A 3D Print Process For Inexpensive Plastic Parts

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Abstract

Many of the currently available RP-Systems are suitable for building design models of arbitrarily shaped parts. However, most of these RP processes use sophisticated and expensive equipment which is not well suited for an office environment. In this paper we present a method and an experimental device for building design models by a modified 3D print process using plastic powder and a photopolymeric binder.

Introduction

In recent time RP-technologies are increasingly viewed under the perspective of their ability to create functional prototypes or tools. On the other hand, the potential which arose from the ability to produce cost-effective design models is still not fully exploited. The advantages of such parts are clearly visible: one can avoid construction errors, solve assembly and production problems, or compare design alternatives. However, there are some special requirements to an "office-compatible" RP process which are not completely met at this moment by commercially available RP systems.

One very important requirement for such a device is that it should be as easy to use for a designer as his plotter for graphic output. Therefore, it has to fit smoothly into the working environment of a design office. That means that its dimensions should be comparable to other office devices, that there are no special interfaces or media, and that waste materials and all other emissions are neglectable.

Such a device should be easy to use and operate under the control of a CAD workstation. Cost of ownership has to be in the range of other office equipment.

The design models should meet the typical requirements for such objects, i.e. sufficient rigidity, mid-range accuracy, good surface quality which eliminates the need for finishing work, and - if possible - compatibility with follow-up processes. An additional requirement would be the ability to recycle design models which are no longer in use.

Experimental set-up

To test this hypothesis, an experimental setup as described below was designed and built at FGB. The above mentioned criteria were applied to the selection of materials for 3D printing. We used powders of polyamide and polystyrene as fillers, and UV-curable resins like epoxides and vinyl ether as binders.

The main components of the experimental setup are:

- an x-y-plotter which is equipped with an ink-jet printhead for binder application,
- a building platform which moves downward from the starting level in small steps,
- a recoating mechanism for the spreading of new powder layers,
- an UV illumination unit above the platform.

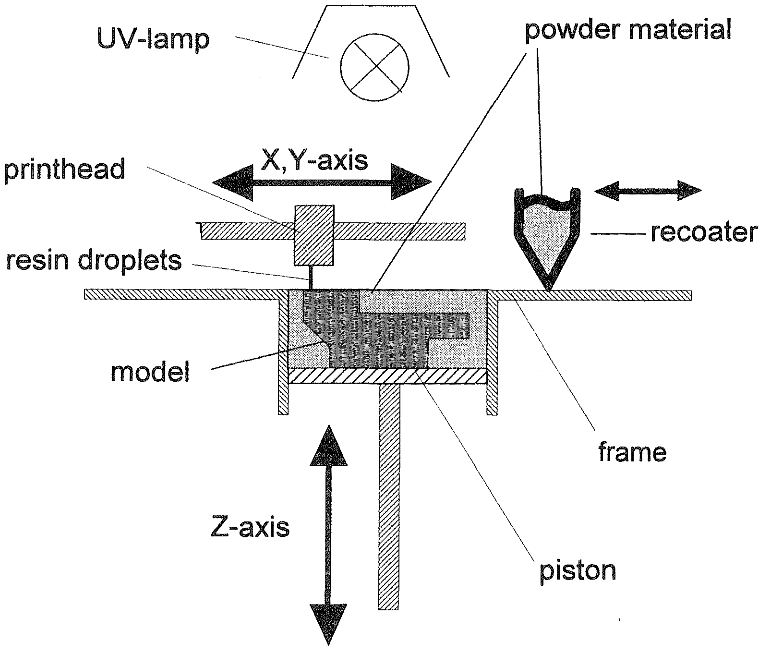

Fig.1: Mechanical setup

Typically, in 3D-printing the building process is performed by repetition of a sequence of several steps like powder spreading and binding by the droplet-generator. In our process, the binder in a newly formed layer is cured by a UV lamp after completion of each layer.

The core of our experimental device is a commercially available ink-jet printhead which had to be modified for this application. The printhead employs piezoelectric actuators to move one of the walls of tiny pump chambers according to an electric signal (Fig. 1). Each pump chamber by itself is connected to a liquid reservoir on one side and to an ejection nozzle on the other side. In our printhead, the pump chamber measures about 2 x 2 x 0.2 mm^3, the nozzle diameter is roughly 80 microns. Most of the liquid path is made of glass, which gives the printhead the chemical and thermal stability we need. We take advantage of the drop-on-demand principle, which makes deflection and catcher units etc., as in continuous jet devices, unnecessary. A drop is ejected only when and where you need it.

