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Design and Development of one Hydraulic Cylinder Driven Press Brake Bending Machine

Mr. Gebremichael Tasew[1], Mr. Ajay Jaswal[2]
[1, 2] Dept. of Mechanical Engineering Parul Institute of Technology - Parul University, Vadodara, Gujarat, India

Abstract: This paper discuses design and development of the most essential components of new feature press brake bending machine. In this study, the right angle lever design used to construct new developed one hydraulic cylinder driven press brake bending machine. In addition to this we develop three port double acting actuating cylinder for driving two lever mechanism of the machine. This cylinder both ends mount on lever effort arm point in horizontal direction. In case of press brake bending down ward bending force is needed, for that it needs a mechanism that convert horizontal direction force into a vertical down ward force. Right angle lever is perfectly satisfy this need, for that we develop two lever mechanisms that is at the right and left side of the machine for handling and converting the direction of both cylinder end forces. In this machine lever have a great roll in addition to converting the direction of force it used to maximize the input piston force. The remaining components of the machine is used to help the lever for achieving its application. All current hydraulic cylinder driven machineries uses only piston force for the purpose of drive its mechanism while cylinder force is lost on cylinder support without any function and it is the main cause for machine failure. The main objective of this paper is to develop new feature hydraulic press brake bending machine that solves the problem we observe from current hydraulic cylinder driven machineries. As a result the machine become light in weight low in cost, easy in maintenance and automatic in operation. The mechanical advantage of the mechanism is 6 times per one cylinder as compared with hydraulic cylinder driven machineries that available in the market. The maximum capacity of the machine is to bend 5mm thickness and 1250mm length AISI 1034 stainless steel sheet with a maximum bending force of 524725N. This maximum bending force is generated from 87454.16N piston force. The critical component of the machine is right angle lever, link, upper beam, lower beam, Machine table, machine frame, three port double acting actuating cylinder, , punch and die.

Keywords: Press brake bending machine; one hydraulic cylinder driven; right angle lever; cylinder force; innovative mechanism and three port double acting actuating cylinder.

I. INTRODUCTION

Bending is a process of produce shapes in metal by the exertion of force beyond the material's yield point but below its maximum tensile strength. During bending, the metal is stretched over its external radius and compressed through its internal radius. The mid-point between these points is called the neutral axis and is the location from which mathematical calculations begin. Bending can be performed in the greater majority of bends are made in "press brakes." Like many other machines used in metal fabrication press brakes may be mechanical or hydraulic in operation. In a typical bending operation, a piece of stock is placed between a set of upper and lower dies. Then a moving upper beam lowers the upper die, forcing the work into the fixed lower die.

A press brake is a machine tool it used for bending sheet and plate material, most commonly sheet material.[18] It forms predetermined bends by clamping the work piece between a matching punch and die.

Three dimensional draft of one actuating cylinder driven press brake bending machine was drawn using CATIA V5 software (Fig. 1). As shown in the bellow figure the critical components of the machine are upper beam(1), machine link(2), machine frame(3), right angle lever(4), piston rod(5), machine table(6), punch(7), die(8) and lower beam(9). The most essential components of the machine are upper beam, machine link, right angle lever and machine frame. Right angle lever is used to receive horizontal piston force, maximize magnitude and convert direction from horizontal to vertical down ward and transmit to the machine link. Machine link is used to connect right angle lever and upper beam and it used to allow perfectly constrained up and down movement of punch. Upper beam of the machine which used to receive a concentrated load, convert it into uniformly distribute bending load and transmit to the punch. Machine frame used to carry the whole components of the machine

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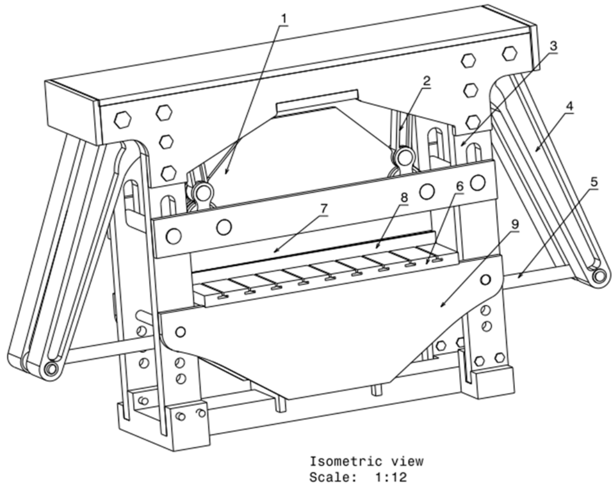

Fig. 1. One hydraulic cylinder driven press brake bending machine

A brake can be described by basic parameters, such as the force or tonnage and the working length.[18] Additional parameters include the stroke length, the distance between the frame up rights or side housings, distance to the back gauge, and work height.[20]

Fig. 2 shows three port double acting actuating cylinder and hydraulic circuit, which used to generate equal in magnitude and opposite in direction collinear forces. Those equal and opposite forces used to drive the right and left side lever mechanism of the machine. As shown in the (Fig. 2) the motor drive the pump for pressurize oil. The pressurize oil pass through filter, direction and speed control valves and injected to middle port of cylinder. This pressurize oil pushes the two piston heads then piston force is generated and cylinder is extracted until its stroke length is completed. When the cylinder retract the piston rod pull the right angle lever effort arm as a result the punch move up.

