Pressing Matters: A Primer

C.J. Crout – Ajax-CECO, Cleveland, Ohio
J. Walters – Scientif c Forming Technologies Corporation, Columbus, Ohio
C.J. Van Tyne – Colorado School of Mines, Golden, Colo.

In this second of four articles on forging equipment, mechanical presses are covered. The same general approach of each individual type of equipment is used. A general overview of the equipment is presented and details about the physics associated with each type of equipment are reviewed. Simulations are used to illustrate various aspects of the operation that cannot be directly observed during production. Other features and characteristics, which are important for the proper use and operation of the equipment, are also described. Finally, a brief overview of the advantages and limitations of mechanical presses is provided.

A mechanical forging press converts rotational energy from a flywheel into the linear motion of a ram, onto which the top forging die is mounted. The total distance of ram movement, which is called the stroke distance, is fixed. There is typically a clutch that connects the flywheel to the eccentric (or crank) shaft. The load capability and ram speed are dependent on the position of the ram during its up and down movement. In contrast to a forging hammer, which is an energy-limited machine, a mechanical press is a stroke-limited machine. In a hammer, the ram stops when all of the energy is dissipated. In a mechanical press, when the ram reaches the bottom of the stroke, it stops moving downward, then reverses direction. The forging deformation only occurs during the last portion of the downward movement of the ram.

Mechanical presses are used for most high-volume applications, including cold-formed fasteners and precision parts, cold- and warm-formed automotive applications, and hot-forged gears for automotive drivetrains. Typical forgings produced on a mechanical press are shown in Figure 1. Features observed in these typical forgings are: either multiple or single parts can be produced; the amount of flash is usually less than with a forging hammer; the size of the forged component is proportional to the size of the press; and deep cavities can be filled.

Figure 2 shows a schematic of a mechanical forging press. The moveable ram holds the upper die while the lower die remains stationary. The flywheel is the source of the rotational mechanical energy. When the clutch is engaged, energy from the flywheel is

Figure 1. Typical hot-forged par ts produced on a mechanical press, which can also be used for cold forging and coining operations.

used to rotate the crankshaft. The pitman translates the rotational shaft motion into a linear motion similar but inverse to the piston in an internal-combustion engine. The brake drum is used to stop the press as necessary. All of these parts are supported by the frame of the press.

Mechanical Press Physics

The physics involved in the operation of a mechanical press are illustrated in Figure 3. To understand the operation of a mechanical press it is important to follow how the initially supplied energy moves from one component to another, finally resulting in the movement of a die that deforms the workpiece.

Electrical energy is supplied to run a motor (Figure 3a). The motor turns a belt, which rotates a flywheel. Because of the flywheel's large mass, a great amount of energy is stored as rotational (kinetic) energy as the flywheel rotates. Connected to the flywheel is a pinion gear, which can engage with the drive gear (Figure 3b). There is a clutch attached to the crankshaft that is usually found inside a rotating ring or drive gear (Figure 3c). Activating the clutch allows the pinion gear and drive gear to engage with the eccentric shaft. The rotational energy from the pinion is transferred to the drive gear, causing it to rotate.

The drive gear is connected to an eccentric shaft (Figure 3d). When the drive gear rotates, so too does the eccentric shaft. The drivetrain converts the rotational motion of the eccentric shaft into linear motion (Figure 3e), causing the guided ram to move down, then up again (i.e. the linear motion). The top die is attached to the guided ram (Figure 3f). The speed of the ram is a sinusoidal function of time, with no velocity at the top and bottom of the stroke and maximum velocity at position halfway through the stroke length. Near the bottom of the stroke the die comes into contact with the workpiece. The linear energy in the ram movement is converted into deformation work, causing the workpiece to flow into the die cavity.

