Proceedings of the
International Conference on Mechanical Engineering 2003
(ICME2003) 26- 28 December 2003, Dhaka, Bangladesh

ICME03-AM-24

DEVELOPMENT OF AN AUTOMATIC FORGING DIE DESIGN SYSTEM FOR TWO DIMENSIONAL COMPONENTS

P.J.Pawar and S.R.Gangurde

Department of Production Engineering, K.K.Wagh College of Engineering,Nasik,India.

ABSTRACT

This paper presents the methodology for automatic forging die design system for two-dimensional components. The three main aspects i.e. forging process design, optimum positioning of the parting line and die shape design are discussed in detail. The rule based approach is used for process sequence design. The component to be forged is broken into primitives, for which alternate standard plans are available in the database. The combination of these plans results into the optimum process for forging the component. Automatic selection of the parting line is done by applying simulated annealing technique with the objective function as minimisation of the overall die cost. This objective function is evaluated over five important parameters affecting the selection of parting line. The various positions of the parting line are generated by shifting the previous parting line through distance equal to pitch and orienting at an angle, values of which are obtained using simulated annealing technique. With input as 2-D drawing of the component to be forged, the output is optimum position of the parting line, optimum forging process sequence and all the variables required for die design.

Keywords: Forging process design, parting line, simulated annealing.

1. INTRODUCTION

The continuous technological modification are taking place in the design of hot forging dies in recent years, mainly in the geometry of the dies and in the dimensional accuracy of the forging. Since hot forging is required to be competitive even for small lot sizes, forging weight and machining allowances and hence subsequent processing is to be reduced. the efforts therefore be made to reduce the overall cost of the die.

Also, due to continuous modification in product design, forging dies needs to be designed frequently. The manual die design process is time consuming and experience dependant task. Whereas, the emergence of modern computer controlled EDM machines and RP techniques has reduced the manufacturing time drastically. Hence it is very essential to automate the design process to cope with the speed of manufacturing and to evaluate the design results according to different forging conditions immediately.

The main objective of this work is, to construct the automatic design system based on the rule based approaches. The system is used to perform mainly tasks like optimum location of the parting line using simulated annealing technique and automatic design and drafting of the edging, blocking and finishing impressions**.**

Material economy and resultant reduction in weight and cost, high productivity, use of unskilled labor, and a high degree of possible precision may rendered forging process indispensable for many mass-produced goods. Adoption of computer aided design (CAD) technique has proved to be one of the best ways to minimize the design cycle time, to reduce material waste and to reduce expensive machining of the forged parts. In this paper an attempt has been made to describe methodologies and steps involved in the development of software for the automatic forging die design system..

2. LITERATURE REVIEW

Various approaches and techniques of forging die design have been reported in literature. These approaches are reviewed in the following four major areas, which are discussed in detail in this chapter.

a)Part and Process sequence design for forging operation. b) Optimum positioning of the parting lines. c) Die shape design. d) Flash design rules.

Kim H. and Altan T.[1]has developed computer aided design tools that can assist the die designer in forming sequence design. The configuration of the system is shown in figure1. Two major components of this system are 1) An initial product and forming sequence design system (DS) module and 2) A forming sequence evaluation module as shown in the figure1. Using FEM simulation programs does further verification of the sequence. The die is designed in the CAD module.

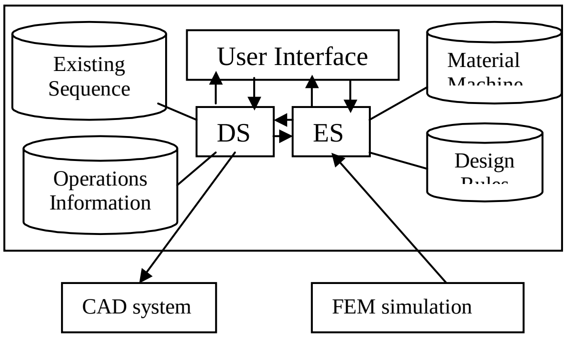

Figure1: CAD system for forging sequence design[1].

