

# Study of methods for measuring thin water films for use in steam turbines

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**Abstract.** This article focuses on the experimental investigation of thin liquid films, with relevance to their behaviour and measurement in steam turbine applications. The main motivation comes from the fact that the formation, atomization, and subsequent droplet distribution of these films play a critical role in the erosion of turbine blades during non-structural operation, a phenomenon that can significantly impact blade efficiency and operational reliability. Understanding the properties of thin liquid films is essential not only for analysing the dynamics of droplet impact and resulting erosion but also for improving maintenance strategies and the longevity of energy systems. The research introduces a novel interferometric measurement device designed to precisely gauge thin film thickness in varying experimental conditions. The development of this instrument draws upon earlier work in optical measurement methods, aiming for high accuracy, non-invasiveness, and rapid responsiveness suited to tracking dynamic processes. The measurement method employs a rotating cylinder, partially submerged in liquid, to create a controlled film, with experimental variables including the rotational velocity and surface treatment (e.g., sandblasted versus polished). The study also highlights the importance of surface quality, since surface roughness and texture directly influence film formation and thickness, which in turn affect the atomization process and the likelihood of erosion events.

## 1 Introduction

The growing interest in research in field of steam turbine erosion led to study of formation, developing and breakdown of thin liquid films on last stage blades. The formation of droplets in steam turbines causing the last stage blade erosion. One of the parameters, which should be described properly is a film thickness. The previous interest [1-3] in optical measurement methods led to developing an interferometric measurement setup able to determine a thickness of thin liquid films.

The further suspect of the interest for this work is to test and compare different types of surfaces and their treatments for the purpose of the determination of film forming and its development. The film may be described by the regime of liquid drainage and its thickness, which is the main observed parameter in this paper. For this purpose, an interferometer able to determine thin liquid film thickness is used. The liquid film is formed by the dives with a rotating cylinder, which is partially submerged into a liquid. The liquid becomes entrained, adhering to the cylinder's surface and forming a film. The thickness of this film can be modulated by adjusting the rotational velocity of the cylinder. The regime and mechanism of film development may be determined by the quality of used surface, its treatment and other aspects. So, the one part of the cylinder is sandblasted, and the other one is polished. Thanks to the ability to measure film thickness

properly, the mechanism of development in connection of surface quality may be described closely.

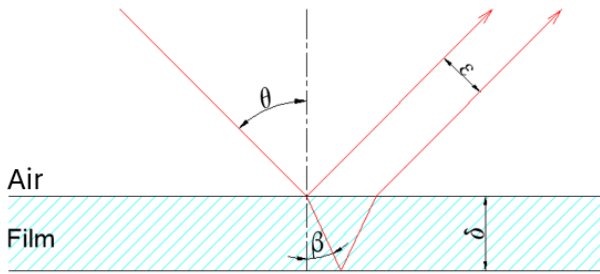
The assumption described above can be used as a technique providing the test of interferometer measurement abilities. It is intended to use the measurement method in larger experimental setup simulating real conditions of energetical devices such as experimental nozzles simulating steam turbines and heat exchangers or other energy devices.

## 2 Measurement method

The purpose of this paper is primarily to describe the measurement principal of device and provide its ability to measure the film thickness. Furthermore, it may be discussed as the developing of thin liquid film depends on the surface quality and its treatment.

After previous research of methods [1, 4-6] suitable for thin liquid film thickness measurement, an interference method was chosen for its non-intrusiveness, non-destructiveness and fast reaction satisfying for use of measuring this dynamic process. The basic interferometer was developed for this purpose. The interference method is based on light interference. When a coherent beam of light hits the interface between air and film, it refracts and reflects, and the emerging beams are separated by a distance ( $\epsilon$ ), which is determined only by the changing thickness of the water film ( $\delta$ ) visible in Fig. 1.

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**Fig. 1. Refraction of light at the interface of a thin liquid film and air**

This applies only if an angle of incidence ( $\theta$ ) and angle of refraction ( $\beta$ ) are fixed. This phenomenon creates an analogy to the double slit experiment, so for films of thicknesses within a certain range, the interference fringe may be observed. A simple mathematical apparatus was developed. A distance between two interference fringes ( $y$ ), which can be easily measured, is determined by a distance between two beams ( $\varepsilon$ ) and can be described by Eq. 1, where ( $\lambda$ ) is a wavelength of the incident light and ( $D$ ) is a distance between the film and the place, where the interference fringes are observed [7].

$$y = \frac{\lambda D}{\varepsilon} \quad (1)$$

After adjustment of Eq. 1, Eq. 2 can be obtained from the geometry in Fig. 1 using goniometric functions, where ( $\theta$ ) is the angle of incidence and ( $\beta$ ) is the angle of refraction and ( $\delta$ ) is the thickness of the liquid film.

$$y = \frac{\lambda D}{2\delta \tan \beta \cos \theta} \quad (2)$$

By using Eq. 3, which is Snell's law, the angle of refraction may be expressed by Eq. 4. Therefore, Eq. 2 can be modified to the form Eq. 5 with variables that are easily measurable during the experiment, or with known material properties, where ( $n_a$ ) is the refractive index of light in the air and ( $n_f$ ) is the refractive index of light in the liquid film. The Eq. 5 is further used to calculate the thickness of the liquid film ( $\delta$ ).

