# Measuring deformations of the fan blade by optical methods

*Vít* Horáček[1,2*], *Vitalij* Yanovych[1,3], *Filip* Bastl[1]

[1]University of West Bohemia, Faculty of Mechanical Engineering, Department of Power System Engineering, Univerzitní 2732/8, 301 00 Pilsen, Czech Republic

[2]Department of Noise and Vibration, Research and Testing Institute Plzen Ltd., Tylova 1581/46, 301 00 Pilsen, Czech Republic

[3]Department of Fluid Dynamics, Institute of Thermomechanics, Czech Academy of Sciences, Dolejškova 5, 182 00, Prague, Czech Republic.

**Abstract.** Across industries, the demand for the ability to analyze components in operation and make decisions on repair based on the data obtained is growing rapidly. There is the potential to ensure safer operations while saving the cost of unnecessary new parts. A quick and relatively inexpensive method is a 3D scanner - the device that can scan a real component and create an accurate 3D model. For stationary cases - inspecting parts or assemblies - these are already established methods. In contrast, measurement of vibrations and deformations in operation is still not widespread and for turbomachinery, it can be a new direction of development.

## 1 Introduction

Currently, there are not many ways to easily observe deformations on turbomachines in operation. It is possible to simulate the task, but a simulation requires a largely idealized model, which may not correspond to reality at all. There are some necessary simplifications in mesh and the model does not include operational wear. Currently, there are various 3D scanning methods have been used to find out the real condition of equipment, which are able to provide a fairly detailed model of the real component. The output can be various comparisons with the original geometry or with scans from previous years. Based on these scans is possible to make numerical analysis with "real" blades. There is still the major limitation that the scanned parts have to be decomposed and it is required to create the mesh. But this step necessarily introduces inaccuracies into the analysis due to the need for the mesh appropriate to computational possibilities. One possibility to solve the problem of blade deformation in real operation is to use a dynamic 3d scanner - a device that is still not widely used compared to "classical" scanners, but theoretically meets all the prerequisites to give good results in certain situations. The advantages of modern 3D scanners include actively

* Corresponding author: vhoracek@kke.zcu.cz

monitoring the studied parameters of scanning models. This feature is most critical for analyzing the behavior of various machine parts in the dynamics and development of their automation systems [1].

It is clear that turbomachines are an integral part of today's energy industry. Therefore, many scientific institutions and researchers have devoted their attention to the research and improvement of these constructions. It should be noted that the behavior of turbulent flow is one of the key issues in these studies. A specialized laboratory was based at the Department of Power System Engineering of the University of West Bohemia to study the topology of turbulent flow. Its work provides by modern measuring equipment and technics. Among them are various high-precision pressure sensors [2], optical measuring systems (Particle Image Velocimetry) [3], and a technique for the measurement of turbulence (Constant Temperature Anemometry) [4]. The laboratory also includes a wind tunnel characterized by high-laminar flow [5].

This tunnel is popularly used to study various aerodynamic phenomena. Their design significantly influences the quality of the created airflow. During the flow generation, the construction parts of the wind tunnel get deformed due to pressure variations. This phenomenon significantly complicates the creation of high-level laminar flow and worsens the results of experimental studies. Therefore, we used the ARAMIS optical measuring system to study this phenomenon [6, 7]. At the University of West Bohemia, we have a dynamic scanner GOM ARAMIS. It is a device made mainly for industrial use, i.e. for deformation checks of structures and constructions [8-10], beams, or in the field of biomechanics. Our desired use for turbomachines, where deformations are mainly due to the combined action of the flow medium and centrifugal forces, is not typical and has not been applied frequently. One experiment carried out with this apparatus on turbomachinery was the measurement of the vibration of a wind turbine tower [11], but here, according to the available record, they only monitor the motion of points located on a "stable" tower. Measurements on turbine blades are also mentioned by the manufacturer of the ARAMIS system on its website, but this is a measurement of vibrations on a removed blade, excited by hammer blows [12].

# 2 Methods and equipment

## 2.1 GOM ARAMIS stereo system

The GOM ARAMIS is a smart solution for determinating deformations by measuring displacements of the measured object. These measured values are observed on the prepared surface. There are two options, for how to prepare the surface for measuring – use reference points or create a stochastic pattern. Stochastic patterns are created by spraying drops on the surface and are suitable for vast objects. Reference points are easier and require only glueing reference points in the area of interest. Both methods depend on the contrast between observed objects (points or drops) and surroundings, the choice between them is based on the specific properties of the measured object. Usually depends on a shape, size, or color of the object – for a variegated object is better to use reference points.

