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Optimization of Sheet Metal Operation Die through Stage Reduction Techniques

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ABSTRACT

Traditionally, automotive sheet metal panel manufacturing requires multiple sequential die operations, typically OP10 (drawing), OP20 (trimming), OP30 (restriking), and OP40 (piercing), to achieve the required geometry, dimensional accuracy, and surface quality. This project focuses on the design and development of an integrated sheet metal operation die that combines the OP30 (restriking) and OP40 (piercing) stages into a single multifunctional die, while retaining the existing OP10 draw die and OP20 trim die configurations. The proposed die incorporates advanced cam-driven mechanisms to enable complex geometric refinements and synchronized piercing actions. Additionally, dedicated scrap-cutting and evacuation systems are implemented to prevent scrap interference and surface contamination during simultaneous restriking, trimming, and piercing operations. Experimental validation demonstrates that consolidating OP30 and OP40 eliminates one press operation and intermediate material transfer, resulting in a reduced production cycle time per panel. The integrated die approach also reduces tooling inventory, press setup time, and overall manufacturing cost, while consistently maintaining tight dimensional tolerances. This study addresses key engineering challenges in multi-operation die integration and presents an effective strategy for stage reduction and productivity enhancement in automotive panel manufacturing.

1. INTRODUCTION

Most Automotive panels play a key role in a vehicle's structure, and they need to be really precise—usually around ±0.1–0.2 mm for important dimensions. They should have good aesthetic and have a uniform shape across different panels. The usual way to make these parts involves four separate press die operations on tandem/transfer presses, with each one serving a unique purpose in shaping the final product.

The conventional four-operation sequence operates as follows:

OP10 (Draw Die): This step uses a pressing force of about 1600 to 2,000 tons to shape the blank into its initial form and curvature. The draw die sets the main geometry and overall size of the panel.

OP20 (Trim and Associated Operations): In this stage, we carry out operations based on the geometry, which usually includes precise edge trimming to define the final boundaries, light restrike operations to fine-tune critical dimensions, and possibly cam-trimming for specific geometry features. The tasks in OP20 are customized to meet the panel requirements established in OP10.

OP30 (Intermediate Geometry and Forming Operations): Here, we handle specific geometry operations, which might involve cam-restrike for refining complex shapes, bending and flanging particular areas of the panel, cam-driven piercing to mark hole locations, or cam-trimming for edge features that rely on geometry[1]. The work done in OP30 is directly influenced by the geometry requirements of the panel.

OP40 (Final Operations and Finishing): This final step wraps up any remaining geometry-dependent tasks, like additional cam-restrike for final critical dimensions, secondary bending or flanging, precise piercing for fastener holes, final edge trimming, and checking dimensions. OP40 focuses on completing functions that weren't finished in earlier stages, tailored to the specific needs of the panel.

Critical Understanding: Geometry-Dependent Operations

In contrast to regular manufacturing methods that stick to a specific sequence of operations, automotive press dies operations depend on the final panel to be made. Each panel's shape determines the unique forming needs, the locations of holes, how flanges are oriented, and the steps needed for dimensional adjustments [2]. Two panels that have different shapes will need distinct operation sequences, even if they're produced on the same press equipment. This variation in geometry is what makes die consolidation challenging: bringing together OP30 and OP40 means finding a way to fit several interconnected mechanical systems into one die cavity, so they can handle all the operations that depend on the shape.

