

Climatic Chamber for the Credibility Evaluation of Profilometric Measurements Construction and Control

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ABSTRACT

The paper shows the construction and control of a climatic chamber used for the credibility evaluation of the profilometric measurements. The paper presents a control model using a PID controller and a solution for air circulation. The data regarding the influence of environmental temperature changes on the three-dimensional representation of the surface realized by means of a tactile profilometer were presented. This work shows the temperature characteristics of a climatic chamber.

Keywords: climatic chamber; thermal distortion; temperature measurement; PID controller; surface topography.

INTRODUCTION

The surface topography is generated in the last stages of the manufacturing processes. Materials contact, sealing, friction, a lubricant retention, a wear resistance and other functional properties are related to the surface topography. Surface roughness is very important and often analysed. Many roughness measuring instruments give absolute measurement of surface heights. The assessment of profiles was employed since the early 1930s [23]. These systems basically involved the use of the mechanical stylus.

The vertical movements of a tip, which follows the roughness profile, are amplified and digitised to extract the roughness parameters. The profile (2D) measurement is typically quicker, simpler and easier to interpret than the areal (3D) measurement. However, most surface interactions are areal in nature. The 3D surface topography is obtained by collecting parallel scanning profiles with a defined step. The 3D surface parameters are more reliable than the 2D profile parameters. Somicronic, a small company near Lyon, delivered a prototype 3D stylus system to the Ecole Centrale de Lyon in 1990 [1].

There are a lot of factors affecting uncertainty in the surface geometry measurement using the stylus (tactile) technique. They are caused by environment, measuring equipment, measured object, software and stylus. One can distinguish various kinds of errors using the stylus instruments like the errors typical for the interaction between a stylus tip and a surface, the errors caused by the digitisation process and the errors obtained during data processing [15, 17].

The lateral resolution of the stylus instrument depends mainly on the size of a stylus tip. The fundamental parameter in the transfer function of the measurement system is the radius of the tip curvature. The tip geometry acts as a low pass filter by removing high spatial frequencies of the signal [12, 14, 31]. The stylus flank angle also affects its resolution. However, the slope limitation is not a problem for most types of smooth surfaces.

The slower the stylus moves, the finer details can be resolved. However, a low stylus speed is the main disadvantage in the areal surface measurement. For a comparatively high speed the stylus flight is possible – it is

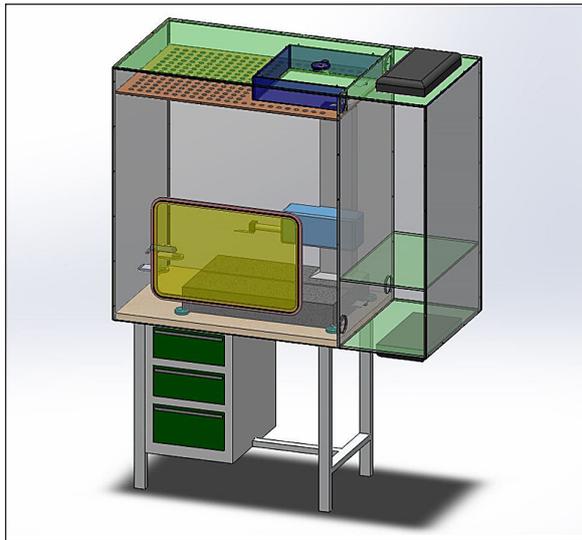


Fig. 1. The view of climatic chamber with the studied profilometer

the potential for the stylus to lose contact with the surface. The parameters that affect this phenomenon are: the stylus speed, the stylus force on the surface, the damping constant and surface characteristics [3, 16, 22,]. The spiral sampling can be used to reduce the measurement time [9]. The stylus method is criticised because it is claimed to damage the surface. However, the effect of the plastic deformation is usually not serious [25, 27].

The effect of a temperature change on the results of the profile measurement is negligible, since the measurement time is low. However, during the measurements of surface topography with the use contact profilometer, the impact of temperatures changes of environment on measurement accuracy and mapping of the topography of measured surface was noticed. The temperature changes of the environment in which the device works influence the thermal expansiveness of the profilometer structure which conditions the interferences during the measurements of surface topography [11, 28].

