STUDY AND EXPERIMENTATION ON MINIMUM BEND POSSIBLE IN CNC BENDING

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Abstract – *The paper discusses about the minimum possible flange length bend that is possible on conventional sheet metal CNC Bending machine. Generally, a bend of about 7-10 mm is possible on regular machine with standard dies (depending on machine), but sometimes Industrial manufacturing also requires lesser flange length bend, about 5 mm or less. In practice, the die of smaller width such as 8 mm is used in manufacturing, but changing the die and setup for, such condition, bending is expensive and time consuming which in fact raises the manufacturing prices for smaller bends. The paper focusses on the possibility and solution for the smaller bend using the die available with the CNC avoiding an expensive setup. For an example, a common die width of 14 -15 mm which only allow bend flange length to 8 – 10 mm. Any bending below is not possible due to the collision between the die and stopper, ultimately stopping the machine. So, to produce bend with a flange length that is smaller than half the width of die, an experimentation is conducted. The bending operation is thoroughly studied. A Number of 3 different CNC press brake model (sheet metal bending) are used in experimentation. Die Shaving, Auxiliary Axes Adjusting, Stopper Attachment are the method or solution that are proposed. The design, manufacturing and employment of each of the solution is done and a set of 5 mm sample bend with each of the solution and on each of the CNC are performed and the result are noted down. Fairly, all the solutions on all the CNCs performed well and our aim of achieving smaller bends with Inexpensive die setups was successful.*

Key Words: Sheet-Metal Bending, CNC Bending, Die Shaving, Auxiliary Axes, Flange Length, Stopper Attachment, Press Brake, Collision detection, Energy mission, Amada, Hindustan Hydraulics, Delem Controller, Errors in CNC, Small Flange Bend, CNC Programming.

1. INTRODUCTION

Sheet metal bending is an operation that involves using forces to change the shape of a sheet. This is done to achieve the desired form or shape needed for a manufacturing process.

In history, before steel came into general use during the latter part of the 19th century, curved structures were frequently constructed from iron, which is cast in liquid form in a curved profile or built up from wrought iron components, either with shaped web plates or in the form of lattice trusses. Because wrought iron was very soft, blacksmiths could curve small components by hot forging. During the 20th century, rolled steel joists were curved by metal benders for use as colliery arches to support underground workings. Hydraulic presses were used initially to curve the joists but eventually, three-roll bending machines were introduced for bending metal. Because joists have very thick webs, they are not susceptible to buckling during the bending operation. As early as 1910, bending equipment incorporating rollers was used to curve bulb flats, bulb angles, and tees for marine use. During the period from 1930 to 1950, small curved steel components were also used in relatively simple building structures. Nissen huts, aircraft hangers, and Dutch barns often had a supporting structure of curved steel angles, tees or small rolled I sections. This is a brief history of the metal bending process

Metal bending is a process by which metal can be deformed when applying force to the subject, which causes it to bend at an angle and form the anticipated shape, which often results in it being in a 'V' or a 'U' shape. A press brake is a tool used to bend sheet metal and uses a punch and die to do this.

The different types of sheet metal operations can fall under two different categories: cutting operations and forming operations.

2. LITERATURE SURVEY

Megson, T.H.G. [1] Generally, a thin plate is defined as a sheet of material whose thickness is small compared with its other dimensions, but which is capable of resisting bending in addition to membrane forces. Such a plate forms a basic part of an aircraft structure, being, for example, the area of stressed skin bounded by adjacent stringers and ribs in a wing structure or by adjacent stringers and frames in a fuselage. This chapter investigates the effect of a variety of loading and support conditions on the small deflection of rectangular plates and presents two approaches—an exact theory based on the solution of a differential equation and an energy method relying on the principle of the stationary value of the total potential energy of the plate and its applied loading. Two types of solution are obtainable for thin-plate bending problems by the application of the principle of the stationary value of the total potential energy of the plate and its external loading. The first, in which the form of the deflected shape of the plate is known, produces an exact solution; the second, the Rayleigh–Ritz method, assumes an approximate deflected shape in the form of a series having a finite number of terms chosen to satisfy the boundary conditions of the problem and also to give the kind of deflection pattern expected.

Guhr et al. [2] Load and shape optimisation are applied to the process of air bending to optimise the damage state in the formed component. The enhanced process of elastomer bending is optimised, which yields a reduced damage state due to the superimposed radial stresses in the critical area of the forming process. The optimisation presented here is twofold. First, the elastomer is replaced by nodal loads to generate optimised loads for a reduced damage state. Second, the elastomer itself is optimised via shape optimisation by adjusting the layer for two kinds of elastomer of varying stiffness. The optimisation is accomplished with the commercial FEM software Abaqus as the solver for the mechanical problem and Matlab is used for optimisation.

Kumar et al. [3] The book is basically written with a view to project Computer Numerical Control Programming (CNC) Programming for machines. This book shows how to write, read and understand such programs for modernizating manufacturing machines. It includes topics such as different programming codes as well as different CNC machines such as drilling and milling. The book is basically written with a view to project Computer Numerical Control Programming (CNC) Programming for machines. This book shows how to write, read and understand such programs for modernizating manufacturing machines. It includes topics such as different programming codes as well as different CNC machines such as drilling and milling.

