ME 4610/5610
Advanced Machining Processes
Final Project

One of the machining operations performed on a single-cylinder engine is boring the cylinder. The block is made of 390 cast aluminum (high silicon). The cast bore has a worst-case (lower tolerance limit) diameter of 95 mm. The final nominal bore diameter is to be 100 mm. The attached drawing shows the relevant features of the block and cylinder bore, including the water jackets, some screw holes, and two crankshaft clearance windows at the bottom of the bore. The production volume is 100,000 units.

Technical Information

Final Part Specifications:

- Nominal machined bore diameter = 100 mm.
- Cylindricity over entire bore height = ± 5 μm (i.e., tolerance on radius, relative to a common axis spanning all z).
- Surface roughness (R_a measured along a worst-case axial trace for N_t feed marks) ≤ 1 μm, where the worst-case effect of tooth throw should be considered, i.e., every other tooth should be at $+\varepsilon_r$ and $+\varepsilon_a$ and the other teeth at $-\varepsilon_r$ and $-\varepsilon_a$, where ε_r and ε_a are the radial and axial throws, respectively.

Structural:

- A FEA indicates that the fixture has static stiffness that translates into bore wall deflection as a function of position up from the top of the fixture. In other words, the deflection of the bore wall in the x- and y-directions, as a function of b (in mm, see drawing) are equal to F_x/k_x and F_y/k_y where

$$k_x = 30{,}000(1-0.0025b)\ \text{N/mm} \qquad \text{and} \qquad k_y = 25{,}000(1-0.0030b)\ \text{N/mm}\,.$$

- FEA also indicates that there exists a bore wall stiffness that relates radial bore wall displacement to radial force with the stiffness

$$k_r = 100(60-R_w)^2\left(\cos(4\theta)+4\right)\ \text{N/mm}\,,$$

  where R_w is the workpiece radius, prior to removing material on the current pass, measured relative to the z- axis.
- The cast hole is offset from the final part/spindle axis by a distance ε_{wo} at an angle δ_{wo}. The added cost of maintaining a casting axis offset with magnitude ε_{wo} is

$$3\left(e^{(1-\varepsilon_{wo})}-1\right)\ \$/\text{unit}\,,\ \varepsilon_{wo}\ \text{in mm}$$

  and with a range $\pm\Delta\delta_{wo}$ about the angle δ_{wo} (i.e., $\delta_{wo_{nom}} - \Delta\delta_{wo} \le \delta_{wo} \le \delta_{wo_{nom}} + \Delta\delta_{wo}$) is

$$e^{(1-0.1\cdot\Delta\delta_{wo})}-1\ \$/\text{unit}\,,\ \Delta\delta_{wo}\ \text{in degrees.}$$

Tool Holder:

- At least two boring bars (8 teeth maximum for this diameter) must be purchased. The cost for each depends on the level of precision as measured by the magnitude of tool-spindle axis offset to be maintained, ε_{to} in μm.
- Boring bar cost (ea.) is $\$2{,}500+\$600\left(e^{(2-0.1\varepsilon_{to})}-1\right)+\$500N_t$, specialty

  $1,000, standard from catalog, $N_t = 1$ only.
- Cartridge cost (ea.) is $25
- Consult (no-charge) Prof. Endres for cost quotes on special boring-bar designs.

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Cutting Inserts:

- Inserts can be selected from the catalog provided – carbide inserts must be "ground", e.g., SN**G**, TP**G**, etc. C• indicates carbide grade.

