Basic Concepts of "Sequence Design" For Cold Forged Parts

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An explanation of sequence design and the factors that need to be considered when designing a forging sequence.

Cold forging is a very cost-effective method of producing a part in large quantities. A good forging sequence allows the part to be manufactured in a fast and accurate way with virtually no scrap. However, designing a good forging sequence can be a daunting task, even for an experienced designer. Mostly, the designer relies on his/her experience to define the sequence and uses a "trial and error" methodology to adjust the process until the right part is created without any defects. This article is an attempt to explain the basic concepts of "Sequence Design" and the factors that need to be considered when designing a forging sequence.

What is a Sequence Design?

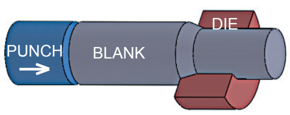
In cold forging, a part is formed progressively in successive forming strokes called blows. The sequence in which the part is formed is called the "Forging Sequence". Many characteristics of the part help define the sequence, especially the final part shape, dimensional accuracy and the part material. Other factors that come into play are available lot size, available forging machines (number of dies/blows), cost of tooling etc.

Basic Forging Processes

The basic approach in forming a part progressively is to form a portion of the part in each station/blow using one of the basic processes such as extrusion, heading, squaring, punching, etc. Examples of these processes are as follows:

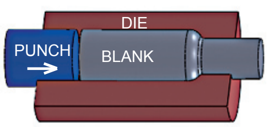
- ***Forward Extrusion*—**This process is used to reduce the cross section of the part. A tool called a punch pushes the blank through a die such that material flows in the same direction as that of the punch. Forward extrusion can be achieved through two processes:

  Open Extrusion—Here the blank is not enclosed in a die while being extruded. The complexity of the part may require an open extrusion. The amount of reduction in open extrusion is limited as the pressure required to extrude cannot exceed the yield strength of the material. However, the desired total reduction can be achieved using more than one open extrusion.



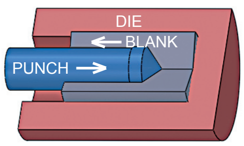
Open Extrusion

  Trap Extrusion—Here the part is fully enclosed while being extruded. Trap extrusion is often used when the part shape is simple and the amount of reduction is high.



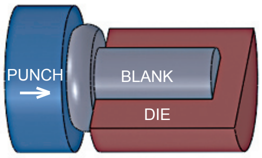
Trap Extrusion

- ***Backward Extrusion*** also reduces the cross section of the blank. Here the flow of the material is in opposite direction to that of the punch motion. This process is used to create a cavity or a bore in the part.



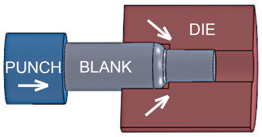
Back Extrusion

- ***Heading/Upsetting*—**By this process, the cross section of the part is increased. The material is gathered creating a head. The direction of the material flow is usually perpendicular to the direction of the punch.



Heading

- ***Squaring*** is the process of reforming a taper or curved surface to change its angle or make it a flat surface with a sharp corner.



Squaring

- ***Trimming*—**The excess material on the outside of the part is removed through trimming.
- ***Punching*—**In this process, the excess material on the inside of the part is removed to create a hollow part.
- ***Threading*—**The process of forming threads on the part is called threading. Generally, this process is accomplished on special machines once the part is formed.

Examples of Sequence Designs

Cold forged parts are generally produced on multi-station machines called headers or a combination of single-station presses. By arranging the forming of a part in steps/stations using the above basic processes, the sequence design is created. When the number of required processes is more than the available steps/stations, the basic processes are combined in a forming step. The forging steps must be arranged such that the tooling design is simple, the part can be easily transferred between stations and dimensional accuracy is achieved in forming.