In order to determine the geometric distortion of a profilometer as a function of the temperature changes of environment, a climatic chamber used for the credibility evaluation of profilometric measurements was constructed. The purpose of the chamber was to simulate the real working conditions of the measuring device in a controlled way [13]. The studied object placed inside the climatic chamber was HOMMEL Etamic T8000 contact profilometer (Fig.1).

The control of the temperature inside the chamber, the change of its values in a determined way and monitoring of response of the contact profilometer on external thermal extortion, allow the compensation of the impact of external thermal disturbances during the measurement of surface topography.

CONSTRUCTION AND CONTROL

The climatic chamber shown in the picture (Fig. 2) was built from PVC boards, in addition, it was equipped with thermal isolation made of expanded polystyrene, separated from the basic construction by an air gap. The important element of the climatic chamber construction for the credibility evaluation of yjr profilometric measurements is the use of the circulation system and the air dosage diffusion system as well as a thermal-storage stove for the prepared warm and cold air. Cooling and heating of air was conducted with the use of Peltier cells located in the walls of the thermal-storage stove of climatic chamber (Fig.3) [2, 30]. The climatic chamber is equipped with the additional upper perforated board which steadily distributes cold air to the inside of the chamber and a passage which channels hot air from the above of profilometer drives. The air flows are controlled by a servo valve.

The temperature regulation system inside the chamber was based on ATmega 2560 microprocessor, DS 18B20+, DHT22 temperature sensors

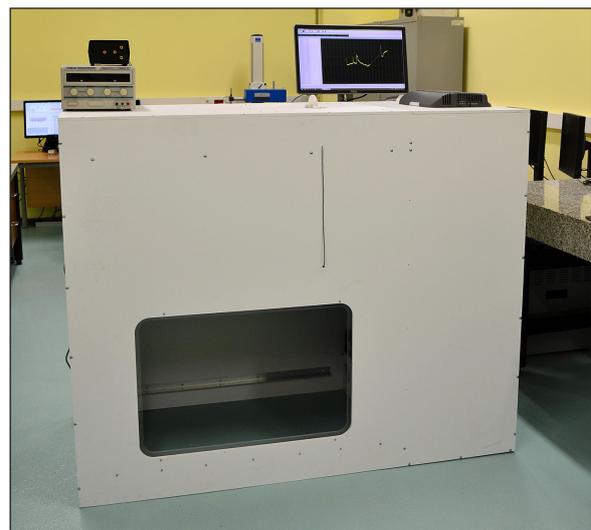


Fig. 2. The actual view of the climatic chamber for the credibility evaluation of profilometric measurements

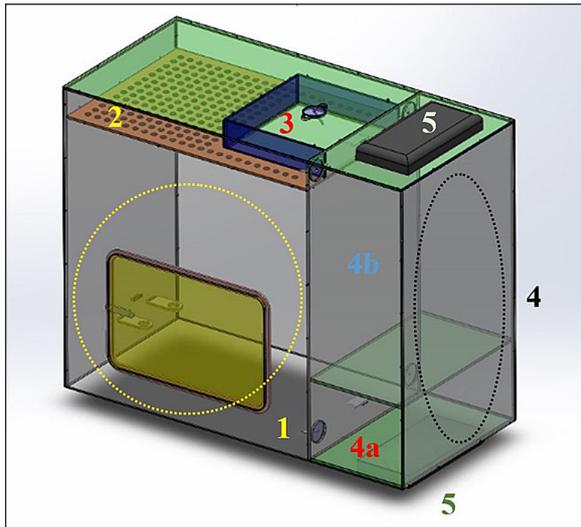


Fig. 3. The structure of climatic chamber – the most important units: 1) the prime part of the measurement, 2) cold air diffuser, 3) passage channeling warm air, 4) thermal-storage stove, 4a) warm air, 4b) cold air, 5) Peltier cells

and executive peripheral systems like servo valves and the set of relays. In a control system PID controller, the mathematical form of which is expressed by the equation (1); was used. The signals from three temperature sensors located inside the measured part of climatic chamber, two sensors in air preparatory part and a sensor placed outside climatic chamber used for measurements of external temperature of environment were carried to the controller. The task of the sensor placed outside the climatic chamber was the early activation of the temperature regulation system inside isolated part of the chamber in case of changes in the environment temperatures.

