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Construction and Performance Test of a Manual Pipe Bending Machine

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Abstract- In modern manufacturing, different type of structures are used that need pipe bending. In today's life SS pipes are frequently used in furniture and decorative works. Pipe bending is quite different from rod bending and it needs special technique otherwise there will be distortion at the bends. Thus, pipe bending machines are used to bend different types of pipe. They can be automatic, semi-automatic or manual type. Manual pipe bending machines are used to bend small diameter pipes and particularly in small entrepreneurs. This paper presents the design, construction and performance test of a 3-roller manual pipe bending machine that could be used to bend a 25mm diameter pipe. The lower two rollers are kept at fixed height and the top middle one could move up and down to give the required shape and bending radius. A lead screw and hand wheel is used to force the middle roller down and give different deflections in the pipe. The rollers were made of cast iron and the base and the structure were made of MS plate. In the performance test 15 and 20 mm GI pipe was used and their bending radiuses were measured for various vertical displacement of the middle roller. It is found that bending diameter depends only on the vertical displacement of the middle roller. The project result shows that for increased displacement in the middle roller, the pipe bending is more accurate and deviation between the theoretical value and the experimental value of bending diameter is reduced.

Key words: Pipe bending, bending machine, roller bender, manual bending.

1. Introduction

For various applications, bent tube or pipe products are employed in manufacturing of many kinds of high-end industries such as aviation, aerospace, ship building, automobile, steel structures, furniture and decorative works, transport appliances, fluid arrangements and in various mechanical parts. This may be because of reduction in the production cost and weight of the structure. But pipe bending is not as simple as rods because there is chance of distortion at the bends, if sufficient care is not taken. Also, for precision works, accurate dimensioning and shape is essential. This needs the requirement of a proper bending machine that could satisfy the above requirements. To reduce the power needed to driving a machine proper arrangement and design is strictly necessary. In modern pipe bending machineries the operation is maintained with accuracy and a wide range of bend operation is performed. There is semi-automatic and automatic version of pipe bending machines that requires minimal need for the presence of an operator. The semi-automatic pipe bending machine seems to be most preferred due to its low running cost, flexibility and requirement of less operator interface. In developed and developing countries automatic or semi-automatic system is widely used while in under-developed countries manual bending machine is useful because of its simplicity and small scale production, particularly for a small entrepreneur.

There are various types of bending machines. For basic pipe bending methods, rotary-draw bending, press bending and roll bending are commonly used. The rotary-draw bending is the most standard method used on rotary type bending machines which are powered either manually or by numerically controlled devices. The rotary-draw bending consists of the rotating bending form, clamping die and pressure die. The work-piece is secured to the bending form by a clamping die. As the bending die rotates, it draws the work-piece against the pressure die.

The press bending method uses simple tooling and is quick and easy to set up. The press bending draws power from a hydraulic power source. The pipe is situated in the die and then pressed; for this the pipe takes the shape of the die. Roll bending is used for producing work pieces with large bending radii. The method is similar to the ram bending method, but the working pulley and the two-stationary counter pulley rotate, thus forming the bend. Normally, there are two fixed pulleys and one moving pulley and the work-piece is passed forward and backward through the pulley while gradually moving the working pulley closer to the counter pulley which changes the bend radius in the pipe. This method of bending causes very little deformation in the cross section of the pipe and is suited to producing coils of pipe as well as long sweeping bends like those used in powder transfer systems where large radii bends are required.

For industrial purpose and where rate of production is important, automated pipe benders are used. But in the developing countries and particularly in rural areas where electricity and other power are not available, manual pipe bender should be the only alternative. Also, for pipes with smaller diameter can easily be bent without the external electric power rather by manual power.

H. Yang et. al. [1] developed one kind of pipe bending machine with the key components having enormous

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quantities and diversities. The bent tube parts satisfy the increasing needs for light-weight and high-strength products from both material and structural aspects. The tube bending has become one of the key manufacturing technologies for lightweight product forming. Through the analysis of bending characteristics and multiple defects, advances on exploring the common issues in tube bending are summarized regarding wrinkling instability at the intrados, wall thinning (cracking) at the extrados, spring buck phenomenon, cross-section deformation, forming limit and process/tooling design/optimization. Some currently developed bending techniques are reviewed in terms of their advantages and limitations. Finally, in view of the urgent requirements of high-performance complex bent tube components with difficult-to deform and light weight materials in aviation and aerospace fields, the development trends and corresponding challenges are presented for realizing the precise and high-efficiency tube bending deformation.

