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DIMENSION CONTROL AND MEASUREMENT OF TURBINE BLADES BY OPTICAL 3D SCANNER

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Abstract: *The paper analyzes dimension control and measurement of turbine blades by optical 3D scanner and software for inspection and control of 3D scanned objects. Turbine blade is one of the most important parts of turbine machinery, and the characteristic parameters, pressure ratio of the engine and rotating speed of the turbine are related to the shape and size of the blades. Therefore, profile measurement of a turbine blade is an essential issue during manufacturing process of the blade. However, determination of profile of turbine blades is complex task because of their complicated shape. Using 3D optical scanner and software for scanning and inspection, it is possible to perform quick and accurate measurement of dimensions in various segments and sections of a turbine blade. Basic precondition for successful inspection and control is appropriate orientation of a measured object with respect to the coordinate axis, which has important consequences for proper implementation of the dimension control process. This paper presents various methodologies for alignment of CAD model and 3D scan of a blade, and discusses measurement errors and uncertainties arising from those alignments. A method of alignment by application of auxiliary elements proved to provide the most stable results.*

INTRODUCTION

Turbine blade represents the part of a turbine that carries out its functionality. The effectiveness, durability and reliability of a turbine, as the most important characteristics of the turbine are dominantly determined by the shape and the material of blades [1][2]. The shape of turbine blades is complex, which represents a considerable challenge for manufacturing and quality control. Numerous methods are applied in order to define and realize efficient, reliable and accurate measurement of blade dimensions [3]. Optical methods of measurement represent one of the most suitable choices for measurement of complex shapes, which is used for similar purposes for more than 20 years [4]. The high accuracy of optical methods and the possibility of automation of measurement process make them also very intriguing choice for quality control in production engineering [5], although they are used in wide area of applications [6] [7].

Three-dimensional (3D) scanning is technology for digitalization of space coordinates of points, which is frequently used for creation of computer models of 3D objects. The technology is in expansion and is used for several important applications in engineering such as reverse engineering, structural analysis and quality control [8]. Due to the complexity of blade shape, the technology is becoming preferable choice for quality control [9][10][11] of blades, but also in static and dynamic structural analysis of behaviour of blades and turbines [12]. The most important feature of application of 3D scanning for dimension control is possibility to compare the digitized model of real object to the CAD model developed by the designer in the phase of design. In this way, a point-to-point comparison between the models is performed, providing comprehensive presentation of deviations in the form of a deviation field, which provides detailed insight into deviations of the manufactured object in comparison to the designed model.

The most important problems in quality control of blade dimensions are how to define the dimension that is to be checked and how to implement the inspection process. The complexity of the shape and function of a blade require close collaboration between the designer, the manufacturing engineers and quality control engineers in order to provide that the results of the inspection process reflect ability of a blade to perform its function in a proper manner. For that reason, 3D scanning appears to be preferable choice for dimension control of blades, because it simplifies the concept of comparison between the intention of a designer (CAD model) and the manufactured blade (3D scan).

This paper presents a case study of dimension inspection process of an industrial blade using a 3D scanner. The research was initiated by needs of a manufacturer to test various methods for dimension control, and 3D scanning was just one of analyzed methods. In the process of development of dimension control procedure, it turned out that the most difficult problem is not digitalization of the real object or calculation of the dimensions, but the implementation of the process of comparison between the CAD model and 3D scan. The paper presents several possible methods to compare the models and results that are obtained.

METHOD

A 3D scan of an object may be compared to a CAD model of the same object in several ways, depending on the criteria for alignment of the models. In the process of alignment, points of one model are attributed to the respective points of the other model. Methods for alignment of the models may be divided to:

- methods that are based on reduction of deviation between the models,
- methods that are based on definition of common features of the models.

Basic method that reduces the deviation between a CAD model and the respective 3D scan is best-fit alignment of models. This method minimizes the overall difference between the models, but does not include specific nature of an object. By this method may be compared arbitrary shapes, which even do not have to have the same features, like various polygons (Fig. 1).

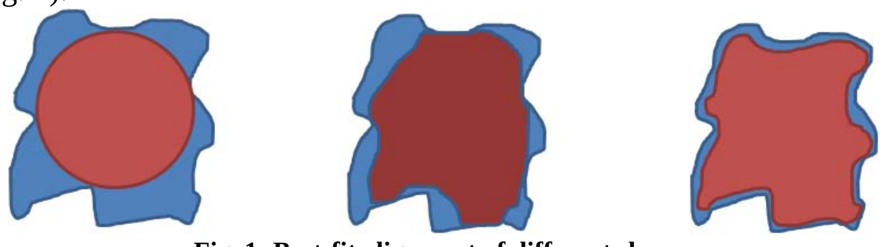

Fig. 1: Best-fit alignment of different shapes

Therefore, the results of comparisons by the methods based on best-fit alignment between the objects may not have any physical or engineering meaning. An extension of the best-fit method is local best-fit method, which fits just selected parts of the models.

