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ADAPTIVE SELECTIVE LASER SINTERING TESTING DEVICE FOR PROCESS RESEARCH IN 3D PRINTING

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Abstract:
Selective Laser Sintering (SLS) has been one of the most promising fields of study among different 3D printing techniques. The purpose of this study is to increase the knowledge of SLS printing and to give better understanding about the factors which affect the quality of printed parts. The article introduces a testing device which is designed especially for experimenting the capabilities of SLS. As a result, a device that enables high modifications from the user was built. The device includes an easily-replaceable and adjustable powder distributor mechanism, a large printing volume, powerful laser-scanner combination and durable building materials. With the construction, user is able to research various parameter effects, such as laser scanning speed, laser power, effect of preheating, printing material, layer thickness and layer building speed.
Keywords: Selective Laser Sintering, plastic, powder, parameter

INTRODUCTION

Rapid prototyping methods and additive manufacturing methods are technologies, which have been developing intensively during past decades. Most commonly these technologies concern 3D printing using polymers and plastics. Selective laser sintering (SLS) is among additive manufacturing methods enabling building components from powdered materials. Technique uses a laser as the power source to sinter powdered material layer by layer to form 3-dimensional objects.

Usually SLS involves the use of a high power laser, e.g. a carbon dioxide laser, to fuse small particles of plastic, metal, ceramic, or glass powders into a mass that has a desired three-dimensional shape. The laser selectively fuses powdered material by scanning cross-sections generated from a 3D digital description of the part from a CAD file or scan data on the surface of a powder bed. After each cross-section is scanned, the powder bed is lowered by one layer thickness, a new layer of material is applied on top, and the process is repeated until the part is completed.[1]

Because finished part density depends on peak laser power rather than laser duration, a SLS machine typically uses a pulsed laser [2]. The SLS machine preheats the bulk powder material in the powder bed somewhat below its melting point to make it easier for the laser to raise the temperature of the selected regions the rest of the way to the melting point. Unlike some other additive manufacturing processes, such as stereolithography (SLA) and fused deposition modeling (FDM), SLS does not require support structures due to the fact that the part being constructed is surrounded by unsintered powder at all times, this allows for the construction of previously impossible geometries.

The concept for process of selective laser sintering (SLS) was invented in mid-eighties and patented in 1986[3]. Over the last decades 3D printing has been a popular field of study and the scientific field of 3D printing is truly widespread because there are multiple different 3D printing technologies available. When considering SLS technique, remarkable work has been done especially in studies of

binding mechanisms of powder particles, mechanical and material properties of printed parts [4][5][6][7]. Kruth et al [4] give a comprehensive overview on different binding mechanisms in selective laser sintering (SLS) and selective laser melting (SLM). The paper classified SLS and SLM processes into four main binding mechanics categories: “solid state sintering”, “chemically induced binding”, “liquid phase sintering – partial melting” and “full melting”. Most commercial applications can be classified into the latter two categories. The understanding of binding mechanism is a prerequisite for developing SLS materials with better mechanical properties. The most relevant mechanical properties studied are yield strength, elongation, Young’s modulus, hardness, surface roughness, linewidth, layer thickness, shrinkage, porosity, wear rate, density, tensile strength and sintering depth [2]. Nowadays the range of printable materials is wide, ranging from metals to polymer and even on some ceramics, from single compound materials to powders that consist from multiple ingredients. [6]
The studies have also focused on other factors which affect the quality of final part. Studies discuss about the ways to spread the powder layer [8][9], importance of powder bed heating [10][11] and the effect of laser properties. When considering the laser used for SLS printing, the relevant factors have been laser power [6], scanning speed and spot size [12][5]. Relevant work has also be done in simulating the printing process and defining optimal parameter values with simulated models [13].
There have been only few companies that manufacture SLS machines and prices of these machines have been quite high, but more and more companies are moving in business. A recent development on commercial field has aimed to produce more available SLS printers for consumer and small business use. [1] The aim of this research is to develop an adaptive testing device to research process in SLS 3D printing method.

METHODS

In order to research the 3D-printing process in laser sintering method, the system needs to be highly adaptive. Three main functions and factors effecting to these functions in SLS printing process with polymers were recognized (Table 1). These were sintering with laser, layer building and material heating. To be able to research the process, the construction has to be adaptive in sense of sintering parameters, methods of building the layers and printing chamber heating system.
Sintering parameters concern the characteristics of the laser and the laser controlling system used. To discover optimal sintering parameters, research has to be done among the possible laser power, scanning/marking speed and laser spot size/focal length. Methods of building the layers are studied by implementing an easily replaceable powder distribution mechanism. This makes it possible to discover the most efficient way (roller, blade etc.) to spread a layer. The speed of the distribution mechanism has to be adjustable in order to research the impacts of spreading speed on layer quality. Due to the fact, that the sintering parameters also affect the depth of the sintered layer, the mechanism that defines the layer thickness has to be adjustable.

