

# DFRA FORGING HANDBOOK

## DIE DESIGN

### 1 INTRODUCTION

There are no fixed rules for the design of drop forging dies since different approaches can often produce acceptable forgings. There are, however, certain guidelines and principles, developed by many years of practical experience which, if followed, will maximise the probability of producing sound forgings with the greatest economy.

Since many factors interact to decide a final die design the designer must often display great ingenuity to resolve many conflicting requirements. The objective of this handbook is to introduce the designer to practical problems and to show the various approaches available to deal with them. Studying the book will however never produce the complete designer who should never miss the opportunity of observing the result of his work in the forge. Probably more can be learned about design here than anywhere else.

The contents of the handbook are the result of reviewing published articles and books and many hours of discussion with leading die designers throughout the drop forging industry.

### 2 PRELIMINARY CONSIDERATIONS

An enquiry for a forging can involve the supply of a forging drawing, a machined component drawing or a sample, the last possibly made by a method other than drop forging.

The first task of the designer therefore will be to decide what the final shape of the forged component will be when due consideration has been given to machining allowances, draft angles, fillet and corner radii, any web or rib dimensions and the position of the parting line.

Before proceeding with a design the designer should be thoroughly familiar with any subsequent machining operations on the component since the need for jig locations, parallel faces and so on can influence both the design of the forging and its method of manufacture.

Having decided the final configuration of the forging the next step is to decide whether the order quantity justifies the design of multi-impression dies including preforming operations to be used on self contained hammers. This will be the case for large order quantities with frequent repeats.

In some cases due to the shape of the forging a moulding impression may be needed to ensure die filling or the avoidance of defects even for small order quantities.

Where small quantities are required and repeat orders are infrequent it may be more economical to produce the forging in a single die impression with any preforming performed on ancillary plant such as dummy hammers.

Where multi-impression dies are used the preforming stages such as fullering and rolling must be designed together with the moulding impression, if one is used.

When all these stages of the die are finalised the layout of the die must be decided taking into account such considerations as the positions of the moulding and finishing impressions relative to each other and the die dovetail, the dowel position and the die clash area.

All the considerations mentioned are discussed in subsequent sections of the handbook and illustrated wherever possible by practical examples.

A check list for designers is given below:

- (1) Check the customer's specification and exactly what is required of the forging.
- (2) Can any design modifications be suggested which may help the die shop to make the dies more easily or the forge to produce more readily.
- (3) Check the order quantity and the frequency of repeat orders.
- (4) Check the material specification and its forging characteristics. This may significantly affect die radii, web thicknesses and the plant on which the forging is made.
- (5) Co-operate fully with the estimating and forging departments.
- (6) Be completely familiar with the characteristics of the company's forging plant.  
e.g. what preforming equipment is available,  
what are the strokes and shut heights of presses,  
what methods are used to hold dies,  
what is the space between hammer legs,  
how well guided are the hammers.
- (7) Observe the results of the design under the hammer or press!

Any or all of the above considerations can influence the final die design.

### 3 BASIC PRINCIPLES OF METAL FLOW

Before discussing die design in detail it is useful to consider some of the basic principles of metal flow as related to some simple forging shapes. These will give the designer a feel for how metal might be expected to flow in more complex shapes and how die shape and billet shape affect metal flow and forging load and energy requirements.

The simplest forging operation is the upsetting of a cylinder to a disc. Curve 1 in figure 3.1 shows the load required to upset a 100 mm long  $\times$  50 mm diameter mild steel cylinder to a disc. As the disc becomes wide and thin very high loads are required due to the high frictional forces which must be overcome as the area of the disc in contact with the die increases.

Curve 2 in figure 3.1 shows the load which would be required to upset the mild steel cylinder if no friction existed whilst curves 3 and 4 show the loads to upset a stainless steel cylinder with and without friction.

## 4 BIBLIOGRAPHY

### BOOKS

**Drop Forging Die Design** by R C Jones. Published by the Association of Engineering and Shipbuilding Draughtsmen 1959.

**Forging Design Handbook**. Published by The American Society for Metals, Metals Park, Ohio 44073

**Kurs för Vertygkonstruktörer** (Course for Die Designers). In Swedish. Published by Sveriges Mekansförbund 1964.

**Combination Die and Tool Design for Quantity Production** by D J Joyce. Published by The National Association of Drop Forgers and Stampers, 245 Grove Lane, Handsworth, Birmingham, B20 2HB, 1965.

