1.1 Anwendung

3D printing has become the most trending, home applicable and favourite production method of the new age. Imagining an object and being able to produce it without any effort or hand work just in your living room was an irresistible idea to the maker communities. Thus the development of the 3D Printing technologies was not only a topic for the commercial parties and the research institutes, but also for the individuals from all around the world, getting together on development hubs.

Although there are multifarious methods and materials to use, the main focus of the public is cumulated around FDM (Fused Deposition Modelling) using the polymers ABS (Acrylonitrile butadiene styrene) and PLA (PolyLactic Acid). The low melting point and ease of utilization were the main reasons which caused them to stand out among other methods and materials. However, these materials do not provide any of the engineering properties of the metals like aluminium or steel which are widely utilized in classical manufacturing methods.

An opportunity to produce the prototype of your idea with approximate material properties is delightful for any R&D department. Today a few methods already are known to the scientific world in the area of metal 3D printing. Those methods can be summarized under powder bed based, binder jetting, magnetojet printing, directed energy deposition and electron beam freeform fabrication.

 Each of these methods require a compatible electronics and software solution. The required electronics have to control various temperatures, tool position, chamber gas composition and provide a high baud rate communication for a high rate rapid prototyping process. The market and research fields are still too young to provide an all in one software solution, where only the defining the manufacturing method and outputs of the system is enough to get ready for the production. Therefore, the development of a new algorithm is necessary, if any new method is developed.

Incremental casting involves generating tiny drops by means of applying a pressure pulse to the chamber filled with molten metal, using a piezo valve. The pressure pulse jets the molten metal through the orifice. The generated drops solidify above and beside each other forming a nonporous surface. A high rate of drop generation is necessary for achieving large printing volumes in short time. Consistent drop characteristics require precise I/O switch times and stabile temperature levels. High accuracy positioning system is mandatory to provide continuous drop path due to the tiny drop dimensions.   
 The software and complementary control electronics for the pre-selected hardware have to fulfil some defined requirements. The system has to work on a real-time frame with watchdog assistance in order to guarantee continuous, in time response along the printing process. Adjusting the temperatures, controlling the axes, switching the pulse generating valve on and off at exact right time have to be processed parallel to each other, in despite of the classical sequential work flows.

1.2 State of the Technology   
 1.2.1 Commercially Available Systems

There are various approaches to metal 3d printing concept. All of these approaches use their own software for their patented methods.  
 Selective Laser Melting project was initialized at Fraunhofer ILT in 1995 and today the method is used in SLM 500 (SLM Solutions GmbH, Lubeck, Germany). This method utilizes a directed laser beam to melt selected areas of a single layer of metal powder. Then the next layer of powder is swept over the old layer.

SLS method is very similar to the SLM. The layers of metal particles are not molten but sintered together. Since the patent of the method is expired in 2014 there are multiple competitors using the SLS technology. One of the important competitors is EOS GmbH. The EOS M 400 (Electro Optical Systems, Munich, Germany) can produce large scale industrial parts using directed laser beams.

1.2.2 Systems in Development  
  
 Magnetojet Printing is inspired by the common inkjet printing process. Liquified metal is jetted through the orifice by the magnetohydrodynamic effects. Currently the MK1 Experimental (Vader Systems LLC, New York, USA) is planned to be released to the market in 2018 and the company has a pending patent.

EBF3 (Electron beam freeform fabrication) technology is initially developed by NASA at the Langley Research Center (US). The aim of the project is to design a system, which can produce objects out of metal using a metal wire and focussed electron beam under zero gravity conditions.   
  
 1.3  
 SLS method uses focussed laser in order to sinter metal dust. During the sintering process the surface of the dust particles diffuse into each other forming necks and hollow areas in between the metal particles. Due to this character of the sintering process not only the surface of the products but also the inner structure is porous. The products manufactured by the SLS process can theoretically be as tough and strong as cast products, due to lack of the strain hardening. However, the properties of a cast part are of course not reachable due to the porosity.

SLM causes the particles to melt together completely, which eliminates the general porous structure. However the inhomogeneity of the metal dust can cause fluctuations of the energy distribution on the spontaneous targeted area. This irregularity causes the problem known as balling, which is building random larger cumulations. This irregularity also causes porosity and leads to notch effect.

The powder bed method causes continuous support for the discontinuous layers of the product, which eliminates the need to print support columns with a weaker removable structure or a second material. These advantages also bring along a disadvantage. Since the whole area is swept over with metal powder after each layer, the inner volumes are also filled with powder. Thus, it is impossible to print hollow closed bodies. The product has to be modified opening a draining collar, in order to let the excess powder out.

