CONVERSION OF THE BLADE GEOMETRICAL DATA FROM POINTS CLOUD TO THE PARAMETRIC FORMAT FOR OPTIMIZATION PROBLEMS

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ABSTRACT

The issues of the blade geometry transformation are considered. The blade is traditionally defined as a set of points at several cross-sections, conversion to a parametric form is necessary for automated optimization problems solution. The method of the blade profile points harmonized displacement at its deformation within the optimization problem and the method of the profile parameters coherent change according to the blade profile height. The algorithm of the specified discretely analytic profile representation without the loss of accuracy is described.

Keywords: blade, three-dimensional model, parameterization, Bezier spline, blade corrugation and smoothness.

INTRODUCTION

Currently, the development of compressors, aircraft engine turbines and power plants with the best parameters is impossible without the optimization problems solution for impeller machines. Relatively recently the technologies of numerical simulation and optimization appear, allowing to solve such problems at the stage of design by the methods based on the repeatable solution of the direct problem [1, 2], which is to evaluate the gas-dynamic perfection of blade row at the given values of such geometrical parameters as the design (blade) angles on impeller at inlet and outlet, the installation angle, the maximum thickness of the profile and other parameters. However, the automation of this direct problem solution requires a formalized blade row representation in the form of parametric computer models [3]. Nowadays, there are several ways to represent the blade geometry [4]:

a) the set (cloud) of points which are usually grouped by sections that describe discretely three-dimensional blade surface;
b) CAD-model with the imposed constraints;
c) software algorithm that implements profiling.

The second and third methods are initially parametric ones unlike the first method that responds poorly to parameterization. Nevertheless, the way of the blade geometry representation in the form of a point cloud is widespread at manufacturing plants, as the production processes and the turbomachinery control are related to such processes. The above stated facts confirm the relevance of the following tasks:

- The development of the agreed method for the blade profile movement during its deformation within the framework of the optimization problem (see Figure-1).
- The development of the agreed change method for profile settings along the blade height;
- The number of parameters reduction involved in optimization and describing the blade in detail.

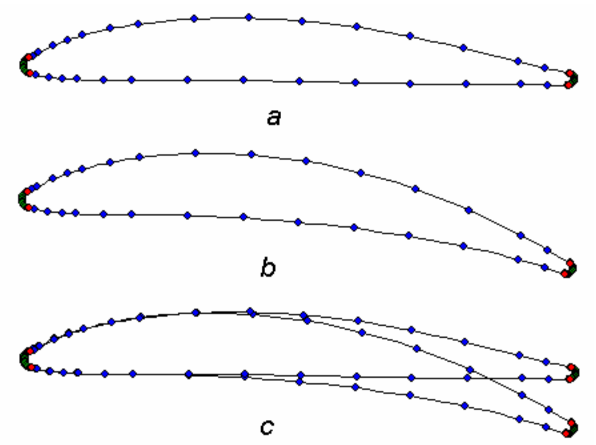


Figure-1. Coordinated movement of points describing the profile at the change of its parameter - trailing edge (TE) angle:
a - TE angle is 8°; b - TE angle is 28°; c - profiles comparison

Method of blade profile points agreed displacement.

Since the profiles of most compressor blades are formed from a symmetric profile by the way of its imposition on the middle line, given parametrically, the most obvious way of the compressor blade change is the reshaping with the midline use. The midline profiling for turbine blades is rarely used, but this method of reshaping may also be applied. It includes three stages.

Stage-1: "Profile removal" - it implements the procedure inverse to profiling: according to the known coordinates of the back and the pressure side points the midline and symmetrical profile (the problem of the so-called reverse-engineering) is formed. The problem solution of the first stage is described in [5].

Stage-2: "Profile bend", which changes the midline and symmetrical profile parameters: the blade angles, the installation angle, the maximum thickness of profile and others. The change of the installation angle profile is an easy task, which is solved by an affine transformation of the suction, pressure side and the midline coordinates of the profile. The blade angles change at the inlet and (or) the outlet of the impeller results in the blade profiles bending. The curving the blade profile with a set of point coordinates for this section is only possible in the process of re-profiling (see. Figure-1).

Stage-3: "Profile assembly" during which the profile with new parameters is formed. This stage is a standard one and it implements the widespread profiling algorithm.