**Forging Industry Handbook**. Chapter 6—Forging Design Principles and Practices. Published by Forging Industry Association, Cleveland, Ohio 1966.

**Bofors Drop Forging**—3-part booklet. Published by A B Bofors S-690 20 Bofors Sweden.

**Aluminium Forging Design Manual**. Published by The Forgings Division, The Aluminium Association Inc., 750 Third Avenue, New York, NY 10017.

### GENERAL ARTICLES

**Drop Forging Design**—F. T. Walker, *Metal Forming*, August 1970.

**Design of forgings for Speedier Production**—O A Wheelon, *Production Engineering*, September, October 1942.

**Design Guide for Steel forgings**—C M Parker & F E Chepko, *Machine Design*, 22 July, 1965.

**Closed-die Forging of Round Shapes, Flash Design and Material Savings**—T Altan & H J Henning, *Metallurgia & Metal Forming*, March 1972.

**The Intermediate Stage in Drop Forging**—O Kienzle & K Spies, *Metal Treatment & Drop Forging*, September 1957.

Articles on die design appear from time to time in the following publications:

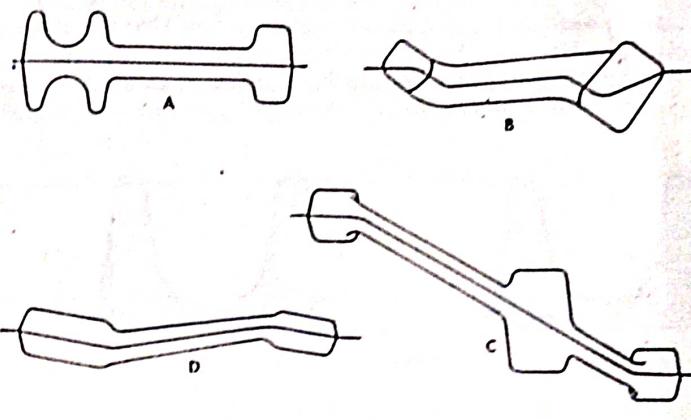
- (1) *Metallurgia*.
- (2) *Journal of Mechanical Working Technology*.
- (3) *Kuznechno-Shtampovchnoe Proizvodstvo* (In Russian).
- (4) *Schmiedetechnische Mitteilungen* (In German).

Translations of foreign language articles can be obtained from The Drop Forging Research Association.

## 5 PARTING LINE POSITION

The die parting line is the plane (or planes) which divides the top and bottom dies in drop forging (figure 5.1). Its position can influence:

- (1) the ease and economy of die sinking
- (2) the ease of die filling
- (3) the formation of forging defects
- (4) the ease of clipping
- (5) the amount of draft required and hence forging weight
- (6) the extent and detection of mis-match
- (7) the ability to nest forgings
- (8) the need to use die locks
- (9) the forging tolerances (see BS 4114: 1967).



A—straight parting line  
B—cradled cranked parting line  
C—unbalanced cranked parting line  
D—balanced cranked parting line

FIG. 5.1  
Types of parting line.

For simple, shallow, symmetrical sections it is usual to select a straight parting line located at the centre of the height of the section (figure 5.2).