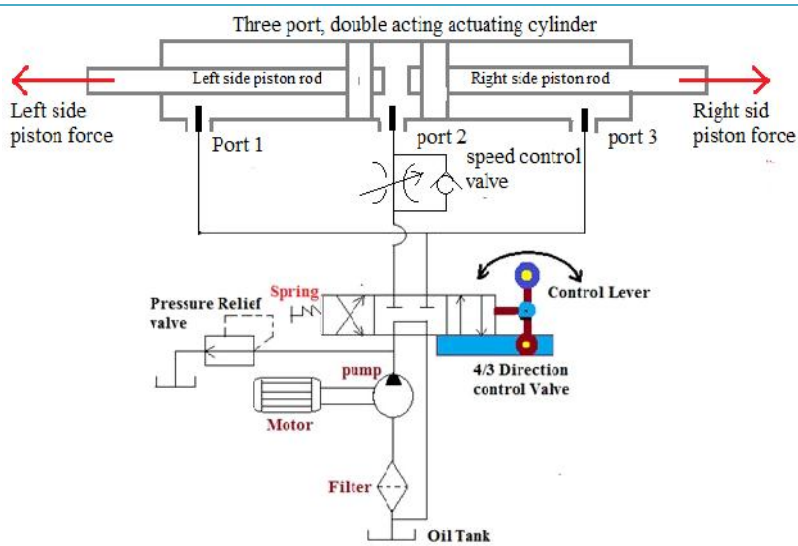

Fig. 2.New developed three port, double acting actuating cylinder circuit

II. RELATED WORK

In hydraulic driven press brake bending machine lots of papers are patented in addition to publish on scientific journals and optimize for making automatic in operation, simple in maintenance low in cost and light in weight. Among those published papers some are taken as references here to see gaps and future works which needs mitigation.

In [1] authors have investigated to design a controller to control electro hydraulic actuator, a model to show the system behavior needs to be obtained first. The work shows that using pole placement method is adequate to control electro hydraulic actuator. The model identification method is Mat lab system identification tool box to approximate the plant model input-output experimental data. In this work simulation analysis shows that the pole placement could achieve better tracking. . In [13] authors investigated to analyze, and discuses on the principle of hydraulic synchronizing system and the hydraulic servo valve synchronous feedback.. the authors conclude that mechanical feedback hydraulic synchronizing valve control bending machine with a control precision of 0.15mm. The synchronous servo principle is new, maintenance is more convenient, therefore mechanical feedback type hydraulic synchronizing valve control system is low cost, reliable, good bending machine control form.

In [4] authors present sheet metal forming process using finite element analysis for large elastic-plastic deformation. The sheet metal bending process is simulated by first element analysis software ANSYS. The simulation result shows that, the bending process occurs only at the bend corner of the sheet. In [5] authors discuss design and static analysis of a connecting rod. Design and analysis of the proposed work is done using solid work software and ANSYS workbench. The stress, deformation and strain evaluation of connecting rod were also done and the result obtained are used valuable in the optimization and improvement to the connecting rod design.

The work carried out in [9] authors focus on a model of the bending process in press brakes is established using Timoshenko beam theory. The methodology presented in this paper proved well suited to analyze the structural behavior and bending precision of existent press brakes and should be useful to optimize their performance and assist in the design of new solution. Work carried out in [15] author shows that, hydraulic press V-bending operation designed, manufactured and modeled with 2 tone maximum press load and the hydraulic circuit are simulated by in mat lab library. The proposed punch and die design consider to reduce the spring back as well as spring forward. The bending press is tested by using a low carbon steel sheet metal with 3mm thickness. The result shows that, there is little amount degree in the spring back and there is no defects on the work piece surface[11].

In [10] author focus on experimental study that have been carried out on the dimension of spring back of bent products. The spring back of several sheet metals with different bending angles was obtained on a modular "V" bending die. The result of the tests were evaluated into graphics and tables. The practical design of bending dies by taking the spring back into consideration was achieved with this study. In [12] authors conducted study on a new incremental bending method based on minimum energy principle. In the proposed method, the steel blank is supported by an array of hydraulic cylinders with rotary head, that insures the blank being properly lifted regardless of its shape and size. According to the work carried out by the authors, the punch location will be at where the error between the current shape and desired shape is maximum. The experiment result shows, the method is successfully used in sheet metal bending. The new method have a number of advantages as comparing the existing method

In [14] authors conducted a study on a robust method for sheet metal bend sequencing. the study concerned on hard rejected criteria and preclusion method of complex bending model. A-star algorithm is described which is able to generate valid bend sequences, that allows to judge bend ability of the work piece. An improved A-star algorithm, lead to an early identification of feasible and near optimization solution. The authors will be focused on the actual circumstances applications of the algorithm for further improving.