Though selection of the parting line plays an important role in designing the forging dies, no efforts are been yet made to automate the positioning of the parting line. In this work the positioning of the parting line is optimised using simulated annealing technique. Authors[2] have successfully applied this technique for optimised blank nesting problem which is reviewed and applied for the present problem.

Caporalli A. et al.[3] have developed an expert system for hot forging design. The stages hot forging planning are as shown in the figure 2.

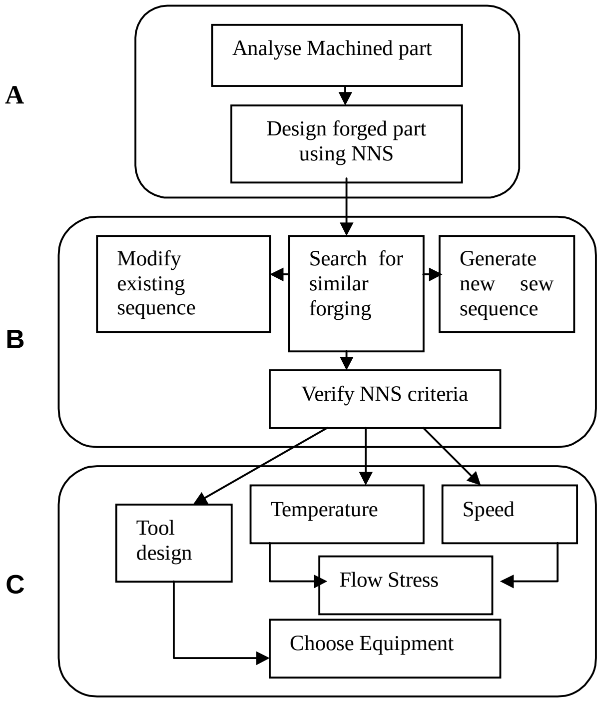

Figure 2: Steps for hot forging planning[3]

As indicated in figure 2, the planning of a new hot forging process can be divided into three groups of procedures. In group A the machined part is modified. The forged is designed considering near net shape (NNS) criteria. The process sequence is designed in group B. Once the process sequence is designed the other process parameters are chosen in group C. The dies are designed considering the preform geometry, thermal expansion and the use of standard tools and inserts.

Lee S.R.[4] et al. Presented a new method for preform design in hot forging operation by using electric field theory. In his study, in order to generate the electric field the initial shape (billet of cylindrical shape) is enlarged sufficiently so that the final shape is located inside the initial shape. The equipotential lines generated between two conductors of different voltages showq similar trend for the minimum work path between deformed and undeformed shape. Based on this similarity, the equi potential lines obtained by the arrangement of the initial and the final shape is utilized for the design of the preform, and then artificial neural network is applied to find range of initial value and potential value of the electric field. The initial and final shapes are set at 1 and 0 Volts respectively.

The different formulae to design the flash are reviewed and given in the table 3.

Table 3: Review of flash design rules[5].

No.	Developed by	Equation	Comment
1	Teterin	$FT=2\sqrt[3]{Q}-0.01Q-0.09$ $FW/FT=(0.0038S_f\ D_0/FT)+4.93/\sqrt[5]{Q}-0.02$	Based on statistical analysis and flow physics.
2	Mockel	$FT=1.13+0.89\sqrt{Q}-0.017Q$ $FW/FT=3+1.2e^{-1.09Q}$	Concluded that flash Design parameters are shape independent
3.	Wolf	$FT=g\sqrt{Q}+qQ+r$ $FW/FT=c+ae^{-dQ}$	Generalized with error range
4.	Voigtlander	$FT=0.018\sqrt{A}$	Non axi-symmetric parts considered.
5	Chambersberg	$FW=0.13\sqrt{D}$	Uses W/T as a function of shape complexity
6	Chamouard	$FW/FT=\sqrt{(P_{fill}-2)/C}$	Based on assumption that $P_{Friction}=P_{fill}+P_{Flash}$

3. METHODOLOGY

This part of the paper deals with the methodology and development of an algorithm for the major aspects of forging die design such as, process sequence design, automatic selection of parting line, edging impression design, preform design and flash design. These methodologies are then subsequently used for developing the automatic forging die design system.

