



## How to cite this article:

Authors: Paweł Pawlus, Rafał Reizer, Dominik Czach

Title of article: „Wpływ rozdzielczości pionowej na błędy pomiaru topografii obrabianych powierzchni” (“The effect of vertical resolution on measurement errors of machined surfaces topography”)

*Mechanik*, Vol. 91, No. 11 (2018): pages 988–991

DOI: <https://doi.org/10.17814/mechanik.2018.11.177>

# The effect of vertical resolution on measurement errors of machined surfaces topography

## Wpływ rozdzielczości pionowej na błędy pomiaru topografii obrabianych powierzchni

**PAWEŁ PAWLUS**  
**RAFAŁ REIZER**  
**DOMINIK CZACH \***

The effect of the quantization error on values of surface topography parameters was examined. Surface topography was measured using an optical profilometer of 0.01 nm vertical resolution. Twenty isotropic and anisotropic, one- and two-process, random and deterministic surfaces were objects of investigations. The vertical resolution was changed using TalyMap software. Tendencies of changes of three surfaces due to quantization errors were analyzed in details. Parameters of the highest and the smallest sensitivity on errors were selected.

**KEYWORDS:** surface topography, vertical resolution, quantization error

In modern technology, measuring the geometric surface structure (GSS) is very important [1]. The measurements of surface stereometry, which are very sensitive to errors, are of particular importance [2]. Errors in measuring the geometric structure of the surface can be divided into: instrumental errors, method errors, measurement errors, human factor, sample errors, environmental errors and errors in data processing [3]. The assessment of the reliability of surface topography measurements is the subject of many studies [4-7].

The method of representing the instantaneous values of an analog signal by numbers is called quantization. The quantization error is the difference between the analog value and the nearest quantization level. The vertical resolution of the digital instrument for surface roughness measurements, i.e. the smallest value that the instrument can display, depends on the measuring range and accuracy of the analog-digital converter. The uncertainty of the instrument should be minimized and the resolution should be increased by selecting the smallest measurement range - if the device has more than one range.

Quantization errors most affect the parameters associated with summits [8]. The number of quantization

levels should be as much as possible - the only limitation is the economic aspects. The minimum number of quantization levels should be 100. With an eight-bit transducer, only 50 quantization levels will occur for a signal with a normal ordinate distribution. This may lead to the disregard of some summits [9].

Thomas [10] recommends using transducers not worse than 10 and 12 bit. When measuring smooth surfaces, e.g. after polishing, quantization errors may occur, even if modern laboratory instruments are used.

This article analyzes the impact of vertical resolution on errors in the topography measurement of machined surfaces.

### Research objects

Measurements of surface stereometry were made using a white light interferometer with a vertical resolution of 0.01 nm. The measured surface area was 3.29 mm × 3.29 mm. Flat surfaces after measurements were leveled, and in the case of the others the second degree polynomial was used to remove the shape. Individual summits (spikes) and depressions were removed, cutting off the apical parts and depressions. The subject of the research were isotropic and anisotropic surfaces, one- and two-process, random and periodic.

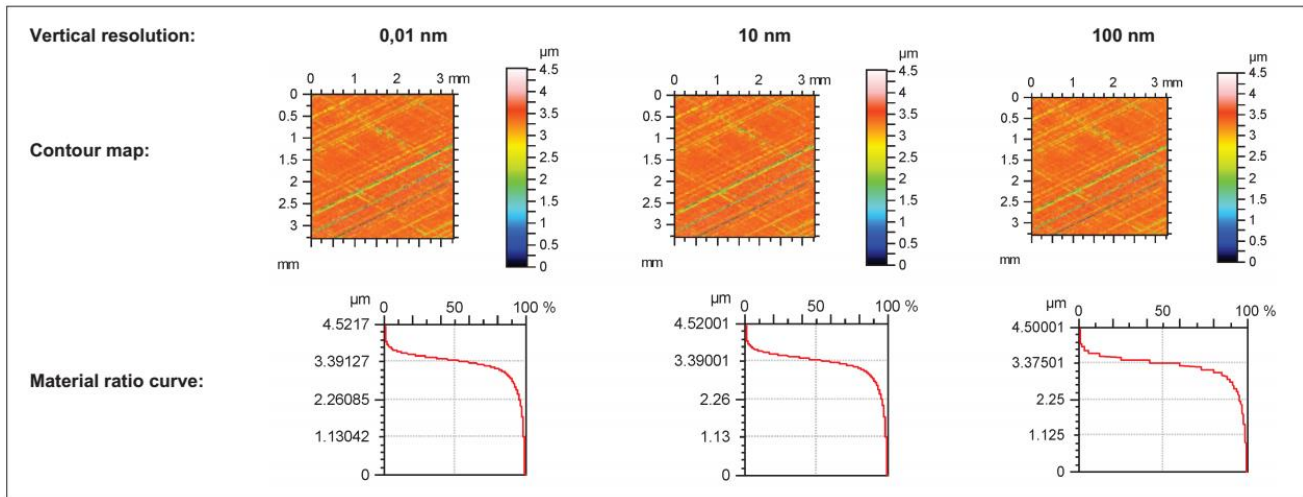
Vertical resolution was changed using the TalyMap program. Parameters included in ISO 25178 [11] were analyzed.