III. PROPOSED METHODOLOGY

In case of this new developed machine design , we set the preliminary optional dimensions and shape of the machine element on the basis of its purpose, nature of fastening with other pats and general layout of the machine, in such a case check calculation of the element are performed to determine the actual stress and safety factors for the given diagram and the force. For doing this paper follow the following methodology:

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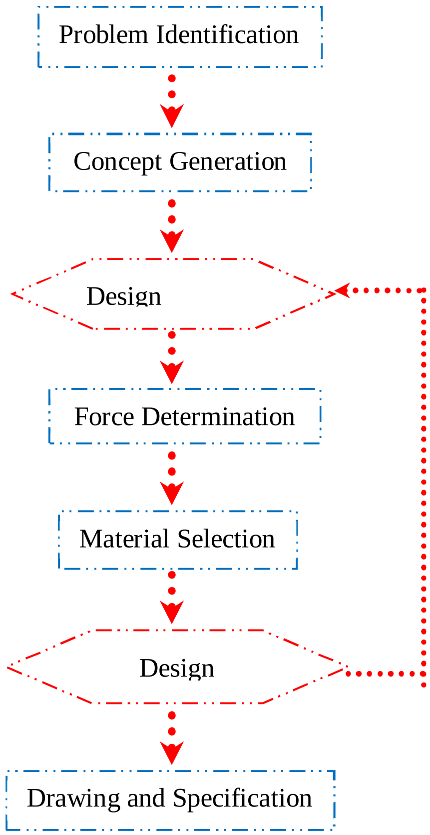

Fig. 3 Methodology flow chart

A. Problem Identification

The main problem identified in this work is:

1) The current hydraulic machineries that available in industries and in the market have a limitation on weight, cost and maintenance.
2) In all hydraulic cylinder driven machineries only use piston force, however the cylinder force is lost on cylinder support without any function.
3) The main cause of failure of hydraulic cylinder driven bending machine is due to high amount of cylinder force that exerted on the cylinder support.

B. Concept Generation

Fig. 4 shows illustration of Pascal principle at work in hydraulic press. According to Pascal's principle, the original pressure p_1 exerted on the small piston A_1 will produce an equal pressure P_2 on the large piston A_2. However, because A_2 has 10 times the area of A_1, it will produce a force F_2 that is 10 times greater than the original force F_1. This effect is exemplified by the hydraulic pres as shown in the bellow fig. 4. based on Pascal principle.

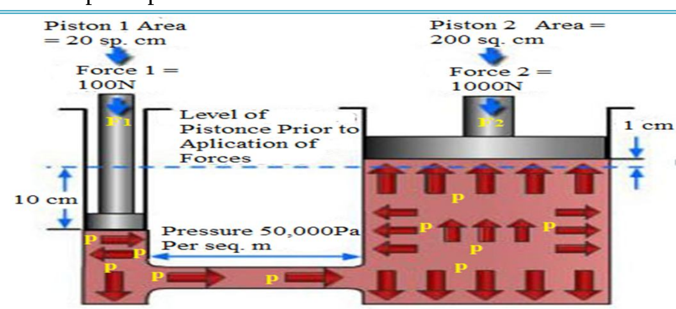

Fig. 4. Pressure distribution in actuating cylinder

Fig 5 shows single acting actuating cylinder pressure distribution and generated pressure force. As shown in the figure the pressure distribution is uniform in all direction therefore the upward force generated on the piston head and down ward force generated on the cylinder base are equal in magnitude and opposite in direction. In this paper we focus on how to use this cylinder force instead of losing to the ground. For this requirement we develop a cylinder that provide two piston rod at both ends with three ports as shown in fig. 7 in addition to this we develop a mechanism that used to receive, maximize and convert the direction of force cylinder as shown in fig. 8.

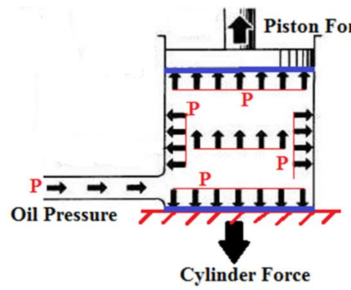

Fig. 5 Single Acting Hydraulic Cylinder Force Generation

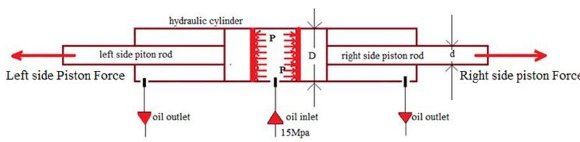

Fig. 6 New developed three port, double acting actuating cylinder

C. Design diagram

After the concept generated diagram, shape and nature of element is shown in simplified form. The force applied on the each element is assumed to be either distributed or concentrated according to fundamental law. the critical components of this machine is one double acting hydraulic cylinder, four right angle lever, two links upper beam, lower beam, bed, frame, punch and die.

1) Hydraulic cylinder gives input horizontal force for deriving the whole operation of the machine.

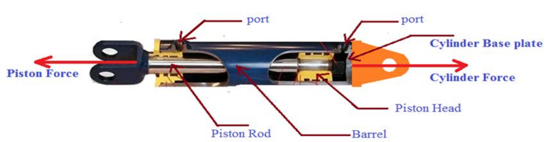

Fig. 7 Currently available in the market double acting hydraulic cylinder

Fig. 8 Model of new developed three port double acting actuating cylinder.

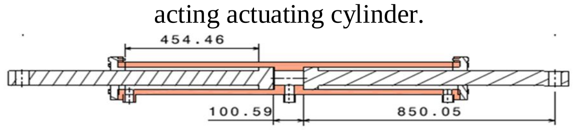

Fig. 9 sectional view of three port double acting actuating cylinder

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In case of press brake bending down ward force is needed therefore it needs a mechanism that convert horizontal direction force into vertical down ward force. Right angle lever is perfectly satisfy this need. In this machine lever have a great roll in addition to converting the direction of force it used to maximize the input piston force due to is mechanical advantage.