Methods of alignment that are based on definition of common features are based on selection of features of both models that should coincide, and further alignment of the models with intention to reduce the deviation between the selected features, while the remaining parts of the models are not considered in the alignment process. Depending on the features of the object that are coincided, several alignment methods based on definition of common features of models exist:

- alignment with three points (3P method), when three points of a model are brought to coincidence with the respective three points of the other model; the method has unique results, but it implies that some points on the real object do not deviate from the CAD model; from the point of view of mechanical engineering, such an assumption is never satisfied, and its adoption is rarely useful;
- alignment of the coordinate axis (3-2-1 method), when the coordinate axis of the two computer models coincide; while the usefulness of the method is obvious, the problem of alignment of the models is transformed into problem of determination of orientation of the 3D scan with respect to the adopted coordinate system;
- alignment by systems of reference points (RPS method), where some features of both models are constructed and then coincided; for example, a minimal sphere containing each of the models is constructed, and in the process of alignment of models are coincided the centres of the spheres. The systems of reference points are usually more complicated, and they include construction of more complex features that are characteristic for the function of the inspected object.

The object of the case study was an industrial blade that was scanned by 3D scanner "ATOS Compact Scan 5M" manufactured by German manufacturer GOM. The scanner has two cameras with resolution of 5 Mpixels and a projector with the blue light. The measurement volume has dimensions 150x110x150 mm with distance between points equal to 0.062 mm. The obtained 3D scans were compared to CAD model of the blade using software package "ATOS Professional".

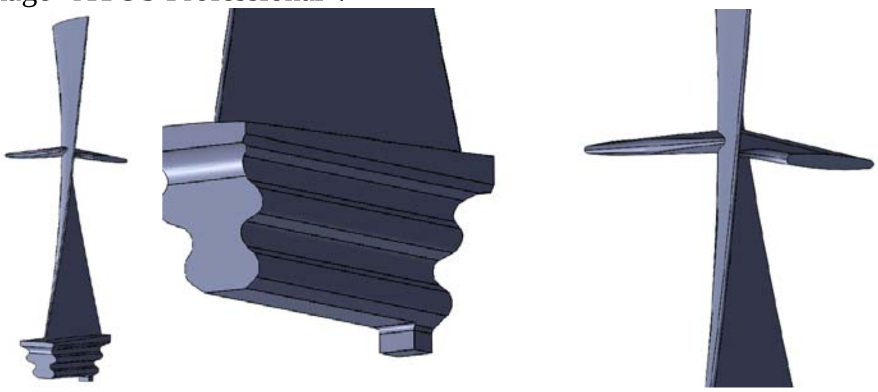

Fig. 2: The body of the blade, the root with the limiter and the snubber

The industrial blade (Fig. 2-left) consists of the root and the body of the blade. The root of the blade is used for mounting of the blade and bears a limiter (Fig. 2-middle), which defines position of a blade in the turbine. The body of the blade, which is twisted, carries snubber (Fig. 2-right), which suppresses vibrations during operation. The critical part of the blade is the root of the blade and especially the limiter, because they influence positioning of a blade in the turbine assembly.

In the studied case, six different methods of alignment were used:

- Best-fit,
- three RPS with alignment of points on the root of the blade, and
- two RPS with alignment of root by an inscribed cylinder and a point on the top of the body of the blade.

RESULTS AND ANALYSIS

The first applied method for alignment is the best-fit method. The deviation fields of the CAD model and the scanned model when they are aligned by best-fit method is shown in the Fig. 3.

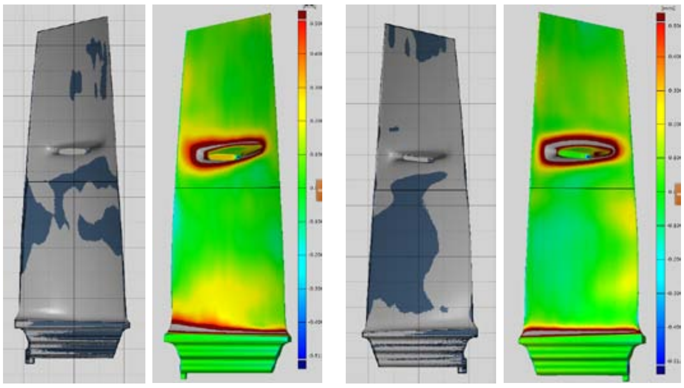

Fig. 3: Best-fit alignment and the respective deviation fields

In that and the following figures, the CAD model is presented with dark points and 3D scan is presented with the light points. The deviation fields present uniformly distributed deviations that vary between -0.15 mm and +0.15 mm. The highest deviations show the points at the body that are close to the root of the blade. This part of the blade is manufactured with the rounded shape, while the CAD model is drawn as flat in that area, because the part of the body close to the root of the blade has no any relevance for functionality of the part. The example shows why the best-fit alignment method is not useful for dimension control of mechanical parts.