3.1 Forging Sequence Design

In a forging operation it is very necessary to perform the deformation process as a series of well defined individual steps, this series of intermediate steps, from initial billet geometry to final desired component shape, being referred to as forging sequence. The sequence design process constitutes the following stages:

1.Input module: All information related to the component to be forged, such as work material, work geometry, forging process to be used, press capacity available, direction of application of load etc. is input by the user.

2. Knowledge base: The knowledge base for the process sequence design contains, a) Material properties for both workpiece and tooling. b) The constitutive relationship related to controlling the flow behavior of the workpiece during the deformation. c) Yield stress and strain rate sensitivity d) Press capacity and speeds available. e) Forging temperature and time. f) Maximum allowable reduction ratio for each stage of operation. And g) Aspect ratio.

3.Reducing parts to primitives: Once the part configuration is input by the user, the component is reduced to the set of simple geometries called as primitives. This approach provides the simple but effective way of classifying components in appropriate groups. Primitives are broken into three categories:

a) Primary: viz. Cylinders, cube, prism.
b) Transitionary: viz. Truncated cones and pyramid.
c) Complex: such as shapes arising out of flattening of cylinders, cones etc.

Each primitive has assigned a certain code and a string of these codes constitute a component. The illustration is shown below.

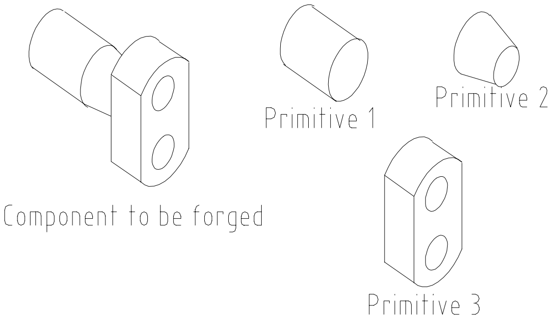

Figure 1: Component Division into primitives.

Codes for the primitives shown in figure 1, are indicated in table 1 given below :

Table 1: Codes for the primitives.

Primitive No.	Name	Type	Code
1	Cylinder [1]	Primary [1]	11
2	Truncated Cone [1]	Transitionary[2]	21
3	Flattened [1]	Complex [3]	31

Hence the string code for the component is 112131.

4. Generation of the alternate plans: The knowledge pertaining to the above code is stored in the database, from which the alternate sequence plans are available for forging the particular primitive. Combination of these plans to develop the particular string results into alternate process plans to forge the component.

5. Selection of the optimum plan: The alternate plans generated are then subjected to the constrained imposed by the knowledge in the knowledge base. The system also takes the relevant information from the knowledge base and then by means of reasoning process produces an appropriate forging sequence. Using the rule base approach, the decisions to be made in arriving at the solution of the given problem are made on the basis of set of "IF-THEN" rules, which embody knowledge specific to that problem. Each rule represents a small element of knowledge related to a given area of expertise. Collectively the a number of related rules corresponds to a chain of inference which starts from some initially known facts to useful conclusions. These conclusions are reached by moving recursively through the rules either in forward or backward direction. The provision is also made to modify and update the database by incorporating the learning module. The process thus can be summarized as below.

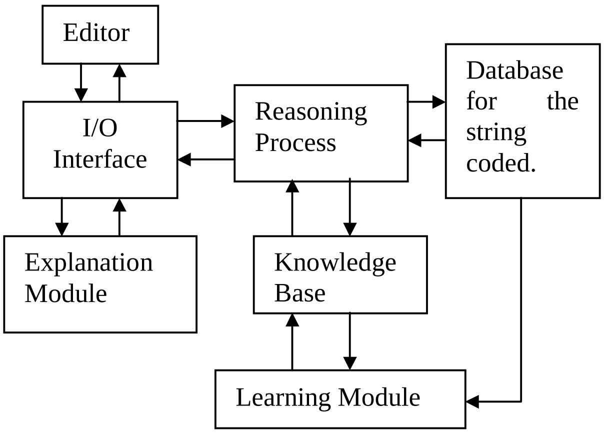

Figure 2: System of forging Sequence Design.

