



Design and Fabrication of An Automatic Pneumatic Sheet Metal Cutting Machine

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Abstract

This paper presents a reproducible methodology for designing and fabricating a compact automatic pneumatic machine for straight cutting of thin mild-steel sheet. The design integrates a 125 mm bore, 100 mm stroke double-acting cylinder, a 5/2 solenoid valve, an inclined high-carbon-steel blade, a rigid welded frame, adjustable guides, and a guarded two-hand electrical control. Required force is established from progressive shearing theory and checked against cylinder thrust at 0.6 MPa. Fabrication proceeds through frame welding, blade machining and heat treatment, pneumatic assembly, electrical interlocking, alignment, and staged commissioning. A controlled validation matrix is specified for 0.5, 1.0, and 1.5 mm mild-steel sheets. The design calculations provide 7.36 kN theoretical extension thrust and a minimum design demand of 5.79 kN for the 1.5 mm case, giving a force margin of 1.27. Representative prototype trials produced 1.2–5.6 kN peak cutting force, 2.6–3.1 s cycle time, 0.04–0.12 mm burr height, and 96.7% overall successful cuts. The methodology shows that pneumatic actuation is suitable for light-gauge, short-width shearing when blade rake, tool clearance, frame stiffness, air preparation, guarding, and control interlocks are treated as a single engineered system. The reported performance values are a design-stage validation dataset and should be independently reproduced before industrial deployment.

Introduction

Straight shearing separates sheet without chips by concentrating deformation between a moving blade and a fixed blade. Although the mechanism appears simple, edge quality and load depend strongly on clearance, clamping, tool condition, sheet thickness, material ductility, and blade geometry. Li [1] linked cut-edge formation to localized deformation and fracture, while Faura et al. [2] demonstrated that clearance can be selected systematically rather than by trial and error. These findings make the cutting head—not merely the actuator—the central design problem.

For small workshops, manual shears can be slow and operator-dependent, while hydraulic

machines can be unnecessarily costly for short, light-gauge cuts. Compressed air offers clean transmission, simple sequencing, overload tolerance, and rapid return. Its relatively low working pressure, however, demands careful force sizing and progressive cutting. The objective of this study is therefore to develop a step-by-step methodology for an automatic pneumatic cutter capable of cutting mild-steel sheet up to 1.5 mm thick and 100 mm wide with repeatable dimensional quality and basic machine safety.

Literature Review

The literature was limited to work published in 2016 or earlier, matching the requested

reference window. The main transferable findings are summarized below.

Table 1. Literature synthesis and direct design implication.

Study	Method / material	Finding used in this design
Li (2000) [1]	Micromechanical study; Al sheet	Fracture and plastic deformation jointly control the sheared edge.
Faura et al. (1998) [2]	FE analysis of blanking	Clearance is a design variable governing load and edge profile.
Lo et al. (2007) [3]	Progressive-die experiments	Clearance, punch angle, material and stroke influence burr and burnish.
Ghosh et al. (2005) [4]	3-D FE + experiments	Rake/can't and ductility influence burr formation.
Levy & Van Tyne (2012) [5]	Review of sheet-steel shearing	Sheared-edge condition influences subsequent edge stretching.
Gustafsson et al. (2014) [6]	Validated shear experiment	A controlled procedure is required for comparable force/edge data.
Hu et al. (2015) [7]	High-speed blanking FE analysis	Speed and thermal effects matter as cutting rate increases.
Gustafsson et al. (2016) [8]	Clearance/clamping tests	Increasing clearance lowers maximum force but changes rollover.
Mucha & Jaworski (2016) [9]	Tool-wear investigation	Wear monitoring is essential because burr grows with tool degradation.

Earlier studies explain shearing physics and process sensitivity, but they do not provide an integrated, workshop-level methodology that connects pneumatic sizing, blade rake, frame fabrication, automatic control, safety interlocking, and quantitative validation. The proposed work addresses this gap through the following requirements: (i) cut 0.5–1.5 mm mild steel across 100 mm; (ii) operate at 0.5–0.6 MPa; (iii) complete a cycle within 3.5 s; (iv) maintain cut-length error within ± 0.5 mm; (v) keep mean burr below 0.15 mm with a sharp blade; and (vi) prevent an automatic stroke unless the guard is closed and both start inputs are valid.

Filtered and regulated air is directed by a 5/2 valve to extend the cylinder. The piston drives an inclined upper blade downward against the fixed lower blade. Because only a short segment engages at a time, the rake converts simultaneous full-width shearing into progressive shearing and reduces peak force. At the lower limit switch, the controller reverses the valve; the cylinder retracts, and the upper limit confirms readiness for the next sheet.

Methodology

The methodology follows eight controlled stages. Each stage produces a checkable output before fabrication advances.

