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ADDITIVE TECHNOLOGY IN AIRCRAFT MANUFACTURING

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Abstract

Purpose: *The purpose of this article is to solve the problem associated with the high cost, high labor intensity and high level of production waste, as well as difficulties in the manufacture of parts of complex shapes that can reduce the weight of the finished product, using subtractive manufacturing.* ***Results:*** *As a result of the analysis, a comparative table of the characteristics of additive and subtractive technologies was compiled, and the advantages of additive manufacturing were highlighted.* ***Discussion:*** *The information of large aerospace companies that have applied additive manufacturing technology has been analyzed and a conclusion has been drawn about the rationality of its implementation in aircraft manufacturing .*

Keywords: additive manufacturing, subtractive manufacturing, Selective Laser Melting, 3D-printing.

1. Introduction

The main characteristics of a modern aircraft that are taken into account in its design are: aircraft weight, strength, manufacturability, and environmental aspects. They are all closely interconnected. The less weight of the aircraft, reduces fuel consumption, and the more payload can be loaded into the aircraft. This has a beneficial effect not only on the financial component of aviation activities, but also on the environment. The creation of a structure with low weight, but high strength is possible by using modern materials and designing parts with a complex geometric configuration. At the manufacturing stage, the process of making these parts can be very time consuming or impossible.

2. Problem statement

Modern production methods can be classified into 2 types: subtractive and additive.

Subtractive manufacturing is considered more traditional in our time and involves the manufacture of parts by machining by casting, welding, brazing, rolling, bending, stamping, milling, turning, drilling, etc., on equipment specially designed for a particular operation. The manufacture of one part may require constant re-equipment of the tooling or the use of a whole complex of machines. These factors make this type of production very time consuming and expensive to prepare.

Cutting operations involve removing material from a workpiece to create a finished part, which entails a lot of waste. Parts created by welding and brazing require careful control of the seams, which increases the labor intensity of production.

The solution to these problems is possible with the use of additive manufacturing technology.

3. Purpose and task of the research

The purpose of this work is to solve the problem associated with the high cost, high labor intensity and high level of waste in the manufacture of parts using subtractive production. And also the impossibility to produce parts of complex geometric shapes using traditional production methods.

4. Materials and research methods

Additive manufacturing is the process of creating an object according to its model created in computer-aided design (CAD) systems, by stacking ultra-thin layers of materials on top of each other using special equipment for 3D printing. The software “cuts” the 3D-model into ultra-thin layers, this information is transmitted to the print head, which applies the material to the previous layer. After cooling or hardening, the material forms a solid three-dimensional object [1-3].

Parts can be created in various ways [2]:
- extrusion;
- by jet spraying;
- lamination;
- ultraviolet curing;

— fusion of materials.

The main technologies for creating products on additive equipment [1-3]:

– Selective Laser Melting (SLM) (Fig.1) – selective laser melting of metal powder according to 3D-models using an ytterbium laser;

– Laser Stereolithography (SLA) – layer-by-layer laser solidification of liquid material;

– Selective Laser Sintering (SLS) – selective laser sintering by laser beams of a powdery material;

– Fused Deposition Modeling (FDM) – layer-by-layer fusing of a filament;

– MultiJet Printing (MJP) – multi-jet modeling with photopolymer or wax;

– ColorJet Printing (CJP) – full color 3D-printing by bonding a special gypsum-based powder.

For additive manufacturing, the local selection is a wide variety in powder, wire and liquid materials. These are mainly: wax, ultraviolet and photocurable liquid polymers, gypsum powder, glass-filled, carbon-filled and metal-filled polyamides in the form of powder, polystyrene, metal alloy powder [1,2].

In the aviation industry, the most widely applied methods of additive manufacturing of metal parts from powdered alloys.

3D-printing of metal parts consists of sequential melting (SLM technology) or sintering (SLS technology) layers of metal powders using laser radiation.

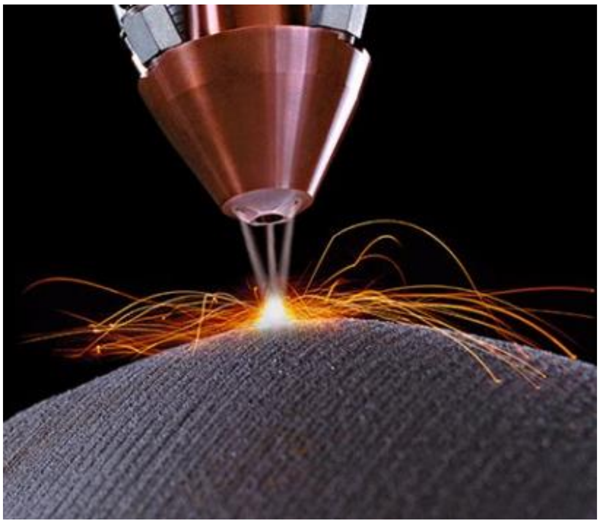


Fig. 1. Selective Laser Melting Technology

Since a more porous structure of the object is formed during SLS, it is rational to use the SLM technology for parts subjected to loads.