$$S_t = K_p \cdot \left[X_b + \frac{X_p + X_b}{T_i} + T_d \cdot (X_b - X_p) \right] \quad (1)$$

where: S_t – control value, K_p – gain, T_i – integration time, T_d – derivation time, X_b – the control deviation at time t , X_p – the control deviation at time $t-1$

The climatic chamber to assess the accuracy of profilometer measurements can operate in two modes. The first mode is to stabilize and maintain the determined temperature inside the main part of the measuring chamber – where the profilometer is placed [21]. The second mode controls the temperature changes in time, inside the measuring part of the chamber according to the determined process or designated periodic function. The control system allows the setting of periodic function, amplitude and the frequency of temperature changes inside the chamber. The change of the temperature setting is within the range 18-26°C. The simulation of activities and selection of controller parameters were carried out in the Matlab Simulink programme (Fig.4) [8, 20]. Temperature regulation inside the prime part of the chamber is performed with the addition of a pre-determined amount of warm and cold air, prepared in a thermal storage stove beforehand (Fig.5). The air inside the chamber is dispersed and continually circulates, which homogenises the distribution of temperature in the whole volume of the chamber.

SUMMARY AND DISCUSSION OF OBTAINED RESULTS

The study on the climatic chamber characteristics for the credibility evaluation of profilometric

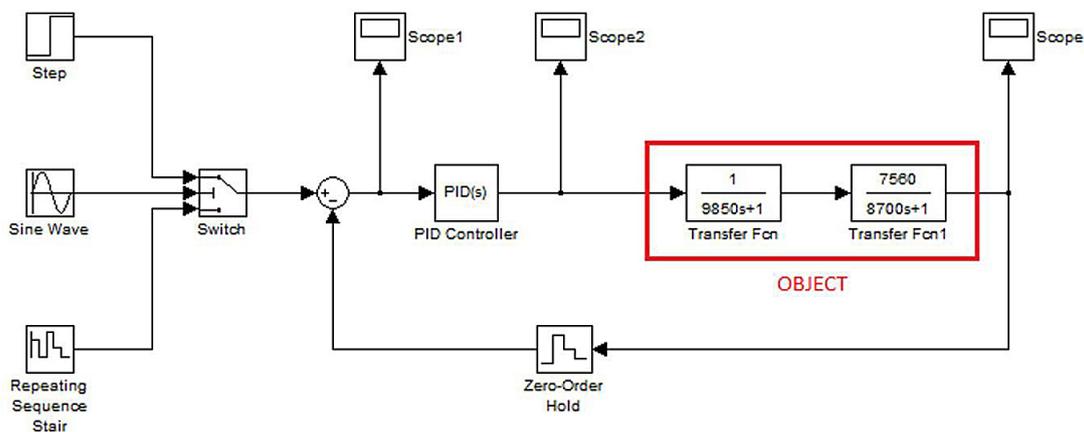


Fig. 4. The simulation model of the control system – Matlab Simulink

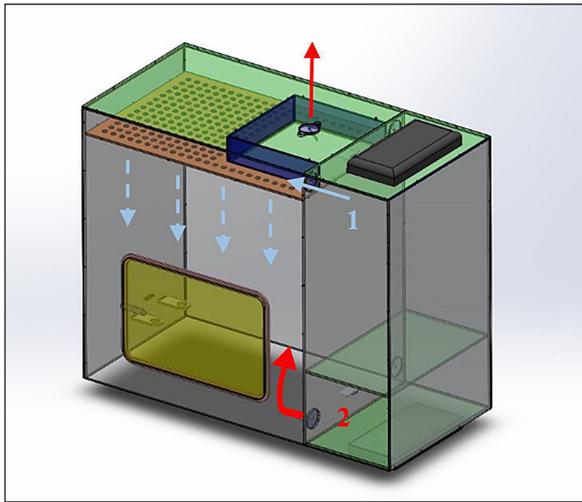


Fig. 5. The diagram of air distribution inside the climatic chamber: 1) cold air – dispersed, 2) warm air

measurements started by checking the tightness of the thermal isolation lining. The inside of the climatic chamber was heated to a temperature higher than ambient, followed by searching of leakiness in the isolating layer with the use of FLIR T620 thermal imaging camera (Fig.6) [5].

