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LECTURE №7

Additive Fabrication technology

The Additive Manufacturing (AF) or 3D-printing denotes the technologies of manufacture by "adding" (thus, "additive") material in contrary to technologies of traditional machining, also referred to as subtractive manufacturing technologies, where "subtracting" ("removal") of material from the workpiece takes place. The additive technologies involve the formation of parts by successively "building up" the material layer-by-layer. These technologies can be used for model materials, liquid, powder, filamentous polymers, casting waxes, but also sheet materials like metal rolling, paper, PVC film, as well as gypsum compositions, clad foundry sand and several others. These technologies are often referred to as "rapid prototyping technologies" or RP technologies (from *Rapid Prototyping*) but this initial name became very quickly outdated. At the time of the advent of RP technologies, no one could have imagined that they would become fast and reliable technologies not so much for the manufacture of models and mock-ups, but much more for the fabrication of final products, even serial ones, to which the term "prototype" is not suitable. Fir example, prosthesis of the knee or hip joint, grown from titanium alloy powder and installed to the patient, cannot be called a prototype, since this is quite the final product, just like a ready-to-use mold grown from tool steel is not a prototype. AM technology is developing especially rapidly in the aerospace industry for manufacturing of piece and small-scale parts from special alloys, but also in medicine, especially in surgery, prosthetics, dentistry (instruments, implants, prostheses, etc.), in the tool industry and a number of other areas.

AM technology is called rightly the 21st century technology. Terry Wohlers, the founder of the consulting company of the same name, and many other analysts note the growing role of AF-technology not only in modeling and prototyping, but

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also in the manufacture of final products. A special role is given to AF systems that "grow" parts from metal powder compositions (EOS, MTT, Concept Laser, Arcam, LENS, etc.). A number of researchers prove the economic and especially environmental efficiency of the use of AM technologies for the fabrication of metal products. The most popular technologies include Terry Wohlers (the order is very arbitrary); PolyJet (multi-jet application of the material and curing of the layer with a UV lamp like Objet and 3D Systems); SLS (laser sintering of powders such as EOS and 3D Systems); classical laser stereolithography (3D Systems); FDM (building a model using filamentous ABS plastics such as Stratasys).

The simplified 3D printers "pulled" themselves a significant amount of work on the manufacture of models that previously had to be done on expensive SLA and SLS machines, leaving the latter to solve more complex and demanding tasks, where their use is economically more justified. Nevertheless, 3D printers remain the most popular, widely available and commercially attractive category of AM machines for manufacturers.

Some researchers distinguish between 3D printers and AM technologies, but this concept is very arbitrary itself, since it is difficult to accurately determine which AM machine should be categorized as 3D printer and which not. Unambiguous criteria have not yet been formulated, and some uncertainty still reigns in the classification of AM machines. Neither by the technology used, nor by the materials used, nor by the size of the working platform, nor by the name of the company, it is impossible to clearly distinguish whether this or that machine is a 3D printer.

Let's consider ZCorp and Voxeljet, they work according to a similar principle: layer-by-layer "bonding" of particles of powder materials due to a binder composition injected onto the layer surface through special nozzles.

Perhaps the only criterion by which it is possible to determine more or less objectively whether a machine belongs to the 3D printer family, is price. Most users understands 3D printer as an AM machine available for a price below 50,000 US dollars. Thus, it covers Desktop (also, incidentally, can be called conditionally) - desktop or "office", as opposed to solid systems like Sinterstation or EOS P 700, that require specially equipped rooms for the installation. But also this sort of classification will not do without exceptions. For example, the ProJet 3000 of 3D Systems are presented by the company itself as a 3D printer, although its price in Europe is 60–70 thousand euros.

In this context, in order to avoid fundamental errors and misunderstandings, we list the machines that mostly are perceived as 3D printers, since there are not so many of them. These are: Objet 250, 260 and Alaris 30 (Objet Geometris, Israel); ProJet, V-flash (3D Systems, USA); Perfactory Mini, Desktop (Envisiontec, Germany); Pollux 32 (Sintermask, Sweden); Desktop Factory (company of the same name, USA); SD300 (Solido, Israel); ZCorp. 310,450 (ZCorporation, USA); Mcor (Mcor Technologies, Ireland); Dimension (Stratasys, USA); Solidscape (company of the same name, USA); DW10,029 (Next Factory, Italy).

3D printer models and their capabilities

Objet Geometries uses the Poly Jet technology. It applies the layers of a photopolymer with a jet head and the subsequent curing of each layer by exposure to an ultraviolet (UV) lamp after it has been formed. This concept is shown in Fig. 7.1.

