International Journal of Engineering Research and General Science Volume 3, Issue 3, May-June, 2015
ISSN 2091-2730

Design and Development of a Tool for Combined Depression and Piercing Operation

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Abstract— the work deals with the development of a combined tool for improvement of a process to be done in rim manufacturing plant. Research work deals with combining two pressing operations done separately. This operation is done for seating the Valve stem which protrudes out of the wheel for inflating tubes &Tyres. In the first pressing a depression flat is observed in the component. And in the second operation a hole is pierced in the same flat. The objective of the research is to develop a tool and process for using a single press for performing dual operation. This is also to reduce down time, reduce operator Fatigue and thereby increase production. Elimination of one operation, one operator and reduction in processing time is also to be achieved.

Keywords— Depression, Piercing, Press, Tonnage, Hydraulic, Mechanical, Blank.

1. INTRODUCTION

In this fast growing economical world requirements for doing thing faster have risen like anything. Rapid Economic Growth is in a great momentum in India. India's ambitious highway under construction, which is going to be the Key driver of the Commercial vehicle industry called the Golden Quadrilateral. To cater the needs of the automobile wheels segment many rim manufacturers has entered in the market. Fully Customers focused approach towards the market will definitely fetch a better result, to rule out the monopoly that the wheel manufacturers in India are having now.

Metalworking comprises of deformation methods in which a metal billet or blank is formed by tools or dies. The design and mechanism of such methods depend on an understanding of the features of the raw material, the parameters at the tool/work piece interact, the mechanics of plastic deformation, the machine used, and the requirement of finished-product. These are the influencing parameters for selection of tool geometry and material as well as processing conditions like work piece and die temperatures and lubrication [1].

1.1 Classification of metalworking processes

In metalworking, an initially simple part--a billet or a blanked sheet, for example is plastically deformed between tools (or dies) to obtain the desired final configuration. Metal-forming processes are usually classified according to two broad categories:

- Bulk or massive, forming operations
- Sheet forming operations

In both types of process, the surfaces of the deforming metal and the tools are in contact, and friction between them may have a major influence on material flow. In bulk forming, the input material is in billet, rod, or slab form, and the surface-to-volume ratio in the formed part increases considerably under the action of largely compressive loading. In sheet forming, on the other hand, a piece of sheet metal is plastically deformed by tensile loads into a three-dimensional shape, often without significant changes in sheet thickness or surface characteristic.

Processes that fall under the category of bulk forming have the following distinguishing features:

- The deforming material, or work piece, undergoes large plastic (permanent) deformation, resulting in an appreciable change in shape or cross section
- The portion of the work piece undergoing plastic deformation is generally much larger than the portion undergoing elastic deformation; therefore, elastic recovery after deformation is negligible.

Examples of generic bulk forming processes are extrusion, forging, rolling, and drawing.

1.2 Types of metalworking equipment

The various forming processes discussed above are associated with a large variety of forming machines or equipment, including the following:

- 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 (presses)

Among those listed above, pressing-type machines are the most widely used and are applied to both bulk and sheet forming processes. These machines can be classified into three types: load-restricted machines (hydraulic presses), stroke restricted machines (crank and eccentric, or mechanical presses), and energy-restricted machines (hammers and screw presses). The significant characteristics of pressing-type machines comprise all machine design and performance data that are pertinent to the economical use of the machine. These characteristics include:

- Characteristics for load and energy: Available load, available energy, and efficiency factor (which equals the energy available for work piece deformation/energy supplied to the machine)
- Time-related characteristics: Number of strokes per minute, contact time under pressure, and velocity under pressure.
- Characteristics for accuracy: For example, deflection of the ram and frame, particularly under off-center loading, and press stiffness

1.3 Piercing

Piercing is the cutting of holes in sheet metal, generally by removing a slug of metal, with a punch and die. Piercing is similar to blanking, except that in piercing the work metal that surrounds the piercing punch is the work piece and the punched-out slug is scrap, while in blanking the work piece is punched out.
Piercing is ordinarily the fastest method of making holes in steel sheet or strip and is generally the most economical method for medium-to-high production. Pierced holes can be almost any size and shape; elongated holes are usually called slots. The accuracy of conventional tool steel or carbide dies provides pierced holes with a degree of quality and accuracy that is satisfactory for a wide variety of applications.

