CHAPTER 10

Principles of Forging Machines

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10.1 Introduction

In a practical sense, each forming process is associated with at least one type of forming machine (or "equipment," as it is sometimes called in practice). The forming machines vary in factors such as the rate at which energy is applied to the workpiece and the capability to control the energy. Each type has distinct advantages and disadvantages, depending on the number of forgings to be produced, dimensional precision, and the alloy being forged. The introduction of a new process invariably depends on the cost effectiveness and production rate of the machine associated with that process. Therefore, capabilities of the machine associated with the new process are of paramount consideration. The forming (industrial, mechanical, or metallurgical) engineer must have specific knowledge of forming machines so that he/she can:

- Use existing machinery more efficiently
- Define with accuracy the existing plant capacity
- Better communicate with, and at times request improved performance from, the machine builder
- If necessary, develop in-house proprietary machines and processes not available in the machine-tool market

10.2 Interaction between Process Requirements and Forging Machines

The behavior and characteristics of the forming machine influence:

- The flow stress and workability of the deforming material
- The temperatures in the material and in the tools, especially in hot forming
- The load and energy requirements for a given product geometry and material
- The "as-formed" tolerances of the parts
- The production rate

The interaction between the principal machine and process variables is illustrated in Fig. 10.1 for hot forming processes conducted in presses. As can be seen in Fig. 10.1, the flow stress, \( \sigma \), the interface friction conditions, and the forging geometry (dimensions, shape) determine (a) the load, \( L_p \), at each position of the stroke and (b) the energy, \( E_p \), required by the forming process.

The flow stress, \( \sigma \), increases with increasing deformation rate, \( \dot{\varepsilon} \), and with decreasing temperature, \( \theta \). The magnitudes of these variations depend on the specific forming material. The frictional conditions deteriorate with increasing die chilling.

As indicated by lines connected to the temperature block, for a given initial stock temperature, the temperature variations in the part are largely influenced by (a) the surface area of contact between the dies and the part, (b) the part thickness or volume, (c) the die temperature, (d) the amount of heat generated by deformation and friction, and (e) the contact time under pressure.

The velocity of the slide under pressure, \( V_p \), determines mainly the contact time under pressure, \( t_p \), and the deformation rate, \( \dot{\varepsilon} \). The number of strokes per minute under no-load conditions, \( n_p \), the machine energy, \( E_M \), and the deformation energy, \( E_p \), required by the process influence the slide velocity under load, \( V_{pl} \), and the number of
strokes under load, $n_p$; $n_p$ determines the maximum number of parts formed per minute (i.e., the production rate) provided that feeding and unloading of the machine can be carried out at that speed.

The relationships illustrated in Fig. 10.1 apply directly to hot forming of discrete parts in hydraulic, mechanical, and screw presses, which are discussed later. However, in principle, most of the same relationships apply also in other hot forming processes such as hot extrusion and hot rolling.

### 10.3 Load and Energy Requirements in Forming

It is useful to consider forming load and energy as related to forming equipment. For a given material, a specific forming operation (such as closed-die forging with flash, forward, or backward extrusion, upset forging, bending, etc.) requires a certain variation of the forming load over the slide displacement (or stroke). This fact is illustrated qualitatively in Fig. 10.2, which shows load versus displacement curves characteristic of various forming operations.

For a given part geometry, the absolute load values will vary with the flow stress of the given material as well as with frictional conditions. In the forming operation, the equipment must supply the maximum load as well as the energy required by the process.

The load-displacement curves, in hot forging a steel part under different types of forging equipment, are shown in Fig. 10.3. These curves illustrate that, due to strain rate and temperature effects, for the same forging process, different forging loads and energies are required by different machines. For the hammer, the forging load is initially higher, due to strain-rate effects, but the maximum load is lower than for either hydraulic or screw presses. The reason is that the extruded flash cools rapidly in the presses, while in the hammer, the flash temperature remains nearly the same as the initial stock temperature.

Thus, in hot forging, not only the material and the forged shape, but also the rate of deformation

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**Fig. 10.1** Relationships between process and machine variables in hot forming process conducted in presses. [Altan et al., 1973]
and die-chilling effects and, therefore, the type of equipment used, determine the metal flow behavior and the forging load and energy required for the process. Surface tearing and cracking or development of shear bands in the forged material often can be explained by excessive chilling of the surface layers of the forged part near the die/material interface.

Fig. 10.2 Load versus displacement curves for various forming operations (energy = load \times \text{displacement} \times \text{M, where M is a factor characteristic of the specific forming operation). [Altan et al., 1973]
10.4 Classification and Characteristics of Forming Machines

In metal forming processes, workpieces are generally fully or nearly fully formed by using two-piece tools. A metal forming machine tool is used to bring the two pieces together to form the workpiece. The machine also provides the necessary forces, energy, and torque for the process to be completed successfully, ensuring guidance of the two tool halves.

