$$C_T[\delta] \approx f_{тр.п} N, \quad (11)$$

а с учетом эмпирической формулы (9) получим, что

$$C_T = \frac{f_{тр.п.}}{k} N^{(1-\alpha)}, \quad (12)$$

а для пары “сталь-сталь”, при $f_{тр.п} = 0,2$

$$C_T = 2,2N^{0,54} (кгс/мкм) \quad (13)$$

После подстановки формул (12) и (13) в выражение для определения искомой частоты ν_c собственных колебаний резца через круговую частоту ω_c, получим соотношение:

$$\nu_c \approx \frac{1}{2\pi}\sqrt{\frac{2Ca^2}{J_0} + \frac{d^2 f_{тр.п.}}{k J_0} N^{(1-\alpha)}} \quad (14)$$

Если резец и приспособление выполнены из стали, то:

$$\nu_c \approx \frac{1}{2\pi}\sqrt{\frac{2Ca^2}{J_0} + \frac{d^2}{J_0} 2,2N^{0,54}} \quad (15)$$

Как видно из формул (14) и (15), нижний предел регулирования ν_c определяется минимальной величиной силы N_{max}, обеспечивающей гарантированное поджатие резца к приспособлению и пьезокерамическим опорам, т.е.:

$$\nu_c \geq \nu_{c\,min}; \; \nu_{c\,min} \approx \frac{1}{2\pi}\sqrt{\frac{2Ca^2}{J_0} + \frac{d^2 f_{тр.п.}}{k J_0} N_{min}^{(1-\alpha)}} \quad (16)$$

Верхний предел для ν_c определяется предельной величиной N_{max}, исходя, например, из механической прочности нагруженных элементов конструкции устройства и условия, чтобы статическое сжатие опор не повлекло пластических деформаций его материала.

$$\nu_c \geq \nu_{c\,max};$$

$$\nu_{c\,max} \approx \frac{1}{2\pi}\sqrt{\frac{2Ca^2}{J_0} + \frac{d^2 f_{тр.п.}}{k J_0} N_{max}^{(1-\alpha)}} \quad (17)$$

Очевидно, что направления поляризации пьезоэлектрического материала при изготовлении опор виброрезца должно максимально совпадать с вектором силы N поджатия сопрягаемых поверхностей резца и приспособления [1].

Изготовление опор из пьезокерамики позволяет существенно увеличить предельную нагрузку N_{max}, а, следовательно, расширить диапазон регулирования силы поджатия резца к приспособлению N, а, следовательно, и частоты колебания резца в инструментальной системе. При достаточно широком частотном диапазоне этой инструментальной системы, возможна быстрая переналадка ее на существенно отличающиеся друг от друга по частоте режимы колебаний режущей кромки резца, что позволит также устранять нежелательный резонанс между резцом и деталью в процессе вибрационной обработки.

Библиографический список

1. Ranier Clement Tjiptoprodjo. On a Finite Element Approach to Modeling of Piezoelectric Element Driven Compliant Mechanisms.- Saskatchewan, Canada.: University of Saskatchewan Saskatoon, April 2005.
2. Кочеткова Т.П. Мелькишев С.В. Инструментальное обеспечение при вибрационном резании материалов. Журнал «Технология металлов», М.: Машиностроение, №2, 1999г., с 22-23.
3. Крагельский И.В., Добычин М.Н., Комбалов В.С. Основы расчетов на трение и износ. М.: Машиностроение, 1977г. 279с.
4. Яблонский А.А. Курс теоретической механики. М.: Высшая школа, 1977г., 327с.

