Development of the heated film probe

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Abstrakt

This paper is focused on possible ways to produce heated films for velocity probe application. It follow-up the project from the year 2015 where was presented the idea of new velocity probe. Now are described materials, proper options for manufacturing heated films and finally assembling of whole probe. In the paper is discussed deposition of the thin film layer – vapour deposition and sputtering. Attention is given also metal etching. Last part describes builded calibration equipment.

Klíčová slova: Heated film probe; thin film layer; 3D calibration

1. Introduction

Development of the heated film probe is a long-term project. The basic principles of the probe were, among others, presented at the STC 2015 Conference. The project focuses on the development of new type of probe for measurement of speed. The probe is based on use of several heated films applied on several surfaces. For speed measurement, the constant temperature heating method is used, whose benefits shall be used within continuation of the project. After placing the probe into the airflow, the air runs over each of the heated films at a different angle. Thanks to this, the films are differently cooled and it is subsequently possible by means of valid calibration to evaluate the flow speed and direction. In further project phases, the design of the probe shall be solved with regard to the high degree of robustness and resistance to fluids. The result of the entire project will thus be a probe for measurement of the entire velocity vector for universal application in both gases and fluids, which shall at the same time, be resistant to rougher handling.

The year 2015 was in the development of the project distinguished by detailed elaboration of the structural design of the probe, solution of the technology for production of the hot element and consequently the entire probe. At the end, the calibration device was designed in detail, and was subsequently made and activated.

2. Film material

The most fundamental task was to solve the heated film production technology. It was first necessary to select suitable film material. Research showed that mainly platinum, nickel and nickel alloys are generally used for similar purposes. The advantage of platinum is its stability, chemical resistance and mainly its resistance coefficient that is almost independent of temperature, which is moreover relatively high 0.0039 K-1. Among the other reasons for general use of platinum for temperature applications is its usability also at temperatures above 150°, which is, however, beyond the intended range of the developed probe. A fundamental disadvantage could be considered the higher price and more difficult workability. Nickel is another material most frequently used for hot working applications. However, it lacks the constant temperature dependent heat transfer coefficient, for which reason the thermometers made from it are linear only for a small range of temperatures. This is not a limiting factor for application in the designed probe because in terms of the full scope of the temperature range, the probe shall function only in its relatively narrow part. The advantage of nickel as compared with platinum is its easier workability and lower price. A further important advantage of nickel as compared with platinum for this project, is its higher temperature coefficient (0.0058 K-1), as a result of which sensitivity to temperature changes is greater. After consideration of all properties, nickel was selected as the initial material, mainly because of higher sensitivity to temperature.

2. Thin film production

2.1. Options in laboratory

Production of the film itself could be approached in several ways. The first on offer is production in laboratory Ú12112. For production by own means, the most suitable would be to opt for soldering of a thin wire from the selected material to the prepared base with suitably arranged soldering surfaces. According to the pattern of the arrangement of the surfaces, it would then be possible to create wire meanders as necessary. The biggest question when using this method is the mechanical resistance of such a sensing element. In order to avoid damage – breaking of the wire, it would most likely be necessary to solve some form of coating. But this would reduce sensitivity to temperature and slow down response to temperature changes.

2.2. Physical vapor deposition

In case of assigning production to an external company, the number of options is larger. For production of thin metal layers are commonly used vakuum deposition or sputtering technology. The most common metal coating method is sputtering, mainly for reason of lower energy intensity and a possibility to create a layer from wider range of materials. Vacuum deposition consists in vaporization of part of the target (source material) and its transfer to the substrate. The entire process runs in a vacuum. Sputtering runs at low pressures in a protected atmosphere, usually argon. The target is charged with a high negative potential. The positive ions subsequently hit the

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negatively charged target and break atoms off the target, which then settle on the substrate. The disadvantage is sputtering is the lower purity of the created layer, which is however in terms of quality still far beyond the requirements for production of the hot film. Due to the available technologies, sputtering was selected.