The solution of the second stage problem is a difficult one, because it is not always possible to find analytical equations in reverse engineering results manages to find the analytical equations used in the initial profiling and binding the midline and symmetrical profile coordinates with the geometric parameters. The profile description remains a discrete one. The issue of the profile suction and the pressure sides coordinated movement with an automated way remains unsolved.

The discrecity of the middle line representation assumes its description as a finite set of point coordinates, rather than an analytical expression (see Figure-2).

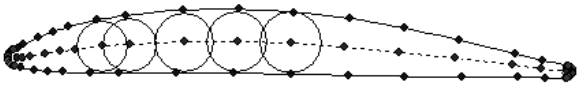


Figure-2. Midline description with a set of points, equally distant from the suction and the pressure side.

This problem may be solved by the midline points approximation with an analytic expression. In this case, the curve described by this expression, is located closely to the midline, but it replaces the midline with only at the loss of accuracy. It is fraught with the profile distortion for the assembly during the third stage. The use of high order approximating functions may result in a wavy curve, which also results in the initial profile deformation (see Figure-3).

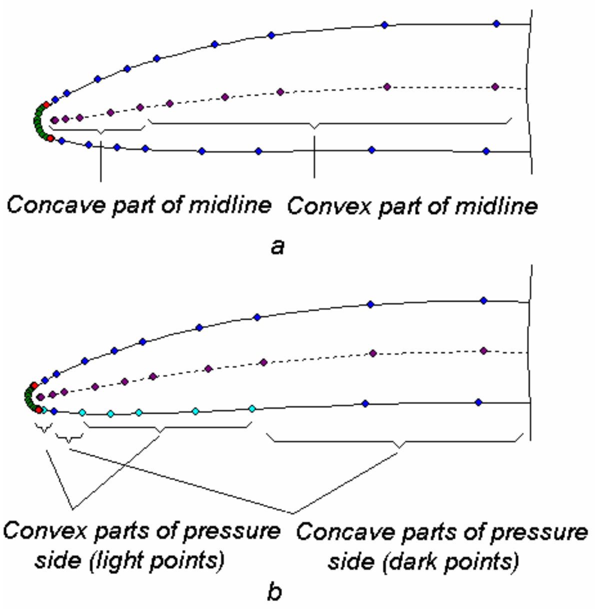


Figure-3. Profile deformation using a wavy midline:
a - initial profile with a wavy middle line;
b - new profile with wavy line of the pressure side

The midline replacement by the low-order analytical curve (Bezier spline of 2-3 order) is proposed to prevent the profile distortion. This curve has the known parameters and exludes corrugation in a sure way. This line, generally speaking, is not the middle line of the profile and does not match with it and is called as the "base line" by the authors. The profile countour pointes are located relative to the baseline in an asymmetric manner, individually for the back and the pressure side.

The iteration algorithm allows carrying out the normals from the profile contour points to the baseline described by spline to find the base of each normal and its length. The following algorithm procedure is carried out for each spline point of the back and the pressure side.

Step-I: The normal is recovered from an arbitrary point (middle) of the baseline spline and naturally does not pass through the profile contour point.

Step-II: The distance (see Figure-4) from this point to the normal is determined, and the normal base moves along the spline within this distance. The normal recovered from the new position position is closer to the considered point, but usually it also does not pass through it due to the base line bending.

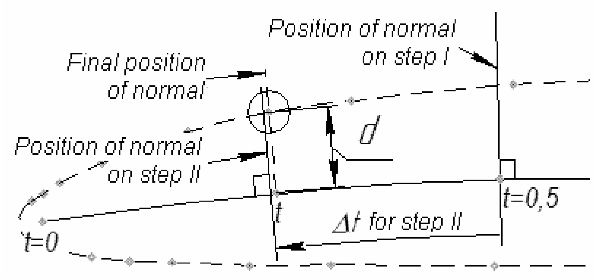


Figure-4. The search of the baseline position “t” and the length “d” of the normal drawn to the baseline through a pressure profile point.

By repeating several shifts (step II) the position of the base normal is determined. At this position the normal is passed through the point with the sufficient accuracy. This coordinate of the normal t base (see. Figure-4) is defined in a dimensionless form with respect to the spline length at its one-dimensional space.

Step-III: The distance from the contour to the baseline is calculated - the normal length d, which is also defined in dimensionless form relative to the profile chord. The profile specified via the baseline and the normals is called by the authors as 'normal' one. The information about the normal profile includes:

- Spline parameters describing the profile baseline;
- Relative coordinates of the normal bases;
- Relative lengths of the normals.