ЭФФЕКТИВНОСТЬ ПРИМЕНЕНИЯ АДДИТИВНЫХ ТЕХНОЛОГИЙ В ИНСТРУМЕНТАЛЬНОМ ПРОИЗВОДСТВЕ

Кугаевский Сергей Семенович,
Канд. техн. наук, доц.
Уральский федеральный университет (Екатеринбург)
Гамберг Алексей Евгеньевич,
Канд. техн. наук, доц.
Уральский федеральный университет (Екатеринбург)

THE EFFECTIVENESS OF ADDITIVE TECHNOLOGY IN TOOL PRODUCTION

Kugaevskii S.S.,
Cand. Sc. (Tech)
Ural Federal University (Ekaterinburg)
Gamberg A.E.,
Cand. Sc. (Tech)
Ural Federal University (Ekaterinburg)

ABSTRACT. This paper reports the effectiveness of additive technology in tool production.
Keywords. Additive technologies, Selective Laser Melting (SLM), drilling heads, effectiveness.
АННОТАЦИЯ. В статье рассматриваются вопросы эффективности применения аддитивных технологий в инструментальном производстве.

Ключевые слова. Аддитивные технологии, послойное лазерное плавление металлопорошковых композиций (SLM), сверлильные головки, эффективность

Additive technologies began to be implemented in manufacturing about 30 years ago. They have emerged as an alternative to traditional metal-cutting machining. In contrast to machining on a metal-cutting machine where a component is produced by the method of "subtraction" of the material from the total volume of the workpiece, when the parts are fabricated on an additive machine, the process goes in the opposite direction. The component grows layer after layer with curing of material by one of the known methods. This principle of addition underlies in the term of additive manufacturing – AM.

There is no straight classification of additive technologies yet in Russia. Numerous authors separate them to different techniques such as: Layer forming; layer fixation; applied modelling (building) materials (liquid, polymeric, metal powder etc.); key technology (laser, other); energy supply for layer fixation (heat treatment, ultraviolet or direct light projection, via binder etc.).

The most common AM-technologies in mechanical engineering branches are:

- SLA, Steriolithography Apparatus – curing the photopolymer layer with a laser beam;
- SLS, Selective Laser Sintering – layered laser sintering of powder materials, usually polymers;
- DMF, Direct Metal Fabrication – kind of SLS technology, layer-by-layer laser sintering of metal powder compositions; sometimes also called as DMLS, Direct Metal Laser Sintering;
- SLM, Selective Laser Melting – kind of SLS technology, layer-by-layer laser melting of metal-powder compositions;
- DLP, Digital Light Procession – photopolymer layer flash via digital spotlight;
- Poly-Jet – applying of a layer of photopolymer through a multi-nozzle head and its curing by the ultraviolet lamp;
- FDM, Fused Deposition Modeling – layering of fused filiform polymers;
- Ink-Jet – curing the layer of powder material by applying a binder composition through a multi-nozzle head (similar to inkjet printer).

The methods differ by the composition of the curable material, performance, accuracy, quality of the internal structure, etc. Researches in this area are continuously expanding and therefore a large number of scientific articles have been devoted to the subject of additive technologies. It is considered that the most promising areas of application of additive technologies are the aerospace industry, medicine, design, engineering, construction and architecture, etc.

It is easy to see that the greatest efficiency from the use of additive technologies can be obtained in the production of complex-shaped parts with various internal cavities that are difficult to obtain by casting and machining. The complexity of the surfaces of parts obtained by additive technologies is limited only by the imagination of the designer.

The initial stage for the production of such parts is the construction of a computer-based 3D model, which later serves as a kind of template for the operation of the additive machine. At the same time, the complexity of developing of a 3D model has long ceased to be a limiting factor due to the use of various CAD systems. The ability to develop a computer-based 3D model has become mandatory for graduates of any modern university or college. The market of CAM-systems is also rapidly developing. They provide an option to develop a control program for the additive machine according to the original 3D-model.

