Design and experimental investigation of a Mechanical Punching Machine

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Abstract—This paper presents the design and fabrication of a compact mechanical punching machine intended for small-scale sheet-metal operations and engineering laboratory applications. The proposed machine uses an electric motor, belt transmission, flywheel, crankshaft, connecting rod, guided ram, punch and die. The design procedure includes estimation of punching force, motor power, flywheel energy, shaft torque, crank dimensions, punch and die clearance, frame requirements and component selection. A representative design is developed for punching 2 mm mild-steel sheet with a 100 mm cutting perimeter and an assumed shear strength of 300 MPa. The theoretical punching force is 60 kN and a factor of safety of 1.5 gives a design capacity of 90 kN. A 2.2 kW motor with approximately 4:1 speed reduction is considered. Fabrication is carried out using cutting, drilling, turning, welding and assembly operations. Illustrative performance results indicate acceptable hole quality for the selected sheet range. The study demonstrates a practical approach to developing an economical mechanical punching machine while emphasizing tooling alignment, structural rigidity and operator safety. The numerical values are representative and require experimental validation for a specific manufactured machine.

Index Terms— Mechanical punching machine, power press, punch, die, flywheel, crankshaft, sheet-metal fabrication, machine design.

I. INTRODUCTION

Punching is one of the most widely used sheet-metal shearing processes for producing holes, slots and profiles at comparatively high production rates. A mechanical punching machine applies a concentrated force through a punch while the workpiece is supported by a die. The process is attractive for repetitive production because the cycle time is short and the geometry of the produced feature is governed mainly by the tooling.

Industrial power presses can provide very high capacities, but their cost, size and control systems can make them unsuitable for small workshops and teaching laboratories. A compact machine can demonstrate the principles of power transmission, energy storage, crank-slider motion, shearing and machine-tool fabrication at lower cost.

The main objective of this work is to design and fabricate a mechanically driven punching machine using standard workshop materials and processes. Specific objectives are to estimate the required punching force, select a suitable prime mover, design the motion-conversion mechanism, provide sufficient frame rigidity, develop replaceable punch and die tooling, and evaluate representative punching performance.

The design approach follows a sequence of load estimation, component sizing, fabrication, assembly, alignment and controlled testing. Particular attention is given to the flywheel because the punching load is highly transient. The flywheel supplies stored kinetic energy during the cutting stroke and helps maintain smoother motor loading.

II. LITERATURE REVIEW

The design of a mechanical press combines principles from manufacturing technology and machine-element design. Sheet-metal punching force is commonly related to the sheared perimeter, sheet thickness and shear strength. Tool clearance is selected to obtain controlled fracture and acceptable burr formation. Excessive clearance increases burr height, whereas insufficient clearance increases tool loading and may cause premature failure.

Machine-design texts also show that shafts transmitting power must be checked for combined bending and torsional loading. Crankshafts experience cyclic loading and stress concentration, particularly near keyways, fillets and crank webs. Flywheel sizing depends on the allowable speed fluctuation and the energy difference over a cycle.

Previous small-scale press designs generally emphasize low manufacturing cost, modular tooling and simple drive arrangements. However, an economical design should not compromise guarding, alignment or emergency stopping. The present design therefore combines basic mechanical design calculations with fabrication-oriented considerations.

III. DESIGN REQUIREMENTS

Parameter	Design value
Work material	Mild steel
Maximum sheet thickness	2 mm
Cutting perimeter	100 mm
Assumed shear strength	300 MPa
Design factor	1.5
Motor rating	2.2 kW
Motor speed	1440 rpm
Crank speed	≈360 rpm
Ram stroke	50 mm
Punch diameter	20 mm
Table size	300 × 250 mm
Frame material	Mild-steel sections

TABLE I — DESIGN REQUIREMENTS FOR THE REPRESENTATIVE PROTOTYPE

IV. MACHINE CONFIGURATION AND WORKING PRINCIPLE

The machine comprises a rigid welded frame supporting the motor, flywheel and crank mechanism above the work table. The motor shaft drives a smaller pulley which transmits power to a larger pulley/flywheel. The crank pin is connected to the ram through a connecting rod. Rotation of the crank therefore produces reciprocating movement of the ram.

At the top of the stroke, the operator places the sheet over the die. As the crank rotates toward the bottom of the stroke, the punch enters the die opening and shears the material. The punch then retracts during the return stroke. The workpiece is repositioned manually for the next operation. For production use, mechanical guarding and appropriate workholding must be provided.