Three surfaces were analyzed in more detail.

### Research results and their analysis

The surface  $P_1$  is the surface of the cylinder after plateau honing. Tab. 1 presents values of its stereometry parameters for different vertical resolution. Relative quantization errors are also shown. Fig. 1 presents contour maps and graphs of the material ratios.

\* Prof. dr hab. Paweł Pawlus (ppawlus@prz.edu.pl), mgr inż. Dominik Czach (d.czach@prz.edu.pl) – Politechnika Rzeszowska; dr Rafał Reizer (reizer@ur.edu.pl) – Uniwersytet Rzeszowski

Fig. 1. Contour maps and GSS  $P_1$  material ratioTABLE I. The results of GSS  $P_1$  measurements and analyzes

Vertical resolution	0,01 nm	10 nm	Error $\Delta$ , %	100 nm	Error $\Delta$ , %	1 $\mu$ m	Error $\Delta$ , %
Parameter							
Sq, $\mu$ m	0,485	0,485	0	0,485	0	0,484	-0,21
Ssk	-2,84	-2,84	0	-2,84	0	-2,82	-0,7
Sku	14,3	14,3	0	14,3	0	14,2	-0,7
Sp, $\mu$ m	1,17	1,17	0	1,17	0	1,2	2,56
Sv, $\mu$ m	3,35	3,35	0	3,35	0	3,3	-1,49
Sz, $\mu$ m	4,52	4,52	0	4,52	0	4,5	-0,44
Sa, $\mu$ m	0,3	0,3	0	0,3	0	0,297	-1
Smr, %	38,2	38,3	0,26	39,5	3,4	42,2	10,47
Smc, $\mu$ m	0,377	0,377	0	0,379	0,53	0,4	6,10
Sxp, $\mu$ m	1,55	1,55	0	1,54	-0,65	1,5	-3,23
Sal, mm	0,0165	0,0165	0	0,0165	0	0,0165	0
Str	0,00904	0,00904	0	0,00904	0	0,00902	-0,22
Std	26	26	0	26	0	26	0
Sdq	0,103	0,103	0	0,103	0	0,104	0,97
Sdr, %	0,522	0,522	0	0,522	0	0,534	2,30
Vmp, mm <sup>3</sup> /mm <sup>2</sup>	1,28E-05	1,28E-05	0	1,25E-05	-2,34	1,02E-05	-20,31
Vmc, mm <sup>3</sup> /mm <sup>2</sup>	0,000242	0,000242	0	0,000241	-0,41	0,000211	-12,81
Vvc, mm <sup>3</sup> /mm <sup>2</sup>	0,000277	0,000277	0	0,000279	0,72	0,000289	4,33
Vvv, mm <sup>3</sup> /mm <sup>2</sup>	0,000113	0,000113	0	0,000114	0,88	0,000121	7,08
Spd, 1/mm <sup>2</sup>	1370	1366	-0,29	1357	-0,95	1005	-26,64
Spc, 1/mm	66	66	0	66,1	0,15	72,7	10,15
S10z, $\mu$ m	4,01	4,09	2	4,01	0	4,2	4,74
S5p, $\mu$ m	1,22	1,22	0	1,22	0	1,22	0
S5v, $\mu$ m	2,79	2,87	2,87	2,79	0	2,98	6,81
Sda, mm <sup>2</sup>	0,000749	0,000751	0,27	0,000748	-0,13	0,000877	17,09
Sha, mm <sup>2</sup>	0,000726	0,000727	0,14	0,000723	-0,41	0,000861	18,60
Sdv, mm <sup>3</sup>	2,73E-08	2,75E-08	0,73	2,73E-08	0	3,34E-08	22,34
Shv, mm <sup>3</sup>	2,22E-08	2,23E-08	0,45	2,21E-08	-0,45	2,77E-08	24,77
Sk, $\mu$ m	0,579	0,579	0	0,57	-1,55	0,499	-13,82
Spk, $\mu$ m	0,25	0,25	0	0,259	3,6	0,36	44,00
Svk, $\mu$ m	1,19	1,19	0	1,19	0	1,05	-11,76
Smr1, %	8,48	8,47	-0,12	9,36	10,38	12	41,51
Smr2, %	82	82,1	0,12	83,3	1,59	80,5	-1,83