The next step in determining the characteristics of operating conditions inside the climatic chamber was to determine the features concerning the accomplishing set temperature (higher from environment temperature) as a function of time (Fig. 7) [4, 10, 29]. The characteristics of the cooling system and the time after which cooling of the inside of the climatic chamber from dedicated operating range follows and re-heating were determined as well. (Fig. 8) and (Fig. 9). These data made it possible to choose the correct parameters of the PID controller [6, 7, 18, 19, 24, 26, 32].



Fig. 6. Thermal view of diagnostics thermal isolation

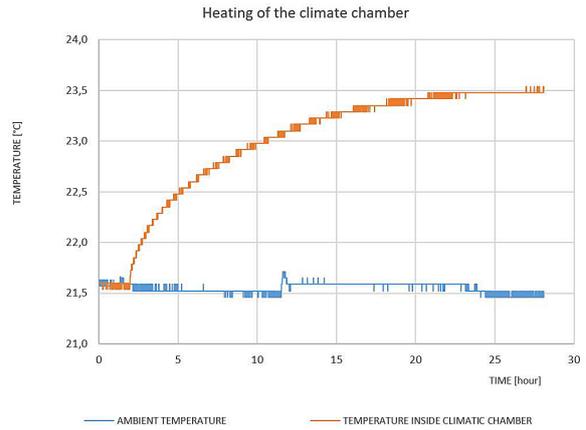


Fig. 7. The characteristics of temperature inside the climatic chamber during heating

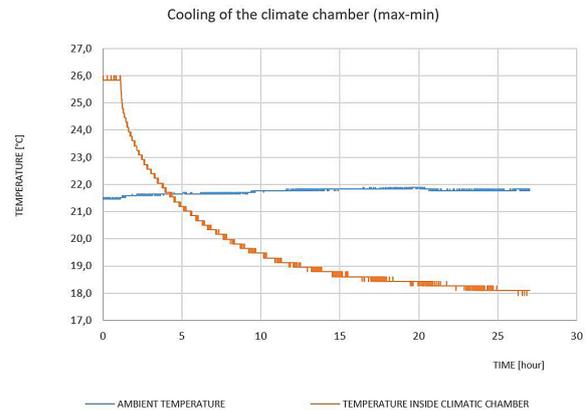


Fig. 8. The characteristics of temperature inside the climatic chamber during cooling

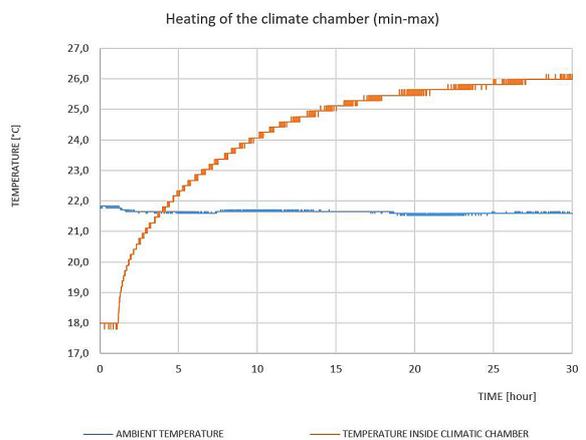


Fig. 9. Characteristics of the temperature inside the climatic chamber during the heating to the temperature below ambient

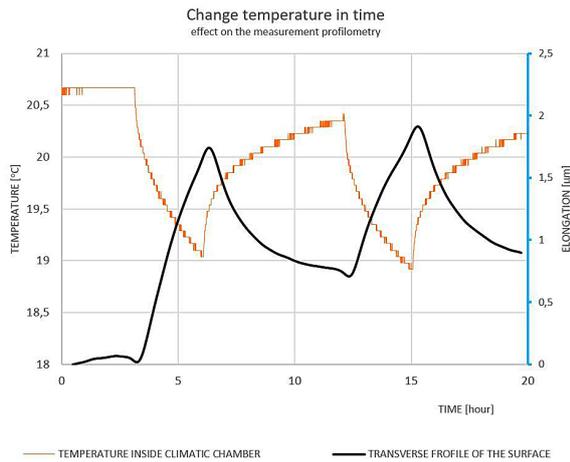


Fig. 10. Temperature variation in the time of measurements of surface topography

Illustrations (Fig.10) and (Fig.11) show the influence of the changes in environment temperature (inside chamber) on mapping of measured surface. The measured surface was model optical flat of known parameters. The nature of topography interferences corresponds to the temperature fluctuation.

