SHEET METAL STAMPING IN AUTOMOTIVE INDUSTRY
STEEL PANELS IN CAR BODY STRUCTURE

Ever increasing competition in automotive industry demands productivity improvements and unit cost reduction. The manufacturing engineers and production managers of car body panels are changing their strategy of operation. The days of ‘a simple washer to a very complicated fender, all in plant stamping facility’, are gone. In-house manufacturing facilities preferably produce only limited number of major car panels, Fig. 5.1.

An automotive plant today produces some 40~50 critical panels per model of car in-house, that require some 100~150 dies.. Criteria for taking decision about the panels to be manufactured in-house vary from company to company. Very lately, the stamping plant of the automobile manufacturers includes the types of panels as given below in-house:

1. External (skin) panels, such as fenders, bonnet, decklid, roof, side panels, doors, etc. Some of these are two panels in a set as left hand and right hand
2. Internal mating panels, such as bonnet inner, decklid inner or door inner deciding subassembly quality
3. Dimensionally critical inner panels that are complicated either because of their complex shape or severe draw condition, such as, floor pans, dash panel, etc.

Automakers prefer to procure the medium and small size panels from vendors depending on the availability (nearer facilities are preferred) and their capability to meet demanded specifications. Some are even farming out the major subassemblies such as doors to specialised vendors. Trends are for farming out as much as possible. The
automobile plants are trying to concentrate on assembly operations, leaving specific technology related manufacturing, such as machining and pressing as separate facilities.

**MATERIALS FOR BODY PANELS**

Materials for car body panels require certain specific characteristics to meet the industry’s challenges: rationalisation of specifications for leaner inventory, improved formability for reduced rejection rate and better quality. Higher Strength Low Alloy (HSLA) steels of thinner gauges, are getting preference for weight reduction and the resulting better fuel economy. Other quality characteristics under demand are higher yield stress (strength), toughness, fatigue strength, improved dent resistance as well as corrosion resistance in materials used for body panels for improved durability and reliability.

To obtain consistent quality of autobody skin panels without failures during stamping, the formability/ductility specifications of strip steels are the basic requirements. The numerical values of the strain hardening exponent (n-value), the plastic anisotropy (r-value), and the forming limit diagrams for the sheet steels provide the index of formability of the panels. Strain hardening to some extent improves the dent resistance. Strain gradients in pressings are not to be unduly severe causing splitting and other related problems. To maintain the shape after the forming operation, minimal ‘spring back’ and high ‘shape fixability’ are also essential. As the panels are welded to shape the body structure with various arc/resistance welding operations, the weldability of the materials in use is very important. Finally, the specific roughness levels (textures) of the steel used for skin panels must be consistent and reproducible. It will be essential for the good adhesion of the various combinations of primers and paints used on autobody pressings to obtain high quality paint finishes (clarity of image and gloss).

Most of the steels used in automotive application are aluminium-killed steels of about 0.7 to 0.9 mm thickness. For inner automotive parts, drawing quality steels, such as SPCD (JIS G 3141), A619 (ASTM), CR3 (BS1449), and Sr13 (DIN 1623), while for outer panels requiring deep drawing such as fenders, hoods, oil pans, etc. Non-aging extra deep drawing steels such as SPCEN (JIS G 3141), A620 (ASTM), CR1 (Bs 1449), and St 14 (DIN 1623), are used. Aluminium-killed steels show little or no stretcher strains for a period of time sufficient to eliminate the need for roller-leveling. Thinner High Strength Low Alloy (HSLA) steels are being increasingly used for certain autobody components including skin panels. It must combine its high strength with a good level of formability, as a strength increase is always accompanied by a fall in formability. The improved bake hardening steels used specially for the external panels possesses sufficiently high formability and provides an increase in strength after the paint baking. A consequence of strength increase obtained during paint baking, is the improved dent resistance of the surface. Difficult autobody pressings of complex geometry have necessitated the use of steel grades with lower strengths too. Vacuum degassed microalloyed steels containing Ti and/or Nb additions are classed as Interstitial-free steels (IF-steels). IF-steels are being used with advantages of extremely high value of maximum drawing ratio, and the absence of the straining effect for difficult-to-form panels. Fig. 5.2 shows panels of High Strength Low Alloy steel, and Table 1 provides a list of special steels for different automobile panels.

<table>
<thead>
<tr>
<th>Steels for Auto Panels</th>
<th>Yield Strength, N/m²</th>
<th>Application conditions</th>
</tr>
</thead>
</table>

Table 5.1 Special Steels for Different Automotive Panels
<table>
<thead>
<tr>
<th><strong>A. High Strength Steels</strong></th>
<th></th>
</tr>
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<tbody>
<tr>
<td><strong>REPHOSPHORISED STEELS</strong></td>
<td></td>
</tr>
<tr>
<td>with additions of P up to 0.08%</td>
<td>220~260</td>
</tr>
<tr>
<td><strong>GRAIN REFINED STEELS</strong></td>
<td></td>
</tr>
<tr>
<td>appropriate alloy additions which forms typically NbCN, TiC</td>
<td>300~400</td>
</tr>
<tr>
<td><strong>DUAL PHASE STEELS</strong></td>
<td></td>
</tr>
<tr>
<td>appropriate alloy additions (Mn, Mo, Cr, V) and processing</td>
<td>400~500</td>
</tr>
<tr>
<td><strong>BAKE HARDENING STEEL</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>200~250</td>
</tr>
<tr>
<td><strong>B. Low Strength Ultra-soft Steel</strong></td>
<td></td>
</tr>
<tr>
<td><strong>INTERSTITIAL FREE STEEL</strong></td>
<td></td>
</tr>
<tr>
<td>Ti and/or Nb additions combined with interstitial C and N to form stable TiC, TiN or NbCN precipitates</td>
<td>130~150</td>
</tr>
</tbody>
</table>

Laser textured steels, and new coatings such as nickel zinc are ensuring better paint finish and corrosion resistance respectively. Galvanised steel panels that provide better corrosion resistance are used to the extent of about 40% or more in a modern car body. Surface texture and coating provided by steel manufacturers demand stricter quality assurance at stamping stage. Dents and damage caused in stamping requiring repair by grinding or any surface deteriorating methods, may take away the basic advantages of special texturing. Fig. 5.3 shows the typical panels manufactured out of galvanised steels.

An intensive research and development are going on for alternate materials, manufacturing processes and stamping tools for sheet-metal components with the main objectives of cutting down the weight and unit cost of the vehicle. Simultaneously, the steel content of the car is falling with the use of aluminium and new materials, such as plastics. Aluminium may provide the most sought after solution to reduce the weight of the vehicles. A reduction of 30% in weight is achievable if the same strength, stiffness, and stability of the component are to be realised by substituting steel with aluminium. Possibility of significant reduction in die cost will be another advantage with aluminium. However, problems related to strength, serviceability, manufacturability, and above all the cost, require effective solutions before the acceptance of aluminium as a substitute to steel for body panels. Plastics for bumpers,
facia, radiator grilles and even fuel tanks have become almost universally acceptable. Other applications will be commercially possible in years ahead.
STAMPING PROCESSES

Stamping processes to be used for a panel depend on its design. However, normally the processes used extensively are blanking, drawing, piercing, forming, notching, trimming, hemming, etc. Blanking prepares the initial approximate form of the part in flat sheet. Drawing is generally the first operation to attain depth related form. Piercing, notching, hemming, are product design related operations. Trimming generally removes the extra material on the periphery of the panel provided for blankholding during draw operation. Decision on trim line is very important and becomes deciding factor to obtain good draw.

BLANKING FOR PANEL STAMPING

Press blanking uses dies specific to the part and is necessary if the shape of panel demands the same depending on part design, or if the volume of production justifies. Presently, the blanking lines operate to produce more than 60 pieces per minute. For quite some panels, rectangular, trapezoidal, or slightly curved shaped blanks may be sufficient and can be produced by shearing machines or line. Oscillating shear is a development used for flexibility in blank preparation with a stroke rate of more than 100 per minute. So, a single shearing and/or blanking line may cater to several press lines. As the coils provide the overall economy, a blanking line includes coil handling, decoiler, flattener/leveler, feeder, blanking press, and stacker for blanks. A corrective leveler is used to remove:

1. ‘Fibre’ length differentials from one surface of the strip to the other, such as coil set or cross bow.

2. ‘Fibre’ length differentials from one edge of the strip toward the centre and then to the other edge such as edge wave or centre buckles.

With gradually reducing batch size, the coil may have to be withdrawn before it is entirely used. A system to automatically take care of the situation and to resupply of the left over coil again in a fully automatic blanking system requires an effective solution.