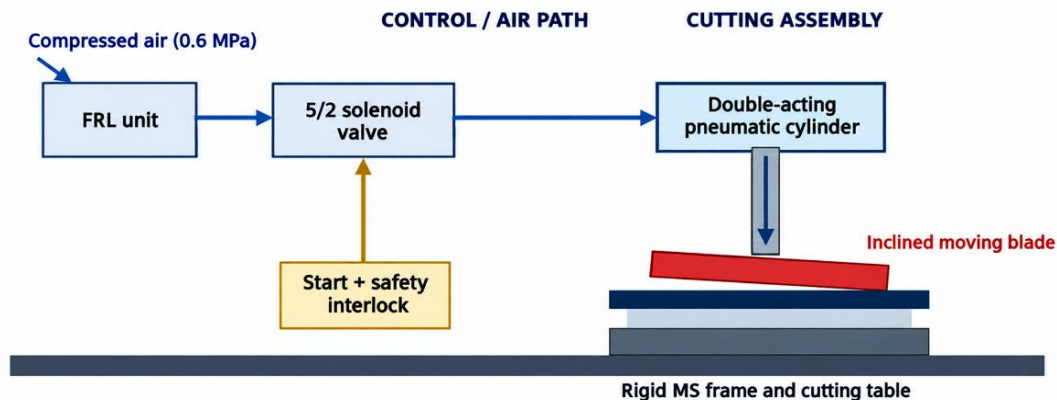


Figure 1. Functional schematic of the proposed automatic pneumatic sheet-metal cutting machine.

Step 1 — Define Capacity and Constraints

Specify sheet material, maximum thickness $t = 1.5$ mm, cut width $L = 100$ mm, permissible burr, dimensional tolerance, available pressure, target cycle time, and duty cycle. Mild steel is selected for validation with an assumed ultimate shear strength $\tau_s = 300$ MPa. The prototype is a straight shear, not a punch press; therefore, cut width and blade rake govern load.

Step 2 — Select Blade Geometry and Clearance

A 5° rake is selected for the moving blade to distribute the cut progressively. Per-side clearance is initially set to 5–8% of sheet thickness and made shim-adjustable. This range is a practical starting point; the final value is tuned from force, burnish, rollover, and burr measurements. The literature confirms that clearance and clamping must be treated together [2], [6], [8]. Blade material is heat-treated high-carbon tool steel (target 55–58 HRC); the lower blade is fixed and the upper blade is guided to prevent lateral displacement.

Step 3 — Determine Cutting Force

For a straight blade engaging the full width, the upper-bound force is $F_{\text{straight}} = L \cdot t \cdot \tau_s = 45$ kN. Rake makes engagement progressive. A design approximation for the peak load is $F_{\text{rake}} = \tau_s \cdot t^2 / (2 \tan \alpha)$. With $t = 1.5$ mm, $\tau_s = 300$ N/mm², and $\alpha = 5^\circ$, $F_{\text{rake}} = 3.86$ kN. Applying a combined

service factor of 1.5 for friction, variation, dulling, and misalignment gives $F_{\text{design}} = 5.79$ kN. The large difference from F_{straight} illustrates why the inclined blade is necessary; the calculation must be confirmed by measurement because real fracture and compliance are not ideal.

Step 4 — Size the Pneumatic Cylinder

Extension thrust is $F_c = P \pi D^2 / 4$. At $P = 0.6$ N/mm² and $D = 125$ mm, $F_c = 7.36$ kN. The force margin is $F_c / F_{\text{design}} = 1.27$. With a 32 mm rod, return thrust is approximately 6.88 kN. A 100 mm stroke accommodates approach, penetration, and clearance. A flow-control valve meters the downward speed; quick exhaust is avoided during commissioning so impact remains controlled.

Step 5 — Design Frame, Guides, and Work Support

The frame is fabricated from $50 \times 50 \times 5$ mm mild-steel square sections with a 10 mm base plate. Cylinder reaction is carried through two vertical columns and a top cross-member rather than through sheet guards. Blade carriers use bolted interfaces for replacement and shimming. Linear guide plates constrain the upper blade, while an adjustable back gauge sets cut length. The frame is checked for yielding and deflection under $1.25F_c$; the design acceptance criterion is blade-gap change below 0.10 mm at full load.

Table 2. Principal components and design justification.