3.2 Automatic Selection of Parting Line

The parting line is defined by adjacent and mating faces of the forging dies, when they are closed. The selection of the parting line is a very important task as it determines the shape of the finisher die. The problem of automatic selection of the parting line can be suitably converted into the optimization problem, with objective as minimization of the total die cost. For proposed work, a simulated annealing approach is selected due to its distinctive advantages over other methodologies.

Simulated annealing is a probabilistic hill climbing optimization technique. A probabilistic algorithm is one in which the objective function is evaluated at sample of points chosen randomly from the feasible region. A hill climbing technique is one, which allows for an increase in the value of objective function in a controlled manner.

Let a feasible configuration (k) is a point in an allowable region and T is a controlling parameter then the cost C(k) is the quantity to be minimized. The neighborhood of a configuration is a set of predefined feasible points from which next configuration is chosen. If T is a quantity analogous to the temperature in annealing of solids then the manner in which the temperature is to be decremented and the number of moves required is to be decided. The cost function is said to be in the state of equilibrium at temperature T when probability of being in the configuration k is:

$$\Pr\left\{config\ .=k\right\}=\frac{e^{-C(k)/T}}{Z(T)}$$

where $Z(T) = \sum_{j} e^{-C(k)/T}$,

if i is the current configuration with cost C(i) then probability of accepting j as next configuration with $\Delta C = C(j) - C(i)$ is:

$$\Pr\{new = j \mid current = i\} = \begin{Bmatrix} 1 & if \quad \Delta C \le 0 \\ e^{-\Delta C/T} & otherwise \end{Bmatrix}$$

Thus the probability of accepting new configuration is either 1 or $e^{-\Delta C/T}$ depending upon sign of ΔC .The process of optimization using this technique is discussed below.

1.Defining the objective function: The objective here is to position the parting line so as to minimize the total die cost. Mathematically it is expressed as,

$$\text{Min. } Z = \sum_{i=1}^{n} w_i * f_i - \text{penalty} * R$$

Where,
n = Number of factor governing selection of P.L.
w = Relative weight of each factor.
f = cost in percentage of total cost due to particular factor.
R = cost due to reduction in strength for a particular position of the parting line.

If any solution makes the grain flow in traverse direction to the application of the load, should not be accepted as a final solution. To ensure this a high penalty is assigned.

2. Formulation of the problem: The parting line could be straight or broken. As already discussed in the previous section the component is broken into primitives. The parting line assigned to each primitive independently leads to a broken parting line. The illustration of this is shown below.

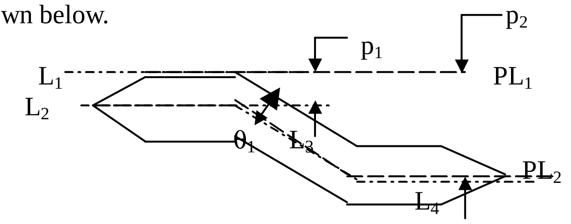

Figure 3: Alternative Parting Lines.

Figure 3 shows alternative parting lines generated by the simulated annealing technique, With initial solution as parting line ‘PL_1’, The another alternative ‘PL_2’ is obtained by the combination of three lines a) ‘L_2’ which is obtained by shifting ‘L_1’ by distance ‘p_1’. b) ‘L_3’ obtained by shifting ‘L_1’ by distance ‘p_1’ and then turned through angle ‘θ_1’. c) ‘L_4’ obtained by shifting ‘L_1’ through a distance ‘p2’ as shown in figure.

3. Defining neighborhood structure: As discussed in above example, the parting line ‘PL_2’ is obtained by set of allowed perturbations in variables, pitch ‘p’ and angle ‘θ’. The neighbor structure defines a set of configuration from which a next move is picked up at random. Let $\delta\theta_1$ (T), $\delta\theta_2$ (T), δx_2 (T), δy_2 (T), and δp (T) be the allowed perturbation in the corresponding variables. If $[\theta_1^i - \delta\theta_1 (T), \theta_1^i + \delta\theta (T)]$ be the set of all the values of variable θ in the length 2 * $\delta\theta_1(T)$ around θ^i, then the neighborhood set is the product of all the sets.