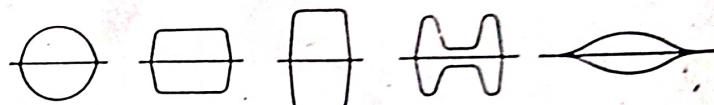
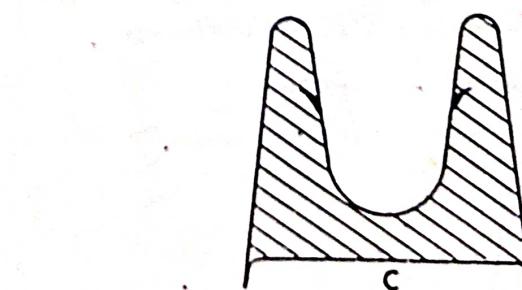
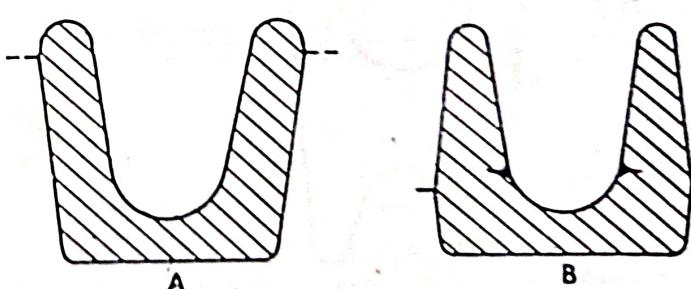


FIG. 5.2  
Straight parting lines in symmetrical sections.

For U-shaped sections in axisymmetric or channel section forgings the parting line should be placed near the top of the ribs (figure 5.3a). Placement in other positions may lead to difficulty in filling ribs and to the occurrence of forging defects (figures 5.3b and 5.3c).



A—preferred parting line  
B—cold shuts due to "suck through"  
C—cold shuts and clip drag

FIG. 5.3  
Parting line positions for channel sections and their effects.

In this type of forging the parting line position also has a pronounced effect on the direction of grain-flow (figure 5.4). Outcropping of grain should be avoided at points of stress in the final component.

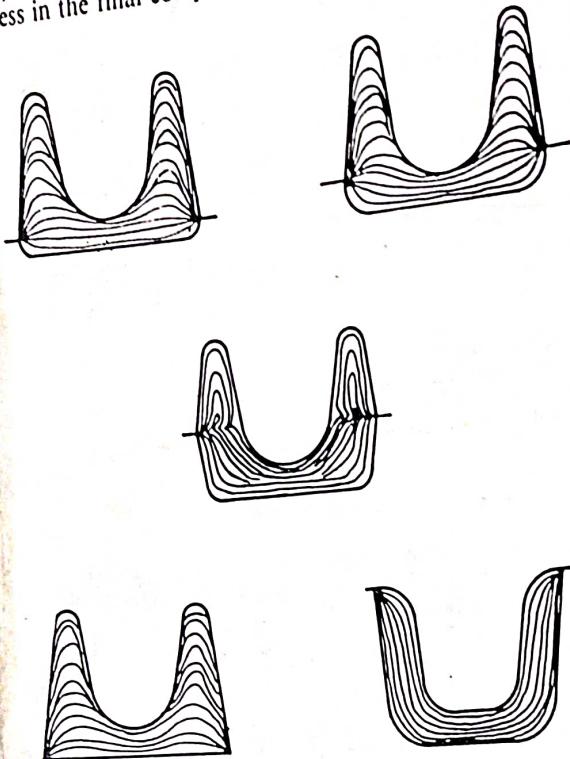


FIG. 5.4  
Effect of parting line position on grain flow in channel sections.

Where rib and web type forgings with deep ribs are made the parting line should be placed near the top of the rib formed in the upper die (figure 5.5). This aids filling of the narrow ribs by restricting lateral metal flow at the earliest possible stage (figure 5.6). It also helps to prevent the formation of folds caused by metal "sucking through" into the flash land if the parting line is placed too low (figure 5.7). This type of defect can also occur if excessive die lubrication is used.

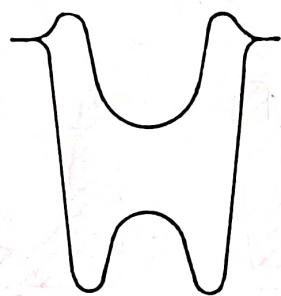


FIG. 5.5

Preferred parting line position in rib and web type forgings.

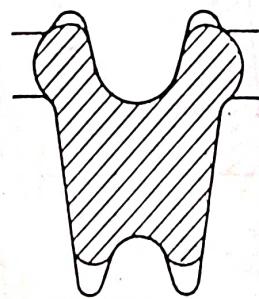


FIG. 5.6

Restriction of lateral flow aids rib filling.

