+0/1/60+

Table No.

Prof. Boillat-Brugger-Moser
- Introduction to AM

Date 21.01.2021 - duration : 1h25

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 12 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.
- You may use a pencil instead of a pen.
- 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)	
4)	
Total	

to be filled by the teacher

Question 1: *This question is scored on 5.5 points*

Fill each of the 22 gaps below with 22 words (or acronyms) giving a sense to each sentence:

- If it uses a shape tool, a process is said to be ..... (1) .
- The shape tool is said to be expendable if it has to be ..... (2) to recover the ..... (3) .
- In casting, master models and lost patterns are used to fabricate the ..... (4) . The difference between a lost pattern and a master model is that the master model can be ..... (5) ..... (6) ..... (7) .
- In ..... (8) ..... (9) , parts are made out of a mould obtained by plastering a cluster of ..... (10) ..... (11) made out of wax.
- In ..... (12) ..... (13) , a part is made out of a mould obtained by immersing a ..... (14) ..... (15) in a silicone bath which is then left to dry. The typical material for the part is ..... (16) .
- In the ..... (17) process chain, metallic parts are obtained by electro-plating ..... (18) counter-parts made by ..... (19) .
- The ..... (20) process is an additive method that can produce wax lost patterns.
- The DLP process can also be used to produce lost patterns. But, in that case they will be made out of a ..... (21) ..... (22) .

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

You develop a new SLA machine with a square platform of side $c = 200\,\text{mm}$.

a) A focusing lens has to be installed between the scan head and the platform in a way that the axis of the lens goes through the center of the platform. To avoid optical aberrations, the *view angle* under which the lens center sees the diagonal of the platform has to be $< 20°$. Use this information to determine the smallest focal length f to be used[1].

b) The radius of the lens is $R = 6.25\,\text{mm}$ and the laser wavelength is $\lambda = 324\,\text{nm}$. Under this condition compute the smallest focal waist w_f^min that you can reach.

c) What is the necessary condition to impose on the laser beam if we want to achieve the particular value w_f^min for the focal waist?

[1] If you cannot answer this question, take the value $f = 800\,\text{mm}$ to continue the exercise.

d) On any laser data sheet, an optical characteristic indicates how far we are from the necessary condition mentioned in the previous item. What is the name and the symbol of this quantity and which value does it take when the smallest focal waist can be achieved?

e) You select a laser such that the smallest possible focal waist can be achieved. The power of this laser is $P_0 = 0.005\,\mathrm{W}$. You consider to work with a photoresist and with a laser scan-peed such that the curing reaction will be limited to regions receiving **at least** a threshold intensity of $I_{\mathrm{th}} = 3.5\,\mathrm{W/mm^2}$.

1) The laser travels over the photoresist from point A to point B over a distance $l = 0.05\,\mathrm{mm}$ (see Fig. 1). It provokes the curing of a certain volume V_{c}. You are asked to hatch on Fig. 1 the shape of the upper surface of this volume V_{c}. You are also asked to compute the precise dimensions of this shape (length L and width w).

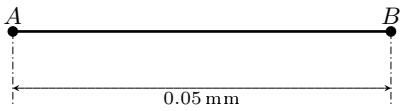


Figure 1: Laser path

2) We assume that the scan head in your system ensures a positioning accuracy of $\delta = \pm 5\,\mu$m for the laser beam on the photoresist surface. Give an estimate of the process resolution in the $xy-$plane. Justify your answer[2].

3) How many Digital Mirror Devices (DMD's) do you approximately need to obtain a comparable accuracy over the **same** build table in the DLP process?

[2] If you cannot answer this question, take any **reasonable** value for the process resolution and continue the exercise.

Question 3: *This question is scored on 9 points*

a) What is the minimum number n of triangular facets required to describe **exactly** the shape of the house of Fig. 2 in an .stl file?

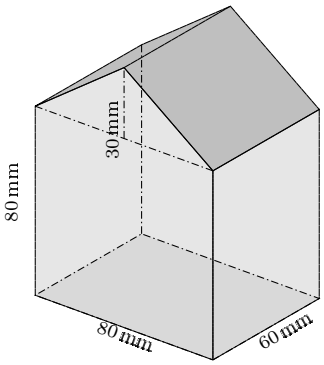


Figure 2: The part to be printed

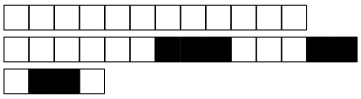
b) Can a higher number of facets increase the precision of the design? Explain.

c) This part of the .stl file describes one bottom facet of the house:

`beginfacet`			
`facet normal`			
	0	0	−1
`outer loop`			
`vertex`			
	40	−30	0
`vertex`			
	−40	−30	0
`vertex`			
	40	30	0
`endloop`			
`endfacet`			

Table 1: A part of the .stl file

Fill the empty boxes below in order to define the other bottom facet and all roof facets:



beginfacet

facet normal

outer loop

vertex

vertex

vertex

endloop

endfacet

beginfacet

facet normal

outer loop

vertex

vertex

vertex

endloop

endfacet

beginfacet

facet normal

outer loop

vertex

vertex

vertex

endloop

endfacet

beginfacet

facet normal

outer loop

vertex

vertex

vertex

endloop

endfacet

Question 4: *This question is scored on 27 points*

You need to produce two polymer parts, part A and part B in small series. You will apply an additive process for that. You ask an offer to your provider. He proposed to apply a process called process 1 and another process referred to as process 2. The offer you get depends on the number of items you order. It is summarized in Tab. 2:

Process	**Part**	**nr. of ordered items**							
		1	2	5	10	25	100	104	1000
1	**A**	22 Frs	44 Frs	110 Frs	220 Frs	550 Frs	2′200 Frs	2′288 Frs	22′000 Frs
	B	11 Frs	22 Frs	55 Frs	110 Frs	275 Frs	1′100 Frs	1′144 Frs	11′000 Frs
2	**A**	110 Frs	120 Frs	150 Frs	200 Frs	350 Frs	1′400 Frs	1′540 Frs	14′000 Frs
	B	96 Frs	101 Frs	116 Frs	141 Frs	216 Frs	864 Frs	975 Frs	8′640 Frs

Table 2: The price for the **whole** series as a function of its size

a) For one of the two processes, the items are built by batches of $n_\mathrm{b} > 1$ items (**same** batch size for part A an B). Moreover for each batch a non-zero set-up price p_b is charged (**same** price for each part). From the price list given in Tab. 2, it is obvious whether this process is process 1 or process 2. You are asked to check the right affirmation and to justify your answer[1]:

☐ The process with $n_\mathrm{b} > 1$ and $p_\mathrm{b} > 0$ is process 2

☐ The process with $n_\mathrm{b} > 1$ and $p_\mathrm{b} > 0$ is process 1

b) You get an extra information. One of the processes proposed by your provider is FDM, the other is L-PBF. Use the results obtained above to guess which process is probably named 1 by your provider and which one is probably named 2. You are asked to check the right affirmation and to **justify** your answer[1]:

☐ process 2 is certainly L-PBF

☐ process 2 is certainly FDM

[1] no points will be attributed if the justification is wrong or missing

c) In process 2, both parts are made of the **same** material and with the **same** process parameters. However, Tab. 2 indicates that, for the same numbers N of ordered items, the manufacturing costs are different for part A and part B: $p_A(N) \neq p_B(N)$. What does it mean? Check the correct answer (no justifications are needed in that case)

- ☐ The cheap part has probably a simple geometry while the expensive one is more intricated
- ☐ The average radius of curvature R_A, R_B of the parts are **necessarily** different. If they would be the same, $R_A = R_B$, then we would have $p_A(N) = p_B(N)$
- ☐ The external surface S_A, S_B of the parts are necessarily **different**. If they would be the same, $S_A = S_B$, then we would have $p_A(N) = p_B(N)$
- ☐ The volumes V_A, V_B of the parts and/or their heights in the build direction H_A, H_B are different. If they would be the same, $V_A = V_B$ and $H_A = H_B$, then we would have $p_A(N) = p_B(N)$

d) In case of process 2, observe that the difference between the prices for two and one items is not the same for each parts:

$$p_B(2) - p_B(1) \neq p_A(2) - p_A(1).$$

What does it mean? Check the correct affirmation and **justify** your answer[2]:

- ☐ The heights of the parts in the build direction H_A, H_B are different. If they would be the same, $H_A = H_B$, then, we would have $p_B(2) - p_B(1) = p_A(2) - p_A(1)$.
- ☐ The volumes V_A, V_B of the parts are different. If they would be the same, $V_A = V_B$ then, we would have $p_B(2) - p_B(1) = p_A(2) - p_A(1)$.

e) The volume of part A is $V_A = 50'000\,\text{mm}^3$. Use the price list for process 2 (see Tab. 2) to determine the volume V_B of part B.

[2] no points will be attributed if the justification is wrong or missing

f) The hourly rate of the machine used in process 2 (including depreciation, manpower and energy consumption etc...) is $R = 72\,\text{Frs/hour}$ and the material costs is so low that it can be neglected. Use these information as well as the price list in Tab. 2 to evaluate the material consolidation rate MCR of this process.

g) For process 2, the price for two items, is less than two times the price for one item: $p(2) < 2p(1)$. How can you justify this and what does the difference $2p(1) - p(2) > 0$ represent?

h) Always for process 2, note that the differences $2p(1) - p(2)$ are not the same if we consider part A and part B. How do you justify this fact? Recall that we have assumed that

- the price p_b for setting up the machine does not depend on the part to be built (see Qu.a)
- both parts are made of the **same** material and with the **same** process parameters (see Qu.c)

i) Use the data in Tab. 2 to determine the batch size n_b for process 2. Recall that the batch size is the same for both parts A and B (see Qu.a).

j) Part A is 25% higher in the build direction than part B:

$$H_A = 1.25 H_B. \tag{1}$$

Use this information and the data in Tab. 2 to compute the set-up cost p_b of process 2.

k) The height of part B is $H_B = 36\,\text{mm}$ and the layer thickness is $e = 100\,\mu\text{m}$. Use this information and the results obtained in the previous questions to compute the time needed to prepare a layer (layering time) in process 2.