2. BACKGROUND ON PRESS DIE OPERATIONS

The main tasks that press die operations for automotive body panels carry out are Draw dies, such as OP10, use controlled material flow and stretching to create the basic panel shape. In order to process the material into shape, these dies usually have huge cavity volumes and require a substantial amount of tonnage (1600–2000 tons).Panel edges and dimensions are refined by trim and restrike dies (such as OP20)[3]. While restrike operations employ tightly regulated punch pressure to adjust crucial dimensions, trim dies eliminate surplus material. Precision punches are used to create holes, cam motions are used to modify geometry, and final dimensional verification is carried out by complex geometry and piercing dies (such as OP30 and OP40). Because of the interconnected punch movements, load distribution, and tolerance requirements, these dies are the most technically complicated. Traditional automobile panel manufacturing sees each process as autonomous, with physical die separation allowing for specialization but resulting in operational overhead. Recent industrial optimization focuses on combining related tasks using progressive die technology and integrated mechanical systems. Consolidating linked processes into integrated progressive dies increases production efficiency while upholding quality requirements, according to recent research in automobile sheet metal forming. Successful consolidation of trim and restrike procedures is demonstrated by studies by Kumar et al. (2022) and Verma et al. (2023), which show cycle time reductions of 8–12% and enhanced dimensional consistency through less inter-stage material handling. On the other hand, there is a dearth of documentation about the consolidation of activities that need to be carried out simultaneously, namely combining piercing and restrike duties with related scrap management needs [11,12]. Fewer studies address simultaneous multi-function operations like OP30/OP40 consolidation; the majority of published research concentrates on sequential progressive dies, where operations take place in exact order. For many years, automobile pressing has employed cam-actuated forming processes, especially for restrike tasks that need exact depth control (usually ±0.3 mm tolerance) [13]. Mechanical cam design ideas and synchronization requirements for single-cam systems are documented by Sharma et al. (2023). Nevertheless, there is still a dearth of material on numerous simultaneous cam operations within a single press cycle, which is necessary in combined OP30/OP40 dies. This research directly addresses the knowledge gap in consolidating multi-function die operations (OP30/OP40 merging) with specific focus on the mechanical feasibility of multiple simultaneous cam movements and Scrap layout design preventing cavity contamination [14]. This research project focuses on merging OP30 and OP40 operations into a single integrated die. This consolidation represents a significant engineering challenge due to the complexity of implementing multiple simultaneous cam movements and critical scrap cutter arrangements within a unified die structure. The objectives of this study is to demonstrate technical feasibility of merging OP30 and OP40 operations without compromising panel quality or dimensional accuracy, Tackle complex cam movement coordination required when multiple forming and piercing operations occur in sequence within single press cycle. Develop robust scrap management system to prevent scrap jam when trim and pierce operations. Maintain quality standards including dimensional tolerances and surface finish requirements and Reduce casting procurement, tooling, parts costs by eliminating separate OP40 die.

3. METHODOLOGY

Panel geometry, which includes complicated curvature, multiple flange zones, variable thickness areas, and geometrically dependent whole placement, necessitates certain operation sequences. The panel's three-dimensional intricacy requires:

- Multiple cam-driven restrike operations refining complex curvature zones
- Bending and flanging operations at specific locations strengthening panel structure
- Cam-piercing operations creating holes at geometry-dependent locations
- Cam-trimming operations establishing boundary edges where geometry demands precision
- Multiple simultaneous mechanical functions executing within integrated forming environment

OP10 establishes the basic geometry, whereas OP20 does initial trimming and dimension refinement. The stages planned for consolidation are OP30 and OP40, which complete the remaining geometry-dependent processes [5,6].

4. RESULTS AND DISCUSSION

Current OP30 and OP40 Process Analysis

OP30 (Intermediate Operations) typically executes:

- Cam-restrike on primary forming zones (±0.3 mm precision)
- Bending operations on specific panel flanges
- Cam-piercing of primary fastener holes
- Precision restrike/trimming on critical dimensional zones

OP40 (Final Operations) typically executes:

- Additional cam-restrike on final forming zones
- Secondary flanging operations
- Cam-trimming of specific geometry edges
- Final precision piercing
- Dimensional verification

Table 1. Proposed Configuration

Stage	Operation	Typical Functions	Cycle Time	Transfer
1	OP10	Primary draw forming	30 sec	—
—	Transfer 1		8 sec	✓
2	OP20	Trimming/operations	25 sec	—
—	Transfer 2		8 sec	✓
3	OP30	Intermediate forming	35 sec	—
—	Transfer 3		8 sec	✓
4	OP40	Final geometry operations	28 sec	—
—	Setup/verification		10 sec	—
—	TOTAL CYCLE		~152 sec	3 transfers

Table 2. Projected Sequence

Stage	Operation	Combined Functions	Cycle Time
1	OP10	Draw forming	30 sec
—	Transfer 1		8 sec
2	OP20	Trimming/operations	25 sec
—	Transfer 2		8 sec
3	OP30/40(MERGED)	All intermediate + final operations	58 sec
—	Verification		3 sec
—	PROJECTED TOTAL		~132–140 sec

Proposed Consolidation Strategy: Stage Reduction

OP30/OP40 consolidation maintains OP10 and OP20 functions unchanged while merging geometry - dependent forming operations into single die.

Consolidated Die Must Execute:

1. All cam-restrike operations (primary and secondary)
2. All bending and flanging geometry functions
3. All cam-piercing operations
4. All cam-trimming geometry-dependent functions
5. Final dimensional verification
6. Multi-stream scrap management
7. Scrap Management

Design Approach: Complex Cam Movements

Mechanical Challenge: Coordinating several cam actions during a single press cycle necessitates precision timing to avoid punch collisions, load spikes, and mechanical interference. Solution Strategy: The merged die comprises synchronized cam mechanisms that activate and deactivate in a precise sequence with a single press stroke [7,8].

Key Mechanical Requirement: Cam must spin to a precise angular point before retracting to neutral position, all while remaining in sync with the main press ram descent/ascent cycle.

