Prof./Ens. Boillat-Brugger-Moser - Introduction to AM

Date 26.01.2019 - duration : 3h00

ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

Open Book Part

Name :

Wait for the beginning of the test before turning the page. This document is printed double-sided, it contains 10 pages, the last ones can be empty. Do not remove the staple.

- Put your student card on the table.
- Any document is allowed.
- The use of a computer or of a cell phone is prohibited during the test.
- After the exam, the teachers reserve the right to cancel any questions which they will consider to be ill-posed.
- Write your name on every page

Question	Number of points
1)	
2)	
3)	

Question 1: *This question is scored on 30 points*

You apply the SLM process to manufacture parts out of a bronze powder characterized by the follwing thermal and mechanical properties:

Table 1: Thermal/mechanical properties of the bronze material

therm. conduc. k, W/mm/K	e.m. absorpt. $A@\lambda = 1070\,\text{nm}$	density ρ, g/mm^3	heat capacity C_p, J/g/°C	melting temp. T_melt,°C	latent heat L_f, J/g
0.170	18%	8.72×10^{-3}	0.380	1005	214

Your SLM machine is to be equipped with an Ytterbium fiber laser ($\lambda = 1070\,\text{nm}$) emitting a quasi top-hat (uniform) beam of quality $M^2 = 17.8$.

a) The power P_0 needed to melt the powder is a function of the scan speed v and of the radius w_f in the focal plane (=surface of the powder bed). For which value of v and w do we get the **minimal** value of P_0? Justify your answer.

b) You use a lens to focus the Ytterbium fiber laser described above. What is the minimal possible value of the focal waist w_f you can expect?

c) You combine the fiber laser with a converging lens with focal length $f = 720\,\text{mm}$ and radius $R = 50\,\text{mm}$. Using this additionnal information, estimate the minimum power P_0^min which is required to melt the powder.

d) You select the laser power by multiplying P_0^{min} with a security factor of 1.5 and by rounding the result to the upper hundred. Give an estimate of the maximum consolidation rate you can obtain.

e) The hatching distance h to be used can only be selected among a discrete number of choices:

Table 2: Possible hatching distance

choice No	1	2	3	4	5	6
h μm	0.00107	0.10700	1.07000	10.0000	80.0000	1000.00

Is one on these choices adequate? If yes tell which one, if not explain why and make a smart suggestion for h.

f) Assume that the layer thickness is $e = 30\,\mu$m and that the hatching distance h is chosen according to what has been said in e). Under these conditions, determine the velocity to be used to achieve the maximum consolidation rate estimated in d).

g) Determine the maximum temperature reached in the powder bed if we apply the scan velocity calculated above. Compare the obtained value to the melting temperature. What do you observe and how do you explain it?

Question 2: *This question is scored on 15 points*

a) Fig. 1 represents a known additive process. Give its acronym and its complete name.