Li et al. [4] The bending sheet metal inevitably exist bending errors including angle error, linearity error and length error of sideline for reasons that the structure of press brake, the manufacturing precision of press brake and mould and the inhomogeneous characteristics of processed sheet metal. The processing errors of sheet metal can affect the assemblage, increasing subsequent repair to the mold and forming calibration, extending the product development cycle, restricting the further promotion and application of bending forming, especially on the forming high strength and high spring-back sheet metal. The PBH110-3100 CNC press brake in Jiangsu Yawei Co.Ltd. is studied to increase the bending precision of press brake in this study. The bending errors in press break are analyzed in depth according to the elastic mechanics theory, and the rule that the manufacturing precision of press brake affect the press precision is educed. The analysis results have real significance on improving the press precision and reliability of press brakes.

Shantanu Garad et al. [5] Presently, bending machines has tremendous use within the field of workplace. The bending machine is one among the foremost important machine in sheet work shop. Its primarily designed for bending. The bend has been made with the assistance of press which exerts large impact force on the work clamped on the die. Manual bending machine takes extra time and also take more efforts to bend the work piece. Hence, it takes longer time for production. Theres lack of reproducibility, repeatability, and effectiveness. It also fails to satisfy customer satisfaction. So, our aim is that the bending machine is meant in such how that, it works automatically. The automation strategy, when implemented give rise to reduced cycle time, costs and improved product quality. Further probable benefits are increased output, ease of operation and incorporation of business systems. This bar bending machine replacement for manual machine and its a semi-automatic one by using electrical motor, gear box etc., it simplify the manual work and economic wise by reducing the labor.

3. MACHINE REVIEW

This section discusses about the CNC Machines, used in the Experimentation. The specification and the model-make of the machines are reviewed briefly. Three models of machines are being used for experimentation. They all are CNC press brake with Indian and Foreign manufacturer standards.

All the CNC machines listed are used for Sheet-Metal Bending operations form Material range of **MS, SS, Aluminum, GI**, etc. The Thickness of the Sheet that can be Bended, Ranges from **0.5 mm to 5 mm**, all machines considered.

Bend of different angle can be achieved either by changing the Die specifications or the bending parameters.

All three types of bending can be performed in the CNCs, Coining, Bottoming and Air bending. The Bending method used in the experiment is restricted to **Air bending**.

Standard sets of Die and Punch are provided with each machine. The width of the Die and Size of Punch also vary according to the Manufacturer. Width of die is standard for a specific CNCs. The width ranges from **12 mm – 15 mm** depending on the tonnage and operation, the machine can perform. These machines are also equipped to perform hemming and large radius bending (curve forming) operations.

All the machines are sold with sets of dies and punches having different sizes for standard quality throughout the manufacturing industries.

Fig-1: Die Width of CNC machines, from left to right, for Energy Mission, Hindustan Hydraulics and Amada.

ENERGY MISSION PBE 315 [6]

Fig-2: Energy Mission PBE 315. [6]

PBE 315 CNC Press brake is a model of Energy mission, an India (Ahmedabad) based CNC machine manufacturer. The specifications of the machines are,

It has 3 Automated axes, namely Y1, Y2, X, and 1 manual axis, Auxiliary axis. The Auxiliary axis can be manually adjusted for the stopper position vertically. The X axis is for the stopper movement in horizontal to and fro direction for the flange length of bend. The Y axis is for the movement of punch in the vertical direction. The Controller in the machine is DELEM DA53 T, an advance Touchscreen Model.

There are 4 stoppers arrangement with accuracy of ±0.01 mm. the bed length is 1500 mm. the capacity of the machine is **30 TON.** Press is powered by a 3 phase AC motor of 3 HP. System pressure of about 150 kg/cm^2. Operation type is Electronic Foot pedal operation. The Movement of the press occurs in Vertically downward direction.

HINDUSTAN HYDRAULICS EHP80 25/20 [7]

Fig-3: Hindustan Hydraulics EHP80 25/20. [7]

EHP 80 25/20 is the model CNC press brake of Hindustan Hydraulics, Punjab, India.

Its working is same as the Energy mission PBE 315 with a controller of, DELEM DA 52S button Operated, it also has 3 automated axes and one manual auxiliary axis and 4 stopper arrangement.

The movement of the press is vertically downward. Accuracy of ±0.01 mm and bed length of 2500 mm. the capacity is higher, **80 TON** with 7.5 KW 3 phase AC motor. Also Electronic foot pedal and No hand detection system.

AMADA SCHIAVI RG 35-20 [8]

Fig-4: Amada Schiavi RG 35-20. [8]

Amada Schiavi RG 35-20 is a CNC press brake model from a AMADA, a Japanese CNC manufacturer.

Controller offered is Master Task 84 with 4 stopper arrangement and 4 automated Axis system. The Auxiliary Axis Automated movement provides the stopper Calibration with accuracy and fast. Bed length of 2000 mm. **35 TON** capacity operated with lever pedal arrangement. The difference between the other machines and this machine is that the vertical upward movement of Die towards the punch. This machine comes with human hand detection system which can be manually override for special usage.