The main components of the GOM ARAMIS system are a 3D camera with a controller, situated on a moveable stand. The ARAMIS Camera is built as a stereo system that can take two pictures from cameras deployed on a frame. There are several sizes of frames, whose choice depends on the volume of the measured object. Based on photoshoots from the camera is possible to determine very accurate coordinates of reference points or stochastic patterns. The acquisition of measured data is managed by the controller, which is responsible for controlling lightning the scene too. Ideal illumination of the measured object is one of the most important conditions and at the same time for this experiment extremely complicated problem. Originally as the accessories, there are two kinds of lights – tracking spots for bigger frames and light projector for the smaller ones. Both lights use narrow-band blue LED light.

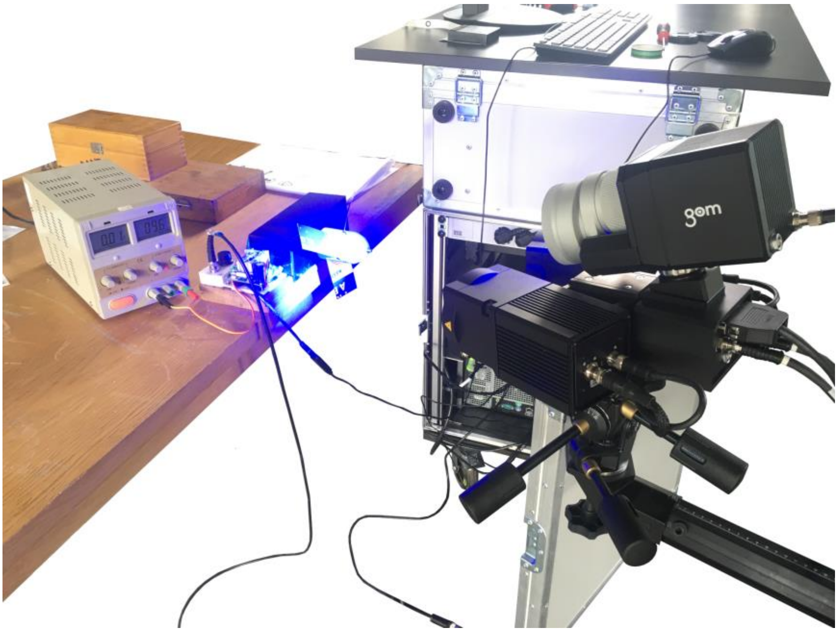


**Fig. 1.** The ARAMIS camera with light projector focused on the measured fan.

## 2.2 Method and equipment

This experiment is performed as an initial before measuring deformations of blades on real turbines, so there were used some assumptions and specific properties. In the experiment was use a homemade fan with paper blades. For this choice, there were several reasons, but the main was the quantity of deformation. Factory fan had blades from plastic with high rigidity, as was tried, deformations of the blade from classic office fan were almost negligible. This property is important for use but not very suitable for the initial experiment. The goal of our effort was to create a small and simple fan where We need only low speed however with easily observed deformations of the blades. The emphasis was focused on simplicity. Most components were designed in CAD and printed from the PLA filament, electric parts are purchased as pre-made modules and assembled into a simple adjustable fan with very elastic blades.

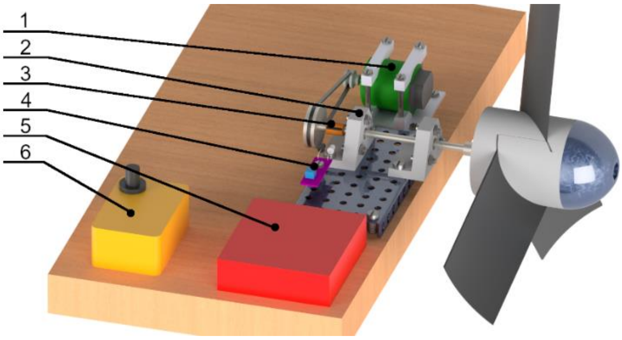


**Fig. 2.** 3D model with marked main parts: 1 – DC motor, 2 – Bearing hose, 3 – contrast element, 4 – phototransisor sensor, 5 – pulse regulator, 6 – control panel