$N(T) = [\theta_1^i - \delta\theta_1 (T), \theta_1^i + \delta\theta_1 (T)]\ [\theta_2^i - \delta\theta_2 (T), \theta_2^i + \delta\theta_2 (T)] * [x_2^i - \delta x_2 (T), x_2^i + \delta x_2 (T),] * [y_2^i - \delta y_2 (T), y_2^i + \delta y_2 (T),] * [l^i - \delta l (T), l^i + \delta_l (T),]$

4.Defining the object: The shape information is input to the computer by the geometric scanning principle. The line can be scanned by defining two end points i.e. length and angle with respect to the origin, whereas arcs, circles can be input by their respective equations i.e. by defining one point on the curve and then making it to move on the locus satisfying its equation. The action of input is repeated for (nv-1) times. Number of vertices is the input to the computer. All these vertices are then joined together to form a polygon. Thus, with this method component of any complex shape can be input to the computer.

5. Calculating objective functions: The factors governing the selection of the parting line considered in this work are a) Maximum periphery in terms of percentage of maximum projected area. b) Maximum use of natural draft in terms of percentage saving in material and machining cost. c) Stress concentration due to end grain runout and in terms of strength of the component. d) saving in die manufacturing cost. Besides these parameters, the effect of other parameters such as forging process, convenience of trimming, prevention of defects like metal push through etc. may be considered.

The illustration for calculation of ‘f’ is shown below.

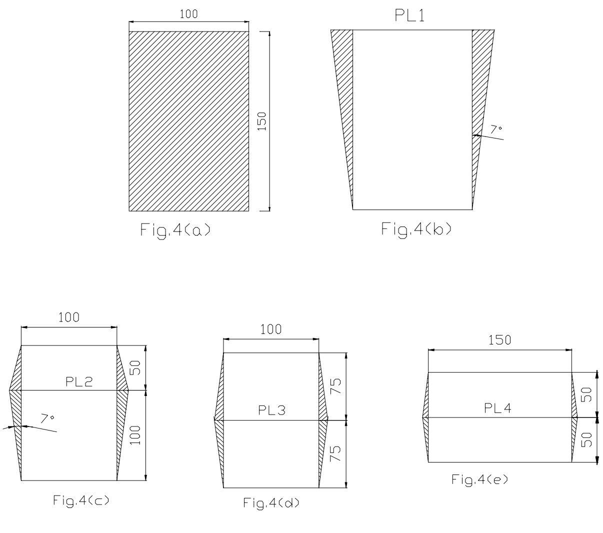

Figure 4: Effect on objective function due to draft.

Table 2: Improvement in the objective function:

Fig.No.	Pitch ‘p’	Orientation ‘θ’	Volume (cm^3)
4(a)	Component		750
4(b)	0	0	1232
4(c)	50	0	1056
4(d)	75	0	974
4(e)	50	90	880

With reference to figure 4, the comparative analysis of figure 4(b) to 4(e) is shown in the table 2 below by assuming the uniform component thickness 50mm.

The figure 4 shows the improvement in the objective function due to draft, which shows parting line ‘PL_4’ has minimum cost. However, the objective function is evaluated for all the variables simultaneously, viz. though parting line ‘PL_1’ shows more costs of the material and machining as it needs only the single half of the die to be machined, thus reducing the overall die cost.

6.Flowchart for the optimization process:

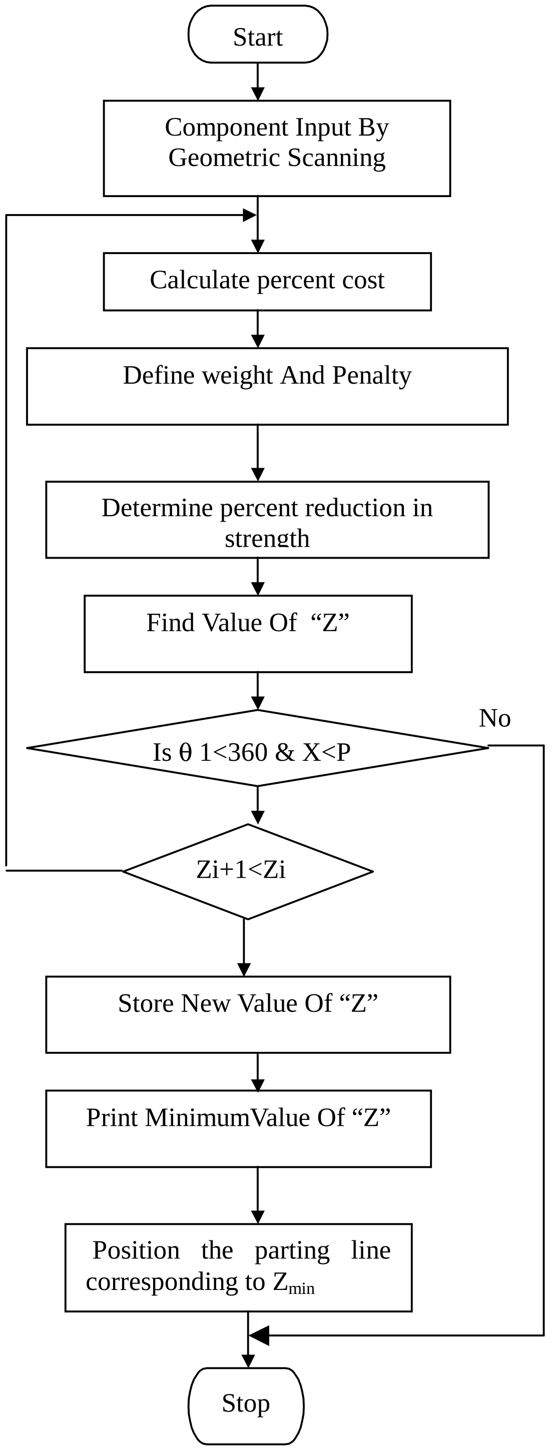

Figure 5: Flowchart for optimum position of P.L.

Edging impression is designed by calculating the area of the cross section at every sectional change of the forged component, which is then converted into radius of equivalent circle at that section.

The type of allowances and tolerances machining allowance, the decurburization allowance for steel forgings, length and width tolerance, the mismatch tolerance, the straight tolerance, the flash extension tolerance, the draft angle tolerance as well as the corner and fillet radius tolerance. The allowances and tolerances are stored in the database. Based on the type of forging material , type of forging process and its weight, these values are selected. The forged size can be evaluated from the finished component as :

Size of forging = Finish size + Shrinkage Allowance + Decurburization + Minus thickness tolerance + Scale pitting +machining allowances – Die wear allowance.

Thin ribs and webs are difficult to forge because of their low mass, rapid cooling and required high forming loads and therefore should be designed such that the actual rib or web thickness exceeds the minimum thickness., depending on the plan area of the trimmed forging. The important design specifications for the finisher die are as follows: a) shrinkage due to temperature difference workpiece and the die. b) shape difficulty factor c) flash thickness and land width d) scale and flash losses. e) dimensions and types of billet and flash gutter f) die block layouts.

Usual formulae can be used to calculate stock size, forging force, shape complexity factor etc.

4.RESULTS

To check the validity of the proposed scheme, variety of component were tested. An illustration for a typical component as is shown in figure 6 is discussed below.

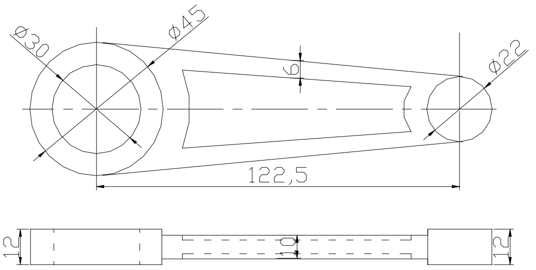

Figure 6: Component to be forged.

The alternative parting lines for the component in figure 6 are shown in figure 7. As discussed in methodology, these parting lines are obtained by shifting the initial parting line by pitch ‘p’ and giving orientation ‘θ’. Their values are obtained by simulated annealing process, as indicated in table 2.