At a resolution of 1 nm, the relative errors of most parameters were small or equal to zero.

With a vertical resolution of 10 nm, typical for contact profilometers, the errors were greater. The biggest discrepancies concerned the  $Sm_{r1}$  parameter, which increased by over 10% due to quantization error. The parameters  $Sm_r$  (by 3.4%),  $Sp_k$  (by 3.6%) and  $Sm_{r2}$  (by 1.59%) also increased, while the parameters  $Sk$  (by 1.55%) and  $V_m$  decreased (by 2.34%). It is interesting to change only parameters related to the material ratio curve.

When the vertical resolution was 100 nm, the stepped nature of the material share curve was observed (fig. 1), indicating the occurrence of quantization error. Only the structure orientation (parameter  $St_d$ ) and parameter  $S_{5p}$

have not changed. Among the hybrid parameters, the relative changes in the  $Sd_q$  slope were smaller than the errors of surface development  $Sd_f$ . Absolute values of relative errors of the following parameters exceeded 10%:  $Sm_r$ ,  $V_{mp}$ ,  $V_{mc}$ ,  $Sp_d$ ,  $Sp_c$ . The same was true for the characteristics parameters:  $Sd_a$ ,  $Sh_a$ ,  $Sd_v$  and  $Sh_v$ . The quantization errors of parameters related to the peak part of the surface were greater than the errors of the parameters describing the valleys.

Fig. 2 and tab. II present the results of measurements and analysis of  $P_2$  surface stereometry. It is a steel surface after blasting, characterized by a relatively high unevenness. With a vertical resolution of 10 nm, relative

errors in determining surface topography parameters are relatively small - do not exceed 2%.

At 100 nm vertical resolution, quantization errors increased, but usually did not exceed 3%. The exceptions are: the  $Sp_d$  parameter, which decreased by approx. 9%,

and the  $Sm_r$  and  $Sp_c$  parameters, which increased by approx. 6 and 4%, respectively. The parameters characterizing the shape of the ordinate distribution  $Ss_k$  and  $Sk_u$  have not changed, in addition  $Sv$ ,  $V_{vv}$  and spatial parameters -  $St_r$ ,  $Sa_i$  and  $St_d$ .