Fig. 2 shows the operating principle of a piezo-driven micropump **1.** Following the inverse piezo electric effect, a piezo ceramics element changes its shape according to an applied voltage. If such an actuator is mounted on a flexible membrane **2,** this so-called bimorph will perform a three-dimensional bending motion. The bending membrane will change the volume of a liquid-filled pump chamber 3. A recess phase b) collects additional liquid from the reservoir and is followed by an ejection phase c), where the chamber volume is rapidly reduced, and the liquid (e.g. epoxi resin) is quenched through a nozzle 4 to form a tiny drop 5, which flies freely towards its target plane. The completion of the cycle is governed by capillary and dissipative effects which refill the nozzle and dampen the oscillation of the liquid.

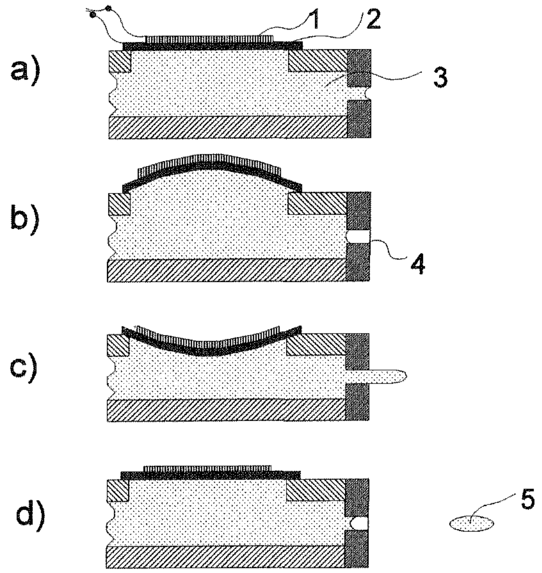

Fig. 2: operating principle of a piezo-driven micropump

Because our printing system was designed and optimized for ink, any other usable pumping liquid must be similar to ink with respect to three material properties:

dynamic viscosity:	1...10 mPas (milli-Pascal-seconds)
surface tension:	72 mN/m (at 20°C)
density:	ca. 1000 kg/m^3

The dynamic viscosity of preferable resins for our 3D printing process is about 80 mPas at room temperature, which is far too high for the selected printhead. Fortunately, the viscosity drops rapidly with rising temperature; at 60°C we achieve 10 mPas, which is a reasonable value for ink-jet printheads. The modified printhead is equipped with a resistive heater, a temperature sensor, and a temperature control circuit.

Thorough investigation of the driving pulse for the piezoelectric actuator revealed the need for a specially adapted timing for ejection of resins. A freely programmable high-voltage pulse generator gave valuable help in these experiments. Following drop ejection characteristics have been achieved so far:

avg. drop mass:	ca. 125 ng (nanograms),
avg. drop diameter:	ca. 60 microns,
ejection frequency:	1000 Hz,
drop velocity:	ca. 2 m/s.

Drop size and ejection frequency are key values for the overall performance of the RP system, because they define the model building speed via the deliverable amount of binder per unit of time.

The table below shows this context. These calculations are based on the assumption that 30 percent of the model volume are binder resin. The given dosing time refers to the building of a cube with 100mm edge length.

frequency [Hz]	number of nozzles	dosing time [h]
1000	1	737
1000	50	15
5000	50	3
5000	100	1,5

By multiplying the operating frequency and using multi-nozzle arrangements, the system performance will grow dramatically.

Similar to some SLS (selective laser sintering) processes, powder coating is performed by a blade mechanism, which covers every cured layer with a precisely defined new powder layer from the reservoir.

After application of the binder pattern for a specific layer, the entire powder-binder surface will be exposed to ultraviolet radiation; thereby the binder resin will be cured rapidly. The employed photopolymers in our experimental setup need a wavelength of about 350...365 nanometers and a specific curing energy of 70...100 millijoules per square centimeter. A reflector-equipped, commercially available UV lamp is mounted at some distance on top of the setup and does a very good job. The lamp delivers about 20 W power in the desired wavelength range; the exposure time for a 200 mm x 200 mm area is only 2 seconds. This time frame can be used for printhead cleaning after completion of each layer.

Conclusion

We could demonstrate a 3D printing process and a 3D printing device which is made up from very simple components and is suitable for creating arbitrarily shaped plastic design models. The total cost of the device (without computer) is well below DM 5000,- (US-$ 3500.-). Despite the selection of a rather expensive photopolymer, running cost is also very low, because no laser system is needed.

Low price and compact dimensions of the device make it ideally suited for desk-top use.

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