Selective Laser Melting involves the complete melting of the metal powder. Excess powder is removed after printing is complete, leaving an object with a smooth surface that usually requires little or no post-processing [4].

A wide range of metals can be used for additive manufacturing, depending on the intended use of the finished product [5,6]:

— stainless alloys (AISI 316L, 17-4PH, AISI 410, AISI 304L, 15-5PH, AISI 904L) have high corrosion resistance and can operate at temperatures of + 550… 800 °C;

— tool alloys (1.2343, 1.2344, 1.2367, 1.2709) have increased hardness and wear resistance;

— nickel alloys (Inconel 625, Inconel 718, Inconel 939, Invar 36, NX) have the ability to dissolve many other metals in themselves, while maintaining ductility, have high heat resistance. Alloy with chromium is used for working and nozzle blades, turbine rotor disks, parts of the combustion chamber of aircraft engines;

— cobalt-chromium (CoCr) is used for the manufacture of cases of complex geometric shapes in electronics, food production, aircraft engineering, rocketry and mechanical engineering, as well as clasp prostheses;

— bronze ($CuSn_6$, $CuSn_{10}$) has high thermal conductivity and is used to create cooling systems;

— aluminum alloys ($AlSi_{10}Mg$, $AlSi_{12}$, $AlSi_7Mg_{0.6}$, $AlSi_9Cu_3$) have a high strength-to-weight ratio and have high corrosion resistance and corrosion resistance;

— titanium alloys (Ti_6A1_4V, Ti_6Al_7Nb) have high strength with low weight;

They can operate at high temperatures (up to + 1100 °C), therefore they can be widely used for the manufacture of parts for jet engines.

Metal alloys for additive equipment are produced in the form of fine grains ranging in size from 4 to 80 microns. The size of the pellets determines the thickness of the part to be manufactured. When creating a metal powder, it is necessary to strictly observe the proportions of large and small granules, because the uniformity of the material supply depends on this, which affects the uniformity of the layers and, therefore, the quality of the finished part [5].

5. Research results

In the course of studying the technology of additive manufacturing, a comparative table of the characteristics of additive and subtractive manufacturing was compiled.

Table

Comparative characteristics of additive and subtractive manufacturing

Additive manufacturing	Subtractive production
Adding material layers to create an object	Removing material from a workpiece to create an object
Includes the use of computers to create a 3D-model and special equipment for 3D-printing	The process is carried out on manually controlled machines or on CNC machines using 3D- models
Requires little or no post-processing	Allows you to get a part with the required accuracy and surface roughness
Ease of creating hollow and parts of complex shapes	Difficulty creating parts of complex shapes
No continuous monitoring required	An operator is required to control the machine or control the manufacturing process in the case of CNC machines
Does not require re-equipment of tooling in the production of parts from one material	In the process of manufacturing a part, it is necessary to re-equipment of tooling or use various machines.

The advantages of additive manufacturing are:

– creation of parts without re-equipment of tooling;
– lower weight of finished products;
– the density of products printed on additive installations is 50% higher than that of products obtained by casting;
– the ability to create parts of complex geometric shapes that are expensive or impossible to create using subtractive manufacturing;
– minimization of the amount of waste from production;
– the ability to create objects that do not require assembly, which allows you to reduce the number of fasteners and reduce the mass of parts;
– low labor intensity of parts manufacturing;
– elimination of the need for optional equipment.

6. Discussion of research results

Additive manufacturing have applied in the Aviation Industry.

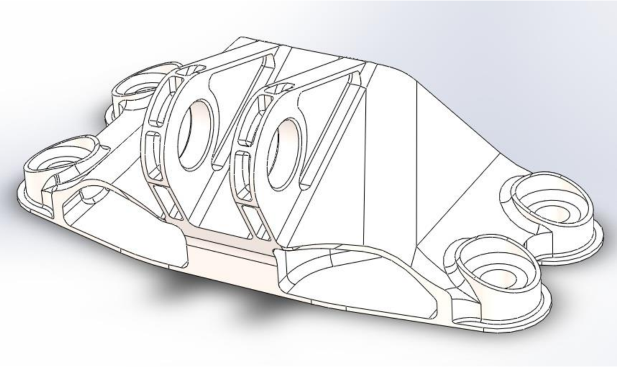
In 2013, NASA successfully tested an SLM rocket nozzle, achieving a thrust of 9,072 kg. According to NASA, using subtractive technology, this nozzle will take over a year to make, while using additive technology, it took less than 4 months, with a 70% reduction in manufacturing costs [7].