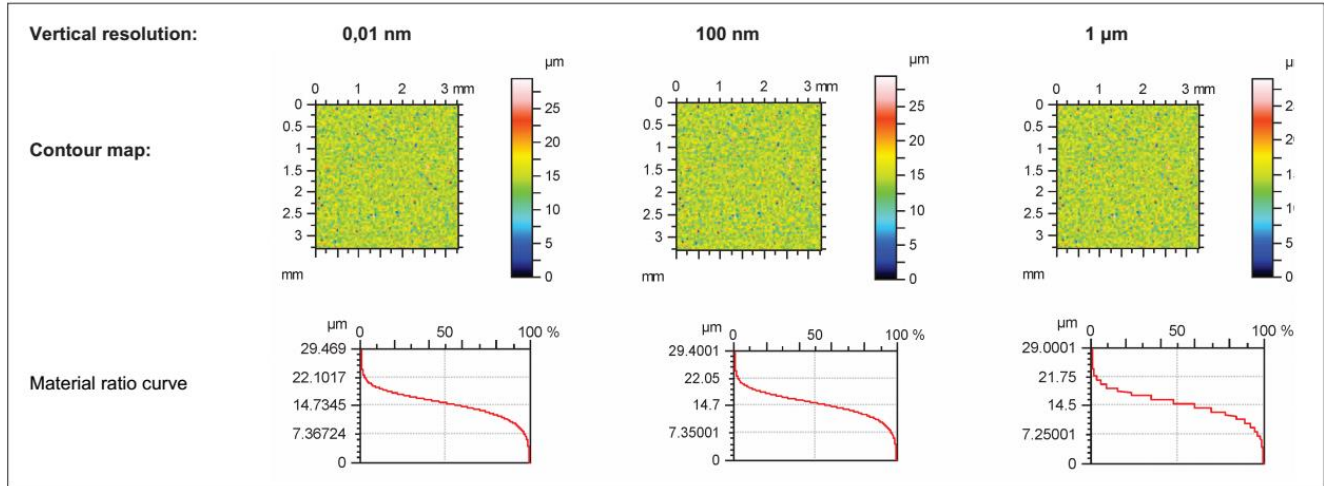


Fig. 2. Contour maps and GSS  $P_2$  material ratio graphs

TABLE II. GSS  $P_2$  measurement and analysis results

Vertical resolution \ Parameter	0,01 nm	10 nm	Error $\Delta$ , %	100 nm	Error $\Delta$ , %	1 $\mu$ m	Error $\Delta$ , %
$Sq, \mu$ m	3,75	3,74	-0,27	3,74	-0,27	3,7	-1,33
$Ssk$	-0,395	-0,395	0	-0,395	0	-0,392	-0,76
$Sku$	3,96	3,96	0	3,96	0	3,95	-0,25
$Sp, \mu$ m	14,3	14,3	0	14,2	-0,70	14	-2,1
$Sv, \mu$ m	15,2	15,2	0	15,2	0	15	-1,32
$Sz, \mu$ m	29,5	29,5	0	29,4	-0,34	29	-1,69
$Sa, \mu$ m	2,87	2,87	0	2,86	-0,35	2,81	-2,09
$Smr, \%$	0,0756	0,0751	-0,66	0,0803	6,22	0,125	65,34
$Smc, \mu$ m	4,33	4,33	0	4,31	-0,46	4,02	-7,16
$Sxp, \mu$ m	8,63	8,62	-0,12	8,59	-0,46	8,02	-7,07
$Sa_i, mm$	0,0218	0,0218	0	0,0218	0	0,0218	0
$Str$	0,846	0,846	0	0,846	0	0,847	0,12
$Std$	93,5	93,5	0	93,5	0	129	37,97
$Sdq$	0,624	0,624	0	0,623	-0,16	0,64	2,56
$Sdr, \%$	15,2	15,2	0	15,2	0	16,1	5,92
$Vmp, mm^3/mm^2$	1,79E-04	1,79E-04	0	1,81E-04	1,12	2,01E-04	12,29
$Vmc, mm^3/mm^2$	0,00317	0,00317	0	0,00316	-0,32	0,00328	3,47
$Vvc, mm^3/mm^2$	0,00398	0,00397	-0,25	0,00394	-1,01	0,00372	-6,53
$Vvv, mm^3/mm^2$	0,000537	0,000537	0	0,000537	0	0,000481	-10,43
$Sp_d, 1/mm^2$	500	495	-1	453	-9	203	-59,4
$Sp_c, 1/mm$	239	240	0,42	249	4,18	344	43,93
$S10z, \mu$ m	26,8	26,7	-0,37	26,6	-0,75	25,8	-3,73
$S5p, \mu$ m	11,8	11,8	0	11,7	-0,85	11,4	-3,39
$S5v, \mu$ m	15	15	0	14,9	-0,67	14,4	-4
$Sda, mm^2$	0,00164	0,00164	0	0,00163	-0,61	0,00177	7,93
$Sha, mm^2$	0,00197	0,00198	0,51	0,00196	-0,51	0,00218	10,66
$Sdv, mm^3$	8,01E-07	8,01E-07	0	7,87E-07	-1,75	9,03E-07	12,73
$Shv, mm^3$	6,29E-07	6,30E-07	0,16	6,12E-07	-2,7	7,16E-07	13,83
$Sk, \mu$ m	8,49	8,48	-0,12	8,5	0,12	7,02	-17,31
$Spk, \mu$ m	3,48	3,48	0	3,52	1,15	4,65	33,62
$Svk, \mu$ m	5,16	5,16	0	5,06	-1,94	4,22	-18,22
$Smr1, \%$	9,06	9,06	0	8,87	-2,1	14,8	63,36
$Smr2, \%$	88,6	86,6	-2,26	86,5	-2,37	84,5	-4,63