Fig. 10 Model of right angle lever

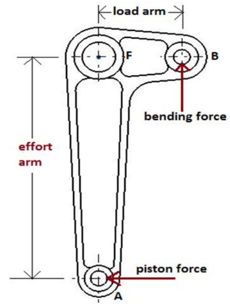

Fig. 11 Free body diagram of lever

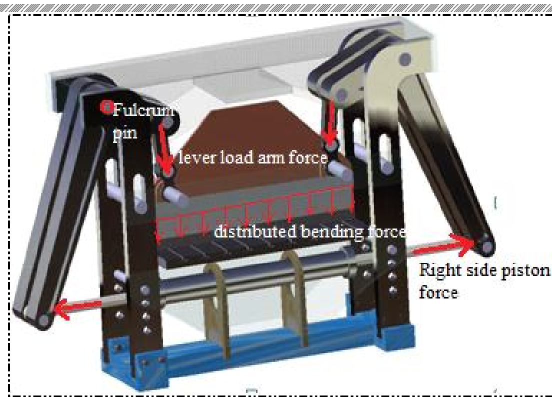

Fig. 12 Three port double acting actuating cylinder driven press brake bending machine force distribution during cylinder extraction.

2) The machine link have a critical application that used to connect the liver load arm point and upper beam. The link is carry a high compressive load therefore it is most probably fail in buckling.

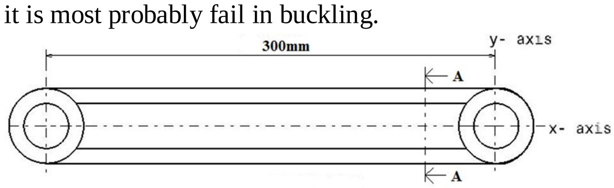

Fig. 13 Two dimensional view of connecting link

3) The upper beam have a trapezoidal shape it carry's uniformly distributed bending force. The shape of the beam is determine by bending and internal shear force analysis for making most economical trapezoidal and triangular shape is recommended.

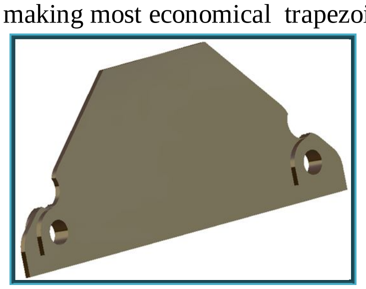

Fig. 14 Model of upper beam

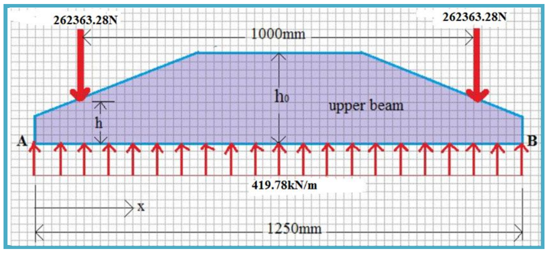

Fig. 15 Uniformly and concentrated force distribution on upper beam

4) The frame of the machine is a vertical column used to carry the fulcrum reaction force. On the frame both tensile and compressive stress is induced due to vertical and horizontal component of fulcrum reaction force.

Fig. 16. CATIA model machine frame

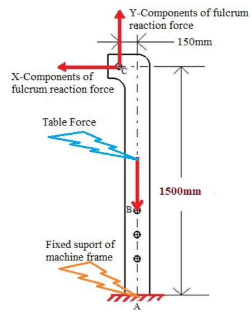

Fig. 17. Free body diagram of machine frame

D. Force Determination

The amount of force acting up on the element in working is determined. This also helps in recognize the element. The aim of this project is to design 5 mm thick and 1250mm length AISI 1034 stainless steel it have 505Mpa ultimate tensile stress.

Maximum Bending Force: In this machine press brake tool is used for bending sheet that forms predetermined bends by clamping the work piece between a matching punch and die.

$$F = \frac{K_{bf} * UTS * L * t^2}{W} \quad (1)$$

Where F = bending force (N)

UTS = ultimate strength of sheet (Mpa)

L = Sheet length along bend axis (mm)

t = stock thickness (mm)

W = die opening dimension W = 8t

K_{bf} = bending factor, K_{bf} = 1.33

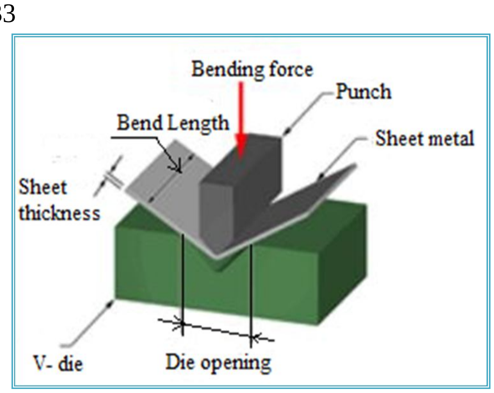

Fig. 18. press brake bending force diagram

$$F = \frac{1.33 * 505 * 1250 * 5^2}{40}$$
$$F = 524{,}726.56N$$
$$F = 419.78kN/m$$