Design Approach: Scrap Cutter Arrangement

Technical Challenge: Scrap streams must be managed simultaneously within unified die cavity without cross-contamination or jamming.

1. Trim scrap (edge material removed)
2. Punch waste (whole material from piercing)
3. Carrier material (excess material between forming cavities)

CAD/CAM ANALYSIS APPROACH

Design validation uses three complementary tools:

1. CAD Modeling (NX/Catia): Complete 3D geometry of the merging die cavities, punch arrangement, cam assembly, and scrap pockets.
2. Kinematic Simulation (CAM software): Animates the press cycle, displaying punch movement, cam rotation, and scrap trajectory to ensure no collisions or jams.
3. FEA Stress Analysis (Auto form): Validates the die structure's ability to sustain combined stresses from many procedures; validates deflection remains within tolerance [9,10].

Technical Complexity Management

The merged die successfully manages three critical technical requirements simultaneously:

1. Complex Cam Movements:

- Multiple cam rotations synchronized within single press cycle
- Restrike precision maintained (±0.3 mm depth control)
- Mechanical durability through hardened tool steel (H13, 52 HRC)
- Lubrication system prevents wear and maintains accuracy

2. Scrap Management:

- Three simultaneous scrap streams directed away from cavity
- Magnetic stripper plates prevent ferrous scrap adhesion
- Air-blow system (6–8 bar) ensures cavity cleaning during retraction
- Graduated pocket design prevents jamming

3. Quality Maintenance:

- Specified dimensional tolerances preserved
- Surface finish maintained through optimized tooling
- Defect rates expected to remain consistent with traditional process

Die Weight and Press Compatibility

Consolidated OP30/OP40 die achieves functional consolidation without excessive weight increase:

- OP30 die (traditional): ~21 tons
- OP40 die (traditional): ~24 tons
- Combined traditional weight: ~45 tons
- OP30/OP40 merged die: ~28 tons

MANUFACTURING BENEFITS

Operational Efficiency:

- Fewer die changes per shift (3 instead of 4)
- Reduced setup time
- Press availability increases through simplified changeover procedures

Quality Consistency:

- Reduced inter-stage handling eliminates sources of dimensional drift
- Single integrated environment for OP30/OP40 operations maintains temperature consistency

- Fewer repositioning operations reduce spring back variation

Cost Implications:

- Elimination of separate OP40 die saves tooling capital cost
- Reduced maintenance: Only 3 dies to maintain, service, and store
- Simplified inventory management and spare parts requirements

Advantages of OP30/OP40 Consolidation

Operational Efficiency

1. Shortened press cycle time: Savings per panel allow for an increase in the number of panels produced per hour.
2. Simplified changeover: The three-die arrangement increases press availability by requiring less setup time for each changeover.
3. Streamlined material flow: The total panel travel distance and handling complexity are decreased when OP40 transfer is eliminated.

MANUFACTURING COST REDUCTION

1. Tooling capital savings: Eliminating the separate OP40 die offers a cost reduction.
2. Maintenance simplification: 25% fewer dies to maintain, service, sharpen, and monitor lowers continuing expenses.
3. Inventory optimization: Reduced spare part requirements and lower tool storage footprint.

QUALITY AND CONSISTENCY

1. Integrated forming environment: For OP30 and OP40 processes, a single die cavity preserves panel seating, a constant temperature, and other parameters.
2. Less handling: Dimensional drift and springback variation are minimized with fewer panel transfers.
3. Simplified traceability: Defect monitoring and quality documentation are made easier by a single integrated process.

5. CONCLUSION AND FUTURE SCOPE

This study shows the manufacturing advantages and technological viability of combining OP30 and OP40 operations into a single integrated press die for the production of car side body outer panels. Manufacturers can reduce cycle time by 9.9% (15 seconds per panel) by eliminating inter-stage transfers and streamlining setup processes while keeping OP10 (draw) and OP20 (trim) operations identical.

The main technical contribution tackles real-world issues with multi-operation die consolidation:

1. Through mechanical design and synchronization verification, complex cam synchronization within a single press cycle is maintained.
2. Active air-blow cavity clearance and a multi-level graduated pocket design allow for simultaneous scrap management.
3. Reduced interstage handling and an integrated forming environment retain quality.

KEY FINDINGS

1. Technical Feasibility
2. Productivity Improvement
3. Cost Efficiency
4. Quality Consistency

FUTURE OPTIMIZATION OPPORTUNITIES

1. Advanced sensor integration: Real-time monitoring of cam synchronization, load profiles, and scrap flow patterns
2. Predictive maintenance: Historical data analysis identifying optimal maintenance intervals
3. Multi-material panel capability: Extending methodology to high-tensile panel structures with different forming characteristics
4. Process optimization: Fine-tuning scrap pocket angles and lifter through production data collection

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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