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IMPROVING THE ACCURACY OF PRODUCTS IN THEIR BUILDING BY SELECTIVE LASER SINTERING USING COMPENSATING DEFORMATIONS OF INITIAL TRIANGULATED MODELS

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ABSTRACT

Questions of technological preparation of triangulated models of industrial products for their building by selective laser sintering are considered. The need to implement compensating deformations on the stage of the technological preparation is justified. It is shown that the use of compensating deformation creates preconditions to improve the accuracy of products in their building by selective laser sintering.

INTRODUCTION

Selective laser sintering (SLS) by materialization of 3D models is performed to sinter powdered material. One of the features of SLS technology is the appearance of permanent deformation of parts.

As a result of heating and subsequent cooling down of the material accompanied by inhomogeneous temperature fields when building products occurs nonuniform volume shrinkage. This shrinkage brings to internal stress which can lead to permanent bending deformation. Bending deformation is characterized by change or appearance of surface curvature of SLS parts [1, 2]. Permanent deformation brings to deviation of correct geometric shape which may adversely affect for functionality and assemblability.

Existing methods do not allow reliably predicting the deformation of SLS parts [1, 2]. Using these methods, determine the character of permanent deformation and deflection by standard products. Form accuracy of part is determined by the base flat surfaces. Therefore, an important task for improving the accuracy of SLS products is to reduce the form error of base surfaces and joint faces.

In SLS systems the parts are manufactured on basis of triangulation model (STL-file) which contains coordinates of triangles vertices – V_1 (V_{x1}, V_{y1}, V_{z1}), V_2 (V_{x2}, V_{y2}, V_{z2}), V_3 (V_{x3}; V_{y3}; V_{z3}) and direction cosines of normal vectors – N_x, N_y, N_z. Triangulation model is obtained the approximation of CAD- model surface the connected triangles with a given accuracy [3]. Therefore, in the step before materialization performed triangulation of CAD model with the post-technological preparation (fig. 1).

The main technological tasks of 3D models preparation to the materialization are reversible structural decomposition, rational spatial orientation, transformation which compensates for shrinkage and optimal placement of parts in the working space of SLS system [4].

To minimize deviations from the correct geometrical form proposed to carry out technological compensated deformation of triangulated models in preparation for materialization.

The aim of article is an approach to improve the building accuracy of SLS systems by application of technological compensating deformation for initial triangulated models.

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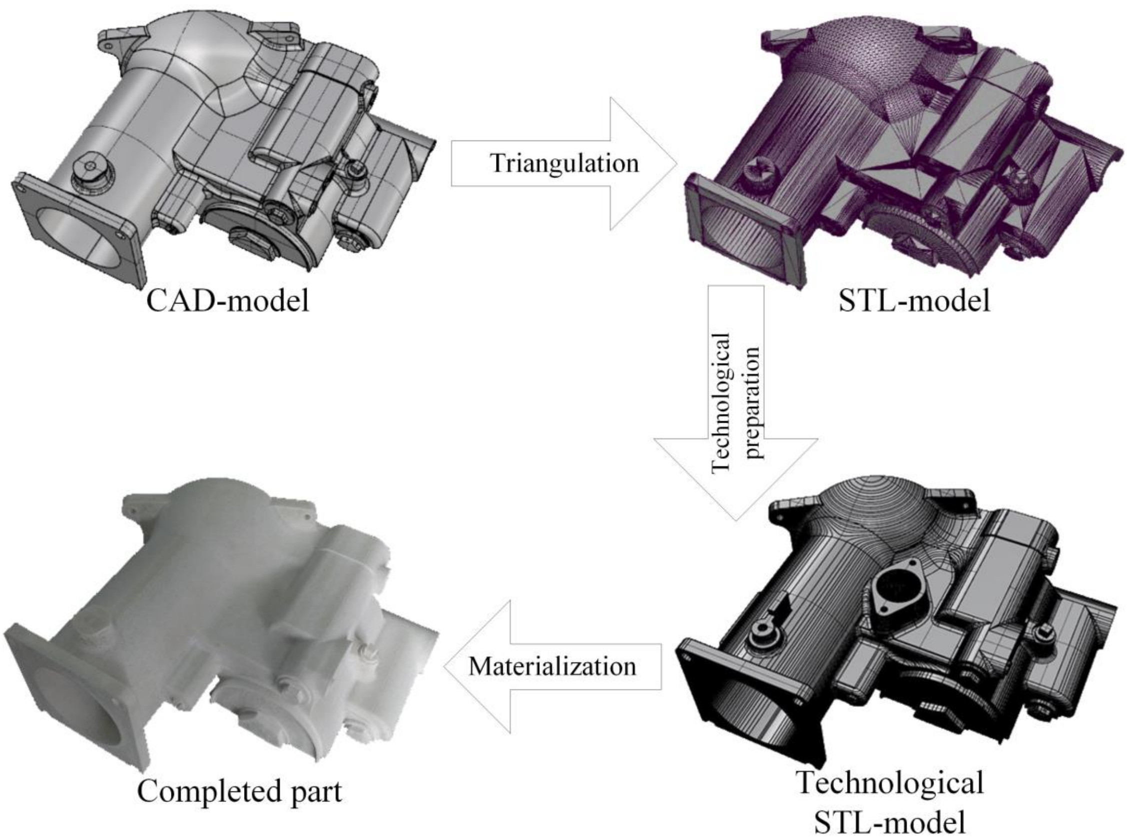