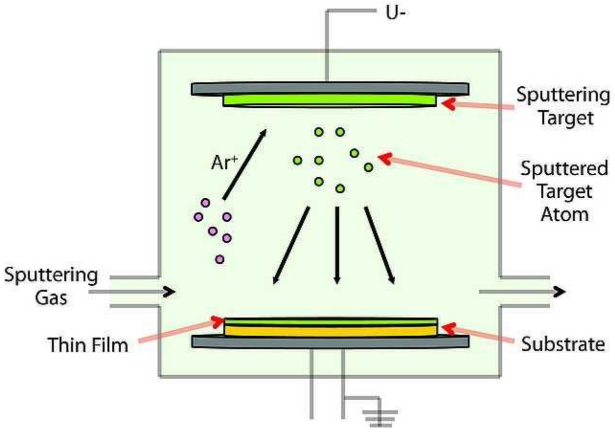

Fig. 1. *Sputtering. [1]*

2.3. Heated film pattern

It is possible create the required pattern in the sputtered substrate in several ways. It is possible to divide them into chemical and mechanical. From the mechanical ways, these are mainly micro-machining and laser cutting. A more appropriate method for creating the pattern is the use of chemical resistant coatings. Two methods are on offer. Either the so-called lift off method, or method with post-etching. The difference is in the moment of usage of the covering mask and resistant chemical coating. When

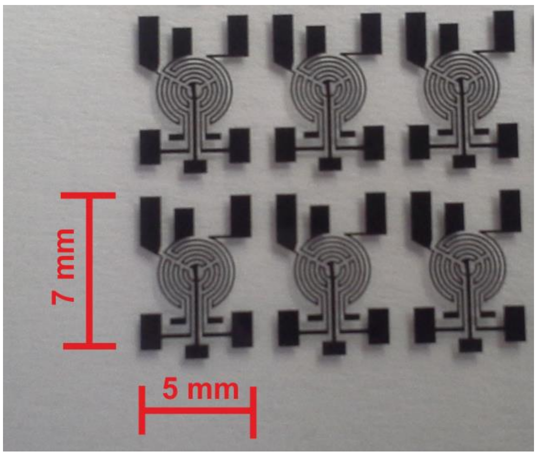

Fig. 2. *Mask for resistant coating.*

using the lift off method, a negative chemical resistant coating is used before the actual application of the thin layer. The chemical resistant coating used here is in comparison with the coated metal layer at least of double thickness. After application of the metal coat, the chemical resistant coating is washed off together with the excessive metal and only the required pattern remains on the substrate. In the post-etching method, the substrate is metal plated in full, and subsequently a positive chemical resistant coating is applied over the photo mask. The metal outside the desired pattern remains exposed, it can then be etched. After washing off the chemical resistant coating, only the pattern remains on the substrate again. The advantage of the lift off method is simpler technology with a smaller number of operations. The process of etching, which requires longer tune-up time, is dropped. On the other hand, the pattern created using the lift off method has worse quality edges. The first heated films were created using the etching method, which at the beginning seemed easier and partially realizable on self-help basis. In the end, it was decided to make the film in future using the lift off method, which produced better results in the overall quality of the pattern.

2.4. Heated film substrate

The basic substrate for production of films in further project stages shall be kapton film; the current prototypes were made on a temperature resistant fibreglass board. This was adopted for reason of easier subsequent production of the entire probe. The nickel layers sputtered on kapton or fibreglass were of higher quality and mainly stronger if a thin layer of titanium is sputtered under the nickel. The thickness of the titanium layer may be only a few nanometres (up to 5 nm). This layer acts as a bond between the nickel and the substrate. During production using the post-etching method on a substrate, the titanium layer remains. This is not a problem because thanks to the small thickness, the layer has high electrical resistance and the individual meanders of the required pattern are short-circuited.

3. Probe production

Two plates were made in this way, each with 80 films. The films were cut-off the plates into single pieces and subsequently applied to a prepared probe. The probe was made of plates for standard printed circuits. The plates had different shapes adapted for easy bonding in the shape of the desired multi-walls. Probes were made from the plates, always with one wall open. The heat control and temperature reading cables passed through this open wall. The cables were connected on the inner side to the individual walls of the probe. The heated films are fitted on the outer side. The films are connected to the cables via the through-holes in the walls of the probe. Cables run out of the probe via its shank.

