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Improvement of the operational characteristics of polymeric scintillation detectors and optophotonic components

Sergiy Lavrynenko[1], Oleg Lavrynenko[1], Miroslaw Rucki [2], Dmitriy Volontsevich[1], Zbigniew Siemiatkowski [2]

[1]*National Technical University "KhPI" Kirpichova str., 2, 61002, Kharkov, Ukraine*
[2]*Kazimierz Pulaski University of Technology and Humanities in Radom, Faculty of Mechanical Engineering, Krasickiego Str. 54, 26-600 Radom, Poland*

Email address of the submitting author: m.rucki@uthrad.pl

Abstract
The paper describes the methods for the monitoring and improving of operational parameters of the polymeric scintillation detectors and optophotonic components in the surface layer forming process and shows some results of the quality control of ultraprecision optical surface in nanoscale. Important correlations between machining conditions, surface characteristics and long-term performance of polymeric scintillation detectors were found.

Keywords: polymers, optics, scintillators, surface layer, ultraprecision single-point diamond machining

1. Introduction

Development of nuclear and solar energy production, elementary particle physics, processes involving radionuclides and sorption lead to a wider use of polymeric scintillators and detectors, as well as other optophotonic components.

Improvement of the polymer products surface layer quality at the stage of its formation during the cutting process is an important problem. Properly solved, it leads to improved performance, increased efficiency and prolonged durability of photonic-optical polymer products, e.g. for luminescent and nuclear detectors, tiles for accelerators of charged particle and calorimeters, planar lightguides, solar light converters, etc.

Precise single-point diamond machining proved to be one of the most effective technological method for generation of the polymer components high quality optical surfaces [1]. Desired yield efficiency (y.e.) and durability depend not only on the polymer quality, but also on micro- and nano-geometrical structure of the surface layer. The results of experimental investigations has determined the mechanism of cutting conditions influence on longevity and functional properties of the finished high quality surface of the thermoplastic polymer scintillation detectors and optophotonic components. These are, among others, high transparency and homogeneity, high light output and maximum emission, short decay time, radiation firmness and optical stability.

2. Methodology

Theory of polymer destruction at the micro level is still not worked out. Recent achievements in the field of polymer destruction mechanics and new methods of modelling enable to study cutting process of these materials and to propose new approach to the creation of special ultraprecision surfaces. It applies theoretical basis of macrodestruction as well as microscale experimental data.

The mechanics of ultraprecision diamond single-point diamond cutting of polymeric components is a dominant link in definition of deformation and contact processes in cutting zone. In essence, it is a key to ensure stable high operating characteristics of the polymeric scintillation detectors and optophotonic components.

2.1. Direct control of new surface generation process

The effective method for direct control of the new surface generation by precision cutting is the mechanoluminescence method, i.e. estimation of luminescence intensity characterized by photoemissivity. The mechanoluminescence is a result of the polymeric material destruction and the flow of photons is a product of micro-destruction process. It is an original information carrier about polymer strain and the photon impulse registers practically without inertia. Thus, the method can be used directly in the real cutting process. It makes possible to monitor fractures during new surface formation and to control the process of polymers precision machining at the level of micro-mechanics [2, 3].

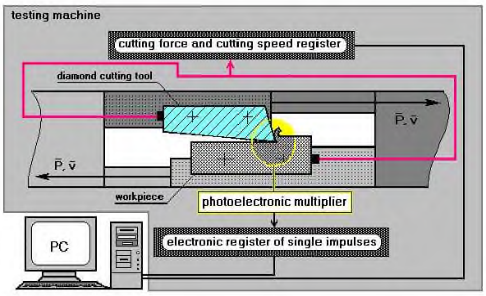

Figure 1. The test bench for modelling of diamond machining process and micromechanics investigation

The advantage of this method, based manly on [3], is the possibility of its application directly in the process of machining in real-time production conditions.

2.2. Investigation of cutting zone temperature in dynamics

In the dynamic process of polymeric optics machining, one of the most important physical factors determining to a considerable extent the conditions of formation of layer surface quality of optical products is heat generation. It is determined by specific characteristics of the polymeric optical materials, such as low heat conductivity and low thermal stability. To perform inexpensive investigation and modelling of thermodynamical characteristics, new method was developed for registration of temperature expansion dynamic into the polymer during the surface generation process by single-point macrocutting. In the method, semi-artificial thermocouple was placed on the back surface of a diamond tool was applied.

2.3. Components conditions control

The most effective and quick non-contact measurement technique for surface microstructure assessment like roughness parameters is the interferometry. Lack of contact is especially important with as soft materials as thermoplastic polystyrene. For surface layer conditions investigation and testing the white-light and laser interferometers and optical profilers WYKO RST500 were used. Analysis of the geometrical parameters was performed by a 3D Topographic Analysis (Rank Taylor Hobson Form Talysurf Series) and the surface layer submicrostructure conditions were monitored with an Atomic Force Microscope (TopoMetrix) [4].

In the study of radiation resistance, polymer optical elements machined with the tools of the same cutting part optimum geometry but made out of different instrumental materials were irradiated with a gamma source of ^{60}Co in a dose range of 1-300 Mrad with a dose rate of 700 R/s. The dose rate was determined by the ferrosulfate method.