Fig. 1
Scheme of technological transition from CAD-model to the part

APPLICATION OF TECHNOLOGICAL COMPENSATING DEFORMATION FOR INITIAL TRIANGULATED MODELS

Deformation of a triangulated model δ_i (in geometrical sense) means a change of vertices coordinates z_i in the building direction (Z axis), depending on values of the coordinate x_i, y_i in building plane (X-Y axes):

$$z_i = z_i^* \pm \delta_i;\ \delta_i = f(x_i, y_i) \neq \text{const},$$

where z_i, z_i^* - the deformation and initial values of vertex coordinates; $f(x_i, y_i)$ - deformation function.

To implement the proposed approach developed a special software subsystem of deformation/transformation of STL-models on the basis of morphological analysis system (fig. 2).

Technological compensating deformation must comply with function of predicted (expected) residual deformation of the part and be reversed in sign. The function and its parameters are selected according to the results of production tests. Sag δ and relative displacement of center of the deformation curvature k_c are the main parameters of compensating.

Technological compensating deformation can be positive or negative (fig. 3). Sign of bending increment corresponds to the sign of deformation: convex is plus (*XP*, *YP*) and concave is minus (*XM*, *YM*). Convex deformation of triangulated model is changing vertex coordinates in a positive way from superimposed (zero) plane to model edges in the X and/or Y axis and negative when concave deformation.

The subsystem is possible to perform three types of deformation for triangulated model: radial spherical and exponential. Each deformation type has a deformation function. The deformation type is selected on basis of geometric features of the product (sizes ratio and shape).