This information is an analytical description of the profile specified discretely without the accuracy loss. It is an analytical description of the baseline that allows you to bend the profile at the second stage of profiling at the gradual change of its parameters (see Figure-5).

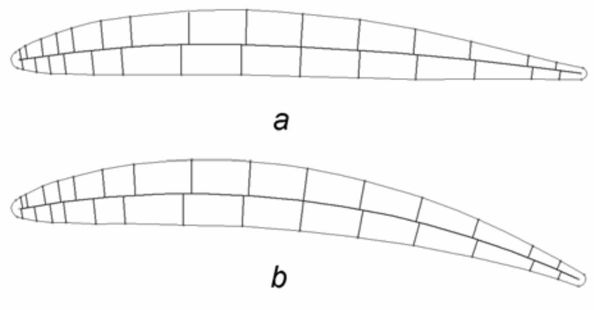


Figure-5. Example of the trailing edge angle changing for profile shown on Figure-1, by bending its baseline at 20°:
a - normal profile with the trailing angle of 8°;
b - normal profile with the trailing angle of 28°

The authors have tested several methods of the baseline bending.

The most obvious is the direction change of the tangent to the spline at the end points (see Figure-6). The advantage of this method is that the blade angles may be set directly by changing the angles between the profile tangents and the chord. The drawback of the method is its low variability, as only two parameters are variable ones, which is not enough for an exhaustive description of the baseline possible variations. For example, the Figure-7 shows several different baselines with the same angles of the tangent inclination to the profile chord.

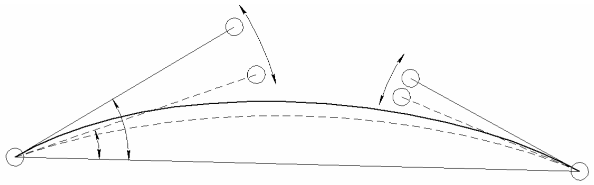


Figure-6. Baseline spline deformation by changing the direction of tangents for spline end points.

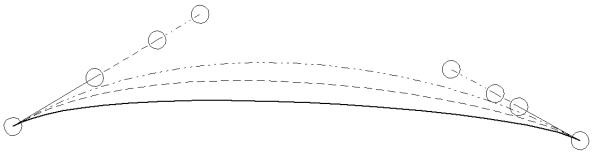


Figure-7. Baseline variability at the constancy of angles between chord and tangents to the profile at input (leading edge) and output (trailing edge).

The second way is the movement of the spline control points. This way is devoid of this shortcoming (see Figure-8), because it allows to set all sorts of the spline baseline shape variations. The disadvantage of this method is that the blade parameters dependence on the reference point coordinates is an implicit one, but at the solution of the optimization problem by direct enumeration method this disadvantage may not be considered.

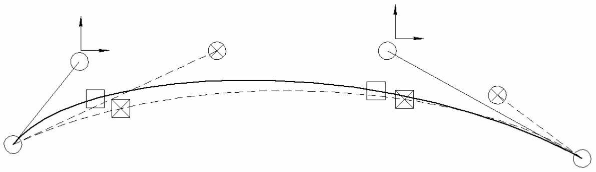


Figure-8. Spline baseline deformation by moving the reference (○) or knot (□) points
(sign “×” marks the new positions of the corresponding points)

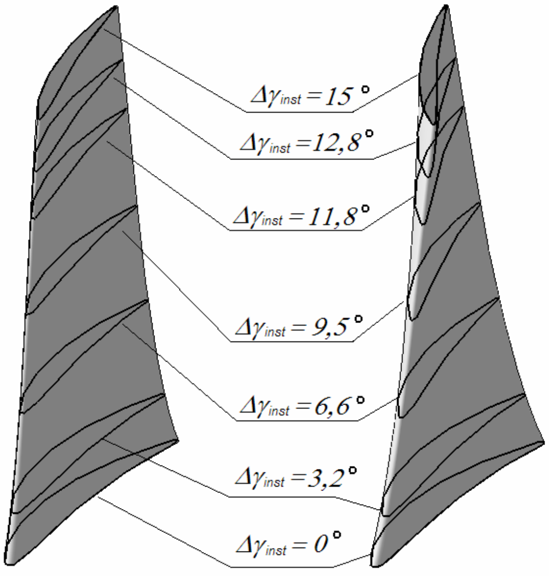
The baseline bending development by the second method is the movement of the knot spline points, not the reference ones (see. Figure-8). The knot and reference points are always moved in unison, but the use of the knot points is more clear, since the movements of the knot points and the baseline shifts associated with these movements always occurs at the distance of one and the same order.