• Uncoated carbide insert cost (ea.):	– C1-C2:	32_ =	\$4.00	43_ =	\$6.00
	– C3-C4:	32_ =	\$5.00	43_ =	\$9.00
	– C5-C6	32_ =	\$6.00	43_ =	\$12.00
• Coated* carbide insert cost (ea.):	– C1-C2:	32_ =	\$7.00	43_ =	\$10.50
	– C3-C4:	32_ =	\$9.00	43_ =	\$13.50
	– C5-C6	32_ =	\$11.00	43_ =	\$16.50
• Diamond (PCD) insert cost (ea.):		32_ =	\$80.00	43_ =	\$100.00

Specific Energies (in N/mm^2, uncut chip thickness in mm, rake angle in radians):

- CVD coated: – C1-C2

$$u_C = 1500 h^{-0.322}(1-\sin\gamma_n)^{-0.95} \quad \text{and} \quad u_T = 800 h^{-0.655}(1-\sin\gamma_n)^{-1.10}$$

– C3-C6

$$u_C = 1450 h^{-0.367}(1-\sin\gamma_n)^{-0.97} \quad \text{and} \quad u_T = 785 h^{-0.741}(1-\sin\gamma_n)^{-1.05}$$

- PVD coated and uncoated:

$$u_C = 1455 h^{-0.288}(1-\sin\gamma_n)^{-1.03} \quad \text{and} \quad u_T = 790 h^{-0.589}(1-\sin\gamma_n)^{-1.21}$$

- PCD:

$$u_C = 1445 h^{-0.250}(1-\sin\gamma_n)^{-0.89} \quad \text{and} \quad u_T = 785 h^{-0.505}(1-\sin\gamma_n)^{-0.99}$$

Tool Life Model Coefficients (tool life in minutes/tool, cutting speed in m/min):

• Uncoated carbide:	– C1-C2:	C = 925	n = 0.21
	– C3-C4:	C = 1,750	n = 0.27
	– C5-C6:	C = 2,700	n = 0.31
• Coated carbide:	– C1-C2:	C = 1,150	n = 0.24
	– C3-C4:	C = 2,000	n = 0.29
	– C5-C6:	C = 4,000	n = 0.36
• Diamond (PCD):		C = 100,000	n = 0.57

Machining Economics Data:

- Overhead cost: $c_o = (1 + 0.1P_m + 0.01P_C)$ \$/min , P_m and P_C are machine and cutting power in kW, respectively.
- Machine efficiency: The machine is 80% efficient from power input to cut.
- Handling time: 12 sec per load, 6 sec per unload (each from a single machine).
- Tool change time: $t_c = 10\left[1 + \left(2.5\,(N_t - 1)\,\mathrm{e}^{-(0.1\varepsilon_r + 0.15\varepsilon_a)}\right)^{1.25}\right]$ min

  where $\pm\varepsilon_r$ and $\pm\varepsilon_a$ are the radial and axial throw envelopes in μm, e.g., $R_t = R_{t,nom} \pm \varepsilon_r$, $L_t = L_{t,nom} \pm \varepsilon_a$.

* Costs given are for CVD (Chemical Vapor Deposition) coated inserts. Add an additional 20% to cost for PVD (Physical Vapor Deposition) coated inserts.

Other:

- Consultation (with Prof. Endres) costs, including “Will this idea work?”, “How do I do this?”, etc., should be charged to your project at $\$200t^2$, where t is in 15-minute units (e.g., 1-15 min: $t = 1$, 16-30 min: $t = 2$, etc.), charged in integer unit increments. Queries for additional/missing information will not be charged.
- Your time is billed at $40 per hour. Keep track of how much time you spend.

Project Objective and Requirements

The objective is to minimize the cost of this operation on a per-unit basis. Fixed costs and other costs (including, but not limited to, your billed time and consultation time) should be spread out over the production volume. The written report must:

- be five (5) double-spaced pages or less, in Times 12 point with one inch (1”) margins all around — I will not read more than these five pages.
- stand on its own without the appendices — i.e., all methods and final results should be mentioned in the written portion.

Another hint: the easier I can find the information, the better off your grade is. Highlight important information in appendices so it is easily identified.

This project is somewhat open-ended. There is no right answer. There are better answers, and wrong (or incomplete) answers. Be creative. Try different things. Pretend you are in the real world. In the end, ask yourself the following question: Was my analysis, including any special approaches I considered, worth the money spent, i.e., the increased cost? Note that some minimal amount of work was required for even the most inefficient and uncertain-to-meet-constraints result. In other words, evaluate your extra efforts versus the outcome — explicitly comment on this with a sentence or two in your conclusion.

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