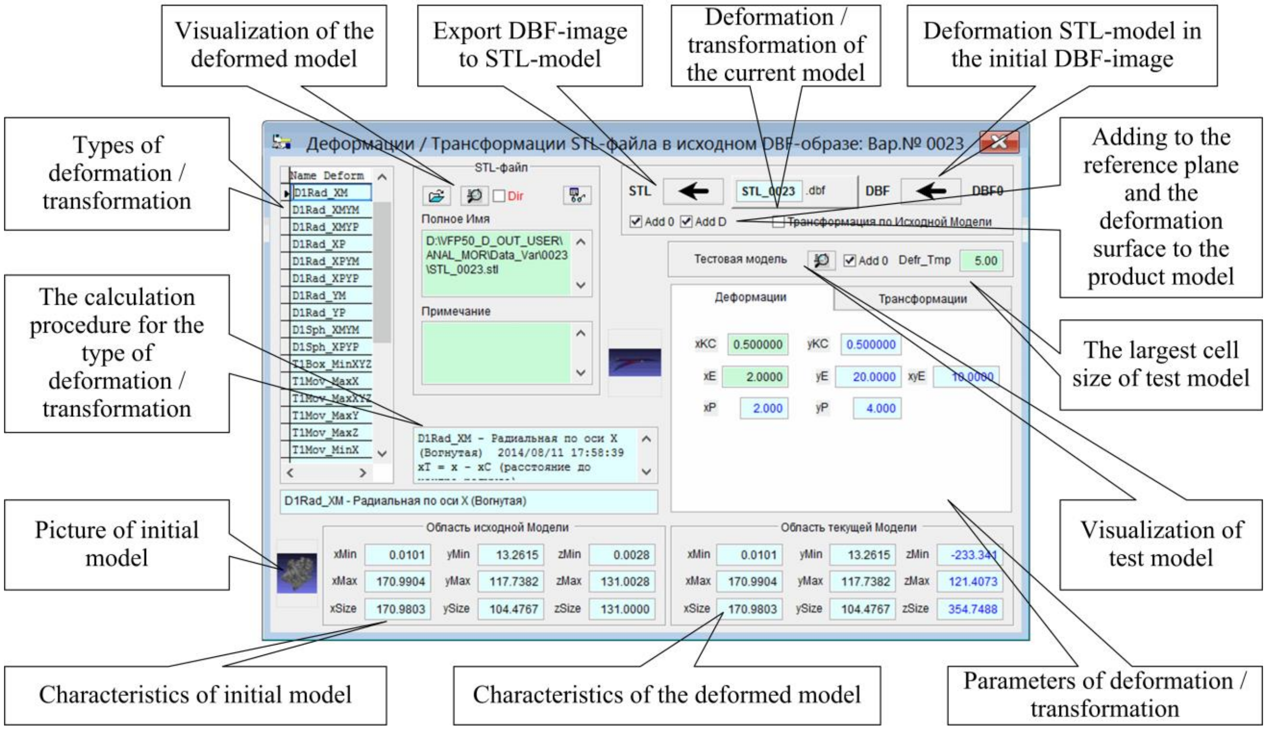


Fig. 2
The subsystem of deformation / transformation of STL-model

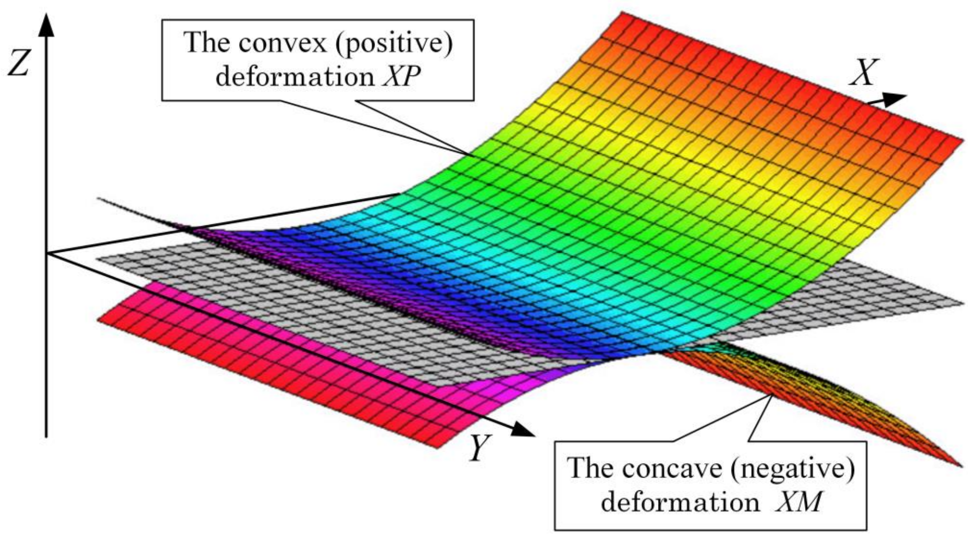


Fig. 3
Convex and concave deformation of surface along the *X* axis

A feature of compensating radial deformation is the ability of an independent task of radial cross-section profiles with a predetermined location of curvature centers along the *X*, *Y* axes (fig. 4).