TAILORED BLANKS

Tailored welded blanks for complex panels are being prepared through different joining processes - laser welding, spot welding, or mash-seam welding that result into a lot of material saving and better strength. Two or more pieces of same and different materials or gauges are welded into a single blank prior to stamping. Use of costlier materials such as thicker, stronger, or coated stock can be limited to just where it is required. Separate stampings of costlier material followed by welding could have meant multiple dies, multiple operations, assembly and checking fixtures. Thin or thick or different strength combinations, result also in weight reduction. In a stamping of a motor compartment rail, the original plan was to manufacture it out of 2 mm thick stock across its entire length. After a finite element analysis, it was decided to use two blanks comprising of 0.8 mm for the front part of the rail and 2 mm thick for the rest portion. It resulted in unit blank weight saving of 3.4 kgs. in purchased galvanised steel and 1.3 kgs. saving in vehicle weight with no loss of rigidity or safety aspects. Splitting the complicated panel in more than one piece may also improve nesting and consequential better yield from the coil stock. Even with addition of laser welding of the two halves prior to stamping, saving may be in million for a mass produced panel for an auto manufacturer. In a door inner, the 0.81 mm and 1.83 mm thick galvanised pieces eliminated the need for hinge and mirror reinforcements and in place spot welding. Fourteen
dies, weld fixtures, and check fixtures were also eliminated. Tailored blanks may cut down the
tolerance stack and improve a car’s dimensional accuracy. A conventional door inner
assembly’s dimensional accuracy covers tolerance in the thickness of steel and tolerances
associated with stamping, piercing, and spot welding reinforcements. With elimination of
reinforcements, the accuracy is improved. With laser welding of blanks, the dimensional
variation of hole location in door panels in one case was reduced from +/- 0.5 to +/- 0.075
millimetre. For the body side panels of Toyota model of cars, 5 straight-cut pieces of mild
and high strength low alloy galvanised steel were laser welded. The blank periphery and door
openings were then cut to the shape as shown in Fig. 5.4.

![Fig. 5.4 Tailored Blank Of Toyota Model Body Side Panel](image)

A  HSLA steel  1.02 mm  20/20 galvanised coat thickness  
B  HSLA steel  1.02 mm  45/45 galvanised coat thickness  
C  HSLA steel  1.02 mm  45/45 galvanised coat thickness  
D  MS cold rolled steel  0.76 mm  45/45 galvanised coat thickness  
E  MS cold rolled steel  1.02 mm  60/60 galvanised coat thickness  

Although material yield was reduced from 65% to 40%, the number of dies required was
reduced from 20 to 4. Reinforcement elimination, weight savings, and improved aesthetics
(no spot welding on door inside) were the additional advantages.

Seam welding (fenders of Ambassador model of cars in India uses seam welding for blank
preparation) or spot welding is also used. However, for preparing a tailored blank, laser
welding blanks provide three distinct technical advantages:

- The narrow weld seam on galvanised sheet enables corrosion resistance
throughout the heat-affected zone.
- Ductility is greater compared to other welding process.
- A laser weld seam is stronger than the base material. Moreover, it results in a
smooth joint between the blanks that minimises die wear in forming.

However, the tailor blanks demand stricter control of the edge quality and butt-joint pressure
and other laser welding parameters such as power, welding speed, assist gas flow, beam
alignment, and depth of focus, etc.

Mash seam welding is a form of resistance welding where blank segments are overlapped
slightly, driven between two electrode wheels under pressure, and welded by electric current.
The process is another method that can be used to prepare tailored blank. As the
overlapping blank segments may vary in thickness, plannishing wheels usually follow the
welding electrodes to cold work the welded joint to less than 10% over the original thickness. The mash seam welding is used for longish panels. At Volkswagen, the L-section members that constitute front chassis rails, are formed from mash seam-welded blanks. The blank for one member comprises three pieces of different thickness, the other four. Besides other advantages, the process improved crash ratings and merited reduction in insurance premium.

Auto-manufacturers have accepted scrap levels of 40% or more as standard due to the technical requirement for blank holding stock in draw operation or best nesting of parts on a coil. Tailored blanks can make the difference. Tailored blanks are destined to growth in the cost conscious automotive industry. As per a supplier of laser welding systems and laser welded blanks of U.S.A, saving due to tailored blanks for the auto industry can total upto $152 per car, or $ 1.47 billion per year (1994 USA production)

**MAIN PRESSING OPERATION STATIONS**

Main goals of the car designer and production engineer or die designers have remained as follows:

- to simplify the panels.
- to combine a number of panels in one.
- to reduce the severity of draw, and ultimately.
- to cut down on the number of stations required to finish the panels.

With change in panel design and improvement in die design, the numbers of stations have significantly reduced. Presently, almost all panels require less than 5 stations. Progress in this direction over the years for a major auto-manufacturer is shown in Fig. 5.5.

**DRAWING ON DOUBLE-ACTION PRESS**

Drawing of automotive panels had been the most demanding process. Conventionally the deep drawn panels use double action press as the first operation in a line (Fig. 5.6). Two slides - the outer for blank holder and the inner for punch - move along the gibbs installed on uprights and ensure accurate pressing. The ‘quick approach- quick return' motion curve of the outer slide ensures better productivity. The blank holder clamps the blank between the draw ring and the hold-down unit and is decisive for the quality of the draw. If the hold-down force is too low, the blank will develop wrinkles in the flange of the drawn parts. If the hold-down pressure is too much, the metal does not yield sufficiently in accordance with the frictional force, and tears. The optimum hold-down force is also dependent on the local behaviour of the material. Varying draw conditions in different portion of a complicated panel cause the hold-down force to vary along the contour of the part. The difference between the smallest and the greatest permissible hold-down force is a measure of the difficulty of the part so far draw is concerned. Tool builders try to adjust the local hold-down forces by the rigidity of the die, and the suitable draw beads in the blank holder. Individual motorised adjustments of the slide of the double action press permit corner or side pinch or grip control of the blank that are to be optimised for quality draw.
Fig. 5.5 Reduction in number of stamping operations

![Diagram showing reduction in number of stamping operations]

Fig. 5.6 Conventional Double-Action Draw and Motion Diagram

Some press manufacturers have installed hydro-pneumatic intensifier type blank holder pressure control device on each suspension point of outer slide. It facilitates the adjustment
of blank holding capacity at each point individually as per the draw requirement for the panel. Using NC servo-controlled system for blank holder pressure control, optimum blank holder pressure can be freely adjusted during the draw operation. Temporary pressure of conventional blank holder may be avoided. (Fig. 5.7)

![Fig. 5.7 NC Servo-controlled Blank holding Pressure Application](image)

The necessity of subsequent turn-over for further processing of the panel on single action press is a big disadvantage for a press line that uses a double action press. It does also mean possibility of damages during manual turnover operation or additional investment of an extra equipment for automatic turn-over.

**STRETCH FORMING**

Traditional double action drawing permits a controlled amount of the blank to draw into cavity. In the stretch forming technique, the blank is clamped so tightly all around that it can not draw in. Rather, it is stretched over the punch or lower die and set by the upper die. A lower blank holding-ring is mounted on a nitrogen pressure pad. It maintains a high load (about 100 tons) against the blank and upper ring while traversing downward with the upper ring. It thus prevents the blank from slipping between the draw beads. As shown in Fig. 5.8, the upper blanking ring drops to the lower holding ring, and locks the perimeter of the blank in the draw bead. Thereafter, the ring lower together to a dwell position, stretching the blank over the lower die. At this point, the upper die descends, completing the operation.

Stretch forming is being used for automotive panels providing advantages such as 15 to 20% smaller blank size, and elimination of turnover operation after the draw. The better quality results from the uniform stretch over the blank’s entire surface. For example, in conventional stamping of a hood, stretching occurs in the corners but very little, if at all, in the centre area. During stretch forming, measurable deformation occurs over the entire surface.
Fig. 5.8  Steps in Stretch Forming

**DRAWING ON SINGLE ACTION PRESS**

With improved drawability of the sheet steel used for car body panels and the simplified panel design, most of the body panels can be drawn on single action press using pneumatically operated cushions (Fig. 5.9). The hold down force is created by drawing cushions and transferred to the blank in the bottom die, which clamps the edge areas of the blank and hold it through friction. Multiple cylinders create the force, which is distributed and transferred to the die via pressure pins. The cushion and blank holding forces are determined by the air pressure in the tank and the cylinders, and are nearly constant during the drawing process. However, the inherent disadvantage is due to the typical vibrations created by the impact of the slide on the pre-tensioned pneumatic drawing cushion. That can cause velocity related fluctuations in the blank holder force and inconsistent quality of the drawn panels.
With a hydraulic cylinder (single point) cushion (Fig. 5.10), the force is produced hydraulically through the displacement of the oil volume by a proportional throttle. Through a pressure transducer and controller, the oil pressure can be kept precisely within the defined limits and can be varied depending on the drawing stroke of the panel. With the development of hydraulic 4-points drawing cushion (Fig. 5.11), the hold-down forces may be transferred to the die in a way similar to the blank holder slide of a double action press. The draw force of the plunger type cylinders of the drawing cushions is transferred to the corners of the blank holder by four pressure rods during the down stroke of the slide. After reaching BDC (Bottom Dead Centre), the drawing cushion either follows the slide during return or returns after a programmed delay. End position damping by means of proportional valves ensures the soft and vibration free TDC (Top Dead Centre) approach of the cushion. A high response electro-hydraulic servo-valve accurately controls the hydraulic pressure. The draw cushion force can be controlled as needed during the drawing operation. The pressure of the four cylinders can also be adjusted independently. It makes the blank holder forces individually controllable over the entire drawing operation on each of the four corners of the die. The short response time for pressure changes helps in optimising the drawing operation. For example, a momentary increase of the blank holder force can initiate a stretch draw, or the material flow...
may be influenced by increasing pressure in sections of the die. Pressure pins, if directly applied can cause some drawing errors if they are not maintained to exact lengths or get elongated through wear or overloading, or by deposits between the contact surfaces. So, the cushion force may be introduced through a frame into the blank holder of the die over a larger surface, simulating the condition in a double-action press.