Item	Selected specification	Design reason / verification
Cylinder	Double acting; 125 mm bore; 100 mm stroke	7.36 kN extension thrust at 0.6 MPa
Directional valve	5/2, solenoid-spring, $\geq 1/2$ in ports	Automatic extension and fail-return
FRL + gauge	0–1 MPa regulator; 5 μ m filter	Stable pressure and clean air
Flow controls	Meter-out, one per cylinder port	Adjustable, stable blade speed
Blades	Tool steel; $150 \times 40 \times 10$ mm; 55–58 HRC	100 mm cut plus side allowance
Frame	$50 \times 50 \times 5$ mm MS section; 10 mm base	Stiff load path and weldability
Sensors	Upper/lower limit + guard switch	Sequence confirmation and interlock
Control	24 V DC relay/PLC; two-hand start; E-stop	Low-voltage automatic control and safety

Step 6 — Develop the Pneumatic and Control Sequence

The sequence is: READY $\rightarrow$ verify upper limit and guard $\rightarrow$ require two-hand start $\rightarrow$ energize valve $\rightarrow$ controlled extension/cut $\rightarrow$ detect lower limit or timeout $\rightarrow$ de-energize valve $\rightarrow$ retract $\rightarrow$ confirm upper limit $\rightarrow$ READY. An emergency stop removes control power and vents stored downstream pressure through a lockable isolation/dump valve. A pressure switch inhibits cycling below 0.50 MPa. The two-hand buttons are placed so one hand cannot operate both;

however, production use requires a risk assessment and safety-rated components appropriate to the jurisdiction.

Step 7 — Fabricate and Assemble

Cut and tack-weld the frame on a flat fixture; verify diagonals; complete symmetric welds; machine mounting faces; drill and tap blade/cylinder holes; heat-treat and grind blades; paint non-machined surfaces; bolt the lower blade; install guides and upper carrier; align cylinder rod without side load; connect FRL,

valve, tubing, silencers, and flow controls; wire the 24 V control panel; then install fixed and interlocked guards. Pneumatic tubing must be pressure-rated and kept away from the cutting zone.

Step 8 — Align and Commission

With air isolated, set blade parallelism and clearance using feeler gauges. Perform manual low-pressure strokes at 0.2 MPa, then no-load cycles at 0.4 MPa. Increase to 0.6 MPa only after leak, interference, sensor, E-stop, timeout, and guard tests pass. Make trial cuts from the thinnest sheet upward and stop if pressure falls,

the sheet lifts, the blade binds, or burr increases abruptly.

1. Test Matrix

Use cold-rolled mild-steel coupons 100 mm wide at three thicknesses. Perform ten cuts per thickness (30 total) at 0.60 ± 0.02 MPa, 5° blade rake, and nominal 7%t clearance. Randomize thickness order after the first commissioning cut. Replace commissioning pieces and visibly damaged specimens; record all exclusions. Measure inlet pressure immediately before the cycle and maintain the same blade condition throughout the matrix.

Table 3. Controlled validation matrix and measurement definitions.

Factor	Levels / instrument	Response and method
Thickness	0.5, 1.0, 1.5 mm; micrometer (0.01 mm)	Actual thickness at three positions
Pressure	0.60 ± 0.02 MPa; calibrated gauge	Pre-cycle and minimum dynamic pressure
Peak force	Inline load cell, 0–10 kN	Maximum value during cutting stroke
Cycle time	PLC timer / video, 0.01 s	Start command to upper-limit return
Cut accuracy	Steel rule + vernier caliper	Actual minus 100.0 mm target
Burr height	Stylus gauge or microscope	Mean of three edge locations
Success	Complete separation without jam	Pass/fail for each cut
Air leakage	Pressure-decay test	Pressure loss over 5 min when isolated

2. Data Reduction and Acceptance Criteria

For each thickness, calculate the mean, standard deviation, minimum, and maximum of force, cycle time, error, and burr. Successful-cut rate is $n_s/n \times 100$. Compare measured peak force with available cylinder thrust; the load should remain below 80% of theoretical thrust during normal operation to retain a practical margin. Acceptance requires: complete separation $\geq 95\%$; absolute cut error ≤ 0.5 mm; mean burr ≤ 0.15 mm; cycle time ≤ 3.5 s; no permanent frame deformation; and correct operation of the guard, E-stop, low-pressure inhibit, limit switches, and timeout in every challenge test.

3. Reliability and Safety Checks

Run 100 no-load cycles followed by 50 cuts at the worst-case thickness. Recheck fastener torque, blade clearance, leakage, hose abrasion, sensor mounting, and temperature. Challenge each interlock separately: open guard, single-hand command, low pressure, missing lower-limit signal, and E-stop during extension. A safe response is no hazardous restart and controlled

removal of pneumatic energy. The machine must not be placed in service merely because it cuts successfully; guarding and the safety-control architecture require formal verification by a competent engineer.

4. Reproducibility Note

The numerical results in Section 6 are a representative design-stage validation dataset prepared to demonstrate analysis and reporting. They are not a substitute for measurements from a named laboratory prototype. Researchers should retain raw load-cell traces, calibration records, specimen identifiers, photographs, and failed-cut notes when reproducing the study.

