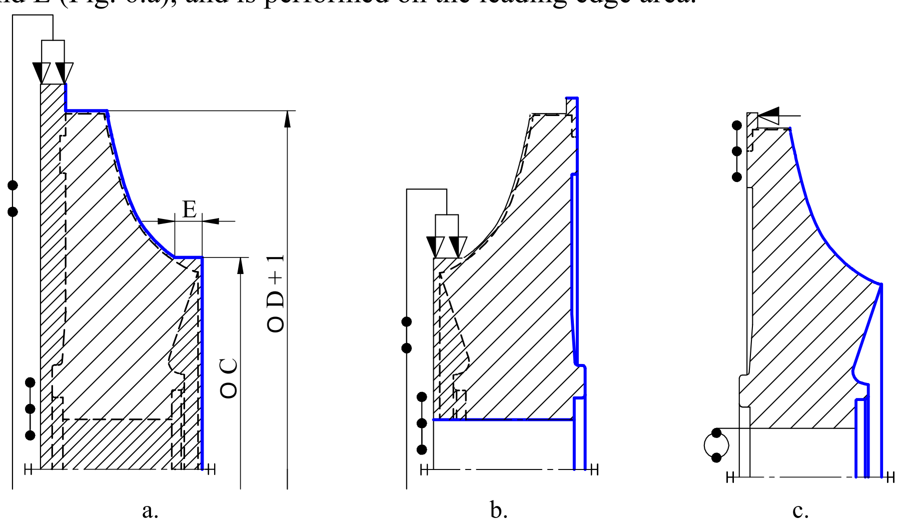


Fig. 6. Rotor turning phases: front face roughing (a); rear face roughing and finishing (b); front face finishing (c)

Material addition is introduced on 2D model utilised for final turning, on blades area. This new model will be helpful for the correct division of cuttings depth and crossings, on the CNC programs. Parameter C should be chosen depending on the impeller geometry, using appropriate software, usually 2D. In case of parameter E, dimensioning will be done according to available chuck and impeller weight. Not least, for the external diameter defined by parameter D, quality surface must allow correct piece orientation at next turning.

Second machining phase is presented in Fig. 6.b. Its purpose is to machine back part entire geometry. Part clamping will be done on the existing shoulder. For this operation is recommended to use soft jaws machined at shoulder diameter performed at last turning phase. A special attention will be given to central bore execution and to zone where is assembled the driven spindle. Accuracy execution of this area will cause appropriate circular runout of rotor in assembly. In case of an incorrect execution, this area has to be grinded, a match expensive machining.

Last turning phase is final execution of the front side surface (Fig. 6.c). Part clamping is made on special designed fixture to avoid possible rotor deformation. This device allows using central bore of impeller alternative with external strip, for fixing, when machining.

5. Unique fixture for impellers machining - a proposal

An important component in machining process is designing of a suitable fixture. In case of prototypes or small series, cost optimisation is required also for fixtures. Some conditions should be considered:

• single device for the entire process should be used;

• the possibility of fixture to be utilised on a range of parts, with similar geometries and close sizes;

• device must allow, for parts fixing, use of additional proposed strip area and impeller central bore, in the same time or alternatively, depending with operations necessities.

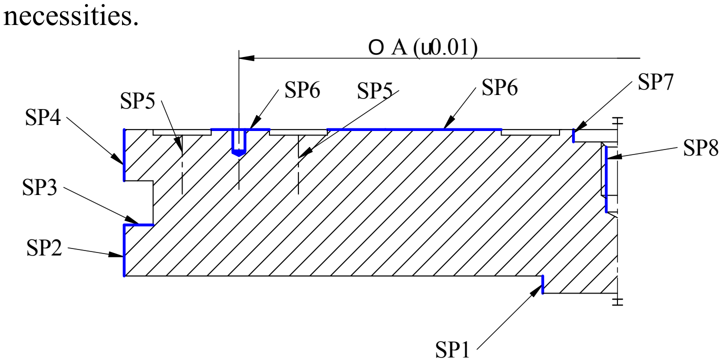


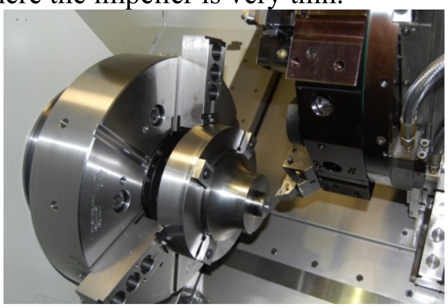
Fig. 7. Unique fixture proposal for impeller prototypes machining

First requirement involves use of device in both usually utilised machines: turning centre and milling centre. In that case, because this fixture should rotate, mandatory will be used a cylindrical shape for it. Rotary plate is the appropriate design. Second condition requires establishing impellers sizes range for fixture designing. For the case when blades milling is done on five axes milling machines equipped with rotary tables, design principles for impellers fixtures are presented in drawing from Fig. 7. Draft responds to all of stated requirements. Here, the next abbreviations are proposed:

• SP1, surface used for fixture orientation on milling centre rotary plate;
• SP2, cylindrical area used for device fixing on lathe chuck;
• SP3, area where clamps using when fixture are fixed on milling centre rotary table;
• SP4, fixture orientation surface at turning a milling;
• SP5, diameter of threated holes used for clamps;

• SP6, frontal orientation surface;
• SP7, surface for radial orientation of impeller in fixture;
• SP8, central thread for part fixing in device.