Sintering	Layer Building	Heating
heat capacity	layer area	heat capacity
laser wavelength	layer thickness	heat conduction
laser power	material flow	heater wavelength
layer thickness	particle size	layer volume
material IR absorption		material IR absorption
scanning speed		material melting point
spot distance		
spot size		

Table. 1. Main functions and effecting factors

The laser sintering system shall be constructed of robust materials to achieve high heat resistance. With the system, it is conceivable that printing material is changed and the influence of preheating the material is discovered.

RESULTS

As a result, a testing device was built. The device is a combination of a high power laser, adaptive powder distribution mechanism and spacious and durable design (Fig. 1). The laser used is a 100 W CO_2 laser combined with a scanning head. With the controlling software provided by the manufacturer, laser power and speed are controllable. The spot size of the laser depends on the lens that is used and laser's raw beam diameter. In our configuration, the lens has a focal length of 591 mm and a spot size of 614 µm.

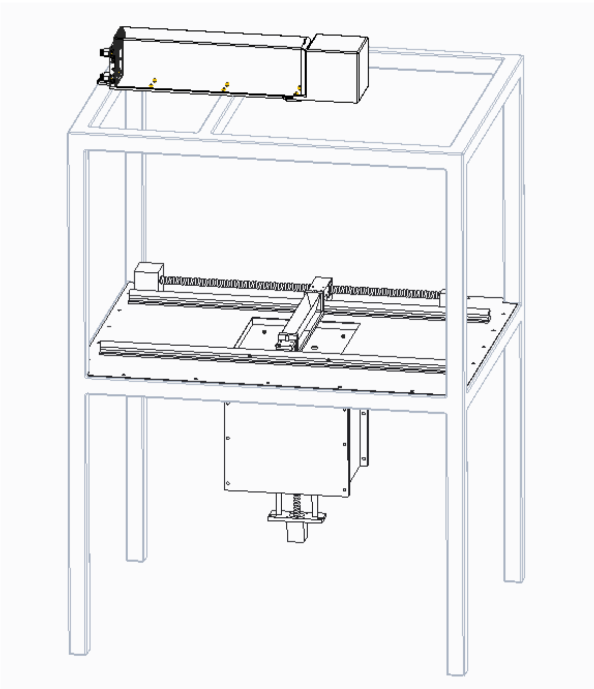

Fig. 1. The test construction

The powder distribution mechanism was constructed to be easily replaced if found out inoperative. Whereas commercial SLS stations usually spread the new layer by swiping with a blade or a roller, our construction implements a moving container (Fig. 2) that simultaneously provides the needed amount of powder and sweeps the layer. The gap between the two smoothing blades on the bottom of the construction is variable (between 0 and 10 mm) in order to find out the optimal value for different printing materials used. The minimum value to achieve the required material flow to produce good layer quality for nylon powder PA12, which was used in the first tests, was around 5 mm. The construction also enables the moving container to be replaced with different mechanisms so the most efficient spreading mechanism can be discovered.

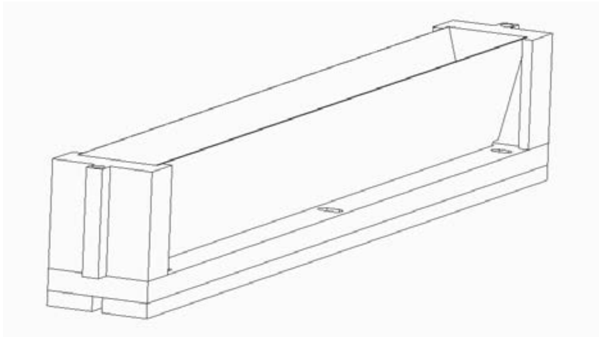

Fig. 2. Moving powder container

The layer thickness is defined as the distance of the building platform travelled in one cycle. The building platform is lowered with a stepper motor via a ball screw. With the combination selected, the layer thickness can be 100 µm or more.

Laser sintering of plastic materials requires preheating due to the strong heat expansion. Every layer is preheated somewhat below the sintering point with four 375 W infrared lamps. With the controlling system of the lamps the optimal value of preheating can be examined for different materials.

The control system of SLS printer can be implemented in many different ways. In this testing device (Fig. 3), the slicing of 3D models is executed with free slicing tools. The slicing tools were not in the scope of this study and the properties or functioning of these tools were not closely evaluated. Used slicing software can import 3D models in *stl* file format, export layers of the model in *png* format and let user to define the layer thickness. These images are moved to a specific directory, which works as a source directory for another software that was programmed for purposes of testing device. This program reads the image files from source directory and converts them to drawing files, which can be operated by the scanning head. The software can be manipulated with Visual Basic code using the ready-made functions of the scanner head, so it is easily adjustable for different needs of SLS research.