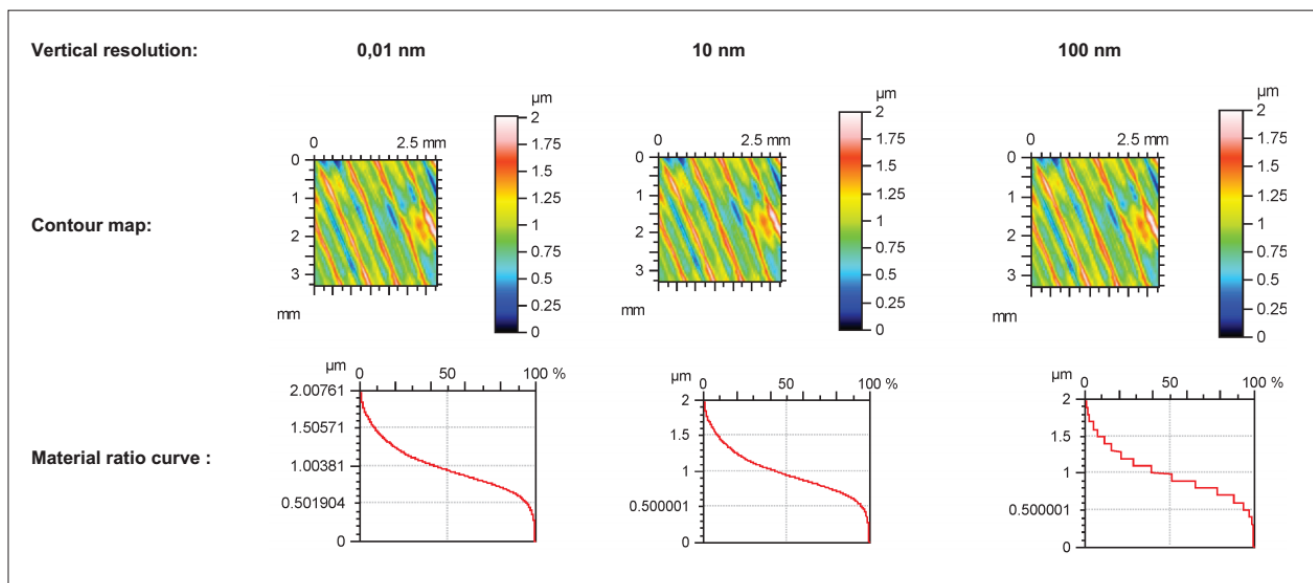


Fig. 3. Contour maps and GSS  $P_3$  material ratio charts

With a  $1 \mu\text{m}$  vertical resolution, all parameters changed outside  $Sa_i$ . A significant increase in the value of the  $St_d$  parameter - by approx. 38% - results from the isotropic character of the surface. The values of the following parameters have increased by more than 20%:  $Sm_r$ ,  $Sp_d$ ,  $Sp_c$ ,  $Sp_k$  and  $Sm_{r1}$ . Slight changes related to  $Ss_k$  and  $Sk_u$  parameters as well as spatial parameters of  $Sa_i$  and  $St_r$ . Generally confirmed were significant changes in parameters related to summits and some parameters related to the material ratio graph due to the occurrence of quantization error.

The last analyzed surface was  $P_3$  surface after milling (fig. 3).

When the vertical resolution was 10 nm, there were quantization errors, but they did not concern the  $Ss_k$ ,  $Sk_u$  and  $S_v$  parameters as well as  $Sa_i$ ,  $St_r$  and  $St_d$  spatial parameters. The absolute values of relative errors did not exceed 5%, with the exception of the parameters of  $Sd_a$ ,  $Sh_a$ ,  $Sd_v$  and  $Sh_v$ .

