CHAPTER 1

INTRODUCTION

1.1 IMPORTANCE

Hexagonal nuts are widely used for temporary fastening. They have been in existence since the first crude machine started functioning. The hexagon faces are made to facilitate shorter spanner movements during clamping. When the nut along with the spanner is rotated through 60°, the spanner again can be brought back to the original position. The hexagonal nuts are invariably used in nearly all temporary fastenings through the bolting system. Not even a single machine can be in existence without this fastening system.

Hexagonal nut blanks are only one operation short of the finished nuts, i.e., threading. Special purpose threading machines are employed for threading. Generally three types of threads are utilised on most of the nuts. They are coarse, fine and extrafine. The coarse thread, having largest pitch on the same size of the nut is mostly used for general and hardware purposes. The fine thread is utilised for all medium types of work such as in the automobile production, aircrafts, machine tools and similar industries. The extrafine series having the least pitch is utilised for
very sophisticated and precise machine tools, measuring instruments, precise tools and jigs and fixtures etc.

The BIS standards describing the specifications of the various types of hexagonal nuts are IS 3138, 1363, 1364, 7795, 2389 and 3139.

1.2 GENERAL

For the production of hexagonal nut blanks both metal removal as well as metal forming processes are used. In the former the metal is removed from the center of the nut blank in the form of chips, and in the latter the metal is made to flow from the central portion of the disc to the corners of the hexagonal cavity of a closed die. The closed die forging can be done with material hot or cold. In hot forging the heated metal is squeezed between the upper and lower portion of the closed die, thereby producing a material shape similar to the die cavity shape. The excess material produced in the form of flash and peripheral thin protruded strips are removed from the component by operations such as trimming. In cold forging the material is placed in the closed die at temperatures lower than the recrystallization temperature. The product thus produced can be with or without flash. Annealing may or may not be required for the subsequent operations. Lubrication is generally required in all cold forging operations for to...
reducing the loads. There are many advantages in the cold forging process as compared to the hot forging process in closed dies. These have been discussed by Wilson (1966), Feldman (1972), Stewart Jones (1970), and Clapp et al. (1972). High dimensional accuracy coupled with good surface finish is the biggest advantage in this process. Besides there may be reduction in machining operations (or even complete elimination of some) resulting in large savings of material. Furthermore, inferior materials can be used in this process. The properties of these materials are upgraded by workhardening and desirable flow pattern.

The parts, which are axisymmetrical, are most suitable for cold forging process. This has been established by Clapp et al. (1972). Non-ferrous materials can also be cold formed extensively by this process as shown by Stewart-Jones (1970).

1.3 VARIOUS METHODS FOR PRODUCING THE HEXAGONAL NUT BLANKS

There are various methods which are being utilised for the production of the hexagonal nut blanks in the industry. The noticeable methods are

1) Drilling, chamfering, turning and parting off, on a special purpose machine tool, of a hexagonal drawn bar.
ii) Hot forging of cut bars through dies in the forging presses.

iii) Cold upsetting and forming through in-line dies in special purpose cold forming machines.

iv) Forming by powder metallurgy.

1.3.1 Method I (Drilling, Chamfering, Turning and Parting off, on a special purpose machine tool)

The first method, which is the oldest of all the methods, is being utilised in the industry nowadays when only special purpose nut blanks are required and the number of such pieces required is low (For the economic analysis see Chapter 4). Evidently the material wastage in this method is by far the maximum, because the bore of the nut blank is made by drilling a hole in the hexagonal drawn bar. However, for nuts of medium and large sizes, this method is the least expensive, because, even though the number of nuts required is small, the central portion of the nut can be taken out by a trepanning operation, where this portion can be further utilised as a round bar stock for producing something else. Also, even if the number of nut blanks required is some what large, still the process is beneficial because for the other processes the press capacity is very large and so is the cost of the die sets.

As is evident, in this method, a round bar is first passed through a draw bench. This round bar is
converted to a hexagonal drawn bar. This drawn bar is either fed directly to an adda (a special purpose machine tool for nut cutting) or after Annealing, depending upon the material requirement of the end product and the production rate of a specific product-tool material combination. This hexagonal bar stock is then drilled on the adda upto the maximum drilling length possible under optimum conditions.