Sag along the X and / or Y axes – δ_X, δ_Y and relative displacement of deformation curvature center of along the X and / or Y axes – k_{cX}, k_{cY} (fig. 5) are the main parameters of the radial deformation. The deformation function is calculated by the equation:

$$\delta_i = \pm\left(R_X - \sqrt{\left|R_X^2 - x_T^2\right|}\right) \pm \left(R_Y - \sqrt{\left|R_Y^2 - y_T^2\right|}\right), \qquad (1)$$

where x_T, y_T, R_X, R_Y - the parameters of deformation function.

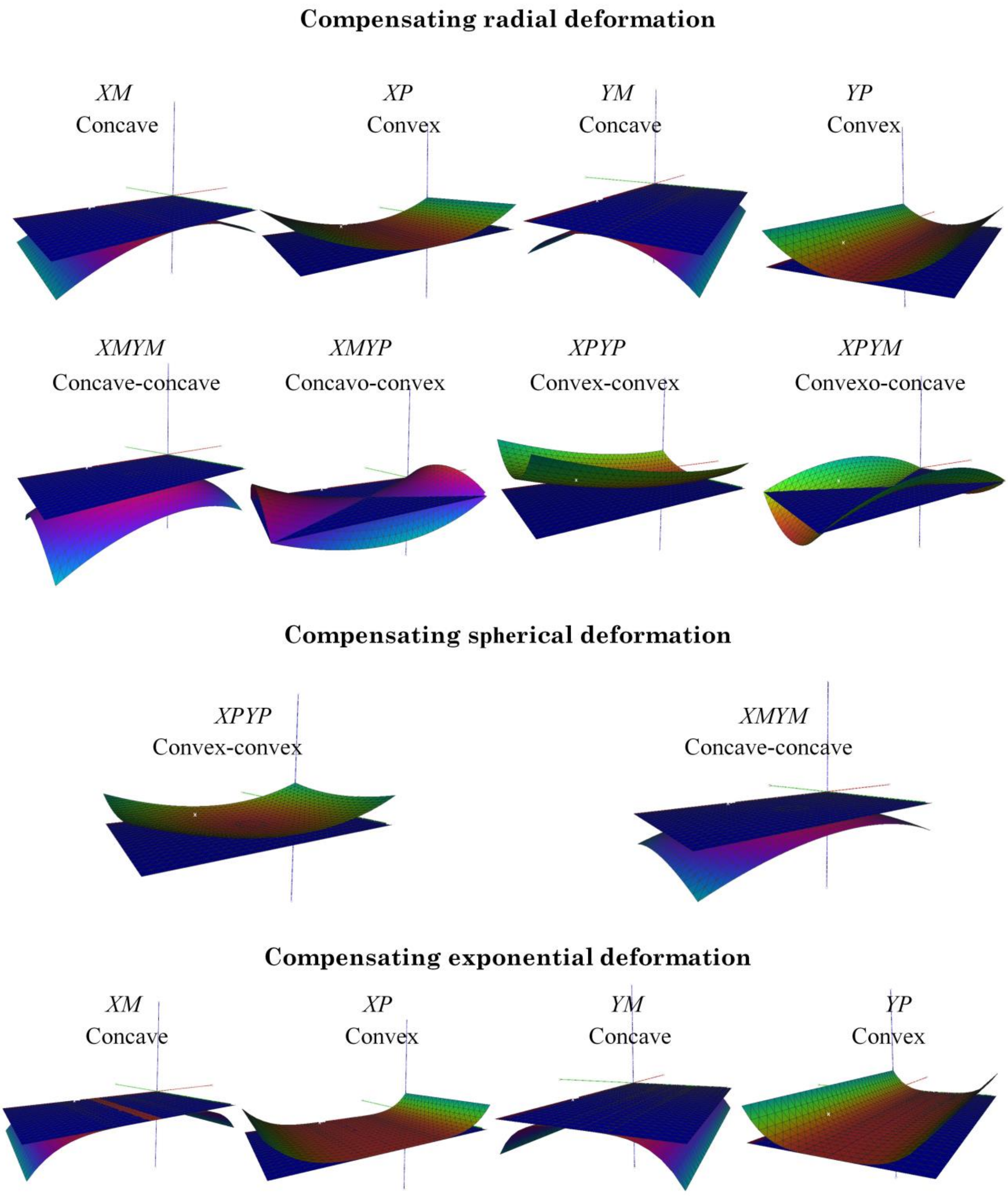


Fig. 4
Examples of deformation for test triangulated model

- radiuses of deformation curvature (X, Y axis) are calculated by the equations

$$R_X = (\delta_X + x^2_{c\,max} / \delta_X) / 2, \quad R_Y = (\delta_Y + y^2_{c\,max} / \delta_Y) / 2,$$