Fig. 5.11. Hydraulic Four point Cushion

Possibility of malfunctions caused by pressure pins is eliminated, but die builder is to work under the constraints of the frame. Advantages of the hydraulic 4-point drawing cushion are:

- Blank holder pressure may be precisely controlled and is not influenced by stroke rate related vibrations.
- Drawn part of the same consistent quality can be produced on single-action presses as on double-action presses
- Stresses on the die, drawing cushion and press are substantially reduced compared to the pneumatic systems resulting in less downtime, longer service life and less noise.

A hydraulic cushion with 15 single individually controllable pressure points (Fig. 5.12), has made an optimum forming process possible. The drawing force can be changed stepwise on each pressure point during the drawing operation. It provides the high degree of flexibility in configuring the blank holding forces along the contour of the drawn part and over the effective drawing stroke.

NC cushions, Fig. 5.13, incorporated with various transfer presses are the further developments. During the pressing, a servo valve controls the pressure exerted by the die
cushion. The optimum load pattern is precisely ensured, so the wrinkling and cracking are prevented. Optimal load patterns are attained through numerical control, stored in memory, and reused in next setup.

Advantages of NC cushion over air cushion are:
- Better result even with sheet steel of poor drawability
- Improved finished shape such as sharp corner, convex surface and possibility of elimination of re-striking
- Reduced thickness variance of drawn panel
- Less machine trouble and better die life due to reduced impact

Fig. 5.12 Hydraulic 15-Point Cushion

Fig. 5.13 Schematic Diagram of NC Cushion
PRESSES FOR AUTOMOTIVE PLANT

Mechanical presses are preferred in mass production for speed. By design, these presses are very fast. One press line can produce a number of panels.

TANDEM PRESS LINE

The line does not envisage any intermediate storage of panels between the presses. One double-action press for the first draw operation and 3/4/5 single action presses for such as trimming/ piercing/ flanging/ restrike, on basis of the sequence decided by the part design constitute a line. Part feeding, transfer, and unloading of the panel between the presses may be manual, semi-automatic or fully automatic (Fig. 5.14).

Fig. 5.14 Different Automation Levels for Tandem Press Lines
In semi-automatic version, the unloading from each press is automated with consequential better quality standard of the panels in comparison with a manual line. For quality and productivity, the fully automatic press line is naturally the best solution. For low or medium volume production, where each press line is used for many types of panels and investment is to be limited, a tandem press line is recommended. Advantages are:

- The construction and controls are simpler, naturally simplest for the line with manual transport, but quite sophisticated for fully automated line
- The stamping process can be easily planned for any number of operations required for a particular panel (without stopping the press)
- Panels of any shape can be transported without difficulty
- There is no need to stop the whole line when one press is out of order
- Dies are of traditional design
- Manpower requirement for tool change is minimum in manual, but very high in fully automated line
- Output for manual and semi-automatic line remains same and the lowest. The work-force requirement for the semi-automatic line with unloading by mechanical devices is almost half of that for the manual line, where it is the highest. Output of an automatic line is higher, and require the fewest numbers of persons to operate among the three versions.
- Additional conveyor and other devices are to be provided for the panels requiring less stamping operations in a fully automated press line. A turnover device is part of the automatic press line.
- Cost of the fully automatic line is obviously the highest, and so also the space requirement.

On a fully automatic tandem press line, the maximum number of strokes per minute is about 4 to 8. Man power is used only for supervision or inspection. For a manual press line, the maximum number of strokes used per minute varies. Depending on work culture of the plant, the effective SPM may be between 2-4 or even lower. The work force requirement per press may be 2 to 5 increasing with panel size, and additional manual operations such as, oil application requirements.

**TRANSFER PRESS**

Conventional tandem lines have recently given way to Transfer press system. Several stations or tools are mounted in one large integrated press to complete all operations. All in-press handling of panels is automatically executed by positive-action cams with drives from the main press or through independent drives synchronised with the stroke of the press. Large panel transfer presses in two-axis or three-axis versions have revolutionised forming technology in recent years. Generally, 10 to 30 different panels may be run on a transfer press with production lot sizes ranging from 3000 to 10,000 body panels.

Main advantages of transfer presses over the automatic tandem line are:

- Integration of several operations in one press
- Higher output rates through single action draw stage, omission of turn-over operation, short transfer distances in the workpiece flow, and so effective production rate 15 to 18 parts per minute or more.
- Compact design with less space requirement
- High change over flexibility for smaller batches through fully automatic die change with a change over time of about 5 minutes or so.
However, the **disadvantages** remain as follows:

- Higher die cost
- Fault in one stage stops the entire process
- Limitation in part variety on one press
- Demanding training requirements for operation and maintenance
- High capital investment to the extent of about 1.5 times higher than the tandem automated press line.

Many variants of transfer presses (Fig. 5.15) are possible and have evolved, mainly based on the requirements from auto manufacturers.

**Legend:**
- DA. Double action, SA. Single action, T. Turnover, F. Feed bar, U. Updraw, C. Cushion

**Fig. 5.15. Some Variants of Transfer Presses**
**VARIANT - A** has a combination of double action drawing press, turn-over station and tri-axis transfer press. Working speed of turn-over and synchronisation of the two presses restrict output that may be about 12 panels per minute.

**VARIANT - B** has a double-action updrawing station integrated in the transfer press itself. Turn-over is eliminated, as drawing takes place from below (Fig. 5.16). Bottom drive adds to the cost and a second pair of upright is also required. Drawing station may have to be preceded with some equipment to change the blank to a shape such as bending to provide with adequate positional stability. Possibility of dirt sucking during down stroke of draw punch may create quality problem.

![Fig. 5.16 Updraw System in a Transfer Press](image)

**VARIANT - C** has a single action draw with the aid of cushion. The blank holder forces are transmitted from the required number of individually controllable cylinders directly or indirectly to the blank holder of the die. For part height upto 250 mm, the quality of draw is comparable provided the slide speed in the working range is reduced by a linkage drive. Four-upright will be advantageous if the tonnage required in the first stage is high compared to that in subsequent stages. With multiple stations under the slide, inclination of dies may be caused at the first station.

**VARIANT - D** has 3-upright with individual stations distributed over two slides, thus eliminating one upright, one set of moving bolsters and one idle station and consequential shorter gripper rails.

**VARIANT - E** has two uprights and a single slide. Part configuration (length to width) is deciding factor. Shorter transfer step reduces the moving masses of slide and transfer mechanism. Output may be as high as 30 parts per minute.
VARIANT - F has a single slide for each forming station, based on the principle of the tandem line with presses arranged one after the other. While the modular construction comprises of single slides, crowns, uprights, and beds, all link drives are connected via intermediate gears and couplings with the press main drive. Flexibility is enhanced with universal stations between the uprights. The variant provides the advantages as follows:

1. High degree of on-centre loading, as the undesirable interaction of the die stations due to cocking or deflection is eliminated
2. Reduced slide deflection since each slide has 4-point suspension.
3. High degree of guiding accuracy and better parallelism between bed and slide due to, 8-way guiding, small distance between uprights and tie rods in feed direction, a relatively large guided length, and direct absorption of horizontal forces by the uprights.
4. Minimal bed and slide deflection
5. Individual adjustment of shut height, press force and overload protection of each slide and thus each die station.
6. Better access to dies, clamps, and toolings on transfer and universal stations.
7. More room for scrap chutes
8. Flexible positioning of the panel possible and thus better die adaptation and simpler dies.

All these result in better part quality, improved die life, increased output, and higher overall efficiency compared to other configurations.

For variants C, D, E and F, micro-processor controlled drawing cushions are being used. The drawing results of panels are same as that achievable with double-acting presses even with complex draw requirements.

As mentioned earlier, the auto-manufacturers are trying to reduce the number of stations (dies and idle stations). It will reduce the probability of mishandling through reduction of the frequency of pick-up/release of panels. Accessibility and visibility of the die areas in transfer presses are considered at the development stage for ultimate press efficiency.

With larger transfer press, it has become possible to stamp complex sheet metal parts in single piece that were earlier fabricated by welding of number of smaller and simpler parts. The glaring example today is that of body side panels that are now stamped in one piece. It has significantly improved the accuracy of parts and the overall quality of vehicles such as gaps and levels of doors. The same press may be used for the manufacture of multiple parts and separation in last operation such as right hand and left hand doors simultaneously (side-by-side, or one-after-the-other).