RPS with alignment of the points at the root of the blade was made with intention to check that part of the blade, which is critical for the blade as a part of the turbine assembly. For that reason, the deviations of the points at the root are more critical for the ability of a blade to be mounted, and three alignments of the root were checked, each using six points for definition of RPS:

- three points on the bottom of the root, two points on the left side of the root, and one point on the front side of the root;
- similar to the previous case with the exceptions of two points which were taken on the right side instead on the left side of the root;
- all six points were taken on the limiter, defining its lower, left and front side

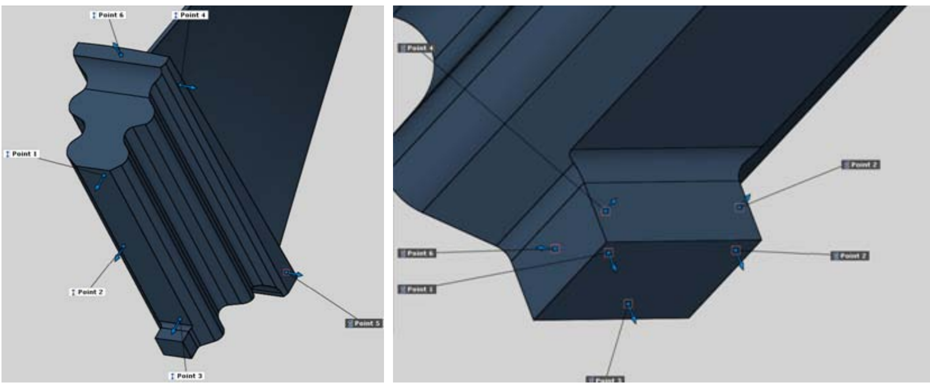

Fig. 4: RPS alignment with points on the root of the blade

The deviations of the object with respect to the CAD model are highest at the top of the blade body, which is illustrated in the Fig. 5 for all the three cases, respectively. The deviations clearly illustrate the fact that the reduction of the deviations at the root of the blade lead to the increase of the deviations in the farthest points, i.e. in the points at the top of the blade. The figures also illustrate the instability of the results, which clearly depend on selection of the points at the root of the blade. Any change of the selected points for definition of RPS leads to significant differences between the results of inspection.

The reason for such behaviour lies in the fact that the root of the blade represents ending part of the blade, and is small in comparison with dimensions of the blade. Therefore, a small deviations of the selected points at the root lead to large changes of positions of points at the opposite part of the blade, i.e. at the top of the body.

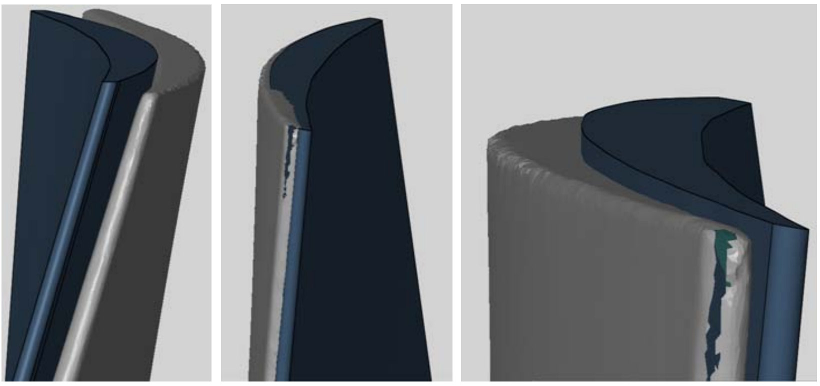

Fig. 5: The deviation of the top of the blade body using RPS alignment with points on the root of the blade

With the aim to obtain the results, which are even more relevant for the assembling of turbines, RPS is defined by construction of the elements that inherently describe fitting of a blade into the assembly of the turbine, but also including points close to the top of the body of the blade. For that sake, two RPS are defined (Fig. 6):

- the first consisted of a cylinder that was fitted to the middle sliding surface of the root and a mid-point of the top of the body of the blade;
- the second consisted of the same cylinder and an end-point of the top of the body of the blade;

