Control the quality of polymers based on the model of Dzeno

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Abstract. Numerical methods for solving mathematical problems describing the state of complex physical systems in modern digital production can be used to assess the quality and viability of materials used in additive manufacturing. In this article, the Dzeno model is chosen, as the physical behavior of the body under dynamic load and the gradual attenuation of the load.

1. Introduction to modeling as an opportunity to assess quality
The MATLAB system is a high-level programming language designed for engineering and scientific computing and the creation of modeling tools for various devices and systems. For ease of use, the entire MATLAB system is divided into sections designed in the form of software packages, the most common of which formed the core. Other packages are combined or exist individually as so-called Toolboxes. Of particular note is the Simulink package, which is designed for modeling linear and nonlinear dynamical systems. Simulink is one of the earlier in the text Matlab subsystems that provides a simple and intuitive procedure for modeling processes in dynamic systems [1].

Thanks to the simulation of physical processes, it will be possible to improve the quality of polymers and their strength properties.
Figure 1. A variety of polymers for modeling the elasticity of a composite material.

The term hardness refers to the ability of a polymer material to resist being pressed into it by other bodies. In fact, it characterizes the mechanical properties of the surface of the material. It is affected by temperature, the magnitude and speed of the applied force, and other external factors. Soft and elastic polymer materials with low hardness can be used as sealants, sealing and sealing materials. In contrast to elastics, solid polymer materials are used for the manufacture of structural parts, namely, brake systems, gears and bearings, parts of threaded connections [2]. Which requires a high strength of the material.

The values of the hardness measurements are used to optimize the content of the plasticizer, the amount and type of filler, and the conditions for processing into products. In addition, the following characteristics are judged by the hardness value:

- Elasticity module,
- Poisson coefficient,
- Plasticity,
- Elasticity.

To determine the hardness, use methods that differ in the geometry of the indenter: Brinell, Rockwell, Vickers [3].

The paper proposes the evaluation of strength properties of the polymer but the mathematical model of Dzeno, when the behavior of a ball of polymer in an ideal simulation environment with specified mechanical properties and depending on the settings selected by observing the behaviour of polymer ball to rate quality composite resin material.

GOST 4670-70 prescribes to determine the hardness of the polymer material to use the Brinell method with the measurement of the depth of the indenter h [4].

The Brinell hardness value (HB) is calculated using the formula:

\[ HB = \frac{N}{\pi \cdot d \cdot h}, Pa, \]

Figure 2 shows the dependence of hardness (HB) on the effort of N.

![Figure 2](image-url)
2. Building a polymer behavior

The system of assessing the quality of polymer-based polymer ball and it bounces like a hybrid system is a dynamic system which displays both continuous and discrete dynamic behavior – a system that is described by the equation distinctive and jump are described by a difference equation or controlled by a graph.

The term "hybrid dynamic system" is used to distinguish between hybrid systems, such as those that combine neural networks and fuzzy logic, or electric and mechanical automotive transmissions. A hybrid system has the advantage of affecting a larger class of systems within its structure, allowing for more flexibility in modeling dynamic phenomena.

In general, the hybrid system is defined by the values of continuous variables and discrete control mode. The hybrid system changes either continuously, according to the flow condition, or discretely according to the control graph. Continuous flow is allowed as long as the so-called invariants hold, while discrete transitions can occur once the given jump conditions are satisfied. A discrete transition can be associated with events [5].

Application example. Hybrid systems have been used to model several cyber-physical systems, including physical systems with impact, logic-dynamic controllers.

3. Bouncing Ball

The canonical example of a hybrid system under consideration is a bouncing ball, a physical system with an impact. Here, the ball is excluded from the initial height and strong impacts from the ground, dissipating its energy with each strong impact. The ball shows continuous dynamics between each violent impact; however, as the ball impacts the earth, its velocity undergoes a discrete change modeled after an inelastic collision. A mathematical description of the bouncing ball follows. Let be the height of the ball and be the speed of the ball. The idea is that depending on the bounce of the ball, you can evaluate the quality of the material that the ball is made of. The hybrid system describing the ball is as follows:

Ball behavior in simulation. When, the flow is controlled by

\[
\dot{x}_1 = x_2,
\]

\[
\dot{x}_2 = -g,
\]

where acceleration is due to gravity. These equations state that when a ball is above the ground, it is pulled to the ground by gravity [7].

Ball behavior in simulation. When, ball jumping controls

\[
x_1^+ = x_1,
\]

\[
x_2^+ = \gamma x_2
\]

Where in the simulation

The bouncing ball is a particularly interesting hybrid system, as it shows Zen behavior. Zen behavior has a strict mathematical definition, but can be described informally as a system that makes an infinite number of jumps in a finite amount of time.