Figure 1 (next page) shows some simple examples of sequence designs using basic forming processes. In the first example, extrusion and heading processes have been applied to create a hex bolt. The same process could potentially be achieved in a two-station machine by combining the heading and open extrusion process in the final two steps. The second process applies heading, back extrusion and punching techniques to create a rivet. The NAGFORM software program has been used to create these progression designs. This program uses the basic forming rules and material properties to generate sequence designs that the designers can use.

It should be kept in mind that the same part can be formed by different processes. For example, the "hex" feature of the bolt can be produced by heading, extrusion or a process called "Crash Trimming". Thus a number of alternative sequence designs are possible to form the same part. NAGFORM gives different alternatives forging designs in a few minutes

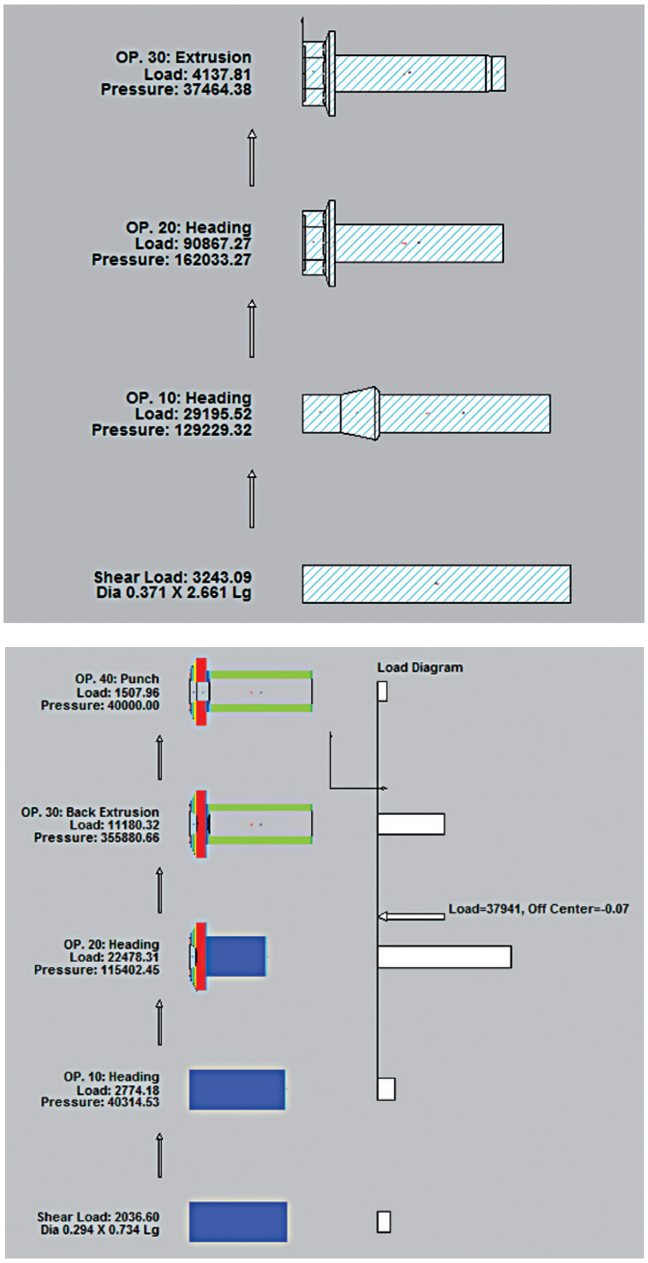


Fig. 1 – Simple examples of sequence designs using basic forming processes.

so that the designer can choose the one that meets his/her requirements.

Sequence design is not just simply putting basic forging processes in a sequence. There are many theoretical and practical considerations that decide the final sequence design. For example, the sheared blank does not have a perfect square face. To maintain dimensional accuracy, forming steps of squaring the sheared ends may be added in the sequence design. To maintain concentricity, heading to final shape may be done in two steps. A cone or curved shaped preform may be added, even though the heading could be accomplished without this preform. To prevent extruding a burr at the corner edge in backward extrusion, the part corner may be rounded in previous step.