Simulated Operation

In contrast to a forging hammer, which often requires multiple hits in each die impression, a well-designed die for a mechanical press will only need one stroke for the workpiece to fill the impression. Figure 4 shows a simulation of a forging made on a mechanical press. The two graphs below the illustration show the ram speed and

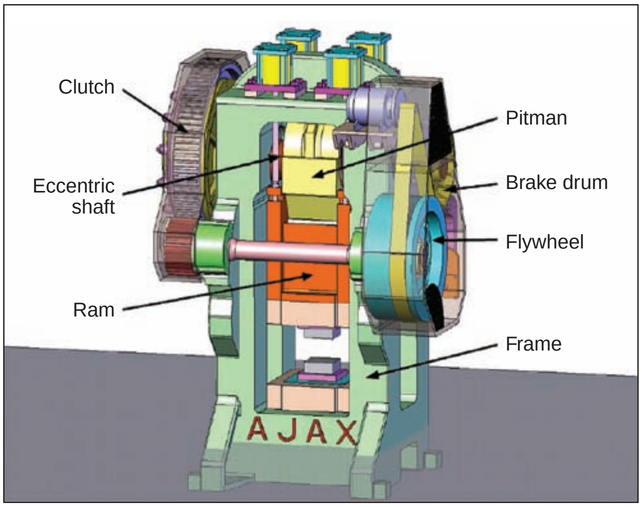


Figure 2. Schematic overview of a mechanical press, with the major components labeled