Based on the type of relative movement between the tools or the tool parts, the metal forming machine tools can be classified mainly into two groups:

- Machines with linear relative tool movement
- Machines with nonlinear relative tool movement

Machines in which the relative tool movements cannot be classified into either of the two groups are called special-purpose machines. The machines belonging to this category are those operated on working media and energy. The various forming processes, discussed in Chapter 2, are associated with a large number of forming machines. These include:

- Rolling mills for plate, strip and shapes
- Machines for profile rolling from strip
- Ring rolling machines
- Thread rolling and surface rolling machines
- Magnetic and explosive forming machines
- Draw benches for tube and rod; wire and rod drawing machines
- Machines for pressing-type operations, i.e., presses

Among those listed above, “pressing”-type machines are most widely used and applied for a variety of different purposes. These machines can be classified into three types [Kienzle, 1965] [Kienzle, 1953]:

- Load-restricted machines (hydraulic presses)
- Stroke-restricted machines (crank and eccentric presses)
- Energy-restricted machines (hammers and screw presses)

Hydraulic presses are essentially load-restricted machines; i.e., their capability for carrying out a forming operation is limited mainly by the maximum load capacity. Mechanical (eccentric or crank) presses are stroke-restricted machines, since the length of the press stroke and the available load at various stroke positions represent the capability of these machines. Hammers are energy-restricted machines, since the deformation results from dissipating the kinetic energy of the hammer ram. The hammer frame guides the ram, but is essentially not stressed during forging. The screw presses are also energy-restricted machines but they are similar to the hydraulic and mechanical presses since their frames are subject to loading during forging stroke. The speed range and the speed stroke behavior of different forging machines vary considerably according to machine design, as illustrated in Table 10.1.

The significant characteristics of these machines comprise all machine design and performance data, which are pertinent to the machine’s economic use. These characteristics include:

- Characteristics for load and energy
- Time-related characteristics
- Characteristics for accuracy

In addition to these characteristic parameters, the geometric features of the machine such as the stroke in a press or hammer and the dimensions and features of the tool-mounting space (shut height) are also important. Other important values are the general machine data, space requirements, weight, and the associated power requirements.
Apart from the features mentioned previously, some of the basic requirements that are expected of a good forging machine can be listed as:

- High tool pressure, which requires the stock to be tightly gripped and upsetting forces completely absorbed.
- Sufficient tool length to permit rigid bar reception apart from filling up the impression.
- The gripping tools must not open during the upsetting process.
- The device for moving the tools must be secured against overloading.
- The heading slide must be provided with long and accurate guides.
- The whole machine must be elastically secured against overloading.
- Design of a crankshaft of special rigidity.
- Readily interchangeable gripping and heading tools.
- The driving motor and the machine must be connected through a security coupling.
- The machine must have central lubrication.

### 10.5 Characteristic Data for Load and Energy

Available energy, $E_M$ (in ft-lb or m-kg), is the energy supplied by the machine to carry out the deformation during an entire stroke. Available energy, $E_M$, does not include either $E_f$, the energy necessary to overcome the friction in the bearings and slides, $E_d$, the energy lost because of elastic deflections in the frame and driving system.

Available load, $L_M$ (in tons), is the load available at the slide to carry out the deformation process. This load can be essentially constant as in hydraulic presses, but it may vary with the slide position in respect to “bottom dead center” (BDC) as in mechanical presses.

**Efficiency factor, $\eta_p$:**

The efficiency factor, $\eta_p$, is determined by dividing the energy available for deformation, $E_M$, by the total energy, $E_T$, supplied to the machine; i.e., $\eta_p = E_M/E_T$. The total energy, $E_T$, also includes in general: (a) the losses in the electric motor, $E_e$, (b) the friction losses in the gib and in the driving system, $E_f$, and (c) the losses due to total elastic deflection of the machine, $E_d$.

The following two conditions must be satisfied to complete a forming operation: first, at any time during the forming operation,

$$L_M \geq L_p$$

(Eq 10.1)

where $L_M$ is the available machine load and $L_p$ is the load required by the process; and second, for an entire stroke,

$$E_M \geq E_p$$

(Eq 10.2)

where $E_M$ is the available machine energy and $E_p$ is the energy required by the process.

If the condition expressed by the former inequality above (Eq 10.1) is not fulfilled in a hydraulic press, the press will stall without accomplishing the required deformation. In a mechanical press, the friction clutch would slip and the press run would stop before reaching the bottom dead center position. If the condition expressed by the latter inequality (Eq 10.2) is not satisfied, either the flywheel will slow down to unacceptable speeds in a mechanical press or the part will not be formed completely in one blow in a screw press or hammer.