The CFM LEAP engine is equipped with 19 additive technology fuel injectors (Fig. 2) from a nickel-cobalt alloy. According to General Electric, these injectors are 25% lighter than the previous ones, 5 times stronger, and also structurally simpler. Previously, the nozzle consisted of 18 parts, now - just one. The 3D-printed injectors are superior to the previous model in terms of design features, in particular the cooling system and support units. To these structural features, 3D-printed parts are expected to last 5 times longer than conventional nozzles [8].

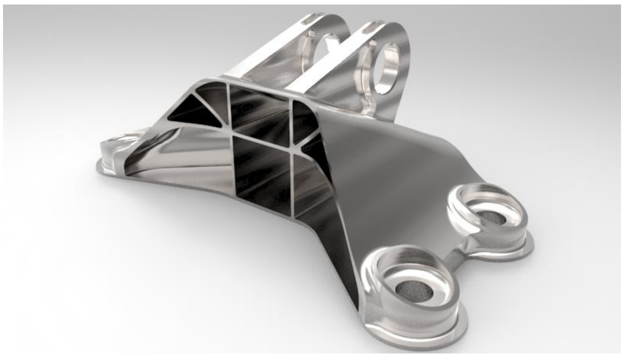
Fig. 2. Fuel injector CFM LEAP, manufactured by additive technology

The GE9X engine installed on the Boeing 777X is equipped with more than 300 additive manufactured parts. According to General Electric, 3D printing has achieved 10% more fuel efficiency than its predecessor, the GE90 [9, 10].

GrabCAD challenge, created for the design of products and their subsequent production using additive technology. At GE's request in 2013, M Arie Kurnivan designed a 3D-printed bracket (Fig. 3) that was 84% lighter than the original bracket. He managed to reduce the weight from 2033 grams to 327 grams. GE Aviation manufactured the titanium alloy bracket using SLM technology. Then the bracket was successfully tested, where it was subjected to axial loads from 3600 kg to 4300 kg and a torque of 565 N/m [11].



a)



b)

Fig. 3. Bracket made with additive technology
a) 3D-model; b) manufactured bracket

7. Conclusions

This article discusses the problem associated with the high labor intensity and high level of waste in the manufacture of parts, as well as the high cost due to the need for a large set of equipment when using subtractive production. A method for solving it by introducing additive manufacturing, which has a number of advantages, is proposed. The use of additive manufacturing makes it possible to reduce the labor intensity of manufacturing parts, due to the absence of the need for re-equipment of tooling or the use of a complex of machine tools, minimizes the number of assembly operations, since it allows the manufacture of objects of complex configuration. It also minimizes the amount of waste during production, since, unlike traditional methods, it does not remove material from the workpiece, but builds it up according to 3D-models.

The information of large companies in the aerospace field, which have applied additive manufacturing technology, is analyzed. The conclusion is made about the rationality of its implementation, since it allowed achieving a reduction in production time and reducing production costs. Also, to reduce the weight of finished products, while maintaining or even exceeding the strength characteristics

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Адитивна технологія у виробництві повітряних суден

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Мета: Метою даної статті являється вирішення проблеми пов’язаної з великою вартістю, високою трудомісткістю та високим рівнем відходів виробництва, а також труднощі у виготовленні деталей складних форм, які дозволяють знизити масу готового виробу, за допомогою субтрактивного виробництва. **Результати:** У результаті аналізу складена порівняльна таблиця характеристик адитивної і субтрактивної технологій, а також виділені переваги адитивної технології. **Обговорення:** Проаналізована інформація великих компаній в аерокосмічній галузі, які застосували адитивну технологію виробництва і зроблений висновок про раціональність її впровадження в авіаційне виробництво.

Ключові слова: адитивне виробництво, субтрактивне виробництво, селективне лазерне плавлення, 3D-друк.

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Аддитивная технология в производстве воздушных суден

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Цель: Целью данной статьи является решение проблемы связанной с дороговизной, высокой трудоемкостью и высоким уровнем отходов производства, а также трудности в изготовлении деталей сложных форм, которые позволяют снизить массу готового изделия, с помощью субтрактивного производства. **Результаты:** В результате анализа составлена сравнительная таблица характеристик аддитивной и субтрактивной технологий, а также выделены преимущества аддитивного производства. **Обсуждение:** Проанализирована информация крупных компаний в аэрокосмической области, которые применили аддитивную технологию производства и сделан вывод о рациональности её внедрения в авиационное производство.

Ключевые слова: аддитивное производство, субтрактивное производство, селективное лазерное плавление, 3D-печать.

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