Mostly these three machine are used in the experimentation and the further details of the machines can be accessed through the official sales and info websites of the respective CNCs given in the Reference Section Below.

4. PROBLEM STATEMENT

Generally, a bend with flange length greater than the half the width of die is possible. But sometime smaller bends are required in manufacturing Industries. This is not possible with the standard CNC bending techniques as the Flange length smaller than the half width of the die, Detects Collision between stopper and die and operation halts.

So, the problem statement is,

To provide a solution to Bend a flange length, in Sheet-Metal, which is about 1 – 2 mm smaller than the Half width of die without Collision Detection.

5. METHODOLOGY

1.1. Identification of Problem Statement.

1.2. Detailed Study of Sheet- Metal Bending Terminologies, Methods, Design.

1.3. Market Survey and Machine Review.

1.4. Designing, Prototyping and Solid Modeling of Solutions.

1.5. Manufacturing and Implementation of Solution.

1.6. Testing, Modification and Noting done the Results.

1.7. Drafting all the research, methods, Modeling, Experimentation and Results, with Conclusion.

6. METHOD

This particular section of paper discusses the methods or Regular procedure used for sheet metal bending using CNC press-brake in manufacturing Industry.

The method or procedure is basically one and same for all the press brake with slight difference in presetting and User interface of the program.

The drafting of job in our example is shown in figure. The machine used is Energy Mission PBE 315 with DELEM DA53 T.

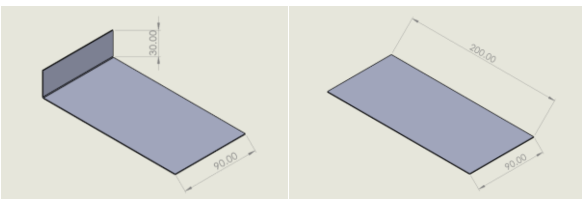

Fig- 5: Drafting with Flat View.

The operator first and foremost studies the drawing and select the right die and punch for operation. Different sizes of die and punch setting comes with the machine. The particular bend length of the job is used to determine the length of die and punch. the bend length is about 90 mm so the die close to the length is 100 mm. The selected die and punch are mounted on the machine and tighten slightly with the allen locating pins. Punch and die are still not in center position and punch has clearance with the clamping which will cause the punch to move while bending which is quite dangersome for the job as well as operator. So a pre-operation procedure is carried out in which the machine is set to Adjust setting and the operator starts the machine and moves the punch to its bottom dead position until the lowest end of punch touches the lowest end in the cavity of the die, in simple word the punch and die meets and a little pressure is applied. These operation requires much skill. Operator is provided is a manual containing Y Axis values required while pressure fitting the Die and Punch. operator applies the pressure manually until the screen shows the Y axis value, given in the manual. The operator removes the pressure, further pressure will damage the die and overall, the machine. Now, the die and punch are tightened thoroughly. This operation ensures the precise mounting of die and punch.

The next step is **Programming** the parameters for bending. Previously G-codes were used for programming. But the advance Delem controller UI provides an application for creating program by input of required bending parameters.

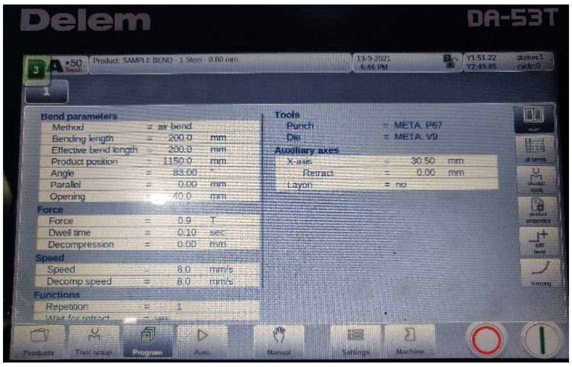

Fig-6: Program Edit Screen.

The program is named as SAMPLE BEND with die and Punch of P67 and V9 respectively.

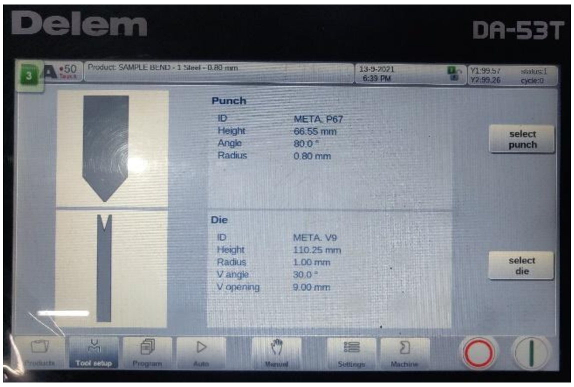

Fig-7: Die selection Screen.

Operator provides the parameter of flange length in Auxiliary Axes 30.50 mm in which +0.50 mm is machine Error Factor for Respective machine, 90º bend angle with -7º Error Factor of Respective machine, 0.8 mm and GI is the thickness and Material of the sheet selected, bend radius of 0.8 mm, type of bending is Air Bending, a 40 mm opening between die and punch for smoother removal of job, etc. all the bending formulae and factor are already programmed in the system by manufacturer and simple input creates the program makes the machine easy to use and time saving.