The drill is then withdrawn and turning and chamfering tools used according to the specifications of the nut blank. After this, a parting tool is used to remove the nut blank so formed which falls into the requisite collector bin through a chute.

1.3.2 Method II (Hot Forging)

The second method, which is hot forging method, is used mostly for medium and large size nut blanks, and where the number of nut blanks required is usually very large. The method can also be applied to smaller size nuts where the material properties of the nut desired are such that no strain hardening of the finished material is required but the toughness required is large. Also in this method the material wastage is much less as compared to the first method, though it is not the least. The wastage goes in the form of web left in the hole of the nut blank which will henceforth called "trimmed wastage" in this thesis. The
scaling produced through the contact of the hot metal with air is also a wastage. Though the material wastage is less in this method, still the cost of production is not much reduced because of the cost of the initial equipment used coupled with the operational and the maintenance cost.

In this method, small blanks are cut out of a bar in a press fitted with a shearing die set, which are then loaded into a furnace for heating to a temperature higher than the recrystallization temperature. These stocks are then fed to the forging presses fitted with the requisite die sets. The material thus formed is transferred to the shearing presses, where the web left in the bore of the blank is removed. The blanks thus produced are subjected to a cleaning process.

1.3.3 Method III (Cold Upsetting and Forming)

The third method, (which is cold forming through in-line dies fitted with the special purpose machine tool) is the most widely used method for small and to some extent medium sized nut blanks, and where the production rate of such blanks required is large. The method is not applied for the nuts of larger bore diameters as the loading required in these cases is very high (National Machinery Catalogue, 1986). The design and production of the special purpose machine tool for these nut blanks is not economical.
In this method a continuous wire is fed through a feeding mechanism into an inline die station. In the first station the upsetting of the protruded wire is done. It is then transferred to the next die set after the cutting operation where it is formed to size. In the next two or three dies, the nut blank is formed and then the web disc is trimmed out of the formed nut blank. This is then transferred to a collecting bin for further operations.

The shape of the material in the different dies is shown in Fig. 1.1. The production rates in this method are very high. As per the catalogue of National machinery West Germany (1992) the production rates are as high as 330 pieces per minute for nut sizes of M4 to M8. Most of the machines available in this type of process are up to a size of M20, and the production rates for this type of the size of nut blanks are approx. 100 to 110 pieces per minute.

1.3.4 Method IV (Forming by Powder Metallurgy)

In the process of forming by powder metallurgy, the requisite metallic powder in a fine mesh is usually poured in the forming dies, made of very hard and tough material and are pressed by very high pressures by the forming presses. The resulting compacts of nut blanks so formed are then passed through the sintering furnaces where
the metallic bonds are strengthened. They are then finished and put to further processing.

Though this method also reduces the wastage of the material to the lowest extent possible, the initial cost of equipment is high. The method is yet not applied to the general category of nut blanks but is applied to a specific category. Nut blanks of high strength are produced by this method. Nut blanks of some alloy steels or of those materials which are difficult to machine, are formed by this process. The production rates in this process, by a single machine set, are also not as high as in the in-line die cold forming process.

The cost of producing nut blanks in this process is the highest because of the higher costs of both the metallic powders and the initial equipment coupled with lower production rates.

The method suggested by the author (1978) is also a cold forming process, but in this method the cost of initial machinery is not very high for a medium size production rate ranging from 40 to 120 pieces per minute. The total number of dies for a continuous production is also less, usually three, i.e., one for blank cutting, the second for forming and the third for trimming.

The nut blank in this process is formed by forcing most of the material of the central hole into the corners. Two identical punches come from top as well as bottom for
forcing the inside material of the bore radially outwards towards the corners. The central web which is left behind is then trimmed by the trimming die. The wastage in this case amounts to 5 to 10 percent depending upon the nut blank parameters and the type of punch used.