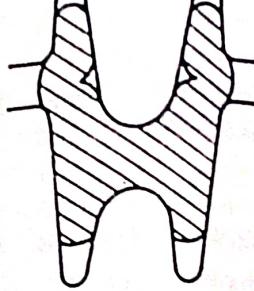


FIG. 5.7  
Formation of "suck through" defect producing fold.

Bottom die pegs which project above the parting line should generally be avoided since they make self location of the billet difficult and can lead to under-filled forgings (figure 5.8). Furthermore protruding pegs add considerably to die sinking costs. Where they are unavoidable, it may be possible to arrange a means of locating the forging in the finishing impression which is not influenced by protruding peg.

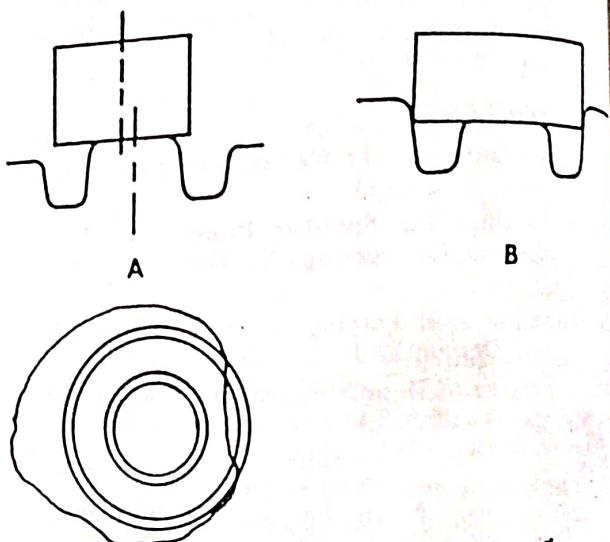


FIG. 5.8  
A—underfilling caused by billet misplacement on projecting peg.  
B—self location of billet when peg is below parting line.

Many forgings contain two or more bosses at different heights connected by other forging features (figure 5.9). If the dies for such forgings are produced as shown in figure 5.9, excessive kick of the top die will occur resulting in mismatched forgings and damage to the hammer slides and legs. (figure 5.10). In addition such a parting line results in excessive preliminary shaping of die blocks prior to sinking the impressions which is wasteful of both time and material (figure 5.11).

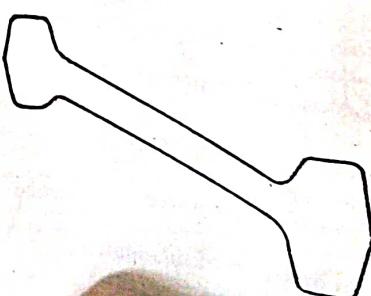


FIG. 5.9  
Forging with bosses at different levels.

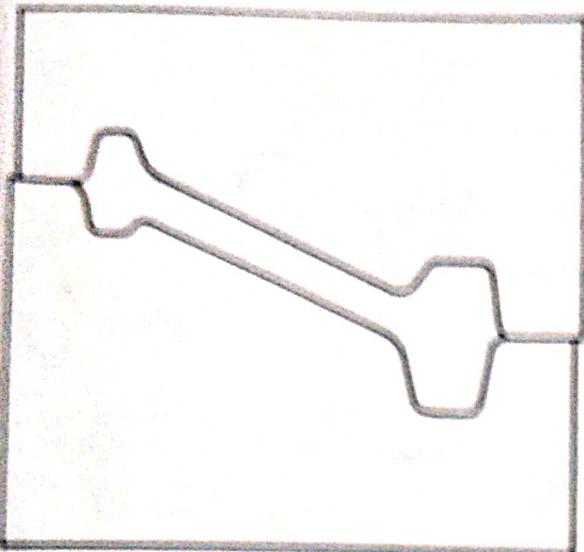


FIG. 5.18  
Other parting line to the base.