Some additional parameters are decided by Program like 0.9 Ton of force, Dwell time of 0.10 sec, 200 mm of bending and Effective bending length.

The Red button is for program stop and Green button is for production on the screen.

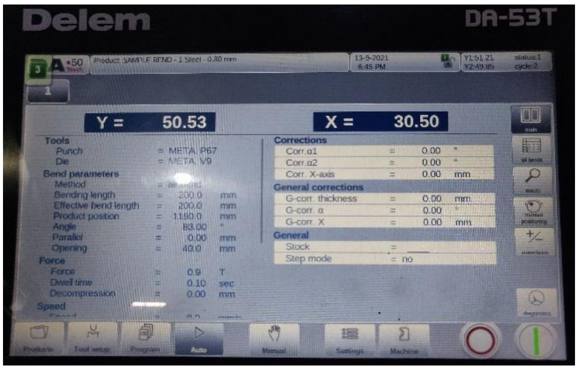

Fig- 8: Auto Program Run Screen.

The model of the setting of die, punch and stopper is shown below.

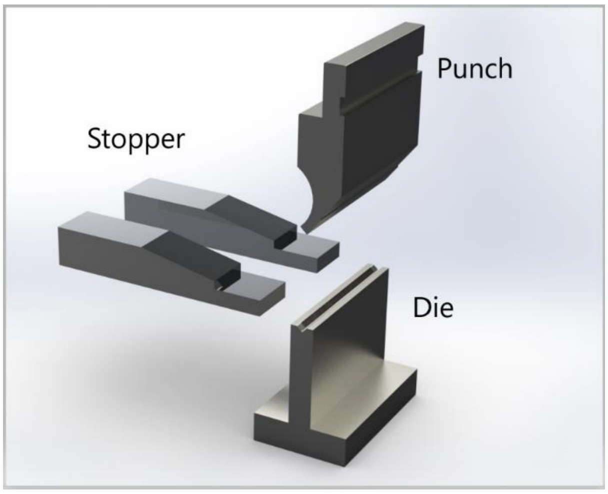

Fig-9: 3D model of Die, Punch and Stopper.

Once the presetting is done the machine is again changed from Adjust to Auto setting and the program is runned. The machine starts to reference the X-axis in which the stopper is referenced to the extent and then to the stated X-axis position in program. Then the machine is ready for production.

The operator rest the sheet on the die and touches it to the two stopper end as shown in figure. All the Step in the Operation are shown Stepwise in Figures below

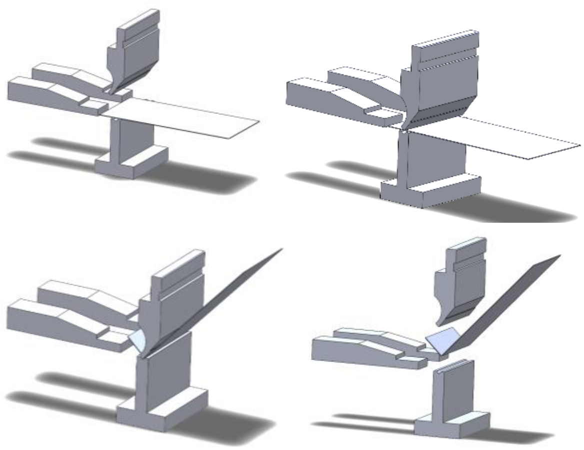

Fig-10: 4 Step in bending (Clockwise).

Then the operator presses the pedal. Which operates the stroke of machine and the punch moves downwards and bends the sheet as clearly shown figure above. Keeping the Center line of Die as datum, the Machine positions the stopper precisely at the input flange length input in programming, so when the bend is performed the flange length of the bend will be accurately as the input given to the machine.

The bending is a forming operation in which the pressure is applied by punch to the sheet metal the metal takes the shape of die cavity. The die and punch are always of harder material (hardened carbon steel) then the workpiece for longer life cycle. Once the bend is complete by the machine then the punch rises and resets itself for the next bend cycle. In air bending the punch and die virtually do not touch each other at all but the punch comes down to the die and stops perfectly about the thickness of sheet, in our case 1 mm. These makes the operation quiet safer for MS, GI and Aluminum, this setting proves effective with these materials because they are comparatively soft. But for material like SS and High carbon Steel the Air bending is not so Effective and Requires other bending techniques like Bottoming, which can also be done on the Same CNC, but will not be covered in these paper.

Fig-11: Actual Sample (Post - Operation).

7. PROBLEM DEFINITION

These section Discusses the main problem, in length, for which the solutions are to be Introduced.

For a standard machine, in standard practice, with the provided standard die width, a flange length of about half the width of die is possible. For instance, In Energy mission the die has a width of about 14.30 mm, so a bend with about 7.2 mm flange length is possible on Energy mission using the given die.