FEATURES OF A MODERN PRESS

Many features have been added to presses to improve productivity and quality as well as to make them more flexible to adapt to lean manufacturing. Features such as, self-propelled moving bolsters, automatic slide and stroke adjustment, automatic slide and bed clamps, and many similar ones, have brought down the time required for setup change-over from one panel to another. Die life is significantly affected by the stiffness of the press frame. Minimum values of the vertical spring constant and the constant of tilting (as per the DIN 56 189) guarantee optimum performance of the press. The constant of tilting of the press is important for the accuracy of the panels stamped. Press frame structure and the slides have been
optimised with help of computer-aided design and techniques such as FEM (Finite Element Method). Deflection of press table under load is also being compensated by various means. One manufacturer places a special pressure pad between the press table and die. Impact absorber as integrated in many presses minimises the ill-effect of high impact loads (as one with stretch draw die). Improved clutch/brake units provide better performance under all operating conditions and also the best possible durability. The “wet” clutch and brake system have almost eliminated the need of adjustment for friction lining wear. The overload protection system employing hydraulic cushions built into the slide housings, provides both physical relief and electrical cut-out to protect the press and die from damage. Over years, every possible aspect of safety against failures causing human injury during the operation of presses has become built-in feature.

Table 5.2-Comparison of Different Types of Press Lines

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Tandem press line-manual, w/o moving-bolster</th>
<th>Tandem press line-Automatic, with moving-bolster</th>
<th>Transfer press with moving-bolster</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total tonnage</td>
<td>100%</td>
<td>100%</td>
<td>60 to 70%</td>
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<tr>
<td>Total weight</td>
<td>85 to 90%</td>
<td>100%</td>
<td>60 to 70%</td>
</tr>
<tr>
<td>Floor space requirement</td>
<td>70 to 90%</td>
<td>100%</td>
<td>50 to 60%</td>
</tr>
<tr>
<td>Energy requirement</td>
<td>90%</td>
<td>100%</td>
<td>30 to 60%</td>
</tr>
<tr>
<td>No. of idle stations</td>
<td>4-6*</td>
<td>5-10</td>
<td>1-3</td>
</tr>
<tr>
<td>Transport distance (feeding direction)</td>
<td>90 to 100%</td>
<td>100%</td>
<td>50 to 60%</td>
</tr>
<tr>
<td>Die adaptation req.</td>
<td>no**</td>
<td>partly</td>
<td>yes</td>
</tr>
<tr>
<td>Part alignment- variable</td>
<td>yes</td>
<td>yes, less output</td>
<td>no</td>
</tr>
<tr>
<td>Tooling cost</td>
<td>80 to 90%</td>
<td>100%</td>
<td>110 to 120%</td>
</tr>
<tr>
<td>Tool rebuilding cost</td>
<td>0</td>
<td>0 to 20%</td>
<td>10 to 100%</td>
</tr>
<tr>
<td>Press parts variety</td>
<td>100%</td>
<td>100%</td>
<td>30 to 50%</td>
</tr>
<tr>
<td>Breakdown of one station</td>
<td>bridgeable</td>
<td>bridgeable, if req.</td>
<td>press stops</td>
</tr>
<tr>
<td>Resetting time</td>
<td>300 to 500%</td>
<td>100%</td>
<td>5 to 50%</td>
</tr>
<tr>
<td>Output w/o die change</td>
<td>40 to 70%</td>
<td>100%</td>
<td>130 to 150%</td>
</tr>
<tr>
<td>Output with 1 die change</td>
<td>20 to 50%</td>
<td>100%</td>
<td>110 to 120%</td>
</tr>
<tr>
<td>Manpower requirement</td>
<td>200 to 400%</td>
<td>100%</td>
<td>50 to 70%</td>
</tr>
<tr>
<td>Investment costs</td>
<td>75 to 85%</td>
<td>100%</td>
<td>60 to 80%</td>
</tr>
<tr>
<td>Part cost without material</td>
<td>120%</td>
<td>100%</td>
<td>40 to 70%</td>
</tr>
</tbody>
</table>

* According to number of presses in the line
** Adaptation of overall height, if necessary

Eccentric gear drive replaced the crank-type presses to eliminate torsional deformation on the main pin, and to ensure positive slide parallelism. Plunger guided system, Fig. 5.17 provided further advantages:
1. The thrust forces generated by the eccentric motion are absorbed by the crown via the
plunger guide. Only the vertical forces act on the connection screw and slide. It effectively prevents the uneven wear of the slide gib and slide adjustment devices caused by the thrust forces. It ensures accuracy of the press over longer period.

2. The enclosed crown confines the rotating gear noise and prevents dirt penetration.

Fig. 5.17 Plunger Guided System over Conventional System

Fig. 5.18 Link Drive System
Touching speed of link-drive press is about one-half of an eccentric-gear press. So it makes the press to start with soft impact of the slide at the beginning of the draw. The overall drawing speed in working range is reduced to one third of an eccentric press. Slower and nearly constant speeds in the working range are ensured. The slide force at the start of the drawing operation is significantly higher than that of an eccentric-gear press and the transitions between the motion phases are smoother. Fig. 5.19 shows these advantageous features.

Fig. 5.19 Velocity and Force Advantages of Link Drive System

Since the drive linkages in the drawing range are nearly in straight line, torque loading is reduced by 25-30% as compared to conventional eccentric presses. Individual press elements are under less load; thereby accelerating and braking masses are less, press stopping distance is shorter, and wear on brake and clutch is reduced. With constant drive torque, the kinematic motion of the link drive produces a more favourable tonnage characteristic than a conventional eccentric drive. With the same nominal tonnage rating, a link drive press allows higher press load within the upper working range.

Advantages of the link drive presses are as follows:

- Production speeds and output may be increased without increasing the drawing speed.
- Drawing conditions and drawing results are substantially improved, and material of lower drawing properties can be used.
- Wear of the dies and drawing cushion are reduced, because of reduced mechanical shocks.
- Noise created during operation of the press is less.

In case of a blanking press, a special drive system reduces the slide velocity by 65% as compared to conventional eccentric drive. The die life is improved and noise level is greatly reduced.
Machine controls in modern presses have become user-friendly. It consists of relay controls for the safety functions, programmable controllers and computer. Control provides various improved functions related to:

1. Operation guide system

2. Automatic die change system provides the data memory for the specific panel, and also displays the progress and time of automatic die change.

3. Diagnostics system displays the fault condition in message or graphic, monitors and indicates the poor action of each actuator sequentially, investigates the cause of fault through the expert system.

4. Maintenance management system indicates the regular maintenance items and the work done. Trends of data for vibration, temperature, pressure, etc., are monitored by analogue sensors and displayed for preventive maintenance.

5. Production management system records the production for each part, shows working efficiency report and maintains communication with the host computer.

The control system is expected to provide all assistance to protect the press elements and the tooling against overload. The control must measure, record, and plot the forming force versus time, and force vs. punch travel diagram (for, say, every fifth panel) for producing panels of consistent quality. A deviation from the established diagram must be detected at the earliest, and the counter measures such as adjustment of stroke length, should be initiated through the control system. The signals of pressure pickups should be processed through a computer and compared with a calibrating diagram. The value of force acting on the press slide should also be digitally shown on the front panel of the control system. The control system one day will be able to arrive at the best combination of parameters that control the quality of panel during stamping, to record in its memory, and to repeat the same during next setup, and if necessary, to modify the same to produce defect free panels.

HYDRAULIC PRESS IN AUTOMOTIVE INDUSTRY

In most of the press shop, 99% of the presses (particularly the larger ones) are used for other work than that for which they are originally procured. Investment for a large press makes it unaffordable to go for the best press for each panel. Cycle time of pressing operations is in unit seconds, so flexibility would be a necessity as the dedicated application keeps the press idle. Different parts even in same family may require operations demanding changes in many parameters along with the set of dies. Cost pressure is forcing to automate not only the transformation process itself, but also the loading/unloading and tool change. Decision for using either a mechanical or hydraulic press can not be made based upon a rule of thumb. For new investment, effective interactions between well-known press manufacturers and the user is a necessity for right decision making. While mechanical presses are still the more predominant in auto industry, hydraulic presses are being increasingly applied. High speed hydraulic presses have been developed to successfully compete with mechanical presses.

HYDRAULIC PRESS - DECISIVE ADVANTAGES:

1. Variable Force
   ✓ Infinitely adjustable force from about 20% of its maximum capacity
   ✓ Present force relatively constant throughout the stroke
✓ Impossible to overload regardless of variations in stock thickness, inaccurate dies, or other factors
✓ Possible to protect dies designed for limited capacities and for various operations on different workpiece materials
✓ Over-dimensioning of dies not necessary (as against that with mechanical presses for maximum power of press)
✓ Possibilities of application of full force at any point in the stroke permits use for both short and long stroke application

On a 500 ton mechanical press, only 175 ton force is available for an operation at 127 mm up on stroke. About 1350 ton mechanical press becomes comparable to a 500 ton hydraulic press.

2. Variable Speed and Stroke
✓ Easily adjustable to stop and reverse the slide at any position in stroke (against fixed stroke of mechanical press)
✓ Variable speed- rapid advance to slow pressing speed just prior to contacting the workpiece provides: improved die life due to reduced shock loads and optimum speed for each operation and work material (and consequential high quality assurance and reduction in setup time)

3. Variable Capacity
✓ Bed size, stroke length, press speed and force capacity are not interdependent (as against mechanical)
✓ Specially designed presses are more cost effective.