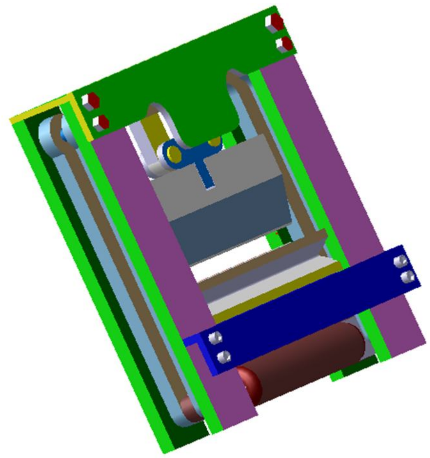

Fig. 19. Preliminary optional shape of the machine

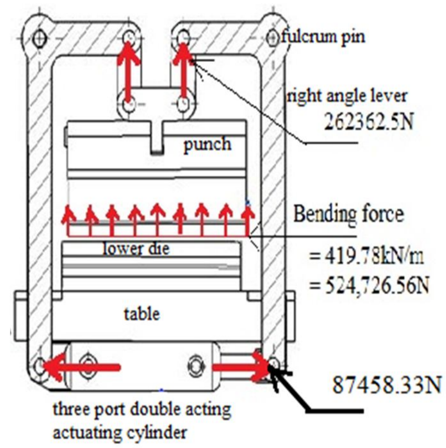

Fig. 20. Distribution forces of the mechanism of the machine

E. Selection of Suitable Material

Proper material is selected for the recognized element and either factor of safety or allowable stress are determined. Material selection is the heart of this project consider the following criteria for selecting proper material.

1) Material property ductile, brittle tough etc.
2) manufacturability of material
3) Environmental effect corrosion, temperature etc.
4) material cost weight of material

The selected material for the critical components of the machine is Stain less steel, aluminum alloy, mild steel and carbon steel

F. Design Dimensions

By using relevant formula of strength of materials the dimensions of the recognized machine element are determined. The most critical components of the machine is right angle lever, upper beam, machine frame, hydraulic cylinder and piston.

Design is a very important stage for creating new products, because it can reduce costs as end product yielded depends on the quality of the design [5].

1) Design of right angle lever: In this paper, right angle lever was designed and applied to press brake bending machine with a capacity of 5mm thickness and 1250mm length stainless steel bending force of 524725N. The amount of force that exerted on the load arm point and effort arm point of the lever is 131181.25N and 43727N force respectively.

The reaction force at fulcrum F is represented by R_X and R_Y

Take moment about F.

$$\sum M_f^{+} = 0; \; F_A\,(1.2m) - F_B(0.4m) = 0$$
$$F_A = \frac{F_B * 0.4}{1.2} = \frac{131181.25N}{3} = 43727N$$

The reaction force at fulcrum point:

$$RF = \sqrt{(F_B)^2 + (F_A)^2} = 138277.1524N$$

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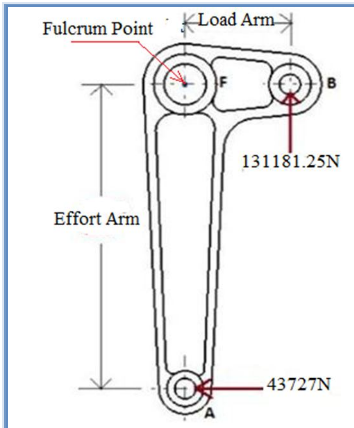

Fig. 21 Free body diagram of right angle lever

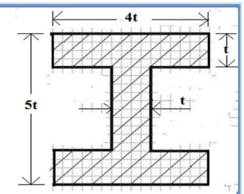

Fig. 4. Standard I section

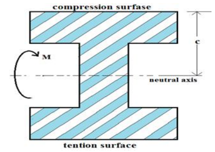

Fig. 22 Pure bending in I section

Moment of inertia for I- Section:

$$I = \frac{4t(5t)^3 - 3t(3t)^3}{12} = \frac{419(t)^4}{12} \quad (2)$$

Determinene the maximum bending moment on section A-A of effort arm at 20mm from the fulcrum poit.

M = F_A* (1200mm-20mm)

M = 43727 * 1180

M = 51597860Nmm

Bending stress is of lever is:

$$\sigma_b = \frac{MC}{I} \quad (3)$$

$$\sigma_b = \frac{51597860 * 2.5t}{\frac{419.78t^4}{12}} 103.33Mpa = \frac{1547935800}{419.78t^3}$$

$103.33t^3 = 3687492.97mm^3$

$t^3 = 35685.53mm^3$

t = 32.9mm = 35mm

weidth of the section = 4*35mm = 140mm

2) *Design of upper beam: Aluminum alloy* upper beam is one very important component of single hydraulic cylinder operated press brake bending machine. By considering fatigue load we choose 62Mpa design stress. The upper beam of uniform thickness b = 20mm exert uniform distributed load ω = 419.78kN/m on the punch. Determine the shape of the upper beam that will be the most economical design. Bending moment measuring the distance x from A and know that internal shear force and bending moment at point A is zero.