1.4 LOAD ANALYSIS METHOD: A REVIEW

It has generally been accepted that mass production becomes more economical when products are produced by moving material rather than removing it. Since nut blanks are produced in very large quantities substantial savings can result from substitution of machining operations by forming techniques. Two most important process parameters in metal forming are the forming loads and strains produced. The former determines the press capacity and the ability of a factory to produce the product with the available system. The latter predicts the ability of the technique to produce quality products. Large amount of strains induced may cause the material to reach an instability point thereby inducing cracks in the material and increasing the scrap. Basic research in most metal forming operations has so far been towards the prediction of forming loads.

Nut blanks can be formed in closed dies hot or cold. Both processes are essentially similar. Predicting the forging loads is of paramount importance in both cases.
because this single parameter to a large extent determines press capacity and its associated investment and maintenance cost.

The process is complex as a central punch forces the metal from the centre towards the corners of the hexagonal cavity. Exact methods to predict the forging variables in such a complex metal flow are not known. Available methods to analyze the process of closed die forging include:

a) Data based on past experience
b) Empirical methods
c) Analytical methods

Presented below is a brief review of these methods and their limitations and advantages as well as their potential role for analyzing the complex process of closed die upsetting of hexagonal nut blanks.

1.4.1 Data Based on Past Experience

Data based on past experience is used in many industries. Products of similar size and shape which are being manufactured in other industries from the same material are taken as the basis for this information. The loadings are taken from this data for future consideration. However, the approach is limited and is not appropriate enough for a variety of products different from the existing
1.4.2 Empirical Methods

The empirical approach is more efficient than the first one. It is based on plan areas, flow stresses and shape complexity factors for calculating the forging loads (American Society for Metals, 1977). As an example the forging load may be calculated as equivalent to a constant multiplied by the average flow stress of the given material at a given average temperature and strain rate and multiplied by the total plan area of the forging including the web (American Society for Metals, 1977). The constant has different values for different shapes as given by Altan and Fiorentino (1971). This approach was earlier suggested by Siebel (1950), Lange (1965) and Raikar (1987). Due to the lack of exactness and extra energy wastage sometimes, this approach is not considered adequate even though it has the advantages of speed as well as simplicity.

1.4.3 Analytical Methods

Analytical methods are very widely used for the calculations of the loads. These methods include

a) Model Theory Technique
Each method has its own advantages and disadvantages. With the introduction of the computer, the solution of complex mathematical equations has become simple enough to predict the loads fairly accurately.

1.4.3.1 **Model theory technique**

The model theory technique proposed by Altan et al (1970) used model materials such as plasticine, wax, lead, sodium etc. for predicting the loads in many metal forming processes. Using this theory approximate similarities were obtained in the deformation of two different materials. The properties of these materials were then co-related. The load displacement curves were then predicted for the closed die forgings by means of this model theory. There was reasonably accurate agreement between the actual and the predicted loads.
1.4.3.2 Slab method

Tiw-slab method was developed by Sachs (1934) and Siebel (1934) and later on applied by Schroeder and Webster (1949). This method is also known as stress analysis technique.

In this method it is assumed that stresses on a plane normal to the flow direction are principal stresses and the deformation is homogeneous throughout the deforming zone. The material is assumed to be isotropic and incompressible and the elastic strains are neglected. A slab of infinitesimal thickness is taken and a force balance is drawn on it. The static equilibrium differential equation is then made and solved for the known boundary conditions.

Kobayashi et al (1959) applied this method to the axisymmetric closed die press forging of discs. Further they also applied this method to a number of closed die forging cylindrical billets. They measured the average forging pressures also. Reasonably good agreement between experimental and theoretical values was reported.

McDonald et al (1960) studied closed die press forgings of lead and aluminium. Experimental data regarding the flash and the quality of forgings was also published. It was reported that there was substantial increase in the average forging pressures due to the extrusion of flash through the flash edge restriction as compared with...
conventional process, 

Lippmann (1960), analysed plan-strain forging with dies having relatively shallow recesses. He derived the expressions for computing the forging energy and the efficiency of the operation through the slab method. Unksov (1960) observed during an experimental investigation that the deformation region extends into the metal part contained in the die-cavities when the flash height becomes smaller and smaller, towards the end of operation. He noticed that the deforming region was nearly lens shaped. This lens shaped region was approximated as a cylindrical region in his analysis through the slab method.