4. Other Advantages
✓ Fewer moving parts, self lubricating except for slide gibbing, or column bearings
✓ Quieter operation (if properly designed and mounted)

HYDRAULIC PRESS- LIMITATIONS

Speed is slower, if assessed on the basis of the possible number of strokes per minute. However, the number of strokes does not always equal the output. Overall productivity difference may be marginal. Improved circuits, new valves with higher flow capacities and faster response time, are also reducing the gap in production rate.

HYDRAULIC PRESSES FOR PRODUCTION LINE

For a highly varied spectrum of parts, a hydraulic press line is advantageous. With free programmability of the press parameters, the presses are easily adapted to new sets of dies. Modern presses are equipped with electronically controlled axial piston pumps, punch dumping systems, die change systems in many variants, and drawing cushions in single or multiple-point versions. The lead press in hydraulic press lines are set for double action operation. The holding force of the blank holder can be set differently point-by-point, similar to the drawing cushion, and adapted to the drawing process. The press can be used both in double action as well as single action modes with help of a coupling mechanism that enables the ram and blank holder to be connected as one functional unit. Hydraulic press lines are presently used in low/medium volume production shops catering to larger varieties of parts.
Die spotting as well as try out can be carried out on the same hydraulic press of suitable specification. The final shape of the die is optimised by die spotting and precision manual working to match the die set. Die spotting presses (Fig. 5.20) must maintain extremely high degree of parallelism between slide and bolster plate at any slide point of the slide stroke during die spotting. It should also be able to provide precise spotting force. A turn over system for the die is incorporated in spotting press. The upper die is rotated automatically by 180 degrees, and placed on the press bed. It avoids overhead working on the upper die that is unsafe, error-prone, and time-consuming. The rotating platen is fixed on the slide by quick clamps. For rotation of the upper die, the slide travels down to rotation position. The splines of the rotating device are introduced in the platen on both sides. The slide is unclamped and locked in upper dead centre. The rotation device turns the platen together with the upper die. The slide comes down again. It is clamped and, after retraction of the splines, it deposits the rotating platen on the press bed. The moving bolster can be used for bringing the upper die out for spotting work or taking in the press.

In bigger stamping plant, a line of hydraulic die spotting and try out presses are installed to prepare dies before shipping for production run. With full control over the spotting forces, and slide speed and positions, all forming operations can be simulated so that the dies are made
ready in optimal condition for production. The try-out line presses are also being equipped with multi-point drawing device with separately controllable cylinders in bed of the first press. With improved similarity of the tryout and production processes, the phase-in of dies will be better in mass production lines. The varying deformations occurring in dies on a mechanical press in actual forming require to be simulated. The try-out presses are being equipped with devices for simulation of slide tilting of the mechanical presses and with an active compensation device for flexible bending of the press bed.

HEMMING PRESSES

Some of the car components (such as doors, bonnets, decklids) consist of two panels such as one external panel with a matching interior panel. The joining of the two panels are executed on hemming presses with help of suitable single/multi-stage hemming (flanging) dies. The presses may be dedicated or flexible to carry out the hemming operations for number of components with die-change.

DIE CHANGE FLEXIBILITY

A lot of work has been done in stamping facilities to reduce the die change time, as it was one of critical reasons for poor productivity of press shops. Shingo’s philosophy of SMED (Single Minute Exchange of Dies) was a target set by Japanese automotive companies with Toyota as pioneer. A setup change time of four hours was brought down to 1.5 hours in 6 months. In next two months, the down time for the setup change came crashing down to 3 minutes. SMED was achieved with proper planning even on conventional presses by converting as many internal setup activities to external set up activities that can be completed before a setup change over is executed. Change over time was reduced using various techniques such as parallel operations using more workforce, standardisation of shut height, elimination of adjustment activities, one turn clamping and other mechanisation. Over the years, every aspect of die change over work has been studied and quick change over elements have been incorporated in presses, dies, and in material transfer mechanism used in press lines. The set of dies required for next setup is made ready outside the press. So the change over is then limited to die exchange, adjustment of press parameters for the new panel and its dies, clamping of the dies, and adjustment of accessories for the new set-up. The outgoing dies are pulled out from the presses, as the new set of dies is pushed in the respective presses. Various types of equipment such as swivel tables, tandem tool changing trolleys or shuttle tables are used for power operated tool changing. Dies are positioned in the presses with accuracy of about 0.8 mm eliminating manual prying and trial-and-error adjustments. Adjustments of press parameters such as the shut height, the stroke, are carried out simultaneously and almost automatically with pre-programmed data. Starting with standardisation of clamping heights of dies, presently auto-positioning clamps are being used to reduce the setup time. AC driven clamps in T-slots of the press slides find the new die with its sensors and clamp it securely regardless of shape and size of dies.

Moving bolsters with high positioning accuracy have become standard features for achieving quick resetting. The next setup dies are made ready on the additional moving bolsters for each press well ahead of the change over schedule. Moving bolsters may be provided in a number of configurations (Fig. 5.21):

- Traveling to the front and rear
- Traveling to the front and afterwards to left and right
Traveling to left and right
✓ Traveling to left or right, and afterwards to front and rear

Fig. 5.21 Various Configurations of Moving Bolster on Modern Presses

In the latest presses, the entire process of die change over starts automatically once the Auto Die Change Start button is pressed. The system includes: high speed moving bolster, automatic bolster clamper, automatic die clamper, automatic air pressure controller (The air pressure for the counter balance cylinders and die cushions is adjusted automatically to programmed value conforming to the workpiece to be stamped). Setup change over operations such as, the retraction of fingers, connections/disconnections of feed rails, adjustments of feed rail distance, are automatically carried out on transfer presses.

AUTOMATION LEVEL AND ITS FLEXIBILITY
Press shop today can be a totally automated plant from material receipt to delivery of finished panels to Body shop. In fully automated tandem lines, an automatic blank feeder is integrated for first double action press. Loading and unloading of panels from one press to the next are carried out through various systems. Some use mechanical arms mounted on individual presses with a shuttle conveyor between the presses. The another system uses independently mounted robots to unload from a press and to load on the next press without any interference between the presses.

**TRANSPORTATION OF PANELS IN TANDEM PRESS LINES**

Automatic transfer of panels between the presses of a tandem line may as follows:

1. Pick and place shuttle devices, Fig. 5.22, that include:
   - One press mounted linear or cam driven extractor
   - One press mounted linear or cam driven loader
   - One floor mounted part transfer

![Fig. 5.22 Pick and Place Shuttle Device](image)

2. Swing arm robot, Fig. 5.23 mounted to a slide or track (unless the presses are with special side slide bolster), with a six-axes articulated arm style robot mounted to an auxiliary swing arm seventh axis to reach large centre to centre distances of the press lines.

3. Pendulum arm, Fig. 5.24, 4-axes (with optional 5th axis) articulated robot that uses a single pick up transfer between large press centre distances without the robot being relocated for die change. Pendulum arm is mounted off to one side of the press line.
Fig. 5.23 Swing Arm Robot

Fig. 5.24 Pendulum Arm
Pendulum arm robot transfer of panels between the presses of a tandem line has certain clear advantages:
1. Installation is possible without shutting down.
2. Die change over time is significantly reduced.
3. Part quality is better because of single grip/release versus two grip/releases and part transfers
4. It requires one robot instead of three transfer devices.
5. It requires only one third of end of arm toolings, fixtures and vacuum cups and reduced air consumption.

TRANSPORTATION IN TRANSFER PRESSES

On transfer presses, the handling of panels from station to station is totally integrated in the press system itself making it a STAMPING CENTRE. The transfer systems may be:
1. Tri-axis transfer
2. Crossbar transfer

Fig. 5.25 Tri-axis Transfer System

TRI-AXIS TRANSFER SYSTEM

The tri-axis transfer system, Fig. 5.25, picks up the panel holding it at its four corners with fingers provided on the feed rails, lifts, and moves the panel to the next station. The system consists of three kinetic elements: Feed/return, Clamp/unclamp, and Lift/lower. The
manufacturer tries to keep the number of moving components to minimum to attain smooth motion at the desired high speed. Provisions for automatic connecting and disconnecting of feed bar are made to reduce the die change time. The inner distance of feed bars is automatically adjustable based on the sizes of dies. The fingers on the conventional feed bars are to be changed with new fingers manually inside the press. On new presses, automatic retractor may also retract all the fingers on to the feed bars on the bolster carrier. All replacement can be made outside the press.

**Advantages** of the tri-axis system are:

1. The press remains compact, as no special space is to be provided between the adjacent dies.

2. Higher stroke per minute is possible, as only single panel production is possible which is its limitation.

**Disadvantages** are:

1. The system is not suitable for handling large size panels, because of the four corners-holding causing buckling of the panel.

2. It is difficult to transfer panels of odd shape.

3. Die becomes complicated.

4. It is impossible to eliminate idle stations because of feed rail drive mechanism on the bed.

5. Accessibility to die area is very difficult.

6. Connection and disconnection of composite feed bars makes the system design complicated.

7. It results in a limitation of number of stations in one slide due to the bending of rails.

**CROSS BAR TRANSFER SYSTEM**

The cross bars with vacuum cups of the transfer system, as shown in Fig. 5.26, lift up the panels from the outer surface without deflecting them, and moves them to the next station.