When the relative resolution was 100 nm, only the orientation of the structure did not change, which is characteristic for anisotropic surfaces. The values of the following parameters have changed by more than 20% due to quantization error:  $Sm_r$ ,  $Sd_r$ ,  $Sp_d$ ,  $Sd_a$ ,  $Sh_a$ ,  $Sd_v$ ,  $Sh_v$  and  $Sp_k$  and  $Sv_k$ . Amplitude and spatial parameters have changed slightly.

Based on the analysis of quantization errors of other surfaces, it was confirmed that the stepped nature of the material ratio curve indicates the existence of quantization error. Especially the  $Sm_r$  parameter is sensitive to this error, but does not depend on the vertical resolution. Quantization error causes significant changes in parameters related to summits - the density of peaks usually decreases and their curvature increases. Vertical parameters do not change significantly (up to 10%).

The parameters from the  $Sk$  group obtained on the basis of the material ratio diagram are more sensitive to quantization errors than the  $V$  family parameters.

Hybrid parameters increase due to quantization errors, with the  $Sd_q$  parameter being more constant compared to  $Sd_r$ . In turn, the quantization error has little effect on the spatial parameters values. With regard to the two-process surfaces, the parameters characterizing the peak part are more sensitive to the occurrence of quantization error than the parameters describing a part of the valleys. Feature parameters  $Sd_a$ ,  $Sh_a$ ,  $Sd_v$  and  $Sh_v$  change significantly due to quantization errors and should not be used in routine surface measurements. Structure orientation does not change with anisotropic surfaces.

## Conclusions

The uplifting nature of the material ratio graph indicates the occurrence of quantization error, which causes significant changes in summit density. The  $Sm_r$  parameter is sensitive to quantization errors. Also the parameters of features -  $Sd_a$ ,  $Sh_a$ ,  $Sd_v$  and  $Sh_v$  - are clearly changing as a result of these errors, as are the distinguishing features obtained on the basis of the material ratio chart, especially from the  $Sk$  group.

Quantization error has little effect on spatial parameter values. Vertical parameters do not change significantly.

The parameters characterizing the peak part of the two-process surfaces are more sensitive to the quantization error compared to the parameters describing a part of the valleys.

## REFERENCES

- Adamczak S. „Pomiary geometryczne powierzchni, zarysy kształtu, falistość i chropowatość”. Warszawa: WNT, 2008.
- Pawlus P., Mathia T., Wieczorowski M. „The errors of stylus method in surface topography measurements”. Szczecin: ZAPOL, 2014.
- Miller T. „Źródła wiarygodności pomiarów topografii powierzchni”. *Mechanik*. 11 (2016): pp. 1722–1723.
- Wieczorowski M., Gapiński B., Grochalski K., Miller T. „Teoretyczne aspekty analizy wybranych źródeł błędów w profilowych pomiarach nierówności powierzchni”. *Mechanik*. 4 (2017): pp. 325–327.
- Adamczak S., Świdorski J., Dobrowolski T. „Wybrane zagadnienia stykowych pomiarów struktury geometrycznej powierzchni”. *Mechanik*. 4 (2017): pp. 328–331.
- 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 Science – Technical Science*. 65, 1 (2017): pp. 53–61.
- Świdorski J., Dobrowolski T. „Zasady dobrej praktyki dla pomiarów chropowatości po bardzo dokładnym toczeniu”. *Mechanik*. 8–9 (2016): pp. 1140–1141.
- Pawlus P. „Topografia powierzchni. Pomiar, analiza, oddziaływanie”. Rzeszów: Oficyna Wydawnicza Politechniki Rzeszowskiej, 2005.
- Whitehouse D.J. “The digital measurement of peak parameters on surface profiles”. *Journal of Mechanical Engineering Science*. 20, 4 (1978): pp. 221–227.
- Thomas T.R. “*Rough Surfaces. Second Edition*”. London: Imperial College Press, 1999.
- Leach R. (red.). “*Characterisation on areal surface texture*”. Berlin: Springer-Verlag, 2013.
- Pawlus P., Reizer R., Wieczorowski M. “Problem of non-measuring points in surface texture measurements”. *Metrology and Measuring Systems*. 24 (2017): pp. 525–536. ■

Translation of scientific articles, their computer composition and publishing them on the website [www.mechanik.media.pl](http://www.mechanik.media.pl) by original articles in Polish is a task financed from the funds of the Ministry of Science and Higher Education designated for dissemination of science.



**Ministry of Science  
and Higher Education**

Republic of Poland