Hiroyuki Goto et al. [2] present a new flexible bending machine and its practical applications. The proposed machine uses a new method. When tubes are fed into the fixed and mobile dies, they are bent by shifting the relative position of the mobile die. The bending radius is controlled by the relative distance and orientation between the mobile die and the tube. The bending angle is controlled by the length of the fed tube. This forming process has a big advantage. A change of the expected bending shape will need no change in the tooling system but only a new definition of the motion of the active die and the length of the fed tube. The active die movements are controlled by a 6-DOF Parallel Kinematics Mechanism (PKM) with hydraulic servo drive. Making use of the PKM serves not only to achieve a complete motion along 6-axes but also to obtain a high dynamic motion of the bending machine. Application examples show that the bending machine can be applied to designer's interiors, universal designed products, and automotive parts. Until now these processes have been difficult to achieve using a conventional bending machine.

H. A. Hussain [3] designed and developed a bicycle integrated pipe bending mechanism. The machine consists of a chain drive, compound gear train that is utilized for bending steel pipe of outside diameter 25 mm and having 2 mm thickness. The kinematic synthesis of bending mechanism is carried out. The dimensional analysis was carried out. The relations deduced predicts the performance of bicycle integrated pipe bending mechanism and all the parameter needs to be optimized to get the best performance of the machine.

N. Nirwan and A. K. Mahalle [4] found a portable rolling pipe bending machine that was used for reliability, ease of convenience and good quality purpose. But there were some difficulties like not to be used for mass production and slow process due to hand operated device.

A. P. Kshar and A. P. Kshar [5] designed and fabricated a portable pipe bending machine considering the cost of machine and ease of use. The machine was based on fixed die and manually operated lever.

As reported in [5], A. Pandiyan of Saveetha School of Engineering, Chennai, India found a zigzag pipe bending machine that was used for making zigzag profile pipe. It was operated by hydraulic bottle jack. This bending machine is only used for zigzag profile. So, This is not used for other bending operations.

N. N. Jadeja [6] designed manually operated pipe bending machine that was used in small industries. This machine was generally used for low cost purchasing purpose. It has low accuracy of bending and force is not uniformly distributed over the whole length of the pipe so, this bending machine is not preferable for precision works.

B. Okafor and D. Obiora [7] found motorized pipe bending machine which was operated by a 2-hp motor. This machine can run in both upward and downward direction. Here, worm and wheel gear mechanism were used. Mandrel is used for less thickness pipes.

P. P. Khandare et. al., [8] has developed a project to design and construct a portable pipe bending machine which was used to bend steel pipes into curve and other curvature shapes. It was easy to carry and use at any time and any place with reduced human effort and less skilled manpower. It could bend up to 4-5 mm thickness of pipe; but it is for small workshop and fabrication shop only.

Considering small entrepreneurship and inconsistent electricity supply in our country, in this project, a manual pipe bending machine with three roller mechanism is considered. The upper middle roller, controlled by a hand wheel and lead screw, is movable in the up and down direction and the lower two rollers are at a fixed height framed with the structure and base. The horizontal distance between the two lower rollers is fixed. The objective of the project is to design, construct and performance test of a manual pipe bending machine.

2. Theoretical Aspects

It is envisioned that while bending a pipe, the material surfaces experiences two types of stresses that are developed in the outer and inner side of the pipe. The 3-roller bending of pipe is similar to a simple supported beam deflection. The middle roller gives the bending force to the pipe at the center of the two rollers and the lower two rollers support the pipe. The bending process may be considered as deflection of a simple supported beam similar to that shown in Fig. 1.

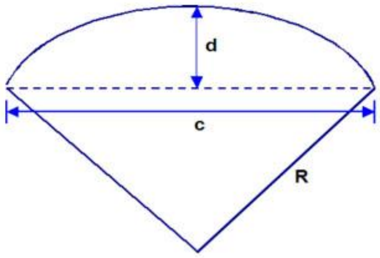

Fig.1: Simple supported beam deflection

For this type of bending according to [11], the radius is given by Eq. (1).

$$R = \frac{c^2+4d^2}{8d} \quad (1)$$

where, R is the bending radius, c is the distance between two fixed rollers and d is the deflection in the middle roller.

