Analysis, topology modification and modeling of the laser head casing taking into account the capabilities of additive equipment

K P Pompeev¹, P A Pyae¹, O S Vasilev² and S G Gorny²

¹ ITMO University, 49, Kronverksky Pr., 197101, St. Petersburg, Russia
² LLC Laser Center, 22, Marshal Tukhachevsky st., 195067, St. Petersburg, Russia

E-mail: kir-pom@mail.ru

Abstract. The article considers the issue of improving the design of the laser head casing in order to ensure its compactness and take into account the capabilities of additive equipment that allows making more complex plastic casing parts without violating the collectability and maintainability of the laser head casing. The manufacture of a laser head casing made of plastic makes it possible to reduce its material consumption in comparison with a casing made of aluminum alloy. At the same time, it is proposed to further reduce the material consumption of the plastic casing due to the introduction of special recesses and stiffening ribs into its design. In the CAE-module of the CAD/CAM-system SolidWorks, a comparative analysis of the strength and stiffness of the laser head casing design options, assembled from parts with recesses and stiffeners, as well as without them. The modeling results of the deformation process for the casing variants convincingly showed that it is possible to replace the material of its parts from aluminum alloy to plastic and that reducing the material consumption and changing the design of the casing does not lead to such a loss of its strength and rigidity which causes an unacceptable deviation of the laser beam from the vertical, that is, does not affect the functioning of the laser head.

1. Introduction
In the contemporary tempos of manufacture development, nomenclature extension of the produced goods and providing their compatibility, it is necessary to substitute outdated equipment with modern efficient NC lathes. It will increase the production tempo and the quality of goods. However, simple reequipping of the machine-shops is not sufficient in some cases. It is necessary to supplement the production process with innovative and complex equipment and appropriate technology of material processing. A laser beam is one of the tools for metal surface processing. Thus, development and introduction of systems-on-a-chip into vertical machining centers (VMC) will both broaden technological and functional possibilities of the equipment and reduce production time, as well as improve technological, precision and functional characteristics of the manufactured object [1].
Technological and functional possibilities of the NC lathes can be broadened as with improving their control systems [2], and by introducing new technological laser units, centers and entire systems into their composition [3], [4]. It will make possible to use one and the same lathe for traditional cutting of work pieces made from different materials as well as for such laser machining as marking [5], surface finish [6], gradient surface texture with a laser beam [7], creating different contour composite regular surface micro topology, carving 3D-patterns [8], [9], ceramics processing [10], [11], macro- and microstructuring of the surface layer [12], [13], cutting carbonplastic [14], local surface finish (decorating), perforation, local thermos hardening, steel pate welding [15], metal coating, information storage on the work piece surface by micro line marks and QR-codes [5], used in information technologies, digital production and so on. Laser heads can be used for a local impact [16], which eases metal removal from the work piece with the tool equipped with cutting ceramics material [17], [18], [19]. Further, a laser system can be applied for microstructuring composite surfaces without preliminary tool preparation for the finishing [20], [21], [22].

Modern industrial laser lathes are NC equipment. They include laser heads (LH), for example, on the basis of the fiber lasers. Their casings include an optic system and a laser beam steering system. As it has been mentioned, there is a possibility to introduce LH into metal processing NC milling and boring machines to implement corresponding technological operations. Casing parts for such laser heads are made from aluminum alloys. The important issue in designing the LH casings is decreasing their consumption of metal. As for LH casings it can be achieved by substituting aluminum alloys with plastic preserving similar mechanical properties. It allows both decreasing their material consumption and applying stamping with the additive installation for their production. In this case an issue arises about the possibility to manufacture less parts of complex design, in order to minimize their junctions when composing the LH casing, and it would be reasonable to make laser heads compact.

That is why the aim of the work is to improve the design of the LH casing to provide its compactness with the account that the parts for its casing will be manufactured on the additive equipment.

2. Materials and methods
Nowadays, a LH casing design is an assembly unit which includes a great number of simple details and several centers. The analysis of the LH casing design (figure 1, a) showed that besides substituting D16 material with plastics, some of the centers can be placed outside the casing which will make the LH casing smaller. It will reduce its material consumption and make LH more compact. The changes in the LH casing parts were as following: bottom wall, back wall, upper wall and a holder.

As a result, parts, more complex in design were produced (figure 1, b): upper half-casing and bottom half-casing. Upper half-casing is a junction of the upper wall and a holder part. Lower half-casing is a junction of the back wall, bottom wall and side parts of the holder. The drive board is removed from the LH design. It decreased the height and width of the LH casing.