But, a bend, smaller than 7.2 mm is not possible, as the stopper setting for smaller bend, collides the stopper with the die and as the machine detects a minute back pressure due to collision which halts the machine immediately. So a smaller flange length bend does not seem possible with this particular setup. But, in the manufacturing industry smaller bend (flange length) are required.

To understand the problem more effectively a practical approach is used. In sample example above, the 30 mm flange length bend was explained. The die of 14.23 mm was being used in Energy Mission CNC. All the parameters and explanation are based on this case only. Any bend above 30 mm is possible until the obvious constraints, but below 30 mm, the lowest in the case, is up till 7.15 mm only (which is half the width of Die). If the Input of X axis is given to about 6 mm the stopper will approach 6 mm but as the die material of 7.15 mm width from the origin or central axis of CNC machine restricts the stopper movement any further as shown in the figure below.

Fig-12: Collision of Stopper and Die.

There occurs a collision between the die and the stopper and a little back pressure to x axis is induced with stops the machine (halts the electric pump and seizes all operation). A prompt is displayed on the display of machine as shown in figure.

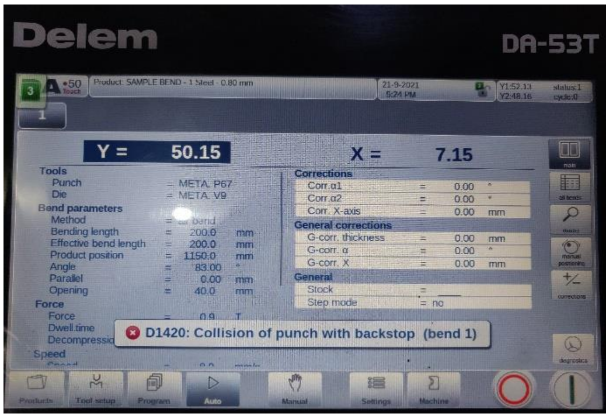

Fig-13: Prompt (back stop means stopper, the value of x axis is true and no error factor).

This problem is also true for Hindustan Hydraulics and Amada as well. So, a solution is required for Bending the sheet to a flange length lesser than half the width of die. The proposed Solutions are discussed in the sections below.

8. SOLUTIONS AND EXPERIMENTATION

Different solutions are proposed and the solutions are considered with respect to all three CNCs, majorly the Energy Mission model and for simple understanding and simplicity a single example is performed in all cases to get required results. A 5 mm flange length bend is taken as constant example throughout the solutions.

An approximate flange length of 7.2 mm can be performed on energy mission model with about 14.30 mm width die and standard settings. The bend any smaller shows a collision error. The main problem with collision error is the back pressure exerted on the stopper by the die which the machine detects and stops the operation.

8.1 DIE SHAVING

The die material restricts the moment of stopper. So, an approach of removing the material, that collides with stopper, is proposed. For bend of about 5 mm to be achieved, a 2.2 mm material (approx.) will be needed to be removed. So for clearance and manufacturing tolerances a 2.64 mm material is shaved. The trimming is done from one edge of the die towards the center. Any one edge could work as the die is symmetric. But the amount of material removal should be critically decided. The die's dimension, terminology and construction is thoroughly studied. The die's valley or cavity is most important and critical area of die and any alteration in that part will damage the die and ultimately the operation. But the die has enough area to work as well. There is an 8 mm flat land on the die which is used for straight placement of flat sheet for operation. So being able to use 4 mm flat land for trimming, the properties of the valley and die are not that much hampered.

Cutting of die is not an easy operation as the die material is high quality tool steel which cannot be cut by standard milling or grinding operations. As the die width is comparatively small, the operation needs to be precise and accurate to a tolerance of about ~0.01 mm.

In this case, Advance milling is used as to shave the material. An advance tool material milling operation is performed to remove about 2.64 mm material of die from the edge of die in transverse direction which will cut about 2.64 mm material of top land and leave about 1.36 mm of top land for the purpose. This will make the total die width to about 11.66 mm. The milling is done using CNC Mill with a side milling cutter in 2 passes with the first rough pass of 2.5 mm depth of cut and a finishing pass of 1.4 mm cut and to a length of 100 mm in horizontal direction and about 26 mm in vertical direction. The figure containing the model of the shaved Die is given below.

Fig-14: Modelled DIE after Shaving.

Any material removal further than 2.64 mm will damage the integrity of the die and any lesser removal will not let the solution to serve it purpose.

There are two possible methods to shave the die material accurately and precisely, one is milling of the die and another method is EDM/Wire cutting of die. Both the methods have its advantages and limitations. As in EDM cutting, die is more accurately machined compared to milling, also the surface finish is high, the drawback of EDM cutting is, it is recommended only for shorter length die as EDM has cutting range of 150 - 200mm length also it is quite expensive compared to milling. On the other hand, milling can be performed on larger die length, also it is comparatively cheaper than EDM.

After the die is machined/ shaved it has a width of 4.51 mm from the center. As previously, using the die allowed only 7.2 mm bend but now the range of bend has increased by 2.64 mm. A sample bend for 5 mm is programmed and the shaved die is mounted on the CNC, now as the stopper approaches 5 mm and stop at 5 mm which still leaves about 0.49 mm clearance between die and stopper faces and no collision is detected. The bend is successfully performed. The same technique is used for other CNC with about 4.7 mm shave for 15.02 mm die of Amada. The same sample bends were performed on the Amada, giving successful results too.

