Series 3.

Exercice 1

a) Name the five major classes of additive processes with which it is possible to make **direct** metal parts.

b) Suggest a classification of these five processes based on the three following criteria:

- the physical state of the raw material,
- the conditioning the raw material just before consolidation,
- the consolidation principle.

Exercice 2

Some of the physical properties of a typical tool steel (maraging steel with high nickel content) are given in Tab. 1:

Thermal conductivity k	Absorption @1064 nm A	Density ρ	Heat capacity C_p	Latent heat of fusion L	Fusion temper. T_melt
$0.026\,\mathrm{W/mm/K}$	40%	$8.04 \times 10^{-3}\,\mathrm{g/mm^3}$	$0.4\,\mathrm{J/g/°C}$	$305\,\mathrm{J/g}$	$1413\,°\mathrm{C}$

Table 1: Physical property of a typical maraging steel

This material is used in a SLM station equipped with a IR-laser ($\lambda = 1064\,\mathrm{nm}$).

a) The laser power is $P_0 = 500\,\mathrm{W}$ and the machine has no pre-heating. Under these conditions, compute the maximal material consolidation rate MCR which is possible to achieve.

b) You are asked to build a part out of a maraging steel powder. Due to porosity, the powder has a relative density of 73% with respect to bulk. Compute the number of layers necessary to construct the part from the data of Tab. 2 and under the standard assumption that, during the consolidation process, shrinkage only arises in the build direction (z):

Part height (in $z-$direct.) h	Part volume V	Powder bed thickness (as deposited), e	Deposition time τ_dep	Powder price p	Laser efficiency in-out η
$50 \pm 0.02\,\mathrm{mm}$	$125\,\mathrm{cc}$	$50\,\mu\mathrm{m}$	$6\,\mathrm{s}$	$45\,\mathrm{Frs/kg}$	10%

Table 2: Some data concerning the part to build

c) The last point is to determine how much you have to charge the customer of the part discussed at point (b). To do so you have to take the situation of your company into account:

 (i) You expect a total depreciation of the machine (520′000 Frs) over three years (250 working days per year). You count on an average machine occupation of six hours per day. Moreover, since the machine has been purchased on your own funds, you target a return on investment of at least 10% per year.

 (ii) The wage level you want to generate and to share among the machines operators (technicians, salesmen, engineers ...) should be at least 100 Frs/h.

 (iii) Naturally, and due to thermal losses, the MCR computed at point (a) cannot be reached. You only expect to operate your machine with at MCR equal to half of the optimal value.

 (iv) The local electrical company charges you a price of $c = 0.25$ Frs per consumed kWh.

Exercice 3

Selective laser melting is used to produce parallelipipedic gold parts. The machine is equipped with a laser emitting a gaussian beam with a total power $P = 400$ W and at a wave length of about $\lambda = 1064$ nm.
The deposited powder beds have a thickness of $e = 50\,\mu$m and the powder has a relative density $r = 74\%$ with respect to bulk density.
Each layer is consolidated with a parallel scanning strategy (see Fig. 1). The hatching distance h and the scanning speed v are not yet given. The goal of this exercise is to determine these values[1].

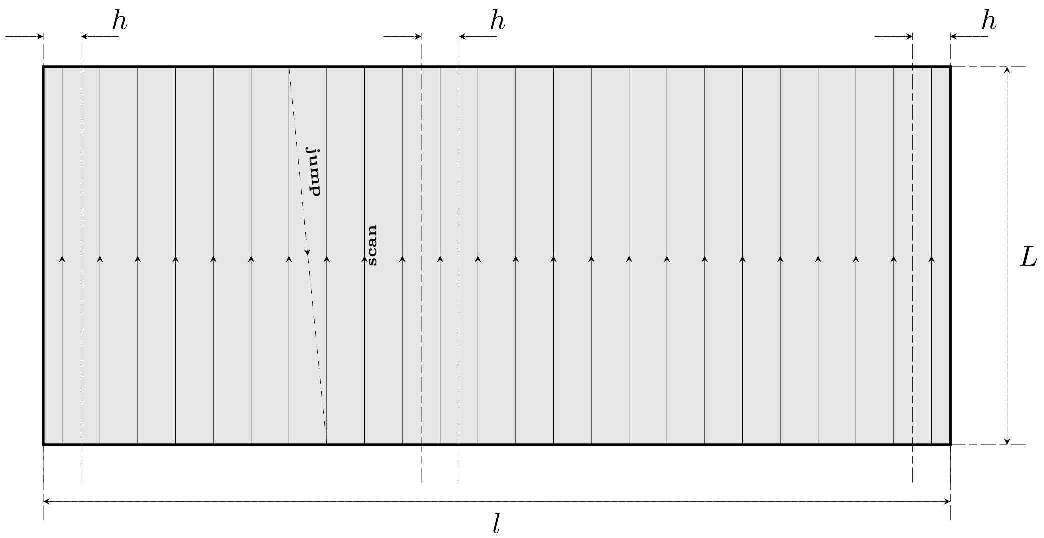

Figure 1: Laser parallel scanning of a given layer (with scans and jumps)

a) During consolidation, it can be assumed that shrinkage only arises in the construction direction ($z-$direction). Under this condition, show that there is a relationship between the material

[1] In this exercise, the speed of the laser when it jumps from one scan to the next one (see Fig. 1) is not known but will be assumed so large that the jump time is almost zero.

consolidation rate MCR on one side and the hatching distance h, the scanning speed v, the bed thickness e and the powder relative density r on the other side.

b) The physical properties of pure gold are given in Tab. 1:

Thermal conductivity k	Absorption @1064 nm A	Density ρ	Heat capacity C_p	Latent heat of fusion L	Fusion temper. T_melt
0.301 W/mm/K	10%	19.32×10^{-3} g/mm^3	0.13 J/g/°C	66.2 J/g	1069 °C

Table 1: Physical property of pure gold

An energy conservation principle can be used to deduce the maximal material consolidation rate $\mathrm{MCR}_\mathrm{opt}$ which can be obtained on our machine. We ask you to find this value.

c) The idea is now to adapt the hatching distance h and the scanning speed v (see Fig. 1) in a way to reach the optimal MCR computed at point b). Two constraints have to be fulfilled:

(i) To ensure overlapping between the consolidated tracks, the hatching distance has to be adapted to the laser beam radius w. A possible rule is $h \simeq w$.

(ii) The scan speed is limited because it has to ensure that melting temperature is reached at least in the middle of the laser beam.

You are asked to check if there are some possible values of h and v satisfying these constraints.

d) At point c), you get quite severe conditions on the possible values of the beam radius w. You are asked to comment on this and to explain why it is actually possible to process gold powder on industrial equipments which are far from satisfying the constraint you found.