After the software convert the images and user starts a printing process, the software sends the first layer drawing to the scanning head, which generates the scanning track. Before the first scanning starts, the scanning head sends a signal to external control unit, which set the piston to the starting position and sweeps the first starting layer. The unit controls stepper motors though stepper motor controllers. Control unit also regulates IR heating, which raises the temperature of powder layer. When the first layer is built and heated, the scanning head turns the laser on and melts the powder according to the layer drawing. In the next phase the software sends the following layer to the scanner head and the cycle repeats until the part is finished.

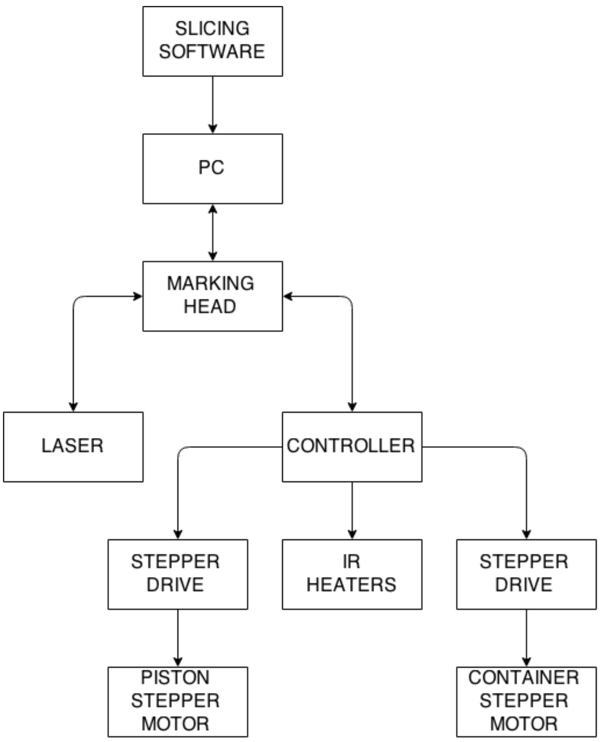

Fig. 3. Process block diagram

DISCUSSION

The design and building process of SLS printer pointed out extremely well the main challenges in SLS printers. Even though the SLS process is studied a lot and there are commercial solutions available, there are still many open design questions concerning laser type, laser positioning, beam sizes, powder distribution, heating and so on. Generally SLS devices are complex because of the challenging fine powder material and precise control and heating requirements.

The design process especially underlined the challenges arising from the heating. When sintering PA12 material without heating, the shapes experience significant deformation due to heat expansion, which leads to curved layers. The deformation happens after the laser has swept particular area and when the heated particles start to cool down to the room temperature. This deformation is especially problematic with SLS printers, where the new layer is swept above the previous layer. If the piston moves downwards one layer thickness, 100µm, there cannot be much curving upwards or the container will hit the printed layer and sweep it away. In this study too little attention was focused on heating. It can be stated that the main observation and outcome of this SLS project was that when designing a SLS device, considerable efforts has to be allocated to the design of the heating system.

IR-heaters should be chosen so that printing material is absorbent to their wavelength; hence required temperatures can be achieved with smaller power consumption. Heaters should also be fast, meaning that they achieve their maximum output in short time and that their power output can be changed quickly. This should make heating process faster and more refined. In our case IR lamp bulbs were chosen because they have short ramp up time, they were easy to use and install for prototyping purposes and they were accessible. Since the material is absorbent for wide range of IR wavelength, this wasn’t considered as main constraint with heater selection.

The heating requirements lead also to other design challenges. When the temperature of the device should be around 180°C, also the structure, linear rails, electronics and other mechanical parts has to be designed so that they can withstand the heat without changing their properties. The temperature is especially difficult when considering moving parts like linear rails, motors and ball screws where proper lubrication is needed. Additionally, 3D printers have long operating cycles, which affects heat generation and wearing of the components.

Powder is a challenging material in 3D printers. Small grain size and good flowing properties are highly valued in SLS materials, but these properties also create design problems. The insulation of the piston is difficult to manufacture in a way that it keeps powder inside in high temperatures without leaking. Another problem was that the container can easily start to plow powder in front of it. Assumed reasons for plowing are the fact that the container is never perfectly aligned and that the powder bed is flexible. The powder bed compresses under the container and expands after the container has swept over it. Because of the plowing the powder piles up on the edges of containers operating range. The solution to this problem could be overflow bins, as presented in EOSINT P700 LS commercial device [14].

The design task was greatly simplified by using commercial laser and scanning head system. The scanning head has built-in tools and interface to change many properties, eg. laser power, scanning speed and area filling patterns. These functions are relatively difficult to implement in a testing system with reliable accuracy and this is why using commercial solutions is highly recommended. It was also possible to acquire extra accessories to the system, like in this study a new lens with a longer focal length. However, when using commercial devices it is extremely important to get familiar with all the properties, functions and restrictions of the device. For example in this study, the scanning head had a hard coded maximum value for lens's focal length, which made it difficult to operate scanning in the right scale.

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