1.4 Selection of die clearance

Clearance, or the space between the punch and the sidewall of the die, affects the reliability of operation of piercing (and blanking) equipment, the characteristics of the cut edges, and the life of the punch and die. Published recommendations for clearances have varied widely, with most suggesting a clearance per side of 3 to 12.5% of the stock thickness for steel.
Establishment of the clearance to be used for a given piercing or blanking operation is influenced by the required characteristics of the cut edge of the hole or blank and by the thickness and the properties of the work metal. Larger clearances prolong tool life. An optimal clearance can be defined as the largest clearance that will produce a hole or blank having the required characteristics of the cut edge in a given material and thickness. Because of differences in cut-edge requirements and in the effect of tool life on overall cost, clearance practices vary among plants and for different applications.
No single table or formula can specify an optimal clearance for all situations encountered in practice. Starting with general guidelines, trial runs using several different clearances may be needed to establish the most desirable clearance for a specific application.

2. LITERATURE REVIEW

Documentation of process influencing parameters of blanking/piercing process covers thorough literature review of the factors have been elaborated by various authors. Comprehensive literature review is conducted by collecting various research papers from various journals, and various popular research related sites viz. Science Direct, Springer Link and various standard Hand Books.

Sneha S Pawar, R. S. Dalu[2],this paper represents a Computer assisted design method to design compound die set for down light housing. The design calculations take account of the quality of the work piece material and they determine the optimal size for the die punch sets. They developed the computer program in .net technology, tool- Visual studio language-C#, project type-Window application which allows the determination of constructive parameters for the elements of compound dies. The proposed method can be used for any configuration of the parts which need to be processed. The output of computer assisted die design for down light housing has been verified with the result of manual die design. It has been observed that computer assisted die design method provided high accuracy and consume less time. The proposed method CADD can be used to any configuration of the processed work piece with little modifications.

Adnan l O Zaid[3], in this paper, the theory and practice of these processes are reviewed and discussed. The main parameters affecting the process like radial clearance percentage, punch and die geometrical parameters, for example punch and die profile radii are presented and discussed. The abovementioned parameters on the force and energy required to effect blanking together with their effect on the quality of the products are also presented and discussed. Recent experimental results together with photo macrographs and photomicrographs are also included and discussed. Finally, the effect of punch and die wear on the quality of the blanks is also given and discussed. It’s been concluded that square ended punch and die produce blanks of better quality, it is essential to provide profile radius at punch and die to improve their lives. Increasing punch and die profile radius caused increase in both blanking force and energy particularly at small radial clearance percentage. Providing the profile radii tends to increase the energy and reduces the blanking force and reduces the quality of the blanks. Furthermore, they caused enlargement of the shear zone, being more affected by the die profile radius. Radius at punch and die profiles caused delay in crack formation at small values and non-occurrence at large values and resulted of lower levels of micro hardness in the vicinity of the radius end.

Soumya Subramonian et. al [4],This paper discusses an experimental study of the interaction between punch, stripper plate and sheet material at various blanking velocities from 20 mm/s to 1600 mm/s to study dynamic loading on the punch. The effect of velocity on punching force is also studied. A methodology to obtain high strain and strain rate dependent material flow stress data using blanking test and finite element modeling is presented. The velocity of blanking has a significant influence on forward and reverse loading. The vibrations of the stripper plate during unpinning apply lateral force on the punch, which could influence the strength and life of slender punches. Modeling of high speed blanking requires both temperature and strain rate dependent material model at high strains. Blanking itself could be used as a test to generate material flow stress data at high strains and strain rates.