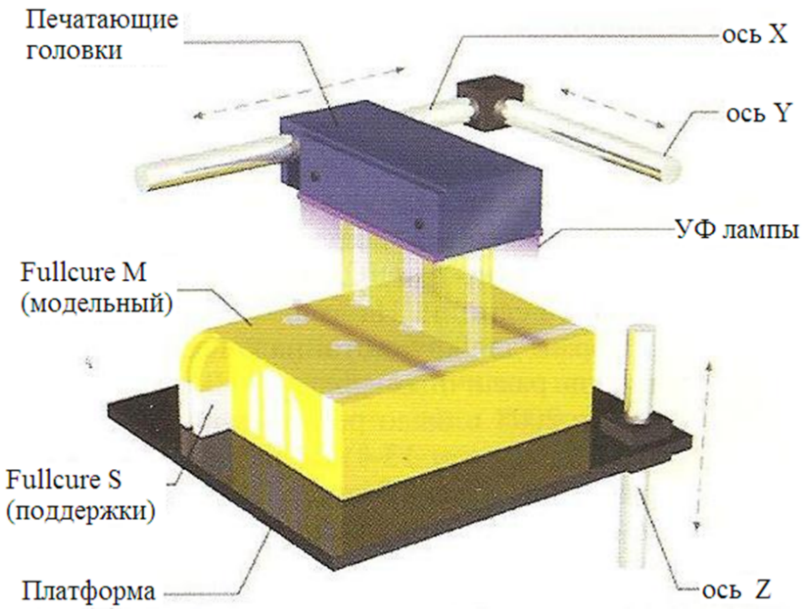

Fig. 7.1. Machine design using Poly Jet technology

The layer is formed by injecting a liquid model material through a multi-nozzle head moving along the model. The curing of the layer is carried out immediately after its formation using a UV lamp mounted on the same head. That is, the subsequent strip of the newly formed layer is exposed to illumination, in contrast to stereolithography, where “spot” exposure is performed by a moving spot (dot) of the laser beam. This technology involves the use of two types of material, the main and supporting ones, for the formation of the so-called supports in order to support

structures. They are removed after the construction of the model is finished.
The Eden series machines use specially designed model photopolymers, namely, acrylate resins, including rubber-like, as well as easily removable supports. The latter is washed off in post-processing of the model with a jet of water.

A wide range of model materials with various properties is offered. They are rigid, elastic, translucent, opaque colored, as well as suitable for medical use materials. Eden machines provide good accuracy of ± 0.1 ÷ 0.3 mm along the length of the construction zone, ana sufficiently thin layer of 0.016 mm. There are very wide possibilities of model materials applications, and in this sense they can be considered universal: they can successfully solve problems of design and functional modeling, both in general engineering and in the jewelry industry, as well as in medicine.

Fig. 7.2. The Objet machines views

The models are well processed, they can be used both as master models for the manufacture of silicone molds and in some cases as burnable models for producing metal castings. Machines can build models with wall thicknesses from 0.6 mm. One of the latest Soppech 500 cars allowed to build two-tone model and received the Grand Prix at the Euro-mold 2007 exhibition.

Since 2009, the production of the new Alaris 30 machine began with a model building area of 300 × 20 × 150 mm, shown in Fig. 7.3. The accuracy of the construction is 0.1 ÷ 0.2 mm (depending on the orientation and size of the model), the thickness of the construction layer is 0.028 mm, the resolution is 600 × 600 × 900 dpi. The cost of Alaris 30 in the USA is about 40,000 dollars, in Europe about 37,000 euros,

Fig. 7.3. The view of Alaris 30 machine

3D Systems' ProJet 3000 Series (SD, DP, and HD indexes) also use UV light to cure the formed layer. When building a model, the layer is added by injecting a liquid photopolymer through a multi-jet head. The Objet machines, supporting structures are used to build the overhanging parts of the model, which, after the model is built, are removed by means of a jet of hot water. The ProJet 3000 HD (High Definition) and ProJet 3000 DP (Dental Professional) differ from the basic version of ProJet SD 3000 (resolution 328 × 328 × 606 dpi, dpi) the ability to work in a reduced area of the model, but with an increased to 656 × 656 × 800 dpi resolution, and are intended for use in the jewelry industry, as well as for the manufacture of hearing aids, dentures, etc. The ProJet DP 3000 comes with a high-precision laser scanner for digitizing dental models.