The cost is also one of the most important aspects, because of the feasibility of the product and high competition in the market. The actual market price for aluminium is about 1.9 USD/kg, whereby the price for AlSi10Mg Aluminium powder is about 120 USD/kg and for 0.8mm 4043 aluminium wire about 4 USD/kg. The cost of material is beyond comparison.

Electron beam freeform fabrication uses an aluminium wire as supply material. Thus the material costs are rather reasonable. One of the main engineering problems is creating a vacuum. Otherwise the electrons would lose a noticeable amount of their energy before reaching the target. The created electron beam hits the aluminium wire on the target where it is supposed to melt. The electrons are decelerated when they hit their target and automatically create a deceleration radiation known as bremsstrahlung, which is practically X-ray. For that reason EBF3 requires an additional prevention against the X-ray radiation.

2.1 Aufgabenstellung

This thesis is framed with the development, implementation and deployment of a control solution for the experiment stand for additive manufacturing of aluminium parts. The control solution should implement the necessary equipment taking part in the control and adjustment of the experiment stand. These are for example temperature adjustment of the chamber, printing plate and the employed nozzles, the control of the material feed. The precise control of the movement of a cartesian XY-stage and the coordination of the movement and drop generation is necessary and the most important aspect of this solution.

The implementation of the software should be based on the software TwinCAT (Beckhoff Automation GmbH). The automation software TwinCAT is integrated with a package of a real time control system combined with PLC and NC functions. The programming should be followed in accordance to the software standard IEC 61131-3.

Before the termination of the project the developed solution has to be tested and put into operation. While doing so each of the functional abilities has to be tested and subsequently as a whole system commissioned.

2.2 Messbare Parameter und Kriterien??

2.3 In order to understand the software and how it works, it is inevitable to comprehend the hardware. The 3D Printer possesses following actuators and sensors:

● Two servo motors for X and Y axes

● Two absolute encoders for the servo motors

● Two stepper motors for Z axis and material feeder

● Two encoders for the stepper motors

● Two virtual Axes for the conversion of the motor movements to H-Bot coordinates

● Three heaters for the plate, nozzle for the main material, nozzle for the structure material

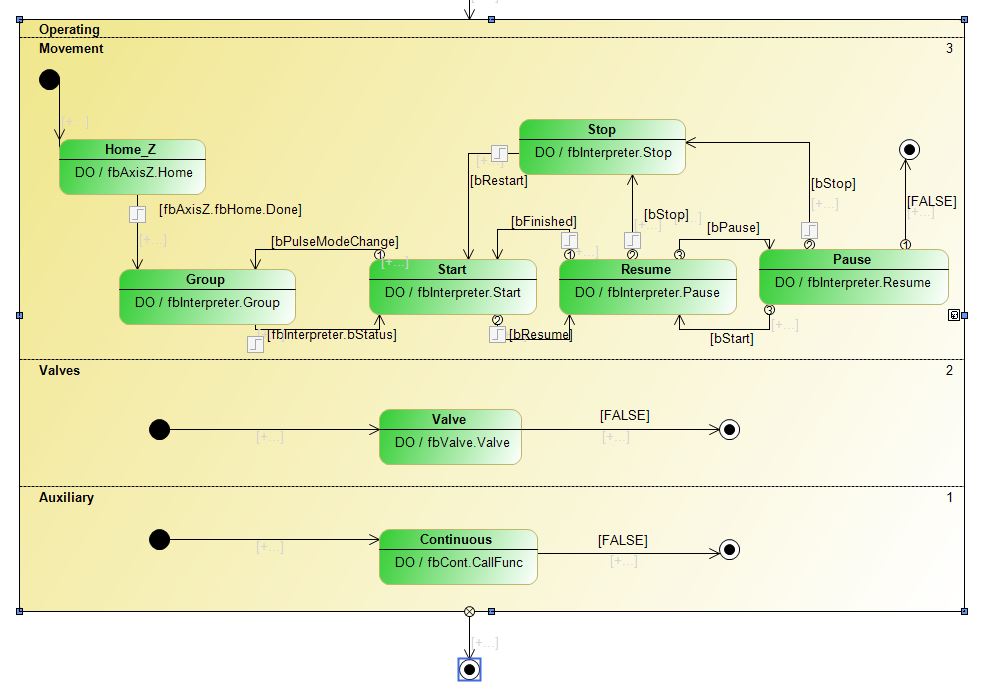
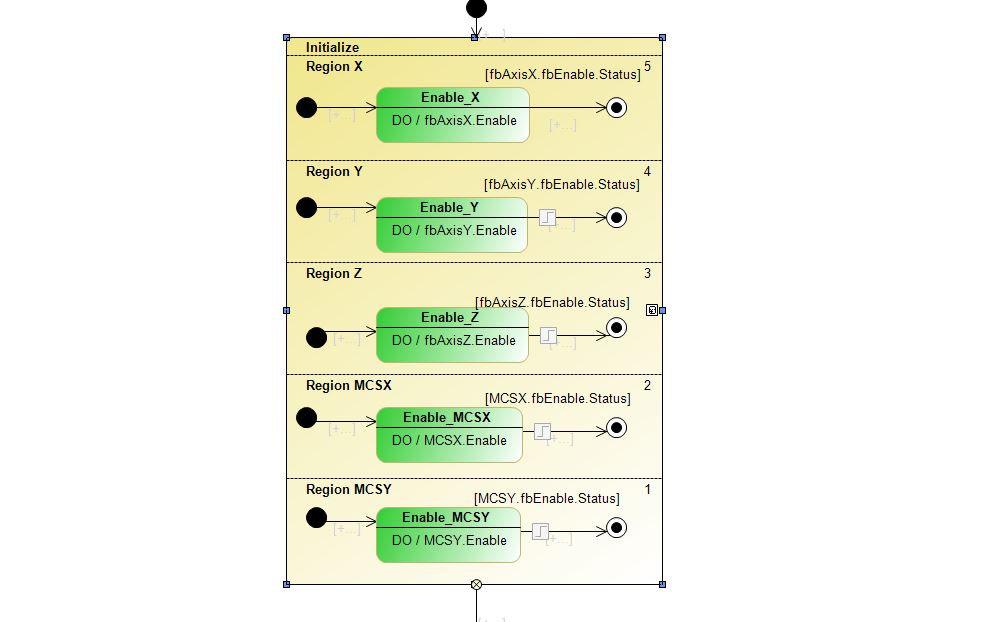
● A cooler fan for adjusting the chamber temperature