3. Design Consideration

Selection of pipe and other design considerations for the different components of the present project are briefly discussed in the following sub-sections.

3.1 Selection of Pipe

For the manually operated pipe bending machine it is necessary to consider that the machine could not bend pipes with higher diameter i.e., with higher wall thickness, that need very high pressure to bend it. Keeping this in mind, in this project only 15, 20 and 25 mm GI nominal pipe sizes (NPS) are considered. Assuming that if the machine could bend 25 mm diameter pipe, it could also bend 15 or 20 mm pipes as well. The design is based on 25 mm nominal pipe. For 25 mm NPS with schedule 5, from [11], the pipe specifications are: outer diameter (D_p) = 33.4 mm, inner diameter (d_p) = 30.1 mm. The pipe material is cold rolled, Mild Steel. According to [11], σ_{ut} = 350 MPa, σ_{yt} = 195 MPa.

3.2 Design of Rollers

As the outer diameter of pipe (D_p) is 33.4 mm, the material was selected for the roller as case-hardened steel. For fewer defects in bending, the larger roller diameter was taken as 5 (five) times the diameter of the pipe [12]. So, the large roller diameter is 167 mm. Roller dimensions are shown in Fig.2.

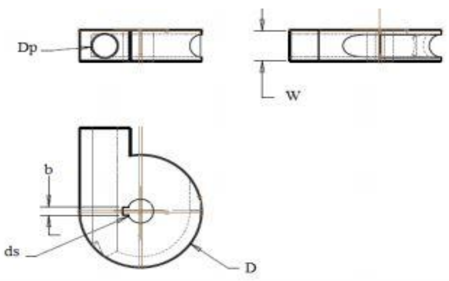

Fig. 2: Roller Dimensions

3.3 Design of Bending Die

The middle roller acts as the bending die. As mentioned before, the roller diameter is taken five times that of the pipe diameter. With the pipe outer diameter of 33.4 mm, the bending roller diameter is 167 mm.

3.4 Bending Moment and Force Calculation

As the selected pipe material is Cold rolled, Mild steel, So, as mentioned before, σ_{ut} = 350 MPa, σ_{yt} = 195 MPa. Assuming stress required for bending the pipe is equal to the yield stress (σ_{yt}); the bending stress is calculated according to [11], as,

$$\sigma_b = \frac{Mc}{I} \quad (2)$$

where, c is distance of outer fiber from the neutral axis = 33.4/2 = 16.7 mm or 16.7×10^{-3} m, I is area moment of inertia = $\frac{\pi(D_p^4-d_p^4)}{64}$ = 20794.40 mm^4 or 2.08×10^{-8} m^4. Thus, the bending moment M is 242.87 Nm.

As mentioned earlier, assuming simple supported beam as shown in Fig.3 and the distance between the two supports L = 254 mm, according to [11], the relation between the maximum bending moment and force is given by the formula, $M = \frac{PL}{4}$. Thus, bending force, P = 3824.8 N.

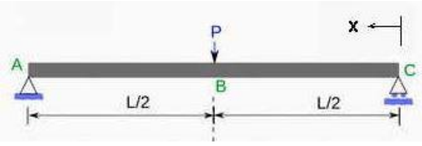

Fig. 3: Force diagram for simple supported beam

3.5 Design of Lead Screw

Assuming single threaded square lead screw. Let, the material of screw is grey cast iron (FG 200) and a factor of safety to be 3. Also, Assuming, nominal diameter, D = 20 mm, pitch, p = 3 mm, lead, l = 3 mm, outer diameter of collar, D_o = 40 mm, inner diameter, D_i = 20 mm, coefficient of friction μ = 0.15 and torque coefficient, C = 0.2. In this case, the load, P =3824.8 N.

According to [11], the relation between the torque to turn the screw and the load is given by equation,

$$T = \frac{PD(tan\lambda + \mu)}{2(1 - \mu tan\lambda)}$$

where, $tan\lambda = \frac{Lead}{\pi D}$ = 0.05, where λ is the lead angle. Thus, the torque to turn the screw T = 7.71 Nm. According to [12], shear stress developed by torque is given by the equation, $\tau = \frac{16T}{\pi D_i^4}$. Thus, shear stress produced due to torque, τ = 245.41 MPa. A schematic of the lead screw is shown in Fig. 4.