The model material for these machines is acrylic photopolymer, the support material is wax. Modifications ProJet CP 3000 and Pro-Jet CPX 3000 are specially designed for growing wax models for precision casting of metals into gypsum-ceramic and shell molds. VisiJet® CPX200 special wax model material and

VisiJet® S200 support material are used. The resolution is 328 × 328 × 700 dpi, the thickness of the build layer is 36 µm, in the XHD (Xtreme High Definition) mode - 656 × 656 × 1600 (xyz) dpi, the layer thickness is 16 µm. Accuracy depends on the configuration, orientation and size of the model, and is ca. 0.025 ÷ 0.05 mm for a length of one inch (25.4 mm).
The 3D Systems' ProJet printers, like Objet printers, are high-level machines, they allow to build high-quality models of a wide range of purposes and are especially popular where there is a need to get not only a prototype, but also to make a small batch of polyurethane (in silicone molds) or metal (investment lost or burned) castings. Since 2009, the 3D Systems began implementing in the US market one of the cheapest RP-machines, V-Flash 3D-printer. The declared cost of the printer in the US is 9,900 dollars. It is positioned not even as an "office" printer, but as a "home" printer, thus emphasizing the democratic nature of the user group, "from engineer to housewife", from professionals to hobbyists. The model material is liquid acrylic photopolymer. The model is built upside down: a thin layer of material is applied to a special transparent plate, the platform is lowered to touch it with the photopolymer, the layer is exposed to light by irradiation with a UV lamp, the platform with the illuminated and polymerized layer rises, a new layer is applied to the plate material, the platform again lowers down until it touches the photopolymer layer, the next layer is illuminated, etc.

The dimensions of the model building zone are 228 × 171 × 203 mm. Layer thickness is 0.1 mm. The minimum wall thickness of the model is 0.64 mm. The model building speed is up to 13 mm per hour in height. Overall dimensions 660 × 690 × 790 mm, weight 66 kg. The main characteristics of the Envisiontec machines of the Perfactory family are given in table. 7.1.

The wide selection of materials for master models, burnable models, models for vacuum molding (withstanding up to 150 °C), conceptual modeling, etc., makes these machines especially attractive when it is necessary to produce a large number and a large range of models for a wide range of purposes.

The time of the construction of the parts, taking into account the preparatory and final operations, for an inlet pipe 32 mm high and a receiver 100 mm high shown in Fig. 7.4, is 1.5 and 5 hours, respectively. It is noteworthy taht a comparable-in-size Viper SLA machine (3D Systems stereolithography machine - author's note) can build such models after at least 5.5 and 16 hours, respectively. The advantages of the technology include the presence of various types of model materials, "sharpened" for various purposes of prototyping.

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Table 7.1.

Key Features of Envisiontec Machines family Perfactory

Type	Dimensions of the construction zone, mm	Layer build thickness, mm	Overall dimensions, mm	Weight, kg	Price EXW, thousand Evro	Price DDP, thousan Evro
Desktop	30×40×100	0.03...0.04	450×450×780	25	30..55	40...42
Mini	44×33×230 59×44×230 84×63×230 73×54×230 90×68×230	0.015...0.05	480×730×1350	70	65…70	80…85
Standart Zoom	120×90×230 190×142×230	0.025...0.150	480×730×1350	70	7...7,5	-
Perfactory Standart UV	100×75×230 140×105×230 175×131×230	0.025...0.150	480×730×1350	70	7...7,5	-
Perfactory Xtreme	320×240×430	0.025...0.150	810×730×2200	480	170...190	250...270
Perfactory Xede	457×431×508	0.025...0.150	810×840×2200	260	240...260	-
Perfactory Xede XL	635×635×635	0.025...0.150	-	-	380...420	-