### Table 10.1 Speed-range and speed-stroke behavior of forging equipment

<table>
<thead>
<tr>
<th>Forging machine</th>
<th>Speed range</th>
<th>Speed-stroke behavior</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydraulic press</td>
<td>0.2–1.0(a)</td>
<td>0.06–0.30(a)</td>
</tr>
<tr>
<td>Mechanical press</td>
<td>0.2–5</td>
<td>0.06–1.5</td>
</tr>
<tr>
<td>Screw press</td>
<td>2–4</td>
<td>0.6–1.2</td>
</tr>
<tr>
<td>Gravity drop hammer</td>
<td>12–16</td>
<td>3.6–4.8</td>
</tr>
<tr>
<td>Power drop hammer</td>
<td>10–30</td>
<td>3.0–9.0</td>
</tr>
<tr>
<td>Counterblow hammer (total speed)</td>
<td>15–30</td>
<td>4.5–9.0</td>
</tr>
<tr>
<td>HERF machines</td>
<td>20–80</td>
<td>6.0–24.0</td>
</tr>
<tr>
<td>Low-speed Petroforge</td>
<td>8–20</td>
<td>2.4–6.0</td>
</tr>
</tbody>
</table>

Source: [Altan et al., 1973]
10.6 Time-Dependent Characteristic Data

Number of strokes per minute, \( n \), is the most important characteristic of any machine, because it determines the production rate. When a part is forged with multiple and successive blows (in hammers, open-die hydraulic presses, and screw presses), the number of strokes per minute of the machine greatly influences the ability to forge a part without reheating.

Contact time under pressure, \( t_p \), is the time during which the part remains in the die under the deformation load. This value is especially important in hot forming. The heat transfer between the hotter formed part and the cooler dies is most significant under pressure. Extensive studies conducted on workpiece and die temperatures in hot forming clearly showed that the heat transfer coefficient is much larger under forming pressure than under free contact conditions. With increasing contact time under pressure, die wear increases. In addition, cooling of the workpiece results in higher forming load requirements.

Velocity under pressure, \( V_p \), is the velocity of the slide under load. This is an important variable because it determines (a) the contact time under pressure and (b) the rate of deformation or the strain rate. The strain rate influences the flow stress of the formed material and consequently affects the load and energy required in hot forming.

10.7 Characteristic Data for Accuracy

Under unloaded conditions, the stationary surfaces and their relative positions are established by (a) clearances in the gibs, (b) parallelism of upper and lower beds, (c) flatness of upper and lower beds, (d) perpendicularity of slide motion with respect to lower bed, and (e) concentricity of tool holders. The machine characteristics influence the tolerances in formed parts. For instance, in backward extrusion a slight non-parallelism of the beds, or a slight deviation of the slide motion from ideal perpendicularity, would result in excessive bending stresses on the punch and in nonuniform dimensions in extruded products.

Under loaded conditions, the tilting of the ram and the frame deflections, particularly under off-center loading, might result in excessive wear of the gibs, in thickness deviations in the formed part and in excessive tool wear. In multiple-operation processes, the tilting and deflections across the ram might determine the feasibility or the economics of forging a given part. In order to reduce off-center loading and ram tilting, the center of loading of a part, i.e., the point where the resultant total forming load vector is applied, should be placed under the center of loading of the forming machine.

In presses (mechanical, hydraulic, or screw), where the press frame and the drive mechanism are subject to loading, the stiffness, \( C \), of the press is also a significant characteristic. The stiffness is the ratio of the load, \( L_M \), to the total elastic deflection, \( d \), between the upper and lower beds of the press, i.e.:

\[
C = \frac{L_M}{d}
\]  
(Eq 10.3)

In mechanical presses, the total elastic deflection, \( d \), includes the deflection of the press frame (~25 to 35% of the total) and the deflection of the drive mechanism (~65 to 75% of the total). The main influences of stiffness, \( C \), on the forming process can be summarized as follows:

- Under identical forming load, \( L_M \), the deflection energy, \( E_d \), i.e., the elastic energy stored in the press during buildup, is smaller for a stiffer press (larger \( C \)). The deflection energy is given by:

\[
E_d = \frac{dL_M}{2} = \frac{L_M^2}{2C}
\]  
(Eq 10.4)

- The higher the stiffness, the lower the deflection of the press. Consequently, the variations in part thickness due to volume or temperature changes in the stock are also smaller in a stiffer press.
- Stiffness influences the velocity versus time curve under load. Since a less stiff machine takes more time to build up and remove pressure, the contact time under pressure, \( t_p \), is longer. This fact contributes to the reduction of tool life in hot forming.

Using larger components in press design increases the stiffness of a press. Therefore, greater press stiffness is directly associated with increased costs, and it should not be specified unless it can be justified by expected gains in part tolerances or tool life.
REFERENCES


SELECTED REFERENCES