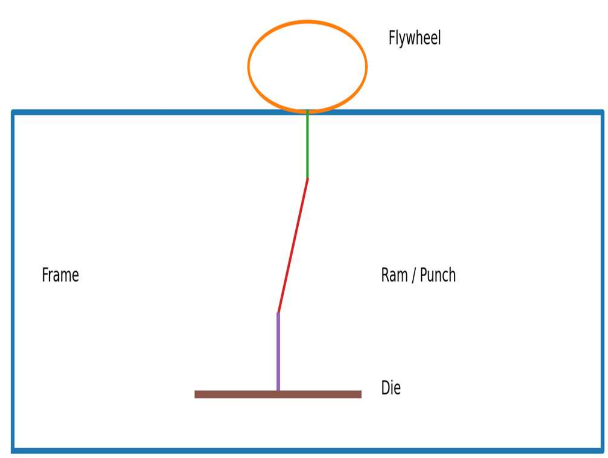

Fig. 1. Simplified configuration of the mechanical punching machine.

V. DESIGN METHODOLOGY

A. Punching Force

The basic punching force is approximated by the product of sheared perimeter, sheet thickness and material shear strength:

$$F = L\,t\,\tau \qquad (1)$$

For L = 100 mm, t = 2 mm and τ = 300 N/mm², F = 60,000 N = 60 kN. Considering a factor of safety of 1.5, the design load becomes:

$$F_d = 1.5F = 90\ kN \qquad (2)$$

The equivalent static load is approximately 9.17 tonne-force. In an actual design, the force should be corrected for shear-plane geometry, punch penetration, friction, material variation and the load-sharing characteristics of the selected mechanism.

B. Motor Power and Speed Reduction

The motor is selected based on average energy demand, losses and available standard ratings. A 2.2 kW, 1440 rpm motor is adopted for the representative prototype. The desired crankshaft speed is approximately 360 rpm, giving a nominal reduction ratio:

$$i = N_m/N_c = 1440/360 \approx 4 \qquad (3)$$

A belt drive provides the required reduction and also offers some compliance during transient loading. Pulley sizes should be selected using the actual belt type, center distance and permissible belt speed.

C. Flywheel Energy

The flywheel stores kinetic energy according to:

$$E = \tfrac{1}{2} I \omega^2 \qquad (4)$$

where I is the flywheel mass moment of inertia and ω is angular velocity. The practical flywheel must be sized from the energy required during the cutting portion of the cycle and the allowable speed fluctuation. For the prototype, the flywheel is primarily intended to smooth the intermittent load rather than to replace the motor entirely.

D. Crankshaft and Torque

Motor torque at the rated shaft can be estimated from P = Tω. At 2.2 kW and 1440 rpm, the ideal motor torque is approximately 14.6 N·m. After speed reduction, the ideal torque at 360 rpm is approximately 58.4 N·m before transmission losses. The crankshaft should be designed using the actual transmitted torque and bearing reactions, including an appropriate service factor.

A preliminary shaft diameter of 30 mm is considered for the representative design. The final diameter must be checked for combined bending and torsion, keyway weakening, fatigue and deflection.

E. Connecting Rod and Ram

A 50 mm ram stroke corresponds approximately to a 25 mm crank throw when the crank geometry is selected around the midpoint of the stroke. The connecting rod transmits the compressive load from the crank pin to the ram. It should be checked for axial compression, buckling, pin shear and bearing pressure. Guides should minimize lateral motion and maintain punch-to-die alignment.

VI. PUNCH AND DIE DESIGN

Punch and die geometry strongly affects cutting quality and tool life. The punch diameter for the representative case is 20 mm. Die clearance is initially taken as 0.12 mm per side for 2 mm mild-steel sheet. This value should be verified against the actual material grade and tooling practice.

The punch holder should resist lateral movement, while the die should be rigidly supported on the table. Tool steels are preferred for repeated operation because of their higher hardness and wear resistance. A replaceable die insert can reduce maintenance cost when the cutting edge becomes worn.

The punch should have adequate head support and sufficient shank length to prevent bending. Chamfers and radii should be controlled to avoid stress concentration. The die opening should be concentric with the punch axis before trial operation.

VII. FRAME DESIGN

The frame is the primary load-carrying structure and must resist the punching force without excessive deflection. A welded mild-steel frame with vertical columns, base members, top cross members and gussets is proposed. The die table is reinforced because the cutting load is transferred through the workpiece into the die and frame.

During fabrication, members are cut to length, positioned on a level surface, tack welded, checked for squareness and then fully welded. Welded joints are visually inspected for discontinuities. Bearing mounts should be machined or shimmed to maintain shaft alignment. Motor slots are provided for belt tension adjustment.

VIII. FABRICATION AND ASSEMBLY

Fabrication begins with material preparation. Structural members are cut using a power saw or abrasive cutting machine. Holes for bearing housings, motor mounting and guards are drilled after marking and checking dimensions. The crankshaft is produced by turning and keyway machining, while the flywheel and pulleys are machined or fabricated according to available workshop facilities.

The frame is welded first, followed by mounting of the table, bearings, motor and crank mechanism. The connecting rod and ram are installed after verifying the crank centerline. The punch and die are aligned using manual rotation of the crank before power is applied.