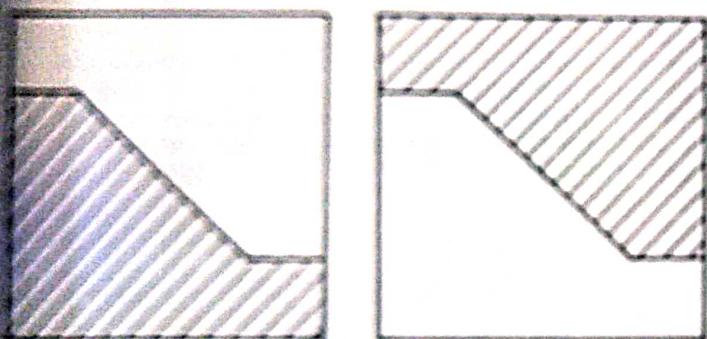


FIG. 5.19  
Cross-sections illustrating dies with unbalanced or balanced parting lines.

Where such a parting line is unavoidable a die lock must be used (figure 5.12). The design of the locks is considered in a later section of the handbook.

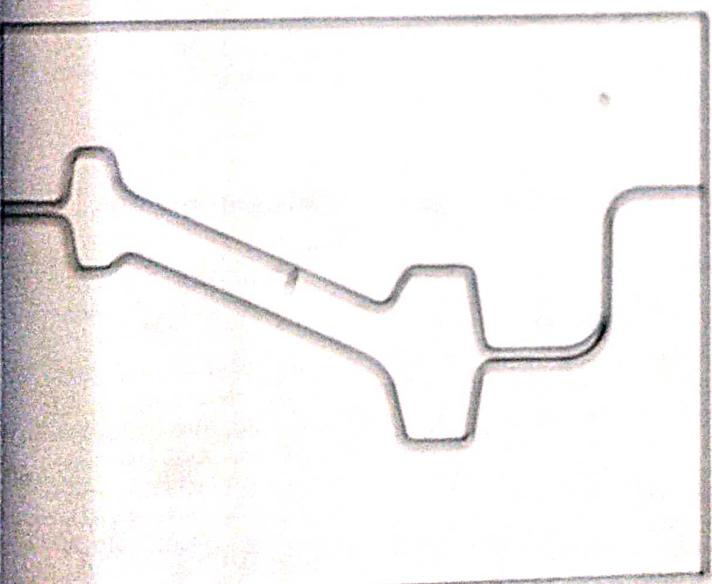


FIG. 5.12  
Use of die lock to minimise shift.

A number of approaches are possible to minimise the problems of forgings with cranked parting lines. If the forging size and shape relative to the hammer size allow, the die tick can be made self compensating by placing two forgings in tandem (figure 5.13).

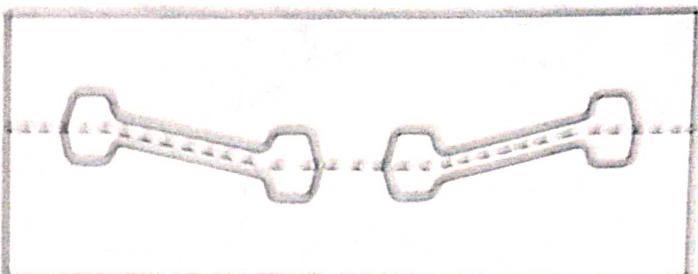


FIG. 5.13  
Self compensation of die tick by placing forgings in tandem.

Where the forging is too big to allow the above approach it may be possible to "tilt" the forging to give a straight or balanced parting line (figures 5.14 and 5.15).

In the case of the straight parting line shown in figure 5.14, the die is still not completely balanced and die tick would occur from the base face. In addition a penalty is paid in the form of extra metal added to the forging due to increased draft on the bases.

The parting line shown in figure 5.15 is well balanced but still shows increased draft of the base faces. This excess draft can be reduced by "trailing the parting line" (figure 5.16).