Table 3: Values of ‘p’ using simulated annealing.

T	C (k)	ΔC	$e^{-\Delta C/T}$	Probability of acceptance
0	6.34	----	----	1
1.6	4.92	1.42	0.41	0.41
5	4.62	0.3	0.94	0.94
6	2.6	2.02	1	1
7.2	5.47	-2.27	0.72	0

The values of pitch ‘p’ determined in table 3 above are for orientation ‘θ’=0^0. Parting line ‘PL6’ is obtained by setting the orientation angle ‘θ’=90^0.But, as it offers minimum spread along the parting line, may not be accepted as feasible solution.

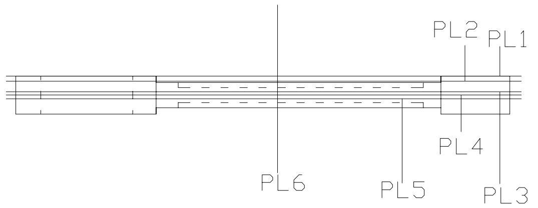

Figure 7: Alternative parting lines

The parting line with pitch ‘p’=6 is selected as it is observed that parting line positioned at this pitch has a minimum cost and shows 100% probability of acceptance, whereas the cost again increases for pitch greater than this value. The figure 8 shows the final position the parting line.

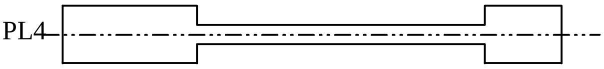

Figure 8: Optimum selection of parting line.

The values of variables obtained are listed in table 4.

Table 4: Output variables.

Sr.No.	Variable	Output value
1.	Part volume	32960 mm^3
2.	Perimeter	360 mm
3.	Projected area	8662 mm^2
4.	Stock size	ϕ 20X 138 mm
5.	Flash thickness	1.4mm
6.	Flash width	5.6 mm
7.	Volume of flash	2822 mm^3
8.	Shape complexity factor	0.32
9.	Forging force	7796 KN.

6.CONCLUSION

Thus, using rule based approaches and simulated annealing technique for parting line selection an automatic system for design of the forging dies can be developed. It is observed that, at an average the software requires 30 to 60 seconds of computational time. This is due to the fact that most of the operations in this algorithm are comparisons at each iteration. The software has its own input module to input the data and part geometry. Thus eliminating the necessity of installing and linking it with any other design or drafting software such as AutoCAD for this purpose.

7. REFERENCES

1. Kim H.,Taylan A., 1992 “Computer Aided Part and Processing-Sequence Design in Cold Forging”, *Journal of Material Processing Tech.*, (33) , pp.57-74.
2. Pawar P.J., Gangurde S.R., 2002, “Minimisation Of Material Waste Through Optimised Strip Layout In Press Tool Operations Using Simulated Annealing Technique”, *Proceedings of International Conference on Agile Manufacturing*, 2002 pp.1-7.
3. Coporalli A.,Luciano A.G.,Segio T.B., 1998, “ Expert System For Hot Forging Design”, *Journal of Material Processing Tech.*, (80-81) , pp.131-135.
4. Lee S.R., Lee Y.K., Park C.H, Yang D.Y.,2002 “ A New Method of preform Design in Hot Forging by Using Electric Field Theory”, *International Journal of Mechanical Sciences”*, (44), pp.773-792.
5. Sleeckx E.,Kruth J.P.,1992, “ Review of Flash Design Rules for Closed Die Forgings”, *Journal of Material Processing Tech.*, (31) , pp.119-134.

7. NOMENCLATURE

Symbol	Meaning	Unit
FT	Flash Thickness	mm
FW	Flash Width	mm
Q	Weight of forging	Kg
S_f	Shape complexity factor	
D_0	Diameter of billet	mm
A	Projected Area	mm^2
D	Diameter of forging	mm
P_{fill}	Pressure needed to fill cavity	N/mm^2
C	Coefficient function of A/D^2	
C(k)	Cost	Rs.
T	Controlling parameter	
c,d,g,q,r	Coefficients	