The final design (on Fig. 2) is based on several tries and it contains six main parts assembled on the base. Electric DC motor with pulse regulator powered by 10 volts from a stabilized laboratory source. Torque from the motor is transferred to the shaft with a bladed wheel via a rubber belt (transmission ratio 0,3). To eliminate tension forces from the belt, which became a significant source of vibration, the shaft was mounted on two ball-bearings (SKF CSN 02 4630). The speed is set by a potentiometer allowing continuous regulation from zero to maximum. For monitoring the speed, there is a sensor module based on a phototransistor placed nearby the driven shaft. On the shaft is one special cylindrical element with very contrasting segments. The number and position of elements determines the frequency and the time of photoshoots. This sensor has a lot of advantages – for operation needs only 5 volts DC, so it is very easy to use every USB as a power source. It includes regulation of sensitivity, so it can be easily tuned to optimal settings. The output is a signal useable for the ARAMIS software as a trigger for creating a photoshoot. Thanks to this sensor, photos are taken synchronized in the required position, automatically sorted, and only the demanded are saved for processing. This is very important for use in the future, now the homemade fan has only three blades, so it is not hard to recognize which is on the shot. But the ambitions are higher, and the option to focus only on a few precisely selected blades from the whole is very useful. In service, the sensor, DC motor, and shaft must be undercover, because light from the projector affects the sensor, and photos are not created at the correct time.

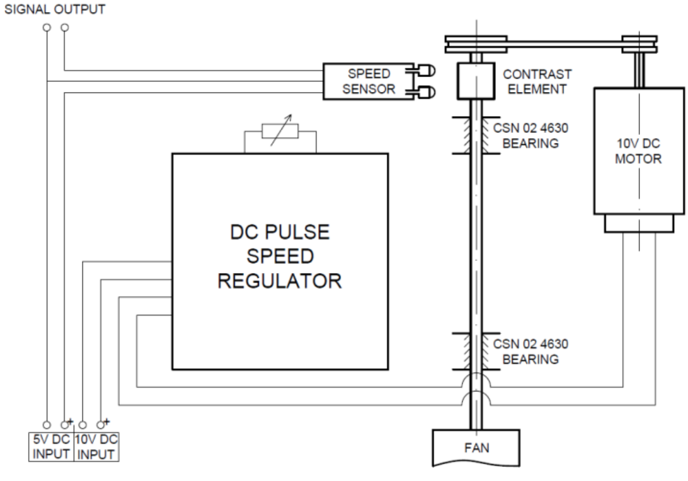


**Fig. 3**. The electric scheme of measured fan.

From experiments with a factory office fan, there was some data showing that a bigger blade is worse at measuring deformation than a tiny one. So it was decided to use cameras on the smallest frame (180 mm) and a direct light projector. This assembly is suitable for blades smaller than 120 mm (finally it was used 95 x 35 mm). The measured blade is relatively small, so it was used reference points glued to the surface of the blade. The used size of the points is 0,8 mm. These points were placed on the blade as positions where will be the deformation determined, and on the hub as a point to measure the displacement of the (theoretically) rigid body. Differences between the rigid hub and deformative blades are values of the measured deformation. Thanks to this difference, there were pure data of deformation independent of the angle of rotation.