U.P. Singh et. Al [5], in this paper the study of the problem was done by using the finite-element technique. 3-Dfinite-element models of various types of punching/blanking tools were developed; these models enabled the analysis of the effects of variations in tool geometry on the punching/blanking force and on the deformation of the punch, a parameter highly relevant to the assessment of tool performance in terms of the accuracy of the manufactured components. The model catered also for variation in the characteristics of the tool material, in the sense that a highly wear-resistant tool is normally composed of carbide tips around its cutting profile. Computed results by FE models were checked against design standards by American Society of Manufacturing Engineers (SME).Some suggestions are offered as to how the efficiency of a punching/blanking tool can be improved.

1. That the radial deformations of punches with balanced convex and concave shear have a minimum value within the shear angle range of 17°-22 ° suggests that a shear angle of 20° can be proposed safely for practical purposes.
2. Amongst the rigidity characteristics evaluated for all types of punches, the punch with balanced convex shear shows the best performance suggests that this type of punch can reasonably be recommended in practice in order to reduce the stress on the tool and thus to enable thicker or more resistant stock to be punched on the same press or to permit the use of a lower-rated press.
3. Since the inclusion of eccentricity due to asymmetric load on the press is an important factor in the punching/blanking process the choice of punch with balanced convex shear, against punch with sintered hard metal around its circumferential cutting edge, is obvious despite the axial stiffness of punch sintered hard metal having a substantially greater competitive edge than punch balanced convex shear.

2.1 Summary derived from literature review

Today customers are more and more quality & Cost conscious. To satisfy the need of the customer any industry needs to adopt an effective approach towards the better process, which involves less cost to the company and also maintain or improve the level of quality. Now increasing number of companies are realizing that by applying new approach towards process concept they will be able to control the quality and cost.

1. The cost of tooling in sheet metal industries contributes a considerable part to the overall cost of manufacturing a component. It is therefore imperative to keep down this cost by ensuring that the tool works for a long period in production without interruption.
2. To achieve this, optimum clearance between die and punch to be kept and it is found that optimum clearance is 10 to 15% of sheet metal thickness.
3. To reduce the stress on the punch a shear angle of 20° can be proposed safely for practical purposes with balanced convex and concave punch.
4. Various Computer assisted designing programs/algorithms are available for optimum design of Punches and dies, which can give accurate and fast results.

3. Problem definition

The rejection data generated from the previous 3 months for tractor wheel assembly are collected from the Quality department of organization and are as follows. From the given rejection report it is clear that about 1% of rims are getting rejected due to only Tool Clamp Marks, Wrong depression and wrong piercing. From the above data it is clear that there is strong requirement for the process control along with necessary changes in the Process and Tool Design.

		Tractor Rear Rim Scrap Report				Date : 05-11-2014		
		W 10 x 28	W 11 x 28	W 12 x 28	W 13 x 28	Total		
AUG	**Production**	**2350**	**1700**	**2500**	**900**	**7450**		
	Tool clamp marks	5	3	4	3	15	74	0.99%
	Wrong depression	5	4	6	5	20		
	Wrong piercing.	10	9	14	6	39		
SEPT	Production	**2700**	**1500**	**3200**	**650**	**8050**		
	Tool clamp marks	3	3	2	6	14	83	1.03%
	Wrong depression	4	2	4	5	15		
	Wrong piercing.	9	13	15	17	54		
OCT	Production	**1800**	**2000**	**1300**	**1000**	**6100**		
	Tool clamp marks	5	6	3	3	17	68	1.11%
	Wrong depression	4	5	5	4	18		
	Wrong piercing.	6	8	10	9	33		

TABLE 1 Tractor rim scrap report [Courtesy to RIM Plant]

3.1 Route cause analysis

To reach at the route cause for the problem, existing process study has been carried out and following observation found.

1. While splitting down the activities the process of handling the rim after it is formed was found to be difficult.
2. Ergonomically speaking the structural shape makes a difficulty.
3. Valve hole Depression has to be made in opposite to the Butt weld area, the operator needs to rotate the component first and place it over the Depression die.
4. Then after the depressed flat area has to be located again once more in the Piercing tool. Then the certain adjustments need to be done to match the punch center with the depression flat.
5. Complete process is dependent upon the operator skill and minor mistakes can lead to the rejection of the rim.
6. When the component is not located in the die holder, the hole that is pierced is not in center and hence the component gets rejected.