8.2 AUXILIARY AXIS ADJUSTMENT

In this Approach, a bending method is introduced in which smaller bends can be produced without damaging or counter fitting any parts in the machine. There are different axes in CNC press brakes, vertical Y axis and horizontal X axis and a Third axis called the Auxiliary axis. This axis is used for the vertical movement of stopper. In some press brake, like Hindustan Hydraulics and energy mission, the auxiliary axis is manual or semi-automated. But also, in some press brakes, like Amada, the auxiliary axis is automated. The auxiliary axis movement can be used to determine the exact positioning of stopper contact surface for different orientation of sheet metal Workpiece. An Auxiliary Axis Adjustment is applied to achieve desire results. As the name suggests, the stopper axis is adjusted manually or by Input and stopper is step in desired position for bending. Amada is used in Implementation and explanation for this Approach as Amada has automated Auxiliary which makes it prime Example.

Amada uses a different method for sensing collision detection. The stopper is actually a loose piece which is attached using a ball joint release, so if the stopper face clashes with the die material in front, due to sudden pressure the stopper detaches safely and pushes itself out of place preventing from further damage to the die or machine as whole.

As the programming for smaller bend does not hinders with the machine working, so X axis can be set to 4 – 7 mm bend. All the other parametric input will be the same as a conventional bend setting requires. Just, in this case, the auxiliary axis is manipulated to a setting where the bottom face of stopper just rest on the top surface of die, when the X axis is approaching the extreme position. Now as there is no possible way for collision between stopper and die the collision detection does not occur and the machine operates as general. About vertical 0.2 mm of clearance is kept so that there is no rubbing friction and also accounts for machine error. The clearance is prescribed as, for 1 – 0.8 mm sheet, it is kept 0.2 mm which gives about 0.8 – 0.6 mm contact area between sheet and stopper. Also for 2 mm sheet the clearance can be set to 0.6 mm. It should be kept in mind that only about 2 - 3 mm excess of stopper material rests on die, flange length of 4 – 7 mm. the setting is shown in the figure below.

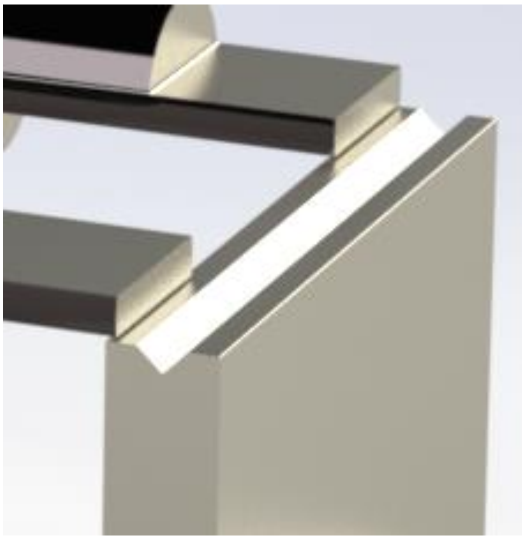

Fig-15: Auxiliary Axis Adjustment.

Any material further will crush the stopper between the die and punch. operator needs to be very precautious while setting the auxiliary axis. As per this setup on Amada, Flange length of 7 – 4 mm is possible and successful without Damaging or counter fitting any parts of the machine.

For Amada, the Auxiliary axis being computer controlled speeds the operation by just an input. For machine like energy mission and Hindustan hydraulics the auxiliary axis is manual and hence the setting is done by using Vernier and gauges and time for calibration is considerable.

8.3 STOPPER ATTACHMENT

In this approach, an external Attachment is used for the smaller bend to performed. Virtually the workpiece needs to positioned, for a 5 mm bend, at about 2 mm offset from the stoppers extreme position in a conventional CNC press brake with collision detection setting. Explaining with an example, the of Hindustan Hydraulics having 13.02 mm Die width will have minimum possible bend of 7 mm, any lees than that will detect collision. So, virtually we need the stopper at 5 mm X axis with the machine detecting the collision. This is only possible by passing the machine setting and introducing an Attachmental Piece which will act as an offset of 2 mm for the bend to be possible.

The design, Modeling and Prototyping of the attachment is done by keeping in mind the terminology and design of Stopper and machine. The material of stopper is also considered. A prototype design of attachment is shown in figure below

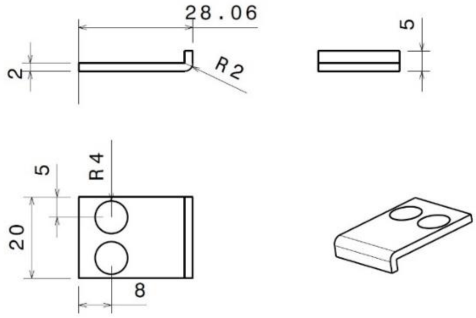

Fig-16: Attachment Geometry.