The **advantages** of the cross-bar transfer system are as follows:

1. It provides a stable transfer of large size panels that are susceptible to buckle

2. It may simultaneously handle two or even more panels

3. The change over of the dies and handling accessories is easy.

4. Idle stations can be eliminated by adopting laterally shiftable moving bolsters.
The disadvantages of the cross-bar transfer is limited to the increased length, because of a space for cross bar parking between the adjacent dies (depending on whether there are idle stations or not). The transfer is driven by special cams developed with help of CAD to provide the best possible motion curve. High-modulus, carbon-fibre composite materials are used for the cross bars to provide the optimised characteristics related to rigidity, weight, and shock absorption.

However, press manufacturers have and are continuously working on minimising or eliminating the disadvantages of cross-bar/ tri-axis transfer systems through innovative designs developed with assistance of the vehicle manufacturers.

Fig. 5.26 Cross Bar Transfer System

**IMPROVED VERSIONS OF TRANSFER**

One of the manufacturer has developed Overhead Cross Bar Transfer System eliminating the vibration especially in the vertical direction of the vacuum cups installed on the cross bars. The vibration causes unstable and inconsistent suction while picking up the panels, resulting in poor press efficiency. Further, the panels get deformed and the vacuum cups leave marks on the surface of panels. The vibration increases with panel size with higher SPM (Stroke per minute). The lifting and lowering bars were replaced by stationary beams with sliding carriages (Fig. 5.27) in the overhead cross bar transfer system. It provides better accessibility and visibility of the dies for easy maintenance during operation. Further, the motion curve of the transfer system to feed the blank to Number 1 station of a transfer press must consider the following factors:

1. Projected size of the blank (especially length in feed direction) is greater than that of the panel after drawing or trimming. Consequently, the feed stroke to Number 1 station is required to be more than that to Number 2 and subsequent stations.
2. The press angle available for transfer motion at station 1 is less than that for subsequent stations.
3. Since the blank is flat, lift stroke required for moving to station 1 can be less than that to subsequent stations.

Some presses are provided with heavy blank loader on the crown for meeting the above requirement. With flexibility in demand for changing the lift stroke as well as feed stroke, on the press with overhead vertical cross bar, special blank loader is not required.

Other design requirements to achieve higher productivity (SPM) from the transfer press through shake-free velocity and acceleration rate for the required stroke length and available press angle are:

- High rigidity of power transmission to transfer system
- Minimum backlash in the drive system
- Minimum moving mass
- Incorporation of device to minimise alternating torque on camshaft.

Some presses are provided with dual transfer motion, so that the stroke may be selected according to the panel depth. For sallower panel, the press can work with higher SPM with less lifting stroke.

**AC SERVO DRIVEN TRANSFER SYSTEM**

Latest in panel transportation in transfer presses is the application of servo motors with dedicated controller, Fig. 5.28, to provide the optimum motion requirement of variety of panels that will be stamped. It offers an unprecedented flexibility that can not be thought of with mechanical cam type transfer system. Stroke of lift and feed axes, the positions of clamps can be freely changed to provide the optimum motion for every panel.

Difference between a cam driven transfer and a servo-driven one will be as follows:
Fig. 5.28  AC Servo Driven Transfer System

1. A wider range of panels can be produced on the same transfer press.

2. A deep drawn panel incompatible with cam driven transfer may be easily handled.

3. A wide range of transfer motion is possible.

4. Higher production speed is achieved by optimising the adjustable stroke on each axis, as well as the adjustable base angle.

5. As the transfer feed motion is independent and each axis can be adjusted individually and fast, die tryout time is significantly reduced.

6. Faster axis adjustment also reduces the automatic die change time.

7. A wide range of die sizes may be used because of adjustable pass line height.

8. The feed stroke can be changed easily without having idle stations.

9. Maintainability is highly improved, because of elimination of PTO shaft, cam box, etc.
10. Unlike mechanical system, all the motions are smooth and stable with no effect of operation-based wear.

**OVERHEAD TRI-AXIS SYSTEM** (Fig. 5.29)

![Image of Overhead Tri-axis System](image)

Some systems have been designed combining the good features of conventional tri-axis transfer system with feed rails, overhead cross bar transfer system, and AC servo-driven transfer system. The system provides advantages as follows:

1. It is vibration and deflection free.
2. There is no limitation on number of stations in one slide.
3. Idle station can be eliminated.
4. Die area easily accessible and visible.
5. The design is simple without any necessity of system such as feed rail connect/disconnect, automatic finger retractor, feed rail support.
6. Die change is quicker and easily possible on moving bolster.

Automation in unloading and the palletisation system for horizontal and vertical stacking of the finished panels have been perfected. A schematic plan is shown in Fig. 5.30. Storage and handling of coils, dies, finish panels can all be automated.
SHEET METAL PRESS TOOLS - Dies and its Limitations for Auto Industry

COST REDUCTION OF DIES

Approximately, the cost of a set of press dies to stamp all the sheet metal panels for a model of car may be as much as Rs. 2500~3000 crores or so. Everything possible is being explored to reduce this cost with certain amount of trade off such as tool life. Developments in conventional soft materials of low-cost press tools such as zinc alloys, resins, etc. that used to be for few hundred panels, have led to considerably increased tool life. Some new zinc alloys are claimed to provide a life approaching 1 million pressings. Low cost tool materials can now selected for low/medium volume production, that are particularly suitable for countries like India, and other countries in South-East Asia. Besides, with the use of these low cost dies, these companies may remain contemporary permitting normal frequency of model changes in a competitive market.

DIE WEIGHT

Conventionally, the dies were made heavy and the minimum rib thickness in the design guidelines used to be far in excess of what is actually needed. Presently, all tool manufacturers are trying to design dies using computers and specific design standards to determine the stress loadings on the shaping tools. In case of complex components, the Finite Element Method (FEM) is being increasingly used to simulate the shaping process. All these efforts are resulting in reduction of the die weight and thus material cost of the dies. In a case example, the reduction in weight of tools used to produce single piece side panels of a mid-size car was as follows:

<table>
<thead>
<tr>
<th>Die Description</th>
<th>Wt. tons, ’81</th>
<th>Wt. tons, ’91</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Draw</td>
<td>59.2</td>
<td>43.0</td>
<td>11</td>
</tr>
<tr>
<td>Trim</td>
<td>28.6</td>
<td>22.0</td>
<td>14</td>
</tr>
<tr>
<td>Restrike</td>
<td>32.6</td>
<td>21.5</td>
<td>30</td>
</tr>
<tr>
<td>Trim</td>
<td>37.4</td>
<td>24.2</td>
<td>15</td>
</tr>
<tr>
<td>Flange</td>
<td>30.0</td>
<td>26.0</td>
<td>34</td>
</tr>
<tr>
<td>Pierce</td>
<td>24.0</td>
<td>21.0</td>
<td>06</td>
</tr>
</tbody>
</table>
This reduction in weight was not by using FEM, but only through the experience of the designer. The tool weight was reduced by more than a third, by using a one-piece casting, by placing the ribs in accordance with the anticipated stress loadings, and by providing apertures in the neutral axis of the casting. Using present technique of FEM, the weight may be further reduced.

**BEST COMBINATION OF DIE MATERIALS**

Using the design-based materials for the different elements of a die dependent on production volume per year, the die cost may be reduced. In one particular case, for top/ bottom dies, and the blank holder of a double action draw operation, the materials for different production volume per year is as follows;

<table>
<thead>
<tr>
<th>Production/year</th>
<th>Material</th>
<th>Hardness</th>
</tr>
</thead>
<tbody>
<tr>
<td>50,000</td>
<td>FC 300</td>
<td>262 HB max.</td>
</tr>
<tr>
<td>100,000</td>
<td>FCD 600</td>
<td>192~269 HB</td>
</tr>
<tr>
<td>200,000</td>
<td>Special</td>
<td>197~241 HB</td>
</tr>
</tbody>
</table>

**HARD CHROME PLATING ON CHEAPER MATERIAL**

Considerable saving is also claimed by a process of hard chrome plating of automotive press tools. The cheaper grade of flake gray iron (typically FC 25 equivalent to GG 25 or PS 11) is used as base tool materials instead of costlier exotic alloys of nodular iron. Cost savings of upto 30% on material costs are possible. Gray iron is easily machinable giving better tool life, faster machining, and related advantages. With four to five times higher surface hardness with respect to cast iron, chromium plated dies provide a high resistance to wear and scoring that means better die life between reworking or polishing of dies. Moreover, the process improves average related down time (pimples, scoring), reduces oil usage because of improved friction characteristics, and improves rework rate and scrap rate because of improved formability.