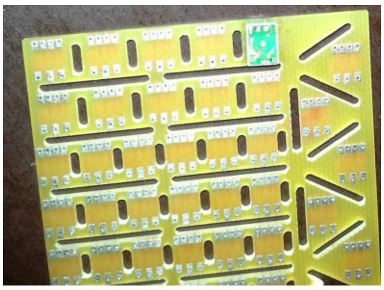

Fig. 3. *Plates for probe production with one film*

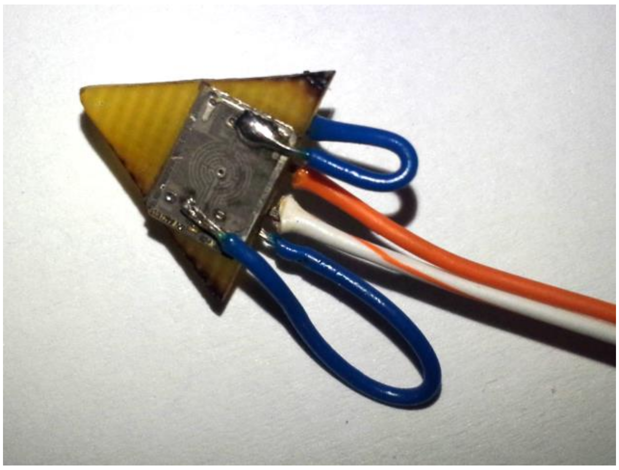

Fig. 4. *Outer surface of each probe side*

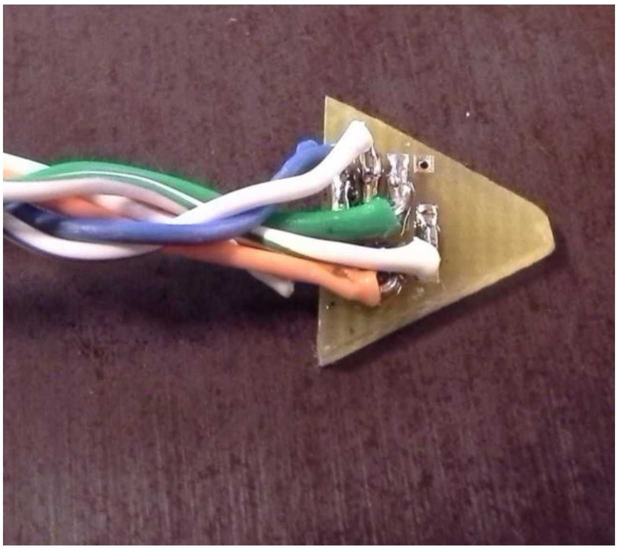

Fig. 5. *Inner surface of each probe side.*

4. Calibration box

It was necessary to design and create a calibration device for testing the probe. Calibration must be done in such a manner that the probe rotates around three mutually perpendicular axes continuously at a single point. The calibrator is conceived as a detachable module for use in an aerodynamics tunnel. The moving mechanism consists of a semicircular arm provided with a toothed belt. The rotation of the arm along the vertical axis is done by a stepping motor located on the exterior with shaft running into the calibrator. A carriage with pulley driven by another stepping motor runs over the timing belt on the arm. The carriage thus runs on the circular path with centre defined by the semicircular arm. A small stepping motor is placed on the carriage to which it is possible to fix the probe shank. This motor turns the probe around the axis that runs through the probe shank.