## 3 Results and discussion

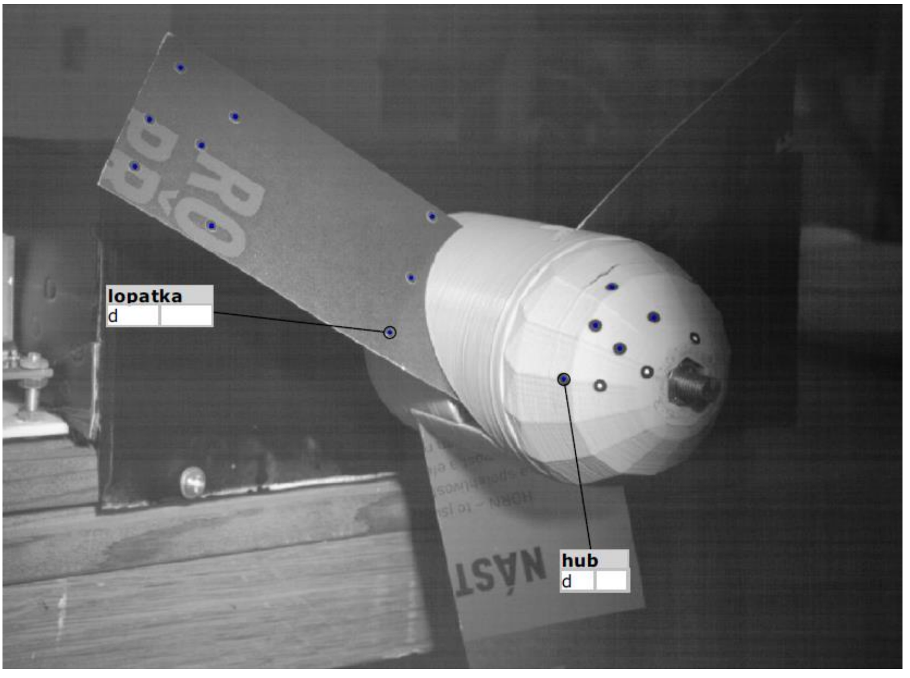


**Fig. 4.** Reference image.

The figure 4 was created as a reference shot. It shows the observed part of the assembly with reference points on the hub and blade. This shoot shows the maximum quality from the camera because it was photographed when the fan stayed.

 https://doi.org/10.1051/matecconf/202236700009

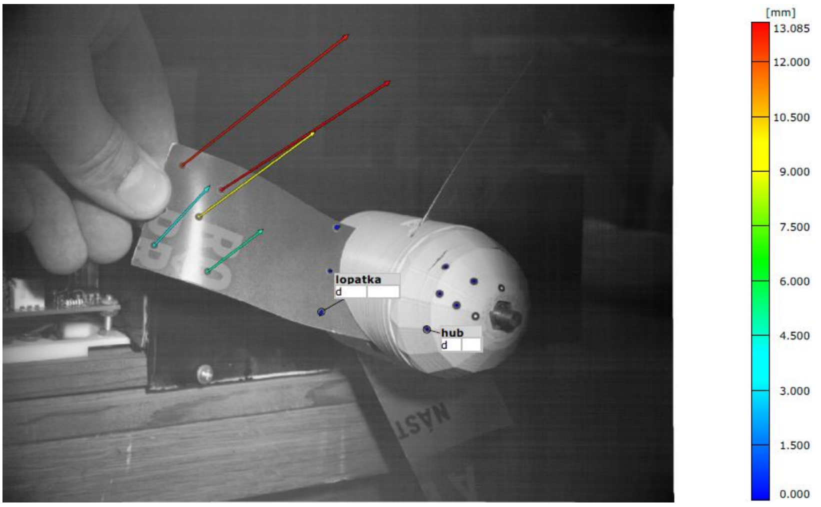


**Fig. 5.** The measured blade slowly deformed with a finger.

The figure 5 was created when the blade was deformed manually with a finger. The data is clear, changes were slow. So there is no problem in determining the deformations because the ARAMIS software can reliably recognize the coordinates of reference points.