4. Rim manufacturing

In Rim manufacturing process a small piece of steel plate is first coiled in to a round band in coiler machine. Then it is welded together in a Butt welder, to make the ends join with each other followed by operation called Trim Roll & Slit. Since the ends are heated to its molten temperature and butt with each other, there may be small porous holes prevailing in between the joints. Hence we need to trim the excess weld bead and then roll the joints each other with pressure where in which the joint gets pressed to certain extent. After rolling operation the joint area gets projected outwards the band size since it is hot and pressed to bring out the perfect joint. This is slit off in the slit station. Followed by Forming operation in cold stage, 4 Stages of forming is required for Tractor rim Sections. First one is flaring. In this operation the ends are flared to certain extent to make the component entry and retrieval easier in the forth coming rolling operations, and make the necessary height variation in the form. Then followed by Roll forming operations where in which the required sectional form of the rim is formed. In this operation the dimensional variation of the component would be more since forming shapes can be done alone. The dimensional spec which needs to be maintained in the tyre seat area is to be done in the next operation Calibration. Since because universally accepted standards between the tyre manufacturers and Wheel rim manufacturers specifies a diameter to be maintained in the component. This is mandatory because wheel rim manufactured in the whole world should be of unique size enabling the automobiles to be exported and availability of tyre and tube anywhere in the nook & corner world. Then followed by valve hole depression where a small flat is made to create a hole in the flat area. The lock nut gets seated over the flat area, making the valve stem protruded out for filling air.

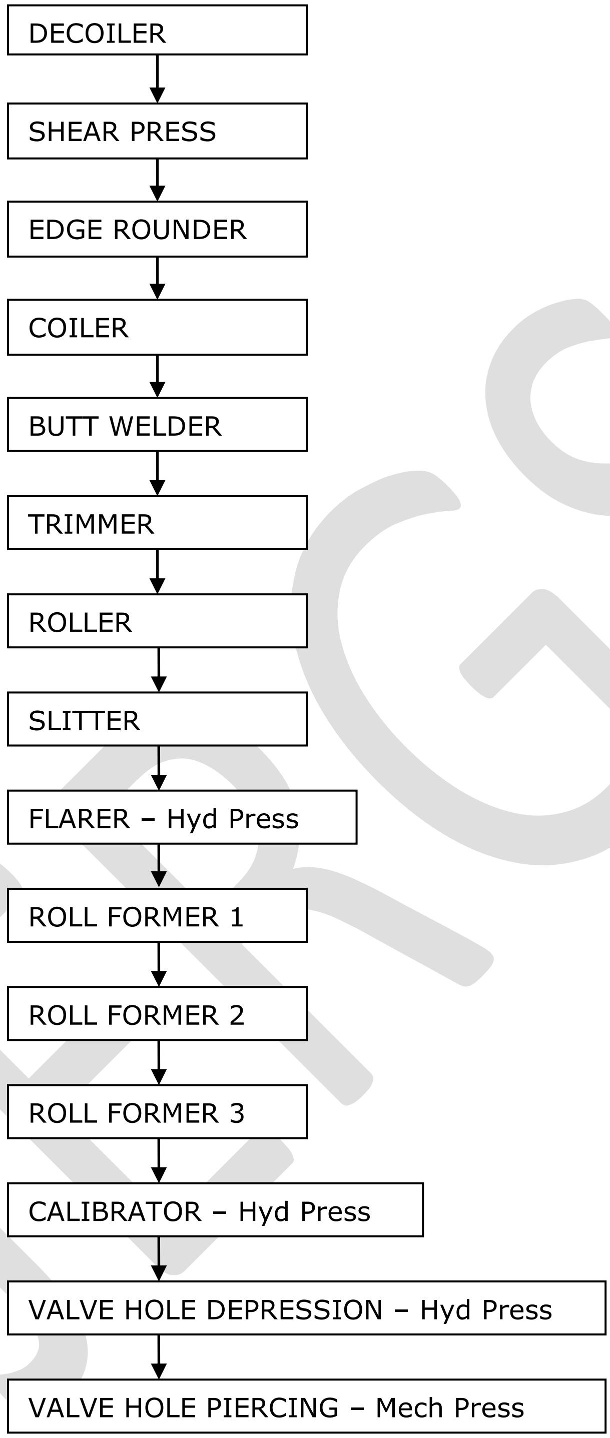

Figure 1 Rim process flow chart[Courtesy to RIM Plant]