where δ_X, δ_Y - defined sag along of X, Y axes;

$x_{c\,max}$, $y_{c\,max}$ – greatest chord on X, Y axes;

- distances from of selected vertex to the center of deformation curve are calculated by the equations

$$x_T = x_i - x_c, \quad y_T = y_i - y_c;$$

- distances to the center of deformation curve along on the X, Y axis are calculated by the equations

$$x_c = x_{min} + k_{cX}\, l_{Xsize}, \quad y_c = y_{min} + k_{cY}\, l_{Ysize},$$

where x_{min}, y_{min} – minimum vertex coordinates along the X, Y axes;

l_{Xsize}, l_{Ysize} – overall dimensions of the model along the X, Y axes.

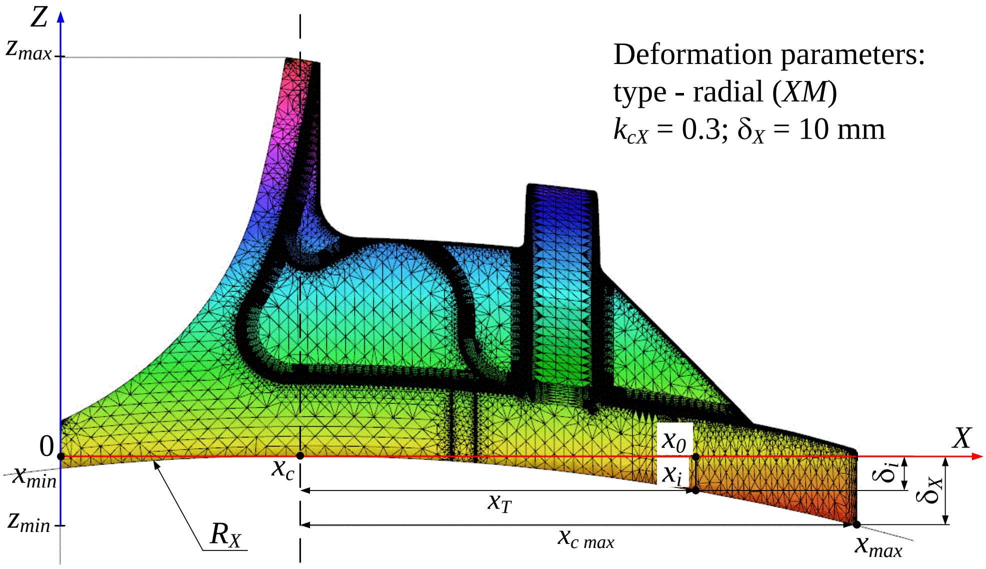


Fig. 5

An example of concave radial deformation (XM) of the triangulated model

Compensating spherical deformation characterized by a general radius of curvature along the axes X, Y (fig. 4). Sag along the X, Y axes δ_{XY} and relative displacement of the center of deformation curvature along the X, Y axes k_{cX}, k_{cY} are the main parameters of spherical deformation.

The deformation function is calculated by the equation:

$$\delta_i = R_{XY} \pm \sqrt{\left|R^2_{XY} - x^2_T - y^2_T\right|}\,. \qquad (2)$$

Radius of curvature of a compensating spherical deformation is calculated by the equation:

$$R_{XY} = (\delta_{XY} + c_{xy\,max} / \delta_{XY}) / 2,$$

where $c_{xy\,max}$ is maximal displacement along the X-Y plane, is calculated by the equation

$$c_{xy\,max} = \sqrt{x^2_{c\,max} + y^2_{c\,max}}\,.$$

Compensating deformation can be given the exponential function, where exponent p defines the nature (type) of curvature. This exponent is chosen within range 1÷9 (fig. 6).