CONCLUSIONS

The use of climatic chamber allowed providing stable operating conditions for the contact profilometer from the independent changes of the environment temperature. This is an important aspect which provides the reduction of external

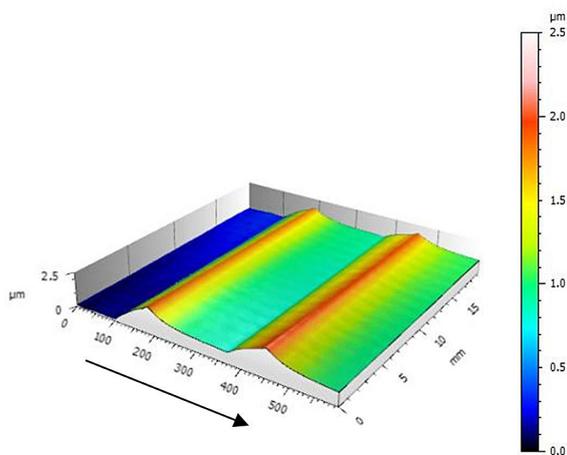


Fig. 11. The view of the surface of optical flat during measurements with the variable environment temperature

disruptions during the measurements of surface topography. The climatic chamber for the credibility evaluation of mapping of the surface topography allowed for simulating the variable conditions of the profilometer environment, which allowed determining the response of the measuring device system. This information will contribute to the creation of an error correction algorithm of surface topography as a function of changing temperatures. The applied construction solutions and microprocessor control system allow the operation of the climatic chamber in different variants, which significantly expands its application in experimental studies.

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REFERENCES

1. Blunt L., Jiang X. Introduction: the history and current state of 3D surface characterisation. *Advanced Techniques for Assessment Surface Topography*, Kogan Page Science, London and Sterling, 1-13, 2003.
2. Czaplicki A., Niedbała R., Wesołowski M. Climatic chamber with Peltier modules, *Zeszyty Naukowe Politechniki Świętokrzyskiej. Nauki Techniczne*, Z. 15, 150-159, 2010.
3. Elewa I. Kocera M., Importance of checking of stylus radius in the measurement of surface roughness, *Wear*, Vol. 109, 7-15, 1986.
4. Flakiewicz K. Wilgotność powietrza i gazów. Pomiar i wzorcowanie, *Metrologia*, Biuletyn Głównego Urzędu Miar, Vol. 4, No. 15, 3-20, 2009.
5. Grochalski K., Jabłoński P. Temperature measurements of turning with WCCo-cBN composite cutting tools, *21st International Conference on Methods and Models in Automation and Robotics*, 284-287, Międzyzdroje 2016.
6. Gürbüz R. Controlling flow rate and fluid level by Variable Frequency Drive unit, *Archive of Mechanical Engineering*, Vol. 57, No. 4, 393-404, 2010.
7. Laskawski M., Wcislik M. Sampling Rate Impact on the Tuning of PID Controller Parameters, *Int.*