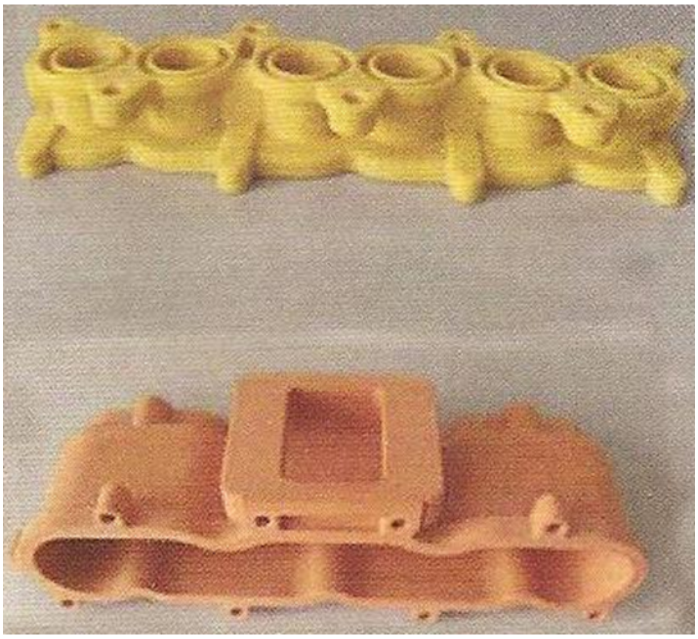

Fig. 7.4. Examples of machine parts produced by Envisiontec Perfactory Family

When testing the Envisiontec model "in practice," castings of the internal combustion engine water pump body shown in Fig. 7.5 were obtained with very high quality, the rating was "excellent." Here, the models were used as burnable. As a drawback, it should be noted the relatively low survivability of acrylic photopolymer resins, which is approximately 6-8 months.

Fig. 7.5. ICE water pump body casting

The quality of the resin must be monitored and changed in time. The cost of consumables (model) materials is relatively high, in the US it is about 250 dollars/kg. Sintermask (Sweden) offers a new SMS technology (Selective Mask Sintering). Unlike Objet and Envisiontec technologies, the model material here is liquid photopolymer. The Pollux 32 printer shown in Fig. 7.6 uses polyamide powder, and powder particles in each layer with model building are interconnected due to the thermal effects of infrared radiation.

Fig. 7.6. Pollux 32 printer using SMS technology

The essence of the process is as follows:

- on a glass plate with the help of a special toner, a negative image of a layer-section of a part is printed, a “mask” is created;

- the mask is located above the layer of fresh powder and is illuminated by infrared radiation, the layer is sintering;

- the working platform is lowered by the value of the construction step of 50 ÷ 120 microns, a new layer of model material is applied to the working platform;

- the process is repeated until the model is completely built.

Desktop Factory Inc. (USA) entered the market of cheap modelers in 2009 as a new player with its own powder printer shown in Fig. 7.7, worth 5–7 thousands dollars. For the polymerization of a composite plastic powder (nylon with aluminum filler) a halogen lamp was used. The size of the construction zone was 127 × 127 × 127 mm. The thickness of the build layer was 0.254 mm. The size of the machine itself was 635 × 508 × 508 mm, weight about 40 kg. The cost of consumables is 1 dollar/inch^3 (approximately 60 ÷ 65 dollars/kg).

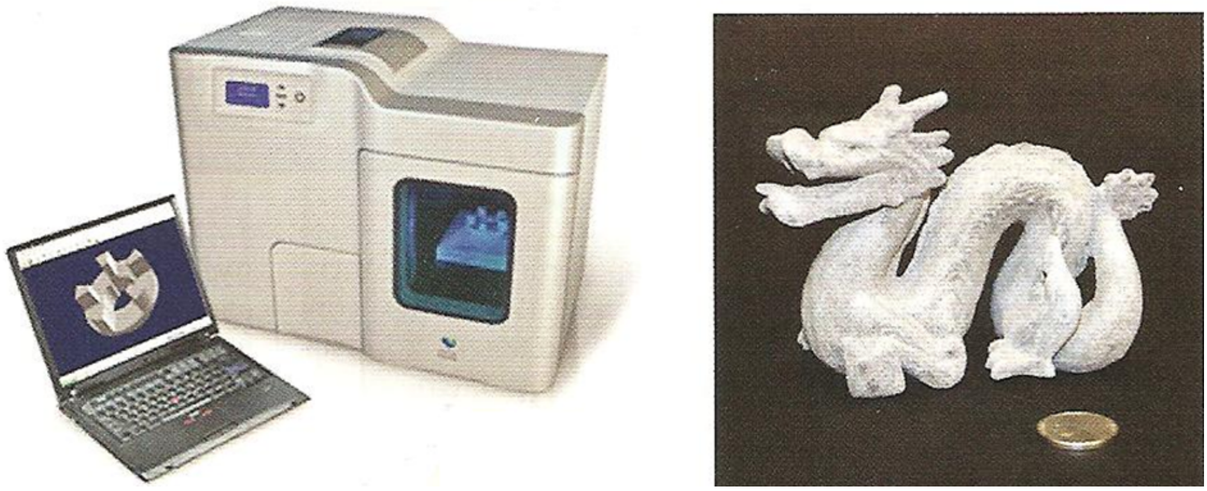

Fig. 7.7. Desktop Factory Inc. Powder Printer

ZCorporation (USA) is one of the world leaders in sales of 3D printers. The popularity of sales in Europe and the United States due to the low price of printers from 20,000 dollars and consumables 30 ÷ 50 dollars/kg. The principle of operation of ZCorp machines is a layer-by-layer "bonding" of particles of powdered materials using a binder composition supplied through a jet head. This technology was developed at the University of Massachusetts and is sometimes called the MIT after Massachusetts Institute of Technology. The "trick" of ZCorp machines is the possibility of color "printing." A large number of printers are purchased for training purposes. Color models are needed not only for design tasks.