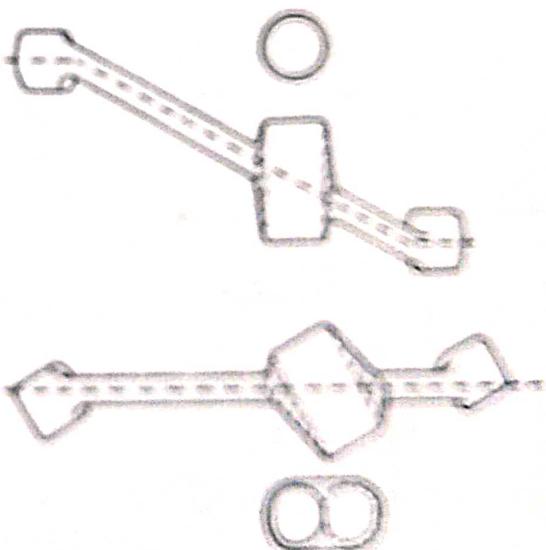


FIG. 5.16  
Trailing of parting to produce straight parting line. Note the extra metal added to half of bases. Note also that option 3 is less expensive because die is tick from base face.

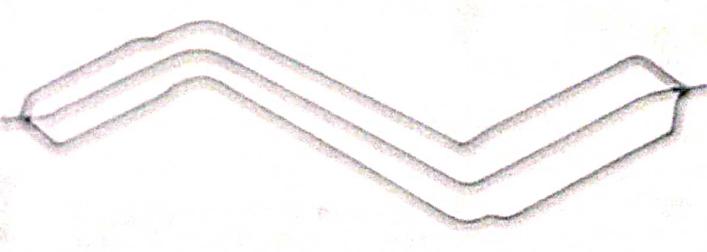


FIG. 5.15  
Balanced parting line.

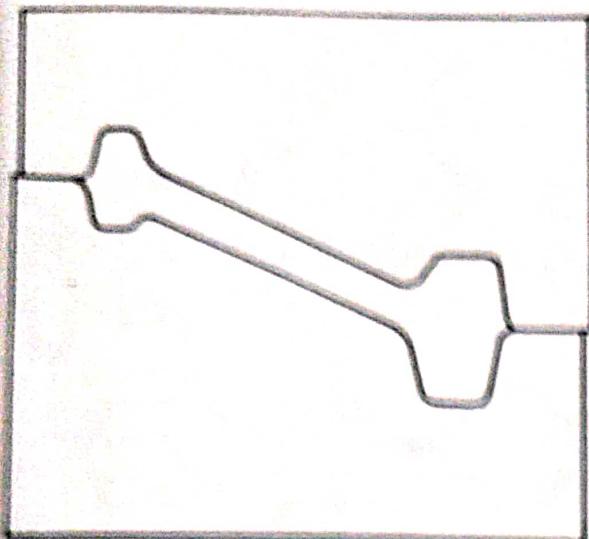


FIG. 5.10

Drawing forging from die block.

A number of approaches are possible to minimize the problems of forgings with cranked parting lines. If the forging size and shape relative to the hammer size allow, the die block can be made self compensating by placing two forgings in tandem (figure 5.13).

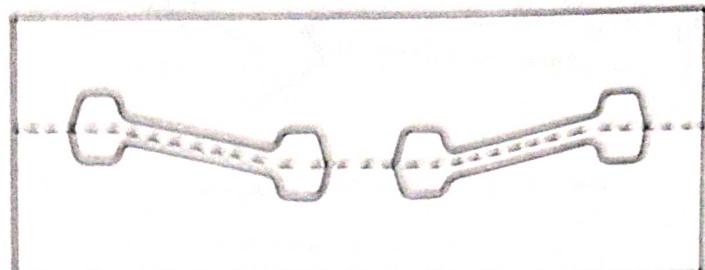


FIG. 5.13

Self compensation of die block by placing forgings in tandem.

Where the forging is too big to allow the above approach it may be possible to "tilt" the forging to give a straight or balanced parting line (figures 5.14 and 5.15).

In the case of the straight parting line shown in figure 5.14, the die is still not completely balanced and die kick would occur from the base faces. In addition a penalty is paid in the form of extra metal added to the forging due to increased draft on the bases.

The parting line shown in figure 5.15 is well balanced but still shows increased draft of the base faces. This excess draft can be reduced by "trailing the parting line" (figure 5.16).