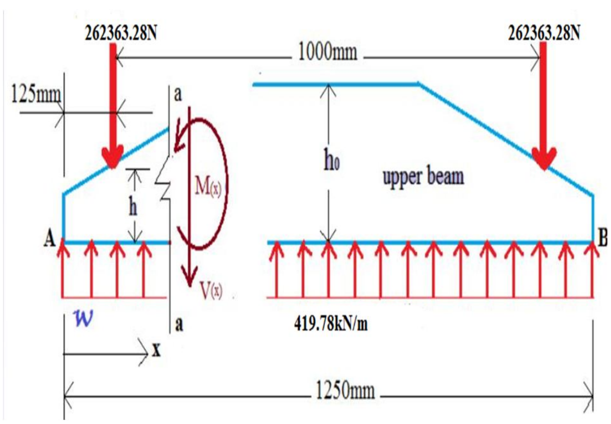

Fig. 23. Bending moment, internal and external forces on upper beam

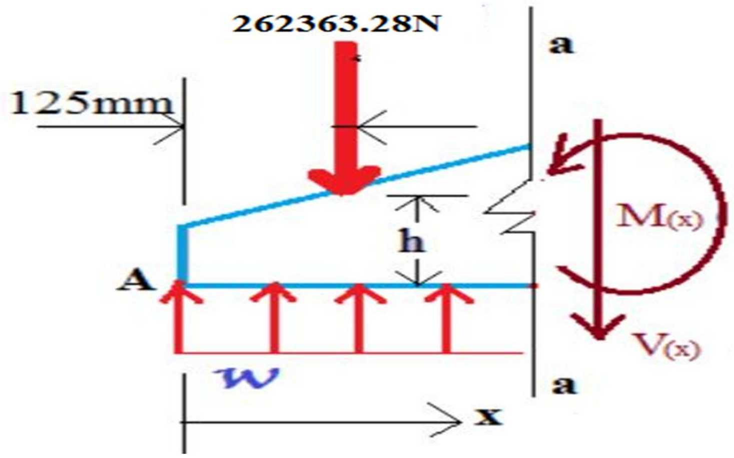

Fig. 24. Section of upper beam @ 0.125m ≤ X ≤ 1.125m

a) Internal shear force:

$$V(x) = \int_0^x \omega dx - 262363.28N$$

$$V(x) = \omega x - 262363.28N$$

b) Bending Moment:

$$M(x) = \int_{0.125}^{x} V(x)\, M(x) = \int_0^x \omega x dx - \int_{0.125}^{x} 262363.28N dx$$

$M(x) = \frac{\omega x^2}{2}$ - 262363.28N(x - 0.125m) , the maximum bending moment occur at the midpoint of the beam that is x = 0.625m.

The maximum bending stress induced is:

$$\sigma_b = \frac{M}{Z} = \frac{6|M|}{bh^2} \quad (4)$$

The maximum height of trapezoidal upper beam is:

$$h^2 = \frac{6(\frac{\omega x^2}{2} - 262363.28(x - 0.125)}{b\sigma_{all}}$$

$$h^2 = \frac{6(\frac{419.78(0.625)^2}{2} - 262363.28 * (0.625 - 0.125))}{0.02 * 62 * 10^6}$$

$$h^2 = \frac{6(81.988 - 13181 - 64)}{1.24 * 10^6}$$

$$h^2 = \frac{78597.91}{1.24 * 10^6}$$

$$h = 0.487885629m = 500mm$$

3) *Design of machine frame:* Frame is the basic component of the machine which used to directly carry the right angle lever fulcrum pine and machine table. The fulcrum reaction force have X and Y components as shown in (Fig. 26)

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Machine frame is a vertical member and it is fixed at the base. It used to carry right angle lever fulcrum reaction force and machine table.

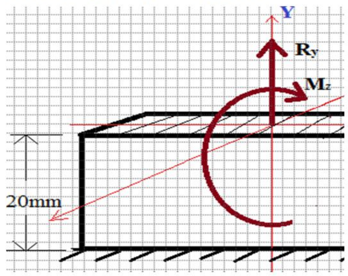

Fig. 25 section of machine frame at 20mm distance from the fixed end

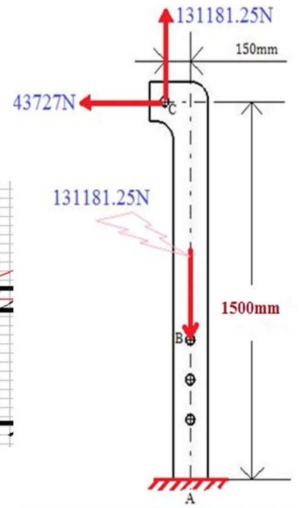

Fig. 26 Free body diagram of machine frame

Area of the machine frame section is A = b * t where b is breadth of the frame, t = thickness of the frame. Assume b = 3t, A = $3t^2$

bending moment about Z-axis

$I = \frac{1}{12}tb^3 = \frac{27t^3}{12}$

$c = \frac{b}{2} = \frac{3t}{2}$

Take factor of safety 3 for mild steel, therefor the allowable tensile stress are

$\sigma_{all} = \frac{\sigma_{ult}}{F.S} = \frac{440}{5}$ = 146.67Mpa

$\sum M_A$ = 43727N * 1500mm – 131181.25N * 150mm

M_A = 65590500Nmm – 19677187.5 Nmm = 45913312.5Nmm

Total stress on the machine frame:

$$\sigma_b = \frac{R_y}{Area} + \frac{M_A * C}{I} - \frac{table\ Force}{Area} \sigma_b = \frac{131181.25}{3t^2} + \frac{M_A * \frac{3t}{2}}{\frac{27t^4}{12}} - \frac{131181.25}{3t^2}$$

$$\sigma_b = \frac{18M_A}{27 * t^3}$$

$$t^3 = \frac{18M_A}{27\sigma_b} = \frac{18 * 45913312.5}{27 * 146.67}$$

t^3 = 208692.132mm^3

t = 59.3mm = 60

therefore b =3t = 180mm

G. Drawing and Spesification

Then the drawing of machine element is prepared showing its dimensions and manufacturing specification, such as accuracy, surface finish and other conditions relating to its manufacture etc. by the help of CATIA software.