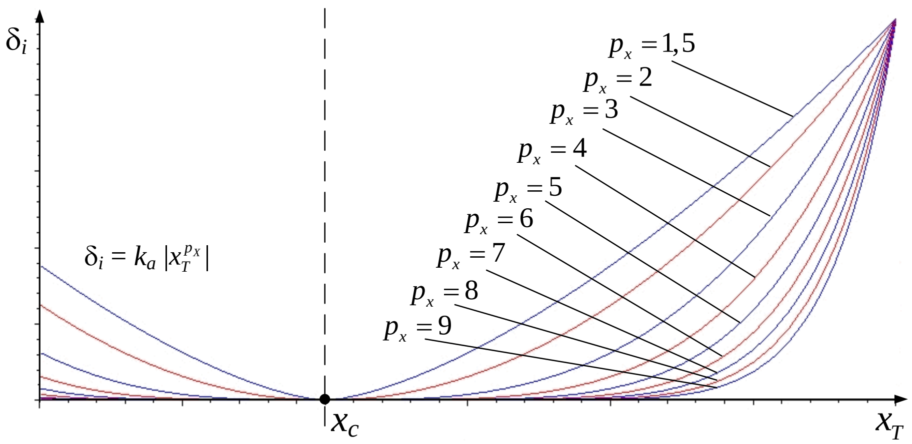


Fig. 6
Example of compensating spherical deformation on test triangulation models

Sag along the X and/or Y axes δ_X, δ_Y and relative displacement of the center of deformation curvature along the X and/or Y axes – k_{cX}, k_{cY} are the main parameters (fig. 4)

The deformation function along the X and Y axes are calculated by the equations:

$$\delta_i = k_{aX} \mid x_T^{p_X} \mid, \ \delta_i = k_{aY} \mid y_T^{p_Y} \mid,$$

where k_{aX}, k_{aY} is align equalizing factor along the X, Y axes which provides given sag, are calculated by the equations:

$$k_{aX} = \delta_X / \mid x_{cmax}^{p_X} \mid, \ k_{aY} = \delta_Y / \mid y_{cmax}^{p_Y} \mid.$$

Experiments showed if product length of 150 ÷ 200 mm, then size of sag Δ is usually less than 1.5 mm.

To balance residual deformation to the model applied compensating deformation along the X and Y axes (fig. 7).

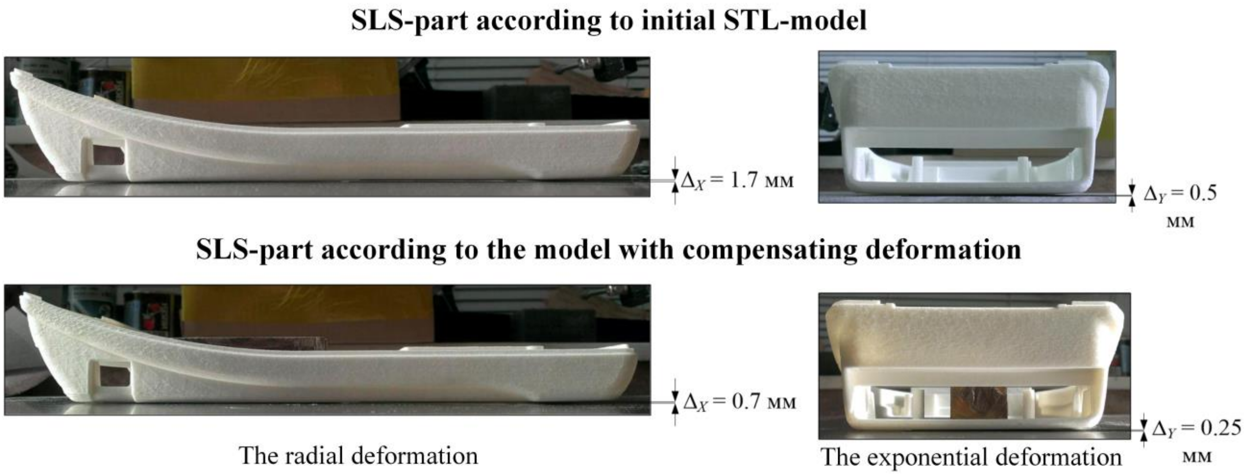
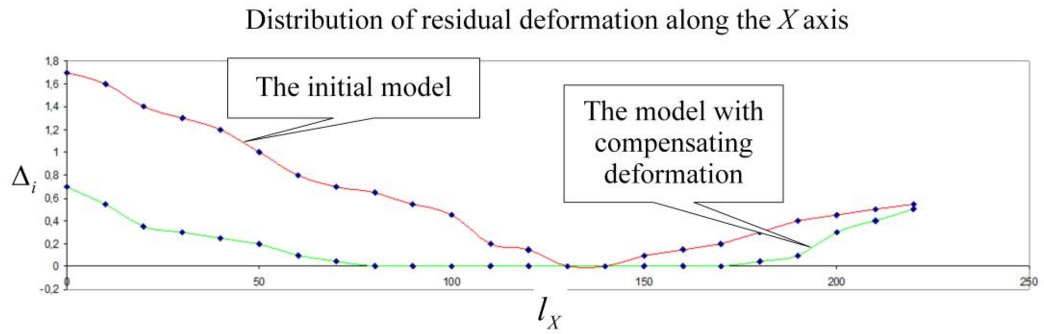