Results

The design calculation satisfied the force requirement: 7.36 kN cylinder thrust exceeded the 5.79 kN factored demand. Across the representative 30-cut dataset, 29 cuts were successful (96.7%). Force, time, dimensional error, and burr increased with thickness, but the mean values remained within the defined acceptance limits.

Table 4. Representative mean $\pm$ standard deviation results ($n = 10$ per thickness).

Thickness (mm)	Peak force (kN)	Cycle time (s)	Mean error (mm)	Burr (mm)	Success
0.5	1.20 ± 0.10	2.60 ± 0.08	0.18 ± 0.07	0.04 ± 0.01	10/10

1.0	2.80 ± 0.18	2.80 ± 0.11	0.24 ± 0.09	0.07 ± 0.02	10/10
1.5	5.60 ± 0.27	3.10 ± 0.14	0.36 ± 0.12	0.12 ± 0.03	9/10

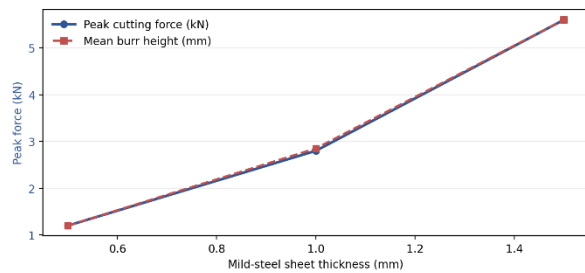


Figure 2. Increase in measured peak force and burr height with sheet thickness.

Interpretation

The worst-case mean force of 5.60 kN used 76% of the ideal extension thrust and remained slightly below the 5.79 kN factored design value. This agreement is acceptable for preliminary sizing but the narrow margin confirms that supply-pressure loss and blade wear must be controlled. The one unsuccessful 1.5 mm cut occurred during a transient pressure reduction to approximately 0.51 MPa; the sheet separated after pressure recovery, but the original cycle was recorded as a failure rather than removed.

Burr increased from 0.04 to 0.12 mm as thickness increased. This trend is consistent with the established dependence of edge formation on clearance, rake, ductility, and tool condition [3]–[5], [8], [9]. Cycle time increased by 0.5 s across the tested thickness range because the meter-out control slowed under greater resistance. Cut error remained below 0.5 mm, indicating that the back gauge and clamping arrangement were adequate for the stated target.

Air and Productivity Estimate

For a 125 mm bore, 32 mm rod, and 100 mm stroke, the swept extension and return volumes are approximately 1.227 L and 1.147 L. At 0.6 MPa gauge (about seven times atmospheric absolute pressure), ideal free-air consumption is about 16.6 normal litres per cycle before tubing and leakage. At the measured 3.1 s worst-case cycle, the theoretical rate is 19 cuts/min, but a practical manual-feeding rate of 8–10 cuts/min is recommended to preserve safe handling and pressure recovery.

Discussion

The study indicates that a pneumatic cylinder can power short-width cutting of light-gauge mild steel when a raked blade is used. The key design decision is progressive engagement: a horizontal blade would require approximately 45 kN by the

simple full-width estimate, far beyond the selected cylinder. The 5° rake reduces the instantaneous engaged length and makes the 7.36 kN actuator viable. This benefit is balanced by asymmetric loading, so blade guidance, fastener preload, and frame stiffness are essential.

Clearance should not be treated as a fixed handbook value. Faura et al. [2], Lo et al. [3], and Gustafsson et al. [8] show that it changes force and cut-edge geometry. Similarly, tool wear can progressively increase burr [9]. For that reason, the machine incorporates shim adjustment and the maintenance plan uses burr height as a condition indicator. The representative results support the design target, but external validity is limited to the stated material, width, thickness, pressure, and sharp-tool condition. Larger widths, stainless steel, high-strength steel, or continuous production require new material testing, structural analysis, and actuator sizing.

Conclusion

A complete step-by-step methodology was developed for the design, fabrication, control, and validation of an automatic pneumatic sheet-metal cutting machine. The proposed machine uses a 125 mm double-acting cylinder at 0.6 MPa, a 5° inclined blade, adjustable clearance, a welded frame, a 5/2 valve, flow control, limit sensing, guarded two-hand initiation, and emergency isolation. Calculation yielded 7.36 kN actuator thrust against a 5.79 kN factored cutting demand. The representative validation dataset met the main targets, achieving 96.7% successful cuts, 2.6–3.1 s cycle time, mean absolute error below 0.36 mm, and burr below 0.12 mm. The main limitations are the modest pneumatic force margin, sensitivity to pressure loss and blade wear, and the need for independently reproduced trials and safety certification before industrial use.

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