● A lambda sensor for the continuous oxygen measurement in the chamber

● A valve for adjusting the argon flow rate

● Two Valves for the structure and main material nozzles

The precise coordination of all of the mentioned sensors is necessary to operate 3D printer. A malfunction of any of the sensors or actuators leads to complete failure of the 3D printing process.



UML

The twincat environment allows the users to control the software algorithms in a various ways . C, c++, c++, c#, Structured text an UML are only a few of these. For the incremental casting project was the main part of the software designed as an UML Chart.   
  
The UML can be portrayed as a state flow chart with Boolean switches to control the flow. Every frame has to have a Start and End states. The information or the workflow is conducted by the flow lines between the states from the start state in the direction of the end state.

The UML is divided into two main parts, in order to separate the preparation and actual control processes from each other. The State flow is firstly delivered to the composite state “initialize”. Before any movement is to be realized each axes has to receive a signal that allows the software to control the axes. Each 6 real and virtual axes has to turn its own Status variable on in order to give the composite state initial the permission to let the signal flow out of the composite state.

The signal continues to the second composite state where the actual control of the printing system takes place. The input signal is divide into two parallel state flow regions. The first one is responsible for the homing, building the kinematic groups for the interpolator and the kinematic transformation. The ready signal is hen passed on between the start, stop, resume and pause states depending on the control input of the user.

The second region is responsible for the auxiliary processes, which have to be run the continuously as long as the system is enabled, like reading values out of the G-Code, measuring and controlling the nozzle chamber and platform temperatures. Thus the flow without an interrupt at a constant pace is necessary. Exiting the second composite state is prohibited, since the system should never be stopped unless it is powered down.

FB\_Axis  
The Function block fb axis takes the responsibility of getting axes ready before the interpreter or a manual commander takes the control. The contained methods as Enable, Home and kill are instanced to enable the movement in both directions homing the stepper motor coupled axes or killing the signal in case of an emergency.   
  
FB\_Interpreter

The Function block FB\_Interpreter takes the control after the axes are enabked and homed.Building the groups, switching between states like start, stopi pause and resume are regulated under the methods of the interpreter.

The method group defines and couples the kinematic transformation and interpreter groups depending on the predefined configuration.  
The method pause holds the workflow iinside of the state Resume. When a pause signal is arrived the state calls the pause method to hold on the movement and let the signal pass to the pause state.

The method resume does almost the same thing as the method pause.