**LEAD TIME FOR MANUFACTURING**

The development work of a production tool from the stage of component design is very much time-consuming. The total development time for a set of dies to produce one panel with conventional method, manual finish grinding for matching through spotting is approximately 12~15 months. Considering the number of sheet metal dies required in a car, the time required to tool up for a new model is critical and all efforts to reduce the same are the subject of research. Methodology used today is simultaneous engineering, where the product engineers as well as the manufacturing engineers work closely to ensure all avoidable delays. CAD (Computer aided design) data have reduced die design and development time and also the time for final trial and error final modifications. Various software that simulate the stamping processes such as deep drawing or stretch forming reduce lead time and reliance on physical proto-typing. Computerised sheet metal forming analysis simulates the friction forces between blank holder, sheet, and die during stamping, taking clamping pressure, sliding velocity, and sheet orientation into consideration. Modeling die elements, say various drawbead sizes on a computer rather than in the prototype shop saves significant time in tool design. Software vendors and the auto-manufacturers are developing complimentary systems to act as a fully associative package. Pro/DIFACE from Parametric technology Corporation and OPTRIS from Matra Datavision are two such examples. With Pro/DIFACE, an engineer creates or imports a surface model of car hood (for example), and defines
specific regions of the die face and related features such as blank holder, part addendum, and trim lines. Designers can then generate solid models of punch, die cavity, and die components. The Pro/DIEFACE program allows users to also define a press direction coordinate system with translation offsets and rotation angles. Any changes automatically alter part features defined in relation to press direction. The program also provides a contour map showing distribution of the punch contact area, and expansion ratios of various section lengths before and after forming. OPTRIS is another such metal stamping simulation program from Matra Datavision that runs alone or with EUCLID family of CAD/CAM products. Inputs are a part drawing, method plan, blue print of the drawing die, and CAD data for the workpiece. The program creates a numerical model of the bottom die, then offsets a portion of this surface to create the punch. Using IGES as a standard translator, the tooling surfaces are transferred to the CAM environment to establish milling tooth paths and define finite elements for die components. Finite element geometry is then translated into a neutral format and exported to OPTRIS, which defines mechanical and kinematic information for nodes and elements to do the stamping simulation. The resultant data indicates the likelihood of breaks, creases and shape defects in the drawn part.

The possibility of tilting and rotation (about z-axis) of press slide and the upper die with respect to press table affects the performance of the drawing and cutting tools. The effective alignment of the press slide and the upper die with respect to the bottom die is ensured generally through two types of guidance system: Pillar Guides, and Heel Blocks. Diameter of pillar guides is critical to bear the moment of slide tilt during operation. The mismatch between the upper and lower die is reduced with increasing the diameter of the pillars and the quality of panels produced gets improved. Increase in guidance with heel blocks can be attained with increase in guiding surface area. However, the combination of pillar guides with heel block guides provides only marginal improvement of guidance behaviour.

**COMPUTERISED DIE MANUFACTURING**

CAD has also eliminated a number of manufacturing steps that were used in conventional die manufacturing. Fig. 5.31 shows a flow chart for die development using CAD and CNC machining.

The CAD data can directly be loaded CNC die sinking machine. Advantages are:

- More accurate machining compared to mechanical copying
- Workpieces produced directly by NC milling can be accurate within 0.2 mm compared with an average of 0.6 mm with copy milling
- Elimination of cumulative inaccuracies due to use of copying masters
- Elimination of dimensional variations on large masters due to the effect of temperature
- Manual finishing reduced by upto 50%

CNC machines are provided with automatic tool changer facilities to complete all operations in single clamping, after the machining of the reference surface. Total die making time in man-hours can be reduced by 30% or more. With a 3-axis machine, the direction of the
Fig. 5.31 A Flow Chart for Die Development Using CAD and CAM

milling cutter axis can not be changed. The effective cutting speed at the centre of the ball-nosed cutter becomes zero. The 3-axis milling requires the tool to remain parallel to its axis. It
results in a poor surface finish on the die, causes heavy cutter wear, and requires long machining time. A better tool material can not be used effectively.

Today, a 5-axis machine is preferred for the reasons as follows:

1. 5-axis milling permits use of an end mill rather than rounded cutter for higher metal removal rates and better surfaces.
2. With 5-axis milling, the tool remains perpendicular to the workpiece surface. It is possible to space the cutter paths more widely apart for a given peak to valley groove depth.
3. Time of manual finishing is drastically reduced.
4. Parts with overhanging edges can only be machined with 5 axis control, since the control is otherwise inaccessible.
5. Tilting the tool relative to the workpiece surfaces additionally increase removal rates, since the tool need not cut at its centre, where the removal rate is near zero.

Fig. 5.32 A 5-Axis Cutter Head

However, the 5-axis milling provides the advantages only in machining of convex surfaces with slight curvature, for example exterior panels of modern car such as roof, bonnet. A 5-axis cutter head is shown in Fig. 5.32

HIGH SPEED MILLING

Presently high speed 5-axis machines are preferred for copy milling. The machine with conventional control, if run at higher feed rates, provides reduced accuracy, as servo errors are proportional to the square of the feed rate. High speed machining requires high speed feed control unit. The feed control unit reads NC data in advance, calculates the effects of inertia and servo response on tool path at the desired feed rate, and issues new data to compensate the error. Even the feed rate is optimised through special features in control so that the dies with varying form can be machined without gouges and overshoot drops. The
ball nose end mill produces a finer finish, or smaller peak-to-valley or cusp height, as the stepover or lateral feed becomes smaller. The finer the surface finish, the less time is needed for the final polishing cycle. High speed milling can reduce finish milling time by a factor of five. However, the main objective of high speed milling is to minimise or eliminate bench finishing or hand finishing that represents about 25% to 38% of manufacturing time for a die. It may reduce highly demanding human skill that is very much in short supply today. Bench finishing is also a source of geometric error of the die profile. The manual grinding cannot be controlled as precisely over a profile as much it is possible with a programmed tooth path on a CNC machine. It may result in rework at tryout stage. High speed milling has reduced the time required for manual finishing and tryout as shown in Fig. 5.33.

![Diagram](Fig. 5.33 Man-Hours Reduction Due to High Speed Milling)

**LASERCAV - a new production method**

Lasercav process is the latest in die manufacturing methods with a lot of possibility for future development. In the process, a light beam is focused to a width of a few tenths of a millimeter cuts away the material line by line. The thickness of the layer of material removed is determined by the process parameters (e.g. laser power, feed rate). A roughing or a finishing operation can be selected, just as with milling. Machines are being developed both in vertical and horizontal versions. However, to enable greater accuracy than what has been achieved, the emphasis is on development of a Lasercav programming module and depth sensors. Lasercav very soon if not replace, will effectively supplement conventional stock removal processes. Besides, it will enable dies to be produced from materials that have hitherto been unmachinable or are difficult-to-machine.

**DIE FINAL FINISHING PROCESS**
For finishing of dies, both rigid grinding wheel or stone as well as flexible disks have been used—each with certain advantages and disadvantages. Main objective all the time in the process is to flatten the cusps top so that the groove bottoms remain untouched. Fig. 5.34 shows surfaces (magnified) as obtained from copying, and one after an undesirable grinding and finally one after an ideally grinding. Some of the major die manufacturers have developed robotised die polishing machines. The process uses a closed loop force controlled robot with a flexible grinding disc. Alternatively, a flexible pad with abrasive holder movement simulates human wrist movement with a continuous measurement of the heights of the cusps till it reaches desirable value. Basically, the bottoms of the grooves represent the desired final surface if the cusps can be perfectly matched to the surface. It has further reduced the manual finishing that becomes limited thereafter, to only the inaccessible areas of the robot hand and the tool used.

![Diagram of grinding characteristics](image)

Fig. 5.34 Surface Characteristics after Milling, Poor, and Correct Manual Grinding

**STANDARDISATION OF DIE ELEMENTS**

Another possibility to reduce the development time comes from the design of dies using modular-type composite tools and plug-in modules. A segmented, form-related tool is constructed on a standard base matrix that is configured as a die set. By the use of standard segments and combination thereof, a die set can be manufactured with lowest lead time.

**NEW AREAS - LASERS FOR TRIM /PIERCING**

Laser cutting machines with 3-axis, 5-axis movements are finding application in sheetmetal component manufacturing and are being used to do number of complimentary operations. Biggest advantage is its flexibility and the torch path can be changed as per the component
design and manufacturing requirements. Blanking, piercing, trimming, notching can be easily performed for varied components. With improved cutting speed, the time cycle achieved may be viable for low volume requirements. The laser may be the most efficient manufacturing technique for the smaller holes in odd positions because of its flexibility. Generally, the punch life becomes critical or die design becomes complex. A number of additional dies may be required. The process may be easily integrated in the existing manufacturing system to increase production and efficiency, and to cut down tooling, maintenance and setup cost. For holes with less than 2:1 hole/thickness ratios, laser provides the best solution. For components such as doors, bonnet or decklid with complex holes and contours, a laser system may improve part quality and reduce production cost.

As the panels are being designed mostly using CAD system, CAM software can develop the laser working program for the process by starting from the description of component geometry. Teach mode program that may be time-consuming and may require skill, may be replaced by the CAM software. Laser cutting is destined to get effectively integrated in stamping plant for automotive components. 5-axis laser cutting machines are already being used for all trimming and piercing operations particularly for low/medium volume operation such as proto-typing or after sales market requirements. The laser cutting speeds based on material thickness may go upto 10 metres per minute for 3-axis cutting. On 5-axis machines, cutting speed of 5 to 6 metres per minute are reached depending on the part geometry of the body panels. Even zinc coated sheets can be cut at 4 metres per minute. Laser capability to combine several processes such as cutting, shearing, and welding into one work station will provide immense opportunity to improve overall part quality, and will ultimately reduce product cost.