While splitting down the activities the process of handling the rim after is formed was found to be difficult. Ergonomically speaking the structural shape makes a difficulty. At Valve hole Depression has to be made in opposite to the Butt weld area, the operator needs to rotate the component first and place it over the Depression die. Then after the depressed flat area has to be located again once more in the Piercing tool. Then the setting adjustments that need to be done are also prevailing for both the machines together. The concept of the improvement to be noted here is the person should not handle the component twice, since because he is locating the same place again and again. Chances of miss-locating the flat also prevails. Hence a detailed study of the existing tools needs to be done before going in for a combined tooling. Detailed study of the depressed flat and piercing is to be done.

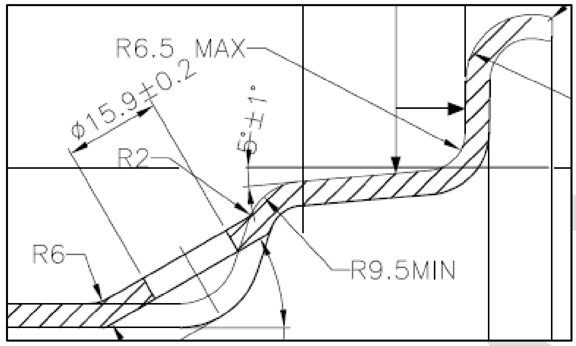

Figure 2 Valve Hole Depression Drawing [Courtesy to RIM Plant]

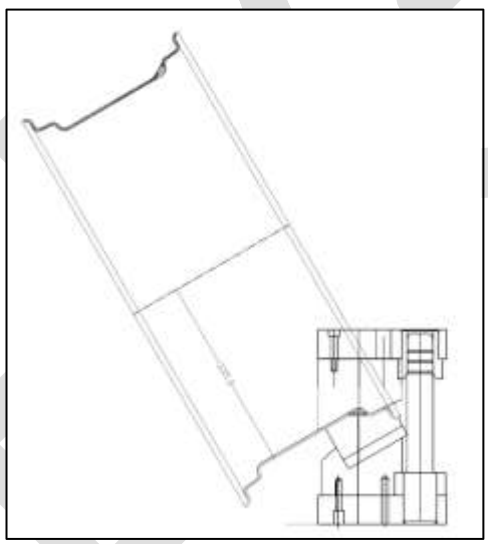

Figure 3 Valve Hole Depression Arrangement [Courtesy to RIM Plant]

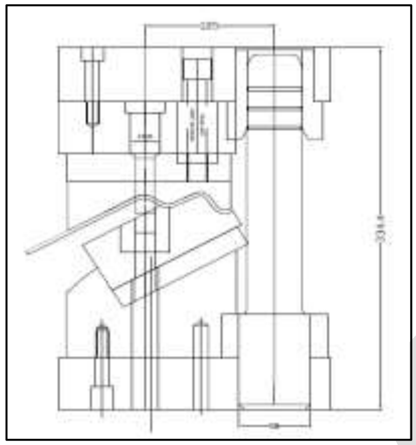

Figure 4 Valve Hole Piercing Arrangement [Courtesy to RIM Plant]