The simplest contact model, which represents the interactions between the ball and the ground, is the relationship of the interdependence between the force and the distance (gap) between the ball and the ground. Demonstrated as:

\[
0 \leq \lambda \perp x_1 \geq 0
\]

This contact model does not include magnetic forces or bonding effects. When a relationship of interdependence are in, you can continue to integrate the system after impact have been and gone: the balance of the system is clearly defined by the static equilibrium of the ball on the ground under the action of gravity, the compensation force of the contact. One also observes from basic convex analysis that the interdependence relation can equivalently be rewritten as an inclusion in a normal cone, so that the dynamics of the bouncing ball is a distinctive inclusion in a normal cone to a convex set. Build a
model train station in the area of computer mathematics for the evaluation of quality indicators of polymers [8]. This paper presents the Dzeno model "Bouncing Ball", built on the basis of MATLAB Simulink, on the basis of this model, an attempt is made to evaluate the quality of the polymer depending on its physical properties.

Figure 3. Model of the jumping ball.

It is possible to simulate not only the material, but also the rebound surface, traditionally in additive miniature additive installations used glass or aluminum substrate with a protective layer of the hot table.

Figure 4. Modeled mof egg tossed at a speed of 15 m/s from a height of 10 m.

After adding a constant and data on the height of the ball to the working field, the desired "Bouncing Ball" model is formed, enclosing the data in the formula below:

\[
\frac{dx}{dt} = v,
\]

When the ball loses energy in the bouncing ball model, a large number of collisions with the ground begin to occur in consistently smaller time intervals. Therefore, the model tests the Dzeno behavior. Zen behavior models allow you to evaluate the behavior of the material in the time interval and the number of bounces of the ball, which is simulated on a computer, but simplified in many engineering applications [9].
Figure 5. Oscillating settings from a base test height in a virtual environment of 10 m.

Figure 6. The layout of the ball.

Figure 7. Ball speed graph.

Sections from the Simulink library such as:
- Continuous are blocks of analog (continuous) signals.
- Discontinuous blocks are non-linear elements.
- Discrete blocks of discrete (digital) signals.
- Look-Up Tables are blocks for creating tables.
- Model Verification is a block for checking signal parameters.
- Model-Wide Utilities — additional utilities subsection.
- Port and Subsystems are ports and subsystems.
- Signal Attributes are blocks for changing signal parameters.
- Signal Routing are blocks that determine signal routes.
- Sinks are receivers and signal meters.
- Sources are the sources of signals.
- User—Defined Function — user-defined functions.

![Diagram](image)

**Figure 8.** Built model of Dzeno.

The resulting model is as follows:

![Diagram](image)

**Figure 9.** Jumping Ball Scheme

4. Conclusion
The introduction of terms: speed (down), elasticity (losing energy), acceleration of free fall. The second-order integrator converts the data entered and calculates the second-order integral, which does not end until the speed drops to 0 (memory controls the further multiplication of the results obtained.

In this article, we considered the model of a bouncing ball based on MATLAB Simulink using various sections of the library. The main concepts of control systems were analyzed, based on which it is possible to evaluate the quality of a composite polymer based on its behavior.

Polymer quality management based on the Dzeno model is impossible without the introduction of additional evaluation parameters and characteristics of the polymer. The Dzeno model can be used as a supplement for evaluating the strength properties of polymers.

References
[1] Chabanenko A V, Kurlov A V, Smirnova A S, Getmanova G V and Gulevitskiy A U 2019 Application of numerical simulation systems when using composite materials used in additive production *IOP Conf. Ser.: Mater. Sci. Eng* **537**(3) 032034

[2] Chabanenko A V, Kurlov A V and Tour A C 2020 Model to improve the quality of additive production by forming competencies in training for high-tech industries *J. Phys.: Conf. Ser.* **1515** 052065
[3] Chabanenko A V and Yastrebov A P 2018 Quality Assurance of Hull Elements of Radio-Electronic Equipment by Means of Control System *J. Phys.: Conf. Ser.* **1515** 052065

[4] Chabanenko A, Frolova E, Balashov V and Smirnova M 2018 Electrodynamic analysis of materials for the antenna elements *IOP Conf. Ser.: Mater. Sci. Eng.* **537** 032034

[5] Batkovskiy A M, Kalachikhin P A, Semenova E G, Fomina A V and Balashov V M 2018 Configuration of enterprise networks *Entrepreneurship and Sustainability Issues* **6(1)** 311–28

[6] Batkovskiy A M, Nesterov V A, Semenova E G, Sudakov V A and Fomina A V 2017 Developing intelligent decision support systems in multi-criteria problems of administrative-territorial formations infrastructure projects assessment *Journal of Applied Economic Sciences* **12(5)** 1301-11

[7] Maiorov E E, Prokopenko V T, Mashek A C, Tsygankova G A, Kurlov A V, Khokhlova M V, Kirik D I and Kapralov D D 2018 Experimental study of metrological characteristics of the automated interferometric system for measuring the surface shape of diffusely reflecting objects *Measurement Techniques* **60(10)** 1016-21

[8] Chabanenko A V, Semenova E G, Smirnova V O, Smirnov A O and Rozhkov N N 2018 Quality assurance of additive manufacturing by means of a layer-by-layer synthesis control system *Issues of radio electronics* **10** 17-24

[9] Chabanenko A V 2018 Quality management of radioactive electronic equipment *RIA: Journal: "Standards and Quality"* **2** 90-4