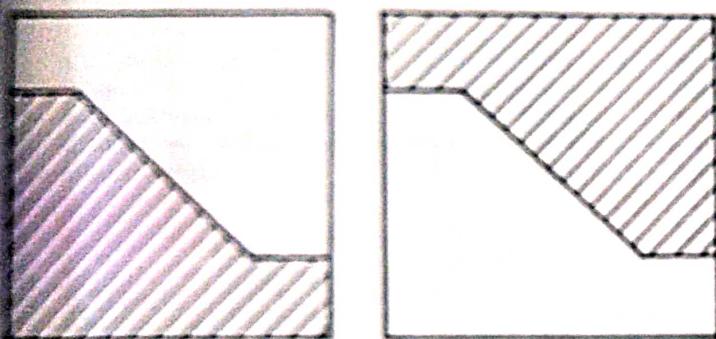


FIG. 5.11

Excessive preliminary shaping of dies with unbalanced cranked parting line.

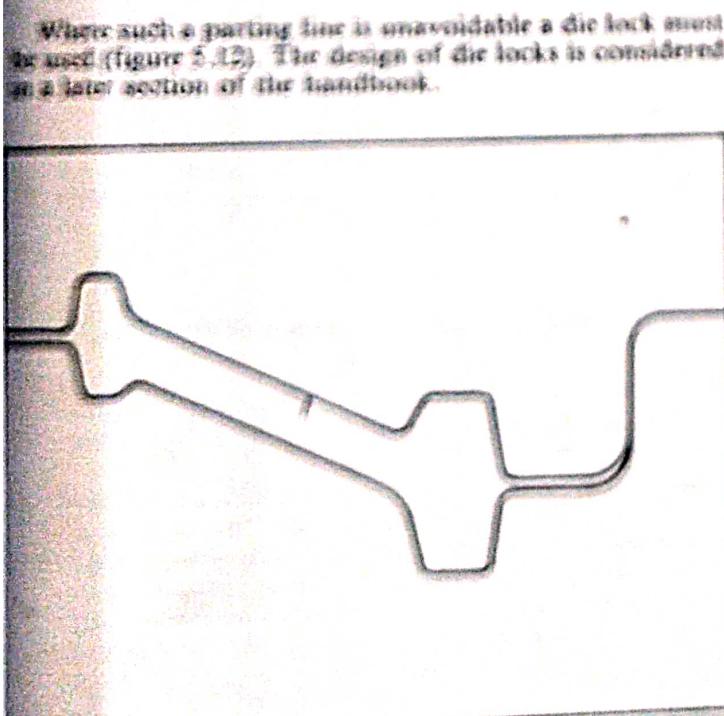


FIG. 5.12

Use of die lock to minimize offset.

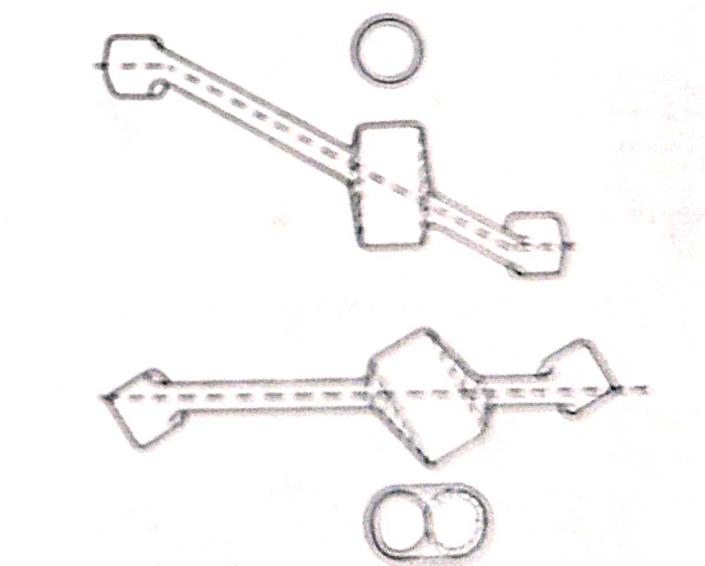


FIG. 5.14

Tilting of forging to produce straight parting line. Note the extra metal added as draft on bases. Note also that parting line is not completely balanced due to kick from base faces.



FIG. 5.15

Balanced parting line.