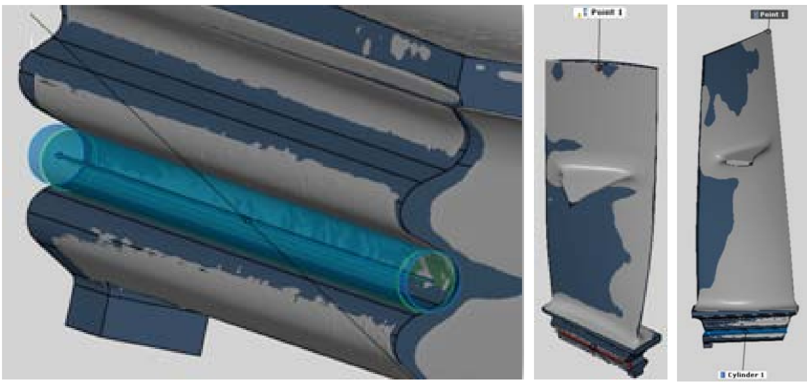

Fig. 6: RPS alignment with a cylinder at the root and a point at the top of the blade

The results show that the deviations at the top of the blade are significantly reduced (Fig. 7) and do not depend much on the choice of the point at the top of the blade, as it was intended. The highest deviations appear at the front and back sides of the root, which were not defined by the selection of the RPS.

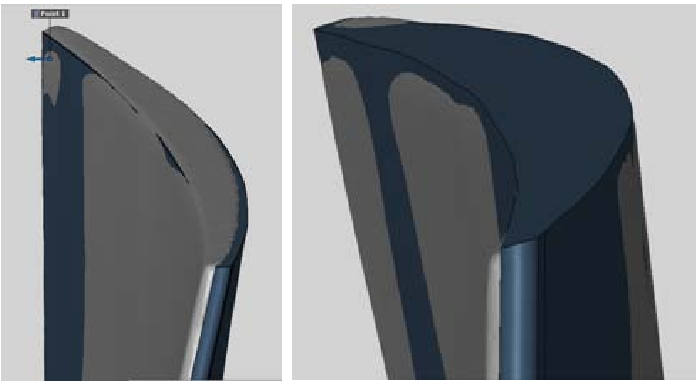

Fig. 7: The deviation of the top of the blade body using RPS alignment with a cylinder at the root and a point at the top of the blade

CONCLUSION

The paper presents an analysis of various possibilities for alignment of the 3D scan of an industrial blade and its CAD model. The possibilities included best-fit alignment, RPS with points at critical part of the blade, and an RPS that included surface close to the critical part, but also a distant point at the opposite side of the blade.

The analysis have shown that the best-fit model is not reliable method for quality control of turbine blades, because, due to the limitations of manufacturing technology, the actual shape of a blade may considerably vary in comparison to the designed model at parts which are not relevant for the functionality of the blade. Therefore, a best-fit of a 3D scan to the CAD model may include points, lines and surface that are not manufactured to fit the shape of the designed model, further leading to unreliable results, which unfavourably present the deviations of the object with respect to the CAD model at critical parts of a blade.

The analysis of various RPS have shown that selection of reference points at critical parts may also lead to unreliable results, because selection of the RPS points on a critical part may lead to unstable results due to proximity of points if the critical part is small in comparison to the whole object.

As the most stable and adequate alignment system arises RPS system that includes surfaces at critical parts and a distant point. However, the selection may lead to large deviations at parts, which are not defined by the used RPS.

Summarizing the previous conclusions, the authors propose application of a quality control system that closely emulates behaviour of a blade in the turbine assembly. It may be achieved by using additional turbine parts, which would enable establishment of a stable and accurate RPS. The most obvious choice is to use the turbine parts, which are used for connection of the blade to the turbine.

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КОНТРОЛ НА РАЗМЕРИТЕ И ИЗМЕРВАНЕ НА ТУРБИННИ ЛОПАТКИ ЧРЕЗ ОПТИЧЕН 3D СКЕНЕР

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Ключови думи: *Контрол на качеството, измерване на размерите, 3D сканиране*

Резюме: *Статията прави анализ над контрола на размерите и измерване на лопатките на турбината чрез оптичен 3D скенер и софтуер за проверка и контрол на 3D сканирани обекти. Турбинната лопатка е една от най-важните части на турбината и характерните параметри, съотношението на налягането в двигателя и скоростта на въртене на турбината са свързани с формата и размера на лопатките. Следователно, измерването на профила на турбинната лопатка е ключов момент в производството на лопатката. Определянето на профила на турбинните лопатки е трудна задача, заради тяхната сложна форма. Бързото и точно измерване на размерите в различни сегмети и сечения на лопатката на турбината е възможно да се направи, използвайки 3D оптичен скенер и софтуер за сканиране и проверка. Основна предпоставка за успешната проверка и контрол е подходящата ориентация на измервания обект спрямо координатната ос, което има важни последствия за правилното изпълнение на процеса. Статията представя различни методологии за подравняване на CAD модела и 3D сканираната лопатка и разглежда възможните грешки при измерването, породени от подравняването. Метод на подравняване чрез прилагане на допълнителни елементи осигурява най-стабилните резултати.*