Let's consider some aspects of the effectiveness of additive technologies for the production of parts made from metallic materials which are the most typical for the engineering industry. From the methods mentioned above method of selective laser melting (SLM) is the most suitable for the manufacture of metal parts. While the cost of manufacturing of a machine-building part on a metal-cutting machine is calculated, the value of the labor intensity of machining $T_{p.u.}$ (min) is frequently used. However, comparing the cost of machining and obtaining parts by additive technology, it is more correct to use the total shop cost of the technological operation C_{op}, which can be calculated by the formula:

$$C_{op} = C\,mat.bas + Cen + C\,tr + Cserv + Cn.ex + W\,bas + Cmat + W\,serv.bas + Cam.eq + Crep + Cmait + Cdet + Cam.t + Cam.b + W\,man + W\,eng + W\,serv.ad$$

Where:

$C\,mat.bas$ - the cost of the main material details;

Cen - the cost of technological energy;

$C\,tr$ - cost of intrashop transportation;

$Cserv$ - costs associated with the payment of services of third parties;

$Cn.ex$ - non-manufacturing costs;

$W\,bas$ - machine tool wages (the main and additional with charges);

$Cmat$ - the cost of materials consumed for the maintenance of the machine;

$W\,serv.bas$ - wages with charges of workers engaged in the maintenance of the main equipment;

$Cam.eq$ - the cost of depreciation of the machine;

$Crep$ - the cost of repairing the machine;

$Cmait$ - the cost of operating a normally worn tool;

$Cdet$ - the costs associated with breakdowns and premature wear of the cutting tool;

$Cam.t$ - the cost of depreciation of equipment;

$Cam.b$ - depreciation of buildings;

$W\,man$ - the wages the administrative and managerial unit;

$W\,eng$ - the wages of engineering and technical workers;

$W\,serv.ad$ - the cost of maintaining the remaining auxiliary workers.

The key point in the comparative analysis of the efficiency of additive technologies and machining technologies is that in the additive method, the part is complete immediately after one operation. After building, the performance of a small number of finishing operations in order to give the surfaces a required level of accuracy and roughness is only needed. Thus, the operation of removing of the support should be added. It is necessary to provide the hardening material with required rigidity and stability while performing the operation of laser sintering.

As a result, the use of a variety of machines (turning, milling, drilling, tapping, etc.) can be changed by one unit. Accordingly, the costs of transportation and depreciation of buildings might be reduced, the number of auxiliary workers could be declined. The cost of cutting tools and fixtures in general can be ignored. The costs of depreciation and repair of the machine, the salary of key workers, energy costs, the costs of maintenance of engineering and technical and management staff for the considered options can be considered as similar.

On the other hand, it should be noted that from the remaining components of the total cost of the product, only the cost of the material slightly increase when additive technologies are implemented. This fact appears due to the high cost of the metal powder from which the part is grown. Moreover, unlike additive technologies, the material consumption during machining can exceed the weight of a part by two times or more because of the removed allowance.

The average market price of imported metal powders based on DDP terms in Russia is: tool steel - $ 115 / kg, titanium (analogue of BT-6) - $ 715 / kg, aluminum - $ 175 / kg, nickel heat-resistant alloy - $ 180 / kg. The final price largely depends on the volume of a one-time order. So, for example, the difference in the cost of 1 kg of Ti-6Al-4V can be more than $ 80 for orders of 50 and 250 kilograms [2].

Comparison the effectiveness of additive methods and methods of machining shows one more potential point of interest. There is a hidden advantage of additive technologies that is not easy to evaluate. This advantage is in a sharp reduction in the duration of the production cycle of manufacturing parts. As the duration of the production cycle, we understand the time between the moment of arrival of the workpiece at the machine shop and the moment of transfer of the finished part to the assembly shop.

Reducing of the production cycle is a powerful tool to improve the production efficiency as it allows to save floating capital, to obtain competitive advantages in urgent orders, etc. At the same time the time of preparation of production could be reduced because the development of operational technology, production of installation equipment and cutting tools are not required.

In conclusion, we give examples of the effective application of additive technologies in the manufacture of tool production. The JSC Sverdlovsk instrumental plant manufactured the cases of modular end mills (Fig. 1) and drilling heads for deep drilling (Fig. 2) using the traditional cutting method on CNC machining centers.