Also, some changes in the scanners support design have been done to provide their fixing with special pins instead of screws. A new casing design has a special scanner cable outlet for their connecting to the control unit outside the LH casing.
Polyamide PA 12 was chosen as a material with the account of its application and possibilities of the external additive equipment. Its mechanical properties are in table 1.

### Table 1. Mechanical Properties of Material PA 12 [21]

| Property                  | Minimum value | Maximum value | Unit   |
|---------------------------|---------------|---------------|--------|
| Bending strength          | 70            | 85            | MPa    |
| Density                   | 1010          | 1020          | kg/m³  |
| Friction coefficient      | 0.3           | 0.4           |        |
| Impact strength           | 0.5           | 2             | J/cm   |
| Shear modulus             | 300           | 500           | MPa    |
| Tensile strength          | 35            | 55            | MPa    |
| Young's modulus           | 1270          | 2600          | MPa    |
| Elongation                | 120           | 300           | %      |

Plastic will decrease material consumption and material intensity (as plastic is more than 2.7 times lighter than duralumin), and 3D-printing allows doing without conventional cutting tools. Special recesses and stiffening ribs in the casing design will decrease material consumption.

To conduct a comparative analysis of the LH casing strength and rigidity in a CAD-system SolidWorks, with the CAE-module in design, some designs of its parts with recesses and stiffening ribs and without them were created. As an example, figure 2 shows corresponding variants of the part “bottom half-casing”.

---

**Figure 1.** Comparison of the LH casing design by topology: a – with the initial topology; b – with the modified topology
In total material consumption of the LH casing of the suggested structure decreases 2.9 times when its parts are solid and 4.1 times – if the parts are with recesses and stiffening ribs.

LH casing parts with recesses and stiffening ribs shown in figure 3 are manufactured using SLS (Selective Laser Sintering) technology on the production 3D-printer.

At the same time reduction in consumption of materials and changes in the casing design should not have an impact on its strength and rigidity; in its turn it should not result in unacceptable deviation of the laser beam from the Y-axis, and impact the LH functioning. It is therefore necessary to design the casing in CAE-system.
3. Results and Discussion

The comparative analysis of the strength and rigidity of the LH casing designs was done in CAE-module of CAD-system SolidWorks. Also changes in LH fastening were taken into account when setting it into the lathe spindle. For every variant of LH casing design its strength under gravity due to its weight was checked as LH will be fixed in the spindle of the vertical machining center in a hanging position.

Preliminary calculations for the considered variants showed that the deformations in LH casing (see figure 4, a), under the gravity force are insignificant, less than 1 µm. In some areas the deformations are not more than 4 µm, besides after placing a metal ring inside the LH casing the deformations level as the ring rests on the massive bottom part of the half-casing with its most part (more than 80%). And on the other side it plays a role of the additional stiffening rib. Herewith, the appearing von Mises stress (see figure 4, b) is also not greater than 0.0003% of material yield value.

![Figure 4](image_url) – Results of modeling: a – deformations; b – tensile stresses

The results of deformation simulation for LH casing variants proved that there is a possibility to substitute the material of the LH casing parts from duralumin D16 to plastic. Besides, recesses and stiffening ribs in the LH casing parts are very effective. Thus, we can decrease significantly (approximately 3…4 times) the LH casing material consumption.

Nowadays, there are works for post processing of LH casing parts manufactured on the additive installation with further assembly of the LH and its trial in the structure of the NC laser marker. It should be noted that a certain path of the laser beam should not be disturbed inside the casing, whose trajectory is affected with LH casing plastic parts. In its turn in the course of time they can change the trajectory of the beam. The reasons for this can be different: external factors and impacts (force and thermal); strains in plastic details after LH assembly, material ageing (plastic); cracks in plastic collets. Disturbance in the laser beam trace on any part of its trajectory results in loss of laser system productivity, that is deviance of the processing field from its initial state. That is why, when trying the LH working capacity we will check the location stability of the processing field, and study the effect of the reflected beaming on the plastic mechanical properties, which is used in LH casing. After that the LH performance testing in the structure of the NC vertical machining center can be conducted.

4. Conclusion

Thus, the suggested changes in the LH casing design make it more compact and lighter without disturbing its functioning. Also, its assemblablility and maintainability were not breached. Further works have been
determined. Finally, the integration of the LH system into the machining center will expand significantly its functional possibilities, complementing them with the mentioned above laser technologies.

Acknowledgements
This work was financially supported by the Government of the Russian Federation, Grant 08-08. The authors are grateful to the company Laser Center LLC for provided consultation and additional information.