Fig. 7
The part with deformation along the X and Y axis

Compensating deformation type selected by measuring results of residual deformation distribution along part length (every 10 mm).

Along X axis l_{Xsize} = 265 mm used a concave radial deformation with sag δ_X = 0.8 mm, along Y axis l_{Ysize} = 128 mm used exponential deformation δ_Y = 0.4 with relative displacement of the deformation curvature center k_{cX} = 0.5 and exponent p = 5.

SLS-part is built by the model with the deformation has a more regular shape then product built by the initial triangulation model (fig. 8). Sag of the product Δ along *X* and *Y* axes of the initial triangulation model was $\Delta_Y = 1.7$ mm and $\Delta_Y = 0.5$ mm, for the model with compensating deformation - $\Delta_X = 0.7$ mm and $\Delta_Y = 0.25$ mm.



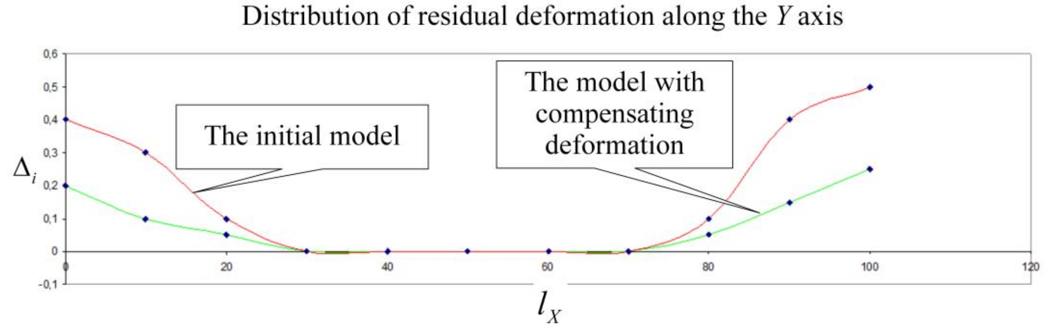


Fig. 8

Determination of residual deformation along the *X* and *Y* axes

Compensating radial deformation is used for incremental deviations. Compensating spherical deformation should apply to models with the same length and symmetrical construction along the *X* and *Y* axes. Exponential deformation is recommended in cases when SLS-part clinch.

CONCLUSIONS

Verification of proposed approach showed that compensating deformation of triangulation models on stage of the technological preparation can reduce deviation from correct geometrical form of products in their building by selective laser sintering. Verification carried out under engineering in common with scientific production association "High technologies in mechanical engineering" at the NTU "Kharkiv Polytechnic Institute".

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