Problem description and questions

You have been approached as a consultant to provide perspective on the manufacture of a heat exchanger element. They are not interested in a redesign, there are clearly several problems here. They want to understand all things, if any, that may be done to keep this specific design while using existing equipment and tooling. Their engineers have provided you with the following information. The element is shown in Fig. 1A. The part must (due to service temperature) be made of a nickel alloy that exhibits work hardening which is similar to the strain hardening of stainless steel. A plunge-turning operation is proposed to generate grooves within a piece of 55mm diameter stock. A 3730 Watt (~5 hp) lathe is to be used. Their first thought is to use a plunge tool of width equal to the groove dimension. The tool is to be fed into the part by \( f \) inches per revolution as shown in Fig. 1B. Figure 2 shows the Taylor tool life data for the tool materials (carbide and ceramic) that are under consideration. Note, the lathe carriage (moves parallel to the spindle’s rotation axis) to be used in this turning operation is manually operated (similar to the better lathes in the building 35 shop and Pappalardo shop) and is equipped with a digital readout on each axis that reads with 0.0004 inch (~10 micrometers) resolution. The lathe is not capable of varying its spindle speed as it plunges and it is not capable of varying the feed into the part during a plunge cut. The lathe is able to auto feed the tool into the part at a given constant feed per revolution. The company possesses one lathe, and they wish to make the part during the day shift (8 hour shift with 1 hour for lunch/breaks) with a single tool as shown in Fig. 3. Their machinist, Bob, has 15+ years of experience working this type of lathe, is entitled to 6 weeks of vacation per year, and his services cost the company $50/hour (salary + benefits). Other useful information:

- Average grain size: 0.020 inch [\( \frac{1}{2} \text{ mm} \)]
- Ultimate strength: 020,000 psi [137.9 MPa]
- Shear yield strength: 012,000 psi [82.7 MPa]
- Young’s modulus: 030,000 ksi [206.8 GPa]
- Parts per year: 125,000 parts/year
- Cost per tool: Carbide: $25; Ceramic: $200
- Total specific energy: 10 J/mm\(^3\) (assuming 80% motor efficiency, \( \alpha = 20^\circ \))
- Material cost: $10/cm\(^3\)

1. Rate [2 pts]:
   (a) List the major steps required to make the part, start with “load material in lathe,” end with “remove material from lathe.”
   (b) Assign reasonable times to each major step. Use engineering judgment when calculations are not possible/practical.
   (c) Estimate the minimum rate, considering only the desired annual volume and the human resource limitations.
   (d) Estimate the maximum rate. Do not forget to consider lathe power and structural integrity of the part in your thinking.

2. Cost [2 pts]:
   (a) Estimate the minimum tooling cost per part if one were to use a (i) carbide tool or (ii) ceramic tool.

3. Quality [2 pts]:
   (a) Is the grain size of the material a concern with respect to quality?
   (b) List strategies for holding the part so as to enable the fabrication without excessive deformation or structural failure.
   (c) The engineers want to change \( \alpha \) to \(-20^\circ\), thereby decreasing cutting force & increasing quality. Do you agree?

4. Summary of findings and recommendations [4 pts]:
   Use the results of 1 – 3, in addition to anything else you would like to add, to provide a concise bullet point summary of your findings and recommendations. Do not write an essay! What matters most here is the relevance of your points to the general concerns that any manufacturer would have; and the quantitative justification of your points. Unnecessary length will not help your grade and listing equations/issues/assumptions without justification will hurt your grade… so don’t list random “stuff” in the hopes that this will help. It is OK to speculate, but you must say you are speculating.
Fig. 1: Element geometry and cutting process parameters

Fig. 2: Tool life diagram (assume valid for flank and/or face wear). The tool wear may be predicted via the normal Taylor tool life equation: \( V \cdot t^n = C \) (\( V = \) cutting velocity, \( t = \) time to tool failure)

Fig. 3: Tool geometry