Micro machine

It should be noted, however, that the simplest, cheapest and most affordable devices, claiming to be a 3D printer, actually have almost nothing to do with printers. We are talking about machine tools with program control, about very compact desktop machines, which are called desktop CNC machines. CNC stays for Computer Numerically Controlled, or, in Russian nomenclature, a machine with numerical program control.

These devices can be controlled directly from CAD programs and they can cut, saw and drill into the material models developed in these programs. Materials can be almost anything, from plastic or wood to soft metals like bronze and aluminum. For example, the MicroMill 2000 Desktop Machining System drilling and milling machine from MicroProto connects to a computer instead of a printer, can process a volume of 23 × 14 × 15 cm and is able to position the tool with an accuracy of hundredths of a millimeter. The machine is shown in Fig. 7.8. It processes aluminum and even mild steels as can be seen in Fig. 7.9. This wonderful machining center costs a little less than 2000 dollars.

Fig. 7.8. Desktop multi-function machine, connects instead of printer

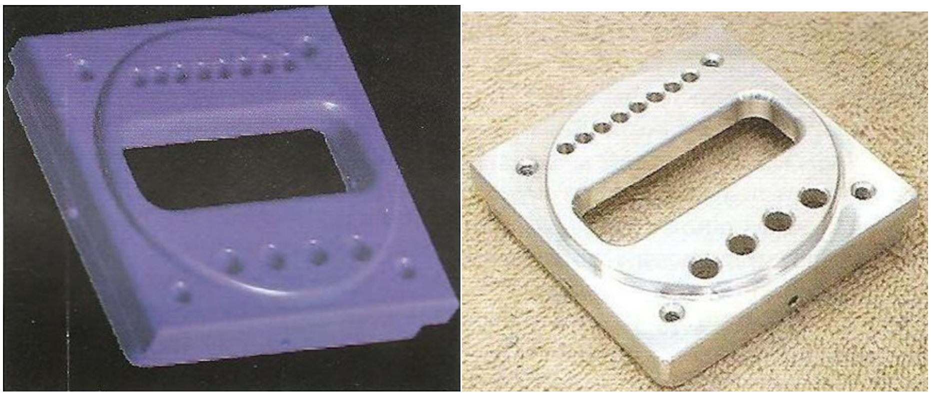

Fig. 7.9. Part model and finished part, made on a CNC machine

Another example of such devices is the Roland line of MDX machines presented in Figures 7.10 and 7.11. “Older” models are designed for semi-industrial use and are, respectively, in the expenses range of 20,000 dollars. But the machine MDX-15 is estimated at about 3,000 dollars, and it can already be categorized as amateur and even home appliances. MDX-15 also allows to process various materials up to aluminum and bronze, has a working area of 15 × 10 × 6 cm and accuracy of the order of hundredths of a millimeter. It is connected to a computer through a serial port. By the way, Roland supplies its machines with a special piezoelectric scanning head, which allows to do the inverse transformation to translate real objects into computer three-dimensional models.

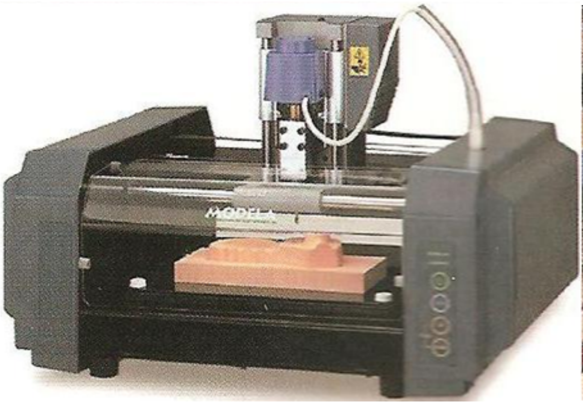

Рис. 7.10. Machine Roland MDX 20

Рис. 7.11. Machine work process

The CNC machines are divided into three main types: routers, mills and lathes.

The machine with four degrees of freedom are also produced, to some extent, combining the capabilities of mill and lathe. You can use all this technique both for the direct manufacture of objects using three-dimensional models, and for the preparation of molds for casting, which significantly expands the scope.