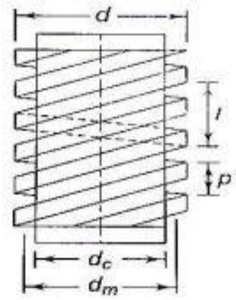

Fig.4: Schematic of the Lead Screw

3.6 Design of Shaft

Material selected for all shafts is C1045 steel (as rolled). According to [11], ultimate strength for C1045, σ_{ut} = 662 MPa, and yield strength σ_{yt} = 407 MPa. Here yield strength is considered.

While the bending force is applied, only the radial force is significant and axial force is not considered. So, shear stress due to bending moment is considered. According to [11], relation between bending moment and shear stress is,

$$\sigma_{yt} = \frac{32Mk_m}{\pi D^3}$$

For gradually applied force and rotating shaft, k_m = 1.5. Assuming length of the shaft L = 25 cm, maximum moment due to applied point load P, M = $\frac{PL}{4}$ = 239 Nm.

Thus, the diameter of the shaft found from the above equation, D = 0.021 m or 21 mm. So, the nominal diameter 25 mm is taken. The schematic of shaft with load is shown in Fig. 5.

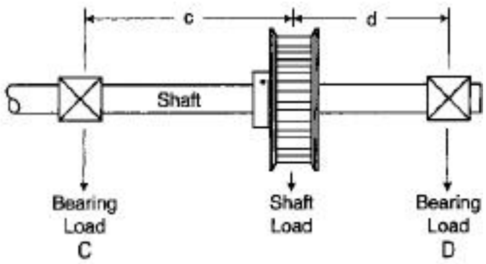

Fig.5: Schematic of the shaft with load

3.7 Design of Bearing

The bearings are used to support the radial loads only. So, the selected bearings are: Bearing no. 6205. The specification of the bearing is housing diameter, D_b = 52 mm, internal diameter, d_b = 25 mm and width of bearing, w_b = 15 mm and static load carrying capacity = 7800 N

3.8 Design of Key

A square key is assumed to be appropriate in this case. Only shear stress acts on the key. So, for the key design only shear stress is considered. The key dimensions are: width b = D/4 = 6.25 mm and height h = D/4 = 6.25 mm; For simplicity, both width and height is chosen as 7 mm. Length of the key: L = 45 mm [Assuming L=1.8D]. A schematic of a square key is shown is Fig. 6.

Fig. 6: Square key

The schematic diagram of the proposed manual pipe bending machine is shown in Fig. 7.

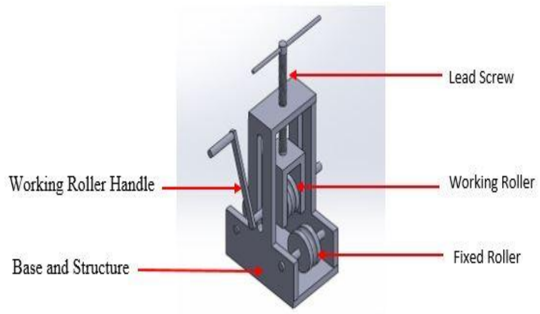

Fig. 7: Schematic of the manual pipe bending m/c.

4. Experimentation and Data Acquisition

The photographic view of the constructed Manual Pipe Bending machine is shown in Fig. 8. For the performance test, samples of three pipes with same dimensions were taken and the average values for each dimension is considered.

Fig. 8: Photographic view of the constructed pipe bending machine

In the performance test, the experiments were conducted with 15 mm and 20 mm GI pipe. The test with 25 mm pipe was not carried out as this size pipe was not available in the lab. For various midpoint deflections of the pipes the diameters were measured. The bending force was applied by giving torque on the lead screw through the lever fitted with the lead screw. Then the pipe was moved forward and backward by using the handle of the middle roller and the required bending diameter was achieved through gradually increasing the bending pressure. By repetitive process, the required bending was achieved and a smooth bending was found. The pipe diameter and the deflection of the pipe were measured and they are shown in Table 1.

Table 1: Data for 15 and 20 mm pipe bending test.

Pipe Diameter (mm)	Deflection (mm)	Bending Diameter (mm)	Remarks
15	31.75	457.20	There was a small damage for 15 mm pipe initially. But no damage for 20 mm pipe.
	38.10	412.75	
	50.80	330.20	
20	31.75	495.30	
	38.10	444.50	
	50.80	361.95	

5. Results and Discussions

The measured data are analyzed and they are presented in the following subsections. In the experiment the length between two fixed rollers was c = 254 mm.