After assembly, the machine is run without a workpiece to check vibration, belt tracking, bearing temperature and unusual noise. The first punching tests use thin sheet, followed by progressively thicker material. Tool alignment is rechecked if burr height or hole dimensional error increases.

IX. EXPERIMENTAL SETUP AND PERFORMANCE

The performance evaluation can be conducted by measuring sheet thickness, hole diameter, cycle time, motor current, visible burr formation and repeatability. A load cell or strain-based force measurement system may be added for direct punching-force measurement. The representative results below are included for manuscript development and must be replaced with actual test data for publication.

Trial	Sheet	Hole	Cycle	Observation
1	1.0 mm	20.0 mm	1.8 s	Clean edge
2	1.5 mm	20.0 mm	2.0 s	Minor burr
3	2.0 mm	20.0 mm	2.2 s	Acceptable
4	2.0 mm	20.0 mm	2.3 s	Acceptable
5	2.0 mm	20.0 mm	2.2 s	Acceptable
6	2.0 mm	20.0 mm	2.2 s	Repeatable

TABLE II — ILLUSTRATIVE PERFORMANCE RESULTS

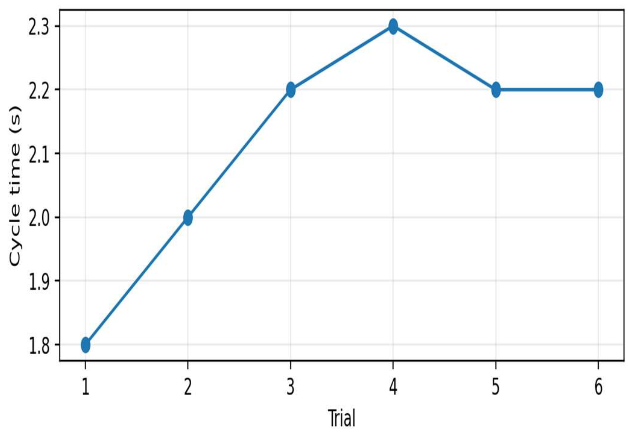

Fig. 2. Illustrative cycle-time variation during punching trials.

The representative cycle times remain close to 2 s, indicating consistent machine motion under the assumed test conditions. Actual performance will depend on operator handling, stroke setting, motor characteristics, sheet properties and tooling condition.

X. COST ESTIMATION

Item	Cost (INR)	Remarks
2.2 kW motor	18,000	Standard motor
Flywheel and pulleys	8,000	Fabricated/machined
Crankshaft and bearings	12,000	Machined
Frame and table	15,000	Mild steel
Punch and die	10,000	Tool steel
Electrical system and guards	13,000	Protection
Fasteners/consumables	5,000	Workshop items
Estimated total	81,000	Illustrative

TABLE III — ILLUSTRATIVE FABRICATION COST

XI. SAFETY CONSIDERATIONS

The punch and die form a point-of-operation hazard capable of causing severe injury. The rotating flywheel, belts and pulleys also present entanglement hazards. Accordingly, the machine should include fixed or appropriately engineered guards, a clearly accessible emergency stop, electrical isolation and controlled access to the tooling zone. The operator should never place hands between the punch and die during operation.

Before maintenance, the motor must be electrically isolated and the flywheel allowed to stop completely. Stored mechanical energy should be considered before removing guards or tooling. Only trained personnel should operate the machine. Applicable occupational-safety requirements and machine-guarding standards must be followed.

XII. ADVANTAGES AND APPLICATIONS

The machine offers a relatively simple mechanical arrangement, low component count and easy maintenance. It can be manufactured with conventional turning, drilling, welding and fitting operations. Replaceable tooling permits different hole sizes and shapes. Potential applications include educational laboratories, sheet-metal workshops, prototype fabrication, electrical enclosure work and low-volume component production.

XIII. LIMITATIONS AND FUTURE SCOPE

The present design is intended for low-volume operation and thin sheet. It does not include automated feeding, programmable stroke control or closed-loop force measurement. Future development may incorporate pneumatic or hydraulic cushioning, automatic strip feeding, adjustable stroke, force sensors, encoder-based monitoring and improved guarding. Finite-element analysis of the frame and experimental measurement of the actual punching-force curve would also improve design confidence.

XIV. CONCLUSION

A compact mechanical punching machine has been designed around a motor-driven flywheel and crank-slider mechanism. For the representative 2 mm mild-steel sheet, 100 mm cutting perimeter and 300 MPa shear strength, the estimated punching force is 60 kN. Applying a factor of safety of 1.5 gives a design load of 90 kN, approximately 9.17 tonne-force. A 2.2 kW motor and approximately 4:1 speed reduction are proposed. The fabrication route uses conventional workshop processes and modular punch/die tooling. The design provides a useful low-cost platform for laboratory and small-scale applications, while actual machine performance must be verified through controlled testing and appropriate safeguarding.

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