The program PROFILER [6] implements all three methods; however, the third method of the baseline change is often used in practice.

Method of blade profile settings agreed adjustment by height

The change of a single profile setting is not a self-sufficient task, since the surface of the blade is described by a bunch of profiles, spaced by diameter. At that it is important that approximating surface of the blade, spanned on the profiles, is a smooth one.

Typically, the blade surface to be optimized is a smooth one already. Therefore, changing the profile parameters, you need to change consistently the parameters of the adjoining profiles. The basic cross section profiles on the stub, peripheral and the average diameter are accepted as the varied profiles. The change of parameters for these sections is set by users or an optimizing program; the values of similar parameter changes are calculated in the intermediate sections so as to ensure their uniformity and, thus, keep the smooth surface (see Figure-9).



a b

Figure-9. Keeping the smooth surface of the blade with a monotonic changing of the installation angles γ_{inst} for the profiles in different sections of the blade height:
a - the original blade; b - the blade "twisted" in the middle and peripheral sections on 9,5° and 15°, respectively.

Figure-10 depicts a graph, the vertical axis of which represents the cross section radius, the x-axis represents the variable parameter increment. By combining the basic points with an interpolating Bezier spline of the second order one may obtain an analytical dependence of the variable parameter increment on the radius. According to the graph the parameter values are determined within the required intermediate sections.

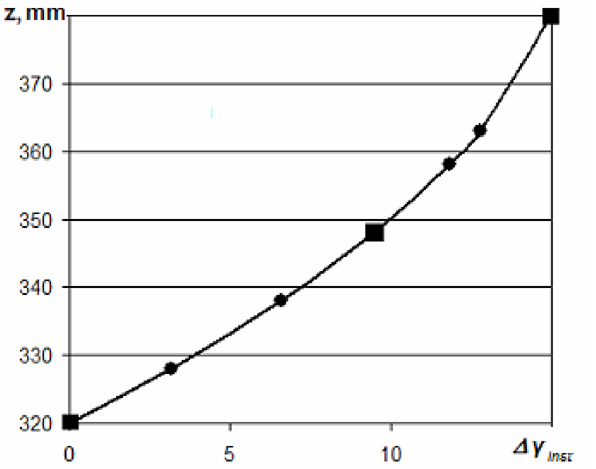


Figure-10. The variation of parameter γ_{inst} changing by the blade height:
■ - specified values in the hub, middle and peripheral sections;
● - values determined for other sections

Parameter number decrease participating in optimization

During the optimization problem solution by direct enumeration method the controlled mechanism for the geometry change is required. In the traditional view of the blade its geometry is given by the coordinates of its suction, pressure side points, the input and output edges parameters in each section. At that the total number of independent parameters is estimated approximately as (two coordinates) × (number of profile points) × (number of sections) and makes a few hundreds, from three hundred to a thousand or more, depending on the number of sections and points in each section used for the blade description. The optimization problem of such an incredibly large number of parameters can not be implemented at the present level of computing technology and optimization algorithms development. At the description of the baseline profiles with third order splines (4 nodes) the number of independent parameters is estimated approximately as (2 coordinates) × (4 spline nodes) × (3 sections) = 24 parameters, and not all of them will be varied in terms of the particular task. Such a number of parameters is quite acceptable for the optimization problem formulation and solution.

Thus, in the course of solving the tasks of an agreed movement of the blade profile points during its deformation within the optimization problem and the development of a coherent profile parameters change by height one managed to move from the traditional view of the blade in the form of a points cloud to a parametric form. An additional result of this parameterization was a sharp decrease in the number of parameters that control the blade geometry. The parametric description of the blade with a small number of variable parameters (within a few tens) allows you to set and successfully solve the optimization problems of turbomachines.

ACKNOWLEDGEMENTS

This work was financially supported by the Russian Federation Government (Ministry of Education) on the basis of the the Russian Federation Government Resolution №218 issued on 09.04.2010.

This work was supported by the Ministry of education and science of the Russian Federation in the framework of the implementation of the Program of increasing the competitiveness of SSAU among the world's leading scientific and educational centers for 2013-2020 years.

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