The light yield (C) was determined by excitation with a $^{90}Sr+^{90}Y$ ($E_{\beta 1}$ = 0,196 MeV и $E_{\beta 2}$ = 0,960 MeV) with registration with a photomultiplier type 9954KA Thorn Emi Electron Tubes.

3. Improvement of polymer scintillators quality

Required high quality of the surface layer of polymer optics products with minimal defectiveness was achieved most effectively at low cutting speeds (v < 30 m/min) with small cross sections of a single-edged cutting tool with the least possible radius of rounding of the cutting edge [5]. Increase the cutting speed when using a traditional high-speed cutting tool and carbide tools, as well as a tool equipped with synthetic diamond, already at v > 50 m/min had some negative consequences. In those cases, the silver cracks appeared on the machined surface due to exceeding critical temperatures in the cutting zone, which irreversibly degraded the performance characteristics of the finished product. When using a tool equipped with a natural diamond single crystal, these negative phenomena disappeared. In the range of ultra-low (v = 1-30 m/min) and ultrahigh (v > 2000 m/min) cutting speeds, at the conditions of sharpening of the blade with ultra-precision equipment, the surface roughness measured by the arithmetic mean deviation of the profile was 1.5 to 3 times lower than after machining on high accuracy machines.

In Fig. 2, profilograms of polystyrene surfaces processed with different parameters of the cutting regime are shown. Numbers 1, 5 and 13 correspond with the sample numbers, and respective Ra values are given below. Despite significant differences in the values of the parameters of the cutting regime, their roughness represented by Ra parameter of the profile differs insignificantly. Namely, average values along the direction of the main cutting motion were Ra_1> = 0.026 µm, Ra_5> = 0.019 µm, Ra_{13}> = 0.037 µm , while in the transverse direction Ra_1^ = 0.111 µm, Ra_5^= 0.099 µm, Ra_{13}^= 0.142 µm. However, significant difference in the nature of the formed micro-topography largely affected the performance characteristics, in particular, the light yield indicator of scintillator.

As a result of the conducted studies it was proved that after diamond blade sharpening, the loss of radiation resistance of polymer components is 3.5 to 10 times less in comparison with the loss of radiation resistance of similar optical elements whose functional surfaces were treated with a tool made of high-speed steel, cermet, and synthetic diamonds.

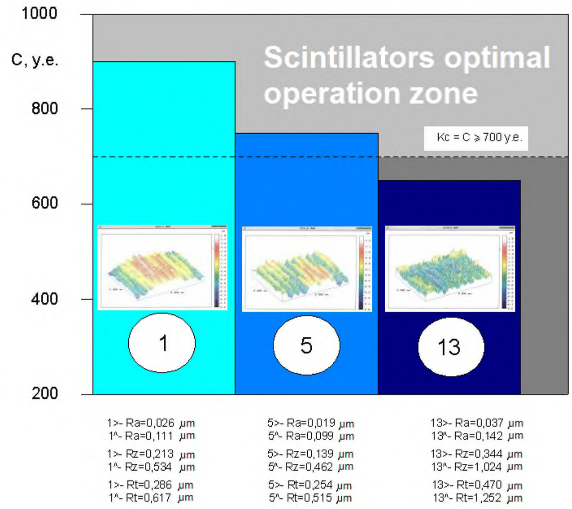

Figure 2. Influence of formed surface microrelief features on light yield indicator of scintillators

Along with the increase in radiation resistance after diamond blade processing, the light yield (C), which may be treated as an integrated indicator of the quality of the finished polymer optical product, also increases.

4. Summary

The results of analysis and modelling of the micromechanical behaviour of thermoplastic optical polymers during the ultraprecision surface layer generation process by the single-point diamond micromachining open the ways and means for elaboration of new technological decisions. They lead also to a comprehensive approach for the manufacturing of a wide variety of high quality and longevity polymeric optics with required operating characteristics.

The theoretical and practical developments based on the proposed technological process were used in the production of plastics scintillators "tiles" for Compact Muon Solenoid. It created a unique detector for experiments in the field of particle physics based on accelerators built with CERN (Geneva, Switzerland) with record energy and, in particular, for one of the most responsible units of the detector of elementary particles, namely, the Calorimeter of Large Hadron Collider. This work was carried out in cooperation with the National Scientific Center "Kharkov Physical-Technical Institute".

References

[1] S.S. To, H. Wang, W.B. Lee, Materials Characterisation and Mechanism of Micro-Cutting in Ultra-Precision Diamond Turning, Springer Berlin 2018, pp. 7-16

[2] Lavrynenko S.N., Verezub N.V., Krauja U.I., and Kalnin P.P. (1987): Method of Estimation of Materials Machinability by Mechanoluminescence. USSR Patent No **1663508**

[3] Verezub N.V., Krauya U.E., Kalnin P.P., and Lavrinenko S.N. (1991): Use of the method of mechanoluminescence to study the micromechanics of the cutting of polymer composites // *Mechanics of Composite Materials*, Springer New York: 1991, V. **27**, Iss. **2**, pp. 207–211. DOI: 10.1007/BF00614740

[4] Yoshizawa T. (Ed.), Handbook of Optical Metrology: Principles and Applications, CRC Press, Boca Raton, 2015, pp. 791-828

[5] Lavrynenko S.N., and Jarmak N.S. (2011) Investigation of dynamic characteristics of optical polymers cutting process // *J. of Mechanics and Machine-building* 2011, **1**, 155-162