The automatic transfer of a part between stations may require that the part be formed in a certain sequence so the transfer fingers can hold the part firmly during transfer. A forging process can be applied only within its limits as explained below.

Factors Limiting Use of a Forging Process

The use of a forming process is limited by:

- ***Material Workability***—If ductility of the part is exhausted, the part will crack. It is critical that the designer keeps this in mind while designing a progression. Simulation software such as NAGSIM can be used to provide critical information on stresses, strains and tensile damage during forming.
- ***Stresses in Tools***—The force applied on the tool by the deforming part produces stresses in the tool. These stresses define the tool life. Simple design considerations such as keeping the part reductions in a forming process within acceptable limits, using proper tool materials, adequately supporting the tools, proper press fitting and so on can help in minimizing these stresses and minimizing breakage of the tools.
- ***Tooling Design***—Complex tooling design through increased tool cost can make a forming process uneconomical to use.
- ***Total load required to form*** must be less than the available load capacity of the forging machine. Away from the bottom dead center, the available load capacity of a mechanical press is less than its specified capacity.

Specifically, the basic forming processes can be applied in a sequence design only within their limits as explained in the following:

- ***Trap Extrusion***—Percentage reduction in trap extrusion is limited by the stresses in the tools and the material ductility. See the simulation of the trap extrusion process found in **Figure 2** on next page of this article. As the reduction increases, so do the stresses in the die and the punch, and the plastic strain in the extruded part. For long extrusions, available load capacity may limit the reduction.
- ***Open Extrusion***—The extent of reduction in open extrusion is limited by the yield strength of the material. See the simulation of combined open extrusion and heading processes in **Figure 2** (on next page). High reduction in open extrusion is causing the part to upset first instead of extruding first.
- ***Backward Extrusion***—This process is limited by the stress in the punch.
- ***Heading***—The material may buckle at the unsupported length of the part during the heading process. The length-to-diameter ratio that can be headed without buckling is increased by use of sliding tools that support the part during heading.
- ***Trimming/Punching***—High pressure may deform the part. Proper design of punch and support of the part during punching/trimming is required.

Use of Analytical Tools

Though designing forging sequence remains in the domain of skilled designers, software programs such as NAGFORM and NAGSIM are being increasingly used. They offer the advantages of reducing the time and cost to design and debug a sequence design. Efforts are being