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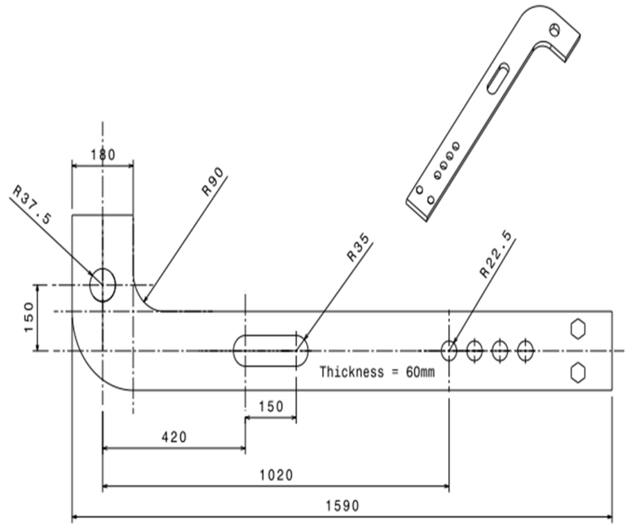

Fig. 27 Manufacturing drawing of Machine frame

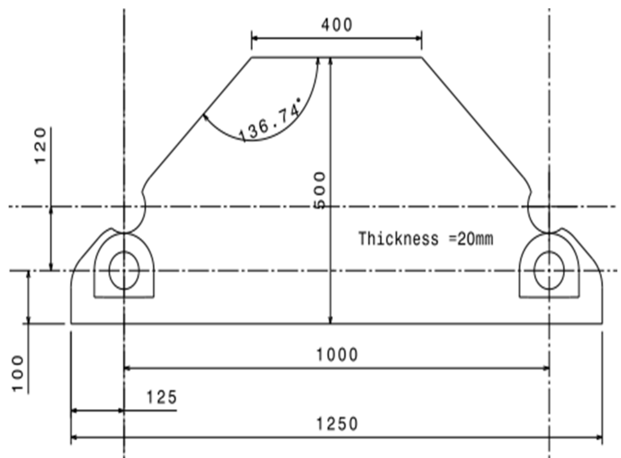

Fig. 28 Manufacturing drawing of upper beam

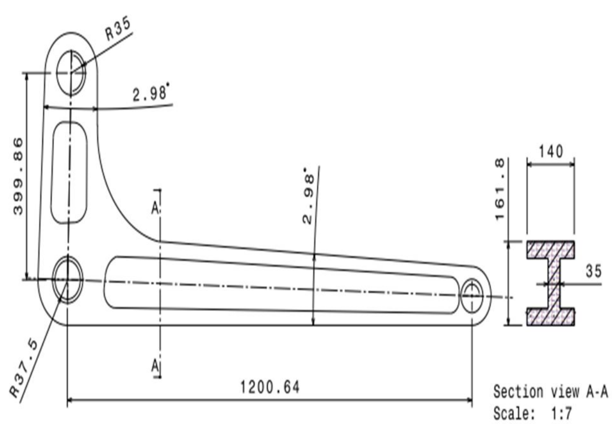

Fig. 29 Manufacturing drawing of right angle lever all dimensions in (mm)

Fig. 30 shows 2D view of full assembly of one hydraulic cylinder driven press brake bending machine with three port double acting actuating cylinder and hydraulic circuit. As shown in the figure the hydraulic cylinder is retracted and all movable components of the machine under initial position.

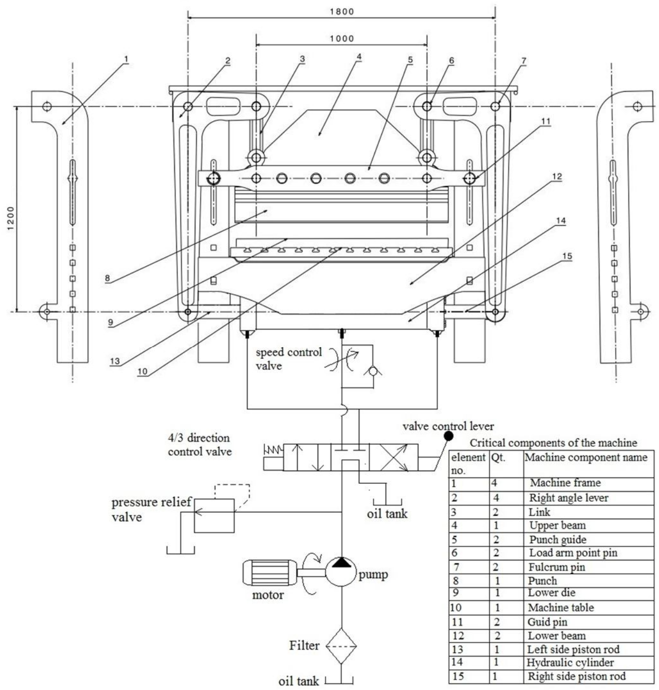

Fig. 30 Details of the machine

Fig. 31 shows that one side lever mechanism of the machine in which full cycle of lever and machine link position and diminution analysis result shown in detail.