5.1 Results

By using Eq. (1), the theoretical bending radius was calculated. From the specimen, the same was measured practically after bending. The comparison between the theoretical and the experimental values are shown in Table 2.

Table 2: Comparison between theoretical and experimental values of bending radius:

Pipe dia. mm	Deflection mm	Bending dia. in mm		Deviation	
		Experi-mental (D_E)	Theoretical (D_T)	(D_E-D_T) mm	% (D_E - D_T)/ D_T
15	31.75	457.20	539.75	82.55	15.30
	38.10	412.75	461.52	48.77	10.56
	50.80	330.20	368.30	38.10	10.34
20	31.75	495.30	539.75	44.45	8.24
	38.10	444.50	461.52	17.02	3.69
	50.80	361.95	368.30	26.35	1.72

The comparison between theoretical and experimental values of the bending radius (diameter) is shown graphically for 15 and 20 mm pipes respectively in Fig. 9 and Fig. 10. From the Table, it is seen that the deviation reduces as the bending radius increases. While bending, the pipe is supported on the bottom roller and pressure is created by the middle roller. In each case the two ends could not be bending properly.

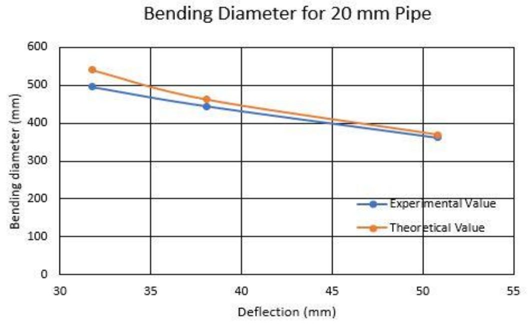

Fig.9: Graphical representation of experimental and theoretical value for 15 mm pipe bending.

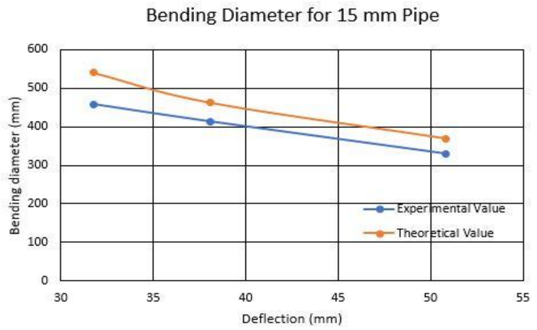

Fig.10: Graphical representation of experimental and theoretical value for 20 mm pipe bending.

5.2 Discussions:

In three-roller bending machine there are two methods for changing the bending angle and radius – one is changing the distance between two fixed rollers and another is changing the vertical displacement in the middle roller. To reduce the complexity in the design, in this project, the latter is considered. Thus, the bending radius is only dependent on the bending force exerted by the middle roller. The bending radius is found from the Eq. (1). As the distance between the two rollers is fixed, the only changeable variable in this case the distance 'd'. From Table 2, it can be envisioned that the experimental result of bending radius for various displacement in middle roller in two pipes. There is a little deviation in the results. By a slow and smooth operation this deviation could be reduced. Also, it is seen that for higher displacement of middle roller the deviation is reduced. From Figs. 9 and 10, one can see that the theoretical value is slightly higher than the experimental value. For 15 mm pipe the curves go in parallel. But for 20 mm pipe the two curves tend to intersect for higher deflection.

From the result it can be said that there is little deviation between theoretical and experimental value. By maintaining proper bending process and smooth operation the deviation could be reduced.

6. Conclusion:

Pipe bending is regular phenomena now-a-days. In mass production various automatic and semi-automatic bending mechanisms are used. But for small production automatic and semi-automatic pipe bending machine are costly. Also, where electricity is rare and costly they cannot be used. On the other hand, manual pipe bending is less expensive and can easily be made and operated. In this report the designs, construction and performance test are illustrated. From the performance test the result can be summarized as:

1) For two fixed rollers the bending diameter depends only on the deflection of the mid roller.
2) For the higher deflection the deviation in results is reduced.

Result shows that various diameter of the pipe bending can be achieved from the designed machine.

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