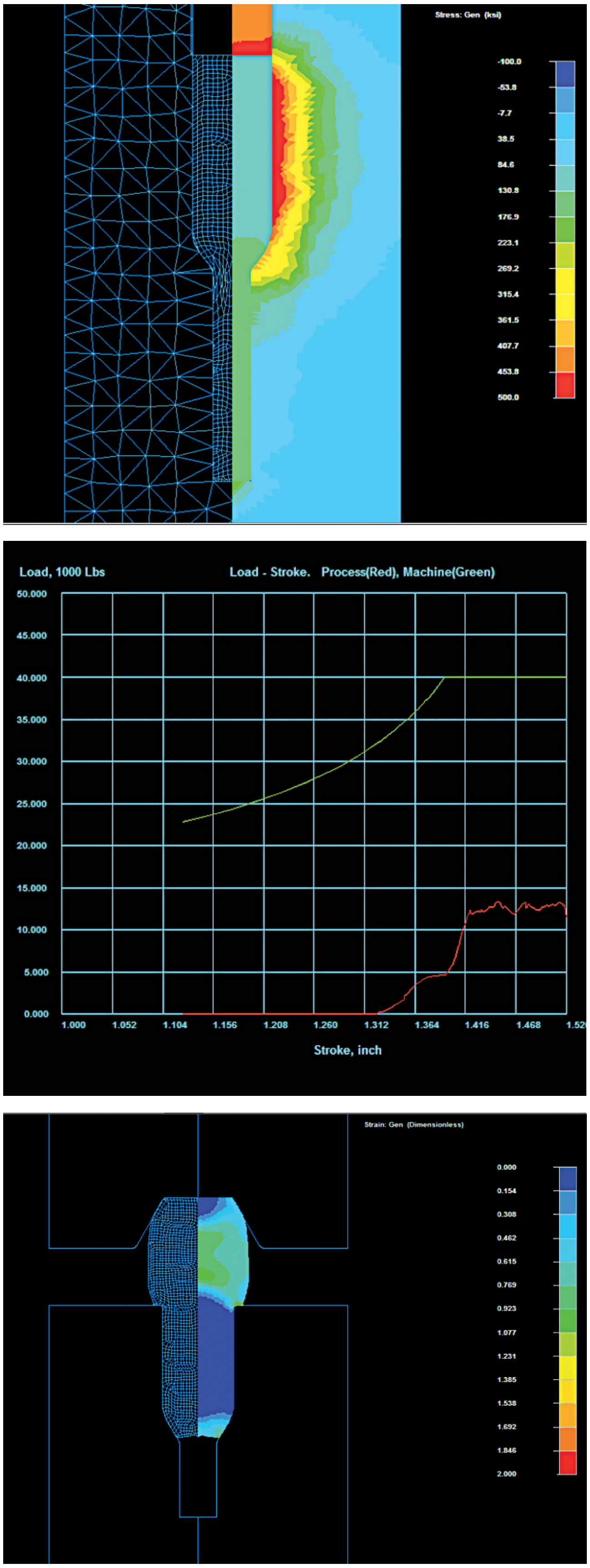


Fig. 2 – Trap extrusion showing high stress on tools (top); Load stroke versus machine capacity (middle); and Open extrusion showing material bulge (bottom).

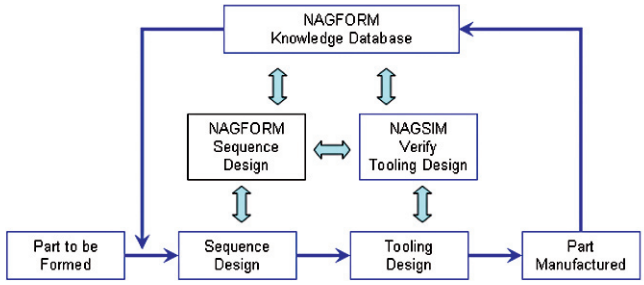


Fig. 3 – Schematic illustrating the roll that the NAGFORM and NAGSIM software systems play in the manufacturing process.

made to include the "experience" and "tricks of the trade" in the analytical sequence designs through "knowledge database". The schematic in **Figure 3** (above) shows the role that these software packages play in the manufacturing process.

NAGFORM is a unique knowledge-based software program that provides alternative progression designs for formed parts in a few minutes. It estimates the load requirements and the average pressure on the tools for each progression design. The user can build the tooling around the forming progression in its Tooling Module. The user can use existing template designs or customize his/her own sequence design templates for a family of parts such as hex bolts and spark plugs. It includes a "smart" database that provides an organized way of retaining and retrieving design and manufacturing knowledge.

With simulation software such as NAGSIM.2D, the forging sequence can be simulated prior to actual production. The user can simulate the part—tool interaction to gather pertinent information such as part nonfill amount, material flow, stresses in the part, tensile damage in the part and the tool stresses. He/she can modify the progression and tool designs and see how that would affect the overall process. New and existing sequence designs can be optimized using these software programs.

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Company Profile:

Metal Forming Systems, Inc. *provides breakthrough technology for forming process design and validation. The company develops and supplies software that helps users advance from part print to the manufacturing process in a short period of time. Process design software offered by Metal Forming Systems includes NAGFORM, Nag Forge and NagNest. Simulation software offered by the company cinlude NAGSIM.2D, NagsimGen.2D and NAGSIM.3D.*

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