In further studies, Altan and Boulger (1973) used the slab method. 

Computerised studies have also been made through this method by Altan and Fiorentino (1971). They based their method on the minimum energy consumption for finding the parameters in the closed die forging when the flash thickness reduces to a minimum. A constant frictional shear stress was assumed at the die-metal interface. There was a good agreement between the theoretical and the experimental results.

Another computerised simulation technique to predict the closed die forging variables was used by Altan (1971). He divided the work piece into unit deforming zones.
The force balance was evaluated in each zone, starting from a free surface and maintaining continuity of the stress. The analysis was carried out in small steps for each deforming zone. The slab method through computers was also utilised by Akgerman and Altan (1972), Subramaniam et al (1978), and Ohga, Kyoichi and Kondo Kazuyoshi (1982).

1.4.3.3 Slip-line field technique

Slip line field solutions are applicable mainly to plane strain closed-die forgings. They are not applicable to axisymmetric closed-die forgings. A slip line field solution of plane strain closed-die forging was given by Kobayashi and Thomsen (1959). Velocity vectors in the flash and body of pure lead were obtained experimentally by observing incremental displacements in a stepwise forging operation. The velocities were in agreement with those from simple disc theory. Further they were in close agreement with the experimental results.

Computers have been utilised in determining the load values through the slip-line fields. The first step in this direction was taken by Ewing (1967). He expressed the radii of curvature of a pair of base slip-lines through a selected origin as a power series in terms of rotations along these lines. The computer increased the accuracy of the calculations. A matrix method for the construction of
complete slip-line fields was proposed by Collins (1968, 1970) as also by Dewhurst and Collins (1973). Solutions for the problems of symmetric hot rolling of strips were given by Dewhurst et al (1973), that of asymmetric hot rolling of strips by Collins and Dewhurst (1975), and asymmetric extrusion by Das et al (1977). Using slip-line field theory.

1.4.3.4 Numerical methods

Two numerical methods viz: a) finite difference and b) the finite elements method are generally used for various metal forming processes. The finite difference method as applied to elasto-plastic analysis was first formulated by Wilkins (1964). He developed the equations of motion in the differential form. Rotations of the stresses during a time step were approximately accounted for. Central differences were employed for displacement and velocity. The spatial gradients of stress and velocity were obtained by a line integral method. Further Brown (1976) and Norris et al (1978) employed this method for similar approaches. Sekhon, Shishodia and Sharma (1979) also did work on closed-die forgings using this method. They wrote the governing equations directly in the finite difference form in terms of the incremental displacements. The rotations of the material element during an incremental step were properly accounted for.
The finite element method was first employed by Gallagher et al (1962). The technique consisted of dividing the component into a number of idealized elements. An appropriate displacement field which satisfies the compatibility conditions with the adjacent elements is chosen. Then a stiffness matrix is formed, followed by the formation of a matrix equation for the whole material. Numerical methods are then employed for the solution. The method is applicable to complex shapes as well. This method was also applied by Argyris (1972), Stricklin et al (1973), Kao (1974), Shah and Kobayashi (1975, 1977), Kim, Oh & Kobayashi (1978), Chen, Oh & Kobayashi (1979), Sharma (1980), Rogers, S.E. (1982).

In the finite element method both the elastic and plastic strains are taken into account. But the formulations of the method are too complex and the solutions take much longer time even on computers as compared to the other methods.

1.4.3.5 Upper bound technique

The upper-bound technique generally assumes the material to be rigid plastic material. The upper bound solutions for closed-die forgings have been initially been reported by Johnson (1958). The whole deforming material was divided into rigid zones and plastically deforming regions. Velocity discontinuities were identified in the plastically deforming region and then the
forging loads were calculated. Kudo (1960) has also given an upper bound solution for simple axisymmetric closed die forging. The forging process was divided into two stages. The first stage was for upsetting and the second assumed to have commenced when the billet side reached the side wall of the die-recess, and thereafter a part of the work material forced into the space between the die lands forming the flash. Assuming kinematically admissible velocity fields he estimated loads by upper bound solutions for the two stages separately. The material was assumed to be rigid-perfectly plastic and without lubrication. A reasonably good agreement was reported between the experimental and theoretical values.