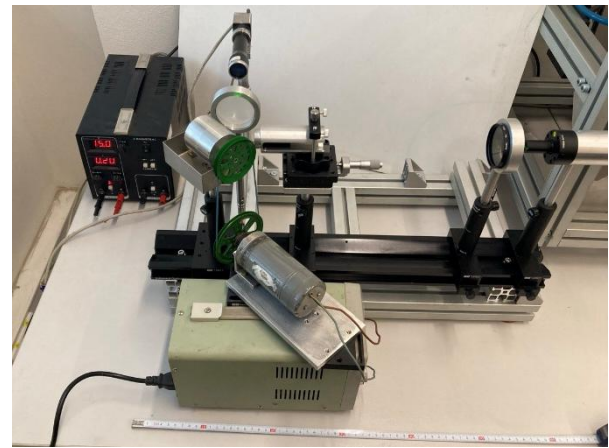
$$n_A \sin \theta = n_F \sin \beta \quad (3)$$

$$\beta = \arcsin \left( \frac{n_a}{n_f} \sin \theta \right) \quad (4)$$

$$\delta = \frac{\lambda D}{2y \tan \left( \arcsin \left( \frac{n_a}{n_f} \sin \theta \right) \right) \cos \theta} \quad (5)$$

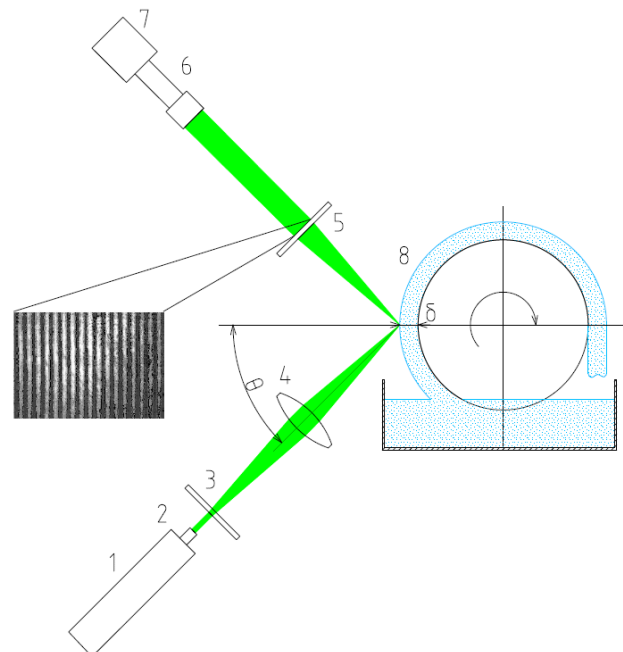
### 3 Measurement setup

The observed measurement setup consists of interferometer and rotating cylinder. Liquid entrainment causes the film to adhere to the cylinder and form a film. The thickness of the adhering film can be influenced by regulating the speed of the cylinder. The developing film should be cohesive and continuous to be measured properly. The experimental setup can be closely seen on photo in Fig 2.



**Fig. 2. Photo of an experimental setup.**

Whole measurement setup is depicted in Fig. 3., where (1) is laser with (2) collimator, (3) polarizing filter, (4) an achromatic optical lens, (5) shade where the interference fringes can be observed, (6) telecentric objective, (7) camera, (8) is observed thin liquid film. The laser beam must be focused on the smallest area possible. Theoretically, this area is the only point, but due to the aberration of the lens used, such accuracy cannot be achieved. An achromatic optical lens which is located on sliding table for its precise and very fine movement was used. The interferometer sets on the aluminium profiles allowing additional elements to be added if necessary and easy manipulation. It also prevents from unintended movements that would alter the geometry, to which the device is very sensitive, especially angles.



**Fig. 3. Experimental setup layout.**

The shade with interference fringes can be placed in front of the camera in exact distance because of use of telecentric objective. This type of objective was chosen for its ability to not distort information about the size of the observed image depending on the distance between the camera and the shade, which is crucial for

determination of the film thickness. The measurement may be performed without a shade with direct picture capture in exact place, where the camera is focused. This setup was chosen for the final measurement.