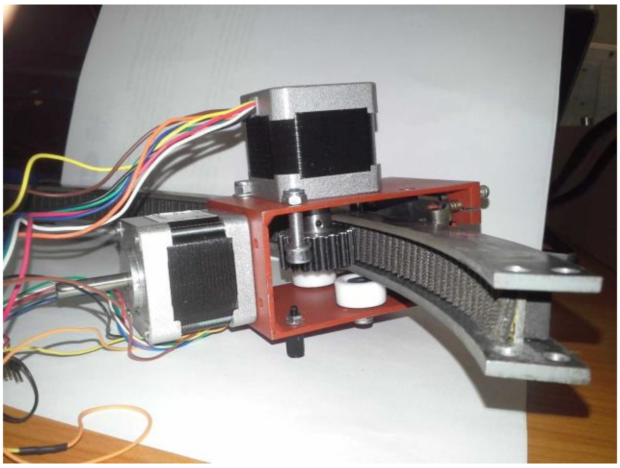

Fig. 6. *Troley with the arm.*

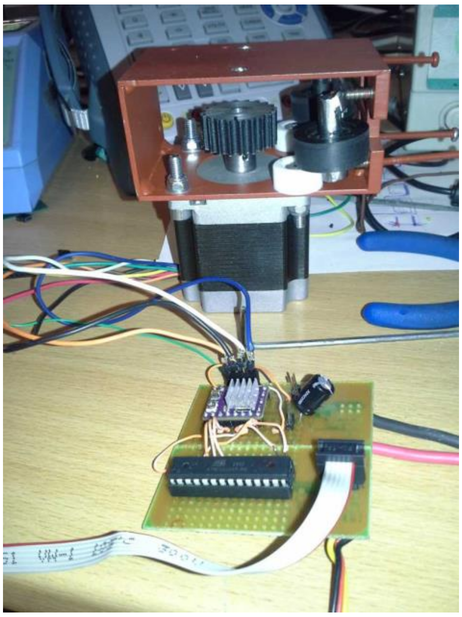

Fig. 7. *Troley with stepper motor and motor driver*.

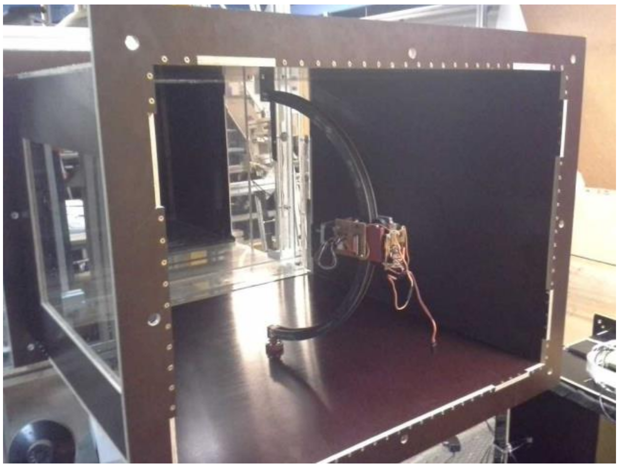

Fig. 8. *Calibration box in the wind tunnel.*

Each of the three motors has an own control unit controlled via the Matlab environment on the master computer. The run around each axis is possible with a resolution of 1.8°. It is however possible to set stepping refinement – the smallest turn of 1.8° can be achieved in one step, or in steps corresponding to the powers 2 to 32. The calibrator is made of plyboard and is equipped by windows. In front of the calibrator is inserted module with honeycombs that have the task of balancing the speed profile.

4. Conclusion

In the 2015 part of the speed probe development project, the technological part of heated films product was mainly solved. The most suitable variant proved to be the production of a large number of films at once using the lift off sputtering method. Its results are the best. The selected sputtering material is nickel. Its advantage is a temperature coefficient that is little dependent on temperature (in the temperature range of assumed usage), easy workability and high sensitivity of electric resistance to temperature change. It is necessary to sputter a layer of titanium with a thickness of several nanometres under the nickel. The finished films can be soldered to the body of the probe with connected cables. A calibration method was designed within the project and a functional calibration device was created.

A further stage in the continuation of the probe development project shall be designing of a mathematical model for processing of calibration. Currently, calibration is highly time intensive and its outcome is a large volume of data, which is difficult to process. The effort will be to establish relationships between the individual measured variables and thus partially make it dimensionless and simplify it. The probe itself shall be further developed and improved.

References

[1] *Physical Vapor Deposition (PVD)*. [online]. Sigma-Aldrich. [cit. 13. 4. 2016]. https://www.sigmaaldrich.com/materials-science/material-science-products.html?TablePage=108832720

[2] MATTOX, D. Handbook of physical vapor deposition (PVD) processing. 2nd ed. Amsterdam: Elsevier, 2010. ISBN 978-0-81-552037-5.

[3] *5] INCROPERA, Frank P. Introduction to heat transfer. 5th ed. /. Hobokenm NJ: Wiley, c2007, xxv, 901 p. ISBN 0471457272-.*