**SOME NEW APPROACHES IN METAL STAMPING**

New methods are being developed to reduce the number of steps as well as to cut down the tooling cost and its development time. The Toyota Flexible Press System is a similar approach for small-lot production, which is becoming the trend and that is expected to grow faster in coming years. The system consists of three major processes:

1. **drawing** performed by a newly developed liquid-pressure press-forming method,
2. **trimming** with a high speed 3-axis laser cutting machine, and finally
3. **cam flanging** by multi-directional press forming method in which the pressure is simultaneously applied from six directions.

Five step process for a fender was reduced to 3 step process (Fig. 5.35)

A significant step is being taken to manufacture panels with a “resilient” tool half, only one tool half specific for the product must be produced. Forming metal with a rubber pad (known as the Guerin principle), as shown in Fig. 5.36 is one such method. The rubber pad is traversed towards the tool with the sheet metal panel lying on it. The rubber pad thus makes contact with the tool under increasing pressure thereby forming the sheet. The higher the pressure chosen, the more uniform becomes the vertical pressure distribution along the tool side wall. Recesses can thus be filled and spring back together with any manual second operation work may also be reduced.
Fig. 5.35 Toyota Flexible Metal Forming System

Fig. 5.36 Principle of a Rubber Pad Press
In another system, Fig. 5.37, the rubber pad is replaced by a rubber diaphragm to which oil pressure is applied thereby bringing the metal panel into contact with the tool contour. Pressure distribution is somewhat more homogenous and somewhat greater drawing depth can be achieved. The processes still require fine tuning for effective application in medium volume production.

![Fig. 5.37 Principle of a Fluid Cell Press](image)

**PRESS SHOP MANAGEMENT**

A press shop is characterised by extremely high capital investments making productivity target as high as possible a necessity. The objective always is to obtain the longest time period of press producing good parts. In a press shop, each period that is longer than the time for a press stroke and that has not led to production of a good part is to be regarded as down time. A typical delay analysis of various operations of press shop provides the data as follows:

- Change over time - die change: 7%
- Unproductive time - trial pressings: 12%
- Organisational idle time: 3%
- Machine downtime: 13%
- Technical idle time - die failure: 7%
- Effective useful time - press time: 58%

The table above is good enough to show that the impression of press stoppages being caused exclusively by the die change is not correct. However, as explained earlier, a lot of work done in area of reducing setup time has brought down the loss time in setup change to SMED level. Data below shows the significant improvement in die change time between 1978 to 1992.

**Reduction in Die Change Time over the Years**

<table>
<thead>
<tr>
<th>Die Change Elements</th>
<th>1978</th>
<th>1979*</th>
<th>1992**</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Die transportation</td>
<td>3.2</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2. Die Setting</td>
<td>4.0</td>
<td>1.8</td>
<td>0.36</td>
</tr>
<tr>
<td>3. Waiting for crane</td>
<td>6.0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>4. Cushion pins setting</td>
<td>1.5</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

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<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>5. Slide adjustment</td>
<td>1.5</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>6. Adjustment for automation</td>
<td>2.3</td>
<td>1.8</td>
<td>-</td>
</tr>
<tr>
<td>7. Conveyor setting</td>
<td>1.5</td>
<td>0.5</td>
<td>0.09</td>
</tr>
<tr>
<td>8. Preparation for blanks and pallets</td>
<td>2.0</td>
<td>1.5</td>
<td>0.12</td>
</tr>
<tr>
<td>9. Preparation for tool setting</td>
<td>1.2</td>
<td>0.9</td>
<td>-</td>
</tr>
<tr>
<td>10. Trial Stamping</td>
<td>3.3</td>
<td>2.0</td>
<td>-</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>26.5</strong></td>
<td><strong>8.5</strong></td>
<td><strong>0.57</strong></td>
</tr>
</tbody>
</table>

* Effect of Quick Die Change System
** Effect of Kaizen

Ways and means to arrive at SMED is known to all through printed materials available on the subject. Perhaps, it will be other areas such as unproductive time in trial pressings, and maintenance of machines and toolings that require careful manufacturers’ attention. A process monitoring that indicates a trend statement concerning the parameters controlling the forthcoming faults, will be desirable to prevent the faults as against the present ones that indicate them only after they have occurred.

New technologies for presses, systems, transfer arrangements and stores have been brought in for ‘Just-in-Time’ production system. Even with in-house stamping facility, unlike machining, the ‘Just-in-Time’ in its true sense is not possible, because of the basic nature of the machine speeds and change over limitations because of dedicated toolings. Effort can only be made to reduce the batch sizes to reduce the inventory/ stock levels of raw materials in circulation and number of finished pressings to a practical minimum level. Some stamping shops are producing the batch sizes that will be sufficient for only 2 to 3 hours in assembly.

An efficient and computerised production control and planning system for requirement-based and capacity related production control is essential for stamping plant. The magnitude of investment in a new press shop requires optimisation of capacity created. All stages of the press shops- from the coil stores to the finished part store-are being optimised. With high level of automation, the press shops may be justified for 24 hour operation through seven days a week.

The basic approach to press shop management is clear from a recent report from AUTOMOTIVE INDUSTRIES: GM’s 13 North American stamping plants have 57 different press configurations. A standardisation programme would reduce that to six either through reconfiguration or total elimination. GM plans to run all its press lines 24 hours a day. The press lines will all have common controls and material handling systems, common end-of-line part handling. “The presses are old and obsolete” should not become the excuse for not achieving the desired productivity. Presses are high cost investment and require very carefully planned and effectively implemented maintenance based on Total Productive Maintenance philosophy. The services of experts, specialised maintenance groups, or original equipment manufacturers may be sought for further improvement of productivity. Planned maintenance and timely repair will be essential to maintain the desired accuracy levels. A rebuilding will be essential to upgrade even a press line of very old technologies. The desired level of productivity may be achieved through retrofits in presses, die change over system, and the panel transfer system. In some of the world’s best car manufacturing plants, even 30~40 year old press lines are producing the panels for the latest cars. It has been possible only with good maintenance and upgradation to incorporate the latest innovations.
With the progress in technology, the presses are sufficiently flexible to accommodate dies for any new product. However, the development time as well as manufacturing time requirement for tools require some major technological breakthrough to meet the market demand.

One major aspect of the pressing systems will be the reliable automatic inspection of the finished panels. The system must have in-line facility to scan the parts contour and finish of the outer surfaces of skin panels for scratches, creases, draw marks, etc. at a speed of the production line.

With engineered blanks, laser cutting and newly developed liquid pressure forming methods, the basic processing sequence may undergo change. Manufacturing engineers will have to work hard to keep in touch with the developments in different areas. It will help them to decide the optimum effective sequences for the processing of the panels for a new facility. They may also explore the possibility of upgrading the existing manufacturing with retrofitment of new innovations.

NEW TRENDS

Competition is forcing auto manufacturers to take an all-out effort to reduce cost. In a production setup of 10,000 panels per month, approximate cost breakups under different heads are as follows:

<table>
<thead>
<tr>
<th>Material cost</th>
<th>75%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Die cost</td>
<td>15%</td>
</tr>
<tr>
<td>Running cost</td>
<td>10%</td>
</tr>
</tbody>
</table>

The next generation of cars will be largely dependent on lightweight construction using steel. The majority of new approaches for weight reducing of structures are based on further development in the fields of materials (sheet qualities and semi-finished products), forming technology, and joining technology. Tailored blanks or patchwork technology, simultaneous stampings of more than one panel, change in blank shape, are the methods used for reduction in material cost. Tailored blanks contribute to lightweight construction as a result of the varying sheet thickness. Patchwork technology makes it possible to manufacture components which are matched to the theoretical sheet-thickness requirements and come very close to satisfying the main goal of weight reduction.

Work on reduction in die cost is covering various activities such as, reduction of number of dies required for each panel, reduction in size and weight of dies, and redesign of panel construction to replace number of parts by one, i.e. Body side (Fig. 5.38)

Running cost saving is coming through new press technology with increased strokes per minute, stable and high speed feeding system, improved servo-controlled drives of transfers, reduced energy consumption through optimised design, and so on. Modular transfer press is the latest that provides the best of tandem line and conventional transfer press, as the dies for the press are interchangeable with those for the tandem line. While automobile builders are gradually switching over to transfer presses (mechanical), the component manufacturers still prefer tandem lines and hydraulic presses. Single action press with die cushion is
replacing double action draw press. Mastering of NC cushions will result in reliable quality of panels.

Trends in stamping have highly influenced by the manufacturing concepts of individual company and the country. For example, when one Japanese company prefers a simple fixed bar type vacuum cup feeder, the another company opts for tiltable bar type feeder. European automakers prefer slide cushion, whereas Japanese prefer die cushion. Japanese were pioneer in reducing the number of work stations to four for almost all major panels, whereas Europeans’ average may still be about six per panel. Level and type of press automation also defer from company to company.