The rotating cylinder has a diameter 50 mm. It is powered by an DC electric motor. By the change of the voltage the rotation speed of cylinder can be regulated and further calculated for the evaluation. A UI-5240CP-M-GL camera equipped with an e2v EV76C560 1/1.8" CMOS monochrome chip was used for the experiment. In addition, a Melles Griot 05 LGR 025 helium-neon laser emitting green unpolarized light with a wavelength of 543.5 nm and a 55-278 achromatic lens with a focal length of 100 mm manufactured by Edmund Optics were used.

### 4 Results

The interference fringes obtained by the optical measurement are further processed. Some of the obtained pictures are shown in Fig. 4. Based on the interferometer geometry and the measurement of the number of pixels between two interference fringes from the photo, the thickness of the water film is calculated. But before using the Eq. 5 to do so, the interferometer had to be calibrated with resolution target to get the accurate displayed scale. Further, to obtain an accurate distance ( $D$ ) distance between the film and the place, where the interference fringes are observed the reverse method based on Eq. 5 is used. To do so, the thickness of the material of known thickness must be measured and compared using the mathematical apparatus based on the geometry described above. For purpose of this paper a transparent 40  $\mu\text{m}$  duct tape was used.

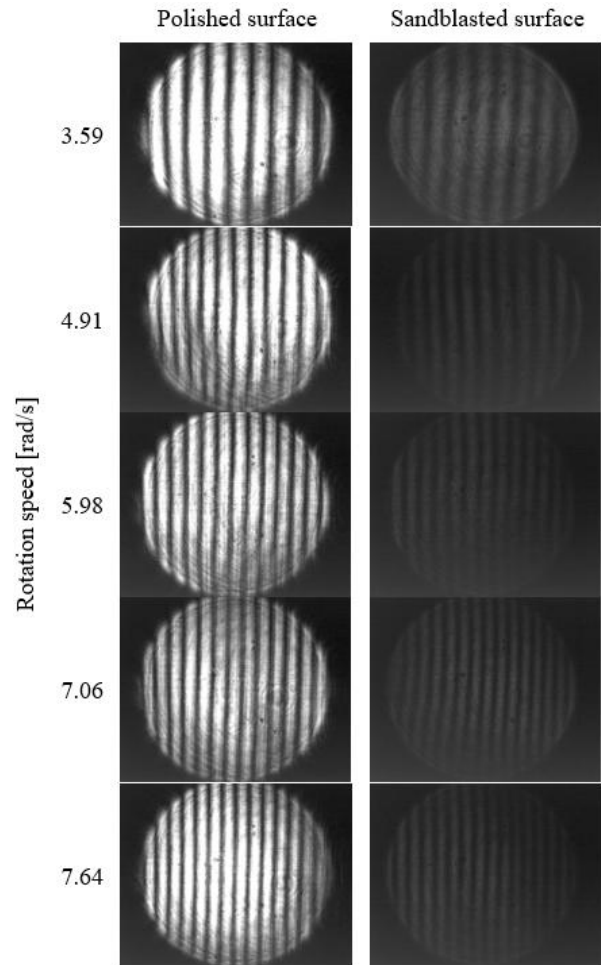
The results for thickness of liquid film forming on the rotating cylinder is described in Tab. 1. The thickness depends on the rotation speed of the cylinder [1], so it is considered to compare the thickness by the rotation speed of the cylinder and its surface quality. In this paper the water was used as the liquid only. For the further measurement, it is recommended to use a wider range of fluids due to different viscosities and densities, which may interact differently in dependence of surface quality.

**Tab.1.** Table of film thickness for polished and sandblasted surface.

Polished surface						
Rotation speed	[rad/s]	3.59	4.91	5.98	7.06	7.64
Measured number of pixels		101.13	93.94	89	75.88	68.31
Distance between interference fringes	[ $\mu\text{m}$ ]	537.31	499.12	472.89	403.15	362.97
Film thickness	[ $\mu\text{m}$ ]	74.87	80.47	85.09	99.69	110.77

Sandblasted surface						
Rotation speed	[rad/s]	3.59	4.91	5.98	7.06	7.64
Measured number of pixels		99.81	92.56	79.69	67.63	56.56
Distance between interference fringes	[ $\mu\text{m}$ ]	530.34	491.82	423.41	359.31	300.54
Film thickness	[ $\mu\text{m}$ ]	75.82	81.64	95.12	112.1	133.81



**Fig. 4.** Photos obtained during measurements on a constructed interferometer showing interference fringes.

From Fig. 4 is clearly visible, that the sandblasted or any rough surface acts primarily like a light diffuser. So, during the measurement, the exposition time must be set very low to prevent excessive noise in the image. On the other hand, the polished or glossy surface acts like a light refractor, so the interference fringes are clearly visible.