Functional role for all fixture surfaces was presented in the above. In Fig. 8a can be observed how additional strip proposed is utilised, for part fixing, when is perform contour turning operation. Clamps are utilised in this zone, clamping forces been directed to rear side, where a bigger disposal area is available. Using this direction of clamping, deformations at external rotor diameter can be avoided, where the impeller is very thin.



a.

b.

Fig. 8. Clamping of impeller using unique fixture at: turning (a); milling (b)

Similarly, supplementary material from outer impeller diameter is utilised at blades milling for solid fixing (Fig. 8.b). In that case, milling operation is performed in the best situation, between two fixing areas.

6. Conclusions

Specific aspects for impellers turning in case of small series or prototype phases were analysed in this paper. The following aspects are new and were developed herein:

• Parts such impellers for air compressor requires complete technological design even if machining in prototype phase.

• Impeller machining supposes creating two models, one specific for turning operation, with technological adaptations, and other, representing the final part, utilised for milling and measurement processes. In fact, turning model is created by CAD designer and modified from CAM engineer in accordance with technological facilities and part particularities.

• In order to avoid deformations and for part orientation during machining, some technological solutions were proposed. First approach consists in using the existing additional blank material at outer rotor diameter. Supplementary material is usually available at prototypes blanks, but it can be especially required also, if necessary. This area can be utilised for fixture and for orientation. Dimension and position of indexing hole allow blank diameter calculation. Second and third proposal is to use additional material available on rotor rear side to place geometrical elements, such bores or slots, for orientation.

• A complete definition for technological solution proposed was done. Equations presented allow calculating blank diameter, width of supplementary strip and other proposed geometric parameters.

• A technological process in three steps for turning of redesigned impeller was proposed. Sensitive points for correct machining have been described. An element of novelty is the design of a shoulder utilised for clamping when turning rear face. This technological adaptation involves blank model modifying when finishing turning is executed in blades area.

• Concept for single fixture impeller main machining, turning and milling, was proposed. This allows fixtures design for particulars impellers manufacturing cases.

Acknowledgements

This work is supported by the Sectoral Operational Programme Human Resources Development (SOP HRD), financed from the European Social Fund and the Romanian Government under the contract number POSDRU/159/1.5/S/ 138963 for Ion CIOCAN.

Thanks for support of National Research and Development Institute for Gas Turbine Comoti, The Technological Research Department.

R E F E R E N C E S

[1]. D*unca G., Muntean S., Isbăşoiu E.C.,* 3D Numerical Analysis of the Impeller – Stator Interaction Into a Storage Pump, U.P.B. Sci. Bull., Series D, **vol. 72**, Iss. 1, 2010.

[2]. *Stanciu V., Popovici E.*, Centrifugal Compressors Surge Simulation, U.P.B. Sci. Bull., Series D, **vol. 75**, Iss. 3, 2013.

[3]. *Ionescu S., Silivestru V., Enescu N., Magheti I., Ionescu A.,* Experimental approaches to reduce noise at source for a centrifugal compressor, U.P.B. Sci. Bull., Series D, **vol. 73**, Iss. 3, 2011.

[4]. *Ciocan I., Iliescu D.*, Optimal Inserts for Profiled Turning of Impellers, Applied Mechanics and Materials **vol. 760** (2015) pp 373-378.

[5]. *Calleja A., Fernandez A., Campa F.J., Lamikiz A., Lopez de Lacalle L.N.,* Reliable manufacturing process in turbine blisks and compressors, Procedia Engineering 63, pp. 60-66, Elsevier Ltd., 2013.

[6]. *Diciuc V.,* Tribosistemul de aşchiere cu freză cu cap sferic (Cutting tribology system of cylindrical end mill cutter), PhD thesis, North University from Baia Mare, 2010.

[7]. *Cosma M.,* Cercetări privind procesul de detaşare a aşchiei şi aspecte tribologice la frezarea în trei axe cu freze cilindro - frontale cu cap sferic (Research on the chip detachment and tribological aspects on milling in three axes with cylindrical ball end mill cutter), PhD. thesis, Baia Mare North University, 2007.

[8]. *Hao Y., Tang G., Zhang M.*, Calculation method of milling contact area for ball-end milling tool with tool inclination angle, U.P.B. Sci. Bull., Series D, **vol. 76**, Iss. 3, 2014.

[9]. *Tang M., Zhang D., Luo M., Wu B*., Tool Path Generation for Clean-up machining of Impeller by Point-searching Based Method, Chinese Journal of Aeronautics 25, pp. 131-136, 2012.

[10]. *Ciocan I., Datcu D., Gheorghe M.,* Basic Conditions for 5-Axis Milling of Impeller Specific Surfaces, Applied Mechanics and Materials **vol. 760** (2015) pp 367-372.