References
[1] Nikolaev A D, Pyae P A, Pompeev K P and Vasilev O S 2018 Modernization of machining centers through integration of laser systems into their composition Modern Engineering, Science and education ed A N Evgrafof and A A Popovich (St. Petersburg: Saint Petersburg Polytechnic University) pp 506-515
[2] Kartavtsev I S 2013 Extending NC lathe in-process monitoring parameters evaluation and adjustment capabilities Modern Engineering, Science and education (St. Petersburg: Saint Petersburg Polytechnic University) pp 905-914
[3] Nikolaev A D, Pyae P A, Pompeev K P and Vasilev O S 2019 Laser processing systems in machines with numerical control IOP Conf. Series: Earth and Environmental Science 378 (1) 012066
[4] Nikolaev A D, Pyae P A, Pompeev K P, Vasilev O S and Gorny S G 2019 Introduction of laser processing systems into multi-operational machining centers Metalloobrabotka 113 (5) 26-33.
[5] Petkova A P and Ganzulenko O Y 2014 Technological aspects of marking engineering products using a precision pulsed laser Modern Engineering, Science and education (St. Petersburg: Saint Petersburg Polytechnic University) pp 1177-1187
[6] Vasilev O S and Ruzankina J S 2016 Laser forming micro geometric structures on the surface of roller rolling mill Journal of Physics: Conference Series 735 (1) 1-5
[7] Olt J J, Maksarov V V and Efimov A E 2018 Impacts of gradient structure on the dynamic characteristics of machining process system 29th DAAAM International Symposium on Intelligent Manufacturing and Automation 1 (1) 190-196.
[8] Andreev A O, Kosenko M S, Petrovskiy V N and Mironov V D 2016 Prototyping of Dental Structures Using Laser Milling Journal of Physics: Conference Series 691 (1) 012007
[9] Mohd Noor Firdaus Bin Haron, Fadlur Rahman Bin Mohd Romlay 2019 Parametric study of laser engraving process of AISI 304 Stainless Steel by utilizing fiber laser system IOP Conference Series: Materials Science and Engineering 469 (1) 012124
[10] Przestacki D and Jankowiak M 2014 Surface roughness analysis after laser assisted machining of hard to cut materials Journal of Physics: Conference Series 483 (1) 012019
[11] Zeng Jie Ma, Yigang Wang, Yukun Li 2016 Processing of Three-Dimensional Models for the Crystal Laser Engraving Nicograph International DOI: 10.1109/NicoInt.2016.21.
[12] Vasilev O S, Veiko V P, Gorny S G and Ruzankina J S 2015 Laser device for microstructuring a metal surface using a fiber laser Optical journal 82 (12) 70-77
[13] Vasilev O S and Gorny S G 2016 Technology for creating surface microstructures on sheet materials using a fiber laser Metalloobrabotka 93 (3) 20-25
[14] Nasedkin Yu V and Khmelnitsky A K 2018 Laser cutting of carbon fiber-reinforced plastic thin sheets Journal of Physics: Conference Series 1109 (1) 012041
[15] Larin M V, Pevzner Y B, Grinin O I and Lasota I T 2018 The use of single-mode fiber laser for welding of stainless steel thin thickness Journal of Physics: Conference Series 1109 (1) 012036
[16] Efimov A E, Timofeev D Y and Maksarov V V 2018 Modeling dynamic processes at stage of formation of parts previously subjected to high-energy laser effects IOP Conf. Series: Materials Science and Engineering 327 (1) 22026
[17] Maksarov V V and Khalimonenko A D 2018 Quality assurance during milling of precision elements of machines components with ceramic cutting tools International Review of Mechanical Engineering 5 (12) 437-441
[18] Maksarov V V and Khalimonenko A D 2017 Forecasting performance of ceramic cutting tool Key Engineering Materials 736 (1) 86-90
[19] Maksarov V V, Timofeev D Y and Khalimonenko A D 2014 Machining quality when lathing blanks with ceramic cutting tools Agronomy Research 12 (1) 269-278
[20] Maksarov V V and Keksin A I 2018 Forming conditions of complex-geometry profiles in corrosion-resistant materials IOP Conference Series: Earth and Environmental Science 194 (4) 62016
[21] Singh I, Amara Y, Melingui A, Pathak P M and Merzouki R 2018 Modeling of Continuum Manipulators Using Pythagorean Hodograph Curves Soft Robotics, available at: https://www.researchgate.net/publication/323955949
[22] Maksarov V, Efimov A and Golikov T 2020 Treatment of Titanium Alloys Based on Preliminary Plastic Impact Key Engineering Materials Submitted 836 63-70