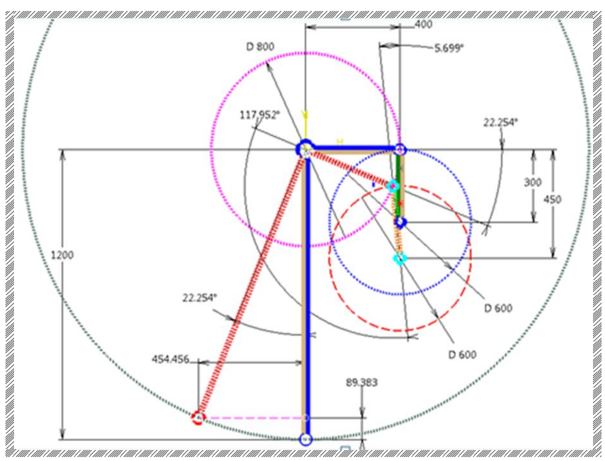

Fig. 31 Right angle lever deflection angle and hydraulic cylinder stoke analysis diagram

TABLE I. MAIN SPECIFICATION OF THE MACHINE

Sr. no.	Machine specification	
	Description	Size/magnitude
1.	Punch stroke	150mm
2.	Cylinder stroke	454.456mm
3.	Maximum bending force	524725N
4.	Height of the machine	1500mm
5.	Width of the machine	1800mm
6.	Width and thickness of sheet	1250mm/5mm
7.	Piston force	87454.1667N

IV. CONCLUSION

In this paper, the need of target market are identified by survey different papers and observing the product in review in patent search. From the observation, shorter operation and fully automatic machine with less maintenance are ideal machine dreamed by bend product manufacturer. Target specifications are estimated after the customer's need have been identified but before product concepts have been generated and the most promising one is selected. This process is done in machine development phase of this work until the best generated concepts is refine and until detail design is generated. A major objective of the new design of sheet bending machine was to be able to ensure that the small scale industries can purchase with small price and light weight for logistic simple operation and maintenance as compare to the current bending machine. the mechanical advantage of the machine is 6 it is the great achievement of this work. in the next phase we will include finite element analysis on overall design of the machine for further optimization and cost reduction.

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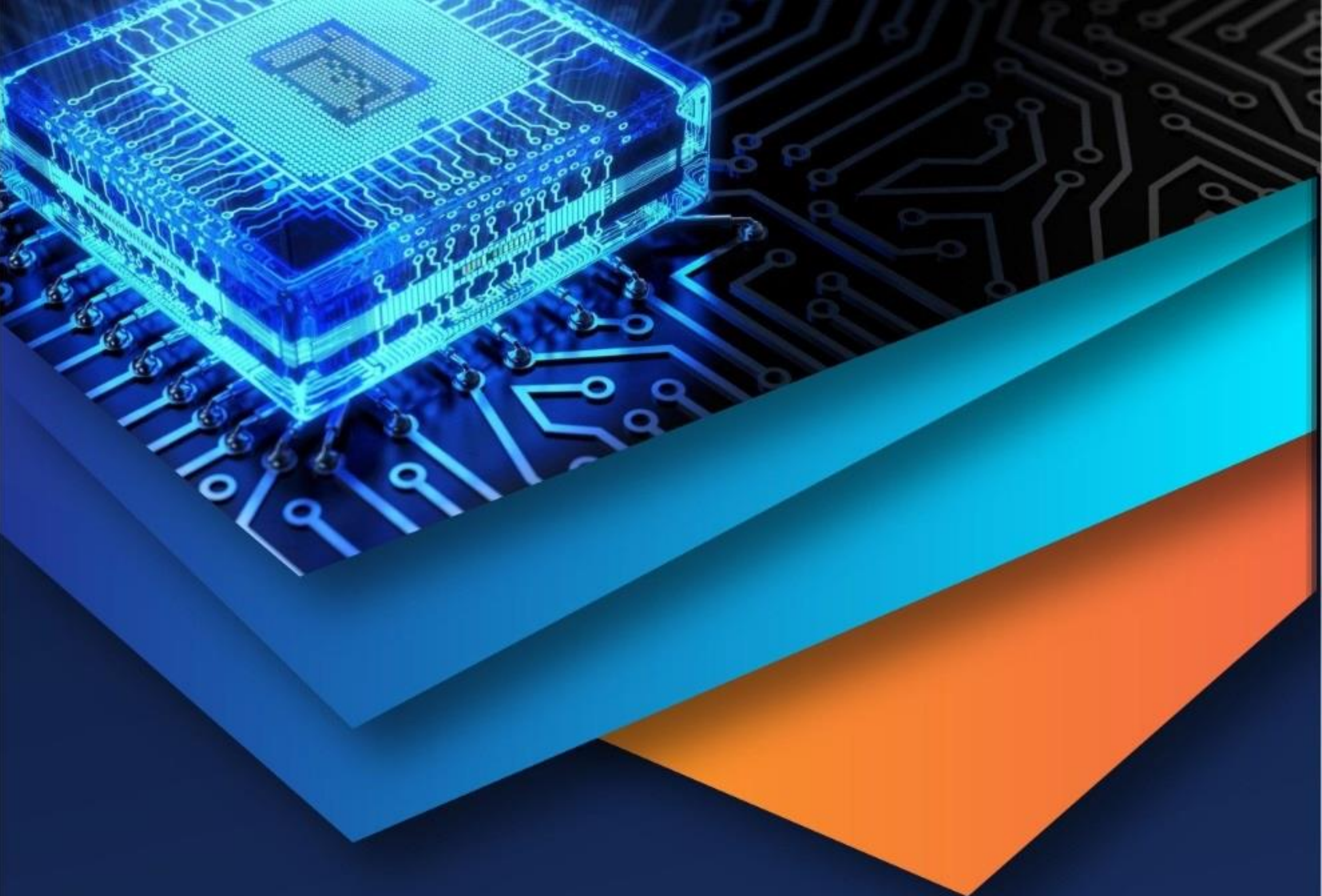

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