5. Concept development

The existing process of valve hole depression is done in a Hydraulic Press of 200T and piercing in a Mechanical Press of 100T. The concept that is to be developed should be such that both the operations are done in a single stage itself. The location problem would get solved if we get success in this concept development. The punch holder should be in such a way that it holds the punch and also plays a role in making the depressed flat. When pierced the burr should be projecting the other side of the area where the tube is not there. The person should also not lift the component fully up to load it in the die set, rather some other technology of handling is also to be provided. When the component is loaded in, where the male depression die is located on the top and other on the bottom, then he needs a mechanical means to locate the component. Even if a mechanical lifter to be provided to lift a component, then also operator has to handle that mass in a particular height, which is well above the hip of the operator. From the figure 4.1 it is evident that the Height of the machine base from Floor level is 800 mm. And then the depression female adaptor height is 200 mm above the machine base. And the operator hands are at a height of 415 mm from that depression flat. To be noted down here is the operator is lifting the component from a conveyor (height 600 mm) by 420 approx. including clearance gap of 20 mm to enter component in to the tool. And he holds the component at a height of 1415 mm from floor level. Taking normal man's average height as 5 feet (1524 mm) the height 1415 comes above his head by 100 mm. Holding 20 Kilograms on average and working is also difficult as because of height.

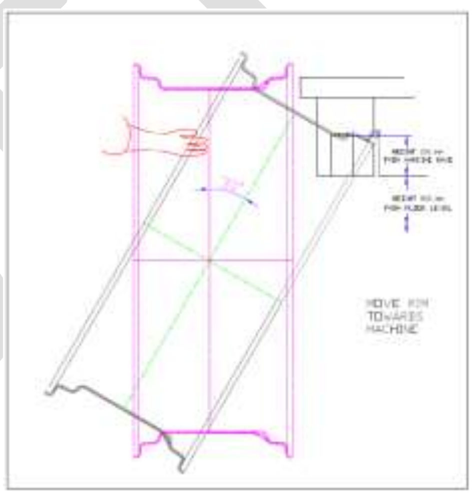

Figure 5 Depression & Piercing Arrangement study

International Journal of Engineering Research and General Science Volume 3, Issue 3, May-June, 2015
ISSN 2091-2730

5.1 Tool design

The tool design phase is required to be started with the concept of having the depression male punch on the top and to have the punch and die in between the depression block also. There will be two strokes from the same press, in the first the depression flat would be made in the component and in the next stroke the piercing would be done.

In the first operation the tool to be designed for making a depression with a male depression flat on the top and the female die on the bottom. In the next operation punch should protrude out of male depression flat by some mechanical arrangement. This mechanical arrangement makes sure that always for the first operation the punch space is not locked. And in the second operation the mechanical arrangement makes the punch to protrude out to the required height for piercing. The piercing load calculation is also indicated in the following table.

Tensile strength of the material	$\mathbf{T_m}$	370	N/mm^2
Thickness of the material	**T**	4	mm
Hole	**Ø**	15.9	mm
Circumference	**C** = π x **Ø**	49.95	mm
Area to be sheared	**A** = **C** x **T**	199.8053	mm^2
Load	**L** = **A** x $\mathbf{T_m}$	73927.96	N
1 Newton = 0.000112404 ton force		Therefore 73928 N **= 8.30 Ton**	

Table 2 Load calculations

Considering the concept as shown in the Figure 5, Mechanical arrangement was required to be identified which can lock the punch after depression is observed on the component. Various presses were studied inside plant premises like Chassis Shop, Press Shop to identify the Mechanical arrangement which can be used for multiple punch selection. Only press found which is working on the multiple tool selection concept is CNC Turret Punching Press located at Chassis Shop. The Press is a Mechanical Press of 200 Ton capacity and controlled by CNC. Press is having a Turret which can hold 14 numbers of various tool varieties. Based on the material thickness it can punch hole diameter ranging from 9mm to 44mm as per requirement.

As the press is working on CNC controller operator has to feed program for a particular component once. Controller automatically selects the tool from the turret as per the program and respective tool location. To select the particular tool from the turret one mechanical block is used to lock the punch. This mechanical block is mounted on the double ball screw nut which is driven by the Servo Motor. Component remains in between the punch and die travels parallel to its length as per the program with pull arm mechanism. Punch & Die assembly together travels parallel to component width which is controlled by another Servo motor.