The Attachment is made about 2 mm Thick, 20 mm in width and 28 mm Long. The material used is 42CrMo Die Steel and the Attachment is manufactured using Wire-Cut EDM process. The clamping on stopper is done using magnets. Two fairly strong Button magnets with 8 mm diameter and 2 mm thickness are press fitted on the attachment. For other bending operations the machine needs to work as usual, so the drilling or tampering with stopper was prohibited for better quality of working of machine. so, magnetic clamping was the feasible solution which does not physically tampers or hammers the stoppers integrity.

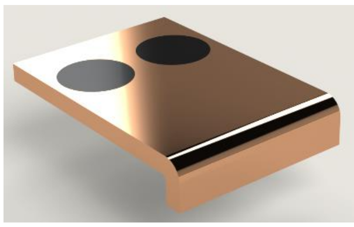

Fig-17: Attachment.

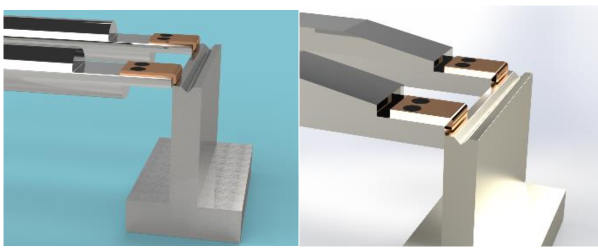

Fig-18: Attachment on Amada Stopper (left), Attachment on Hindustan Hydraulics Stopper (Right).

The attachment is mounted on stopper as shown in the figure. This virtually increases the stopper Length by 2 mm, so, now any input to the stopper's X axis will act as (-)2 mm for the flange length. For example, if we input 10 mm on X axis, the Stopper Will Exactly stop at 10 mm X axis but due to the Attachment the Flange length of the bend will come out to be 8 mm. Also the attachment is not on the collision path to the die, which allow the Attachment Surface to move over the Die with enough Clearance. This finally helps in Bends like for 15 mm width of die, if the bend requirement is 5.8 mm the X axis value will be 7.8 mm, which clearly predicts that there should be no collision and a successful bend of 5.8 mm can be made, if the Attachment is mounted.

The material for Attachment is chosen as tool steel purposely as it will be in Simultaneous Contact with the SS or MS sheet and over time any Softer material will degrade. No other conventional Manufacturing Technique is recommended and heat treatment is must.

9 RESULTS AND OBSERVATION

A set of sample bend of 5 mm Flange length were performed using all three Solution on every CNC press brake. The results were observed and noted.

The die shaving method was tested on energy mission and Amada. Hindustan Hydraulic was neglected as the thickness of flat land on the die of Hindustan hydraulics was less than 3 mm. The availability of Flat land for shaving, in case of Amada and Energy mission was high which increased the range of the solution. The Test bends had Considerable Accuracy. The below figure shows the shaved Die of Energy Mission with 2.64 mm of shaved face on one side.

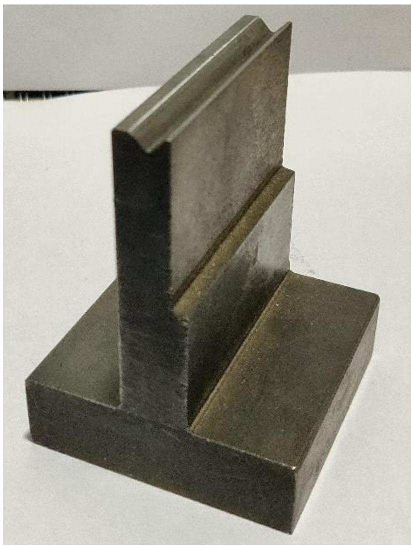

Fig-19: Actual Shaved Die of Energy Mission.

The solution is quite suitable in General Practice as no extra equipment setting is required. Also the same shaved die can be used for bends with any flange lengths, so multi bend operations is supported by this method. This works as an Excellent Advantage of the solution. Some testing on multi bend operation was also successfully performed for checking the speed and accuracy of machine with the shaved die. The main drawback of this solution is, that the integrity of the die decreases. As the die, further of shaving, was rated by the manufacturer for about 3 – 4 mm sheet thickness bending. After shaving the die's rating is considerable dropped to 2 mm sheet thickness bending. This is true for Energy mission as well as Amada. The Amada Die Showed Better results in Bending Cycles than Energy Mission. The Shaving Operation of die is also Expensive, weather using Wire-cut EDM or Advance milling. This also acts as a drawback.

Auxiliary Axis Adjustment was mostly tested on Amada. Some testing was done on Hindustan and Energy Mission as well. This method was quite promising on Amada CNC. Amada having the feature of Automated Auxiliary Axis of Stopper, which only required the operator to note down the auxiliary calibration value of stopper for Smaller bends, once. After that only the operator needs to punch the value during the programming. The Actual Setting of Die and Stopper Using Auxiliary Axis method for Amada is shown in the Figure below.

Fig-20: Actual Figure of Stopper arrangement on Die using Auxiliary Axis Adjustment Method.