The concept of a "fictitious disk" model was proposed by Kobayashi et al (1959) who assumed that at the end of forging, the material flows into the flash by shearing along a disk having the same thickness as the flash. Experimental observations by Unksov (1960) and Zunkler, (1964) have shown that the deformation zone is lens shaped and its height is not limited to the flash thickness. An approximate model based on the lens shaped geometry has been used by Altan, et al (1971) in their slab analysis of closed-die forging. For a homogeneous mode of deformation, and assuming a constant frictional stress at the material tool interface, the loads and stresses were calculated. Also the height of the deforming zone was measured.
determined by minimising the expression for axial stress at the centre of the die cavity. The resulting relationship indicates that the height of the deformation zone is a function of the radius of the die cavity and the flash thickness.

Dadras (1981) reported an upper-bound analysis of axisymmetric, closed die forging. He proposed a kinematically admissible velocity field. The forging power and loads were calculated and compared with experimental values. It was found that the theoretical predictions gave estimates that were substantially higher than the actual loads and powers. Also, the effect of different parameters on the height and shape of the deformation zone was investigated and it was shown that the height is independent of web thickness and length. Also, the angle of convergence of flow from the die to the flash decreased as the flash thickness increased.

An upper bound elemental approach was proposed by Islam and Bramley (1983). They described the use of the upper-bound elemental technique to analyse the effect of various parameters in forging. Effects of flash geometry and flash position, draft angle and central web were discussed. It was shown that the upper bound elemental technique was well suited for the analysis of axisymmetric forgings. The predicted results by this technique were shown to be well in agreement with the results obtained from actual industrial
operations (Fig. 1.2).

Sagar (1980) studied the closed die forgings of hexagonal and square shaped discs without the central hole. He formulated the upper-bounds through a proposed kinematically admissible velocity field. It was found that the theoretical and the experimental values agreed to a large extent.

Grover (1980) did work on closed die forgings of polygonal discs with protrusion. He used the upper bound technique for the same.

Upper-bound solutions for the process of cold forming of hexagonal nut blanks with central holes have been proposed by the author. The nose of the central punch which makes the central hole in the nut blank has been taken of different shapes e.g. conical, parabolic, spherical and flat. A kinematically admissible velocity field is proposed.

1.5 PRESENT WORK

As described earlier in para 1.3.1 the conventional method utilised large percentage wastage of material. It is therefore to be seen that if the wastage of the material is reduced, automatically the cost of the product will come down, assuming that there is no abnormal rise in the initial cost of the machine. As seen in para 1.3.4 though in the powder metallurgy method the wastage is
approximately nil, the cost of the end product is very high because of the initial cost of the machines and equipment and also the raw material. Therefore a method needs to be developed for reducing the wastage, but without excessive increase in the initial cost of the machine tool. The process parameters must also predict in advance for starting the production with sufficient confidence regarding the ability of the equipment to produce quality products.

The author has tried to present a method by which the wastage of the material is considerably reduced without abnormally increasing the initial cost of the machine tool. A brief description of the suggested procedure is given in Chapter 2.

The feasibility of closed die forging of hexagonal nut blanks, though suggested in 1978 (Appendix-1), does not permit the economies of the process to be predicted without mathematical analysis of the metal deformation. In the present work, therefore an upper bound approach has been adopted for the prediction of loads. The experimental set up for the various types of punch end shapes (conical, parabolic, spherical and flat) has been developed and loads and the material savings have been noted. This data have been utilised further in the correlation between the experimental and the theoretical values. Economic analysis has also been made by utilising the experimental data both from the experimental set up of the author as well as the data
obtained from various industrial groups engaged in hexagonal nut blank forming in Northern India. The results have been compared for the various methods of production of hexagonal nut blanks and the suggestions made thereafter. Necessary conclusions have been drawn.
BLANK SHAPES IN SUBSEQUENT DIE OPERATIONS FOR AN IN-LINE DIE SET.

FIG. 1-1
CORELATION BETWEEN MEASURED AND PREDICTED LOADS.

(REF. ISLAM ET AL. (1983))

FIG. 1-2