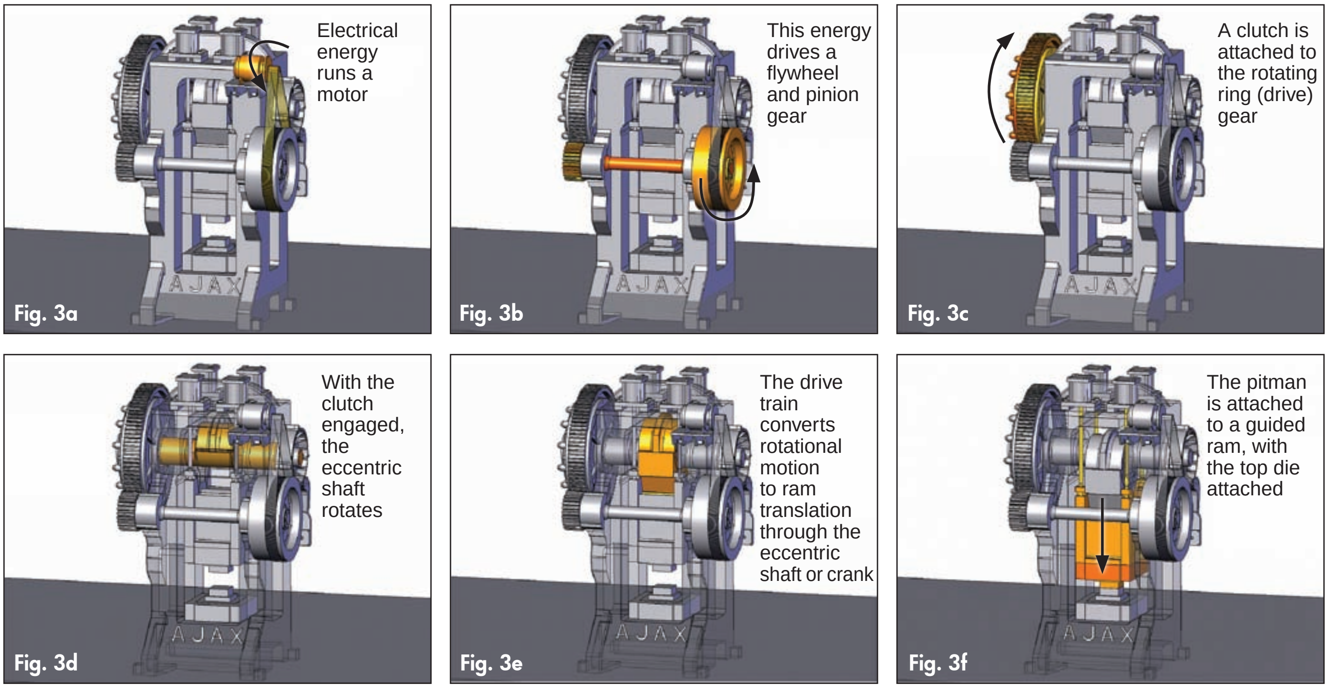


Figure 3. Operational features of a mechanical press

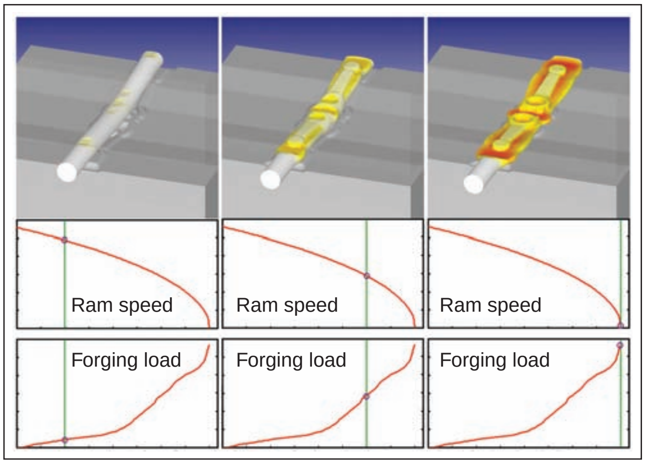


Figure 4. Simulation of a mechanical press forging with the ram speed and forging load indicated. The simulation is shown at the very end of the stroke when the load is the highest and the die cavity is filling. Note that the ram speed is slowing down until it comes to a stop at bottom dead center. The forging load increases at the first point of contact between the die and the workpiece.

the forging load as a function of stroke position. This simulation illustrates that the workpiece deformation occurs near the end of the stroke as the ram approaches bottom dead center. The forging load increases dramatically during the final part of the stroke for typical closed-die forging applications. Because the stroke is fixed, if an oversized billet or an undersized press is used, the forging load could surpass the tonnage capacity of the press. If this occurs, significant problems can result (e.g., fracturing of the die, breakage of a gear tooth, burning out of a motor, excess clutch wear, etc.). Hence, it is important to know the load required for the forging and use a mechanical press of appropriate capacity.

Other Effects and Features

There are a number of other features about mechanical presses that should be understood in order to operate them successfully. These include: press frame stretch, ram tilting due to off-center loading, controls, drive systems and frame systems.

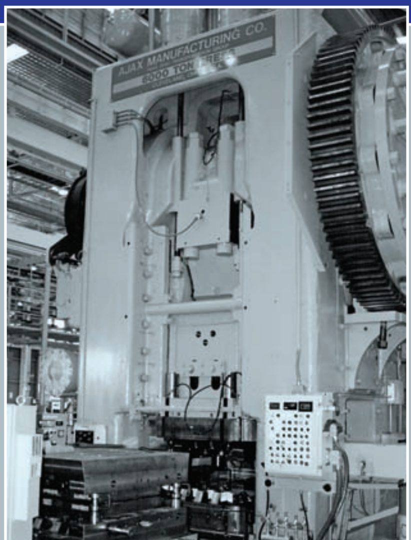
Press Frame Stretch – Although a mechanical press is a sturdy and robust machine, when deformation occurs between the dies, the press will undergo some elastic stretch. If the press stretch is not accounted for, a thicker than anticipated flash will result. Because of this effect, a wider manufacturing tolerance on the forging is often needed when using a mechanical press. Press stretch is lost energy. The elastic energy in stretching the frame does no useful work in deforming the workpiece and is dissipated as heat.

Off-center Loading – Most mechanical presses have one or more die stations located off-center, causing eccentric loading when these stations are used. Eccentric loads tilt the ram, which bends the frame at the contact points. This tilt bends the eccentric shaft. Off-center loading can result in a tapered forging and side wear.

Mechanical Press Controls – The speed of the press is determined by the speed of its motor. Variable-speed drives are available but less common. Bottom dead center (BDC) is fixed. Die clearance at BDC is controlled by die stack-up and shims and/or wedges. The maximum forging load occurs at BDC. Overload protection on the main ram will be by clutch slippage, which is not a recommended approach. Overload protection on the ejector can be via breaker bolt or hydraulic pressure.

Drive Systems – The three most common drive systems for a mechanical press are: direct pitman drive, wedge drive and Scotch yoke drive. For a pitman-drive system, a connecting rod is used. A twin-pitman design, which can increase the off-center loading

ADVANTAGES AND DISADVANTAGES OF MECHANICAL PRESSES



Advantages

- The shut height position is repeatable due to the fixed stroke of the equipment.
- Mechanical presses have a large amount of stored energy in the flywheel, enabling them to complete the deformation stroke without a significant slowdown in production.
- Top and bottom ejection can be used to remove the part from the die, allowing deeper cavities in the impression and shallower draft angles. These ejectors can be either mechanical or hydraulic.
- High production rates can be achieved with mechanical presses.
- Automation can be easily added to a mechanical press.
- There is shorter contact time between the die and the workpiece in a mechanical press than in a hydraulic press.