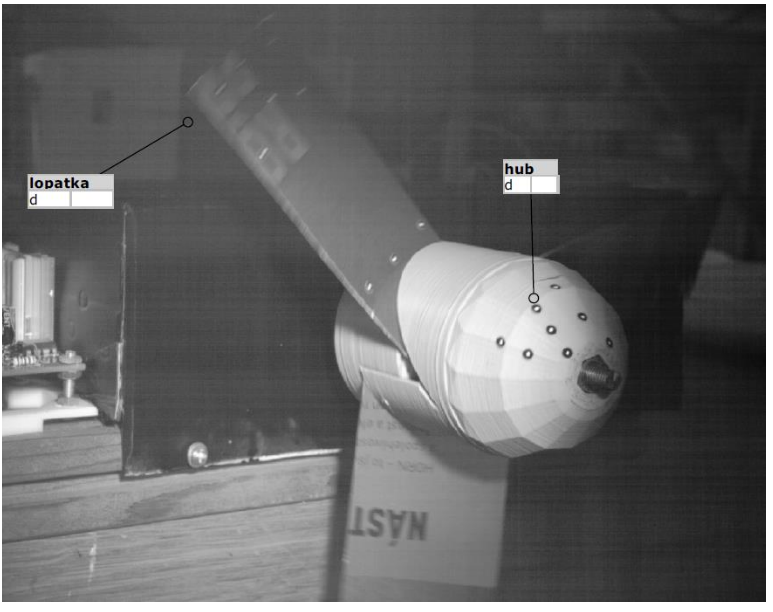


**Fig. 6.** Unusuable data from measuring the fan in service.

Picture taken while the fan was running, fully showing problems with using the ARAMIS dynamic scanner for measuring on turbomachinery. Points on the hub are useable, but with growing distance from the center of rotation, the velocity is linearly growing. For this experiment, we used small velocities (frequency 4 Hz). Despite this, reference points on the blade are not sharp and not useable to determine a deformation. It is clear, that with bigger velocities, these problems will grow. At now, there is no useable solution to determine deformations by ARAMIS dynamic scanner.

## 4 Conclusion

It is clear that the current state is not satisfying. This initial experiment shows the way, but there must be added some breakthrough solution leading to sharpening photoshoots. The biggest problem is about the illumination of a scene. So first, what we want to do is move the equipment outside the laboratory and try to measure deformations in the sunshine. This can lead to solving the problem for small velocities. But it means making it all measurement outside, and the majority of interesting objects are somewhere inside, usually in bad light conditions. So we believe, that the solution can be based on a combination of particular improvements current status. One of these solutions can be using stronger contrast by using reflexive reference points. It can be a possibility for bigger measured objects. But unfortunately, there are no 0,8 mm reflexive points to purchase. Another direction of the consideration is the type of illumination – there is a requirement for a very powerful lighting system, based on LED or laser. This system can be based on very short flashes directed by signals from a phototransistor sensor. Solution of the problems with illumination is the first and most important goal in the future.

## References

1. V. Yanovych, T. Honcharuk, I. Honcharuk and K. Kovalova. Design of the system to control a vibratory machine for mixing loose materials. Eastern-European Journal of Enterprise Technologies, 6 (3-90), pp. 4 - 13, (2017)
2. V. Yanovych, D. Duda, V. Horáček and V. Uruba. *Creation of recombination corrective algorithm for research of a wind tunnel parameters* in Proceedings of the Power System Engineering, AIP conference 2118, Pilsen, Czech Republic (2019).
3. D. Duda, V. Yanovych, V. Tsymbalyuk, V. Uruba. Effect of Manufacturing Inaccuracies on the Wake Past Asymmetric Airfoil by PIV. *Energies* **2022**, *15*, 1227.
4. V. Yanovych, D. Duda, V. Uruba and T. Tomášková. Hot-Wire Investigation of Turbulence Topology behind Blades at Different Shape Qualities, *Processes* **10(3)**, 522 (2022).
5. V. Yanovych, D. Duda, V. Horáček and V. Uruba. *Research of a wind tunnel parameters by means of cross-section analysis of air flow profiles,* in Proceedings of the Power System Engineering, AIP conference 2189, Pilsen, Czech Republic (2019).
6. V. Yanovych, D. Duda. Using ARAMIS system for measurement of structural stability of running wind tunnel. MATEC Web Conf. 328 01003 (2020)
7. V. Yanovych, D. Duda. Structural deformation of a running wind tunnel measured by optical scanning. (2020) Strojnicky Casopis, 70 (2), pp. 181 – 196
8. Peterkova, Eva & Srefl, Milan. (2016). Use of 3D measuring system aramis for analysis of tube flaring process. MM Science Journal. 2016. 1392-1397.
9. Walotek, Konrad & Bzówka, Joanna & Ciołczyk, Adrian. (2021). Examples of the Use of the ARAMIS 3D Measurement System for the Susceptibility to Deformation Tests for the Selected Mixtures of Coal Mining Wastes. Sensors. 21. 4600. 10.3390/s21134600.
10. Urbańska, Krystyna. (2017). Application of aramis system for measurement of deformations of masonry. Zeszyty Naukowe Uniwersytetu Zielonogórskiego / Inżynieria Środowiska. 166. 48-59. 10.5604/01.3001.0010.6034.
11. CIMCo – Especialistas en CAD/CAM y Metrología 3D. (2017, May 5). *GOM ARAMIS - Vibración en turbina* [Video]. YouTube. https://www.youtube.com/watch?v=RpOl-XEvNwQ
12. GOM a ZEISS company. (n.d.). *Speeding Up Fan Blade Integrity Testing with ARAMIS.* https://www.gom.com/fr/industries/aeronautique/vibration-analysis-fan-blade.html