This mechanism benchmarked for mechanical arrangement. As Servo Motor with double ball screw nut along with the controller is costly affair to be adopted as a solution only for single tool selection, for only material selection criteria manufacturers supplied drawings were referred. A mechanism as shown in the figure 6 proposed and reviewed with the Production, Quality, Maintenance, and Tool Maintenance and Manufacturing Engineering department to avail various inputs. Mechanism is simply consisting of wedge piece mounted on the pneumatic cylinder, and will move to and fro as per the cylinder movement in expanded or retracted condition. It is required that when operator presses the ram movement button after locating the component on the press first depressed flat should be observed and punch should not get locked. This will be ensured by pneumatic cylinder by remaining in the retracted condition while taking the first stroke. As the first stroke completes and ram starts for moving towards up condition cylinder should come in expanded condition which will ensure locking of the punch and second stroke movement should start and component will be pierced.

The proposed idea accepted and modeling started based on this concept. At various development stages reviews conducted with the various departments to update the progress of the design and to avail valuable inputs to be incorporated in the design. Many of the raw materials were available in-house like Pneumatic cylinder with maintenance department, Top Bolster, Bottom Plate and guide pillar with Tool Maintenance department, which were required to be modified as per the design and drawings proposed.

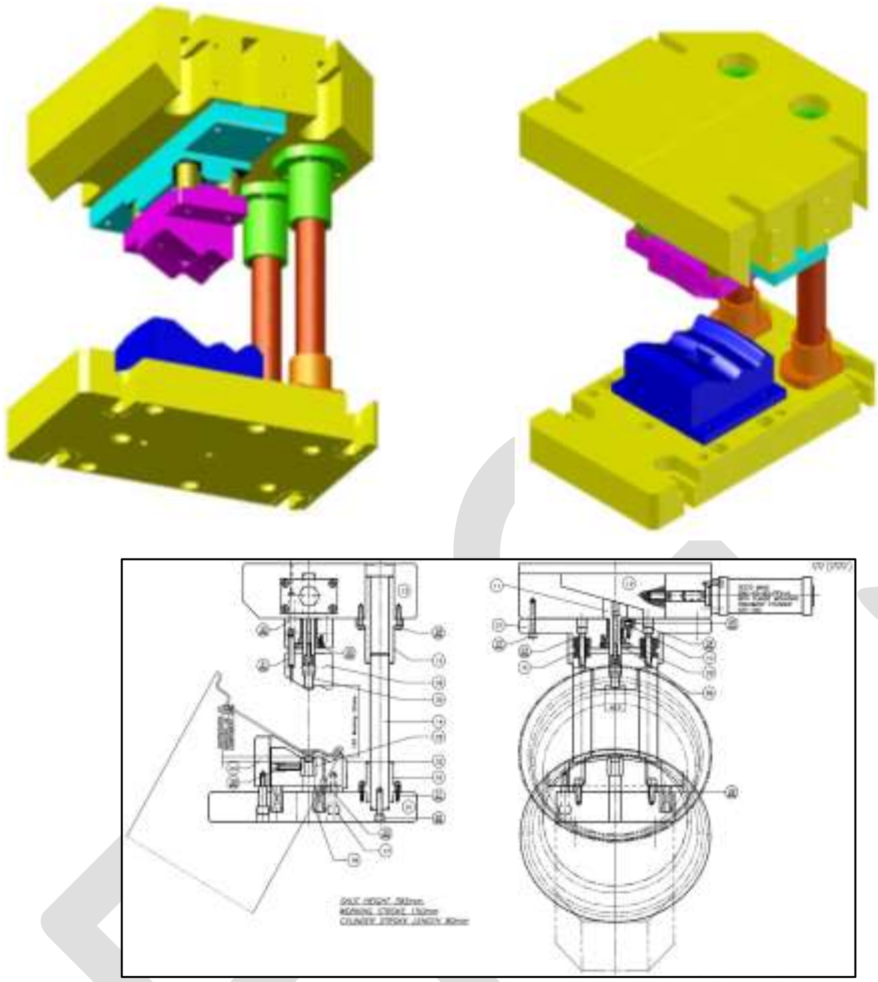

Figure 6 Assembly Arrangement

6. Results and Discussion

As the tool design & acceptance phase completed, the next phase was to manufacture it. It has been subcontracted since in-house tool room was fully engaged for new tool development for new products. Quotations invited from the known tool manufacturing sources. The lowest quote considered by the management and issued a purchase order after calculating the following Return on Investment (ROI).