Fig.1 End mill of the production of Sverdlovsk instrumental plant

Fig.2. Drilling heads manufactured by Sverdlovsk instrumental plant for deep drilling

Labor intensity of the basic operations in machining of the drilling heads with a diameter of 31 mm with a traditional method was 287 min with a length of the production cycle of 14 days. The processing was carried out on a turning center. Computationg of the CNC program was based on the computer simulations with a 3D modelling (Fig.3).

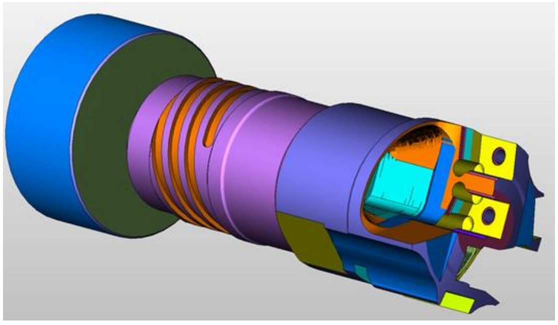

Fig.3 Computer-based 3D model for CNC program in CAM-system

As an experiment, it was decided to manufacture these parts with an additive machine. For the production of parts of the ball involved additive SLM-machine mod. EOSINT M280 (Fig. 4) installed in the Additive Technology Center (Ekaterinburg).

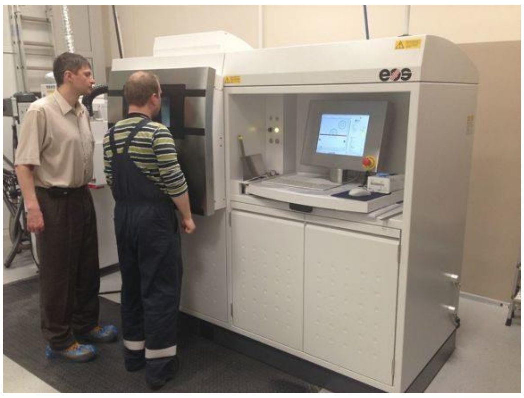

Fig.4. Additive SLM Machine

As a result, the batch of 49 cases of such drilling heads was manufactured in 87,5 hours. The production time per unit was fixed at the level of 107 min. In this case, the same 3D models were used that were taken as a base to estimate control programs for machining centers. The complexity of finishing operations to refine the base surfaces was about 25 minutes.

Acknowledgments: The work was supported by Ministry of Education and Science of the Russian Federation, contract № 02.G25.31.0148.

References:

1. Zlenko M.A. Additive technologies in mechanical engineering / M.V. Nagaytsev, V.M. Dovbysh // manual for engineers. - M. GNTs RF FSUE “NAMI” 2015. 220 p. 2.

2. Makarov M. Industrial 3D printers - expensive “toys” or the real way of modernization of mechanical engineering in Russia? - Photonics number 5/53/2015. P. 20.

3. Fe-
felov A.S., Merkushev A.G., Chikova O.A., Finkelstein A.B. Microstructure and mechanical properties of work pieces manufactured by selective laser melting of AlSi12 powder / Metallurg 2018, N5, p.61-66

Список литературы:

1. Зленко М.А. Аддитивные технологии в машиностроении / М.В. Нагайцев, В.М. Довбыш // пособие для инженеров. – М. ГНЦ РФ ФГУП «НАМИ» 2015. 220 с.

2. Макаров М. Промышленные 3D-принтеры – дорогие «игрушки» или реальный путь модернизации машиностроения в России? - Фотоника № 5 / 53 / 2015г. С. 20.

3. Фефелов А.С., Меркушев А.Г., Чикова О.А., Финкельштейн А.Б. Микроструктура и механические свойства изделий, изготовленных методом селективного лазерного плавления порошков АКД12/ Металлург, 2018, №5, с.61-66.