Figure 12 shows the Arrangement without the Method being used which Results in Collision of the Stopper with Die. And Figure 20 above shows the use of Auxiliary axis method and preventing the collision between die and stopper and successfully completing the operation. This method works in multi bend programme as well, but drawback is that considerable long flange lengths bend, example – 100 mm and more, are not Suitable as the sheet metal slips below the stopper due to its own weight. The method has same results with the Hindustan Hydraulics and Energy Mission CNC, but only problem there was the Auxiliary axis was manual. So the operator needed to calibrate the axis using measuring tools and this took quite some time which directly affects the cost of manufacturing. Also this problem of calibration was not a onetime thing in case of Hindustan and Energy Mission. It had to be done every time the die is replaced or re-mounted on CNC. This seems to be the main drawback of the solution that the method is only compatible with machine having automated auxiliary axis in built. Skill of operator requirement is high for this operation to performed successfully. Tolerance needs to be provided between die Stopper So Vertical Crushing or frictional rubbing is prevented. This solution is mostly Inexpensive of all the solutions, as it does not require any external equipment mounting or tampering of in built equipment. This solution only requires auxiliary axis for stopper which comes in built in all Regular Press brakes.

For the Attachment Method several Test bend were performed on Amada and Hindustan Hydraulics. All the bends Produced Satisfactory results. Several Design of Attachment were tested from which the Proposed Attachment Design was the most Economical and Simple. The material of Attachment 48CrMo is a tool steel with high hardness to begin with which increased the Life of Attachment. All type of bends, smaller or Larger, can be produced using this method as the only variation will be the (-)2 mm Offset to the desired flange length should be the input. Magnetic clamping turned out to be great as the Attachment would hold its place correctly and mounting and Unmounting was quiet easy. The Attachment surfaces which remain in contact with the stopper surface are precisely machined and surface finished. Manufacturing and material selection is expensive, but a onetime Investment. As the stopper design of Energy mission is Not compatible with our design of Attachment, this solution did not work well with Energy mission model. But a specific design of attachment for specific models of machine is also an option. The attachment was used for about 100 cycles and not a scratch on workpiece or attachment was observed.

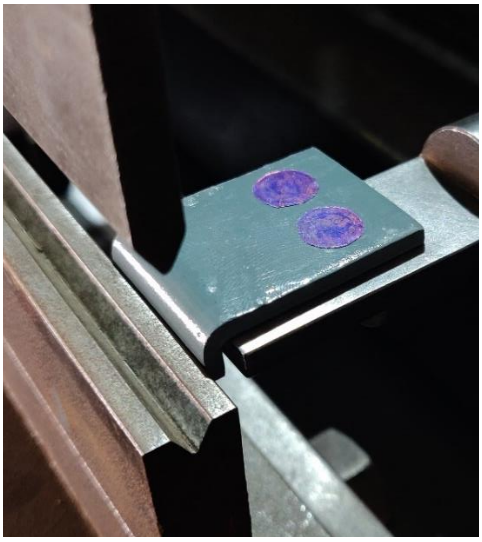

Fig-21: Actual Setting of Attachment on Stopper.

10 CONCLUSIONS

The objective of the experimentation and the paper was to derive some simple solutions for the problem faced in manufacturing of smaller bends using conventional CNC press brakes. The solution of Die shaving turned out to be the most compatible with Energy Mission. Auxiliary Axis Adjustment showed higher compatibility with Amada Variant. Stopper Attachment Method was useful for Hindustan as well as Amada and to some extent Energy mission too. So, this tell us that the compatibility of every solution proposed can only be Stated by study the Particular CNC press brake in use.

There are currently many solutions for the same problem like using a Die having smaller Width to begin with, special purpose CNCs for small bend Operations. But this solution itself are quite Costly and can only be preferred in very large scale manufacturing. Our solution is Better suited for Small scale manufacturer using CNC Bending. Our solutions are proposed, keeping in mind the Investment Cost, Tampering Constraints, Skill of Operator and precision of operation for small Scale CNC users. The overall Results of all solution with Different CNC was Quite satisfactory to the Small scale manufacturing Standards Required by the Industry.

11 ACKNOWLEDGEMENT

This Study and Experimentation was Supported by **METACRAFT ENGINEERS.** They provided us with Adequate Manufacturing Knowledge, Guidance, CNC Machines, working Space, Measurement Tools, Modeling Software (SolidWorks 2020), Financial Compensation.

The CNC Milling and Wire-Cut EDM operation for die shaving and Attachment respectively, were out-sourced.

12 SAFETY MEASURES

While Performing the Experiment, using the CNCs, some Basic Safety Measures were followed,

12.1.1.1 Wearing Rubber Gloves while handling Sheet metal.
12.1.1.2 Short Sleeved Clothing or Apron were used while operating the CNCs.
12.1.1.3 Compulsory Safety Shoes On Work Floor.
12.1.1.4 Switching Off the CNCs when not in use.
12.1.1.5 Strictly Avoiding and part of body like finger or hands to come in contact with the CNC bend volume, while the machine is On.
12.1.1.6 Double checking all the Clamping Bolts, programme inputs, Workspace Environment before starting the production.

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