Savings Per Annum	
Description	**Cost/Year**
Manpowercost by eliminating one operator (Rs 10,000/Month for a Casual Operator, from HR Department)	1,20,000
Cost of power consumption at Mechanical Press (Data availed from the Maintenance Department)	25,000
Cost of reduced Air consumption (Data availed from the Maintenance Department)	1,000
Total	**1,46,000**
Total Investment (As per Purchase order)	**1,41,110**

Table 3 ROI Calculation

As stated above the total cost invested can be taken back within 12 months, if the volume of the productions, Productivity doesn't change. Or if the production volume rises then the pay back can be achieved very quickly than the time projected. The calculation is only based on the present volume being constant for at least a year.

After receipt of the tools as per the purchase order it was inspected thoroughly by Quality department and confirmed as per the drawings. Tools like Top Bolster, Bottom Plate, Guide Pillar and Guide Bush manufactured in-house. Shutdown of the machine planned on the weekend and assembly and installation of the tools completed by Tool Maintenance, Manufacturing Engineering and Production department jointly. Maintenance department also started modification work in the control circuit of the machine to incorporate the suggested changes in the machine.

Automation and modification done by maintenance department for the following:

1. Two stroke of the ram after in a single press of push button.
2. At the first stroke of the ram Pneumatic Cylinder remains in retracted condition
3. After completion of first stroke cylinder extends and hence wedge piece which locks the punch before second stroke proceeds
4. After completion of the second stroke Pneumatic cylinder comes to retracted condition.

After completion of the assembly of the tools and automation of the machine, first trial taken for only depression operation, once depressed portion confirmed as per the quality then punch installed and combined trial taken. It was planned to take the volume of 500 rims for confirming and repeatability and reproducibility for quality of the combined operation.

7. Conclusion

As discussed in concept development, proposed design accepted by the Rim Manufacturing Plant and tools has been partially outsourced and manufactured in-house. Subsequent trials been conducted for combined operation and found successful. Trials confirmed on a lot of 500 pieces for confirming the repeatability and reproducibility. Modified design has been successfully implemented and following benefits are noted and observed by the organization.

1) Elimination of one operation.
2) Improved product quality.
3) Reduction in Cost per Rim.
4) Reduction in processing time.
5) Reduction in operator Fatigue.
6) Reduction in skill level of the operator.
7) Reduction in Rejection Percentage.
8) Reduction in Tool down time.
9) Reduction in Machine down time.

7.1 Future scope

1. The proposed design is implemented only for the Tractor Rear Rim, which can be extended for the other Rims in which similar operations are required. E.g. Truck or Car Rims.
2. In proposed design both the operations are completed in two strokes, more brainstorming required to identify the mechanism through which both operation to be completed in a single stroke.
3. Different materials can be selected in this design, material criteria is limited in this design as company has already fixed the material selection criteria based on standardization amongst all press tooling based on Tool Maintenance.

ACKNOWLEDGMENT

I am grateful to my respected guides Prof. Kunal Motwani Assistant professor, Department of Mechanical Engineering, HJD Institute of Technical Education and Research, Kera, & Mr. N. Vinoth Kumar, Manager R&D Rim Manufacturing Plant, for providing me direction and inspiration during my dissertation work.

I am grateful to Principal Dr. Rajesh Patel and Head of the Mechanical Engineering department Mr. Navnit Patel who has always been ready to offer assistance at any time during his busy schedule. I am grateful to all the faculty members of Mechanical Engineering Department and all my friends who have directly or indirectly helped me during this dissertation work.

I would like to thanks my family who has provided me every prospect and inspiration.

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