Disadvantages

- Mechanical presses are usually not used for forging components that require long deformation strokes (i.e. greater than 25% of the total available stroke length).
- Forgings with thin sections are rarely produced on mechanical presses. The heat losses from these thin regions are too high.
- They are rarely used in hot (greater than 500°F) die applications, which are usually performed on hydraulic presses.

capability of the press design, can be used. For a wedge-drive system, the wedge operates between the frame top and the ram. The crank is loaded with one-half of the ram force due the 30° wedge angle. The Scotch yoke design uses a sliding box in place of the pitman. The eccentric shaft is inside the box. As the shaft rotates, the ram is driven down then up as the box slides front to back. The design yields a somewhat shorter press.

Frame Systems – The three types of press-frame systems are fabricated frames, solid cast frames and cast frames with tie rods. The advantages of fabricated frames are their more uniform density and the avoidance of casting difficulties in the small section areas. The disadvantage of fabricated frames is their lower rigidity, which leads to larger press stretch. Fabricated frames are usually reserved for presses of less than 1,300 tons capacity. Cast frames can be very large in size. They are more rigid and have a large mass. Solid cast steel is the best material for these frames, but it is difficult to produce cast steel for press sizes larger than about 7,000 tons. Cast steel with tie rods, which reinforce the thinner sections, may also be used. The tie rods can also be used to pre-stress the frame. A multi-piece cast-steel frame with tie rods is also an option. Such a frame system is easier to produce, but it has less rigidity than a solid cast frame.

Frame stiffness influences the thickness tolerances and variances within the forging. Close-tolerance forgings require stiffer mechanical presses and may require the use of preloaded tooling or kiss blocks. Lower stiffness leads to more stretch, which increases the contact time between the die and the workpiece. Low stiffness can also cause excess bed deflection, leading to premature bolster failure.

Potential Issues

Die mismatch is a concern in all forging equipment. For mechanical presses, mismatch can become greater due to off-center loads. Tapered forgings are more commonly seen in press forgings than in hammer forgings. The taper that is observed usually runs from front to back unless the finish impression is located off-center left to right. The thickness control of a mechanical-press forging is primarily governed by the stretch of the press. Material volume, forging temperature and lubricant control can be significant contributors to the tonnage developed and, hence, the amount of stretch and the amount of thickness variation obtained.

Summary

Mechanical presses are rugged pieces of equipment that are capable of producing a wide variety of forgings. They operate with a fixed stroke, so proper die design and proper billet sizing are necessary to stay below the load capacity of the equipment. In contrast to hammers, mechanical presses operate at slower speeds with greater contact time between the workpiece and the dies. Press dies should be designed so that they can be filled in a single stroke. The choice of frame system is important to control the stiffness of the press. Because of their repetitive motions over a fixed distance, automation can be easily integrated with mechanical presses.

Acknowledgements

The support for these papers from Ajax Manufacturing Company, the Forging Industry Association, the Forging Defense Manufacturing Consortium, Scientific Forming Technologies Corporation and the PRO-FAST Program is appreciated. The PRO-FAST Program is enabled by the dedicated team of professionals representing both the Department of Defense and industry. These teammates are determined to ensure that the nation's forging industry is positioned to meet the challenges of the 21st century. Key team members include: R&D Enterprise Team (DLA J339), Logistics Research and Development Branch (DLS-DSCP) and the Forging Industry Association (FIA).

Co-author Charles J. Crout is president of Ajax Manufacturing Company (dba Ajax-CECO), Cleveland, Ohio. He may be reached at (216) 531-1010 or ccrout@park-ohio.com. Co-author Dr. Chet Van Tyne is FIERF Professor, Department of Metallurgical Engineering, Colorado School of Mines, Golden, Colo. He may be reached at (303) 273-3793 or cvantyne@mines.edu. Co-author John Walters is vice president of Scientific Forming Technologies Corporation, Columbus, Ohio. He may be reached at (614) 451-8330 or jwalters@deform.com.