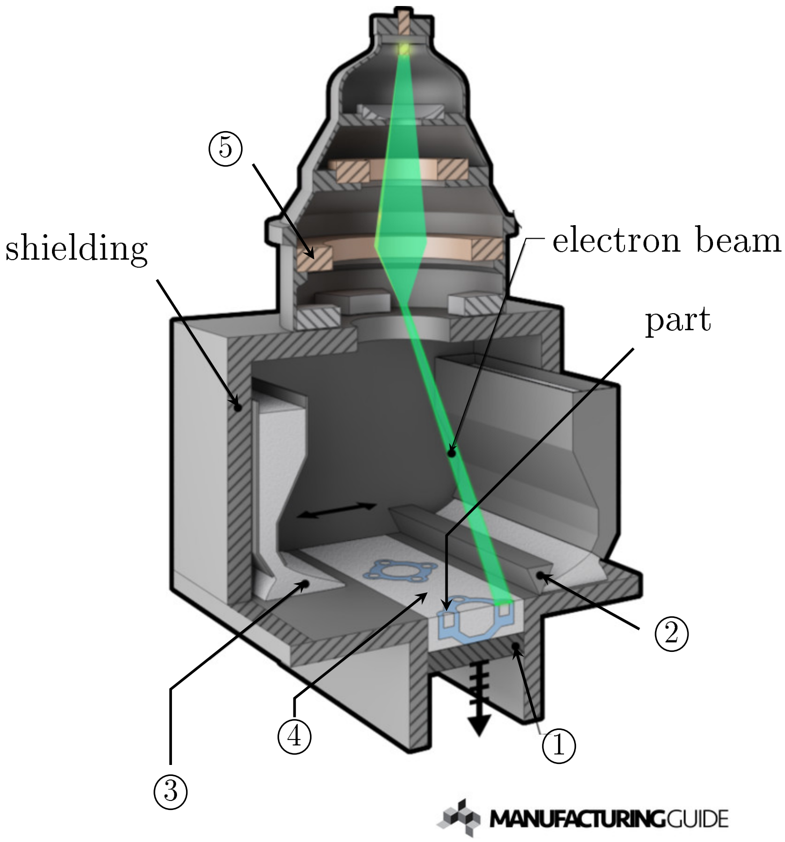

Figure 1: Schematic representation of an additive process

b) In Fig. 1, five elements are not named but numbered ①-⑤. Describe those items below:

①: ....

②: ....

③: ....

④: ....

⑤: ....

c) In Fig. 1 it can be observed that the shielding is thick. What is the reason behind it?

d) Explain briefly which physical mechanism(s) are used in the process of Fig. 1 to achieve consolidation.

e) Is it possible to apply the process of Fig. 1 to polymer or to ceramic materials? Justify your answer.

f) Is the process of Fig. 1 a direct (leading directly to the part in the right material) or an indirect additive process?

g) Name at least **two** different additive processes using the **same** base material as the process of Fig. 1. For each, precise if it is a direct or an indirect process.

	Process name and acronym	**direct**	**indirect**
1)	....	☐	☐
2)	....	☐	☐

h) In which country has the process of Fig. 1 been developed and industrialized (**<u>Hint</u>**:*this country is also known for producing matches* ☺)

Question 3: *This question is scored on 23 points*

a) The part in Fig. 2 represents a bearing with an internal lubrication system. It contains a particular feature wich makes additive process well adapted for its fabrication. Describe this feature and justify your answer below:

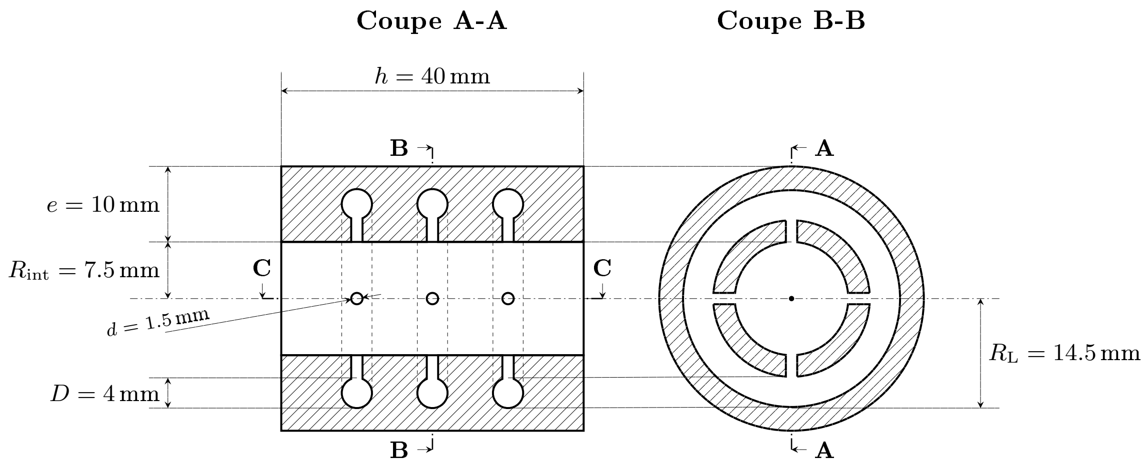

Figure 2: Drawing of the part to be produced, with dimensions of utilization

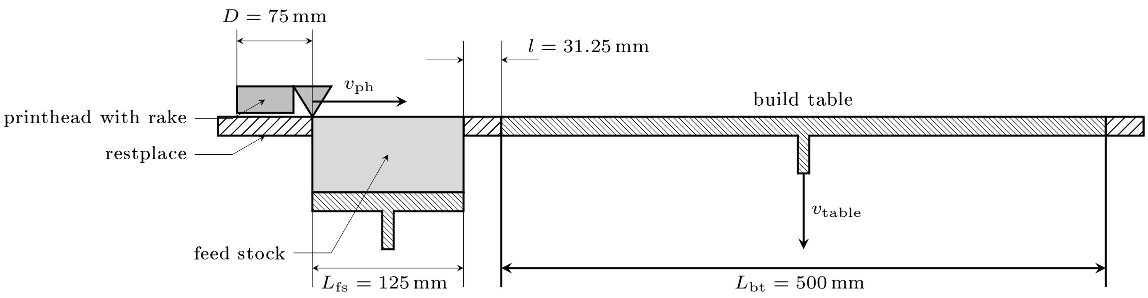

Figure 3: Schematic representation of the Digital Metal$^{\mathrm{TM}}$ machine

b) Whithout this feature, the part would certainly be easy to manufacture by traditional processes. Name at least one such process which could be applied in that case.