The graphic interpretation of Tab.1 and results are shown on graph in Fig. 5. The number of pixels was calculated in MATLAB. A pixel true size was determined using the USAF 1951 1X 2x2 resolution target as 1 pixel is equal to 5.313  $\mu\text{m}$  with the geometric layout of the interferometer used. Film thickness was calculated using Eq. 5. It is notable, that the film thickness is increasing faster with increasing cylinder speed. To compare two types of surfaces, the sandblasted surface shows forming thicker films than polished surface which is increasing even more with increasing rotation speed. This phenomenon leads to thought, that the quality of surface may influence a droplet formation and therefore a last stage turbine blade erosion.

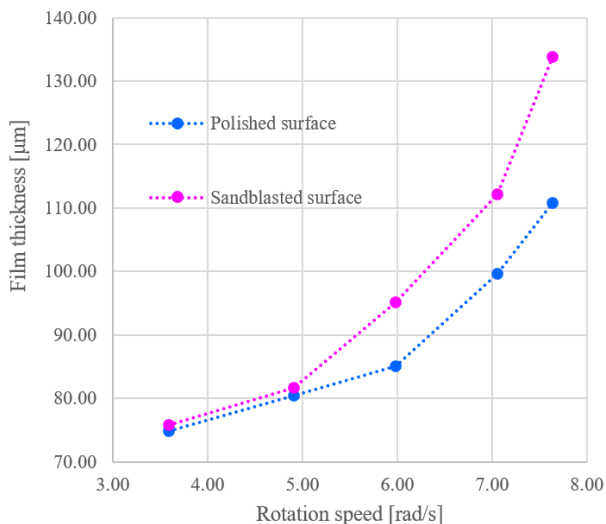


Fig. 5. Graphical comparison of results.

## 5 Conclusion

This paper has focused on advancing the measurement of thin water films and establishing a quantitative relationship between surface quality and their thickness, with direct implications for steam turbine blade erosion mitigation. The fundamental motivation underlying this research stems from the phenomenon of droplet formation on the last stages of steam turbines, where these droplets subsequently impact turbine blades and cause progressive erosion that degrades operational efficiency and compromises mechanical reliability. The degree of erosion may be related to the film thickness on stator blades. Thicker films produce larger coarse droplets, because the larger amount of liquid is displaced by mechanism described in [8] to the trailing edge, where the film break up and forms coarse droplets (diameter up to 1 mm). Later, those coarse droplets break up into smaller droplets with a diameter (50–200 µm) which is the most dangerous for turbine blades [9]. Although thin film measurement methods exist within the scientific literature, their application to dynamic films on curved surfaces under controlled conditions has not been thoroughly explored, creating a significant gap in the experimental techniques available for turbine research.

This paper has successfully demonstrated a simple yet robust interferometric method capable of measuring dynamic thin water films on curved surfaces, addressing a critical measurement challenge in the field. The methodology's strength lies in its non-intrusive nature, rapid response capability, and applicability to real-world geometries. By deliberately selecting surface quality as a variable of interest, the study employed an innovative dual-surface cylinder consisting of both sandblasted and polished halves to systematically investigate how surface characteristics influence film formation and development.

There is no doubt that this method was used on a smooth liquid film, which at first glance may lead to the conclusion that it cannot be used on rough films. In conditions where the flow is turbulent, for example due

to higher gas velocity in two-phase flow, measurement can be difficult. This phenomenon needs to be thoroughly discussed. On the other hand, the speed of data collection is an undeniable advantage of the laser interference method. This leads to the possibility of obtaining more data and solving it in the future using an algorithm. In the case of reduced reflectivity, interference fringes do not occur. So, with higher Reynolds numbers of two-phase flow, which lead to a wavier flow regime of the film, it is expected that more data will need to be processed by the algorithm to select suitable images.

The experimental data collected and processed on the constructed interferometer conclusively demonstrate that surface quality directly affects the thickness of water films that form during entrainment. Nevertheless, the interference method data may be processed automatically with a well-designed processing algorithm. Specifically, the results indicate that degraded surface quality characterized by roughness and irregularities correlates with increased film thickness compared to smooth, polished surfaces. This finding has significant practical implications for turbine blade design and maintenance strategies. Rougher surfaces, which may accumulate thicker liquid films, may experience different atomization characteristics and droplet size distributions, potentially altering erosion patterns and rates. Future applications of this measurement technique extend naturally to larger experimental setups that simulate real operational conditions, particularly experimental nozzles and configurations that replicate steam turbine and heat exchanger environments. The validated interferometric method now provides engineers with a powerful tool for optimizing blade surface treatments, predicting erosion behaviour, and ultimately enhancing the durability and efficiency of steam turbine systems in power generation equipment and other energy devices.

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