- Journal of Electronics and Telecommunications, Vol. 62, No. 1, 43-48, 2016.
8. Łukaszuk M. Measurement and regulation of temperature of thermostatic chamber, *Zeszyty Naukowe Politechniki Białostockiej. Mechanika*, Z. 25, 81-89, 2003.
 9. Majchrowski R., Wieczorowski M., Cellary A. The influence of spiral sampling on surface topography parameters – simulation analysis, 11th International Conference on Metrology and Properties of Engineering Surfaces, pp. 361, Huddersfield 2007.
 10. Makowska-Woźniak I. Research of the distribution and analysis of the quality of air temperature and humidity regulation in the working space of climatic chambers, *Pomiary Automatyka Kontrola*, R. 60, No. 9, 671-674, 2014.
 11. Maszybrocka J., Stwora A., Gapiński B., Skrabalak G., Karolus M. Morphology and surface topography of Ti6Al4V lattice structure fabricated by selective laser sintering, *Bulletin of the Polish Academy of Sciences Technical Sciences*, Vol. 65, No. 1, 2017.
 12. McCool J.I. Assessing the effect of stylus tip radius and flight on surface topography measurement. *Transaction of the ASME, Journal of Tribology*, Vol. 106, 202-210, 1984.
 13. Miller T., Adamczak S., Świdorski J., Wieczorowski M., Łętocha A., Gapiński B. Influence of temperature gradient on surface texture measurements with the use of profilometry, *Bulletin of the Polish Academy of Sciences Technical Sciences*, Vol. 65, No. 1, 53-61, 2017.
 14. Pawlus P. Mechanical filtration of surface profiles, *Measurement*, Vol. 35, No. 4, 325-34, 2004.
 15. Pawlus P. The errors of surface topography measurement using stylus instruments, *Metrology and Measurement Systems*, Vol. 9, No. 3, 273-289, 2002.
 16. Pawlus P., Smieszek M. The influence of stylus flight on change of surface topography parameters, *Precision Engineering*, Vol. 29, No.3, 272-280, 2005.
 17. Pawlus P., Wieczorowski M., Mathia T. The errors of stylus methods in surface topography measurements, *ZAPOL*, Szczecin 2014.
 18. Pelc M. Self-tuning run-time reconfigurable PID controller, *Archives of Control Sciences*, Vol. 21, No. 2, 189-205, 2011.
 19. Rajinikanth V., Latha K. Setpoint weighted PID controller tuning for unstable system using heuristic algorithm, *Archives of Control Sciences*, Vol. 22, No. 4, 481-505, 2012.
 20. Rusak Z. Precyzyjna regulacja temperatury w małych urządzeniach chłodniczych za pomocą sterowania strumienia ciepła dopływającego do chłodzonego medium, *Chłodnictwo: organ Naczelnej Organizacji Technicznej*, R. 40, No. 9, 20-23, 2005.
 21. Samborski T., Zbrowski A. Accelerated assessment of the thermal condition of a prototype chamber for temperature testing, *Problemy Eksploatacji*, No. 2, 29-38, 2013.
 22. Song J. Vorburger T.V., Stylus flight in surface profiling, *ASME J. Manuf. Sci. Engr.*, Vol. 118, 188-196, 1996.
 23. Stout K.J., Sullivan P.J., Dong W.P., Mainsah E., Luo N., Mathia T., Zahouani H. The development of methods for the characterisation of roughness in three dimensions, *Publication EUR 15178 EN Commission of the European Communities*, 1993.
 24. Taler D., Sury A. Inverse heat transfer problem in digital temperature control in plate fin and tube heat exchangers, *Archives of Thermodynamics*, Vol. 32, No. 4, 17-32, 2011.
 25. Thomas T.R. *Rough Surfaces*, Imperial College press, London 1999.
 26. Tomera M. Regulator PID, *Automatyka, Elektryka, Zakłucenia*, Vol. 1, No. 2, 89-93, 2010.
 27. Vorburger T.V., Dagata J.A., Wilkening G., Iizuka K. Characterization of surface topography, *CIRP Annals*, Vol. 46, No. 2, 597-620, 1997.
 28. Wałach T. Emissivity measurements on electronic microcircuits, *Measurement*, Vol. 41, 503-515, 2008.
 29. Więcek B., De Mey G. *Termowizja w podczerwieni. Podstawy i zastosowania*, Wydawnictwo PAK, 2011.
 30. Wieczorowski M. The analysis of vibrations influence on surface roughness measurements, *Archiwum Technologii Maszyn i Automatykacji*, Vol. 18, No. 2, 77-91, 1998.
 31. Zahouani H., Variolu R., Kapsa P., Loubet J.L., Mathia T. Effect of lateral resolution on topographical images and three – dimensional functional parameters, *Wear*, Vol. 219, 114-123, 1998.
 32. DIN 50011-12:1987-09 Artificial climates in technical applications; air temperature as a climatological quantity in controlled-atmosphere test installations.