c) As a first manufacturing option, you select the Digital Metal™ process by the Swedish company Höganäs (see Fig. 3). In which categorie of additive processes does this particular process belong?

d) The other option for fabricating the part is the SLM process (see Fig. 4).

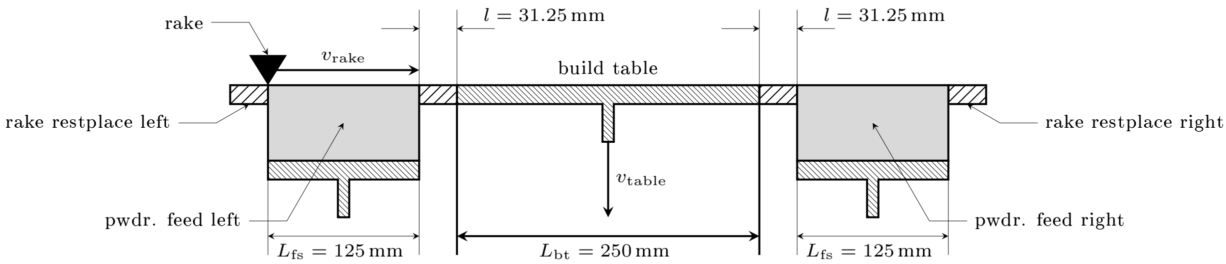

Figure 4: Representation of the SLM machine

Your first intention is to base your final decision on the fabrication time. The tables below give you numerical information about the process parameters to be applied on the two different machines:

Table 3: Process parameters to apply on the SLM machine

table speed	**rake speed**	**scan speed** laser on	laser off	**hatching distance**	**layer thickness**
$0.1\,\mathrm{mm/s}$	$40\,\mathrm{mm/s}$	$1000\,\mathrm{mm/s}$	very large	$75\,\mu\mathrm{m}$	$50\,\mu\mathrm{m}$

Table 4: Process parameters to apply on the Digital Metal™ machine

table speed	**printhead speed** homing motion	printing motion	**layer thickness**
$0.4\,\mathrm{mm/s}$	$150\,\mathrm{mm/s}$	$75\,\mathrm{mm/s}$	$50\,\mu\mathrm{m}$

Have you enough information to compute the layering time and the MCR for each process? If yes fill the following table (value and corresponding unit, explain your calculation on the pages at the end of the exercise):

Table 5: Layering time and MCR

Process	**SLM** value	unit	**Digital Metal™** value	unit
layering time	....	....	....	....
MCR	....	....	....	....

e) Assume that the build direction is the axis of symmetry of the bearing and use the results obtained in Tab. 5 to compute the fabrication time (per part) for each process and for different batch sizes (write the details of calculation at the end of the exercise):

Table 6: Fabrication time per part

	SLM			**Digital Metal™**		
	h	min	s	h	min	s
1 part:	....	....	....	....	....	....
10 parts:	....	....	....	....	....	....

Hint: *The volume of a torus is the volume of a cylinder with equivalent section and a height equal to the perimeter of the circle joing the centers of the sections.*

f) The internal surface of the bearing has to be smooth (N7 standard: $R_\mathrm{a} \simeq 1.6\,\mu\mathrm{m}$) and to resist to deformation (Young modulus E at least as high as 200 GPa). Are the two additive processes (SLM and Digital Metal™) able to deliver a part with such properties? If not, fill the following table with the list of the postprocessing steps which will be needed:

Table 7: Needed postprocessing

SLM	**Digital Metal™**
....	....
....	....
....	....
....	....
....	....

g) In case you select the Digital Metal™ is that true that you have to produce the fabrication file (.stl file) by respecting exactly the dimensions of utilization given in Fig. 2? If it is not the case, justify your answer and explain how the dimensions have to be modified.

h) You would like to decrease the diameter d of the lubrication holes. Is it possible to make this quantity as small as you want, or, due to manufacturing reasons, is there a limit under which you cannot go? If it is the case, please justify your answer.

+0/10/51+